Submission to South Australian Nuclear Fuel Cycle Royal Commission

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This submission is made in response to the Terms of Reference (TOR) - given below - presented by South Australia's Nuclear Fuel Cycle Royal Commission (NFCRC). No single paper can answer, in full, all the issues raised by the TOR. That the extent of the nuclear activities Australia might embark upon is not known also makes comment problematic. This paper, therefore, mainly gives an overview of the key points, along with some details on specific issues.

Electricity Generation

The feasibility of establishing and operating facilities to generate electricity from nuclear fuels in South Australia, the circumstances necessary for that to occur and to be viable, the relative advantages and disadvantages of generating electricity from nuclear fuels as opposed to other sources (including greenhouse gas emissions), the risks and opportunities associated with that activity (including its impact on renewable sources and the electricity market), and the measures that might be required to facilitate and regulate their establishment and operation.

Management, Storage and Disposal of Waste

The feasibility of establishing facilities in South Australia for the management, storage and disposal of nuclear and radioactive waste from the use of nuclear and radioactive materials in power generation, industry, research and medicine (but not from military uses), the circumstances necessary for those facilities to be established and to be viable, the risks and opportunities associated with establishing and operating those facilities, and the measures that might be required to facilitate and regulate their establishment and operation.

In inquiring into the risks and opportunities associated with the above activities, consideration should be given, as appropriate, to their future impact upon the South Australian:

a) economy (including the potential for the development of related sectors and adverse impacts on other sectors);

b) environment (including considering lessons learned from past South Australian extraction, milling and processing practices); and

c) community (incorporating regional, remote and Aboriginal communities) including potential impacts on health and safety

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[1] The author has over 30 years experience of working on nuclear issues nationally (UK) and internationally (Europe and the Asia-Pacific region); including the management and financial arrangements for the storage and disposal of nuclear wastes and materials. She has also worked extensively on nuclear technology and material transfer, with regard to non-proliferation. She has commented on policy and legislation on nuclear matters through consultations and in evidence to Parliamentary committees in the UK, Australia and the EU. She has worked for Greenpeace UK and Greenpeace International; and was a member of the Nuclear Safety Committee of ARPANSA. She holds a Masters in Policy Studies. Born in Barrow, Cumbria, she is the author of *'Living in the Shadow, The Story of the People of Sellafield.*

The author wishes to thank Martin Forwood of Cumbrians Opposed to a Radioactive Environment, CORE, for contributing research for this submission. http://www.corecumbria.co.uk/

CONTENTS

Page	
3	1. Introduction to the issues
6	2. What is spent fuel?
7	3. Spent fuel storage and conditioning (encapsulation)
11	4. Costs of storage
12	5. Disposal of unreprocessed spent fuel
14	6. Land ownership and trans-boundary/state issues
15	7. Social issues – advantages versus disadvantages
19	8. Spent fuel reprocessing – for civil purposes
22	9. Thermal Oxide Reprocessing Plant (THORP) Sellafield, UK
24	10. Sellafield MOX Plant (SMP) UK
27	11. Wastes from reactor and reprocessing operations
28	12. High Level Liquid Waste (HLW) tanks at Sellafield
31	13. Costs / Liabilities
31	14. Hinkley C – new reactors in the UK
38	15. Waste and spent fuel costs & contracts: issues for consideration
44	16. Nuclear workforce
46	17. Regulatory inspection regime
47	18. Fast reactors / fast breeder reactors: types, wastes, costs and safeguards
56	19. Time to develop a nuclear programme v. time to realise the benefits
57	20. Political / Treaties
61	21. Security

List of Attachments

1. TS 088: Improvements to CoRWM Inventory: Study Report CoRWM Document Number: 1277 ELECTROWATT-EKONO (UK) LTD. Ref. No 200520.01/01 June 8, 2005
File name:
CCSA-ACF-FOE-ATTACHMENT 1 - ELECTROWATT EKONO CORWM JUNE 2005.pdf

2. TRANSCRIPT THORP: Ref No: S20060084. IN THE CROWN COURT AT CARLISLE Courts of Justice, Carlisle Cumbria 16th October 2006
Before: THE HONOURABLE MR JUSTICE OPENSHAW
REGINA –V – BRITISH NUCLEAR GROUP SELLAFIELD LTD
File name:
CCSA-ACF-FOE-ATTACHMENT 2 - THORP TRANSCRIPT 2007.pdf

3. Committee on Radioactive Waste Management
CoRWM's Radioactive Waste and Materials Inventory –
July 2005 CoRWM Document No: 1279 FINAL
File name:
CCSA-ACF-FOE-ATTACHMENT 3 - CORWM FULL INVENTORY Final.pdf

4. Fukushima Fallout (Greenpeace International)
Antony Froggatt, Dr David McNeill, Prof Stephen Thomas and Dr Rianne Teule
February 2013
File name:
CCSA-ACF-FOE-ATTACHMENT 4 - FukushimaFallout.pdf

5. Research Report
Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations
Independent Report for Greenpeace UK • 1st March 2011• Issue 1

Jackson Consulting
File name:
CCSA-ACF-FOE-ATTACHMENT 5 - FINAL JACKSON FUP Subsidy Report (Mar2011)[1].pdf

6. Response to Funded Decommissioning Programme Guidance and Waste Transfer Price consultations. DECC's Consultation on revised Funded Decommissioning Programme Guidance for New Nuclear Power Stations (FDP) and the Consultation on an updated Waste Transfer Pricing Methodology for the disposal of higher activity waste from new nuclear power stations (WTP) Greenpeace UK March 2011
File name:
CCSA-ACF-FOE-ATTACHMENT 6 - GREENPEACE UK SUBMISSION 2010 CONSULTATION WASTE CONTRACTS.pdf

Acronyms
BNFL − British Nuclear Fuels Ltd.
CFD − Contract for Difference
CoRWM – UK Committee on Radioactive Waste Management
GDA – UK Generic Design Assessment process
GDF − Geological Disposal Facility
HLW − High level waste
IFR - Integral Fast Reactor
ILW − Intermediate level waste
LLW − Low level waste
MOX − Mixed Oxide Fuel
MRWS – UK Managing Radioactive Waste Safely process
NDA – UK Nuclear Decommissioning Authority
ONR – UK Office of Nuclear Regulation
SFR − Sodium-cooled fast reactor
SMP − Sellafield MOX Plant
WCMRWS − West Cumbria Managing Radioactive Waste Safely process
WNA − World Nuclear Association
WTP − Waste Transfer Price

1. Introduction to the issues

Nuclear activities of the kind outlined in the Royal Commission's TOR would, in order for them to come to fruition, impose an unreasonable commitment on Australia - and most likely lead to a need for taxpayer funding - for many decades, if not hundreds of years. The hazardous and long-lived nature of most of the radioactive wastes and nuclear materials involved in the activities listed are such that the environmental impacts, and risks to health, could extend tens of thousands of years into the future. The processing of these wastes and materials - and their possible reuse in reactors - poses a risk of a major release of radioactivity; the extent of which, along with its wider impacts, would not necessarily be contained within a state's boundary. Because of the wide-ranging environmental and financial risks of the nuclear activities referred to in the TOR, this paper refers in general to Australia rather than South Australia, as all the activities considered are of relevance across the Commonwealth. This is not to show any disrespect to the Royal Commission, or to diminish its powers or responsibilities within South Australia, but is raised in recognition of the importance of this debate to Australia as a whole.

As the Royal Commission is aware, each nuclear activity listed in the TOR is a complicated matter; and is inherently linked to other, equally complicated matters. With regard to the nuclear activities referred to, the following matters need to be considered in concert with each other:

- If progressed, the activities in the TOR could see Australia import highly radioactive and intensely hot spent fuel for disposal; or for the spent fuel to be reprocessed (which includes pyroprocessing) for use as fuel in reactors. The conditioning (encapsulation) and disposal of spent fuel; as with reprocessing and reactor operations, pose risks to the environment and worker and public health. Plans and funding will be required to deal with any incident involving localised or widespread contamination; not only to secure the site (if possible) but also to be able to implement countermeasures to protect public health (e.g. distribution of potassium iodate tablets to reduce the uptake of Iodine-131); as well as protecting the agricultural, fishing and wine producing industries; and wildlife and its habitat.

- The reprocessing/pyroprocessing of spent fuel, which results in the recovery of nuclear materials for reuse could, depending on the processes deployed, also raise concerns around weapons proliferation that will have to be taken into account

- As all the different processes would, eventually, entail the management and geological disposal of highly radioactive wastes (which might not take place for many decades) particular attention needs to be paid to ensuring taxpayers are not left with the burden of paying for this liability – as has happened in other countries when their nuclear industries have failed to set aside money for this eventuality. A timeline for the storage, conditioning *and* disposal of nuclear wastes – which private companies must commit to – is also a prerequisite.

- The activities referred to will, in total, involve the expenditure of tens of billions of dollars. It is vital, therefore, that there is certainty that the private companies concerned can, and will, pay for all of their operations. To protect the public purse from paying for any of the processes, such as reactor construction, legal measures would have to be implemented to ensure the costs fall wholly on the companies concerned. Measures would also be needed to protect industrial and individual electricity consumers from cost escalation. Checks would need to be made on the financial status of the relevant overseas and Australian companies; and regular stress-testing undertaken to determine their long-term economic viability in order to protect taxpayers.

- Powers to allow Federal and State parliamentary oversight - and right of intervention in any contract proposed between the private companies involved - needs to be established through legislation; which should include provision of an up-front bond to guard against public subsidy. Such measures would have to have public input in their formulation; and the right of veto if the measures were not believed to be sufficient.

  To help in understanding the scale of the finances needed for their plans, any proponent of a particular scheme should provide State and Federal Parliaments with a total budget – and a break-down of the cost for each stage of the processes they intend to carry out – for independent assessment and verification.

- To facilitate the range of activities mentioned in the TOR would also necessitate significant changes to Australia's national laws to allow them to proceed; a change to the national nuclear regulatory regime; changes to liability and compensation laws in the event of accident; strengthened security measures - and most likely controversial changes also to worker and civil liberty safeguards. This would have to be accompanied by consultation and agreement with every State and Territory administration, as well as the Australian public.

- There would need to be a review of Australia's legally binding obligations under international treaties covering safety and non-proliferation; and its duties under bilateral and multilateral trade agreements. There would need to be a major overhaul of its domestic safeguards regime – and expansion of its capacity to enforce the requisite conditions.

- To undertake the activities would also require, among other things, the rapid development of a skilled nuclear workforce (e.g. scientists, construction and engineering, plant operators) and an increase in the regulatory/safety inspectorate; an increase in funding for, and expansion of, the domestic nuclear research capacity and technical ability; and the development of an accredited manufacturing base for the nuclear sector.

For Australia to take what would, in effect, be a standing-jump into operating a large scale nuclear industry, the following facilities would be needed (based on the activities canvassed in the TOR). These could, in brief, be any of the following:

Note: Any of the activities listed, if intended as a large-scale commercial venture, would require a fleet of purpose-built spent fuel carriers; a suitably secure reception facility at a port; and road and/or rail links to the site of operation. There would also need to be facilities and specialist transport for the security personnel needed to safeguard the nuclear materials.

<u>Proposal: Import spent fuel for disposal only</u>
Surface works including a spent fuel import storage facility; and conditioning plant to encapsulate the spent fuel for disposal (if it is imported unconditioned); a disposal facility/facilities which could be a deep mined or borehole repository (depending on the type of spent fuel imported). There may also be a need for a sub-surface disposal facility for some of the wastes from spent fuel conditioning.

<u>Proposal: Import spent fuel for reprocessing and reuse of plutonium and uranium – as Mixed Oxide (MOX) fuel - in reactors</u>
A spent fuel storage facility; a large scale conventional reprocessing plant; storage facilities for the resulting solid wastes; high level (liquid) wastes and plutonium and uranium inventories from spent fuel reprocessing; a MOX fuel fabrication plant; MOX reactors; new electricity transmission lines; stores for spent fuel from the MOX reactors; conditioning plants for the wastes from reprocessing, the decommissioning of reactors and associated plant - and for the encapsulation of spent fuel from reactor operations; a deep disposal facility/ facilities - which could be a deep mined and/or borehole repository (depending on the types of wastes and materials involved). There may also be a need for a sub-surface disposal facility for some of the wastes from the different processes involved.

<u>Proposal: Import spent fuel for pyroprocessing and reuse in Integral Fast Reactors</u>
A spent fuel storage facility; a spent fuel pyroprocessing (reprocessing) plant and an Integral Fast Reactor(s); new electricity transmission lines; stores and a conditioning plant for fission product wastes from pyroprocessing and fission wastes (used fuel) from reactor operations; stores and conditioning plants for wastes from decommissioning reactor(s) and associated plant; a disposal facility/facilities such as a deep mined repository and, depending on the classification of materials imported and wastes produced, a sub-surface disposal facility.

A time-line, from the planning to deployment stage, of all of the referenced nuclear activities needs also to be established.

2. What is spent fuel?

Spent fuel is the term used for fuel, usually low enriched uranium, that has been partially 'burnt' - through the fission process - in a conventional nuclear reactor. [2] Because of the fission process, spent fuel is intensely radioactive; and, because of the radioactivity, is also extremely hot. The combination of radioactivity and heat are both significant and unavoidable factors in spent fuel management (including disposal).

- Spent fuel is made up of approximately of 96% unburnt uranium; 1% plutonium – with the rest, approximately 3%, made up of radioisotopes known as fission products. The relatively short-lived fission products, which account for approximately 93% of the radioactivity in spent fuel, give rise to most of the radioactivity over the medium-term; up to 500 years after production. [3] However, due to it also containing long-lived radioisotopes, spent fuel is hazardous for many thousands of years. At all stages, the management of spent fuel requires extreme care. [4]

- The radioisotopes in spent fuel have different half-lives - which can be measured in milli-seconds, through to billions of years. As the list of isotopes in spent fuel is long, they are not listed here. However, two reports are referenced which give all the necessary details. The first report was prepared for the UK's independent Committee on Radioactive Waste Management (CoRWM). [5] As there is no web link for the first report it is attached. The second report, prepared for NIREX UK - a now defunct nuclear industry body - gives details of the isotopes in a range of spent fuel types from reactors operated around the world. [6]

- Spent fuel can be disposed of 'in-tact'. Or, it can be reprocessed to extract uranium and plutonium for reuse; leaving fission product waste and other long-lived isotopes for disposal. An alternative process for dealing with spent fuel, pyroprocessing, has also been proposed. This would entail extracting uranium, plutonium and the other long-lived isotopes; leaving only fission products for disposal.

A report by the Swedish Nuclear Fuel and Waste Management Company states that unshielded spent fuel, after one year's storage - at a range of one metre - will kill in 20 seconds. [7] Using the figures in that report it can be estimated that after 40 years storage, unshielded spent fuel would kill in five minutes; or be lethal within 30 minutes after 100 years storage. The US Nuclear Regulatory Commission offers the following information: *For example, 10 years after removal from a reactor, the surface dose rate for a typical spent fuel assembly exceeds 10,000 rem/hour*

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[2] Used fuel from fast reactors is not discussed here.
[3] US Environmental Protection Agency (EPA) 'Spent Nuclear Fuel and High-Level Radioactive Waste', http://www.epa.gov/radiation/docs/radwaste/402-k-94-001-snf_hlw.html
[4] US EPA. 'QUANTITIES, SOURCES, AND CHARACTERISTICS OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE IN THE UNITED STATES', See section 5.4. http://www.epa.gov/radiation/docs/yucca/bid/yucca_bid_060501_ch5.pdf
[5] CoRWM, Terms of reference, 2003 https://www.gov.uk/government/organisations/committee-on-radioactive-waste-management/about/terms-of-reference
[6] Electrowatt-Ekono (UK) LTD. Ref. No 200520.01/01 Date June 8, 2005. TS 088: Improvements to CoRWM Inventory: Study Report CoRWM Document Number: 1277. For isotopes – and their half-lives, see page 25, table 5.2. http://www.nda.gov.uk/publication/radionuclide-content-for-a-range-of-irradiated-fuels-electrowatt-ekono-ltd-report-to-nirex-september-2002
[7] Swedish Nuclear Fuel and Waste Management Co, 'Spent Nuclear Fuel – How dangerous is it?' 1997 http://www.skb.se/upload/publications/pdf/tr%2097-13webb.pdf
The 20 seconds is referred to on page 21

(100 Sieverts) – far greater than the fatal whole-body dose for humans of about 500 rem (5 Sieverts) received all at once. [8]

A breach of a spent fuel flask during transport - through accident or malicious act - would risk massive radiation doses to any emergency workers sent to deal with the situation. Similarly, the significant loss of cooling water from a spent fuel pond, or containment in a spent fuel store, would be a major issue for any on-site workers or emergency service personnel. Shielding people from the extremely high gamma doses, in such an event, would be extremely problematic.

Under the appropriate controlled environment spent fuel, even when properly contained, will still give rise to low doses of radiation; just how much being dependent on the operation involved. The exposures for workers are now generally very much lower than those in an accident situation e.g. the average dose rate for workers at the Sellafield nuclear complex (Cumbria, England) is now in the region of 1 milliSievert (mSv) per annum (a significant reduction on earlier years). As the impacts of radiation doses are cumulative, workers have to be monitored over their working life to assess their total radiation exposure; a recent report on the risks to workers of low level exposure to ionising radiation is referenced. [9] Bad practices or lax environmental rules can, however, lead to higher radiation doses than those prescribed by international and national organisations. Every step in handling spent fuel needs to be closely managed, monitored and regulated to keep radiation exposures 'as low as reasonably achievable' (government/industry views) or as low as the 'best available technology' can achieve (environmental view).

3. Spent fuel storage and conditioning (encapsulation)

Storage systems for spent fuel are relatively well known and are utilised internationally by the nuclear industry. Dry storage, although not used by all nuclear companies, is preferable over storage systems which depend on water for coolant e.g. spent fuel ponds used at reactor sites and reprocessing plants. [10] Corrosion of spent fuel in cooling ponds has led to problems at various sites. If Australia was to allow spent fuel reprocessing or reactor operations the source of water for cooling reactors, and the spent fuel in ponds, would be a significant factor in the siting of such facilities.

For the purposes of this paper it is assumed that any spent fuel Australia agrees to accept for disposal is in a form that can be dry stored and has already been conditioned (encapsulated) for disposal.

Australia, if it considers importing unconditioned spent fuel, needs to be aware there is no generic 'one size fits all' form of spent fuel conditioning that makes it suitable for disposal in any type of repository. This is because there are different types of spent fuel; and also because the type of conditioning is dependent on the geology into which the final 'waste form' is placed. Encapsulation will delay, but not stop, the canisters sent for disposal from breaking down. [11] It is

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[8] US Nuclear Regulatory Commission (NRC), Backgrounder on Nuclear Waste, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html#waste

[9] International Agency for Research on Cancer (World Health Organisation) 'Even low doses of radiation increase risk of dying from leukaemia in nuclear workers, says IARC', 22nd June 2015 http://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr235_E.pdf Link to study in The Lancet: http://www.thelancet.com/journals/lanhae/article/PIIS2352-3026%2815%2900094-0/fulltext

[10] Directly after spent fuel is discharged from a reactor it is placed in a cooling pond because of the extreme radioactivity/heat; water also acts as an effective shield to help reduce radiation exposures.

[11] International Atomic Energy Agency; 'Storage and Disposal of Spent Fuel and High Level Radioactive Waste.' See para 19. http://www.iaea.org/About/Policy/GC/GC50/GC50InfDocuments/English/gc50inf-3-att5_en.pdf Para 19

only one of a number of measures designed to slow down, but not prevent the process of radioactive releases from a repository.

The Nuclear Decommissioning Authority (NDA) – which oversees the UK government's nuclear decommissioning and radioactive waste disposal programme - has issued a series of reports assessing the general suitability of spent fuel disposal, for example the spent fuel that will be produced by the EPR (European Pressurized Reactor or Evolutionary Power Reactor), which Électricité de France (EDF) proposes building in the UK. [12] The NDA's reports, while seeming to confirm that spent fuel can be disposed of, are not final assessments. The work includes a number of caveats e.g. they are based on 'assumed characteristics for a generic UK Geological Disposal Facility (GDF) site'. The reports also rely on analysis and information from nuclear companies which has not been fully tested by the regulators.

For Australia, the geology of a disposal site would need to be known well in advance of import or waste creation as this has implications for the type and amounts of spent fuel (or radioactive wastes or nuclear materials) that can be disposed of. The form of the disposal site (drift mine or borehole) will also influence the type of conditioning or encapsulation required. The UK industry did not give much thought to this until the mid-1990s and it is only now, after two costly failed attempts to find a waste disposal site in the UK - both of which led to the geological investigations being heavily criticised – that the UK Government is now using a different approach. In an effort to respond to public and scientific concerns over the need to know more about geology - before it progresses a waste disposal process - the UK Government is now undertaking a national pre-screening review of geology.[13] Any area thought to be suitable for disposal would then only be examined if there was also a volunteer community in a potentially suitable geological setting. This acknowledges that public/community acceptance and the 'right' geology are linked primary criteria.

Geology is one issue concerning the disposal of spent fuel; a complex process which will require many things to be known before work can begin on a site. As the most recent UK White Paper on radioactive waste disposal notes: [14]

5.1 The underground environment in which a GDF (geological disposal facility) is engineered provides an important element of the multi-barrier containment system. Developing a detailed understanding of the sub-surface characteristics of a potential site is therefore of great importance in developing a safety case for any proposed facility. The ultimate safety of any GDF proposal will rest on a range of factors – not just the basic geological setting (e.g. rock type, faults and fractures), but a detailed understanding of features such as the hydrogeology, geochemistry, and how the developer proposes to design, engineer and operate a facility within that setting.

5.2. All the relevant factors are brought together in what is known as a 'safety case'. This will be a series of detailed documents created, owned and updated by the developer throughout the lifetime of GDF design, construction and operations. For a GDF, there will be a number of safety cases required, covering operational safety, environmental safety, and transport. A safety case may also relate to a particular stage of development (e.g. site investigations,

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[12] NDA 'Geological Disposal Generic Design Assessment: Summary of Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK EPR', October 2009 Technical Note no. 11261814
http://prtfdcsd.com/file-docdc/1elT/nda-technical-note-no-11261814-rev1-geological-disposal-.html
[13] NDA website: National Geological Screening,
http://www.nda.gov.uk/rwm/national-geological-screening/
[14] Dept of Energy and Climate Change (DECC, UK) 'Implementing Geological Disposal', July 2014
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332890/GDF_White_Paper_FINAL.pdf

commissioning, operations, closure, post-closure etc.). The various safety case documents will be considered by the independent regulators in their assessment of the safety, security and long-term environmental protection aspects of a GDF as they assess whether to licence or authorise the facility to operate.

The above is the briefest distillation of the some of the technical issues that have to be finalised in order to try to demonstrate the viability of a disposal facility for spent fuel and other nuclear wastes. There is a huge international library of documents online concerning the risks of disposal. The NDA's website, and those of independent specialist groups in the UK (see links), explain some of the many technical steps that still need to be researched, let alone signed off on, in order to validate the opinion that spent fuel (and other higher activity wastes) can be disposed of safely. [15] The complexity of some of the outstanding issues in the UK will give the Royal Commission an idea of the difficulties surrounding disposal; particularly when a complex mix of wastes is involved; as might arise in Australia under some of the activities listed in the TOR.

Note also, on the issue of disposal, that the UK's plans are for geological *disposal*: not for a storage facility underground that would allow for the retrieval of nuclear materials (e.g. plutonium) or spent fuel for future use. On this point, the relevant IAEA convention - to which Australia is a signatory – states that: *"disposal"* means the emplacement of spent fuel or radioactive waste in an appropriate facility without the intention of retrieval. [16] Thus it needs to be clear from the outset if companies are applying for disposal or storage (with a view to retrieving wastes or materials) when they mention a nuclear 'disposal' site.

A viable and publicly acceptable disposal site would have to be known well before Australia imported any spent fuel - if it is to avoid the risks than could arise with long-term storage e.g. possibly for 50, 100 or 150 years. It should not be thought, though, that because spent fuel storage is a mature technology that it is without environmental, safety and security risks. Indeed CoRWM, which was set up in 2003 to examine ways forward for nuclear waste management (using a broad range of criteria and with a consensus based approach) expressed reservations about the long term storage of nuclear wastes, spent fuel and nuclear materials. As the Committee noted in its 2006, when it eventually recommended disposal: *Most members considered that the risks from geological disposal were substantially smaller than those from long term storage, which they considered to be vulnerable to terrorist actions, war, loss of institutional control, and severe environmental change.* [17] CoRWM's recommendations did, however, also acknowledge that storage had to be improved until disposal took place; and also because storage would be the unavoidable fallback option if disposal did not occur.[18]

For Australia to avoid the kind of risks CoRWM had concerns over - the long term storage of radioactive wastes and spent fuel - the disposal site; financial arrangements (costs, terms of payment, structure and the liability arrangements of the companies involved) and technical problems; along with the size of the inventory for disposal, would need to be settled in advance

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[15] NDA's Radioactive Waste Management's issues register, November 2014
http://www.nda.gov.uk/2014/11/update-to-rwms-issues-register/
Nuclear Waste Advisory Associates, 'Outstanding Scientific and Technical Issues Relating to the Production of a Robust Safety Case for the Deep Geological Disposal of Radioactive Waste.'
http://www.nuclearwasteadvisory.co.uk/wp-content/uploads/2011/06/NWAA-ISSUES-REGISTER-COMMENTARY.pdf

[16] International Atomic Energy Agency, 1997, 'Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste.'
https://www.iaea.org/Publications/Documents/Conventions/jointconv.html

[17] CoRWM 'Managing Our Radioactive Waste Safely', Recommendations to Government, July 2006 Extract from Recommendation 2, page 111, https://www.gov.uk/government/publications/managing-our-radioactive-waste-safely-corwm-doc-700

[18] Ibid, Recommendation 2, page 111

of any imports. Indeed, many governments landed with finding a disposal site have openly criticised the failure of their own national nuclear corporations for creating wastes without thinking through the consequences; in particular the risks of the long-term storage of spent fuel and how disposal will come about. For Australia to import radioactive waste (e.g. spent fuel) without a feasible and acceptable management and disposal plan, which it is guaranteed can be paid for by customer companies, would be viewed as reckless.

Finding a 'solution' to the disposal and secure containment of spent fuel, throws up many questions; including many around the contractual and financial arrangements. For example, foreign companies might be asked to pay the full amount, in advance, for storage and disposal; which is extremely risky for the taxpayer because of the inevitable cost-overruns that will arise. Or, customer companies might be asked to agree to contracts on the basis that they pay some money in advance; and pay also for whatever additional financing becomes necessary (a cost-plus contract). That, however, could be an extremely risky venture for the companies.

Companies engaged in nuclear operations are well aware that spent fuel cannot simply be encapsulated and put in the ground straight away; as much depends on how long it is cooled for and in what way it has been stored e.g. in ponds which can lead to problems with corrosion (alternately there may be issues with drying out spent fuel in order to prepare it for encapsulation).

An example of the debate about the length of time needed for spent fuel storage – before encapsulation and disposal - came during discussion of spent fuel storage for the new reactors proposed for the UK. Initially the UK Government's documents stated the spent fuel might have to be stored for at least 100-160 years; most likely at reactor sites. [19] Following concerns raised over this, the NDA subsequently produced a report in which it claimed pre-disposal storage times could be reduced to 50 years by the 'judicious mixing' of long-term and short-term cooled fuel in batches for disposal. [20] The NDA's proposed option has, however, not been agreed by the UK nuclear regulators as viable; nor has it been tried anywhere else in the world. As it is, the NDA's reduced timeline remains an aspiration rather than an assured option: and the timeline of at least 100 years storage for new build spent fuel pre-disposal remains the most likely outcome.

The time needed for spent fuel storage pre-disposal would certainly be an issue for Australia if it operated its own reactors. Assume, for example, Australia commissions its first reactor by 2035; with the first batch of spent fuel discharged around five years later, in 2040. The spent fuel then has to be cooled for 100 years before it can be disposed of, around 2140. If the reactor operates for 60 years, as current reactor vendors propose, the last spent fuel from Australia's first nuclear power plant will be discharged in 2095; and buried in 2195. [21] This hardly meets the criterion of this generation not leaving future generations with the burden of having to deal with radioactive wastes. The Royal Commission has to consider these timescales in combination with any reactor building and spent fuel disposal programme.

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[19] DECC 'Draft National Policy Statement for Nuclear Power Generation', November 2009 Para 3.8.17 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228630/9780108508332.pdf

[20] NDA 'Geological Disposal Feasibility studies exploring options for storage, transport and disposal of spent fuel from potential new nuclear power stations', Report no. NDA/RWMD/060 November 2010 http://www.nda.gov.uk/publication/geological-disposal-feasibility-studies-exploring-options-for-storage-transport-and-disposal-of-spent-fuel-from-potential-new-nuclear-power-stations/

[21] If the NDA's assumptions about mixing longer-cooled with new build spent fuel are right – and if Australia has acquired enough overseas longer cooled fuel – then it might be able dispose of spent fuel arising from domestic reactor operations sooner; with the last of the spent fuel going underground around 2145

It has been claimed that pyroprocessing of spent fuel – a form of reprocessing – with reuse of the plutonium and actinide waste extracted in an integral fast reactor, could significantly shorten the time period over which the spent fuel is highly radioactive. This method is, however, not a proven solution; and it also brings its own unresolved challenges. For example, pyroprocessing will result in wastes that require geological disposal (see discussion on integral fast reactors and pyroprocessing, pages 47-56).

4. Costs of storage

Reference has been made to the global inventory of spent fuel and the management cost per annum, per tonne; and that profit could be made by Australia taking in spent fuel and storing it. Unfortunately, in this context, 'management' is a very vague term: proponents of such plans need to explain, in full, the precise detail of what they mean. Do they mean storage alone; or storage and disposal? Or, does management also include reprocessing?

There is little or no exact information in the public domain about the costs of managing spent fuel per metric tonne or by volume (m^3); the industry normally works on costs per fuel-load from a reactor. To test any proposals the Royal Commission will need to have full access to the activities listed in any contract for the 'management' of spent fuel in Australia; along with the right to examine the funding arrangements for such activities e.g. import and storage through to disposal. A question that needs to be asked is whether the costs reflect the capital outlay on storage and auxiliary facilities; workforce development and regulatory oversight; encapsulation costs and disposal costs. Getting an exact figure from the companies which currently handle spent fuel, in order to test any claims made, may prove difficult for a number of reasons: operators might share storage facilities for spent fuel from a number of reactors with different costs levied; or they may be using government subsidised facilities; or may not release the full information for commercial reasons. The spent fuel management costs of current nuclear operators might have no bearing on the cost of spent fuel management in Australia; because of the existing infrastructure of overseas companies; the contractual arrangements (e.g. for disposal) and other costs already expended. Suggestions of monetary gain - based on unspecified amounts of spent fuel; and management costs based on a range of as yet unknown factors within Australia - are guesstimates.

Another notion put forward is that nuclear savvy countries would willingly pay to export their spent fuel, rather than risk the eye-watering amounts some spend on searching for a disposal site. On the face of it this seems logical. Yet it also assumes, among other things, that Australia will be able to offer a solution (an uncontested disposal site, a fully costed and paid for process, a developed workforce etc) where others have failed: and that Australia will not encounter any of the problems experienced overseas.

In the UK most figures for spent fuel management are treated as commercial in confidence. Some figures, for certain aspects of spent fuel management, have been referenced in official reports. [22] For example, in one report the NDA looked at the cost of reprocessing approximately 5,000 tonnes of spent fuel (from current reactor operations) and disposing of the resulting waste; compared to direct disposal of the spent fuel. The conclusion was that there is little difference between the two options in terms of cost, the size of repository space for the wastes, and the radiological implications. However, at the very end of the report, it stated: *It is important to recognise that none of the calculations in this Technical Note include the cost of reprocessing, nor of packaging and transporting the wastes, and these will be of fundamental importance when considering the economic case for continued reprocessing*.

[22] NDA 'Geological Disposal; Assessment of the Implications for the products of reprocessing compared to direct disposal of the spent fuel.' Technical Note 1658861. February 2012 http://www.nda.gov.uk/publication/geological-disposal-assessment-of-the-implications-for-the-products-of-reprocessing-compared-to-direct-disposal-of-the-spent-fuel/

Examples of the complications which could arise from determining disposal costs in Australia – and who might bear the burden for them (along with issues around contracts) are covered on pages 33-34 and 37-42.

5. Disposal of unreprocessed spent fuel

Spent fuel, if not designated as a nuclear material for future use, would, under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, be defined as radioactive waste, which: *means radioactive material in gaseous, liquid or solid form for which no further use is foreseen by the Contracting Party or by a natural or legal person whose decision is accepted by the Contracting Party, and which is controlled as radioactive waste by a regulatory body under the legislative and regulatory framework of the Contracting Party.* The spent fuel would then, under international guidelines, be classed as high level waste.[23]

As noted earlier, if Australia decided on the import and disposal of overseas spent fuel the requirements would be at least; ships for transport; rail and/or road transport routes to the repository; and storage facilities at the surface works of the repository (assuming the spent fuel is already conditioned for disposal). Otherwise it would also require an encapsulation plant for the spent fuel. Sweden, which has permission to build such a plant, is not expecting to do this until the 2020s. [24] There is presently a scant amount of information upon which Australia can draw in terms of the risks and costs of a commercial spent fuel encapsulation plant.

The encapsulation process could throw up unexpected technical problems. The large scale handling of spent fuel is likely to involve a number of issues; not least of which is radiation exposure to workers – and possible risks of off-site releases of radioactive materials if there was an accident or malicious act. The method proposed in Finland and Sweden for spent fuel disposal is to encase the fuel in copper canisters for disposal; although this is not entirely without concerns. [25] The UK is working on spent fuel disposal based on a similar form of encapsulation; but until the geology of a specific site for disposal is known the NDA has said the exact method cannot be determined.

The siting of a repository would need to involve Aboriginal communities, Federal and State governments, local authorities, local communities and those who live along transport routes.

The volume of waste, its form; its potential for releasing radioactivity into the environment - even when packaged and underground - all add to the complexity and cost of disposal. The amount of radioactivity contained in wastes, and particularly the amount in spent fuel, is also a major issue. In most countries there is a limit on the amount of radioactivity that can be disposed of in a single repository as this will impact on the long term radiological risk from the site. [26] That radioactivity might be released from the disposal of higher-activity wastes and spent fuel is not disputed; even if actions are taken to minimise the risks e.g. using engineered barriers underground. [27] Such measures will delay, but not prevent the escape of radioactive elements into the environment. Because of this the US Environmental Protection Agency has set

[23] Full title see ref. 15 https://www.iaea.org/Publications/Documents/Conventions/jointconv.html
[24] Swedish Nuclear Fuel and Waste Management Company: Encapsulation Plant http://www.skb.se/Templates/Standard____33911.aspx
[25] Dr Helen Wallace for Greenpeace International 'Rock Solid? A scientific review of geological disposal of high-level radioactive waste', September 2010 http://www.greenpeace.org/eu-unit/en/Publications/2010/rock-solid-a-scientific-review/
[26] For full title see ref. 10. See Para 16 for ref on limits http://www.iaea.org/About/Policy/GC/GC50/GC50InfDocuments/English/gc50inf-3-att5_en.pdf
[27] Nuclear Energy Insider, 'Early lessons from Onkalo', 16 March 2015 http://analysis.nuclearenergyinsider.com/decommissioning/early-lessons-onkalo

radiation dose standards, for up to one million years into the future, to cover the impact of radioactive releases from the Yucca Mountain site - which is still very much disputed as a possible national repository for the USA's spent fuel (the Department of Energy first started examining the site in 1978). [28]

The upper dose limit set for Yucca is 1 mSv per annum from 10,000 years – 1 million years after disposal. This dose limit (for members of the public) is the internationally recognised maximum recommended limit: which should not be exceeded. In the UK, the Office of Nuclear Regulation, in its Safety Assessment Principles (for nuclear plants; waste management facilities etc) advocates a Basic Safety Limit of 1 mSv; and a constraint limit of 0.3 mSv per source in an specific area, or at single site, where there are multiple facilities.[29] The ONR has, however, also set a Basic Safety Objective of 0.02 mSv as a target for nuclear sites. [30]

Whether Australians will find it acceptable that a spent fuel repository could lead to off-site releases that might result in a radiation dose of 1 mSv or whether they would expect exposures from disposal to be kept down to 0.02 mSv, is the kind of question that will have to be dealt with in discussion with communities, regulators and legislators.

The amount of spent fuel under consideration for disposal might even lead to Australia having to find more than one repository; a concern acknowledged by the UK in consideration of its own waste and spent fuel stockpile. [31] Knowing how much waste might come into Australia, and what the final amounts will be for disposal, is crucial: no community or government could reasonably be asked to accept an open-ended commitment to imports, and waste disposal operations, without knowing the inventory and time-scale for disposal.

Concerns over spent fuel are, understandably, one of the key issues around the nuclear debate. As the OECD's Nuclear Energy Agency reports, '*Spent nuclear fuel and high-level waste from the fuel cycle of commercial nuclear power plants represent a small proportion of the radioactive waste produced globally by different industries, but they account for the greatest radioactivity content and longevity. Yet while technologies are well developed and widely employed for the treatment and disposal of the much larger volumes of less radioactive low-level and short-lived intermediate-level waste, no final disposal facilities have yet been fully implemented for spent nuclear fuel and high-level waste. A lack of experience in the complete deployment of deep geological repositories, combined with the extensive periods required for the implementation of back-end solutions, have thus contributed to growing uncertainties about the costs associated with managing spent nuclear fuel and high-level waste. The issue has*

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[28] US EPA 40 CFR Part 197, 'Public Health and Environmental Radiation Protection Standards for Yucca Mountain', Nevada; Final Rule Wednesday, October 15, 2008
http://www.epa.gov/radiation/docs/yucca/yucca_mtn_rule_fed_reg_version.pdf

[29] 'Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment.' Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10) August 2012
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296390/geho1202bklh-e-e.pdf
The document notes 'the maximum constraint of 0.3 mSv/y should be used when determining applications for discharge permits or authorisations from a single new source, defined as "*a facility, or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals*" Thus the 0.3 mSv level applies to a source – e.g. a single plant on a multi-facility site; or in an area which hosts a number of nuclear facilities.

[30] Office for Nuclear Regulation, 'Safety Assessment Principles for Nuclear Facilities', 2014
http://www.onr.org.uk/saps/saps2014.pdf

[31] For full title see ref 13. See paras 3.18-3.20 for issue mentioned
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332890/GDF_White_Paper_FINAL.pdf Paras 3.18- 3.20

become a central challenge for the nuclear industry and a matter of continued concern and debate for the public.' [32]

To date the only operating deep disposal facility for higher activity wastes that the nuclear industry can reference, is the US Waste Isolation Pilot Plant (WIPP) in New Mexico.[33] The waste to be disposed of at that site is limited mainly to plutonium wastes, and some other long-lived transuranic waste; which, while representing some problems, do not represent those of spent fuel because they are not heat generating. The waste inventory for the WIPP was, in general, known - in terms of the amounts estimated for disposal - and more uniform in terms of the types of wastes, than for other repositories; which made planning somewhat easier than for repositories taking a complex mix of wastes. In February 2014 an accident at the WIPP, believed at first to involve a single drum of waste leaking, led to closure of the facility while investigations took place. However, it has since been reported that up to 500 drums of waste were involved. The fault, apparently, lay in the wrong type of cat litter being used to absorb liquids in the barrels of waste; leading to a release of contaminated gases. [34] It has been estimated that the cost of this problem, in terms of recovery of wastes, could be US$240m. [35] It is expected limited operations at the WIPP will resume in 2016. [36]

6. Land ownership and trans-boundary/state issues

Some of those proposing spent fuel disposal appear to have predicated their assumptions on the basis that the best, or even 'good enough' geology, might be found in SA: and that any area chosen can, therefore, be used also to safely dispose of all types of waste and nuclear materials that would result from the various activities listed in the TOR. Linked to assumptions about the geology are presumptions that the targeted community will be willing to host a disposal facility. It was that kind of fundamental error – over geological suitability *and* social acceptability - which the nuclear industry consortium, NIREX, made in the 1990s; and which the UK Government repeated during the more recent Managing Radioactive Waste Safely (MRWS) programme (which officially commenced in 2008 and finished in 2013).

In this context the legal and social elements are essential aspects of any nuclear waste disposal plan: particularly whether the owners of the land which might be thought most suitable for disposal are prepared to allow disposal. These owners might be Aboriginal people, or others who refuse to accept any of these operations on their land. If they refuse to accept any such proposals their views must be respected. On the other hand, no one person, or organisation, can volunteer an area for waste disposal: that is something which has to have agreement at every level, from the Federal Government down to the people who live in the relevant area.

In addition the Royal Commission needs to consider the potential for trans-boundary issues, concerning other states, which might arise over radioactive waste and spent fuel disposal in

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[32] OECD Nuclear Energy Agency, 'The Economics of the Back End of the Nuclear Fuel Cycle.' http://www.oecd-nea.org/ndd/pubs/2013/7061-ebenfc.pdf

[33] For details of what constitutes 'higher activity wastes', in the UK, see page 83 of this 2011 consultation document http://www.westcumbriamrws.org.uk/images/242-Full%20Consultation%20Document%20-%20West%20Cumbria%20MRWS%20Partnership%20November%202011.pdf

[34] World Nuclear Association, 'Wrong kitty litter the culprit for WIPP release', 27 March 2015 http://www.world-nuclear-news.org/RS-Wrong-kitty-litter-the-culript-for-WIPP-release-27030151.html

[35] Nature, 'Nuclear waste facility on high alert over risk of new explosions', 27 May 2014 http://www.nature.com/news/nuclear-waste-facility-on-high-alert-over-risk-of-new-explosions-1.15290
See also Daily Mail 15 March 2015 http://www.dailymail.co.uk/news/article-3014109/Wrong-kitty-litter-led-radiation-leak-New-Mexico-nuke-waste-dump.html

[36] World Nuclear News 'Path mapped to WIPP reopening', 1 October 2014 http://www.world-nuclear-news.org/rs-path-mapped-to-wipp-reopening-0110147.html

South Australia. What if the best or 'good enough' geology straddles the border with another state? Or lies wholly within the boundary of another state? This is precisely the type of question the most recent process to find a nuclear dump in the UK had to grapple with: how to address disposal in an area of suitable geology which might (even only partially) be under council areas that had not volunteered for disposal, but which were next to those considering a repository.

Another matter for consideration is that the disposal site might be in South Australia, yet the predicted pathway for radioactive releases (e.g. due to water flow) could see contamination arising in a neighbouring state. For this reason the States, and the Northern Territory, which share a border with South Australia, must be involved in discussions over any such plans. Canberra and Tasmania would have to be involved also because of the risk of contamination if there was an accident during spent fuel encapsulation; the overland transport of spent fuel; or during the maritime transport of waste/spent fuel around the coast of Australia e.g. in the Bass Strait.

If South Australia was allowed to pursue spent fuel disposal, reprocessing and reactor operations, it might also have to consider a number of large-scale nuclear facilities spread across a large area. The reactors would most likely have to be situated next to the coast to take advantage of sea water as a coolant. For radiological reasons – not having too many hazardous nuclear operations all on the one site – a spent fuel reprocessing plant might have to be sited at another area on the coast. For the disposal facilities it might be required, as envisaged for the UK, that the surface works (including spent fuel stores and encapsulation plant) could be 10km-20km from the underground repository. [37]

7. Social issues – advantages versus disadvantages

Beyond the technical issues and the 'right geology' there are many other complex issues that need to be resolved before a disposal programme could proceed: most important of which there has to be a fully-resourced, informed - and willing – community (having a land owner's consent alone is not sufficient). Disposal cannot be imposed on any community 'after the fact' e.g. after spent fuel imports are agreed.

Yet, even defining a community is problematic; in terms of an area which might be physically impacted on by disposal operations; and by disposal of the spoil – the earth and rock from excavation of the repository. A wider, and equally valid stakeholder community, would include also those industries that could be disadvantaged – even if only by geographical proximity to nuclear activities. The perception of South Australia could change, and not for the better, if it opted to go down the nuclear route. This was an issue during the discussions of the West Cumbria Managing Radioactive Waste Safely (WCMRWS) process, which looked at nuclear waste disposal from 2008 to 2013. For example, preliminary surveys were undertaken on the impact of disposal on, for example, locally 'branded' Cumbrian produce; the relevant reports can be found here. [38]

Regardless of the potential problems with nuclear activities, some people have presented the various nuclear options for South Australia as if they are risk-free; and that they will bring billions into the state coffers: and be a boon for everyone. The issue of the potential economic benefits of a nuclear waste disposal site in West Cumbria, the area that hosts the Sellafield

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[37] 'The Final Report of the West Cumbria Managing Radioactive Waste Safely Partnership', August 2012 http://www.westcumbriamrws.org.uk/images/final-report.pdf
See page 15 regarding 10km. In earlier reports, published during the process which looked at siting a repository in Cumbria, it was stated the surface facilities could possibly be up to 20km distance from an underground facility.
[38] For a complete list of documents see: http://www.westcumbriamrws.org.uk/all_documents.asp

nuclear complex, was debated in depth by the WCMRWS[39] (see also other documents on the WCMRWS website[40]).

Despite government assurance over benefits, the search for a suitable site – for further investigation only – did not progress beyond stage 3. The process was halted in January 2013, when the Conservative-led Cumbria County Council voted against taking it any further; a remarkable outcome given the area is one of the most nuclear dependent economies in Europe; if not globally. The decision not to proceed was taken despite the benefits promised: direct 'cash' benefit packages for local authorities; benefits from jobs and transport infrastructure for the disposal site; and the linked benefits of associated nuclear activities e.g. if a disposal site was found for waste and spent fuel it would make it much easier to get permission to build new reactors at Sellafield in Cumbria.

As Eddie Martin, Conservative leader of the Cumbria Council explained, part of the problem was the degree of cynicism over the benefits which, it was claimed, would flow from hosting a nuclear dump. His comments on the day of the vote, on this issue, are very telling: '*It would be remiss of me not to mention, however, that Britain's Energy Coast Business Cluster (based in Cumbria) is privately funded by nearly 200 organisations who employ over 30,000 people. These organisations rely on work in the nuclear sector. Without the continued Nuclear Investment the nuclear program and its supply chain will be put in jeopardy and a significant number of jobs may be lost. But what of the 52% of children in Sandwith, Whitehaven, who are living in relative poverty next to Sellafield? What is the nuclear industry and the government - any government - doing for them? Please do not mention community benefits; such as we receive are, frankly, derisory...and always have been but, in any case, I am not prepared to prostitute our Cumbrian soul or heritage for a few silver coins.'* [41]

The County Councillors who voted 'no' were not alone in their concerns; many Parish and Town Councils, some immediately adjacent to Sellafield, also voiced their opposition to proceeding with the process. [42] The Cumbrian Association for Local Councils (CALC), the umbrella organisation for towns and parishes, spelt out its opposition to proceeding with a repository in late 2012. As letter from CALC to the Minister explained, only 8 of the 88 town and parish councils had expressed support for proceeding into Stage 4 of the MRWS process; with 43 opposing proceeding. The remaining 37 chose not to express an official view as opinion was split over the issue.[43] The proposal to dispose of waste in Cumbria also saw public protests; with hundreds marching over snow-covered ground to voice their opposition; [44] and hundreds

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[39] For example of the debate on this see: DECC response to Partnership's Community Benefits Principles http://www.westcumbriamrws.org.uk/documents/227-DECC%27s_response_to_the_Parntership%27s_Community_Benefits_Principles_Sept_2011.pdf
[40] See ref 36
[41] Extract, minutes, speech by Eddie Martin, leader of Cumbria County Council, 30 January 2013 http://www.nuclearwasteadvisory.co.uk/wp-content/uploads/2013/02/Eddie_Martin_Speech_30thJan2013.pdf
[42] Response by Ponsonby Parish Council to 2012 consultation on waste disposal in Cumbria http://www.westcumbriamrws.org.uk/images/Consultation%20submission%20-%20Ponsonby%20Parish%20Council.pdf
See response to question 8, page
See also Isle of Man government; only 20 miles west of Sellafield, it is closer to the plant than many areas of Cumbria
http://www.westcumbriamrws.org.uk/images/Consultation%20submission%20-%20Isle%20of%20Man%20Government.pdf
[43] Letter from Cumbrian Association of Local Councils, October 2012
http://www.westcumbriamrws.org.uk/documents/318-Letter_from_CALC_to_DECC_22_October_2012.pdf
[44] BBC 'Protesters march over Cumbrian waste site plans', 26 January 2013
http://www.bbc.co.uk/news/uk-england-cumbria-21214374

more packed into meetings to listen to geology experts express their concerns over the suitability of Cumbria's geology as a safe place for waste disposal. [45]

The growing political and public campaign against the repository, topped off by the no vote from the county council, was a body blow for the industry; which had been relying on councils and communities which are not 'anti-nuclear' to support the disposal plans. Clearly the benefit package on offer, and the possibility of a few hundred jobs, did not outweigh the risk to employment in other industries; and the threat of reputational damage to the area. Cumbria was not going to provide a 'solution' to the existing and future nuclear waste problem by having a potentially unsafe repository foisted on it. [46]

That some of the most economically deprived areas in England are in Cumbria – in Copeland (where Sellafield is situated), in Allerdale (immediately north of Copeland), and Barrow in Furness (south of Copeland) - where the UK's nuclear submarines are built - is an indicator that the nuclear industry does not always bring widespread prosperity to an area. In fact, during the WCMRWS debate many comments were made, often by pro-nuclear politicians, that over the years the economic wealth promised by Sellafield's operations had been very much a hit and miss affair.

Of course, some local people have benefitted from these activities; from employment in reprocessing and decommissioning; but the area has also experienced 'boom and bust' in terms of construction projects, with many workers coming from outside the region. Moreover the large salaries of 'imported' managers were sent back to their home region, or country (in the case of the US and French managers in the consortium presently running Sellafield). [47]

There is a back-story to Cumbria County Council's decision in 2013. It started with the establishment of NIREX in 1982 – an industry body set up to look for a radioactive waste disposal site in the UK. After considering hundreds of different sites, NIREX's investigations led it to conclude that the most suitable geology for further exploration was around the spent fuel reprocessing plants at Dounreay (Scotland) and Sellafield; an announcement greeted with scepticism in many quarters because of the links these areas already had with the nuclear industry. Subsequently NIREX applied to build a rock characterisation facility – a precursor underground facility – but only for the disposal of Intermediate Level Wastes (not the high level wastes from reprocessing, or spent fuel) near Sellafield. In 1996, Cumbria County Council rejected the proposal, as did the Secretary of State; both cited unsuitable geology as a key issue. It was the failure of NIREX to get a site in Cumbria that led to Sellafield's then operators, British Nuclear Fuels Ltd (BNFL) giving £5m of UK taxpayer money to Pangea Limited; the company which proposed Australia become an international dumping ground (a plan that fell at the first hurdle).

Eventually an alternative approach to waste disposal was sought in the UK, with the establishment of CoRWM in 2003. The official process that followed CoRWM's final report,

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[45] Carlisle Times & Star, 'Big turnout at nuclear store meeting', 18 January 2013 http://www.timesandstar.co.uk/news/politics/big-turnout-at-nuclear-store-meeting-1.1028522

[46] Much had been said, throughout the MRWS process, that the majority of the UK's nuclear waste was already at Sellafield – approx 95% by bulk; which was used to justify proposals to dispose of the waste in that region. Whilst reprocessing had created most of the bulk waste, the majority of the spent fuel – and therefore the radioactivity in the inventory – had come from reactors across the UK. Only a relatively small proportion of the radioactivity in the inventory was created by the Magnox reactors at the Sellafield site.

[47] Regeneration in parts of Cumbria, for example the nuclear submarine building programme in Barrow, has come about primarily through billions in government funding for the defence project. Following mass redundancies in the early 1990s, the number of workers at the shipyard dropped from around 14,000 to 2,500 workers. It has taken over 20 years to get the numbers to the present level of 10,000 employees; in the meantime many skilled workers have left the area for employment elsewhere.

which invited communities to volunteer, led to three councils, Copeland, Allerdale and Cumbria County Council 'expressing an interest.' It was acknowledged that this 'volunteering' - by economically threatened areas already dependent on the nuclear industry – was an attempt to safeguard jobs, rather than a sound proposal. In short, it was not seen as straightforward volunteering to help find a solution to radioactive waste; but one based on economic neediness. Because of the economic concerns there were worries over whether the geology of the area - considered unsuitable by leading independent geologists – had become a secondary issue. [48]

That West Cumbria would continue with the process of siting a repository, that it was a foregone conclusion, led officials to become overly confident – and hold internal discussions about accelerating the disposal process without involving local people in what that might mean. [49] Those discussions were one of a number of actions which, when they came to light, angered Cumbrians; who felt they were being taken for granted.

The Royal Commission can gain an understanding of the complexity of the debate and the divergent views of those involved through the documents produced during the WCMRWS process, the final consultation and the responses to that consultation. [50] These papers, the result of nearly five years of consultation and discussion – just to get to the next stage of investigating the *possible* disposal of radioactive waste in Cumbria - indicate the extent of knowledge gathering, research and discussion which is needed to progress such matters.

After years of encouraging West Cumbrian communities to volunteer to host a repository, and working with local and regional government, and others, on whether to progress such proposals, the political atmosphere over volunteering has now changed. The UK Government still hopes communities will volunteer; but if they do engage in the process they will not take the final decision on a repository. The House of Commons, on the last sitting day before Parliament closed for the General Election, passed legislation which gives the power over the final decision, on where a repository might be sited, to the Secretary of State for Energy and Climate Change. This move effectively takes away the community's agreed 'right of veto' much earlier in the repository siting process; in the previous MRWS process the veto could have been used much later.

There is also the possibility a repository could be forced onto a community, as the most recent White Paper on radioactive waste, states: '*4.6 As has been the case since 2008, the UK Government continues to reserve the right to explore other approaches in the event that, at some point in the future, such an (voluntary) approach does not look likely to work.'* [51]

Yet, on the issue of a disposal site in the UK, the World Nuclear Association (WNA) report referenced in the Royal Commission's issue paper, states that *'deep disposal has been selected and the site selection process has commenced'.* [52] The truth is the process in the UK is pretty much back at square one; except that the UK Government has moved to have much more control over nuclear waste disposal following Cumbria's refusal to take forward the search

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[48] Response to MRWS Consultation from Prof Stuart Haszeldine, OBE FRSE March 2012
http://www.geos.ed.ac.uk/homes/rsh/Haszeldine_Response_to_westCumbria_MRWS_Consultation.pdf
Response to MRWS Consultation, Emeritus Prof David Smythe, March 2012
http://www.geos.ed.ac.uk/homes/rsh/Smythe_consultation_response_march_2012.pdf

[49] Response to MRWS Consultation, Jean McSorley, March 2012. See pages 16-17
http://mrwsold.org.uk/wp-content/uploads/2011/11/McSorley_CONSULT_RESPONSE_23_MARCH_2012-FINAL1.pdf

[50] WCMRWS website http://www.westcumbriamrws.org.uk/page/123/Consultation-submissions.htm

[51] For full details see reference number 13
https://www.gov.uk/government/publications/implementing-geological-disposal

[52] As referenced by the NFCRC http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Appendices/Radioactive-Waste-Management-Appendix-2--Storage-and-Disposal-Options/

for a nuclear dump site. Would Australians accept their government having the right to impose a disposal facility upon them – for foreign radioactive wastes?

Another question for Australians to consider is: who stands to gain from importing spent fuel for storage and disposal? Who might gain from reprocessing and reactor operations; and from introducing novel (and risky) reactor designs – the untested commercial fast reactor processes that are being promoted? What hard evidence has been submitted – and what are the vested interests of those concerned – that the proposals they are putting forward will bring widespread and sustainable economic benefits? These are the kinds of questions that need to be discussed because there is nothing to date that gives any certainty that South Australia, let alone the rest of Australia, will gain economically (or significantly reduce its carbon emissions) through the nuclear programmes being proposed.

If a community like Cumbria, which is so reliant on the nuclear industry, said no to a disposal site – because it did not believe claims about the benefits – how much greater will be the scepticism amongst Australians asked to take foreign nuclear wastes? How much greater also will be the suspicion that the organisations that will benefit the most will be the overseas nuclear companies who will gain by offloading very problematic radioactive waste – with its inherent political burden –by getting Australia to deal with it instead.

8. Spent fuel reprocessing – civil purposes

Most conventional spent fuel is made up of metal pellets formed into a fuel rod by encasing it in an outer cladding. The cladding is dependent on the type of reactor fuel used in e.g. light water reactors use zircaloy or steel for fuel cladding.

Spent fuel reprocessing involves stripping the fuel rod of its cladding; which then becomes intermediate level waste. The fuel rods are then chemically dissolved; followed by separation of the component parts into three streams: fission product (high level liquid waste – HLW), plutonium and uranium. The plutonium extracted during this process is regarded as weapons usable; although not weapons grade. [53] (The issues paper from the Royal Commission which, amongst other things, covers spent fuel reprocessing, does not mention that reprocessing results in separated weapons-usable plutonium).

Reprocessing can also lead to significant aerial and marine discharges - the latter in particular being a long-standing source of contention in relation to Sellafield's operations - unless the most exacting state-of-the-art technology is employed.[54] During reprocessing a number of waste products are created e.g. gases, liquids, irradiated steel and sludges.
Reprocessing does not actually reduce the radioactivity in the spent fuel; in effect it splits it up and moves it around. Moreover, reprocessing significantly increases the volumes of solid wastes. The reprocessing of 4.0m^3 of spent fuel results in the production of 2.5m^3 of high level waste (HLW), 40m^3 of intermediate level waste (ILW) and 600m^3 of low level waste (LLW): a staggering total of 642.5m^3 – or 160 times the original spent fuel volume. [55] The different wastes that result from reprocessing – which require different types of conditioning – as well as the volume for disposal, all add to the technical and financial complexities for any country

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[53] Oxford Research Group 'The Proliferation Consequences of Global Stocks of Separated Civil Plutonium', Oxford Research Group, June 2005
http://www.oxfordresearchgroup.org.uk/sites/default/files/plutonium.pdf

[54] NFLA / KIMO report on radioactive discharge concerns at Sellafield to the OSPAR Commission Radioactive Substances Committee, February 2014
http://www.nuclearpolicy.info/docs/radwaste/Rad_Waste_Brfg_47_OSPAR_RSC_2014.pdf

[55] House of Commons, The Environment Committee, First Report, 12th June 1985, Volume 1, Page 281.*Source: CEGB Evidence to Sizewell B Public Inquiry*

considering this option. Note: LLW, ILW and/or HLW are produced through operating other nuclear facilities e.g. nuclear reactors. [56]

Fresh water is usually used – for cooling and shielding the spent fuel – while it is in ponds awaiting reprocessing. Where any Australian reprocessing plant, or reactors, would source their water, for cooling systems or emergencies, is an issue which needs to be considered.

Spent fuel reprocessing has been undertaken by different countries for different reasons; to extract plutonium for military purposes; or to use the recovered plutonium and uranium for electricity production in civil nuclear reactors. Few countries have adopted commercial reprocessing on a large scale; because of the environmental risks and also because of the technical and economic difficulties with such programmes. Only around 5 – 10% of world annual spent fuel arisings are sent for reprocessing; with the rest stored pending final disposal. [57]

France, India, the UK, Russia and Japan currently reprocess spent fuel for civil purposes. [58] Japan's first reprocessing plant, Tokai Mura – designed to reprocess around 90 tonnes of spent fuel per annum - experienced a number of incidents, including a serious accident in late 1999, which led to two workers dying.[59] Tokai reprocessed its last batch of spent fuel in 2006. [60] Japan's newer commercial reprocessing plant at Rokkasho Mura experienced significant problems during commissioning. First proposed in 1985, Rokkasho was due to start commercial reprocessing operations in November 2008. In November 2014, Japan Nuclear Fuel Ltd announced that its plant at Rokkasho would not start operation until March 2016, and not reach full capacity until 2019.[61]

The US abandoned reprocessing for civilian purposes in 1977. The US has, though, accepted some overseas spent fuel as part of its non-proliferation programme.[62] Those imports, small amounts of spent fuel containing highly enriched uranium from research programmes, are very small compared to America's domestic spent fuel arisings. The US has not imported spent fuel from overseas for large scale commercial reprocessing operations.

The only two countries in the EU that have reprocessed foreign spent fuel are France (which has completed its overseas contracts) and the UK. The following examples of problems with reprocessing focus on Sellafield in the UK, but this does not mean the French have not experienced problems at their main civil reprocessing plant, at Cap de la Hague in Normandy.

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[56] Spent fuel, if not reprocessed, is classed as High Level Waste
[57] World Information Service on Energy, submissions to the 'European Parliament Scientific and Technical Options Assessment', November 2001 (page 9)
http://www.wise-paris.org/english/reports/STOAFinalStudyEN.pdf
[58] Processing of Used Nuclear Fuel, World Nuclear Association, April 2015
http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Processing-of-Used-Nuclear-Fuel/
[59] BBC 'Nuclear accident shakes Japan', 30 September 1999
http://news.bbc.co.uk/1/hi/world/asia-pacific/461446.stm
The Tokaimura Accident (29 September 1999)
http://www.mun.ca/biology/scarr/4241_Tokaimura_Accident.html
World Nuclear Association, Tokaimura Criticality Accident, October 2013
http://www.world-nuclear.org/info/safety-and-security/safety-of-plants/tokaimura-criticality-accident/
[60] ibid
http://www.world-nuclear.org/info/safety-and-security/safety-of-plants/tokaimura-criticality-accident/
[61] World Nuclear Association: Japan - Nuclear Fuel Cycle, May 2015
http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan--Nuclear-Fuel-Cycle/
[62] US Nuclear Regulatory Commission report to the US Congress: Highly Enriched Uranium, 12-15 May 2014
http://nnsa.energy.gov/sites/default/files/nnsa/07-14-multiplefiles/May%2014%20-%207_GARY%20LANGLIE%20NRC%20Report%20to%20Congress%20HEU.pdf

La Hague has experienced operational problems and accidents and, like Sellafield, is now host to a large amount of problematic wastes for which France does not have final disposal options. [63]

Concerns over the French plant have, however, been tempered by the national government giving almost unlimited financial and political backing to its domestic nuclear industry; as well as public support - although much eroded since Fukushima - due to the industry supplying up to 75% of the country's electricity. In effect France's domestic electricity market and taxpayer subsidies have protected the industry. More recently, however, La Hague's operator, Areva, has come into conflict with EDF, France's nuclear electricity producer, over spent fuel reprocessing contracts. Ageing plant and a lack of customers are also having a negative impact on Areva's finances and its operational capacity. [64] Areva's reactor business is also in trouble; with EDF recently cleared to offer a takeover of its ailing sister company. [65] The French Government is also going to put public money into a bailout to support Areva; with reports of the amount possibly reaching 10 billion Euros. [66] That Areva, one of the world's most subsidised nuclear operators – which also enjoys political backing - is in trouble, is a matter the Royal Commission needs to note when considering the viability of any company which wants to do business in Australia.

The UK, which has yet to complete its overseas reprocessing contracts, has experienced significant problems with its domestic spent fuel and overseas reprocessing contracts. Major problems have arisen with the UK's most modern facility, the Thermal Oxide Reprocessing Plant; THORP (see pages 22-24). The UK expects to end all commercial reprocessing operations by 2018. No further contracts are envisaged with overseas companies or domestic utilities. On reprocessing domestic spent fuel from the UK's Magnox reactors, the NDA, in its Magnox Operating Plan (No 9), states that it expects the Magnox reprocessing plant to complete the reprocessing of Magnox spent fuel over 2017-2028 - depending on how well the plant operates.

There are many examples of the potential and real financial, environmental, public health and proliferation risks from reprocessing.[67] A number of these issues are discussed below.

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[63] French Nuclear Reprocessing – failure at home, coup d'etat in the United States
https://www.citizen.org/documents/Burnie%20paper%20on%20French%20reprocessing.pdf
Sean Burnie, May 2007
Institute for Energy and Environmental Research & WISE-Paris; On risks at La Hague, see Summary in English of 'Post-Fukushima Nuclear Safety in France: Analysis of the Complementary Safety Assessments (CSAs) Prepared About French Nuclear Facilities', 2 March 2012
http://ieer.org/wp/wp-content/uploads/2012/02/NuclearSafetyFrance_2012-RapportECS_EnglishSummary.pdf

[64] Reuters, 'Crisis for Areva's La Hague plant as clients shun nuclear', 6 May 2015
http://www.reuters.com/article/2015/05/06/us-france-areva-la-hague-idUSKBN0NR0CY20150506

[65] Reuters, 'French govt backs EDF takeover of Areva reactor', 3 June 2015
http://uk.reuters.com/article/2015/06/03/us-areva-m-a-edf-govt-idUKKBN0OJ28920150603

[66] Reneweconomy, 'France begins its costly nuclear bailout', 12 June 2015
http://reneweconomy.com.au/2015/france-begins-its-costly-nuclear-bailout-49807

[67] Another problem with Sellafield was spent fuel reprocessing also caused it to be a heavily polluting facility. The House of Commons Environment Committee noted in its 1986 report that Sellafield was '*the largest recorded source of radioactive discharges in the world and, as a result, the Irish Sea is the most radioactive in the world.*' Retrofitting, to reduce radioactive discharges and decrease radiation exposures to the public – which were seen as too high - was claimed to be an unfair economic burden by Sellafield management: and also a risk to workers as it risks increasing radiation doses as more radioactive waste was kept on site. The row over the contamination of the sea (which spread well beyond the UK's territorial waters) and public exposure from discharges – versus more liquid and solid wastes on site and potentially increasing worker doses (with the possibility of spending more money to avoid further

9. Thermal Oxide Reprocessing Plant (THORP) UK

THORP was built at Sellafield to reprocess spent fuel from the UK and several overseas utilities; in Switzerland, the Netherlands, Japan, Italy and Germany. Under the reprocessing contracts, the HLW is returned to customer countries; with the bulkier intermediate level waste created by reprocessing kept under a substitution agreement in which a corresponding amount of radioactivity is included in the HLW returned (whether all customer countries will, eventually, take back their HLW is unclear). The plutonium recovered from foreign spent fuel is meant to be returned to customer utilities as MOX fuel – for reuse in reactors (see pages 24-27).

Over its first ten years, THORP was to have reprocessed 7000 tonnes of spent fuel; a target it missed by almost 2000 tonnes because of a catalogue of unplanned closures.[68] The first problem at THORP struck within days of its opening, when a spillage of nitric acid ate its way through cables and instrumentation; forcing a shut-down for several weeks.

Further accidents and unplanned stoppages then added to planned outages; contributing to major losses in operating time over the following 20 years – and resulting in the 7000 tonne base-load contracts being completed only by December 2012; some 9 years late. [69]

Almost three of the lost years of THORP's throughput are attributed to the leak, in 2005, inside part of the plant. This incident involved 83,000 litres of nitric acid, containing 22,000 kilograms of highly radioactive spent fuel (including 160 kilograms of plutonium) leaking into an internal structure, which, despite warnings and alarms, had been ignored by workers and management for nine months before action was taken. [70] Rated at Level 3 on the International Nuclear Event Scale, the accident cost BNFL significant loss of face; a Crown Court fine of £500,000, and permanently cut THORP's future spent fuel throughput by almost 50%.

The full transcript of the trial, the prosecution of BNFL by the nuclear regulators over the THORP accident, is attached. [71] The Royal Commission is encouraged to read this transcript, which details the failures by BNFL years before the accident (to implement its own recommendations on safety); failures to ensure the plant was built to specification and ongoing failures and negligence by workers and management in operating the plant. The transcript is particularly relevant in understanding the consequences of an event which did not lead to harm to the environment or human health (such accidents are in the main well known), but which did cause significant economic problems – and which is still having a negative impact on the management of radioactive waste and spent fuel at Sellafield.

As a further damning indictment of THORP's under-performance and its missed annual targets for reprocessing, the new throughput was recently set at around 400 tonnes per year; a pale

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exposure to staff) indicates the kind of unforeseen problems the industry can face years after operations begin.

[68] From BNFL/BNG annual returns for THORP's Baseload period 1994-2003 during which the plant processed a total of 5045 tonnes – i.e. almost 2000t short of 7000t

[69] Sellafield Ltd presentation to the Spent Fuel and Nuclear Materials Working Group of the West Cumbria Sites Stakeholder Group, 22nd January 2013: '*The 7000te Baseload milestone was achieved on 4 December 2012.*'

[70] 83,000 litres (containing 22 tonnes of spent fuel and approx. 160 kg Plutonium (Nuclear Installations Inspectorate) Report , 13th December 2005, Summary, Page 4)

[71] TRANSCRIPT THORP: Ref No: S20060084. IN THE CROWN COURT AT CARLISLE Courts of Justice, Carlisle Cumbria 16th October 2006 Before: THE HONOURABLE MR JUSTICE OPENSHAW: REGINA –V – BRITISH NUCLEAR GROUP SELLAFIELD LTD
http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/8065.pdf
Judgement and sentence, Justice Openshaw, October 16 2006
http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/8066.pdf

shadow of BNFL's original claim that THORP would reprocess 1000 tonnes per year in the first ten years of operation (a design target not once achieved) and 800 tonnes per year thereafter: a figure now wholly out of THORP's reach. [72]

Little wonder that overseas companies, from whom two-thirds of the plant's base-load order book had been secured, soon lost faith in THORP - and patience with Sellafield's management. At a meeting in 2000, the frustrated overseas companies complained of BNFL's inability to reprocess their fuel within the contracted timeline. They also expressed their annoyance at the ever rising costs forced on them by BNFL; including the additional charges being levied for plant repair and refurbishment because of equipment failure and accidents – the blame for which they placed firmly at Sellafield's door. [73] In 2000-2001, BNFL asked customers to cover £100m in additional capital costs not initially anticipated (approximately US$150m in 2003 dollars).[74]

Against this background it is unsurprising that those customers – on whose continued support BNFL relied - were not prepared to give THORP any further business. Indeed, rather than securing a single new contract from overseas, as originally projected, contracts from German utilities were cancelled in THORP's first year of operation; losing BNFL an estimated £250m. [75] Further overseas contracts, all of which would have been on a cost-plus basis, were subsequently abandoned; resulting in BNFL losing 1000 tonnes of overseas reprocessing business. The majority of the financial impact fell on German utilities who, by 2005, had opted to store their spent fuel at the power station site rather than have it reprocessed, an option they had not anticipated and which cost them dearly.

The price for THORP, initially put at £350m, has since been estimated at £2.83bn; although the final cost is unknown.[76] The projected financial benefit of THORP, yet to be confirmed, is that it would make £500m profit in the first ten years of operation. The repeated refusal by Sellafield's operators to publish individual accounts for THORP raises suspicions that the projected income has not been achieved. It is known, though, that the plant's profitability was dented by the then government's one year delay in approving the plant opening; which BNFL complained was losing THORP £2m per week. That initial loss of some £100m, plus the £260m loss of the early German contracts, would leave little of the projected £500m profit intact. Any balance will have been further eroded by the loss of other overseas business and the costs of accidents – the 2005 leakage accident was estimated by the NDA to have resulted in £112m of lost revenues.[77]

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[72] NDA personal communication with Cumbrians Opposed to a Radioactive Environment (CORE) January 2006. See also NDA presentation to National Stakeholder Group's Nuclear Materials Issues Group, 21st February 2006, Slide 6. Damage by the 2005 accident has left THORP with just one Head-End Accountancy Tank rather than 2 reducing the maximum daily feed of dissolved fuel from ~ 6teU/day (as per original specification) to 3 teU/day and annual throughput max from 1200 to 600teU. (teU – tonnes of enriched uranium).

[73] Written Statement from 'Non-UK Baseload Customers (BLC)' to BNFL at London meeting on 18th September 2000. **"**Such cost increases and uncertainties are commercially highly unsatisfactory and make it impossible to manage our own fuel cycle business economically, given the cost pressure we are under".

[74] Nuclear Fuel, 'BNFL, Overseas Customers Agree on New Reprocessing Contract Terms', 15 October 2001, Ann MacLachlan.

[75] Harold Boulter (former BNFL director) describes in his book ***'Inside Sellafield'*** (ISBN 0 7043 8017 X), page 86 the lost business from Germany valued at £360m – with expected compensation payment of £100m from customers for contract cancellation.

[76] The Independent, 14 November 1993 http://www.independent.co.uk/arts-entertainment/throwing-good-money-after-bad-thorp-british-nuclear-fuels-new-reprocessing-plant-has-cost-nearly-pounds-3bn-to-build-the-plan-to-make-money-recycling-the-nuclear-waste-other-countries-didnt-want-in-their-own-backyards-twenty-years-later-everything-has-changed-but-final-approval-is-now-being-sought-for-an-operation-whose-eventual-costs--in-more-ways-than-one--are-unknown-1504299.html

[77] NDA Annual Report & Accounts 2006/07, Page 11 http://www.nda.gov.uk/publication/annual-report-and-accounts-20067/

The public (planning) inquiry into THORP was held from 1977-78, but the plant only became operational nearly twenty years later in 1997. Put forward as an essential facility needed to recover uranium and plutonium from spent fuel, because uranium stocks would become scarce due to a massive global expansion of nuclear power, the raison d'être for THORP disappeared within a few years of it getting the official go-ahead. There was no huge expansion in nuclear power plants; fresh uranium did not become a prohibitively expensive fuel. Yet even in the early 80s, when THORP was described by The Economist as 'no more than a hole in the ground'; when it could have been cancelled, those backing it continued to promote its construction. Even when licensing the technology and getting the necessary workforce caused further delays (along with lack of government funding) the project staggered on: despite its initial purpose having long since diminished. THORP stands as a glaring example of how projects, particularly those which it is known will be bailed out by governments and/or consumers, can take on a life of their own, and continue in the face of economic reason or environmental justification.

10. Sellafield MOX Plant (SMP)

As noted above, the THORP plant was operated to extract plutonium and uranium for reuse as MOX; mixed oxide fuel. MOX is used, as a partial fuel load (e.g. 30%) in some reactors in Europe. Japanese reactors are also licensed to use MOX, but this is now a very controversial issue following Fukushima. The WNA figure for MOX use in reactors is only 5% of the world's operating reactors. [78]

The UK MOX fuel fabrication plant at Sellafield (SMP) was completed in 1997 but only commenced operations in 2001, after several legal actions; one of which challenged the economic basis for the plant. SMP was built to manufacture 120 tonnes of MOX fuel per year; and licensed to produce fuel only for overseas customers e.g. Germany and Japan. With an operating lifespan of 20 years, SMP produced no fuel whatsoever until its third year of operation; and even then only produced a total of 13 tonnes in its 9 years of operation: a failing which saw a number of contracts having to be sub-contracted to SMP's arch-rivals in Europe. In 2000 SMP's operators, BNFL, became the subject of a damning indictment when it was discovered that quality control data for MOX fuel for Japanese reactors, had been falsified. [79] Poorly manufactured MOX fuel can lead to serious operating problems for reactors in which it is used; it has to be manufactured to the most exact specifications.

Despite dire warnings in 2006 and 2007 from government commissioned consultants Arthur D Little (who had originally provided Westminster glowing reports of the plant's prospects) that without further investment the plant would never operate as originally planned, the NDA continued to support SMP's operation - and in so doing wasted an estimated £1.4bn more of taxpayers' money. An internal government report on the SMP, released in June 2013, revealed that the plant had, in total, cost the taxpayer £2.2bn and that it was 'not fit for purpose'. [80] The SMP was closed in 2011; the final nail in the coffin being Fukushima and the subsequent withdrawal of interest in MOX use by Japanese utilities.

The call for another MOX plant to be built (estimated cost £6bn), by Sellafield's unions and political backers, the day after the announcement that the SMP would be closed, was met with

[78] World Nuclear Association, MOX - Mixed Oxide Fuel, December 2014
http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Mixed-Oxide-Fuel-MOX/
[79] Parliamentary Office of Science and Technology, Mixed Oxide Fuel, Research Briefing, 1 April 2000
http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-137
Office for Nuclear Regulation, 'Pellet falsification, Sellafield MOX plant.'
http://www.onr.org.uk/mox/mox3.htm
[80] The Independent, 'Revealed: £2bn cost of failed Sellafield plant', 9 June 2013.
http://www.independent.co.uk/news/uk/politics/revealed-2bn-cost-of-failed-sellafield-plant-8650779.html

astonishment. [81] Regardless of past problems, the UK Government's currently preferred policy option is to reuse its plutonium stockpile in MOX reactors. This was discussed in evidence given by a senior Whitehall official in 2013; when it was stated that building another MOX plant, to produce fuel for UK reactors only, would be more expensive than the worth of the fuel itself. [82] One of the reasons given for pursuing a MOX programme, regardless of its lack of economic underpinning, is that burning the UK's recovered plutonium (the total stockpile is expected to reach approx. 140 tonnes) will turn it into what is known as 'spent fuel standard': and put it beyond use for weapons purposes. For countries with plutonium already separated from spent fuel, achieving the 'spent fuel standard' might be seen as a strong incentive for MOX reactors. However, that would clearly not be the case for plutonium still 'locked' within spent fuel. Thus, if Australia imported spent fuel, to recover the plutonium for use, it would be removing it from a form which is already at 'spent fuel standard' i.e. radioactive enough to deter anyone from accessing it for nefarious purposes. In such a situation, reprocessing spent fuel and separating plutonium would add to, not detract from, security and proliferation concerns.

Repeating past processes - reprocessing spent fuel, with the possible reuse of plutonium in MOX – is not proposed by the companies hoping to build and operate new reactors in the UK. In 2008 Westinghouse and EDF applied for sign-off on their reactor designs (respectively the AP1000 and the EPR) under the Justification process; a requirement under UK and EU law through which practises involving ionising radiation have to be 'justified' by weighing the disadvantages against the advantages. [83] Neither company applied for, nor was granted, the option of reprocessing the spent fuel from their proposed reactors. Nor was the use of MOX fuel proposed, or cleared, by the Government. The disposal route envisaged for spent fuel from new build in the UK, as in most of the rest of the world, will be 'direct' disposal.

The proposed new MOX plant at Savannah River in the US, which was to have converted Russian and US plutonium into fuel for electricity generation, is beset by a range of technical difficulties; including problems in sourcing components. In late 2014 the plant's builders, Shaw Areva, applied for a ten year extension on the construction licence process. [84] The US MOX plant, entirely government funded, was originally estimated to cost US$4.9bn; but the US Government Accountability Office now estimates it will cost US$7.7bn. The start date for the project, which commenced construction in 2007, has been pushed back from 2016 to 2019. There have been calls by the Union of Concerned Scientists in the US to abandon the project. [85]

Other issues to consider regarding MOX are:

- The heat generation of MOX spent fuel is greater than for conventional low enriched uranium spent fuel; and would require more room in an underground repository for disposal. [86] Any expected saving in terms of volume, by using MOX fuel in reactors to

[81] The Independent, 'Day after Sellafield plant is shut, Government told to build another', 5 August 2011 http://www.independent.co.uk/news/science/day-after-sellafield-plant-is-shut-government-told-to-build-another-2332158.html

[82] Public Accounts Committee, Minutes of Evidence, 4 November 2013 http://www.publications.parliament.uk/pa/cm201314/cmselect/cmpubacc/708/131104.htm

[83] DECC, Regulatory Justification decisions on nuclear reactors, 18 October 2010 https://www.gov.uk/government/publications/regulatory-justification-decisions-on-nuclear-reactors

[84] World Nuclear News, 'More time to build US MOX plant', 17 November 2014 http://www.world-nuclear-news.org/ENF-More-time-to-build-US-MOX-plant-1711144.html

[85] Union of Concerned Scientists, 'Excess Plutonium Disposition', January 2015 http://www.ucsusa.org/nuclear-weapons/nuclear-terrorism/excess-plutonium-disposition#.VS0wOZP1ncc

[86] International Panel on Fissile Materials, 'Managing Spent Fuel from Nuclear Power Reactors', September 2011 http://fissilematerials.org/library/rr10.pdf; page 7

gain a greater energy output, would most likely be offset by the additional spacing needed for MOX spent fuel disposal underground.

- The range of radioisotopes in nuclear waste and materials, and the radiation emitted (alpha, beta or gamma) – as well as the half-life of each isotope – are also key aspects of managing not only spent fuel, but also nuclear materials extracted during reprocessing. A range of plutonium isotopes are separated during reprocessing; all of which require extremely careful management e.g. Plutonium-241, a beta emitter with a half-life of 14.4 years (the general rule of thumb is that it takes ten half-lives for a radioisotope to fully decay).

- One of the problems in processing plutonium into MOX fuel - which requires approx 7% of Plutonium-239 content - is the Plutonium 241, which decays into Americium-241; an isotope with a half-life of 432 years. [87] Americium 241 is an alpha and gamma emitter. [88] This can create problems as the 'in-growth' of Americium-241 - from the decay of Pu-241 - can lead to increased radiation exposure to workers during MOX fuel fabrication. [89] [90]

If Australia imported spent fuel for reprocessing, with a view to reusing the plutonium and uranium in reactors, it would need to build:

- a spent fuel reception/storage facility
- a conventional reprocessing plant
- facilities for the storage of separated plutonium and reprocessed uranium
- HLW tanks (and other waste stores)
- a MOX fuel fabrication facility
- MOX reactors
- MOX spent fuel stores
- waste and spent fuel conditioning plants (in preparation for disposal); and
- a disposal facility/facilities.

Another issue to note when considering other national reprocessing programmes is that the technology emerged from military programmes; it was not a 'jump start' process where workers and technology had to be imported. Reprocessing operations in countries like France and the UK have always been subsidised by large amounts of government money; levies on consumers; or cost-plus contracts with customer companies: an entirely different situation from the one which Australia will face.

Conversion and re-enrichment of uranium separated by reprocessing has been demonstrated by a number of countries - Russia, the Netherlands and the UK – but it is not necessarily worth reprocessing spent fuel to recover uranium. The nuclear industry is somewhat cagey about providing figures of how much of the uranium recovered from reprocessing has been reused. In the UK some 16,000-17,000 tonnes of uranium recovered from approximately 44,000 tonnes of

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[87] US EPA: Americium
http://www.epa.gov/radiation/radionuclides/americium.html#affecthealth
[88] US EPA: Americium
http://www.epa.gov/radiation/radionuclides/americium.html
[89] NDA consultation: 'NDA plutonium options', August 2008
http://www.nda.gov.uk/publication/plutonium-options-for-comment-august-2008/
[90] Another issue, for the disposal of wastes from reprocessing which contain Americium-241, is that it decays into Neptunium-237, an alpha emitter with a half-life of 2.14 million years: this creates a particular problem over the long-term for spent fuel disposal. See Institute for Science and International Security:
http://isis-online.org/uploads/books/documents/New%20chapter%205.pdf
http://www.isis-online.org/uploads/isis-reports/documents/np_237_and_americium.pdf

Magnox spent fuel (UK reactors) has been used to make about 1650 tonnes of enriched AGR fuel.[91] The WNA notes that of uranium recovered through reprocessing, 'most of the separated uranium (RepU) remains in storage.'[92] The Association also notes that, '*allowing for impurities affecting both its treatment and use, RepU value has been assessed as about half that of natural uranium'.* It is highly unlikely Australia will be approached with a view to reprocessing spent fuel and exporting the recovered uranium as the price of natural uranium makes this economically unattractive.

If fewer countries opt not to reprocess their own spent fuel it will not necessarily mean greater amounts of spent fuel for Australia to import for reprocessing. Company policies might be determined by their own domestic laws which, for example, could prevent the export of spent fuel. Customer companies will be aware also of the economic risks, as well as the proliferation implications, of reprocessing. They may not want to increase the risk to the environment of spent fuel transport and reprocessing: indeed some will have strong views on their legal duties and moral obligations not to take unnecessary risks with wastes they have created. There may also be some countries that are reluctant to send spent fuel overseas because they hold the view it is a valuable resource that they might want to exploit in the future. In this regard, what is seen as good for Australia could also be seen as good for others; and perhaps even more attractive in those countries which already have a nuclear workforce which can be employed on reprocessing operations?

11. Wastes from reactor and reprocessing operations

The UK's radioactive waste inventory is a good example for Australia to consider when it examines the range of nuclear activities in the Royal Commission's TOR. Details of these inventories are given in the papers referenced. [93] The relevant inventory, prepared for CoRWM, is attached (there appears to be no web link for it). Although prepared in 2005, this is presented as it best explains the types of waste which have arisen in the UK. It also gives a good overview of what different inventory projections might arise; depending on future nuclear operations.

The following, from a UK White Paper on radioactive waste (2008), gives an idea of the volumes of radioactive wastes and nuclear materials – and the amount of radioactivity in them – which it is proposed to dispose of in a repository (unless reused e.g. plutonium). [94]

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[91] The NDA, in a reply to a FOI request (20th May 2015), could only give figures for uranium recovered from spent fuel owned by the authority; information from commercial operators could not be disclosed.
[92] World Nuclear Association, Processing of Used Nuclear Fuel, April 2015
http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Processing-of-Used-Nuclear-Fuel/

[93] Links to all the NDA's radioactive waste and nuclear materials inventory reports
https://www.nda.gov.uk/ukinventory/the-2013-inventory/2013-inventory-reports/
[94] Various Govt. agencies: 'Managing Radioactive Waste Safely – A Framework for Implementing Geological Disposal', July 2008. Information from table 1 – for table with notes see page 20:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228903/7386.pdf

Materials	Packaged volume Cubic metres (% of total)		Radioactivity Terabecquerels (% of total)	
High level waste HLW (from reprocessing)	1,400	0.3%	36,000,000	41.3%
Intermediate Level Waste ILW	364,000	76.3%	2,2000,000	2.5%
Low-level Waste - LLW – not suitable for shallow burial	17,000	3.6%	<100	0.0%
Spent nuclear fuel	11,200	2.3%	45,000,000	51.6%
Plutonium	3,300	0.7%	4,000,000	4.6%
Uranium	80,000	16.8%	3,000	0.0%
Total	**475,900**	**100**	**87,200,000**	

Supporters of the nuclear industry will point out a number of issues in comparing the UK's waste and nuclear materials inventory with any that might arise in Australia. The UK undertakes military and civil nuclear activities. It might also be said the difficulties the UK has in dealing with its radioactive wastes are due to lax management from the early days, the 1950s and 60s, when the nuclear programme was heavily focussed on weapons production. To a limited extent that latter point is true. It is also true, though, that many of the nuclear waste problems the UK faces, which started in the sixties and continue today, result from civil nuclear activities e.g. reprocessing spent fuel for plutonium and uranium reuse in reactors. So, while it might be true that *exactly* the same problems would not be experienced in Australia in the future – as a result of 'lessons learnt' – it is also likely that unforeseen difficulties could arise for which Australia will have to find its own solution (or be the same problems which still vex other countries).

On the issue that the size of the inventories and range of different types of waste would be different in Australia, and therefore no comparisons can be drawn with the UK, nuclear proponents can make no firm claim over that point. Who knows what will or will not happen: no plans are in place; no clear idea of what might happen has been given. One example of a major problem, the high level liquid waste from reprocessing, is discussed below.

12. High Level Liquid Waste (HLW) tanks at Sellafield

Liquid HLW (which contains the majority of the fission products and radioactivity from spent fuel) is an unavoidable result of conventional spent fuel reprocessing. In the UK the storage and immobilisation of HLW, at Sellafield, has proven problematic. The extremely dangerous liquid HLW, stored in 21 stainless steel tanks, must be constantly cooled and ventilated because it is so radioactive that it generates its own heat. [95] If the cooling system fails the liquid in the tanks could get so hot it would boil: leading to radioactive releases and contamination of the surrounding area.

The UK's nuclear regulator has stated that the consequences of prolonged cooling failure could be 'very severe'. [96] The timings involved are very short; cooling failure would lead to boiling of the waste after 12 hours, and to the tank drying out after three days. A cooling failure in the

[95] Institute for Resource and Security Studies 'High Level Liquid Radioactive Waste at Sellafield: Executive Summary', June 1998. http://www.nuclearpolicy.info/docs/briefings/a99.pdf
[96] Institute for Resource and Security Studies, 'High Level Radioactive Liquid Waste at Sellafield - Risks, Alternative Options and Lessons for Policy: Full Report by Gordon Thompson, June 1998) - Section 4.1 http://www.irss-usa.org/pages/documents/Completew-oapp.pdf

HLW tanks at Sellafield on 1st April 2009 was so serious that the Site Emergency Control Centre arrangements had to be called upon. The 2009 event is one of a series of problems experienced with the tanks; in another incident, it was found that another of the tanks had slowly leaked significant amounts of radioactivity into the ground over a number of years. [97]

Some of the HLW problems at Sellafield are undoubtedly due to lack of foresight – and sheer carelessness – from the earliest days of the site. In the 1950s and 1960s, little thought was given to setting up a HLW immobilisation programme as a necessary follow-on from the creation of the HLW; it was left instead to sit in tanks that became degraded.

More recently, attempts to condition the HLW – by which the liquid wastes are solidified into borosilicate glass (vitrification) - have not been helped by the delays and cost escalation in building facilities needed to increase the rate of immobilisation. For example, the cost of a new evaporator, proposed as part of a programme to increase the amount of HLW sent for vitrification, rose from £90m in 2006, to £400m by 2012 (with a further £80m-£100m expected). [98] Concerns over the price of the evaporator (due to technical issues) - coupled with significant delays to the project - led to a severe caution from the Common's Public Accounts Committee to the NDA over its inability to foresee or control costs. [99]

The HLW vitrification programme is an example of how it would be essential to have every part of all the processes – from spent fuel reception facilities through to waste immobilisation technologies – lined up and ready to work (as planned) if Australia decided on reprocessing. Experience has shown that it is not sensible to delay embarking on waste management plans until years after the problem (the waste) has been created. That everything will run to plan – on cost and on time - with no problems, cannot be guaranteed.

What kind of problems might come from a leak at a HLW tank? There is a slender chance a major technical failure, accident, or malicious act *might* result in only limited contamination e.g. on site. However, such is the nature of HLW – because of its extremely high levels of radioactivity and because it is liquid – that even a limited spread of contamination would cause long-lasting and quite possibly irresolvable problems across a site; and make any further operations untenable.

Contamination could, of course, spread over a wide region from a breach of HLW tanks; depending on the nature of the event that led to the breach. In 2013 the Norwegian Radiation Protection Agency took the unprecedented step of issuing a report which considered an accident involving a release from the HLW tanks at Sellafield. Entitled the *Consequences in Norway after a hypothetical accident at Sellafield (Predicted impacts on the environment);* the report looks at the impact of the release of 1% of the Highly Active Liquor (liquid HLW) at the site. [100] The report considered, in particular, what might happen due to contamination from Caesium-137 in the HLW. Caesium-137, with a half-life of 30 years, is particularly relevant as a large amount of this is in the HLW tanks e.g. an estimate published in 1998 stated the Sellafield HLW tanks contained around 2,100 kg of Caesium-137; compared with the 30 kg of Caesium-137 released in 1986 during the Chernobyl disaster in Ukraine.

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[97] In 1976 excavation work accidently uncovered a huge leak of radioactivity into the ground from a waste storage tank. About 1.8 million gigabecquerels of radioactivity was officially estimated to have leaked out over the previous four years at a rate of 400 litres a day.
[98] Cumbrians Opposed to a Radioactive Environment, 'NDA's Evaporator D Project', 5 January 2012 http://www.corecumbria.co.uk/newsapp/pressreleases/pressmain.asp?StrNewsID=299
[99] House of Commons Public Accounts Committee report, 'Nuclear Decommissioning Authority: Managing Risk at Sellafield', 23 January 2013
http://www.publications.parliament.uk/pa/cm201213/cmselect/cmpubacc/746/746.pdf
[100] Norwegian Radiation Protection Agency, 'Consequences in Norway after a hypothetical accident at Sellafield - Predicted impacts on the environment.'
http://www.nrpa.no/dav/a368e9b53c.pdf

The Norwegian paper estimated, depending on wind speed and direction, that deposition of Caesium-137 in Norway, from Sellafield, could result in contamination levels 7 times higher than that which resulted in Norway from the Chernobyl accident. Due to its half-life, Caesium-137 contamination caused problems for many years after the accident; Norway experienced significant problems with its reindeer farming through contamination of grazing land.

The distance between Sellafield and southern Norway is approximately 650 miles; where, according to estimates in the report, the worst contamination would most likely occur following an accident. The report also estimated radioactive contamination, at lower levels, in more distant regions of northern Norway (1,250 miles from Sellafield). Given this, it is clear the potential for an accident which might result in contamination - from HLW tanks and/or other nuclear facilities – is relevant not only to South Australia, but other areas of Australia also: and indeed possibly those further afield who might be contaminated, such as New Zealand. Adelaide is 1,899 miles from Christchurch on the south island of NZ. The possibility of contamination at such distances needs to be assessed; it should not be dismissed. Chernobyl, which caused short-term higher levels of contamination in the UK, also caused longer-term contamination through Caesium-137. This led to restrictions on the consumption of sheep-meat from hill farms in Scotland; 1,520 miles from Ukraine. Many other upland areas of the UK, in particular Cumbria and parts of Wales, were also affected by the fallout. The restrictions in the UK following Chernobyl were only lifted in 2012; twenty-six years after the accident. [101] The cost of dealing with the immediate and long-term impact of the fallout from Chernobyl in the UK, and other European countries, was met by the relevant national governments.

To give a sense of how radioactive Caesium-137 is, the amount of it released from Chernobyl - which caused a fine dusting of radioactive contamination out to the Atlantic fringes of Europe – was equivalent to approximately fifteen two-kilogram bags of sugar. That led to contamination which, although classed as ‘low level’, was sufficient to cause short-term contamination of some water sources and foodstuffs, and longer term contamination of land and livestock, right across Europe. As the UN has reported, Belarus, an immediate neighbour of Ukraine, suffered significantly as a result of contamination from the radioactive releases from the shattered reactor. [102]

Nor is the disaster completely dealt with. A large area around Chernobyl is still a restricted zone. Only as recently as April this year, the EU committed a further 70 million Euros to help pay for a sarcophagus to secure the crippled reactor. [103] This latest amount follows tens of millions of Euros already donated to help Ukraine since the accident.

If Australia is to consider a ‘buffer zone’, to protect people and the environment from the short-term and long-term consequences of a major release of radioactivity from large scale nuclear facilities, it will need to think not only of a 2km or 3km evacuation zones around plants; but also how big an area might have to come under countermeasures such as restricted livestock grazing.

It is possible that Australia could be asked to take HLW from reprocessing; such as that which the UK is currently turning into[104] glass blocks. Although this waste is not high in volume it is

[101] The Telegraph, ‘Chernobyl sheep movement restrictions finally lifted’, 20 March 2012 http://www.telegraph.co.uk/news/uknews/9156393/Chernobyl-sheep-movement-restrictions-finally-lifted.html
[102] The United Nations and Chernobyl: briefing on the Republic of Belarus. http://www.un.org/ha/chernobyl/belarus.html
[103] RT, ‘EU commits Euros70mn to make Chernobyl exclusion zone ‘safe again’, 28 April 2015 http://rt.com/news/253601-eu-70million-chernobyl-ukraine/
[104] The percentages given are from CoRWM’s inventory report of 2005. The proportion of radioactivity from any given waste stream cannot be seen as absolute e.g. because the final amount of spent fuel for disposal is not yet determined.

very radioactive. In the UK the HLW, from legacy wastes, accounts for approx 41% of the radioactivity in the inventory for disposal (with 51% contained in waste spent fuel which will not be reprocessed). If Australia were to accept HLW, there is every chance that it would also be asked to take other 'higher activity wastes' – such as Intermediate Level Wastes (as per the definition for these wastes in the UK[105]) as this waste, like the HLW, has no reuse potential. Proliferation concerns should not arise with these wastes; but safety and security around transport, packaging and disposal operations, along with funding, would be matters for consideration.

13. Costs / Liabilities

Under international law, it is national governments which risk shouldering the burden, at least in part, for the costs of countermeasures - human and environmental protection - should there be a major accident at a facility owned by private nuclear corporations. The most recent amendments to the international liability (insurance) regime, although appearing to increase the amounts that would be paid by nuclear companies, also set a financial limit on the companies: which is woefully inadequate to meet the full monetary costs of a major accident. [106] The cap on operator liability leaves the taxpayer at risk; and victims with no route to full compensation. A report on this by specialists in the field, which examines the impact of Fukushima, and looks at the relevant liability systems, is attached. [107] The Royal Commission is strongly recommended to read this report.

There are other aspects of nuclear finance deals that need considering by Australia if it is to go down the nuclear path. An example of this is the discussion over the costs of new reactors proposed for the UK.

14. Hinkley C – new reactors in the UK

The go ahead for new reactors in the UK, in 2006, ended in failure because the original consultation played down the impacts of waste and spent fuel from new build. This landed the UK Government in the High Court, facing a judicial review by Greenpeace UK. The successful legal action, in early 2007, saw the judge condemn the official consultation on new build; in particular it was concluded that the first consultation had been '*seriously misleading as to CoRWM's position on new nuclear waste*.'[108] Indeed, the Government had wilfully ignored CoRWM's recommendations that new build wastes should be considered separately from existing (legacy) waste; and that CoRWM's proposal to dispose of radioactive waste must not be extended to include new build wastes and spent fuel.

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[105] NDA 'An overview of NDA higher activity waste', February 2012, See section 2.1 http://www.nda.gov.uk/wp-content/uploads/2012/02/An-overview-of-NDA-higher-activity-waste-February-2012.pdf

[106] Greenpeace International, 'Greenpeace condemns the new International Nuclear Liability Convention', 15 April 2015
http://www.greenpeace.org/international/en/press/releases/Greenpeace-condemns-the-new-International-Nuclear-Liability-Convention/

[107] Expert report for Greenpeace International, 'Fukushima fallout', February 2013
http://www.greenpeace.org/international/Global/international/publications/nuclear/2013/FukushimaFallout.pdf

[108] See paragraph 102. CO/8197/2006 IN THE HIGH COURT OF JUSTICE QUEEN'S BENCH DIVISION ADMINISTRATIVE COURT Royal Courts of Justice London, Thursday, 15th February 2007
B E F O R E: MR JUSTICE SULLIVAN
THE QUEEN ON THE APPLICATION OF GREENPEACE LIMITED (Claimant)
- v- SECRETARY OF STATE FOR TRADE AND INDUSTRY (Defendant)
http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/ERJRSullivanJudgement.pdf

The UK Government then moved to reduce the risk of further challenge to its policy, by creating a new unit to facilitate new reactors within the Department of Energy and Climate Change; the Office for Nuclear Development (OND). The OND then took over radioactive waste policy from the Department for Environment, Food and Rural Affairs; giving it control over all the processes concerning legacy *and* new build wastes and spent fuel. A couple of years later the OND also took over decision making on plutonium from the NDA. Various laws were also changed, such as those covering planning, to make it easier for new reactors to be built.

Despite a second questionable consultation, new reactors were subsequently given a green light in 2008. [109] Since that decision all the UK companies that were initially interested in taking part in new build – along with some overseas nuclear operators (e.g. Germany's RWE) - have withdrawn from the programme.

The current frontrunner to build Britain's first reactor in 20 years is Electricite de France (EDF); 85% owned by the French Government. It proposes to build reactors at the existing nuclear site at Hinkley in Somerset, England. The new nuclear station of Hinkley C will be comprised of two EPRs, each with a capacity of 1.6GWe. They will use conventional uranium fuel; the spent fuel will not be reprocessed.

Due to government offers to facilitate new build, nuclear industry optimism was high; so much so that by 2009 the head of EDF in the UK was claiming that, if the conditions were right, people would be cooking their Christmas dinners with electricity supplied by Hinkley C in 2017. [110]

One move, however, that appeared not to favour the industry was that it had been told it would have to pay for its waste and spent fuel costs. [111] This policy, issued in 2008, stated:

'New nuclear power station operators will be required by law to set aside money from day one of generating electricity for their eventual decommissioning and waste costs, Business Secretary John Hutton made clear today.

Draft guidance published today sets out how clauses in the Energy Bill requiring operators of new nuclear power stations to meet the full cost of decommissioning and their full share of waste management costs would work.

Companies would be required to:

** Demonstrate detailed and costed plans for decommissioning, waste management and disposal, before they even begin construction of a nuclear power station;*

** Set money aside into a secure and independent fund from day one of generating electricity; and*

** Have additional security in place to supplement the Fund should it be insufficient, for example, if the power station closes early.* (emphasis added).' [112]

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[109] UK Government, 'Meeting the Energy Challenge – A White Paper on Nuclear Power', January 2008 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228944/7296.pdf

[110] Utility Week, 'Nuclear dinner a turkey?' 17 February 2010 http://utilityweek.co.uk/news/Nuclear-dinner-a-turkey/803432#.VZaNJfn4Hcc

[111] BBC, 'New nuclear plants get go-ahead', BBC, 10 January 2008 http://news.bbc.co.uk/1/hi/uk_politics/7179579.stm

[112] Dept for Business, Enterprise and Regulatory Reform, 'Clean-up fund is precondition for new nuclear – Hutton,' News Release (2008/040) Government News Network on 22 February 2008 http://www.nce.co.uk/clean-up-fund-is-precondition-for-new-nuclear-hutton/766426.article

The Conservative−Liberal Democrat coalition government which formed the next UK administration also said new reactors would not be subsidised: and that legislation would be passed to ensure operators of new reactors would be made to pay for the full costs of decommissioning, waste management and disposal. [113] However, one part of the official policy that was of help to the industry was that the disposal costs of ILW and spent fuel would be capped.[114] Capping these costs raised concerns that there might yet be a subsidy; as the sums needed for disposal could well increase, over and above any funding set aside, in 100 years before disposal takes place. [115]

Having claimed it would not need any subsidy or underwriting for reactor construction, the nuclear industry then lobbied for the opposite. First EDF got the government to agree to guarantee the project debt for Hinkley. [116] At the same time, because of the spiralling estimates for reactor construction costs, EDF lobbied for, and was granted, government approval for a 'contract for difference' (CFD) - or 'strike price' - for electricity from Hinkley.[117] The CFD was to subsidise operating costs to give certainty to investors - who were concerned they would not see repayment of their investment. From the perspective of potential investors in Hinkley, concerns that they might not see a return on their investment appeared well founded. [118] In 2013, during parliamentary discussions on the CFD, it had been stated the cost of new build at Hinkley would be £8bn per reactor. [119] Yet by late 2014, it was reported that the EU estimated the cost of Hinkley's two reactors at £24.5bn (with the possibility of the final cost rising to £34bn). [120]

The CFD deal, between EDF and the UK Government, will see a subsidised rate for electricity - for 35 years (rising with inflation) of £92.50 per megawatt hour (MWh): twice that of the current wholesale cost of UK electricity of £45 per MWh. The CFD kicks-in if the price of electricity from Hinkley C falls below £92.50; when the additional monies will be paid by the government to EDF. If the wholesale price is higher than £92.50, EDF is meant to repay the difference to the

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UK Government, 'A White Paper on Nuclear Power', January 2008. See e.g. para 1 and page 6; para 89 http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file43006.pdf

[113] Speech by the then Minister announcing new nuclear waste cost expectations, 13 October 2011 https://www.gov.uk/government/speeches/the-rt-hon-chris-huhne-mp-speech-to-the-royal-society-why-the-future-of-nuclear-power-will-be-different
World Nuclear News, 'Waste costs for New Build', 8 December 2011 http://www.world-nuclear-news.org/WR_Waste_costs_for_UK_new_build_0912111.html

[114] Financial Times, Pledge to cap costs of decommissioning', 11 January 2008 http://www.ft.com/cms/s/0/aed4009e-bff9-11dc-8052-0000779fd2ac.html#axzz3f7AjabZS

[115] Annex III to Greenpeace EU submission to the European Competition Commission 7 April 2014 (paper previously submitted, March 2011, in response to UK Government consultation) http://www.greenpeace.org/eu-unit/Global/eu-unit/reports-briefings/2014/State%20aid%20SA.34947%20%282013C%29%20Greenpeace%20Annex%20III.pdf

[116] DECC, 'State aid approval for Hinkley Point C nuclear power plant', 8 October 2014 https://www.gov.uk/government/news/state-aid-approval-for-hinkley-point-c-nuclear-power-plant

[117] BBC, Q&A: Nuclear strike price, 21 October 2013 http://www.bbc.co.uk/news/business-22772441

[118] 'Subsidising the nuclear industry', briefing for government, 26 March 2012 http://tomburke.co.uk/wp-content/uploads/2012/03/subsidising_nuclear_26March.pdf

[119] Nucleonics Week, "EPR costs in Finland, France not sustainable, Areva executive says", 23 May 2013.

[120] European Commission, 8 Oct 2014, http://europa.eu/rapid/press-release_IP-14-1093_en.htm
The Telegraph, 'Hinkley Point nuclear plant to cost £24.5bn', 8 October 2014 www.telegraph.co.uk/finance/newsbysector/energy/11148193/Hinkley-Point-nuclear-plant-to-cost-34bn-EU-says.html

government. The state aid subsidy for the Hinkley deal is estimated at £1bn per annum over the 35-year contract. [121]

It is not surprising EDF lobbied for a guaranteed price for electricity; the potential for a large scale nuclear operator failing is very much a recent experience in the UK - as happened with British Energy when, in 2002, the price of electricity fell significantly. British Energy was forced to apply for a government bailout; leading the UK, in 2004, to apply to use state aid intervention to prevent the company going into liquidation. British Energy was sold to EDF in 2008, after the government had agreed to pick up the tab for its existing spent fuel and waste liabilities. [122]

Westminster had argued that because the cost of the CFD would fall mainly on electricity consumers – not taxpayers per se – it did not amount to a state aid subsidy. The EU Competition Commission, which oversees such matters, felt differently due to the nature of the CFD guarantee; and called the agreement in for investigation. [123] In October 2014, the EU cleared the UK Government state aid proposal, leaving it to finalise the deal with EDF (final agreement has not yet been reached). Since then, the governments of Austria and Luxembourg, along with some European and UK electricity companies, have announced their intention to appeal, in the European Court, against the EU Commission's decision to allow the UK to implement the CFD.[124] Reports have also stated that German lawmakers have said the Hinkley CFD is illegal and should be annulled.[125]

At the same time concerns were growing around reactor construction and operating costs, there were also increasing worries - for EDF and other industry players – over the additional several billion needed for reactor decommissioning; waste and spent fuel storage and conditioning pre-disposal; and disposal costs - which will be the largest portion of new build waste management costs (these issues are also discussed, in relation to possible nuclear programmes in Australia, on pages 37-42). In particular the industry had concerns over how the methodology for funding ILW and spent fuel disposal from new build – known as the Waste Transfer Price (WTP) – will be determined. The main reasons for the industry's concerns are that the WTP measures will cover ILW and spent fuel disposal from *all* future UK nuclear reactors; therefore whatever is decided will impact across the whole industry. Because of the risk of a shortfall in waste disposal funding - and the potential for subsidy - the WTP methodology is set to go before the EU Competition Commission: with the attendant risk, for the industry, that the WTP might fall foul of competition rules and be declared an illegal subsidy.

It has since come to light that in 2013, before the CFD was agreed by the EU, the UK Government, in a behind the scenes deal, had also agreed that all decommissioning, waste and spent fuel costs would come under the CFD. [126] Having all waste costs guaranteed under the

[121] See ref. 110
http://tomburke.co.uk/wp-content/uploads/2012/03/subsidising_nuclear_26March.pdf
[122] The Guardian, 'Taxpayers £184m to aid private energy firm', 18 July 2005
http://www.theguardian.com/environment/2005/jul/18/energy.business
[123] Professional Engineer (IMechE), 'European Commission to probe nuclear strike price plans', 18 December 2013
http://www.imeche.org/news/blog/european-commission-to-probe-nuclear-strike-price-plans
[124] The Telegraph, 'Austria to file legal complaint against UK's Hinkley Point plans', 23 June 2015
http://www.telegraph.co.uk/finance/newsbysector/energy/11694857/Austria-to-file-legal-complaint-against-UKs-Hinkley-Point-nuclear-plans.html
[125] Sputnik International, 'German lawmakers call for end to subsidies as nuclear failures continue', 17 June 2015
http://sputniknews.com/europe/20150617/1023469374.html#ixzz3dP5kVXnJ
[126] The Independent, 'Treasury rebuked by EU over hidden nuclear costs, 27 October 2014
http://www.independent.co.uk/news/business/news/treasury-rebuked-by-eu-over-hidden-nuclear-costs-9819900.html

CFD means the subsidy will be higher than it would be for construction and operating costs alone. Because of this, when the WTP is finally put before the EU (it has not yet been fully submitted) the issue is likely to receive closer scrutiny from the Competition Commission.

Ultimately the WTP on waste and spent fuel costs, along with the CFD, will have to be signed off together by the Secretary of State; although there is no firm date for when this might happen. It is unlikely to be finalised until mid-late 2016; because the WTP first has to go before the EU - and because of the legal challenges over the CFD itself. Yet back in February 2008, the then Secretary of State, following the advice of officials and consultants, claimed that the first deal covering ILW and spent fuel (the WTP) could be settled by mid-2009. [127] As with the CFD, most delays to date over a deal on the WTP have resulted from the government and companies being unable to reach an agreement; not from EU intervention (see further details of ILW and spent fuel subsidy pages 38-44).

It should also be noted that government policy has always been that new build companies would not be expected to find a site for, or solely fund, their own nuclear waste disposal repository. The agreement is that commercial nuclear operators will hand over the necessary funds to the NDA's Radioactive Waste Management Ltd., which will build a nuclear waste repository for legacy *and* new build wastes (an assumption challenged during the MRWS process).[128] The agreement is that the government would pay for its waste disposal from past (and some existing) operations; and new build operators would pay their share of waste and spent fuel storage and packaging/encapsulation costs pre-disposal – and their share of disposal costs (for information on cost sharing see page 40). Even under the proposed cost-sharing and subsidy scheme, there might still be a further call on public money if the nuclear operators fail to put aside enough of the taxpayer/CFD funding for their waste costs. Of course, the WTP is not a certainty; the industry might well find itself having to fund its waste costs as the EU could reject the UK Government's proposals over the WTP.

Nuclear operators are not alone in receiving subsidies; these are also given to renewables in the UK: although the renewables subsidies are for 15 years, not 35 years as is the case with nuclear plants. The point here is that nuclear power companies, which once stated they did not need subsidies, asked for them to support their construction, operating and waste costs; otherwise they would not take the risk of investment.

What the changing estimates for the price of new reactors reflects is the reality that all prices are subject to increases due to inflation; changes in interest rates; and safety improvements - such as those made following Fukushima. It all demonstrates that, in general, the price put forward for a nuclear reactor at the beginning can be vastly different from the actual cost. The support subsidies for construction, electricity generation and waste and spent fuel management are also a graphic example of the failure of the system originally proposed for financing new build. Many of those who gave assurances there would be no subsidies for new build - ministers, officials and consultants - have since left the government or moved on to other posts. They are no longer around to witness the construction delays - or the abject failure to establish the waste and spent fuel funding agreements which, it was said, would protect taxpayers.

The timeline for Hinkley's reactors to become operational – if all the outstanding finance deals are settled; and the funding agreements for ILW and spent fuel disposal are cleared, and all technical matters through all stages of licensing are settled - is put at 2023/2024 at the earliest.

Further information on this issue is contained in emails to the author, which will be forwarded to the Commission

[127] New Civil Engineer, 'Clean-up fund is pre-condition for new nuclear – Hutton', 22 February 2008 http://www.nce.co.uk/clean-up-fund-is-precondition-for-new-nuclear-hutton/766426.article

[128] NDA, 'Creates new subsidiary, 1 April 2014 http://www.nda.gov.uk/2014/04/nda-creates-new-subsidiary/

That latest deadline, though, now looks uncertain as in early April 2015, it was reported EDF was going to lay-off 400 workers engaged on pre-construction works, while it delayed – yet again – its final investment decision. [129] It was claimed the delay was due, in part, to another problem EDF is facing; how to settle a deal with the Chinese companies which, it hopes, will become co-financers of the project. [130] (It is understood that concerns over Chinese involvement in the UK's nuclear industry have led the UK Government to start discussions over whether it can hold a 'golden share' in the Hinkley project; to give it oversight over foreign ownership and health and safety). [131]

EDF has recently said that although it is making progress on investment talks for Hinkley, it will not go to the consultation stage on Sizewell, its second proposed nuclear project "until we know how we are paying for the first." [132] All things considered, it is more likely the final decision on whether to proceed with Hinkley will be made not in 2015, but in 2016; if then. All the delays will impact not only on EDF's other plans, but also on those of other company's such as NuGen - which proposes to build three reactors at Moorside near Sellafield. NuGen is unlikely to proceed if Hinkley does not go-ahead; even though the UK Government has agreed to provide some funding for elements of Moorside's development. [133] Last year NuGen put back the date when it will take up the full option on the land - and make the final investment decision on the reactors - from 2015 to 2018. Delays might also arise from construction and design problems, as the reactor NuGen proposes to deploy, Westinghouse's AP1000, is not yet a tried and tested design.

There is no likelihood of direct government investment in Hinkley (even though the agreed subsidies are very substantial). Only recently the UK Chancellor, a Conservative minister and supporter of nuclear power, has gone on the record as saying the government could not afford to build the Hinkley reactors; and that other promised projects could not be funded if it were to do so. [134] The amounts needed to build Hinkley are now also being seriously questioned by commentators, with one recent article in The Sunday Times noting:

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[129] The Telegraph, 'EDF cuts workers at Hinkley nuclear project pending deal', 2 April 2015
http://www.telegraph.co.uk/finance/newsbysector/utilities/11512472/EDF-cuts-workers-at-Hinkley-nuclear-project-pending-deal.html
The Guardian, 'Hinkley Point C nuclear workers face layoff', 2April 2015
http://www.theguardian.com/environment/2015/apr/02/hinkley-point-c-nuclear-project-workers-face-layoff-power-station-investment-edf

[130] For completeness, and also to give an idea of the shifting nature of large-scale nuclear projects, Saudi Arabia and Qatar have also been mooted as possible co-financers of Hinkley.
Intersectinsight, 'Saudi keen on stakes in Hinkley nuclear power project', 19 November 2014
http://www.intersectinsight.com/saudi-electric-keen-stakes-hinkley-nuclear-power-project/
Nuclear Energy Insider, 'Qatar eyes investment in Hinkley Point', 8 December 2014
http://analysis.nuclearenergyinsider.com/new-build/qatar-eyes-investment-hinkley-point

[131] The Independent, 'Government's golden share request could stall construction of Hinkley C nuclear plant,'
5 March 2015
http://www.independent.co.uk/news/business/news/governments-golden-share-request-could-stall-construction-of-hinkley-c-nuclear-plant-10086821.html

[132] The Ipswich Star, 'EDF says it has not been sitting on its hands over Sizewell C plans', 17 June 2015
http://www.ipswichstar.co.uk/news/edf_says_it_has_not_been_sitting_on_it_hands_over_sizewell_c_plans_1_4116874

[133] Utility Week, 'Nugen to secure government finance for Moorside nuclear power project', December 2014
http://utilityweek.co.uk/news/nugen-to-secure-government-finance-for-moorside-nuclear-power-project/1077962#.VX61vEb1ncc

[134] The Western Daily Press, 'Osborne: Britain can't afford to build Hinkley', 21April 2015
http://www.westerndailypress.co.uk/Osborne-Britain-t-afford-build-Hinkley-C/story-26365685-detail/story.html#ixzz3Y29lcDZG

David Cameron is about to sign you up to pay for one of the most expensive man-made objects in the world. The proposed nuclear power station at Hinkley Point in Somerset will cost an estimated £24.5bn, take a decade to construct, and tie British households into an (sic) astonishingly expensive electricity subsidies until 2060.

For that price you could pick up eight Queen Elizabeth-class aircraft carriers, build forty Royal London Hospitals, or pay for Crossrail - twice. You could also just about afford another Three Gorges Dam, the 1.5-mile long monstrosity that spans the Yangtze River. The latter, which required the relocation of about 1.5m people, cost £26bn. But it also produces 22.5 gigawatts of power, more than seven times what Britain's version will generate.[135]

Whether to offer government support for a costly nuclear project, instead of paying for other public works, is the kind of dilemma Australia could face if it allowed new reactors programmes to get started. Getting firm financial backing from commercial partners, or subsidies from government, are not the only problems facing Hinkley. On 7th April 2015, EDF announced serious faults had been found with the reactor pressure vessel - a crucial safety component which must be made to the highest standards - that is being fitted at its Flamanville plant in France. [136] This component was jointly manufactured by Japanese companies and Areva; EDF's French partner company (also majority owned - 87% - by the French state). The French nuclear regulatory agency, Autorite de Surete Nucleaire (ASN) has reported to the Senate that the results of investigations into the pressure vessel problems, originally expected in October, will now not be known until early 2016. [137] It has also been reported that the same type of faulty component, manufactured by the same companies, could well have been fitted in the EPRs being built in China; leading regulators there say no nuclear fuel can be loaded until the situation is resolved. [138] Areva, which had already manufactured the pressure vessel for Hinkley, will now be testing the pressure vessel head to 'destruction' instead of fitting it into the reactor. [139]

More recently it has been reported that leaked documents reveal that France's nuclear safety authorities have also learnt of "multiple" malfunctioning valves in the Flamanville EPR that could cause its meltdown; similar to the 1979 accident at the Three Mile Island nuclear plant in the US. [140]

Even before the technical problems came to light with Flamanville, France's flagship new nuclear reactor, the project was experiencing delays and by early 2012 the cost was estimated

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[135] The Sunday Times, 21 June 2015
http://www.thesundaytimes.co.uk/sto/business/Industry/article1571248.ece

[136] World Information Service on Energy briefing, 'Fabrication Flaws in EPR Flamanville', 12 April 2015
https://dl.dropboxusercontent.com/u/25762794/20150412Fabrication-Flaws-EPR-Flamanville-v2.pdf

[137] Wall Street Journal, 'Areva finds flaws in new nuclear reactor', 7 April 2015.
http://www.wsj.com/articles/areva-finds-flaws-in-new-nuclear-reactor-1428408394
ASN, press release, 'Flamanville EPRA reactor vessel manufacturing anomalies', & April 2015
http://www.french-nuclear-safety.fr/Information/News-releases/Flamanville-EPR-reactor-vessel-manufacturing-anomalies
Bloomberg, ' EDF's Normandy EPR Vessel Fault Decision Seen in 2016', ASN Says,' 16 June 2015
http://www.bloomberg.com/news/articles/2015-06-16/edf-s-normandy-epr-vessel-fault-decision-seen-in-2016-asn-says

[138] Climate News Network, 'Unfinished nuclear plants raise safety doubts', 13 April 2015
http://www.climatenewsnetwork.net/unfinished-nuclear-plants-raise-safety-doubts/

[139] Bloomberg, 'Nuclear test risks blowing lid off UK's plans to keep lights on,' 16 June 2015
http://www.bloomberg.com/news/articles/2015-06-19/nuclear-test-risks-blowing-lid-off-u-k-s-plan-to-keep-lights-on

[140] The Telegraph, 'Faulty valves in new-generation EPR nuclear reactor pose meltdown risk, inspectors warn', 9 June 2015
http://www.telegraph.co.uk/news/worldnews/europe/france/11662889/Faulty-valves-in-new-generation-EPR-nuclear-reactor-pose-meltdown-risk-inspectors-warn.html

have risen to Euros 8.5 billion; a massive increase on the 2005 estimate of Euros 3.3 billion. [141] It is now uncertain whether, as predicted, the reactor will be operational by 2016/2017.

The Areva new build project, at Olkiluoto in Finland, has been the subject of lawsuits and legal claims between an industrial group, TVO (which is contracted to use the electricity from the reactor); and has also experienced significant delays. Started in 2005, construction is now nine years behind schedule and is not expected to come on line until 2019; and the budget has more than doubled. [142]

The reactors planned for the UK and other countries are, in general, larger than current reactors; approximately 1GW-1.6GW each. Providing these plants in a timely and cost-effective way, with the best safety features, is clearly becoming increasingly problematic. So much so that even in countries where there are plans for larger-scale conventional reactors - claimed as essential for base-load electricity - there are now calls from some quarters for 'small modular reactors' – factory produced, less remotely-sited, smaller scale units. A 2014 report by the House of Commons on this issue, and the Government's response, can be found in the link given. [143] This is not to advocate these reactors but to demonstrate that, even in the midst of a supposedly firm programme to construct several large-scale reactors, problems encountered in construction can lead to plans being questioned as thinking changes. The issue here is whether, in backing nuclear power, countries are backing the right nuclear technology.

In all there are many difficult questions for Australia to consider with regard to reactor costs. For example, in relation to importing spent fuel for reprocessing - and using the separated products in a reactor - how much spent fuel would have to be imported to make it economically worthwhile? Who would build the reprocessing plant? How much plutonium and uranium would have to be extracted to make new reactors a financially attractive proposition? Who decides what is cost effective; what is a good price for a reactor? Who would buy the electricity; where are most of the consumers? Who would pay for any grid upgrade; which could require pylon replacement over considerable distances (another contentious issue for new build in England)? How much electricity might be lost in transmission; and how much would that lessen the CO_2 cost-effectiveness of any deal? What would be the back-up source of electricity in the event of planned and unplanned outages of reactors, as happened in the UK last year.[144]

15. Waste and spent fuel costs & contracts: issues for consideration

In the UK new build decommissioning, waste and spent fuel management, will be covered under two connected agreements; the over-arching Funded Decommissioning Programme (FDP), under which comes the linked Waste Transfer Price (WTP) deal for ILW and spent fuel disposal.[145] As noted earlier, these are currently being discussed between nuclear operators

[141] Reuters, 'EDF raises French reactor costs to over $11 billion,' 3 March 2012 http://www.reuters.com/article/2012/12/03/us-edf-nuclear-flamanville-idUSBRE8B214620121203
[142] World Nuclear Industry Status Report, 2014 http://www.worldnuclearreport.org/-2014-.html
[143] House of Commons, Energy & Climate Change Select Committee, 'Small Nuclear Power', 17 December 2014 http://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/inquiries/parliament-2010/small-nuclear-power/
[144] The Daily Mail, 'Fears of winter blackouts repairs mend boiler cracks shut EDF nuclear power plants for two years', 18 October 2014. http://www.dailymail.co.uk/news/article-2797966/fears-winter-blackouts-repairs-mend-boiler-cracks-shut-edf-nuclear-plants-two-years.html
[145] DECC, Funded Decommissioning Programme – Guidance for New nuclear Power Stations ', 11 December 2011 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/70214/guidance-funded-decommissioning-programme-consult.pdf

and the government. The WNA fact sheet referenced by the Royal Commission states: *Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product*. [146] Yet, as has also been discussed in this submission, and will be in the following, in the UK new build operators will now not actually have to find the money for their waste management; which underlines a recurring problem with the nuclear industry: that 'fully' costing waste management is not necessarily the same thing as paying for it. In this regard the UK Government's proposed deal with EDF over waste and spent fuel provides a useful indicator of issues which could arise between Australian governments, private companies and overseas customers.

The UK Government, as previously noted, initially ordered that, in order to minimise the risk to the public purse from dealing with the costs of radioactive waste from future operations, there would be a FDP with the costs split into 3 areas:

Decommissioning: In the UK this will cover decommissioning reactors and spent fuel stores at reactor sites, and other relevant facilities.

Waste management: Storage and conditioning and/or encapsulation - prior to disposal. In the UK a 'lump sum' handed to the NDA is meant to cover the costs of wastes and spent fuel transport, storage and conditioning or encapsulation once it has left the reactor site (by when title and liability for the wastes and spent fuel will have passed from the private company to the NDA). A submission giving details of the concerns around the lump-sum fund, along with other matters connected to paying for disposal costs, is attached (and referenced). [147]

On an import/store/dispose contract with Australia, overseas customers would, presumably, be expected to pay for transport and spent fuel store decommissioning (assuming encapsulation takes place in the country of origin).

If Australia's nuclear programme expanded into spent fuel reprocessing and reactor operations, decommissioning would need to be covered by the commercial operators of the plants: these costs would not necessarily fall to the customer companies, which might only have paid for disposal. The Australian operators would have to pay for all aspects of the reprocessing operations, and waste storage and packaging prior to disposal.

ILW and spent fuel disposal costs: In the UK these are to be covered separately by the Waste Transfer Price (WTP).

On the WTP, an attempt has been made to estimate what disposal costs might be in 100-160 years. This matter was the subject of three iterations and consultations before the final consultation, which ended in February 2011; with the finished methodology published later that year. [148] The paper attached (referenced above) gives an idea of the complexity of this issue; which is linked to numerous other technical, legal, social and political issues. [149]

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[146] World Nuclear Association, 'Radioactive Waste Management', as referenced by the NFCRC http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/

[147] Greenpeace UK submission, discusses issues around the lump sum (page 14). Presented to the UK government in March 2011 http://www.greenpeace.org/eu-unit/Global/eu-unit/reports-briefings/2014/State%20aid%20SA.34947%20%282013C%29%20Greenpeace%20Annex%20III.pdf

[148] DECC, 'Waste Transfer Pricing Methodology for the disposal of higher activity wastes from new nuclear power stations, ' December 2011 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42629/3798-waste-transfer-pricing-methodology.pdf

[149] Ibid reference 138

The various papers on the WTP acknowledged problems in determining costs because of a number of outstanding issues; including there being no final waste form for spent fuel (it *might* be encased in copper which is the option favoured by Sweden, for example [150]); no agreed site for a repository etc: issues Australia will face in determining contracts.

Australia will probably have to separate out the cost components of a spent fuel import/store/dispose deal from a reprocessing deal, rather than attempt to cover all costs in a single fee; especially if there are different operators for the different processes - and different customers requiring different services.

In the UK the new build spent fuel deals are based on the following: no reprocessing of new build spent fuel and no use of MOX fuel. New build in the UK will, however, have the advantage of sharing encapsulation and disposal costs with legacy wastes and spent fuel (most of which are government owned). Thus, even before the decision to fully subsidise new build waste and spent fuel costs, this sharing made the waste deals more attractive to EDF and others, than any commercially funded repository (such as Australia might offer). That is because the per-unit disposal costs of a stand alone, commercial-waste only repository, if they fall solely on the private sector – as it is claimed would happen in Australia - could be much higher because there will be no sharing of costs. Even a seemingly straightforward spent fuel import-disposal deal could bring problems if the costs had to be apportioned to different companies, from different countries; with different spent fuel types.

The cost of a repository depends, of course, on the amount of waste and spent fuel for disposal. The UK repository cost has been estimated at around £12bn; with some estimates as high as £30bn: dependent on a number of as yet undetermined factors such waste forms, volume and levels of radioactivity in spent fuel.[151] As noted earlier, over reprocessing, overseas customers would likely be very wary of entering into contracts for disposal which do not give final costs. Yet cost-plus contracts, as overseas spent fuel reprocessing in the UK has shown, can be very problematic for overseas customers.

Getting to the bottom of what funds are needed – and who will pay - could also be difficult because of the commercial confidentiality clauses invoked by private companies, and often by government agencies also: all of which play a part in the problems around of determining reactor and wastes costs. It cannot be assumed either that a disposal deal, involving spent fuel from Australian reactors, would be fully covered by the expected profits from reactor electricity production. The alternative might be that Australia is asked to allow reactors to proceed after an amount is set for disposal costs – pre-reactor commissioning. But will those costs be high enough to cover everything? What is the level of risk that the actual costs come out as higher – and that taxpayers will have to fund the difference? This is a reasonable question because with no set amount for waste and spent fuel management and disposal costs, investors might not come forward.

The when and how of trying to settle these issues is clearly crucial. For example, prior to its 2013 decision to fully subsidise new build waste costs, the UK Government published a consultation on waste costs, which was not only complicated, but could only give broad figures – through modelling different scenarios - over what the final cost of spent fuel disposal might be.

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[150] Dr Helen Wallace, 'Rock Solid', September 2010. For a critique of copper encasement of spent fuel, known as SKB process, see
http://www.greenpeace.org/belgium/Global/belgium/report/2010/10/GeneWatch_Report.pdf
[151] Nuclear Engineering International, 'Estimating the disposal costs of spent fuel', October 2011
http://www.mng.org.uk/gh/private/jackson_nuclear_waste_disposal.pdf
Prof. Stuart Haszeldine, 'Investigations to site a radioactive waste repository in Cumbria', January 2013
http://www.geos.ed.ac.uk/homes/rsh/Investigations_to_site_a_radioactive_waste_repository_in_Cumbria_4pages_Haszeldine_EVIDENCE_10Jan2013.pdf

[152] A report (March 2011), commissioned by Greenpeace UK from a nuclear economist, indicated the cost of subsidy for spent fuel disposal. For a single reactor with a 60 year operating life, the estimated subsidy was put at £1.5bn; on top of what the industry was to have paid.[153] To give an idea of the complexity of this issue the report, 'Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations' is attached. This is especially pertinent as it is the kind of process Australia would have to go through if it went down the path of allowing nuclear waste disposal, reactors etc to be implemented in South Australia.

Despite publishing some information on the *possible* costs, the UK Government has decided not to be fully transparent about the actual waste and spent fuel agreements; because the full details of the deal would not be palatable to the public and Parliament? Refusing to publish the full information the government – in a move against openness - has instead left it to EDF to decide what should be disclosed. As the UK guidelines note:

2a.2 The Secretary of State, mindful of the public interest in such arrangements, would expect an Operator to publish as much of its FDP [Funded Decommissioning Programme] as possible except for material of a sensitive nature. An Operator should, therefore, set out in the FDP proposals regarding publication, clearly identifying those issues that are commercially confidential or may have security sensitivities. The Operator would be expected to publish and make available on the Operator's web site such material on or shortly after approval of the FDP by the Secretary of State. The decision by the Secretary of State will also be published.

That this is still the case, that all the relevant information will not be made public – or given to Parliament - has been confirmed in emails from the Department of Energy and Climate Change. [154]

Another problem for the UK in determining waste and spent fuel disposal costs is attributing the costs, proportionally, across the different organisations intending to use the repository e.g. the NDA is handling mainly civilian wastes and some military wastes; the Ministry of Defence has waste it wants to dispose of; and there is waste from current commercial operations to take into account. On the issue of wastes from defence programmes, the Royal Commission is looking only at the possible import of civil nuclear wastes and materials. What if imports were proposed from dual-purpose civil-military programmes e.g. the UK's Magnox reactors were operated in such a way that plutonium was created for weapons, as well as electricity generation? [155]

There are a number of other complications to consider when examining disposal costs apart from volume; which is – deceptively – often the only measure used in discussing this issue. The industry in Britain initially portrayed the wastes from a 10GW nuclear programme as a minor addition to the UK's legacy waste problem: the spent fuel resulting from a 10GW programme –

[152] DECC, 'Consultation on Waste Transfer Pricing methodology for the disposal of higher activity wastes from new nuclear power stations', December 2010
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42622/984-consultation-waste-transfer-pricing-method.pdf
[153] Research Report Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations Independent Report for Greenpeace UK • 1st March 2011• Issue 1 Jackson Consulting
http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf
See also http://www.mng.org.uk/gh/private/jackson_nuclear_waste_disposal.pdf (full details ref. 145)
[154] Email from DECC 11 April 2014 sent to this author. See also: DECC, 'Funder Decommissioning Programme Guidance for new nuclear power stations' December 2011
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/70214/guidance-funded-decommissioning-programme-consult.pdf
[155] World Nuclear Association, 'Fuel Recycling plutonium,' May 2015
http://www.world-nuclear.org/info/nuclear-fuel-cycle/fuel-recycling/plutonium/

some 31,900 tonnes in total - would add somewhere between 2% - 8% to the overall volume of legacy wastes.

Over time, however, further issues emerged around new build spent fuel; particularly when estimates from CoRWM revealed that the spent fuel from a 10GW programme would contain nearly a three-fold increase in terms of radioactivity - or an additional 265% - over the level of radioactivity contained in all of the UK's nuclear wastes *and* nuclear materials produced over the past sixty years. [156] This is because new build spent fuel is twice as radioactive as spent fuel from existing UK reactors, and therefore generates much more heat. Its disposal would significantly impact on the size of a repository:

- Official agencies estimate that a 'legacy waste' only repository in the UK would be approximately 3km^2 – 9km^2 (depending on the type of geology of the disposal site).

- They also estimated that wastes from a 10GW programme would add between 3km^2-11km^2 (an increase of between 50%-100%; depending on rock type) to a repository footprint; this is in order to allow for enough spacing between the canisters containing the spent fuel.

- A repository which has to accommodate spent fuel from a 16GW programme is estimated at 25km^2. Details of this can be found in the relevant consultation document. [157]

A further problem identified, concerning the heat generation of new build spent fuel, has led senior geologists to predict that radioactive releases could occur as early as 100 years after disposal. [158]

The other issue Australia will have to consider is how to enforce a payment system, and review it over time, if a deal was spread over a number of payments; few systems envisage all payments made up front. [159] Unless overseas operators offered to pay all possible costs up front (including a substantial risk premium for cost overruns) how would subsequent payments be guaranteed e.g. a contract for spent fuel storage is paid for 100 years; but payment for disposal is only agreed – and made - when a repository is confirmed. A one-off capped payment is risky to the taxpayer; and overseas customers will resist an open-ended cost-plus contract.

If it is agreed that payments are made in instalments what guarantee can be put in place that the costs will be met in full? Who will ensure - Federal or State government - that the necessary funds are accruing: how will they safeguard those funds? The Federal Government might demand that no wastes or spent fuel can be imported – and no contract made for disposal – until there is a repository: but if so, who pays for the development costs? The cost of all the relevant facilities, over possibly a 150 year timeline, is relevant: and is not adequately

[156] CoRWM 'Inventory Summary Information', Doc 1531, January 2007 http://webarchive.nationalarchives.gov.uk/20130503173700/http:/corwm.decc.gov.uk/assets/corwm/pre-nov%202007%20doc%20archive/plenary%20papers/2006/25%20-%2026%20january%202006/1531%20-%20inventory%20summary%20information.pdf

[157] WCMRWS consultation, 'Geological disposal of radioactive waste in West Cumbria?' November 2011 See page 85. http://www.westcumbriamrws.org.uk/documents/242-Full_Consultation_Document_-_West_Cumbria_MRWS_Partnership_November_2011.pdf

[158] Environmental Earth Science 'Modelling groundwater flow changes due to thermal effects of radioactive waste disposal at a hypothetical repository site near Sellafield, UK,' July 2015 Vol. 74 http://link.springer.com/article/10.1007/s12665-015-4156-6/fulltext.html

[159] For full details see reference 148 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42628/3797-guidance-funded-decommissioning-programme-consult.pdf

understood through quoting the cost of management per tonne of spent fuel per annum. On the issue of costs, an OECD paper on back-end costs is referenced for the Royal Commission's consideration. [160]

The size of the inventory envisaged for disposal will influence another costs issue: how many repositories might be required for waste and/or spent fuel disposal. The type of repository - mined or borehole – is another significant cost factor. Most relevant also is the limit on the level of radioactivity in the inventory to be disposed of; which is determined by the radiological (dose) limit. The proliferation potential for some materials – and how proliferation resistance configuration of waste disposal would result in stronger security barriers – is yet another factor.

As noted previously, the cost of a repository for Australia might be very difficult to predict as the complexity and scale of such a facility is complicated by the different wastes types for disposal; their volume and how they are packaged, the radioactivity levels and the half-lives of the wastes involved: and which organisations are involved. Here is an example of the complexities that could arise:

> Company A wants a straightforward import and disposal of its spent fuel; and will pay only for that. Company B is prepared to sell its 'asset rich' spent fuel to Australia. If Australian companies then want to reprocess the spent fuel, and reuse the plutonium and uranium, they will have to pay the cost of all connected activities and wastes produced in the future. This means Company B is left to pay only for the disposal of the HLW waste 'recovered' during reprocessing: the portion of spent fuel which an unusable waste. Company C will allow its spent fuel to be pyroprocessed for use in an integral fast reactor; but will pay only for the conditioning and disposal of the shorter-lived radioactive wastes it is claimed will result from pyroprocessing and reuse of uranium, plutonium and other actinides in an integral fast reactor (IFR) (e.g. see pages 47-56). All other wastes that result from pyroprocessing and use of an IFR fall on the Australia operators

As a result of a complicated waste disposal deal, it might be suggested that all of this be dealt with through a government agency, as it is sometimes thought that nuclear waste and decommissioning operations are less problematic if under central government control; where profit motives will not undermine safety concerns. Yet taking this approach is certainly not a guaranteed route to environmental protection or cost efficiency. The quasi-autonomous and heavily subsidised state-owned nuclear fuel and technology company BNFL went bankrupt in 2004 because it could not meet its liabilities; leading the UK Government to split up the company. The decommissioning and waste management obligations were passed to the newly formed NDA, which was given responsibility for most of the UK's nuclear legacy liabilities (civil and some military wastes). [161]

Yet since the NDA was formally established in 2005, its costs have risen year on year. This is not entirely due to its failures; some of the problems it has encountered were, effectively, hidden when it inherited the government's nuclear estate. Yet even taking those issues into account, the NDA has not proven to be good at maintaining or reducing its costs. For example, in 2014, the NDA announced that its discounted liability was estimated to be in excess of £64.9bn (£110bn undiscounted) — an increase of £6bn over the previous year and a significant increase

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[160] Nuclear Energy Agency, OECD, 'The Economics of the Back End of the Nuclear Fuel Cycle,' 2013 http://www.oecd-nea.org/ndd/pubs/2013/7061-ebenfc.pdf

[161] There will also be spent fuel for disposal from EDF's current operation of former British Energy reactors. IN addition, further spent fuel and wastes will arise from extending the operating life of some NDA operated reactors. This will see a change in the waste and spent fuel figures for disposal, as quoted earlier in this report, as they are based primarily on earlier inventories from official bodies and committees.

from the less than £34bn estimate given in 2007. [162] Furthermore, the NDA has stated, with regard to total costs: "The NDA has reviewed a number of scenarios with a range of possible outcomes; the estimated cost could have a potential range from £88 billion to £218 billion." [163]

In order to reduce costs, in 2007 the NDA decided to try semi-privatising some of its workload; by contracting out the decommissioning and clean up of Sellafield, the authority's most complex and hazardous site, to commercial companies. The contractor appointed was Nuclear Management Partners (NMP) – a consortium of URS (US), Amec (British) and Areva (French). All three companies were said to have a good track record and, it was claimed, would be vital in helping quicken the pace of decommissioning and lower costs. By late 2012 it was evident there were significant problems with cost escalation at Sellafield; and that decommissioning timelines were slipping by a number of years at the site. The National Audit Office and the House of Commons' Public Accounts Committee both issued reports criticising the ongoing environmental and financial failings of the NDA regarding Sellafield. [164]

Despite the concerns subsequently raised over NMP's involvement in the problems at Sellafield, the NDA re-awarded the consortium a second contract. [165] By early 2015, with problems mounting – and an additional £5bn - £6bn added to the NDA's projected budget − it was decided to cancel NMP's contracts, only six years into what was initially envisaged as a 17-year deal, and bring all the work at Sellafield back under the direct control of the NDA. The cost of the NDA exiting the contract with NMP is put at around £430,000. [166]

16. Nuclear workforce

At present Australia has a very limited nuclear workforce, with ANSTO employing just over 1,000. Many of these people - although skilled - are specialists in areas which might not be able to be utilised in the kind of nuclear projects listed in the Royal Commission's TOR.

Some of the countries referred to in this document, Finland, France and the UK, have workforces experienced in nuclear reactor construction; although finding the right number of skilled workers in the UK, even for Hinkley C's construction, has been raised a number times as an ongoing problem.

Finland has imported a significant number of overseas workers to build the Olkiluoto plant; many of them subcontractors from the companies contracted to the French company Areva, which is building the reactor. [167] There have been reports of workers from 40 different countries

[162] Nuclear Decommissioning Authority, Annual Report and Accounts 2013/14, 2014 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/323982/Annual-Report-and-Accounts-2013-to-2014.pdf

[163] See also CORE press release, 'Sellafield's costs soar to £53bn', 4 March 2015 http://www.corecumbria.co.uk/newsapp/pressreleases/pressmain.asp?StrNewsID=355

[164] UK National Audit Office, 'Managing Risk Reduction at Sellafield', 7 November 2012 http://www.nao.org.uk/report/managing-risk-reduction-at-sellafield/

[165] World Nuclear News, 'UK to change way Sellafield is managed', 13 January 2015 http://www.world-nuclear-news.org/C-UK-to-change-way-Sellafield-is-managed-13011501.html
Nuclear Free Local Authorities press release, UK Government's decision to strip NMP of £9bn Sellafield contract – another expensive nuclear policy debacle is finally resolved', 13 January 2015 http://nfznsc.gn.apc.org/docs/news/NFLA_NMP_loses_Sellafield_control.pdf

[166] CORE press release, 'Sellafield nuclear consortium stripped of its contract', 13 January 2015 http://www.corecumbria.co.uk/newsapp/pressreleases/pressmain.asp?StrNewsID=353
The Guardian, 'NMP set to lose contract to clean up Sellafield nuclear waste', 12 January2015 http://www.theguardian.com/environment/2015/jan/12/nmp-lose-contract-clean-up-sellafield-nuclear-waste

[167] Radio Canada International website, 'Olkiluoto construction staff to double in 2015', 17 December 2014

working on the Finnish project and, although English and Finnish are the official languages, signs have had to be posted in several different languages. This is not a criticism of the trans-national movement of workers; but is offered as an example of an issue that has to be considered in any future Australian nuclear workforce. Similarly, the workers will have to know the relevant codes and regulations for an Australian nuclear site.

The needs of the UK nuclear industry indicate the extent of what is required to secure a skilled workforce – even in a country which already has nuclear reactors. [168] Yet this problem will worsen as 70% of skilled nuclear workers in the UK are to retire over the next ten years.[169] Australia does have a sizeable uranium mining workforce; but this involves a very different set of skills to those needed for nuclear reactors. Retraining workers from other industries to work in the nuclear sector is not straightforward; as an industry memo noted a few years ago: *Difficulty of Nuclearising Oil & Gas Workers. Although DTI/DECC had encouraged skills transfer from the oil & gas sector to the nuclear sector (particularly for NDA nuclear decommissioning contracts), in practice EDF found that 'nuclear is special' and it is difficult to retrain workers. EDF wanted specific government-sponsored training programmes for nuclear energy staff. Because of the UK's ageing/retiring nuclear workforce, EDF compared the UK skills position with China, commenting that the UK may need to re-learn new nuclear build skills from scratch, and set-up new training programmes accordingly.*

Other nuclear workforces, such as that for the planned UK nuclear submarine programme (which is trying to recruit hundreds of new staff) not only need to be developed, but also maintained as older workers retire or when staff leave for other types of work. [170] The current shortage of skilled workers is an issue for both the civil and military nuclear industries in the UK (a problem Australia is aware of from recruiting for other sectors e.g. health, for which skilled workers often have to be recruited from overseas).

Australia will also have to consider housing, medical facilities, schools and shops for any workforce brought together for a large-scale nuclear project. Depending on where it is situated, this could be a very costly addition to a nuclear programme. The question is who will pay for this?

Discussions have gone on over many years about whether the manufacturing base in the UK will ever be able to meet the demands of a new nuclear programme; or whether it will remain reliant for major components on overseas companies – and their manufacturers. [171] Efforts to stimulate such a base in the UK, by use of government subsidies, have not yet borne any fruit.

Australia is not yet at stage one in terms of being able to develop a large scale nuclear industry – which can design the reactors; manufacture all the relevant components; undertake the

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http://www.rcinet.ca/eye-on-the-arctic/2014/12/17/finland-olkiluoto-nuclear-construction-staff-to-double-in-2015/

[168] UK Government, 'Nuclear Industrial Strategy: the UK's nuclear future', 23 March 2013 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/168048/bis-13-627-nuclear-industrial-strategy-the-uks-nuclear-future.pdf

[169] Recruiter, 'Graduate body to help redress nuclear industry skills gap', 18 June 2015 http://www.recruiter.co.uk/news/2015/06/graduate-body-to-help-redress-nuclear-industry-skills-gap/
Randstad, '3.1m shortfall in UK workforce by 2050', 2015
https://www.randstad.co.uk/about-us/press-releases/randstad-news/31m-shortfall-in-uk-workforce-by-2050/

[170] UK Government, 'Sustaining our nuclear skills,' 20 March 2015
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/415427/Sustaining_Our_Nuclear_Skills_FINAL.PDF

[171] The Engineer, 'Power struggle developing the UK's nuclear manufacturing capacity', 13 October 2013
http://www.theengineer.co.uk/in-depth/the-big-story/power-struggle-developing-the-uks-nuclear-manufacturing-capacity/1017117.article

necessary contracts (to protect the taxpayer); build and decommission reprocessing plants and 'conventional' nuclear reactors - let alone construct and operate 'innovative' plants like integral fast reactors. In this context the idea of Australia leap-frogging the current reactor designs and building fast reactors is, quite simply, not tenable. On top of that, it does not have the skills for a long term, large scale radioactive waste and spent fuel management and disposal programme.

17. Regulatory inspection regime

In 2014 the UK set up the Office for Nuclear Regulation (ONR); an autonomous nuclear inspectorate which is meant to be more at 'arms length' from government departments to avoid the risk of political interference (although that does not make it entirely free of having to implement or facilitate policy objectives that it might not fully agree with).

One of the main reasons for establishing the ONR, in place of the long-standing Nuclear Installations Inspectorate, was to allow the ONR to hire inspectors on better wages and terms than those permitted under civil service rules. This was because the inspectorate was facing significant difficulties in keeping or hiring staff with the appropriate expertise. [172] Despite the changes made, the ONR is still experiencing problems in recruiting and retaining personnel with the necessary expertise; whether for assessing new reactors or overseeing the decommissioning programme.

Australia does have a nuclear oversight body – the Australian Radiation Protection and Nuclear Safety Agency. If Australia allowed a spent fuel reprocessing/conventional reactor/plutonium reuse/fast breeder programme its regulatory system, in terms of staffing, would have to undergo such a massive and rapid transformation that it would, effectively, be starting from scratch.

Another ongoing issue for the UK's ONR, apart from retaining and recruiting staff, is that they need inspectors with the necessary knowledge and, if possible, working background to oversee the generic design assessment (GDA) process for new facilities e.g. new reactors. Without a fully staffed team of inspectors with the requisite skills-set, regulators struggle to sign-off on licences for construction, commissioning and operations. For this reason the industry is encouraged to be more practical and opt for evolutionary, rather than revolutionary designs – such as an integral fast reactor. On that point, a salutary speech given at the 2005 annual conference of the US Nuclear Regulatory Commission, on nuclear reactor 'evolution' rather than 'revolution' is referenced. [173] Although this speech ended on something of a positive note for the nuclear industry, it is worth noting that no new reactors have been commissioned in the US in the past eighteen years.[174]

It should also be noted that the designs presented for use in the UK are untried and untested; only one to date, the French EPR, has passed through the UK's pre-construction phase of the GDA process. Further problems could well arise, from the regulatory licensing process, during the construction phase; as has happened with the building of the EPR in other countries. Changes to reactor designs; especially spent fuel storage systems, such as those

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[172] The Independent, 'The reactors are coming but the inspectors are going', 9 May 2014
http://www.independent.co.uk/news/business/comment/mark-leftly-the-reactors-are-coming-but-the-nuclear-inspectors-are-going-9341744.html

[173] "Are We There Yet?" The Honorable Jeffrey S. Merrifield, Commissioner, U.S. Nuclear Regulatory Commission 2005 Regulatory Information Conference Rockville, MD March 8, 2005. Doc number S-05-004
http://www.nrc.gov/reading-rm/doc-collections/commission/speeches/2005/
See also http://pbadupws.nrc.gov/docs/ML0506/ML050670584.pdf

[174] World Nuclear Association, Reactor database
http://world-nuclear.org/NuclearDatabase/rdResults.aspx?id=27569
World Nuclear Status Report, 2014,
http://www.worldnuclearreport.org/-2014-.html. Page 99

recommended after the Fukushima disaster, need to be factored into any future programme. For example, in the UK increased recognition is now given to strengthened protection for the 'nuclear island' (reactor, spent fuel store and essential auxiliary plant) from the risks of storm surge.

This paper has not looked at reactor accidents; much is already in the public domain concerning what happened after the Windscale (Sellafield) fire in 1957, Three Mile Island in 1979, Chernobyl in 1986 and Fukushima in 2011 - even though lessons are still being learnt from these last two accidents. The industry will claim those accidents will not happen in new reactors; lessons have been learnt and new technologies are being applied. Whilst it might be true that precisely the same accidents will not occur that does not mean other accidents cannot happen. A draft paper published by the MIT Technology Review on the potential for accidents in the future might prove of some interest to the Royal Commission. [175]

18. Fast reactors / fast breeder reactors: types, wastes, costs and safeguards

It has been suggested there is the potential to dispose of significant amounts of the world's spent fuel - and separated plutonium – through fast reactor programmes and/or conventional reprocessing-reactor systems. Some details of national programmes, in terms of an overview of spent fuel management, have been provided by Princeton University. [176]

One project which considered options for the international spent fuel inventory was the Global Nuclear Energy Partnership (GNEP) which was established in 2006. The Partnership's work on the use of advanced nuclear fuel cycle technologies ended in 2008; when US Government funding was withdrawn. Its work was then taken up, to an extent, by the International Framework for Nuclear Energy Cooperation (IFNEC).

IFNEC has 33 member nations; 31 observer nations and several international observer organisations. [177] It is not surprising it has as many observers as participants, as many of the nuclear technologies and processes it is considering have proliferation implications: i.e. they involve weapons-usable materials or activities that can be used to extract plutonium.

For example, one of the Integral Fast Reactor (IFR) designs or 'Power Reactor Innovative Small Module' (PRISM) - a Generation IV reactor concept raised as a candidate for use in Australia - would rely on pyroprocessing to source its fuel. Pyroprocessing is a form of reprocessing: as the relevant IAEA convention notes "reprocessing" means a process or operation, the purpose of which is to extract radioactive isotopes from spent fuel for further use. [178] Like conventional reprocessing plants, pyroprocessing facilities, depending on how they are operated, can give rise to concerns around proliferation because the process can be used to separate out weapons-usable materials.

In Australia, however, it is said that any metal-fuelled, sodium-cooled PRISM reactor deployed would be used in conjunction with a form of advanced pyroprocessing that would extract a mix

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[175] Technology Review, 'The chances of another Chernobyl before 2050, 50% says safety specialists', 17 April 2015
http://www.technologyreview.com/view/536886/the-chances-of-another-chernobyl-before-2050-50-say-safety-specialists/
[176] International Panel on Fissile Materials, 'Spent fuel from Nuclear Power Reactors' June 2011
http://fissilematerials.org/library/ipfm-spent-fuel-overview-june-2011.pdf
[177] The International Framework for Nuclear Energy Cooperation
http://www.ifnec.org/ . See also:
http://www.world-nuclear.org/info/inf117_international_framework_nuclear_energy_cooperation.html
[178] For full details see ref. 17 – IAEA Convention on Spent Fuel and Radioactive Waste
https://www.iaea.org/sites/default/files/publications/documents/infcircs/1997/infcirc0546.pdf

of uranium and plutonium along with other actinides.[179] This would avoid many of the proliferation risks associated with conventional reactors and spent fuel reprocessing.

Another benefit claimed for pyroprocessing is that it will allow the recovery of the long-lived radioisotopes that would otherwise be left in wastes for disposal – and thus reduce costs and problems in a waste disposal repository over time.

Using an advanced form pyroprocessing would, however, leave the fission products (from the spent fuel) as waste. This fission product waste is considered less of a problem, in terms of disposal, because its main radioisotopes (e.g. Caesium-137, Strontium-90) have much shorter half-lives than the materials recovered for reuse through pyroprocessing.

Caution needs to be exercised over these proposals; pyroprocessing on a commercial scale has not yet been demonstrated; nor have IFRs themselves. Some of the concerns are discussed below.

Proposals for using PRISM

The NDA initially rejected the PRISM design as part of the process to dispose of the UK's plutonium stockpile, because it felt the reactor technology was immature and commercially unproven. The reasons for the NDA's lack of enthusiasm were stated in an email to General Electric Hitachi (GEH) - vendor of the PRISM design - on 29 November 2011; in which the NDA's strategy and technology director wrote that the two organisations "*have struggled to reach a clear agreement on the work necessary to demonstrate credibility, without which neither NDA nor government can consider Prism further in the development of our strategy*." [180] In short, the NDA did not believe the technology was viable. [181]

Then, in an about turn in 2012, the NDA said it would reconsider the PRISM design - as one of a suite of options - to deal with the UK's plutonium stocks (which will be approximately 140 tonnes when reprocessing ends in the UK). [182] The primary purpose for the NDA considering the PRISM design (as with MOX reactors) would be to make the plutonium more radioactive; for non-proliferation purposes rather than for electricity production. The idea is that PRISM would be used to burn through the UK's stockpile of plutonium in about five years. [183] After 45-90 days in PRISM, the resultant spent fuel would meet the IAEA's 'spent fuel' standard of a maximum radiation dose rate of 1Sv/hour at 1 metre's distance. [184]

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[179] Atomic Insights, 'Common myths nuclear waste huge problem', 1 April 1995
http://atomicinsights.com/common-myths-nuclear-waste-huge-problem/
Different papers on fast reactor refer to the separation and use of either transuranics or actinides. For the purposes of this paper actinides will be the term used.

[180] The emails, quoted in the Guardian article referenced below, were sent to the author of this paper following Freedom of Information requests to the NDA. Copies can be made available to the Commission.

[181] The Guardian, 'Sellafield plutonium reactor plans rejected', 24 January 2012
http://www.theguardian.com/environment/2012/jan/24/sellafield-plutonium-reactor-plans-rejected

[182] The Independent, 'Untested nuclear reactors may be used to burn up plutonium waste', 20 August 2012
http://www.independent.co.uk/news/science/untested-nuclear-reactors-may-be-used-to-burn-up-plutonium-waste-8061660.html

[183] The Engineer, 'Prism project: a proposal for the UK's problem plutonium', 13 May 2013
http://www.theengineer.co.uk/energy/in-depth/prism-project-a-proposal-for-the-uks-problem-plutonium/1016276.article

[184] Journal of Nuclear Science and Technology, 'Spent Fuel Standard as a Baseline for Proliferation Resistance in Excess Plutonium Disposition Options', 7 February 2012
http://www.tandfonline.com/doi/pdf/10.1080/18811248.2000.9714945
Princeton University, Center for Energy and Environmental Studies, Interim storage matrices for Excess Plutonium: Approaching the "Spent fuel standard" without the use of reactors', August 1994
http://www.princeton.edu/sgs/publications/center-reports/CEES%20REPORT-286.pdf

Although it is now looking at the GEH concept for PRISM, a number of concerns remain for the NDA; as expressed in its report of January 2014:[185]

- PRISM, in contrast to other reactor plutonium disposition options is a "paper reactor," i.e. it has never been built.
- liquid-sodium-cooled fast neutron reactor systems have a troubled past; and present safety issues the UK safety regulatory system has not confronted since the shutdown of the UK Prototype Fast Reactor at Dounreay in 1994.
- PRISM fuel would raise "unique challenges" to disposal - as the fuel rods contain sodium to conduct heat from the fuel "meat" to the rod cladding. This could make the spent fuel pyrophoric, i.e. capable of igniting spontaneously on contact with water, and therefore unacceptable for disposal underground.

Despite having spent fuel which will not be reprocessed in a conventional reprocessing plant, the NDA has not asked GEH to look at pyroprocessing to deal with this spent fuel; which is to be disposed of as a waste. [186] Because MOX and PRISM reactors – neither of which have been presented for regulatory design assessment in the UK - are not guaranteed, the option of direct disposal of plutonium as a waste form has not been completely ruled out by the NDA.

Some commentators have expressed the view that the NDA's interest in PRISM might only be a means by which it can leverage a better price for conventional MOX reactors to burn the plutonium. [187] This is a realistic view given the UK Government, which has policy control over the UK's plutonium stockpile, very much favours the MOX route for disposition of its plutonium stockpile. However, another issue that should be taken into account in discussing the UK's plutonium stocks - the world's largest stockpile of separated civil plutonium – is the politics of the situation. The nuclear establishment perceives a need to reuse the plutonium in order to justify decades of dangerous and environmentally polluting – and expensive state-subsidised – reprocessing operations at Sellafield. For some, to dispose of the plutonium as a waste would be tantamount to an admission of failure.

The NDA has also said that the facilities required by the PRISM approach have not been industrially demonstrated; further development work needs to be undertaken and the cost and time to complete that work still needs to be defined in detail. The NDA noted, with regard to development, licensing and construction of a PRISM reactor, that the: '*overall implementation timetable to first irradiation is claimed by GEH to be in the range of 14-18 years, with these estimates being supported by ABWR delivery results outside the UK. NDA believe this to be ambitious considering delivery performance norms currently seen in the UK and European nuclear landscape.'* [188]

A PRISM reactor might not be considered a viable option for plutonium disposal and/or electricity production for decades yet. The NDA is certainly not going to embark on a plutonium disposition programme, using the PRISM design, any time soon. Indeed, on choosing and implementing a plutonium disposition programme, the NDA's strategy director has said: 'this is

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[185] NDA, 'Progress on approaches to the Management of separated plutonium: position paper', 20 January 2014
http://www.nda.gov.uk/publication/progress-on-approaches-to-the-management-of-separated-plutonium-position-paper/

[186] Responses to FOI requests from the NDA also show that the authority has not considered any of the wastes, as listed in the current inventory, for use in a fast reactor.

[187] International Panel on Fissile Materials, 'Alternatives to MOX - Direct disposal options for stockpiles of separated plutonium', April 2013
http://fissilematerials.org/library/2015/04/alternatives_to_mox_direct-dis.html

[188] NDA, see ref. 182
http://www.nda.gov.uk/publication/progress-on-approaches-to-the-management-of-separated-plutonium-position-paper/

a marathon not a sprint.' [189] Quite what route for disposing of its plutonium the UK will take has not yet been decided. The decision may not be made for many years: and even then the 'chosen option' might well not be PRISM - it remains only a remote possibility not a preferred option. Only recently it has been reported that Candu Energy's proposal to turn Sellafield's plutonium into MOX, on-site, using the Canmox process, has emerged as a front-runner among options under consideration by the NDA. [190]

It is understandable that the UK is reluctant to back non-conventional reactor technology, such as fast breeders. As has been remarked, between 1955 and 1995 the UK spent more than £4bn of taxpayers' money on a fast breeder with nothing to show for its expenditure but a radioactive mess at Dounreay (Scotland). The problem with fast breeders (and PRISM) which use sodium as a coolant lies in the boilers, which have thousands of thin metal tubes with water on one side and molten sodium on the other. Every plant of this kind ever built has had boiler leaks with potential hydrogen explosions that make the plant extremely difficult to introduce as a viable and reliable addition to an electricity system. [191]

Yet advocates of fast reactors are presenting the technology as something on which a decision has to be made almost immediately; with one commentator arguing (with regard to nuclear power in general) that 'the discussion will need to be pretty quick with some winners picked.' [192] Taking time to choose the right technologies – ones which do not leave a country with a long-term problem - is vital. These choices cannot be based on bias towards an option which is not yet even out of the starting-gate; one with no form to indicate it should be considered a firm favourite.

Funding for IFRs is also an issue. The costs of using Advanced Disposition Reactors (ADR), similar to PRISM reactors - for plutonium disposition in the US - were discussed in a report released by the US Department of Energy (DoE) in April 2014. [193] The estimates for ADRs - for capital and operating costs - came to a total of US$50.45 billion (€36.8bn), or "more than $58 billion life cycle cost when sunk costs cost are included." That is twice as much as the next most expensive option for plutonium management:

- immobilisation (ceramic or glass) with high-level waste: US$28.65 billion
- irradiation of MOX in light-water reactors: US$25.12 billion
- downblending and disposal: US$8.78 billion

As can be seen from the above, most discussion on IFRs such as PRISM has focussed on using the technology as a means of disposing of plutonium stockpiles; which some have said is one of the world's most problematic long-lived wastes. Yet plutonium is not classed as waste in the UK, but designated as a nuclear material. [194] Only when, and if, it is decided that the UK's plutonium stockpile will not be reused will it then be classed as nuclear waste.

[189] The Whitehaven News, 'Delegates to focus on use of plutonium', 28 November 2013 http://www.whitehavennews.co.uk/news/delegates-focus-on-use-of-plutonium-1.1101586
[190] Professional Engineer (IMechE) 'UK/Canada deal for radical nuclear waste solution', 30 June 2015 http://www.imeche.org/news/engineering/uk-canada-deal-for-radical-nuclear-waste-solution
[191] The Guardian, 'Sellafield plutonium reactors plans rejected', 24 January 2012 http://www.guardian.co.uk/environment/2012/jan/24/sellafield-plutoniumreactor-plans-rejected
[192] The Breakthrough, 'Green hypocrisy on nuclear', 7 May 2013 http://thebreakthrough.org/index.php/programs/energy-and-climate/green-hypocrisy-on-nuclear
[193] US Department of Energy 'Analysis of Surplus Weapons-Grade Plutonium Disposition Options', 6 April 2014 http://nnsa.energy.gov/sites/default/files/nnsa/04-14-inlinefiles/SurplusPuDispositionOptions.pdf
[194] NDA, 'Nuclear Materials Not Reported in the 2013 UK Radioactive Waste Inventory' February 2014 https://www.nda.gov.uk/ukinventory/wp-content/uploads/sites/2/2014/02/14D043_NDASTSTY140013_-_Radioactive_Wastes__Materials_Not_Reported_in_the_2013_UK_Radioactive_Waste_Inventory.pdf

In a recently published study of six future reactor designs being worked on by the U.S.-led "Generation IV International Forum", France's Institut de Radioprotection et de Sûreté Nucléaire (IRSN - Radioprotection and Nuclear Safety Institute) put Sodium Fast Reactors (such as PRISM) at the top of the table of Generation IV technology: noting that only the sodium-cooled fast reactor (SFR) model was far enough along in the development process to envisage building a prototype during the first half of this century. [195] While seeming to support the PRISM concept, this IRSN paper is noteworthy because it is the first significant public criticism of the next-generation designs from nuclear safety officials of the Generation IV International Forum's 13 member countries; which includes Britain, South Korea and Canada.

As the IRSN (which is the technical adviser to France's ASN) noted, SFRs may not be safer than reactors being built today and that while the SFR reactor - unlike PWRs - could operate at low pressure, its main disadvantage was that sodium was highly reactive with water and air. The agency also questioned the degree to which the reactor would be able to burn up the actinides in spent fuel; among the most dangerous and long-lived by-products of nuclear fission. Arguments that SFRs would reduce the amount of nuclear waste, and the subsequent need for deep disposal, were considered by the IRSN as a feature that offered "only a very slight advantage" over current designs: and would not be the deciding factor in the choice of future reactors in France.

Meanwhile Japan's long and expensive pursuit of fast reactors is teetering on the brink of failure, amid new government concerns about its runaway costs. The four-decade project to realise a workable fast breeder, has consumed more than $13 billion in funding; so far producing only accidents, controversies: and a single hour of electricity. Whether the project will ever be completed is doubtful. [196]

Wastes from IFRs

The view given by proponents of IFRs is that these plants present less risk than conventional reactors; and produce less radioactive waste. Yet the IFRs proposed for Australia are dependent on a number of potentially hazardous operations:

- In order to produce the spent fuel – which will be converted into fuel for an IFR – a conventional reactor has to have been operated; this is not a risk free activity.

- The spent fuel produced by operating conventional reactors is highly radioactive. The handling of spent fuel at the site of origin, its transport and subsequent storage and handling at a PRISM site are all potentially hazardous operations.

- To produce fuel for an IFR from spent fuel it has to be fed into a pyroprocessing plant. Pyroprocessing separates out two types of wastes from spent fuel: short-lived gaseous wastes (which would need to be captured and stored rather than released) – as well as fission product wastes which would have to be stored and conditioned prior to disposal.

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[195] IRSN,' Generation IV nuclear energy systems safety potential overview', 27 April 2015
http://www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx. See also
http://www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf
IRSN 'A Review of Generation IV Nuclear Energy Systems' April 2015
http://www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx

[196] The Washington Post, 'Japan losing hope for its pricey 'dream reactor', 31st Jan 2012
http://www.washingtonpost.com/world/japan-losing-hope-for-itspricey-dream-reactor/2012/01/26/gIQAktERTQ_story.html

- Once used in the reactor – or series of reactors - the IFR fuel will contain long-lived wastes; unless it is 'continually recycled' until such time as all the long-lived radioactive materials have been converted into short-lived (but highly radioactive) fission products. [197] Because of this, IFR's can also be considered as 'converters'; turning longer-lived isotopes into short-lived fission product wastes. [198] Fission products, in a disposal facility, are less of a problem long-term than conventional spent fuel containing long-lived actinide wastes. However, over the short-term, when the fission product waste is stored above ground (which could be for decades) this waste could present many of the same risks as spent fuel.

Who pays?

In the debate over IFRs the general impression is gained that foreign companies and governments will willingly pay Australia in order to offload their spent fuel. Such would be the amount paid by other countries to be rid of their spent fuel, it is claimed, that there would be no start-up costs for a programme in Australia. [199] Yet the same people extol the virtues of reusing spent fuel because it is an asset-rich material which should not be squandered by disposing of it. Given this, will overseas companies pay Australia to take their 'asset rich' material? It might be that some companies will pay only to get rid of that part of the spent fuel which is truly an unusable waste product; but will expect payment for the 'asset rich' portion of the spent fuel. In short, if spent fuel was imported into Australia, for use in an IFR, the IFR operators might be expected to pay for the reusable materials (e.g. uranium and plutonium) in the spent fuel.

The Royal Commission might, then, have to consider very different contractual arrangements, for the import and use of spent fuel, to those being mooted. Consider the following. A Japanese company agrees to export spent fuel to Australia for use in an IFR. This company will, however, only pay a contribution towards the costs for pyroprocessing; to cover separating out of the fission products - and management and conditioning of this initial fission waste from the original spent fuel.[200]

The Japanese company believes this to be a reasonable deal because, although the fission product waste accounts for the majority of radioactivity in the spent fuel, by volume it is only approx 3% of spent fuel; and the fission products are radioactive for much less time than the longer-lived isotopes which lead to increased costs in engineering a repository to prevent their release from underground. The Japanese company, therefore, also suggests an agreement whereby it pays a small contribution towards the costs of a repository - for the disposal only of the fission product waste from its spent fuel.

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[197] Nuclear Technology, Vol. 178, PRISM: A COMPETITIVE SMALL MODULAR SODIUM-COOLED REACTOR, 12 July 2010
http://gehitachiprism.com/wp-content/themes/geh_prism/resources/PRISM_Triplett_Loewen_Dooies.pdf
'*The Integral Fast Reactor - IFR - concept proposes the recycling of the 96% of the fissionable material ~uranium and transuranics remaining in LWR UNF. In this process, the uranium and transuranic material is continually recycled via electrometallurgical processing – pyroprocessing - in a metal-fuelled, sodium cooled fast reactor.*' The authors note also: '*the waste that is discharged at the back end of the fuel cycle is composed of only the fission products.*'

[198] Nuclear Energy Agency, OECD, The conversion of actinides in advanced liquid metal reactors'
https://www.oecd-nea.org/pt/docs/iem/cadarache94/session-3/Session3Thompson.pdf
It should also be noted that IFR's do not get rid of all actinides from pyroprocessed spent fuel; it is expected the reactors will reduce actinide levels to insignificant amounts in the waste sent for disposal.

[199] World Nuclear News, 'South Australia's nuclear vision', 23 March 2015
http://www.world-nuclear-news.org/V-South-Australias-nuclear-vision-2303151.html;

[200] See document ref in 194; Page 187 – 'The waste that results from the NFRC process is the genuine waste from nuclear processes, the fission products.'

The Japanese base their offer on the fact that uranium, plutonium (and other actinides), in the context of an IFR programme, are a valuable fuel source; not a waste. If there is a problem; if the actinides are not effectively converted into fission waste IFR fuel (as suggested by the IRSN report); or if the reactor, or some other part of the process, fails and the programme comes to a halt, the Japanese company will still only contribute towards the fission product waste disposal: as this requires less engineered barriers in a repository (because most of the radioactivity in the fission product will have decayed before any radioactive releases are predicted to arise from a repository).

Even if the processes go to plan, how the 'medium-lived' fission product wastes from an IFR programme will be managed - which pose a radioactive hazard for around 400 years; and how long those wastes will be stored prior to conditioning and disposal, needs to be examined thoroughly. [201]

The radioactivity in conventional spent fuel is dominated in the first few hundred years by the fission products.[202] Fission product waste from IFRs remains a risk for up to 300-400 years; its radiation decaying '*to the level of the ore from which it came in several hundred years.*' [203]

Supporters of IFRs have focussed on the problems around conventional spent fuel disposal – with its problems of radioactive releases from a repository over thousands of years; which require costly engineering to reduce them – in order, it seems, to justify the creation of fission product wastes in fast reactors. Yet, as the American Nuclear Society explains in discussing fast reactor fuel cycles: *Virtually all long-lived heavy elements (from spent fuel) are eliminated during fast reactor operation, leaving a small amount of fission product waste that requires assured isolation from the environment for less than 500 years.* [204]

Yet fission wastes, like spent fuel, are very radioactive during above-ground storage; when they are also at their most vulnerable. These wastes could, therefore, present many of the same problems as spent fuel, over the decades before disposal, in terms of security and safety and risks to the environment and human health. That fission wastes from IFRs could pose a significant risk pre-disposal is an issue which is as high on the list of public concerns as the longer-term risks of spent fuel post-disposal. This is why an explanation of the processes pre-disposal - and timing of disposal operations and repository closure - is as important for IFR wastes as for conventional reactors.

Depending on how soon disposal can be achieved, there is a possibility, as with spent fuel, that this problem will be left to future generations to deal with. This is not to dismiss the impact of secure disposal of spent fuel in order to protect against the release of long-lived isotopes; but to make readers aware also of the problems with fission wastes.

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[201] This submission does not discuss the long-lived fission products (e.g. Technetium-99) which will be contained in IFR wastes.

[202] International Panel on Fissile Materials: Managing spent fuel from nuclear reactor', September 2011 http://fissilematerials.org/library/rr10.pdf. Page 8 notes:
For much of the first 100 years, the radioactivity of spent fuel is dominated by the fission products — by two 30-year half-life fission products, strontium-90 and cesium-137, after the first ten years. After a few hundred years, the total radioactivity is dominated by the transuranics: plutonium, americium, neptunium, and curium.

[203] Scientific American, 'Smarter Use of Nuclear Waste', December 2005, http://gehitachiprism.com/wp-content/themes/geh_prism/resources/SciAm_Dec_2005.pdf
see also ref 194; page 197
http://gehitachiprism.com/wp-content/themes/geh_prism/resources/PRISM_Triplett_Loewen_Dooies.pdf;

[204] American Nuclear Society, Position Statement No 74
http://www.ans.org/pi/ps/docs/ps74.pdf

The not inconsequential issue of fission waste seems to have been lost sight of in the hype over IFRs. Yet as a report from the Argonne National Laboratory has noted, the use of spent fuel in IFRs does not get rid of all nuclear wastes: *But it should also be realized that even if the actinides are removed (from the spent fuel) and the radiological lifetime of the high-level waste is reduced to a few hundred years, the need will remain for a geologic repository. The everlasting nature of the waste is eliminated, but for decades the activity will still be high and geologic repository would still be required to store such high level wastes, regardless of the actinide contents.*[205]

What can be utilised as fuel in an IFR has also been misunderstood; with an article in an Australian journal claiming: '*As an added benefit, the large-scale deployment of fast reactor technology would result in all of the nuclear-waste and depleted-uranium stockpiles generated over the last 50 years being consumed as fuel*.' (emphasis added) [206] Yet the industry's radioactive waste stockpile consists of a range of materials; graphite (used as a moderator in different types of reactors e.g. AGRs in the UK); irradiated steel and concrete; contaminated sludges; spent fuel cladding; liquid HLW and vitrified HLW from conventional reprocessing: which cannot be used as nuclear fuel. [207]

Plan B?

As should happen with any consideration given to importing spent fuel for reprocessing, and reuse in conventional MOX reactors, there cannot be an assumption that all the processes will go to plan for an IFR programme. Pyroprocessing plants could experience problems (witness the difficulties with conventional reprocessing); as might an IFR.

For the PRISM design there is no operational experience to draw on to estimate the likelihood of a major accident; or to determine what is a realistic time-scale over which operators must accumulate funds for decommissioning and waste management – e.g. out of profits from electricity sales. There might also be issues around the integrated nature of the PRISM process – the physical proximity of each part of the system – which could raise issues not experienced at conventional reactors.

A serious technical failure could, depending on which part of the process it involved, result in Australia being left with a stockpile of spent fuel; fission wastes from pyroprocessing and partially used IFR fuel in a reactor (which could have a range of fission products and actinides in it). Thus any commercial operators in Australia would have to be made liable – in legislation, in advance – for any additional costs which might arise from disposing of spent fuel, partially used IFR fuel and other wastes that result from an abandoned or curtailed programme. Australia already has experience of the cost of clean-up at uranium mines and nuclear weapons test sites; and how steeply costs can escalate over time. As a contingency measure against these costs falling on the taxpayer, perhaps a bond should be set aside by the commercial companies – in a firewalled account - to cover the possibility of a failed programme (similar to the bonds uranium miners have to establish – albeit with better funding and oversight and control).

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[205] IAEA, 'Evolution of the Liquid Metal Reactor: the Integral Fast Reactor (IFR) concept' 2 June 1989 https://inis.iaea.org/search/search.aspx?orig_q=RN:20066241

[206] Barry W. Brook and Corey J. A. Bradshaw, 'Key role for nuclear energy in global biodiversity conservation', 9 December 2014, Page 7 http://onlinelibrary.wiley.com/doi/10.1111/cobi.12433/pdf

[207] The link to 'CoRWM's Radioactive Waste and Materials Inventory, July 2005'; CoRWM Document No: 1279 is no longer available via a weblink; this document is attached. It is referenced in CoRWM's recommendations to the UK Government (below). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/294118/700_-_CoRWM_July_2006_Recommendations_to_Government_pdf.pdf

Safeguards

There are also safeguards and proliferation issues around IFRs and pyroprocessing which need to be examined in detail. Could an IFR be modified to operate as a 'breeder' of plutonium rather than just a reactor which burns it? Could the fuel be configured in the reactor - without reactor modification - to produce rather than consume plutonium? [208]

Any IFR in Australia would most likely have to be designed to maximise the efficacy of safeguards inspections; but such technical additions could cost dearly. A paper for a non-proliferation seminar in 2007 noted, for the new reactor designs being contemplated, that: *It is evident that new safeguards approaches are required for these reactor types to mitigate the CoK (Control of Knowledge) vulnerability.*

Other points raised were that:

- *Some of these reactor designs – sodium-cooled fast reactors, pebble-bed high-temperature gas reactors, and molten-salt fueled reactors – pose unique safeguards challenges that prohibit the traditional item accountancy approach favored by the IAEA for reactor safeguards.*

- *Sodium-cooled fast reactors pose challenges to reactor safeguards approaches for a variety of reasons. These stem from the visual opacity of the liquid sodium, the chemical reactivity of sodium, the remote handling of the fuel assemblies and the canning of spent fuel.*[209]

The following are just some of the questions that need to be asked about a pyroprocessing/IFR programme:

- Would a single IFR - or series of them - be needed to produce the same amount of power (e.g. 1.2GW – 1.6GW) as conventional reactors under construction?
- How much conventional spent fuel would be needed to provide the base-load fuel to power all of the IFRs?
- Would the radioactive gases be captured, or released, during spent fuel pyroprocessing?
- How much fission product waste (radioactivity and volume) would result from the initial spent fuel pyroprocessing?
- How much waste would be created by reactor operations overall - not just that relating to the spent fuel?
- How much fission product waste would be created by 'continually recycling' the actinides in the original fuel load?
- How long is used fuel stored for, after it is discharged from an IFR, before it is put back in the reactor to fission more of the actinides? [210]

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[208] For full details see ref. 194. See page 191: http://gehitachiprism.com/wp-content/themes/geh_prism/resources/PRISM_Triplett_Loewen_Dooies.pdf.

[209] U.S. Department of Energy/National Nuclear Security Agency Office of Global Security Engagement and Cooperation and Nuclear Nonproliferation Science & Technology Center, 'Nuclear Safeguards Challenges at Reactors Types That Defy Traditional Item Counting', Japan Atomic Energy Agency JAEA-IAEA Workshop on Advanced Safeguards Technology for the Future Nuclear Fuel Cycle 13-16 November 2007 http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2007/cn1073/Papers/3.1%20Ppr_%20Beddingfield%20-%20Nuclear%20Safeguards%20Challenges%20at%20Reactors%20Types%20That%20Defy%20Traditional%20Ite.pdf

[210] See ref. 194 which notes (page 197) '*Reactor refueling occurs in intervals of between 12 and 24 months, depending on the fuel cycle operation and mission. Fuel assemblies are allowed to decay in in-*

- How long would it take, in a reactor, before all the actinides in the original spent fuel load was converted into fission products?
- What would be the total amount of fission product waste - in terms of volume and radioactivity - at the end of the IFR programme?
- How long would that fission waste have to be stored before it could be safely conditioned and disposed of?
- Will the resulting fission product waste from the IFR be more radioactive – and over what period - than the original spent fuel load? Has there been a net loss or a gain (per tonne) in radioactivity by the time of disposal?
- What other forms of committed (unavoidable) wastes – low level and intermediate level wastes and other higher activity wastes – would be created by pyroprocessing and IFR operations; and associated waste management/conditioning? How radioactive would those wastes be; and what would be the volume? [211]
- What radioisotopes are in the IFR wastes; and in what proportion to each other e.g. Caesium-137 and Strontium-90; what are their half-lives; what radiation do they emit?
- What timeline do IFR operators envisage from the first imports of overseas spent fuel to final waste disposal and repository closure?

19. Time to develop a nuclear programme v. time to realise the benefits

Given all the points raised about conventional and fast-reactors, the Royal Commission needs to ask how long is Australia prepared to wait before a nuclear programme comes to fruition. How much will be spent, and who by, on workforce and inspectorate development; on research laboratories; the development and licensing of conventional reactor designs; reprocessing plants; prototype fast reactors; and test disposal sites - before it is thought enough has been done to move forward into a large scale programme?

What timescale will be set, 20 or 30 years, before all concerned feel confident enough that the 'essential components' are in place for a reprocessing and reactor programme? Where will Australia source the reactor technology? Is that technology operating safely, economically and to its estimated generating capacity?

Proponents of integral fast reactors, even if the reactors could be made to work, have not answered some of the key questions. How much do they cost and can they be built to budget? How long will they take to build; can they be built within the necessary timescale?

The industry drawing up designs which look good on paper is a far cry from sorting out the reality of the engineering and economic issues that it takes to deliver affordable and low-carbon energy. That is why ideas like fast reactors work much better in the headlines than they do as viable electricity generating plants.

Is Australia prepared to gamble on a 'first of a kind' (FOAK) reactor: which could have significant environmental and financial risks? On this, some pro-PRISM commentators dismissed the notion the UK would worry over building a new class of fast-reactor because, it was claimed, there were no worries in the UK over the French EPR as the same type of reactor is being built in Finland and France (although not actually in operation). The UK Government

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vessel, ex-core storage positions for one cycle before they are removed and transferred to the NFRC for processing.'

[211] On this see details provided on page 19, of the waste volumes created by conventional reprocessing operations. How much waste would result from 4 m^3 of spent fuel being used in an IFR – as per the figures given for conventional reprocessing of the same amount of spent fuel? It is essential to know precisely what is in the wastes from pyroprocessing and the final spent fuel form to understand issues around management and disposal options.

and regulators, it was claimed, were fine with Areva building EPRs in the UK. [212] A lot has happened in the two years since those remarks were published; things that have dented confidence in new conventional reactor designs - the most recent being the newly discovered problems with the components Areva has manufactured for the EPR, EDF's latest reactor design.

Australia also needs to look at the opportunity cost; what it might lose out on in not pursuing other energy programmes - the environmental and economic benefits of implementing a renewable energy and energy efficiency and conservation programme - while it takes even the first steps towards a nuclear programme. It has to be mindful also that an expansion in renewable electricity generation will impact on the economic viability of nuclear power plants: unless, that is, Australia intends to implement anti-competitive legislation to deliberately disadvantage renewables and/or gives massive subsidies to nuclear power to give it a significant advantage.

None of these questions are asked facetiously: they are central to the TOR the Royal Commission has published. They are particularly germane to the timing of the economic benefits it is claimed will come from a nuclear programme and whether this demanding technology is going to quickly deliver economic benefits; if any at all.

20. Political / Treaties

Australia is signatory to a number of nuclear treaties and bilateral agreements; covering the use of uranium mined in Australia; non-proliferation and safeguards issues; and the transfer of dual use (civil and military capable) technology; and safety protocols. [213]

Any changes to domestic nuclear activities in Australia would require significant changes to existing national legislation, as most of the topics under discussion are currently prohibited in Australia. Specifically, the Environment Protection and Biodiversity Conservation Act 1999 and the Australian Radiation Protection and Nuclear Safety Act 1998 both prohibit construction of a nuclear fuel fabrication plant, a nuclear power plant, an enrichment plant, or a reprocessing facility.[214]

In tandem there would have to be a full review of the international treaties Australia is a signatory to; as well as the bilateral or multilateral agreements between Australia and other countries e.g. what it might mean if waste from those countries was disposed of permanently in Australia. That review must be overseen by independent people; and any papers produced would need to be 'stress tested', to determine their credibility, by wholly independent specialists.

The proposed system of payment for services - and the impact of commercial-in-confidence clauses of those agreements – also needs to be examined through Parliamentary processes. The Royal Commission will doubtless examine those aspects of South Australian laws that

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[212] The Engineer, 'Prism project a proposal for the UK's problem plutonium,' 13 May 2013
http://www.theengineer.co.uk/energy-and-environment/in-depth/prism-project-a-proposal-for-the-uks-problem-plutonium/1016276.article

[213] Australian Dept of Foreign Affairs and Trade, Australia's network of nuclear cooperation agreements,
http://dfat.gov.au/international-relations/security/non-proliferation-disarmament-arms-control/policies-agreements-treaties/Pages/australias-network-of-nuclear-cooperation-agreements.aspx
Nuclear Energy Agency, OECD, 'Regulatory and Institutional Framework for Nuclear Activities – Australia', 2008
https://www.oecd-nea.org/law/legislation/australia.pdf

[214] Australia's Environmental Protection and Biodiversity Conservation Act, 1999
http://www.austlii.edu.au/au/legis/cth/consol_act/epabca1999588/
Australian Radiation Protection and Nuclear Safety Act, 1998
http://www5.austlii.edu.au/au/legis/cth/consol_act/arpansa1998487/

would have to be changed to accommodate any parts of the nuclear industry covered by the TOR; along with details of what legislation the Federal Government would need to introduce to control it (including those areas where Australia is obligated under international treaties).

It is the national government's responsibility for regulatory oversight and intervention for activities given in the TOR; particularly those that come under the non-proliferation safeguards system, or which pose a national risk through the potential for major radioactive releases. [215] So, even if Canberra wanted to cede, or devolve, powers over a nuclear programme to South Australia, it is doubtful it could: under international agreements the burden of compliance and oversight – including 'last defence' on costs; radiation dose limits (routine and accident); security measures; the safety regulatory regime and non-proliferation safeguards – rests with national governments. For example, it is the national government (and taxpayers across Australia) which would be the fallback for compensation, under the international (insurance) liability regime if there was an accident at a nuclear facility and the costs were not wholly covered by the nuclear operator concerned.[216]

A review of existing international agreements and protocols concerning nuclear waste would, therefore, have to take place before Australia could accept spent fuel for disposal; reprocessing (including pyroprocessing) and the reuse of the extracted plutonium and/or uranium in conventional or fast reactors. It will need to consider those activities in relation to Australia's obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, to which it is a signatory.

- The convention ('Implementing Measures', Article 18) states that each Contracting Party – that is the national government which is the convention signatory – '*shall take, within the framework of its national law, the legislative, regulatory and administrative measures and other steps necessary for implementing its obligations under this Convention*.'

- Also (iv, Article 4) that each Contracting Party: *shall take the appropriate steps to: provide for effective protection of individuals, society and the environment, by applying at the national level suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards.*

How future nuclear deals might pan out would depend on which country Australia accepts spent fuel from; what treaties the other country has signed; details of the companies involved; the government policy of the country involved; what materials are covered under obligations to third parties e.g. conditions on spent fuel between the US and Japan. The Royal Commission should address these issues as a priority: unless it is prepared to risk broadly agreeing to an activity in South Australia, only to find the details make any deal unacceptable.

Further, no changes to laws should be made without overwhelming public support from across Australia. Yet it should also be noted, with regard to public support, that one of the most significant risks to the nuclear industry is the decrease in public support which follows financial or technical scandals: or major disasters such as Fukushima. The risk of a downward shift in public support for nuclear power is a key issue for investors; who seek certainty for their investments. Without proof that a range of issues are settled; that there is continuing support

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[215] See ref. 212 https://www.oecd-nea.org/law/legislation/australia.pdf
[216] See ref 106 for full details
http://www.greenpeace.org/international/Global/international/publications/nuclear/2013/FukushimaFallout.pdf
http://www.greenpeace.org/international/en/press/releases/Greenpeace-condemns-the-new-International-Nuclear-Liability-Convention/

from the majority of the public; that the technology will work – on time and to budget – it will prove difficult to attract investors.

Any Federal inquiry on these matters needs to involve all stakeholders and, along with considering legal obligations under existing agreements and treaties, also needs to dig deep into company-company contracts: how they are framed and what impact they might make on the public purse if they fail. The form of any such agreements would also be dependent on who was sending the fuel e.g. a company or a national government. Yet, as has been acknowledged previously, this is a difficult topic to examine in full as little information is available outside the relevant companies or government agencies: even though consideration of financial agreements between organisations is vital. In the UK, costs generally are only made public when a deal starts to fail; even when there have been attempts at Parliamentary oversight. A recent example of this is the report which questioned the viability of NMP continuing as the consortium to decommission and clean up Sellafield. Despite the Commons' Public Accounts Committee taking evidence from the NDA over costs and decommissioning, it took a determined individual (using FOI requests) to get the relevant information before the Committee. [217] The subsequent review by the Committee of the once-secret document showed significant failings (cost blow-outs and time delays) in nine out of the eleven decommissioning projects: and led the NDA to terminate its contract with NMP. [218]

Another issue is the level of control overseas customers companies might want over operations in Australia. The foreign companies that contracted for reprocessing in THORP (Sellafield) were not happy at their lack of control over contracted costs; realising their mistakes only when costs escalated due to technical failures, accidents and lack of financial foresight. Any company considering a waste disposal contract would, however, be keenly aware of the 'cost-plus' problem; and would most likely not agree the same terms. In giving up control over costs and operations, overseas companies might insist on clauses whereby any additional costs – which are almost inevitable – would have to be met by Australian companies; with the attendant risk that those extra costs could come from the public purse. Thus it is critical that all contracts are examined independently and under due process: and before they are signed.

There also needs to be the right of Parliamentary oversight, and public input, into changes to contracts overseen by government agencies. For example, in 2013 the NDA – without specific public consultation on the issue – added 4 tonnes of German plutonium to the UK's stockpile; a significant change to an agreement which the NDA had previously been adamant could not be altered. It was a move which also infuriated a number of the pro-nuclear local authorities engaged in the waste disposal discussions which were then in progress. Not only had they been kept in the dark over this change (which meant keeping more plutonium at Sellafield) but it also highlighted their lack of powers in preventing contractual changes. The change to the terms of the deal with German utilities came despite government officials insisting that a UK disposal site would not, sometime in the future, become a disposal site for additional foreign wastes or nuclear materials. Parliamentarians must have powers of oversight on such contracts – and that must be coupled with regulations that include mandatory public consultation: these matters cannot be left to officials and company directors to determine behind closed doors.

Changes to international treaties, particularly for any activities that might have nuclear proliferation implications, would have to be referred to the relevant international governing bodies; and might also include reference to the different countries involved in the oversight of nuclear materials (depending on bilateral agreements).

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[217] The Independent, 'Report damns Sellafield firm over clean-up', 10 November 2013 http://www.independent.co.uk/news/uk/politics/report-damns-sellafield-firm-over-cleanup-8930953.html

[218] House of Commons, Committee of Public Accounts, 'Progress at Sellafield', Forty-third Report of Session 2013–14. 3 February 2014 http://www.publications.parliament.uk/pa/cm201314/cmselect/cmpubacc/708/708.pdf

There are also broader proliferation issues for any country which considers embarking on the kind of nuclear activities under discussion by the Royal Commission. It might be believed that these can simply be answered by improved regulation and increased safeguards; including better measures to physically protect nuclear materials. Those measures will not answer the wider concerns, or changed perceptions, over why Australia, a country rich in coal; and which has significant gas and oil reserves; and significant renewable energy resources and potential, would think of going down the nuclear path. [219] Some will answer that point by claiming that nuclear power is needed to reduce Australia's and global CO_2 emissions. It is a reply which would only hold true if, in pursuing nuclear power, Australia also significantly reduced or banned coal use and export.

Other nations will know that Australia's CO_2 emissions could be reduced in ways other than the building of hazardous nuclear plants. It is famously one of the world's sunniest countries – with massive potential for solar power. It also has a huge potential for onshore and offshore wind; and, with the world's seventh largest coastline, a vast untapped source of tidal and wave power. [220] The issue of reactor costs – and what might be lost by way of delaying implementing renewable programmes while pursuing the nuclear option – is also being posed in other countries, such as South Africa.[221]

Doubtless it will continue to be said that there are economic benefits for Australia in importing spent fuel; and for reprocessing. But as the economics of an import/dispose programme are untested, and the economics of reprocessing do not stack up, that looks very questionable: and is an inadequate response to concerns over activities which are central to proliferation concerns. That Australia might take spent fuel purely as an altruistic act (one which might also bring in some cash) would also most likely be met by scepticism in many quarters. In short, this is an industry which raises questions about proliferation; and Australia should reflect long and hard on what it means politically if it permits an industry which rings alarm bells over its real intentions. It should not forget that apart from Japan (whose reprocessing programme has led to concerns in East Asia), reprocessing is only undertaken by the existing weapons states: or the 'midnight states' which secretly developed their nuclear weapons programmes; some of which are now, in effect, openly weapons-capable.

Veterans of this debate will know that national nuclear programmes in North East Asia, which involved reprocessing and plutonium separation or stockpiling, first gave rise to proliferation concerns some decades ago. [222] In the 1990s, the nuclear activities of North Korea, South Korea and Japan became more well known because Pyongyang used Japan's reprocessing as an incitement and justification for its own programme (with South Korea at the time also pressing the US for it to be allowed to reprocess spent fuel). South Korea, prohibited from reprocessing, has been mooted as a potential customer for Australia if it decided on spent fuel

[219] CIA, World Factbook – Natural Resources
https://www.cia.gov/Library/publications/the-world-factbook/fields/2111.html
CIA World Factbook – crude oil
https://www.cia.gov/library/publications/the-world-factbook/rankorder/2244rank.html
CIA – World Factbook – natural gas
https://www.cia.gov/library/publications/the-world-factbook/rankorder/2253rank.html
[220] Maps of the World – Longest coastlines
http://www.mapsofworld.com/world-top-ten/world-top-ten-longest-coastline-countries-map.html
[221] Business Day, 'Pursuit of nuclear energy likely to be more time wasted', 25 May 2015
http://www.bdlive.co.za/opinion/2015/05/25/pursuit-of-nuclear-energy-likely-to-be-more-wasted-time
Business Day, 'Murky nuclear plan no light at end of tunnel', 22 June 2015
http://www.bdlive.co.za/opinion/columnists/2015/06/22/murky-nuclear-plan-no-light-at-end-of-tunnel
[222] Greenpeace International, 28 April 2005.
http://www.greenpeace.org/international/Global/international/planet-2/report/2006/4/Proliferation-Korea-Japan.pdf

imports. However, recent changes to US and South Korean policy, which could allow Seoul to pyroprocess spent fuel, might mean that potential business for Australia will not eventuate. [223]

In the face of its huge renewable energy resources it would not come as a surprise if other countries took the view that at some time in the future Australia could, if it reprocessed spent fuel, use its plutonium stocks for weapons. This is not a fallacious argument: it is exactly the point raised, in Australia in the 1990s, to argue against nuclear developments proposed for Indonesia. Questions were asked back then as to why Australia's close neighbour, with its coal reserves and potential for small to large scale hydro, solar and geothermal, as well as tidal and wave power; wanted large-scale nuclear reactors. A number of commentators came up with the answer that it was part of a covert weapons programme by Jakarta. Whether this was reasonable is another issue: the key point is that perceptions of Indonesia's intentions over nuclear weapons changed when it appeared to want nuclear power. (As an aside, it should also be noted that the Japanese and US companies which proposed building in Indonesia pointed to experience in Japan as proof that any reactors they built would be able to withstand all earthquakes and tsunamis).

Australia, although it does not have nuclear weapons, has something of a tarnished reputation in terms of non-proliferation through it support of countries with nuclear weapons - and its support of nuclear programmes which are dual purpose. Concerns that Canberra might seek nuclear weapons could follow the pursuit of uranium enrichment, nuclear power and conventional spent fuel reprocessing and plutonium separation: there is no less reason for regional neighbours to mistrust Australia than Canberra has mistrusted them. The same holds true for pyroprocessing for integral fast reactors, which, as explained earlier, could raise safeguards concerns beyond those even of conventional reprocessing due to problems in accounting for stocks of nuclear materials. Australia has to be mindful – given the majority of nuclear technology is dual-use capable; and because there is a range of nuclear materials that can be used in weapons - that it does not cause consternation for other countries.

With this in mind the Royal Commission must consider a report released in April that looks at MOX programmes in France, Japan, the UK and the US.[224] Published by the highly respected International Panel on Fissile Material, and authored by Frank Von Hippel and Prof Gordon MacKerron (former chair of CoRWM), the report advocates plutonium stockpiles to be disposed of as waste rather than for them to be reused.

21. Security

There are too many security concerns around spent fuel transport and storage, reprocessing plants, reactors and disposal facilities to cover here. However, an attack on a spent fuel carrier, or rail or road transport, is not beyond the realms of possibility. [225]

To reduce threats to nuclear security, or stop attacks - particularly to facilities that hold highly radioactive material like spent fuel, or weapons-usable plutonium - would need a significant increase in civilian and worker surveillance; and a corresponding loss of their civil liberties. For example, in recent years - depending on the nuclear materials a worker might be handling – it is not only the worker who applies for a job who is vetted; but also their immediate family members.

[223] Reuters, 'S. Korea, US reach deal to revise civil nuclear pact', 22 April 2014
http://uk.reuters.com/article/2015/04/22/southkorea-usa-nuclear-idUKL4N0XJ1R920150422
[224] For full details see ref 184
http://fissilematerials.org/blog/2015/04/alternatives_to_mox.html
[225] US Council on Foreign Relations, 'Are nuclear spent fuel ponds secure?' 7 July 2005
http://www.cfr.org/weapons-of-mass-destruction/nuclear-spent-fuel-pools-secure/p8967

Increased surveillance is not a new notion that has sprung from recent events; it was first warned of nearly 40 years ago, in the UK Royal Commission on Environmental Pollution: Sixth Report on Nuclear Power and the Environment (September 1976). Known as the Flowers report, after its chairman Sir Brian Flowers, the report raised a number of concerns about the impact of any country embarking on a 'plutonium economy'. Whilst not advocating the abandonment of nuclear power (conclusion 45) the report did, however, note (conclusion 44) that *'the dangers of the creation of plutonium in large quantities in conditions of increasing world unrest are genuine and serious. We should not rely for energy supply on a process that produces such a hazardous substance as plutonium unless there is no reasonable alternative.'*

Written nearly four decades ago, at a time when the world was much safer - relative to the current situation - the report's conclusion stands as a stark warning. It is a useful prompt to the Royal Commission also to consider the types of threat; and possible impacts of sabotage on a specific facility, or a critical part of one of them (e.g. back-up cooling systems) or an attack by a disturbed individual or foreign-based terrorist group: none of which can be fully discounted. [226] Increasingly there are concerns over the vulnerabilities of civil nuclear facilities in the context of conflict – with these being described as pre-deployed nuclear targets. The continuing tension between Russia and Ukraine, and fighting in the Middle East, has again focussed global attention on these security concerns.

Security measures – physical, technical and organisational - have to take this into account. Some might think the likelihood of terrorist attacks is remote, given Australia's relative physical isolation. Yet sadly, as recent operations by Australian security agencies to prevent terrorist attacks have demonstrated, distance is no guarantee of safety. Nor can distance negate the risk of cyber-attack: such as that which was believed to have happened on South Korea's nuclear plants in late 2014. [227] In fact, only recently the International Atomic Energy Agency held a conference on cyber security to discuss the risks of such an attack on nuclear facilities. [228]

Drones, which have flown over French nuclear facilities a number of times in the past year, are also another security threat to nuclear installations. [229] A further threat - one probably not yet discussed in Australia (with its relatively small nuclear facility) - is that of pandemic. [230] This

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[226] The Daily Mail, 'Suicide pilot sparks MI5 alert on Britain's rogue insiders',
http://www.dailymail.co.uk/news/article-3026033/Suicide-pilot-sparks-MI5-alert-Britain-s-rogue-insiders-Staff-nuclear-transport-industries-subjected-continuous-psychological-tests-crash.html
Union of Concerned Scientists, 'Nuclear plant security'
http://www.ucsusa.org/our-work/nuclear-power/nuclear-plant-security#.VV9LKkb1ncc
Bloomberg, 'Nuclear reactors in US seen at risk of terrorist attack', 15 August 2013
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[230] Nuclear Energy Institute, 'Pandemic Licensing Plan' - letter to US Nuclear Regulatory Commission, 17 December 2007
http://atom.nei.org/Portals/4/1_LIC/Pandemic/PLPr1_complete.pdf
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http://pbadupws.nrc.gov/docs/ML0812/ML081210310.pdf

issue has, however, been debated in the US and other countries because of the impact a life-threatening communicable disease could have on a nuclear workforce or those covering essential associated facilities. It is an issue that must, however, be factored into assessing the risks of the nuclear activities being proposed.

The probability of a terrorist attack is a risk that cannot be assessed in the same way that the probability, for example, of component failure can be estimated. As the UK Parliamentary Office for Science and Technology noted (with reference to reprocessing plants): *While there is evidence that the probability of such a large release occurring accidentally lies within established safety limits, there is no equivalent framework for establishing the probability of a large release occurring through deliberate action, and thus it is difficult to place these analyses in context*. [231]

For proliferation and security reasons, if Australia opened its doors as an international disposal site for nuclear waste and spent fuel disposal, it is likely it would require extensive oversight by international agencies. Indeed, during the debate about Pangea – and its failed attempt to make Australia into a nuclear dumping ground - it was suggested an international disposal site, because of the competing interests of customer companies and their attendant government obligations, might require the establishment of a form of 'nuclear Vatican' within Australia - effectively a state within a state subject to direct international regulatory oversight and intervention.

List of Attachments

1. TS 088: Improvements to CoRWM Inventory: Study Report CoRWM Document Number: 1277 ELECTROWATT-EKONO (UK) LTD. Ref. No 200520.01/01 June 8, 2005
File name:
CCSA-ACF-FOE-ATTACHMENT 1 - ELECTROWATT EKONO CORWM JUNE 2005.pdf

2. TRANSCRIPT THORP: Ref No: S20060084. IN THE CROWN COURT AT CARLISLE Courts of Justice, Carlisle Cumbria 16th October 2006
Before: THE HONOURABLE MR JUSTICE OPENSHAW
REGINA –V – BRITISH NUCLEAR GROUP SELLAFIELD LTD
File name:
CCSA-ACF-FOE-ATTACHMENT 2 - THORP TRANSCRIPT 2007.pdf

3. Committee on Radioactive Waste Management
CoRWM's Radioactive Waste and Materials Inventory –
July 2005 CoRWM Document No: 1279 FINAL
File name:
CCSA-ACF-FOE-ATTACHMENT 3 - CORWM FULL INVENTORY Final.pdf

4. Fukushima Fallout (Greenpeace International)
Antony Froggatt, Dr David McNeill, Prof Stephen Thomas and Dr Rianne Teule
February 2013
File name:
CCSA-ACF-FOE-ATTACHMENT 4 - FukushimaFallout.pdf

5. Research Report

[231] UK Parliamentary Office of Science and Technology, 'Assessing the risk of terrorist attacks on nuclear facilities', Report 222, June 2004. See page 74, section 9.1
http://www.parliament.uk/business/publications/research/briefing-papers/POST-Report-8/assessing-the-risk-of-terrorist-attacks-on-nuclear-facilities

Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations
Independent Report for Greenpeace UK • 1st March 2011• Issue 1
Jackson Consulting
File name:
CCSA-ACF-FOE-ATTACHMENT 5 - FINAL JACKSON FUP Subsidy Report (Mar2011)[1].pdf

6. Response to Funded Decommissioning Programme Guidance and Waste Transfer Price consultations. DECC's Consultation on revised Funded Decommissioning Programme Guidance for New Nuclear Power Stations (FDP) and the Consultation on an updated Waste Transfer Pricing Methodology for the disposal of higher activity waste from new nuclear power stations (WTP) Greenpeace UK March 2011
File name:
CCSA-ACF-FOE-ATTACHMENT 6 - GREENPEACE UK SUBMISSION 2010 CONSULTATION WASTE CONTRACTS.pdf

FINAL DRAFT

ENERGY BUSINESS GROUP

200520.01/01

June 8, 2005
1

TS 088: Improvements to CoRWM Inventory:
Study Report
CoRWM Document Number: 1277

ELECTROWATT-EKONO
Jaakko Pöyry Group

X7952.MJP

EXECUTIVE SUMMARY

This report presents the results of a study to update the information contained in the Preliminary Report on the Inventory (CoRWM Document No. 542) in support of long-term waste management options that CoRWM is proposing to short-list. This process has included the following elements:

- Address and act on feedback from the first phase of Public Stakeholder Engagement;
- Make use of draft 2004 UK Radioactive Waste Inventory data in place of 2001 Inventory data;
- Identify short-lived ILW that potentially may be suitable for near surface disposal;
- Address the impact of spent sealed sources that have no current disposal route;
- Give further consideration to the impact of a future programme of nuclear power station build;
- Give further consideration to waste substitution;
- Give further consideration to NORM wastes.

The main findings of the study are (all volumes are packaged):

The use of draft 2004 UK Radioactive Waste Inventory in place of 2001 Inventory data leads to a 12.5% increase in HLW volume but no significant change in ILW volume. There is a 20% increase in the volume of LLW unsuitable for Drigg disposal, but only a 12.5% increase in the figure for non-Drigg LLW volume in CoRWM's preliminary inventory report.

Only 2,320m^3 of ILW can be classified as short-lived under the EU system of classification and so potentially suitable for near-surface disposal. Only 1,710m^3 of ILW meets Drigg's CfA.

In the 2004 Inventory waste produces have identified about 19,000m^3 of ILW that they plan to decontaminate or decay store with the intention of disposing the wastes to Drigg as LLW. There could be potential for further ILW to be decontaminated to LLW. A further 8,950m^3 of ILW are likely to be processed to segregate ILW and LLW fractions. This has the potential of reducing the ILW inventory.

Early decommissioning of nuclear power stations is unlikely to have any significant impact on wastes potentially suitable for near surface disposal.

The quantities of spent fuel and radioactive wastes from a new build nuclear power station programme are reported for four types of reactor (AP1000, EPR, ABWR and PBMR). Up to about 15,000tHM of spent fuel and between about 90,000m^3 and 190,000m^3 of ILW and LLW are forecast.

The adoption of ILW substitution for overseas-owned wastes will result in the UK retaining 5,000m^3 of ILW and returning an additional 60m^3 of HLW.

Spent sealed radiation sources will have no significant impact on overall volumes of radioactive waste. However the radioactivity of Co60 sources could be significant.

In addition to this report, EEUK has updated the CoRWM inventory to include the findings of this study. EEUK has also amended the CoRWM inventory report with the aim of improving clarity and providing summary tables and diagrams. Furthermore EEUK has prepared a "high level summary" incorporating the results of this study and the update of the CoRWM inventory report, and a "questions and answers" document for CoRWM members regarding the findings of this study and the update of the CoRWM inventory report.

Contents

EXECUTIVE SUMMARY		**3**
1	**INTRODUCTION**	**5**
2	**FEEDBACK FROM THE FIRST PHASE OF PUBLIC STAKEHOLDER ENGAGEMENT**	**6**
3	**USE OF DRAFT 2004 UK RADIOACTIVE WASTE INVENTORY DATA**	**7**
4	**SHORT-LIVED ILW AND NEAR SURFACE DISPOSAL**	**9**
4.1	Introduction	9
4.2	Basis of analysis	9
4.3	Volumes of short-lived ILW	10
4.4	Impact of near surface facility CfA on ILW volumes suitable for disposal	10
4.4.1	EU classification system alpha limits	10
4.4.2	Drigg radioactivity limits	13
4.4.3	Drigg material restrictions	16
4.5	Potential for decay storage or decontamination	17
4.6	Impact of early decommissioning	19
4.7	Potential for short-lived and long-lived waste segregation at source	19
4.8	Non-Drigg LLW	20
4.9	Facility design, cost and transport impact of near surface disposal of short-lived ILW	20
5	**WASTE AND MATERIAL CHARACTERISTICS AND THEIR IMPACT ON LONG-TERM MANAGEMENT**	**22**
5.1	Introduction	22
5.2	Radionuclides and radioactivity	22
5.2.1	Radioactive wastes	22
5.2.2	Radioactive materials	22
5.3	Physical and chemical properties	22
6	**WASTE FROM NUCLEAR POWER STATION NEW BUILD**	**27**
6.1	Introduction	27
6.2	Advanced Passive (AP1000)	27
6.3	European Pressurised-Water Reactor (EPR)	29
6.4	Advanced Boiling Water Reactor (ABWR)	30
6.5	Pebble Bed Modular Reactor (PBMR)	30
6.6	Summary	31
7	**WASTE SUSTITUTION**	**32**
7.1	Background	32
7.2	Analysis	32

8 SPENT RADIATION SOURCES 33

8.1 Introduction 33
8.2 Inventory 33

9 NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) 35

10 OTHER WASTES 37

11 REFERENCES 38

1 INTRODUCTION

The Committee on Radioactive Waste Management (CoRWM) is an independent body appointed by UK Government Ministers set up to make recommendations on the best option, or combination of options, for the long-term management of radioactive waste so as to ensure protection of both people and the environment.

The Inventory Working Group (IWG) was established by CoRWM to determine the inventory of radioactive wastes, including some radioactive materials (uranium, plutonium and spent nuclear fuel) not currently classed as waste that will need to be managed in the long-term. In order for the potential solutions to be assessed, CoRWM needs to determine the quantities of wastes, in terms of both volume and radioactivity; the form of the wastes and any associated technical difficulties; the current location of the wastes; and any special considerations that may apply, such as security.

A key aim of CoRWM is to establish a baseline inventory and identify the range of possible inventories and associated uncertainties in order to measure their different effects on the long-term management options that have been have short listed by CoRWM. The range of inventories include the extent to which the baseline inventory would be altered if for example:

- Uranium, plutonium and spent fuel were to be managed as wastes;
- Plutonium and uranium were to be burned as fuels in existing or new UK reactors;
- New nuclear power station were built;
- Decommissioning programmes were revised.

A preliminary report on the CoRWM inventory [1] was published in October 2004 and was issued for consultation to public and key stakeholders during the first phase of CoRWM's engagement programme. The preliminary report identifies a 'baseline inventory' and begins to analyse uncertainties and to suggest the extent to which they could affect the size and make up of the inventory.

The feedback CoRWM has received from the first phase of the public & stakeholder engagement process has been summarized in a 'headlines Issues' paper [2]. The purpose of this report is to address these issues, and to facilitate the IWG in delivering an improved and updated inventory report as a Phase 2 deliverable of CoRWM's work programme by early July 2005.

A major element of the CoRWM inventory update is the use of draft 2004 UK Radioactive Waste Inventory (RWI) data [3] in place of the previous 2001 UK RWI data [4]. It is currently anticipated that waste producers will approve the 2004 UK RWI data for publication in June/July 2005. Reports will then be printed, and published in October/November 2005.

The work has included a determination of the uncertainties associated with the inventory data and the extent to which these could affect the size and make up of the CoRWM inventory. Agreed and undisputed knowledge areas, and any knowledge gaps and major uncertainties have been highlighted.

2 FEEDBACK FROM THE FIRST PHASE OF PUBLIC STAKEHOLDER ENGAGEMENT

The feedback CoRWM has received from the first phase of the public & stakeholder engagement process has been summarized in a ‘headlines Issues’ paper [2]. Key issues concerning the volume of waste raised on CoRWM’s preliminary report on the inventory include:

- Short-lived ILW that may be suitable for near surface disposal;
- The impact of different reactor types on any new build programme;
- The impact of waste substitution of LLW & ILW for radiologically equivalent HLW from spent fuel reprocessing for overseas customers;
- Spent high activity sealed sources;
- NORM waste.

These issues are addressed in the Sections 3 to 7of this report.

The feedback also included comments on the following aspects:

- CoRWM’s remit – what waste is included, what waste is excluded?
- The Government LLW review;
- Clarification of waste categories and definitions;
- More information on waste streams;
- Waste minimisation;
- Accelerated decommissioning and site clean up.

These aspects have been addressed in preparing an update of CoRWM’s inventory report.

3 USE OF DRAFT 2004 UK RADIOACTIVE WASTE INVENTORY DATA

The CoRWM IWG has requested that draft 2004 UK RWI data [3] is used in place of 2001 UK RWI [4] for this study and for the update of CoRWM's inventory report. Approval for use of the data before its publication in the 2004 UK RWI reports is being sought from the waste producing organisations that provided the data, and from Nirex and Defra, the sponsors of the 2004 UK RWI.

For comparison, Table 3.1 gives the volumes of HLW, ILW and LLW identified as unsuitable for Drigg for 2001 and draft 2004 data.

Table 3.1: Comparison of waste volumes in the 2001 and draft 2004 UK RWI

Waste type	**2001 UK RWI**	**Draft 2004 UK RWI**
HLW		
Conditioned volume	1,510	1,340
Packaged volume	2,000	1,750
ILW		
Conditioned volume	237,000	242,000
Packaged volume	349,000	348,000
LLW unsuitable for Drigg		
Conditioned volume	25,500	31,200
Packaged volume	29,900	37,200

All HLW is generated from reprocessing spent nuclear fuel at Sellafield.

The total conditioned volume of HLW is 170m^3 less than in the 2001 Inventory. The principal reason for this decrease is that the 2004 UK RWI assumes less spent fuel is reprocessed in Thorp, including no "uncommitted" wastes from reprocessing spent LWR fuel. Uncommitted wastes were potential arisings from reprocessing fuel further to existing contracts. Also, PFR raffinate at Dounreay has been reclassified as ILW.

The total conditioned volume of ILW in the 2004 UK RWI is 242,000m^3. Approximately 95% of this volume is from the following sources:

Sellafield	124,000m^3
Magnox power stations	53,600m^3
AGRs power stations	30,600m^3
Dounreay	11,900m^3
AWE Aldermaston	7,200m^3

The total volume of ILW is about 5,000m^3 more than in the 2001 Inventory. There are revised estimates of ILW volumes throughout the 2004 UK RWI as a result of changes in the scale of future activities and re-evaluations of future arisings.

The principal increases are the result of:

- The inclusion of newly reported wastes. In particular miscellaneous waste at Sellafield consisting of a large number of mainly small volume heterogeneous wastes that arise from a wide range of operational and research activities;
- The reclassification of much of the final stage decommissioning graphite waste at Trawsfynydd from LLW to ILW, giving a further;
- A revised decommissioning strategy at Calder Hall and Chapelcross, giving a further. The strategy is now the same “Deferred Site Clearance” strategy as other Magnox power stations;
- Revised estimates of waste from facilities decommissioning at Sellafield;
- A revised estimate of waste from decommissioning the Prototype Fast Reactor at Dounreay;
- The extrapolation of waste from decommissioned nuclear powered submarines to 2100 rather than 2050.

Some estimates of ILW volumes are lower than in the 2001 UK RWI. The principal changes are:

- A correction to the anticipated total quantity of EARP floc at Sellafield;
- The exclusion of uncommitted wastes from reprocessing spent LWR fuel in Thorp;
- A revised estimate of miscellaneous beta/gamma wastes at Sellafield.

4 SHORT-LIVED ILW AND NEAR SURFACE DISPOSAL

4.1 Introduction

One of the waste management options that CoRWM proposes to short-list is the near surface disposal of short-lived wastes. The advantages of this option are that the technology is tested and in principle such wastes could be disposed of where they are produced. In particular it has the potential to allow future decommissioning wastes to be managed at existing sites, removing the need to transport large volumes to a central or regional facilities.

Because near surface disposal is suited to short-lived wastes that lose their radioactivity over a few hundreds of years, it would not be suitable for wastes that contain a mix of short and long-lived radioactivity, such as the wastes from spent fuel reprocessing, unless this radioactivity was at a low level.

It is fundamental to the assessment of the near surface disposal option that CoRWM has a clear and detailed understanding of which wastes might be suitable, where they are produced, their volumes and the associated uncertainties. To this end the analysis has included the following assessments:

- The characteristics and volumes of ILW that can be designated at "short-lived" under international classification systems;
- The uncertainty in the volume of short-lived ILW resulting from uncertainty in radioactivity concentrations;
- An examination of those ILW streams and their volumes that satisfy Drigg CfA [5], and by how much the CfA would need to differ in order to accommodate ILW at a near surface disposal facility;
- The potential for decay storage or decontamination of ILW;
- The impact of early decommissioning;
- The potential for segregating short-lived waste from a mix of short and long-lived radioactivity.

We have also considered non-Drigg LLW and examined under what criteria this would be suitable for near surface disposal.

4.2 Basis of analysis

We have used draft 2004 UK RWI data for ILW [3]. The total reported volume of ILW 242,000m^3 conditioned volume (348,000m^3 equivalent packaged volume).

The UK does not classify radioactive wastes as short and long-lived. This study is based on the EU classification system [6]. This system states that the short-lived low and intermediate level waste category "includes radioactive waste with nuclides half-life less than or equal to those of Cs137 and Sr90 (around 30 years) with a restricted alpha long-lived radionuclide concentration (limitation of long-lived alpha emitting radionuclides 4,000 Bq/g in individual waste packages and to an overall average of 400 Bq/g in the total waste volume)".

In our calculations to identify short-lived waste as classified by the EU we have used a limit of 400Bq/g long-lived (>30 years) alpha radionuclides in the conditioned waste form, and excluded all wastes that contain any beta/gamma emitting radionuclides with half-lives of >30 years. As we are considering waste streams and not individual waste packages we have not considered the individual waste package limit.

The EU classification system is based on the IAEA classification scheme [7], which includes the same criteria for radionuclide half-life and the concentration of long-lived alpha emitters. With regard to beta/gamma emitters, the IAEA scheme states that in applying the classification system attention should also be given to inventories of long-lived radionuclides that emit beta or gamma radiation, and that allowable quantities, of for example I129 or Tc99, will depend on radionuclide toxicity and site-specific conditions. It also states that a general boundary between near surface and geological disposal of radioactive waste cannot be provided as activity limitations will differ for individual radionuclides and will be dependent on the actual planning for a near surface disposal facility (e.g. engineered barriers, duration of institutional control, site specific factors).

In practice any new proposed UK near surface disposal facility would have conditions for acceptance that impose waste concentration limits on both alpha and beta/gamma radionuclides, as Drigg does today. It is therefore appropriate to examine how such limits would define the quantities of waste for near surface disposal.

4.3 Volumes of short-lived ILW

The result of applying the EU classification system to ILW in the 2004 UK RWI is that only a small volume of ILW (2,320m^3 in terms of conditioned volume) can be classified as short-lived. A breakdown of this conditioned volume (and the equivalent packaged volume) into sites and regions is presented in Table 4.1. There are 780m^3 of short-lived ILW at 1 April 2004 and 1,540m^3 in future arisings.

The main component of the short-lived waste is pond skips at Magnox power stations (1,050m^3 conditioned volume; 1,310m^3 packaged volume). However BNFL is proposing to decontaminate pond skips and dispose of them to Drigg as LLW (see Section 2.5). Other components include ion exchange material at Trawsfynydd and tritium contaminated items at Cardiff and Culham.

There are only 360m^3 conditioned volume (420m^3 packaged volume) of decommissioning ILW that can be classified as short-lived; these are from uranium and plutonium facilities at Dounreay and Aldermaston, and from JET at Culham. There is no short-lived ILW from decommissioning nuclear power stations.

All radionuclide activity data in the 2004 UK RWI have quantified uncertainties that indicate lower and upper limits on activity concentrations. An analysis of the uncertainties indicates that the total conditioned volume of 2,320m^3 could be up to 1,090m^3 lower.

4.4 Impact of near surface facility CfA on ILW volumes suitable for disposal

4.4.1 EU classification system alpha limits

There is a relationship between the EU classification system for radioactive wastes, and the management of the wastes, in particular their disposal. Thus short-lived wastes are those potentially suitable for near surface disposal. It is recognised that suitability will depend on national arrangements and site-specific safety assessments.

While the EU classification system places an activity concentration limit on long-lived alpha emitting radionuclides (on average 400Bq/g in the conditioned waste) there is no activity concentration limit for long-lived beta/gamma emitting radionuclides.

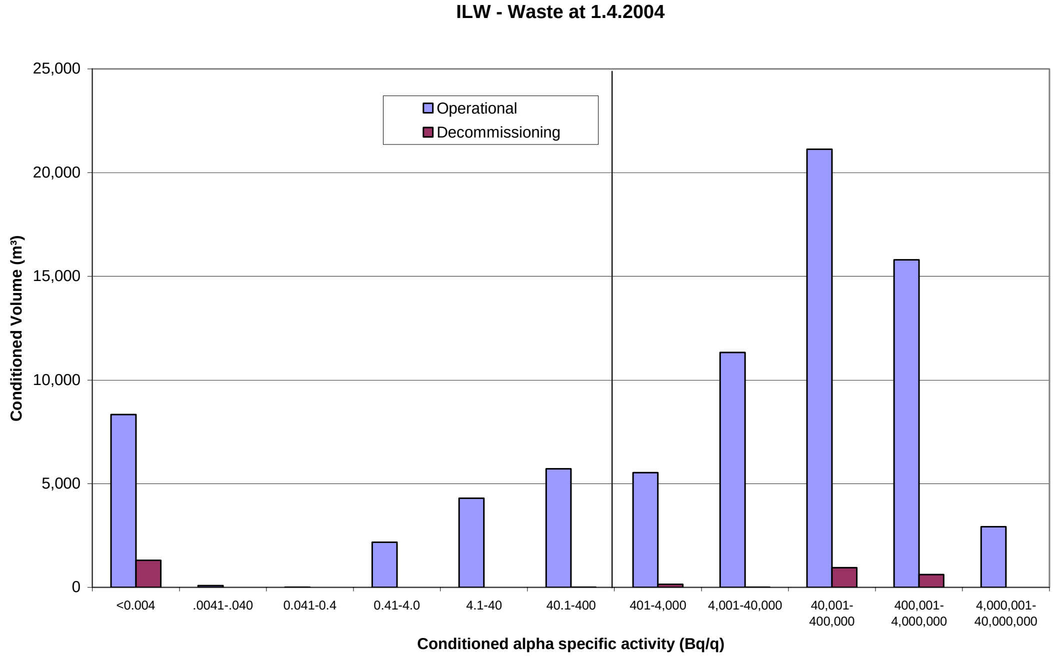
Table 4.1: Volumes of short-lived ILW in the UK (based on EU classification system)

Site	Region	Waste at 1.4.2004 and future arisings	
		Conditioned Volume	Packaged Volume
Bradwell	East of England	43	54
Sizewell	East of England	209	261
East of England Total		**252**	**315**
Chapelcross	North West	0.2	0.3
Sellafield	North West	22	26
North West Total		**22**	**26**
Torness	Scotland	24	25
Dounreay	Scotland	290	337
Scotland Total		**314**	**362**
Amersham	South East	57	72
Harwell	South East	0.1	0.1
Culham	South East	135	160
AWE Aldermaston	South East	199	237
HMNB Portsmouth	South East	0	0
Dungeness A	South East	171	213
South East Total		**562**	**682**
Winfrith	South West	23	27
Hinkley Point A	South West	454	566
Berkeley Centre	South West	2	2
South West Total		**479**	**594**
Cardiff	Wales	186	216
Trawsfynydd	Wales	300	1,400
Wales Total		**486**	**1,620**
Oldbury	West Midlands	203	253
West Midlands Total		**203**	**253**
Overall Total		**2,320**	**3,850**

Note: The total volumes of ILW in the 2004 UK RWI are 242,000 conditioned and 348,00 packaged.

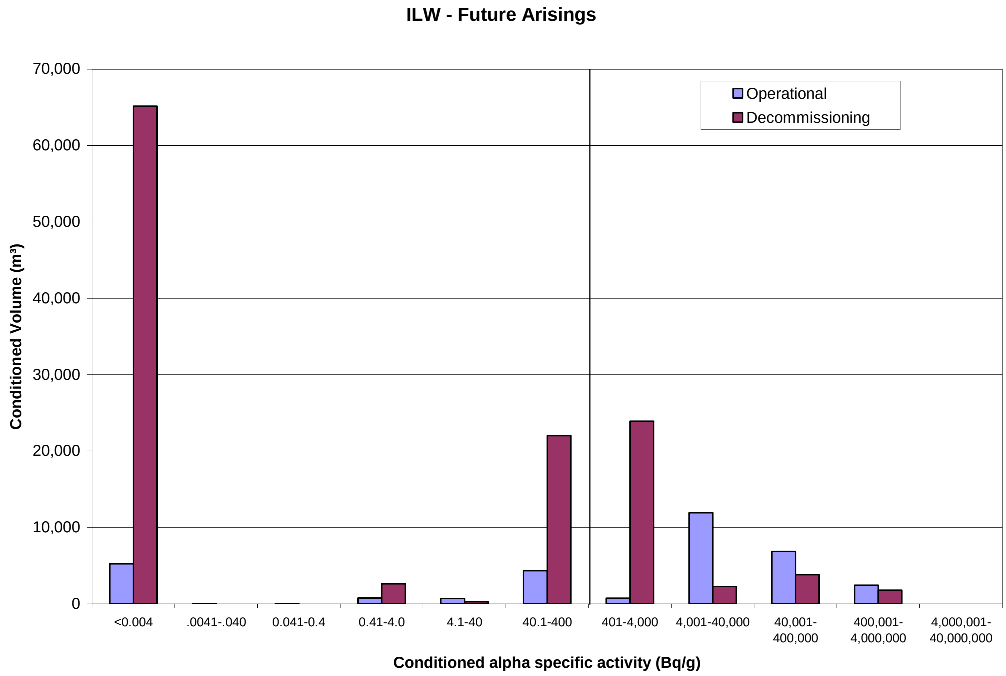
Figures 4.1 and 4.2 illustrate, for waste at 1 April 2004 and for future arisings respectively, the volumes of ILW (when conditioned) at different concentrations of long-lived alpha activity. We have included those wastes from early stage decommissioning at power stations (defuelling and Care and Maintenance preparations) with operational wastes because they are similar and occur immediately after the end of generation. There is a total ILW conditioned volume of 123,000m^3 with a long-lived alpha emitting radionuclide concentration of 400Bq/g or less, and a volume of 112,000m^3 where the long-lived alpha emitting radionuclide concentration is greater than 400Bq/g. There are 6,020m^3 of ILW with no quantified radionuclide concentrations.

Figure 4.1: Long-lived alpha nuclide concentration in all ILW at 1 April 2004



Note: Excludes 1,280m^3 (conditioned volume) for which there is no quantified activity data.

Figure 4.2: Long-lived alpha nuclide concentration in all ILW future arisings



Note: Excludes 4,750m^3 (conditioned volume) for which there is no quantified activity data.

There are 21,900m^3 of ILW at 1 April 2004 with a long-lived alpha emitting radionuclide concentration of 400Bq/g or less (see Figure 4.1). Most of this waste is operational, and major components include Magnox and graphite fuel element debris at Magnox power stations, and graphite and stainless steel AGR fuel assembly components at Sellafield.

There is 101,000m^3 of ILW in future arisings with a long-lived alpha emitting radionuclide concentration of 400Bq/g or less (see Figure 4.2). More than half of this waste (59,200m^3) is from final stage decommissioning of Magnox and AGR power stations, and is made up of graphite and steel wastes. A further 30,900m^3 is from decommissioning other nuclear facilities, principally at Sellafield.

4.4.2 Drigg radioactivity limits

In practice, a near surface disposal facility would have specific limits for beta/gamma emitters as well as alpha emitters. Therefore in determining what ILW streams might be suitable for near surface disposal we have utilised the CfA for the Drigg site, and we have examined how much additional ILW volume might be accommodated in a near surface disposal facility should the CfA be less onerous than those imposed at Drigg. We have also examined the ILW radionuclide activity data in order to determine which radionuclide activity concentrations would restrict or prevent near surface disposal of ILW.

The Drigg near surface LLW disposal site imposes the following limits on waste stream radionuclide concentrations (specific activity trigger levels) and on waste stream radionuclide activities (total activity trigger levels) averaged over the lifetime of a waste stream (see Table 4.2 below).

Table 4.2: Drigg site radionuclide specific activity trigger levels

Activity group	Total activity trigger (GBq/t)	Specific activity trigger (GBq/t)
Uranium	90	0.09
Radium 226 & Thorium 232	9	0.009
Other alpha	90	0.09
Carbon 14	15	0.015
Iodine 129	15	0.015
Tritium (H3)	3,000	3.0
Cobalt 60	600	0.6
Others	4,500	4.5

(1) Others also includes the Cobalt 60 content

Applying these limits to ILW in the 2004 UK RWI gives a conditioned waste volume of 1,170m^3 that meets all these trigger levels. Increasing the levels by factors of 10 and 100 gives corresponding conditioned volumes of 5,080m^3 and 36,500m^3 respectively. These conditioned volumes and their equivalent packaged volumes are summarised in Table 4.3.

Table 4.3: ILW volumes meeting different disposal criteria

Criteria	Waste at 1 April 2004 and future arisings (m^3)	
	Conditioned volume	Packaged volume
Meets Drigg nuclide trigger level	1,170	1,410
Meets Drigg nuclide trigger level x10	5,080	7,960
Meets Drigg nuclide trigger level x100	36,500	49,400

Table 4.4 provides a breakdown of the conditioned volumes by site and by region. The data exclude 6,020m^3 (conditioned volume) of ILW streams that could not be analysed, as they have no quantified radionuclide specific activity data in the 2004 UK RWI.

Table 4.4: ILW volumes by site and region for different disposal criteria

Site	Region	Conditioned waste volume at 1.4.2004 and future arisings (m^3)		
		Meets Drigg nuclide trigger levels	Meets Drigg nuclide trigger levels x10	Meets Drigg nuclide trigger levels x100
Bradwell	East of England	23	78	578
Sizewell	East of England	58	305	1,090
East of England Total		**82**	**383**	**1,670**
Hartlepool	North East	3	3	303
North East Total		**3**	**3**	**303**
Chapelcross	North West	0	0	495
Heysham	North West	0	108	1,250
Sellafield	North West	263	737	22,400
Windscale	North West	0	1	18
North West Total		**263**	**846**	**24,100**
Dounreay	Scotland	198	241	301
Hunterston	Scotland	0	662	2,980
Torness	Scotland	0	433	433
Scotland Total		**198**	**1,340**	**3,710**
AWE Aldermaston	South East	0	0	2
Culham	South East	0	0	0
Dungeness	South East	40	277	753
Harwell	South East	0	0	83
South East Total		**40**	**277**	**839**
Berkeley	South West	85	315	422
Hinkley Point	South West	258	694	1,860
HMNB Devonport	South West	2	14	14
Rosyth & Devonport (Submarines)	South West	0	349	349
South West Total		**345**	**1,370**	**2,640**
Cardiff	Wales	0	0	0
Trawsfynydd	Wales	0	529	2,520
Wylfa	Wales	0	62	62
Wales Total		**0**	**591**	**2,580**
Oldbury	West Midlands	236	276	633
West Midlands Total		**236**	**276**	**633**
Overall Total		**1,170**	**5,080**	**36,500**

We make the following observations in regard to the 1,170m^3 (conditioned volume) of ILW that meets the Drigg nuclide trigger levels:

- About 660m^3 is from Magnox power stations, and consists mainly of miscellaneous contaminated items and pond skips. BNFL has reported in the 2004 UK RWI that it plans to decontaminate pond skips so they can be disposed to Drigg as LLW.
- About 260m^3 is miscellaneous solid waste at Sellafield. This stream contains several radionuclides known to be present in significant concentration but not quantified. From the data available in the 2004 UK RWI we believe it is likely that this waste would meet the Drigg CfA.

Increasing trigger levels by a factor of 10 captures a further 3,920m^3 of ILW. About 3,040m^3 of this additional waste is from power stations, with 2,360m^3 from Magnox power station (see Table 4.3). The major components that make up the additional waste from the power stations are fuel skips, miscellaneous contaminated items, ion exchange materials and desiccant. Other waste is principally short-lived ILW from nuclear submarine decommissioning and waste from fuel storage pond decommissioning at Sellafield.

Increasing trigger levels by a factor of 100 has a much greater impact on volumes, capturing a further 35,300m^3 of ILW. There are increases at many sites (see Table 4.4), but by far the largest increase is from Sellafield. Most of the additional waste from Sellafield is concrete, brickwork and blockwork from the final stage decommissioning of reprocessing/associated plants, stores, and treatment and service facilities.

Most of the remaining additional waste is from Magnox and AGR power stations. The major components of additional waste from Magnox power stations are Magnox fuel element debris, ion exchange material (at Trawsfynydd) and graphite fuel element debris (at Hunterston). The major component of additional waste from AGR power stations is desiccant.

We have also examined how the material nature of the waste affects its suitability for near surface disposal. Table 4.5 lists principal waste types that make up much of the volume of ILW in the 2004 UK RWI, including the principal decommissioning wastes. For each waste type we have indicated the radionuclide that most restricts near surface disposal because its activity concentration does not meet the Drigg trigger level, and by how much its activity concentration exceeds the Drigg trigger level. The data illustrate the magnitude of the barrier to near surface disposal for most of the major ILW streams in the 2004 UK RWI.

Table 4.5: Types of ILW and typical nuclide concentrations pertinent to near surface disposal

ILW stream groups	Conditioned volume (m^3)	Principal nuclide(s) restricting near surface disposal	Typical nuclide concentration (multiple on Drigg trigger level)
Magnox power stations			
Miscellaneous activated components	2,470	Co60	>30,000
FED Magnox	3,000	Co60	20 - 400
FED graphite	2,240	C14	100 - 400
Ion exchange materials	2,140	Other beta/gamma	50
Final stage decommissioning steel	7,680	C14	4 – 5,000
Final stage decommissioning graphite	28,400	C14	3,000 – 6,000
AGR power stations			
Desiccant / catalyst	3,600	H3	10-100
Final stage decommissioning steel	5,280	C14	100 - 500
Final stage decommissioning graphite	17,900	C14	1,000 – 10,000
Sellafield			
Magnox cladding / miscellaneous (B38)	9,310	Other alpha	3,00 – 30,000
Magnox cladding	10,300	Other alpha	3,000
PCM	5,530	Other alpha	1,000 – 40,000
Floc	10,700	Other alpha	300 – 5,000
Miscellaneous beta/gamma waste	6,100	Other alpha	300
Pond furniture	7,390	Co60	300
Misc. plants initial decommissioning	28,500	Other alpha	7 – 7,000
Misc. plants final decommissioning	19,600	Other alpha	~40
Dounreay			
Decommissioning	4,260	Other alpha	5 – 8,000
AWE Aldermaston			
PCM operational	2,840	Other alpha	8,000 – 20,000
PCM decommissioning	3,480	Other alpha	800 – 2,000

4.4.3 Drigg material restrictions

The Drigg near surface LLW disposal site imposes the following conditions regarding the physical and chemical composition of wastes consigned for disposal:

- No free liquid must be present
- Materials likely to give rise to a fire or explosion hazard (e.g. combustible metals, pyrophoric materials, fixed liquids with flash points <22˚C, phosphorus, hydrides, pressurised gas cylinders and aerosol cans.
- Ion exchange materials must be stabilised.
- The waste should be chemically inert and must not contain chemicals that have a significant reaction with water, alkaline grout or materials likely to be found in the waste.
- Complexing agents must be excluded as far as reasonably practicable, and in any event not exceed 0.1% by weight
- Putrescible waste must be excluded as far as reasonably practicable, and in any event not exceed 5% by weight
- Hazardous, biological, pathogenic and infectious materials must be treated to minimise potential hazards

- "Special wastes" content must be approved
- Lead content must be approved
- Asbestos content must be approved

We have limited our assessment of the material composition of ILW to the 123,000m^3 (conditioned volume) with a long-lived alpha emitting radionuclide concentration of 400Bq/g or less (see Section 4.4.1). We have assumed that any free liquids would be eliminated, materials giving rise to a fire or explosion hazard would be made safe, and ion exchange materials stabilised. The assessment shows that, in terms of conditioned volume, there are:

- 7,330m^3 of waste containing lead;
- 2,530m^3 of waste containing asbestos;
- 700m^3 of waste containing complexing agents; and
- 6,620m^3 of waste containing hazardous or problematic materials.

These volumes should not be summed as some wastes fall into more than one category – the total conditioned volume is 14,200m^3.

However, only 440m^3 of this volume meets Drigg's nuclide trigger levels, and 135m^3 of this is miscellaneous solid waste at Sellafield where the material composition has not been assessed. A further 260m^3 is also miscellaneous solid waste at Sellafield containing hazardous materials that could be made safe before disposal.

We have also examined the larger volumes of ILW that would meet Drigg trigger levels if these were increased by factors of 10 and 100. At Drigg x10 levels there is an additional 90m^3 of waste containing asbestos and at Drigg x100 a further 2,430m^3 of waste, which is predominantly Sellafield decommissioning waste containing asbestos and lead.

The conclusion of our assessment of the material composition of ILW is that it is likely that only a very small volume of waste meeting radioactivity limits for a near surface disposal facility would be restricted because of their material composition.

4.5 Potential for decay storage or decontamination

There a number of ILW streams in the 2004 UK RWI that waste producers plan to decay store or decontaminate, so that the waste can be disposed as LLW at Drigg. The waste streams can be grouped into a number of different material types, and these are listed in Table 4.6 with their conditioned volumes and equivalent packaged volumes. The total conditioned volume is 15,200m^3. The major components are Magnox and LWR pond furniture at Sellafield, desiccants and some catalysts at AGR power stations, short-lived ILW from decommissioned submarines and redundant pond skips at Magnox power stations.

Table 4.6: ILW that waste producers plan to decontaminate or decay store to LLW

Site / ILW stream type	Decay storage / Decontamination	Conditioned volume (m^3)	Packaged volume (m^3)
Sellafield / Pond furniture	Decontamination	7,390	9,240
AGR stations / desiccants & catalysts	Decontamination	3,440	4,230
Navy bases / decommissioned submarine	Decay storage	1,840	2,300
Magnox stations / Pond skips	Decontamination	1,510	1,890
Navy bases / resins etc.	Decay storage	790	990
Magnox stations / miscellaneous	Decontamination	220	270
Amersham / stored ILW	Decay storage	60	70
Total		**15,200**	**19,000**

We have further examined ILW streams in the 2004 UK RWI in order to identify other waste types that might be amenable to decontamination in addition to those in Table 4.6. In our analysis of wastes that might be suitable for decontamination we have selected only contaminated solid waste streams. Table 4.7 lists the waste types, their conditioned volumes and equivalent packaged volumes. However, the wastes add only about 10% to the total volume.

Table 4.7: Additional ILW that might be suitable for decontamination

Site / ILW stream type	Conditioned volume (m^3)	Packaged volume (m^3)
Magnox stations / contaminated gravel	230	280
Magnox stations / desiccant	260	300
Sizewell B / miscellaneous contaminated items	250	300
Magnox stations / miscellaneous contaminated items	780	950
Total	**1,520**	**1,830**

Large quantities of contaminated ILW from facilities decommissioning will arise in the future at many sites. For example at Sellafield the total conditioned volume is estimated to be about 45,000m^3. We have not addressed the technical feasibility, radiological impact and economics of decontaminating such wastes in this study. But it is clear there would be large increases in waste volumes for near surface disposal if suitable decommissioning wastes were to be decontaminated.

A study carried out by EEUK for Defra based on the 2001 UK RWI [8] shows that after 120 years the quantity of ILW that has decayed to LLW is about 45,000m^3 (conditioned volume). At 300 years a further 5,000m^3 only has decayed to LLW.

4.6 Impact of early decommissioning

The decommissioning strategy for the Magnox reactor sites is "Deferred Site Clearance" [3]. After defuelling, exterior cladding on the reactor containment building would be replaced as necessary with high-integrity materials and un-needed openings would be in-filled to create a low-maintenance structure. Final dismantling and site clearance is assumed to commence between 85 and 112 years after the end of operation. Similarly British Energy has proposed an "Early Safestore" strategy for reactor decommissioning, with the start of final reactor dismantling deferred for a period of at least 85 years after the end of generation for AGRs and a period of up to 50 years for the Sizewell B PWR [3].

One factor that could affect the volume of ILW suitable for near surface disposal is early decommissioning of power reactors. Early decommissioning would give less time for radioactive decay and hence final stage decommissioning wastes (steels and graphite) would more radioactive. However no final stage decommissioning waste stream have been identified as "short-lived", or suitable for near surface disposal even at 100x Drigg nuclide trigger levels. The radionuclide activity data for final stage decommissioning graphite show that C14 activity concentrations are between 10,000 and 100,000 times greater than the Drigg trigger level. For final stage decommissioning steels C14 and other beta/gamma activity concentrations are between 100 and 10,000 times greater and up to 1,000 times greater respectively than the Drigg trigger levels.

4.7 Potential for short-lived and long-lived waste segregation at source

One of the uncertainties in determining the volumes of waste suitable for near surface disposal is the ease or difficulty of segregating short and long-lived wastes from the mix of radioactive wastes that are produced.

In the UK most existing nuclear facilities have been shut down or are nearing the ends of their operational lives. As a result, most operational waste reported in the 2004 UK RWI has already been produced, is held in stores, and, if amenable, would require sorting to segregate short and long-lived waste items. In contrast most facilities decommissioning waste in the UK will arise in the future, so in principle practices could be implemented to segregate short and long-lived wastes when they are produced.

To a very large extent wastes that are suitable for near surface disposal in the UK are already segregated – as a LLW fraction. However there are a number of ILW streams in the 2004 UK RWI that have the potential for segregation into ILW and LLW fractions (see Table 4.8).

Table 4.8: ILW suitable for segregation

Site / ILW stream type	Conditioned volume (m^3)	Packaged volume (m^3)
AWE Aldermaston / PCM	6,330	7,340
AWE Aldermaston / sea disposal packages	200	240
Harwell & Winfrith / sea disposal packages	1,180	1,370
Total	**7,710**	**8,950**

All operational and decommissioning PCM wastes at Aldermaston are classified as ILW until they can be accurately classified as either ILW or LLW.

AWE intends to size reduce and repackage ILW sea disposal packages. Some of the waste will be reclassified as LLW.

A small number of sea disposal packages at Harwell and Winfrith may be segregated as LLW after detailed inventory investigation. Furthermore a waste management strategy is being developed for the ILW packages – waste may be removed, in which case the bulk of the concrete/mild steel containers may be segregated as LLW.

Segregation of wastes in these streams has the potential to increase waste suitable for disposal as LLW by several thousands of cubic metres.

It may be the case that other ILW streams in the 2004 UK RWI contain components that could be segregated and routed to near surface disposal, but information is not available to identify them.

4.8 Non-Drigg LLW

There is a total of 31,200m^3 (conditioned volume) of LLW in the 2004 UK RWI unsuitable for disposal to Drigg and for which there is no alternative disposal route (see Table 3.1). All apart from 780m^3 of this waste is graphite from final stage decommissioning of Magnox and AGR power stations. The graphite wastes are unsuitable for Drigg because they do not meet the limit on C14 content.

An analysis of the C14 activity concentrations in final stage decommissioning graphite indicates that they are between 1.5 and 370 times greater than the Drigg specific activity trigger level.

The reported uncertainties on activity concentration indicate that up to 3,120m^3 (conditioned volume) of AGR graphite could meet the Drigg C14 specific activity trigger level. This is also the volume of graphite that would meet a disposal facility limit 10x higher than that at Drigg. This volume would increase to 14,100m^3 with a limit 100x higher than that at Drigg.

4.9 Facility design, cost and transport impact of near surface disposal of short-lived ILW

Short-lived ILW will generate higher dose rates than LLW in the short to medium term. The waste may require packaging in shielded containers (e.g. Nirex 4m box) for transport and to allow contact handling at the near surface disposal facility. Alternatively short-lived ILW could be packaged in containers without integral shielding such as the half-height ISO containers currently used at Drigg for LLW or Nirex ILW containers (e.g.500 litre drum). These containers would likely require transport in shielded overpacks, and remote handling and shielded facilities at the near surface disposal site. Radiological assessments would need to be carried out to determine the suitability of short-lived ILW for different transport and handling regimes.

There would be cost impacts if short-lived ILW could not be transported or handled in the same way as LLW. The need for shielding would likely reduce the waste volume per transport, and so increase the number of transports. Capital and operating costs for a near-surface disposal facility would be higher if short-lived ILW has to be handled and processed separately from LLW.

Should it be necessary to handle short-lived ILW separately from LLW, the economics of near surface disposal would favour a centralised facility over regional or site facilities. However, transport costs would be higher for a centralised facility. The overall cost implications would need to be assessed.

5 WASTE AND MATERIAL CHARACTERISTICS AND THEIR IMPACT ON LONG-TERM MANAGEMENT

5.1 Introduction

We have undertaken a review of information in order to identify key radionuclides and their activities in wastes, the physical and chemical properties of wastes, and other parameters that may need to be considered by CoRWM for safe handling, storage, transport and long-term management radioactive wastes and materials.

This review has included the following radioactive waste categories:
- HLW;
- ILW;
- LLW not suitable for Drigg;

and the following radioactive materials that may need to be managed as wastes:
- Plutonium;
- Uranium (depleted and enriched);
- Spent nuclear fuel.

5.2 Radionuclides and radioactivity

5.2.1 Radioactive wastes

Nirex has identified a total of 112 radionuclides that are likely to be present in UK ILW in sufficient quantities that they could potentially impact on the safe management of the waste during its transport, handling, disposal and post-disposal [9]. For the 2004 UK RWI exercise, waste producers adopted this list of radionuclides –no additional radionuclides of potential significance in HLW, ILW and LLW were identified.

Table 5.1 gives the radioactivities of HLW, ILW and non-Drigg LLW in the 2004 UK RWI.

5.2.2 Radioactive materials

The list of 112 radionuclides identified by Nirex, and endorsed by waste producers, would also apply to spent fuel. Table 5.2 gives radioactivities in spent fuel reproduced from Reference 10, which reports activities for 72 radionuclides.

Plutonium and uranium inventories are given in Table 5.3 also reproduced from Reference 10. They include plutonium and uranium isotopes and principal radioactive decay products.

5.3 Physical and chemical properties

In addition to its radiological hazard, radioactive wastes and other materials may present additional hazards owing to its physical, chemical or pathogenic characteristics, and these should also be taken into account in pre- ands post-disposal waste management.

Hazardous materials, including chemically toxic materials, or which will generate hazardous materials over time, particularly gases, need to be packaged in such a way as to meet requirements for safe transport, handling and disposal. For example, materials that could give rise to fire, explosion or excessive heat generation are excluded unless the packaging of such materials makes them safe.

Organic materials and their degradation products can form complexes with radionuclide species and affect the migration of long-lived radioactivity post-disposal.

The Drigg near surface LLW disposal site imposes a number of conditions regarding the physical and chemical composition of wastes consigned for disposal. Section 4.4.3 lists these conditions.

Conditions would also be applied on wastes for deep geological disposal. Nirex has developed wasteform specifications that provide guidance on the contents of packages and best practice for producing a wasteform with the required chemical and physical properties.

The guidance includes:

- Radionuclides should be immobilised, and loose particulate material minimised;
- The wasteform should be free of proscribed items and hazardous materials should be made safe;
- Consideration of materials that may modify the high pH environment (e.g. organic materials that can degrade into acid species, materials such as zeolites and diatomaceous earth with potentially reactive silicon content);
- Wherever practicable known complexing agents (e.g. EDTA, oxalic and citric acids) should be eliminated;
- Control of organic materials with degradation products that may act as complexants (e.g. cellulosic materials - paper, wood and cotton, and condensation polymers);

Table 5.1: Radionuclide activities in HLW, ILW and non-Drigg LLW

Nuclide	Radionuclide activity at 2150 (TBq)			Nuclide	Radionuclide activity at 2150 (TBq)		
	HLW	ILW	LLW		HLW	ILW	LLW
H3	-	6 8E+02	9.8E-01	Eu155	5.2E-04	2.4E-05	3.4E-08
Be10	4.6E-02	2.8E-01	3.4E-08	Gd153	-	-	-
C14	-	3 3E+03	5.9E+01	Ho163	1.1E-05	1.5E-05	-
Cl36	2.2E+00	2 9E+01	1.4E+00	Ho166m	9.4E-02	2.0E-01	2.3E-02
Ar39	-	6.7E-01	-	Tm170	-	-	-
Ar42	-	3.0E-08	-	Tm171	-	-	-
K40	1 8E-14	4.3E-02	-	Lu174	-	7.5E-17	-
Ca41	3 0E-01	2 2E+01	1.1E+00	Lu176	-	1.3E-08	-
Mn53	1.6E-07	1.7E-06	-	Hf178n	-	4.2E-04	-
Mn54	-	-	4.9E-55	Hf182	2.7E-10	6.1E-09	-
Fe55	4.6E-12	1.6E-06	2.8E-13	Pt193	-	3.1E-03	-
Co60	4 3E-04	1.5E-01	3.4E-05	Tl204	-	3.0E-08	-
Ni59	4.0E+00	8 5E+03	1.8E-01	Pb205	6.4E-07	1.7E-07	-
Ni63	1.7E+02	3.6E+05	7.8E+00	Pb210	4.1E-03	2.2E+01	3 3E-06
Zn65	-	-	5.9E-69	Bi208	-	1.9E-07	-
Se79	1.4E+02	5 3E+00	-	Bi210m	2.0E-11	5.1E-04	-
Kr81	-	1.6E-05	-	Po210	4.1E-03	2.2E+01	3.3E-06
Kr85	-	6.8E-01	-	Ra223	9.8E-03	1.1E+00	1.2E-07
Rb87	9 5E-03	6.9E-06	-	Ra225	2.6E-04	1.6E-02	4.2E-12
Sr90/Y90	8.0E+05	2 5E+04	4.2E-03	Ra226	5.1E-03	2.2E+01	4.2E-06
Zr93	8.0E+02	1.1E+02	-	Ra228	5.6E-08	6.0E-01	9.1E-06
Nb91	5 0E-12	9.1E-01	-	Ac227	9.8E-03	1.1E+00	1.2E-07
Nb92	1 3E-09	6 3E+02	-	Th227	9.7E-03	1.0E+00	1.2E-07
Nb93m	8.0E+02	1.1E+02	4.0E-07	Th228	2.9E-04	9.0E-01	1.3E-05
Nb94	2.7E-01	2.7E+02	2.3E-02	Th229	2.6E-04	1.6E-02	4.2E-12
Mo93	3.1E-01	8.7E+01	1.4E-03	Th230	7.9E-02	1.2E-01	6.9E-05
Tc97	1.1E-08	5.1E-09	-	Th232	5.6E-08	6.0E-01	9.1E-06
Tc99	4.0E+03	6 0E+02	2.8E-04	Th234	3.6E-02	2.5E+01	1.2E-03
Ru106/Rh106	-	4.2E-12	1.4E-51	Pa231	9.9E-03	1.1E+00	1.5E-07
Pd107	4.2E+01	6.0E-01	-	Pa233	6.6E+01	9.1E+01	3.0E-06
Ag108m	2 3E-03	1 8E+03	4.9E-03	U232	2.8E-04	3.0E-01	3.8E-06
Ag110m	-	-	-	U233	3.6E-02	7.5E-01	9.3E-10
Cd109	-	-	-	U234	6.0E-01	2.5E+01	1.2E-03
Cd113m	3.7E+00	6.3E-02	-	U235	1.4E-03	1.6E+00	4.8E-05
Sn119m	-	-	-	U236	1.5E-02	1.8E+00	1.3E-07
Sn121m	9.9E+02	3.4E+01	1.4E-01	U238	3.6E-02	2.5E+01	1.2E-03
Sn123	-	-	-	Np237	6.6E+01	9.1E+01	3.0E-06
Sn126	3.0E+02	6 3E+00	-	Pu236	9.4E-18	3.1E-14	-
Sb125	1.6E-10	2.8E-10	3.7E-22	Pu238	1.0E+03	1.9E+03	3.2E-03
Sb126	4.2E+01	8.9E-01	-	Pu239	3.8E+02	9.8E+03	2.3E-02
Te125m	1.6E-10	3.0E-10	3.9E-22	Pu240	1.2E+03	1.0E+04	2.9E-02
Te127m	-	-	-	Pu241	7.7E+01	4.9E+02	7.9E-04
I129	1 2E-01	5.2E-01	1.8E-04	Pu242	1.5E+00	6.6E+00	2.8E-06
Cs134	3 2E-15	1.9E-08	6.3E-25	Am241	3.7E+05	3.2E+04	6.0E-02
Cs135	2.5E+02	7 0E+00	-	Am242m	7.1E+02	2.6E+02	-
Cs137/Ba137m	1.2E+06	2 5E+04	1.1E-01	Am243	2.5E+03	2.4E+01	3.8E-09
Ba133	8.1E-08	2.7E-03	6.6E-05	Cm242	5.9E+02	2.2E+02	-
La137	6 3E-04	1.3E-02	-	Cm243	7.4E+01	1.0E+01	1.4E-05
La138	1 9E-08	2.2E-10	-	Cm244	8.3E+02	6.2E+00	8.6E-08
Ce144/Pr144	-	4.0E-15	3.9E-65	Cm245	3.3E+01	4.7E-02	-
Pm145	2 0E-04	8.3E-02	3.8E-05	Cm246	7.1E+00	8.7E-03	-
Pm147	8 0E-10	2.5E-09	1.9E-22	Cm248	5.7E-05	6.5E-07	-
Sm147	3.6E-03	4.8E-04	2.7E-16	Cf249	3.4E-04	3.0E-05	-
Sm151	5.5E+04	1.6E+03	1.8E-02	Cf250	8.5E-07	3.3E-07	-
Eu152	1.3E+00	4 2E+01	7.9E-03	Cf251	1.8E-05	2.2E-09	-
Eu154	6.6E+00	7.4E-02	2.6E-04	Cf252	-	1.2E-18	-

Table 5.2: Radionuclide activities in spent fuel [10]

Nuclide	Radionuclide activity at 2040 (TBq)		
	AGR fuel (1)	PWR fuel (2)	Submarine fuel (3)
H3	1.8E+04	1.1E+04	1.4E+03
Be10	2.7E-04	1 8E-04	-
C14	3.5E+02	6.4E+01	2.3E-01
S35	6.0E-28	2 5E-06	-
Cl36	1.8E+00	4 9E-01	5.8E-03
Ca41	3.8E-02	6.1E-03	5.2E-05
Ca45	5.7E-14	3 0E-05	-
Cr51	-	5 3E-13	-
Mn54	1.3E-05	3.4E+01	6.1E+00
Fe55	8.1E+02	8.1E+03	1.1E+02
Co58	8.7E-35	1.4E-03	-
Co60	2.4E+03	5.8E+04	2.4E+00
Ni59	3.1E+03	1.8E+02	1.2E-02
Ni63	3.0E+05	2.5E+04	1.3E+00
Zn65	1.9E-05	2.1E+00	1.8E+01
Se79	3.7E+01	1.9E+01	3.6E+00
Sr89	-	4 0E-11	-
Sr90	3.5E+06	2.0E+06	5.4E+05
Y91	-	1 8E-09	-
Zr93	1.7E+02	9.5E+01	2.2E+01
Zr95	-	4 2E-06	-
Nb93m	1.2E+02	5.9E+01	1.3E+01
Nb94	1.8E+01	5.9E+01	2.0E-02
Nb95	-	9 3E-06	-
Mo93	1.8E-01	1.1E+00	-
Tc99	1.2E+03	6.0E+02	1.5E+02
Ru103	-	8 2E-14	-
Ru106	2.3E+01	5.2E+04	3.7E+04
Pd107	1.0E+01	4.6E+00	1.2E-01
Ag108m	2.2E+00	1 5E-01	1.2E-07
Sn121m	1.1E+01	2.3E+01	1.8E+01
Sn126	6.2E+01	3.3E+01	3.3E+00
I125	-	-	-
I129	2.5E+00	1.4E+00	2.0E-01
I131	-	-	-
Cs134	4.3E+03	1.3E+05	5.4E+04
Cs135	5.7E+01	1.8E+01	5.1E+00
Cs137	5.0E+06	2.8E+06	5.8E+05
Ce144	1.4E+00	4.1E+04	3.9E+05
Pm147	1.3E+04	2.0E+05	2.3E+05
Sm151	1.5E+04	1.5E+04	5.3E+03
Eu152	3.2E+01	1.1E+02	2.5E+00
Eu154	9.5E+04	8.2E+04	6.4E+03
Eu155	1.7E+04	2.5E+04	1.7E+03
Ta182	1.0E-23	2 9E-06	-
Pb210	1.0E-04	3.1E-05	2.2E-04
Po210	1.0E-04	4.7E-05	2.2E-04
Ra226	3.6E-04	1.1E-04	6.1E-04
Th229	8.8E-06	8.1E-06	6.9E-07
Th230	5.0E-02	1 6E-02	6.1E-02
Th232	3.5E-08	1.4E-08	6.3E-09
Pa231	2.4E-03	1 2E-03	4.6E-03
Pa232	-	-	-
U233	4.2E-03	2 2E-03	2.3E-04
U234	1.7E+02	6.5E+01	1.6E+02
U235	1.6E+00	9 0E-01	4.8E+00
U236	2.5E+01	1.3E+01	4.0E+00
U238	4.2E+01	1.4E+01	4.6E-02
Np237	2.7E+01	1.6E+01	3.8E-01
Pu238	1.0E+05	9.0E+04	9.7E+02
Pu239	2.2E+04	1.5E+04	4.8E+01
Pu240	4.9E+04	2.1E+04	2.0E+01
Pu241	2.8E+06	2.0E+06	1.6E+03
Pu242	2.3E+02	7.2E+01	2.5E-02
Am241	2.7E+05	1.2E+05	3.3E+01
Am242m	2.3E+03	5.9E+02	5.1E-02
Am243	1.4E+03	6.7E+02	5.6E-02
Cm-242	1.9E+03	5.4E+02	1.4E+01
Cm243	8.7E+02	3.8E+02	4.6E-02
Cm244	4.8E+04	3.2E+04	1.3E+00
Cm245	4.0E+00	5.2E+00	4.1E-05
Cm246	8.6E-01	9 8E-01	6.7E-06

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(1) Revised from Ref. 10 for 3,500tU AGR fuel, steel cladding, skeleton and graphite.
(2) For 1,200tU Sizewell B fuel and skeleton.
(3) For 75 submarine cores. Excludes cladding and skeleton.

Table 5.3: Radionuclide activities of plutonium and uranium [10]

Nuclide	Radionuclide activity at 2040 (TBq) (1)		
	Plutonium (2)	Depleted, Natural & Low enriched U (3)	Highly enriched U (4)
Pb210	2.0E-05	8.7E-04	5.5E-05
Po210	2.0E-05	8.4E-04	5.3E-05
Ra226	5.7E-05	2.8E-03	1.7E-04
Th229	1.8E-06	5.0E-06	-
Th230	6.1E-03	3.3E-01	1.9E-02
Th232	2.4E-12	6.1E-08	-
Pa231	4.7E-06	3.7E-02	1.6E-03
U233	1.1E-03	1.6E-03	-
U234	2.2E+01	9.9E+02	5.2E+01
U235	8.2E-03	4.7E+01	1.8E+00
U236	3.9E-01	4.1E+01	-
U238	3.7E-06	1.9E+03	1.2E-02
Np237	1.0E+02	-	-
Pu238	1.3E+05	-	-
Pu239	1.7E+05	-	-
Pu240	2.7E+05	-	-
Pu241	4.0E+06	-	-
Pu242	4.8E+02	-	-
Am241	8.9E+05	-	-

(1) Possible contamination by trace quantities of fission products in plutonium recovered from spent fuel is not accounted for.
(2) Civil and military plutonium. Revised from Ref. 10 for reduced spent AGR fuel reprocessing.
(3) Civil and military uranium. Revised from Ref. 10 for reduced spent AGR fuel reprocessing.
(4) Civil and military uranium.

6 WASTE FROM NUCLEAR POWER STATION NEW BUILD

6.1 Introduction

CoRWM recognises that there are large uncertainties in the quantities and nature of radioactive wastes and materials that are dependent on the future means of electricity generation in the UK. The CoRWM preliminary inventory report has examined the impact of a new build programme of 10 AP1000 reactors over the next 20 years.

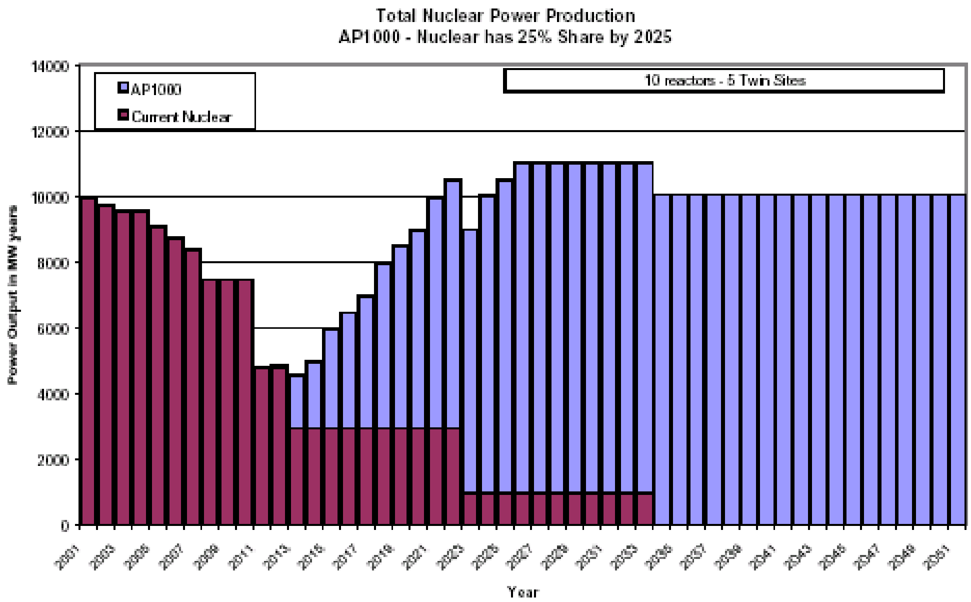
New build gives an opportunity to control material specifications and therefore influence the nature of the wastes produced.

This study has considered the impact of alternative designs to the AP1000. Quantities of spent fuel and waste volumes are estimated. It is assumed that spent fuel would not be reprocessed to recover uranium and plutonium.

6.2 Advanced Passive (AP1000)

The AP1000 is a 1,100MWe 2-loop advanced PWR nuclear power plant designed by BNFL-Westinghouse. It has been designed to operate for 60- years. It uses passive safety features that do not require the active intervention of, say, a plant operator to initiate them. These are also replicated (redundancy). BNFL is collaborating with BE to study the feasibility of UK deployment of the AP1000 reactor. CoRWM chose a programme of 10 reactors to be consistent with the BNFL and BE proposals in their submissions to the UK Energy Policy review [11,12]. This programme would restore the nuclear element of UK generating capacity to 25% by 2025 (see Figure 6.1).

Figure 6.1: Scenario for generation by AP1000 reactors



For the scenario illustrated in Figure 6.1, the first reactor would start operating in 2013 and the tenth in 2027. Therefore operational waste from the programme would cease in 2087. The current decommissioning scenario for the Sizewell B PWR is for final stage decommissioning and site clearance to start 50 years after end of generation and last 8 years. Assuming the same decommissioning timescales for an AP1000 reactor, the programme of AP1000 reactors would produce radioactive waste up to 2145.

The Energy White Paper announced that the Government would review the current strategy in 2005/06. Any specific support for new build would be set out in a White Paper, and licensing, siting and public consultation could then start. There is no certainty on the timetable for this process. Any delay would make start of generation in 2013 unlikely.

The CoRWM preliminary inventory report gives the following volumes of wastes from the operation and decommissioning of a series of 10 AP1000 reactors. The information was provided to CoRWM by BNFL:

Spent fuel	14,000tU
ILW	9,000m^3
LLW	80,000m^3

The total quantity of spent fuel is based on an arising on 23tU per year of operation. The quantities of ILW and LLW are packaged volumes.

Scaling the 2004 UK RWI data for Sizewell B from 40 years to 60 years operation, and including decommissioning, the following waste volumes would be produced for ten reactors (see Table 4.1).

Table 6.1: Volume of ILW and LLW from programme of 10 Sizewell B PWRs

Volume (m^3)	**ILW**	**LLW**
Conditioned	12,000	117,000
Packaged	18,600	142,500

In terms of packaged waste the AP1000 is forecast to generate about half the amount of ILW and LLW compared with a series of ten Sizewell B reactors operating 60 years. Lower volume would be expected as the AP1000 design has fewer components and less building volume (see Figures 6.2 & 6.3).

Figure 6.2: Component numbers in AP1000 versus current operating PWR [13]

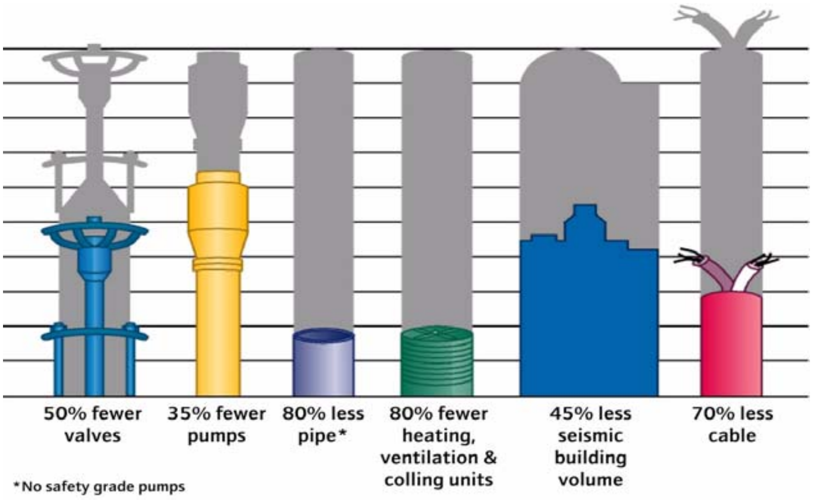
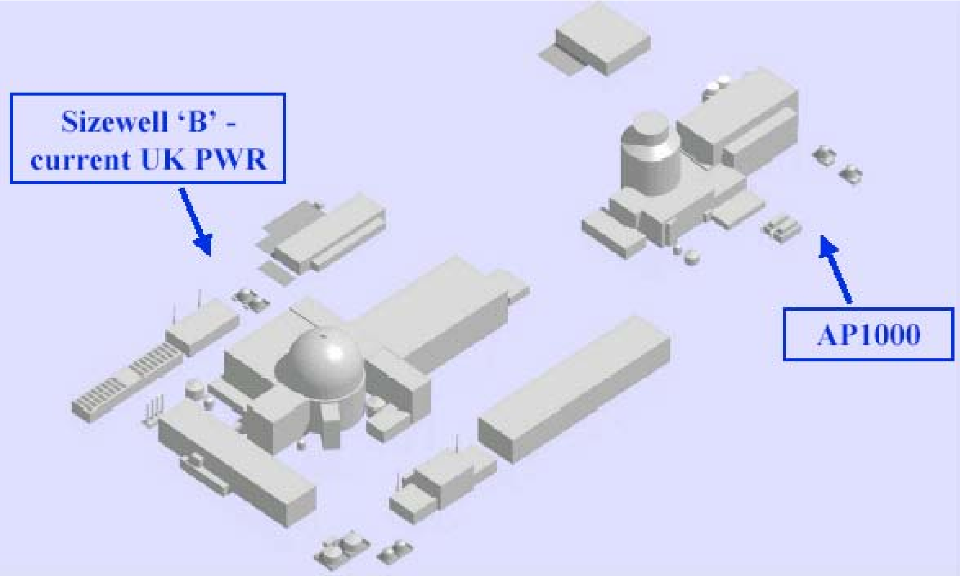


Figure 6.3: Plant buildings for Sizewell B and AP1000 [11]



The amount of spent fuel produced by the AP1000 programme can be verified. Using a load factor of 83% (the value for Sizewell B), the amount of fuel ranges from 12,600 tonnes to 15,600 tonnes for burn-ups ranging from 40 to 50 GWd/t. This corresponds with the 14,000 tonnes of fuel reported by BNFL. It is possible to express this as packaged volume using the most recent SKB disposal concept [14]. In this option, the canister is 4.8 metres tall and 1.05 metre in diameter. This gives an external volume of $4.2m^3$, which holds four PWR assemblies. From Reference 15, one assembly contains typically 0.46tU, resulting in 7,588 canisters, or $31,900m^3$ of packaged volume.

To summarise, the programme of 10 AP1000 reactors generates $9,000m^3$ of packaged ILW, $80,000m^3$ of packaged LLW, and 14,000tU spent fuel. The latter occupies a packaged volume of $31,900m^3$ for the SKB concept. The ILW nuclide activities are expected to be similar to Sizewell B. The same is true for LLW, which could therefore be disposed at Drigg or a similar facility. Fuel activities have been calculated for enriched fuel and for MOX fuel at a burnup of 48GWd/t, a value within the range envisaged for the AP1000 [16].

6.3 European Pressurised-Water Reactor (EPR)

The EPR is a 1,600MWe 4-loop advanced PWR nuclear power plant designed by Framatome ANP. It has been designed to operate for 60 years [17]. Unlike the AP1000 the EPR does not have extensive, advanced passive safety features, but builds on the idea of containment and redundancy. Safety trains are replicated.

The reactor has a thermal efficiency of 37%, and fuel burnup to 60GWd/t. A fleet of 7 units would be required to generate the same amount as a fleet of 10 AP1000's. Construction is estimated to take 5 years [17].

Scaling the 2004 UK RWI data for Sizewell B from 40 years to 60 years operation and including the decommissioning, leads to the following waste arisings for seven EPRs (see Table 6.2).

Table 6.2: Volume of ILW and LLW from programme of 7 Sizewell B PWRs

Volume (m^3)	ILW	LLW
Conditioned	8,400	82,000
Packaged	13,000	100,000

The amount of spent fuel produced by the programme can be estimated. Using a load factor of 83% (the value for Sizewell B), the amount of spent fuel is 9,200 tonnes for a burnup of 60 GWd/t. It is possible to express this as packaged volume using the SKB disposal concept [14]. From reference 15, one assembly contains typically 0.46tU, resulting in 5,000 canisters, or 21,000m^3 of packaged volume.

To summarise, a programme of 7 EPRs generates 13,000m^3 of packaged ILW, 100,000m^3 of packaged LLW, and 9,200t of spent fuel. The latter occupies a packaged volume of 9,200m^3 in the BNFL concept, or 21,000m^3 in the SKB concept. The ILW nuclide activities are expected to be similar to Sizewell B. The same is true for LLW, which could therefore be disposed at Drigg or a similar facility. The fuel activities are expected to be close to values reported elsewhere for 55GWd/t burnup enriched fuel and for MOX fuel [18].

6.4 Advanced Boiling Water Reactor (ABWR)

The ABWR is an evolution from the General Electric BWR design. Several ABWRs already operate in Japan and Korea [19]. A typical example is Kashiwasaki-Kariwa 7 with an output of 1,356 MWe, fuel burnup is 40GWd/t, a core containing 150tU in 872 fuel assemblies [20].

A fleet of 8 similar units s would be required to generate the same amount as a fleet of 10 AP1000's. Construction is estimated to take 52 months [19].

A fleet is 8 reactors would generate a total 187,000m^3 of packaged ILW plus LLW, extrapolated from the amounts produced by the Leibstadt BWR in Switzerland [21]. The radiological characteristics of the wastes would be broadly similar to those from the PWRs. The amount of fuel generated would be 15,400tU. The SKB system for BWR fuel envisages 12 fuel assemblies per canister [14]. This would generate 7,500 canisters occupying a volume of 31,500m^3. The radiological characteristics of the fuel are expected to be close to values reported elsewhere for 41 GWd/t irradiation of BWR enriched fuel [18].

6.5 Pebble Bed Modular Reactor (PBMR)

The PBMR is a high temperature helium-cooled reactor. The enriched fuel is in particles embedded in a graphite matrix that is anticipated to retain all fission products. The PBMR design is being proposed for construction in South Africa. It has a 170MWe output, fuel burnup of 80GWd/t, and a 40-year service life. Construction is estimated to take only 2years [22-24].

A fleet of 98 modules would be required, ultimately producing 6,210tU, representing a volume (accounting for packing fraction), of 130,000m^3. In addition there would be a volume of 10,800m^3 of pure graphite moderator spheres. Operational wastes are difficult to asses, but might be less than for water reactors because the PBMR is an entirely dry system, and because the fuel has very high integrity. Wastes from decommissioning the vessel and associated shielding cannot be assessed from the sparse design information available. The radionuclide characteristics of the fuel have been reported elsewhere [18].

6.6 Summary

The CoRWM Inventory considers the introduction of a fleet of ten AP1000 reactors. Alternative reactor types EPR, ABWR and PBMR and fleets producing the same amounts of electricity have been considered. The result of the comparison is summarised in the table below in terms of packaged waste volume.

Table 6.3: Comparison of estimated waste quantities from nuclear reactors (10GW installed)

Reactor type	Spent fuel (tHM)	Packaged volume (m^3)		
		Fuel in SKB canisters (m^3)	ILW	LLW
AP1000	14,000	31,900	9,000	80,000
EPR	9,200	21,000	13,000	100,000
ABWR	15,400	31,500	187,000	
PBMR	6,200	130,000 (1)	10,800 (moderator and other plant) (1)	

(1) Unpackaged volume.

Note that the total radionuclide content in the fuel is similar (+-30%) for all types considered here.

Nirex has presented information on projected volumes should spent fuel be declared as waste and packaged [25]. The packaged volume reported for the 1,200tU Sizewell B PWR spent fuel (1,293m^3) is based on an earlier design of SKB package for PWR fuel. With the more recent design that is used to estimate the packaged volume for AP1000 spent fuel (Section 6.2), the packaged volume of Sizewell B spent fuel would be 2,740m^3.

7 WASTE SUSTITUTION

7.1 Background

A proportion of the waste arising in the Thorp and Magnox reprocessing plants at Sellafield results from reprocessing spent overseas fuel. All overseas reprocessing contracts signed since 1976 include a provision to return packaged wastes back to the country of origin.

Waste substitution is the process whereby an additional amount of HLW would be returned that is equivalent in radiological terms (but smaller in volume) to the ILW and LLW that would otherwise be returned.

Government policy has allowed BNFL to engage in LLW substitution, with the waste being disposed at Drigg. In December 2004 the Government announced that its policy would also allow ILW substitution arrangements that ensure broad environmental neutrality for the UK.

7.2 Analysis

The principle supporting waste substitution is one of radiological neutrality. Therefore there should be no significant effect on the CoRWM Baseline Inventory in terms of radioactivity.

The 2004 UK RWI includes the following packaged volumes of waste belonging to overseas customers that are subject to return of waste provisions:

HLW	400m^3
ILW	5,000m^3
LLW	25,000m^3

About 4,000m^3 of the LLW has already been disposed of at Drigg [3].

Hence the volume of the CoRWM Baseline Inventory would increase by 5,000m^3 of ILW, representing about 1% of the total packaged volume. It is expected that all LLW would be disposed at Drigg.

The volume of HLW would decrease by about 60m^3. This volume is based on the guideline assumption of 15% extra HLW volume returned to overseas customers [26].

8 SPENT RADIATION SOURCES

8.1 Introduction

Spent sealed radioactive sources (SSRSs) are widely used in industry, medicine and research. Their applications include medical diagnostics, therapy and research, industrial radiography, bulk irradiation for sterilisation, and thickness and density measurements. There are also a large number of more routine uses, e.g. smoke detectors and illuminated *Exit* signs.

SSRSs have been in use from the beginning of the 20th century, with radium (Ra226) the most common radionuclides in widespread use up to the 1950's. From the 1950's with the advent of the nuclear power programme sources containing cobalt (Co60), strontium (Sr90) and caesium (Cs137) became more prevalent, although Ra226 continued to be used. In today's market the radionuclides most commonly in use are tritium (H3), Co60, Cs137, Sr90, iridium (Ir192) and americium (Am241).

Today the UK has a large and complex market for sealed sources. There is one major manufacturer, two organisations that recycle sources, importer/distributors and up to 6,000 registrations issued for the use of sources (although many may no longer be in use).

8.2 Inventory

Some spent (redundant) sealed radioactive sources (SSRSs) can be recycled into new sources, or stored to allow their decay and disposal. Others however remain as ILW for long periods.

The nuclear industry uses SSRSs, and has facilities for storing redundant ILW sources. These wastes are included in the UK RWI.

SSRSs produced by the non-nuclear industry (small users) that fall into the ILW category are mostly relatively short-lived. Special arrangements are required for their storage. UKAEA and GE Healthcare operate storage facilities at Harwell and Amersham respectively, and these wastes are included in the UK RWI. However large numbers of sources are retained on small user premises under registrations, and these are not included in the UK RWI.

It has been reported that there is an estimated 22,000 SSRSs in use or in users store in the UK, with approximately 3,000 Co60 sources and 11,000 Cs137 sources [27]. Based on typical activities, the total activity from these sources are in the range 100,000 to 3,000,000 TBq Co60 and 4 to 800 TBq Cs137. In the case of Co60 sources, the activities may be as high as 2,000 TBq per source and therefore significant decay storage may be required.

These activities compare with approximately 2,300,000TBq Co60 and 700,000 TBq Cs137 in ILW in the 2004 RWI. This indicates that for Co60 sources, the total activity, and also the activity of individual sources, are potentially significant.

There are no reliable data for the quantities of older redundant Ra226 sources in the UK. The French RWI [28] reports on their scheme for recovery, which has so far yielded 28.5g (1.05TBq) of Ra226 from former medical and research and development sources. They report a diminishing rate of collection, as the recovery scheme has been well publicised. If it is assumed that the French data are broadly applicable to the UK, we can anticipate a total inventory of about 50g (1.85TBq) to account for any further collections. This activity compares with approximately 23.6TBq in ILW in the 2004 RWI.

The volumes of SSRSs vary, but many are typically of the order of 0.1 litres. Consequently, it is anticipated that the total volume of SSRSs that might need to be managed as ILW would amount to only a few cubic metres. Nirex report N/85 includes an estimate of <$1m^3$ for the volume of recovered redundant sources. However, in view of the large uncertainties, it would be prudent to increase this estimate by a factor of 10, and assume a volume of <$10m^3$.

9 NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM)

Naturally Occurring Radioactive Materials (NORM) contain primordial radioactive elements such as uranium, thorium, and their radioactive decay products. In the UK their use falls under regulatory control if handling or processing leads to a dose in excess of 1mSv/y [29]. In the last few years there has been an increasing awareness by industry and regulators of NORM and of the enhancement of naturally occurring radioactivity concentrations in non-nuclear industrial processes.

The majority of NORM arises from industrial processes. Most of the process wastes are produced in very large volumes, but are of low specific radioactivity. They are routinely disposed of in slag heaps or landfill, if necessary using Exemption Orders issued under the Radioactive Substances Act 1993.

In the UK significant NORM streams arise from coal-fired electricity production, oil and gas production, water treatment and metal mining and processing. Nirex has reported estimated quantities and radioactivity concentrations for these industries [10]. The estimate for oil and gas scale and sludges was extrapolated from data for the USA, as suitable UK data were not available. However, the Scotland and Northern Ireland Forum for Environmental Research have recently published estimates of NORM from the UK oil and gas industry [30]. Information from these two sources is reproduced in Table 7.1.

Table 7.1: Estimated current annual quantities and radioactivities (mainly uranium and thorium) of NORM

NORM	Annual production (tonnes)	Specific activities of main nuclides (Bq/kg)
Coal ash (1)	6,200,000	500
Oil and gas scale and sludge (2)	2,000	5,000 – 80,000
Water treatment sludge (1)	1,430,000	10,000 – 200,000
Metal mining and processing residues (1)	6,200,000	10,000 – 100,000

(1) Reproduced from Ref. 10.
(2) Reproduced from Ref. 30.

Coal ash

Coal contains uranium and thorium, and their decay products. Burning coal in power stations increases concentration of these non-volatile species in the ash residue.

Oil and gas scale and sludge

A recent study has examined the production and disposal of NORM from the North Sea oil and gas industry. NORM is a by-product of hydrocarbon extraction, and occurs in two main forms:

- As mineral scales, and sludges of particulate scale, containing radium and its decay products;
- As thin coatings and "black sludges" in gas and condensate processing equipment, mainly containing decay products from Radon-222, predominantly Lead-210 and Polonium-210.

The scales are normally found on installations where injected water has mixed with water present in the formation. Barium sulphate is formed and precipitated as well fluids are brought to the surface. Some barium is substituted by radium and the precipitate is therefore radioactive. NORM can be found as hard, insoluble scales adhering to equipment, or as contaminated sand and silt sludges inside vessels.

These deposits then have to be removed either by onshore decontamination or discharge to sea as scale and sludge. The largest arising of solid NORM occurs through offshore decontamination, either through routine cleanout and descaling operations or from decommissioning. Terminal vessel sludges and pigging waxes account for the bulk of NORM solids dealt with onshore. Onshore equipment decontamination accounts for a small fraction of the total activity and volume of solids discharged to sea. The masses of solids from decommissioning are small in comparison to offshore decontamination.

Oil and gas installations are authorised to dispose of NORM as solid or liquid waste. Solid waste includes contaminated equipment sent to land for decontamination. Liquid waste includes solids in suspension discharged to sea. Currently there is only one onshore facility that routinely disposes of NORM waste.

Until recently AEA Technology undertook commercial well component descaling operations at Dounreay, and the resulting sludge waste has been cemented into drums. It is included in UKAEA Dounreay LLW in the 2004 UK RWI, but because of its high radium content is unlikely to be suitable for disposal at Drigg.

The general trend in solid NORM is a slight increase in operational arisings in the next 2-3 years, as new facilities outpace decommissioning, followed by a steady decline as decommissioning increases in pace. Total arisings peak in about 2007 and are sustained by decommissioning arisings until around 2012, after which there is a sharp decline. By 2040, mass and activity via all disposals is estimated to be between 5-10% of its current value.

Water treatment sludge
The treatment of large volumes of water offers the potential for sludges, which may contain uranium and its decay products.

Metal mining and processing
Naturally occurring radionuclides can be found in slag, foundry sands, and ores in general. The thorium industry is a special case, where the more active wastes (from thoria catalysts) are included in the 2004 UK RWI.

Reference 10 also includes an estimate of phosphate tailings, but it appears that this material is no longer produced in the UK [29].

Much of the NORM in the UK is routinely disposed of in slag heaps or to landfill, if necessary under Exemption Orders issued under the Radioactive Substances Act 1993. Some coal ash is used in road construction.

10 OTHER WASTES

We have identified a European Union report on particle accelerator decommissioning [31]. This report considers charged particle accelerators such as Van de Graaffs, cyclotrons, linacs and synchrotrons, but excludes linacs used in hospitals. The report estimates that there are 20 such machines in the UK. The authors of the study approached the operators of these machines to establish whether there were decommissioning plans and waste arising estimates. Seven out of the 20 installations responded, but the details of these responses are not given in the report. However, the report does provide an estimate of the amount of LLW material arising from decommissioning one particle accelerator (see Table 11.1). The ranges cover the different types of machine.

Table 11.1: Estimated mass of LLW from decommissioning a particle accelerator

Scenario	**Mass of LLW (t)**
Immediate dismantling	650 – 850
Deferred dismantling (70 – 105 yrs)	0.005 – 6

We have scaled these quantities up for the 20 machines in the UK (see Table 11.2).

Table 11.2: Estimated mass of LLW from decommissioning UK particle accelerators

Scenario	**Mass of LLW (t)**
Immediate dismantling	13,000 – 17,000
Deferred dismantling (70 – 105 yrs)	0.1 - 120

These wastes are activated steel and concrete. Radionuclide concentrations are not available. The EU report does not give times of arising.

In the 2004 UK RWI scenarios for nuclear power station decommissioning assume several decades of care and maintenance before final decommissioning of the reactor cores. Assuming the same deferred decommissioning approach for particle accelerators, only small quantities of LLW (0.1 – 120 tonnes) would be expected.

We also approached a manufacturer of medical linacs, who indicated that Defra are not concerned about the very small amounts of short-lived radioactivity in these machines.

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Ref No: S20060084

IN THE CROWN COURT AT CARLISLE

Courts of Justice
Earl Street
Carlisle
Cumbria
CA1 1DJ

16th October 2006

Before:

THE HONOURABLE MR JUSTICE OPENSHAW

REGINA

-V-

BRITISH NUCLEAR GROUP SELLAFIELD LTD

Transcript prepared from the official record by Cater Walsh Transcription Ltd,
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Mr R Matthews appeared on behalf of the Prosecution.
Mr M Monaghan appeared on behalf of the Defendant.

PROCEEDINGS
SENTENCING REMARKS

16th October 2006

THE CLERK: Mr Monaghan, on behalf of British Nuclear Group Sellafield Limited do you admit that at Whitehaven Magistrates Court on 8 June 2006 British Nuclear Group Sellafield Limited was convicted of three offences of breaching licence conditions pursuant to Section 46 of the Nuclear Installations Act 1965 as amended?

MR MONAGHAN: Yes.

THE CLERK: And is it right that in respect of those convictions British Nuclear Group Sellafield Limited has been committed to this court for sentence?

MR MONAGHAN: Yes. I have instructions to deal with the matter on behalf of the defendant.

MR JUSTICE OPENSHAW: Thank you very much indeed.

MR MONAGHAN: Thank you, my Lord.

MR JUSTICE OPENSHAW: Yes, Mr Matthews?

MR MATTHEWS: May it please you, my Lord.

MR JUSTICE OPENSHAW: I am very grateful to you for your case statement, which I have read. There is obviously a high degree of public interest in the case, so of course it has to open fully, but so far as I am concerned you should not feel under any obligation to read each of the 41 pages.

MR MATTHEWS: My Lord, I will not. There are substantial sections I intend to summarise.

MR JUSTICE OPENSHAW: That will be very helpful but, as I say, plainly the matter must be opened fully and please do so.

MR MATTHEWS: I am very grateful, my Lord. My Lord will have seen the copy exhibits are in one volume and the case statement and other supporting documents in another. Clearly it has been a substantial investigation and my Lord will appreciate that the papers that you have are condensed enormously from the original material.

It is right that the summonses were issued on 3 May of this year and the company entered its guilty pleas on 8 June, very much at the earliest possible opportunity and I stress the company co-operated with the investigation throughout.

Nuclear site licence conditions are attached to site licenses and the HSE issues the licence and the conditions to each site and operator engaged in nuclear activities in the United Kingdom. Under the Nuclear Installations Act it is an offence to breach a condition of such a licence and my Lord is concerned with three breaches of three licence conditions over a period of time.

The licence and the conditions are the cornerstone of safety in the nuclear industry. They are the means by which the HSE, on behalf of the State, regulates safety and regulates the activities that are undertaken on the sites. At paragraph 9 of the case statement much reference will be made to documents produced by the company that form part of the safety case and my Lord will have seen from the case statement that a safety case is embodied in the conditions attached to all nuclear site licenses. It is effectively the means by which the company operating the site demonstrates in writing that relevant standards have been met and that risks have been reduced to a level which is as low as reasonable practicable. In this way the safety case underpins all safety related decision made by a licensee.

My Lord no doubt has read the explanation of radiation. What we are concerned with in this case is ionising radiation. Clearly that is something that can be harmful to the human body in excessive doses because it damages individual cells and results in damage to organs or other long term effects. However, effective protection from radiation can be gain by containing it, shielding against it, moving away from it or removing the source, but if a body or any substance picks up or is covered by radio-active material then it is said to be contaminated. Throughout the time that it is contact with radio-active material it will be irradiated by the radiation produced by that material.

Presently we are concerned with uranium and plutonium. Different isotopes of each of these elements can have different physical properties, even though they are chemically identical. Many matching occurring elements have unstable isotopes which are radio-active. Very few types of atom, such as uranium 235, which refers to the protons and neutrons, and plutonium 239, have nuclei that can easily by destabilised by collision with a neutron. These nuclei, instead of undergoing normal radio-active decay, can split into two, which is known as fission, releasing much more energy or radiation than by simple decay, and again more neutrons which in turn can cause further fissions in nearby atoms. This fission process, a chain reaction, is the basis of mankind’s use of nuclear energy. In a nuclear reactor the number fissions is controlled to produce a steady supply of heat.

Sellafield is located on the West Cumbrian coast just north of the village of Seascale and covers an area of about four square kilometres. It is the largest nuclear licensed site in the United Kingdom and due to the scale, the nature and complexity of site operations it is also the most hazardous nuclear site in the UK. Nuclear operations commenced at the site in the late 1940s with the purpose of producing materials for Britain’s nuclear weapons and in the 1950s two plutonium producing reactors were operated, known as the Windscale Farms[?]. From 1971 British Nuclear Fuels PLC owned, managed and operated the farms on the Sellafield site and was the subject of the nuclear site licence for Sellafield. Since that time the site has mainly engaged in commercial operations, using the site chemical plants to take used fuel from the United Kingdom and overseas reactors for re-processing.

On 1 April 2005 the Sellafield site became managed and operated by the same company but with a changed name, this defendant, British Nuclear Group Sellafield Limited, but ownership of the Sellafield site passed to the Nuclear Decommissioning Authority and my Lord will have seen from the addendum an explanation of who the NDA are and what they do.

In effect, what has occurred in the past year is that the Nuclear Decommissioning Agency has issued contracts to various companies within the British Nuclear Group, one of them being this defendant, to operate and effectively pays them a fee to do so. This company, British Nuclear Group Sellafield Limited, is effectively state-owned, the shares being held by the Treasury Solicitor and the Minister for the Department of Trade and Industry.

Can I turn then, my Lord, to the incident that my Lord is concerned with and that is at paragraph 16. It was on 20 April 2005 that the company discovered a leak from a pipe that supplied highly radio-active liquid or liquor to an accountancy tank in part of the THORP re-processing plant at Sellafield known as the feed clarification cell. In total approximately 83,000 litres of dissolver product liquor containing about 22,000 kilograms of nuclear fuel, mostly uranium incorporating about 160 kilograms of plutonium, it was discovered that it had leaked on to the floor of the cell. That leak had begun prior to 28 August 2004 and had remained undetected until April 2005.

My Lord will have seen, as a result of the investigation carried out by the Nuclear Installations Inspectorate, that various recommendations concerning shortcomings at the Sellafield site were made to the company, in total some 55 recommendations. My Lord's bundle in file 2 at tab 25 there is a letter that sets out 27 of those recommendations. Can I tell my Lord that others were communicated to the company within a matter of weeks of this incident and still others on a slightly later time scale. Some of them were highly technical in nature. The ones set out at tab 25 come behind a letter dated 13 December 2005. Can I draw my Lord's attention simply to page 1271 in that bundle, which I think neatly summarises the nature of the findings.

MR JUSTICE OPENSHAW: Yes, I have it.

MR MATTHEWS: And my Lord sees under a heading "Operations" what was identified was failures to comply with the existing arrangements for responding to alarms, undertaking sampling and in maintenance and testing, inadequate arrangements for response to alarms and sample results, inadequate maintenance and proof test arrangements for leak detection devices, inadequate provision of means for operators to identify which alarms were important and what action should be taken in response to them, which may include shutting the plant down, and sampling and trending and monitoring of information, inadequate provision of means in respect of those two and this resulted in many items of plant status information that masked important indicators, an inadequate understanding of the importance of sump alarms as a result of an inadequate safety case, failures to identify or provide other diverse leak detection systems as safety related or safety mechanisms and that there were difficulties in identifying non-routine faults on complex parts.

And my Lord sees also under the heading “Management and systems” a lack a adequate management controls and supervision resulting in the inadequate monitoring, challenge, review and leadership of plant operations at all levels, a lack of an adequate safety management system, in particular independent monitoring, audit and review of operations and the resources to do this, and the lack of clarity in roles and responsibilities for long term plant trending and monitoring, coupled with a lack of specific resources to provide this function.

Then under the heading “Cultural” there is a culture of tolerating alarms, non-compliance with instructions and a lack of a questioning approach.

My Lord, really those criticisms feed into the breaches of these licence conditions. Paragraph 18 of the case summary importantly, the Crown say, the investigation identified that the company had been in breach of licence conditions. Three of these breaches can be demonstrated to have been serious, to have continued over a long period of time and to have directly contributed to the incident that involved the loss of primary containment of the 83,000 litres of liquor over a period of at least nine months. The Crown say the company fell well below the standard required by the licence conditions and these breaches amount to serious offences.

The THORP plant then; Sellafield is principally now involved with re-processing fuel. It includes units whose activities are centred on the mediation, decommissioning and the clean up of the historic legacy of radio-active waste. Sellafield as such is divided into several operating units. These include the THORP and Magnox[?] re-processing plants and the Sellafield Mox[?] Plant and a wide range of waste management and effluent treatment facilities.

My Lord is concerned in this case with THORP, an acronym for the Thermal Oxide Reprocessing Plant. This operating unit contains several ponds and plants which have been reprocessing fuel on nuclear power plants since 1994. Used nuclear fuel from reactors is transported to one of the THORP ponds for cooling and storage. Once it has cooled the fuel is then moved to another of THORP’s ponds for marshalling immediately prior to reprocessing. The used nuclear fuel is then moved in customer specific batches to the THORP head end plan where it is sheared into small chunks, dissolved in nitric acid and that is what then forms the dissolver product liquor. It is then centrifuged to clarify the product liquor and accounted to ensure non-proliferation and safeguarding.

Once accountancy is completed the clarified dissolver product liquor is fed forward into the chemical separation area and other downstream areas within THORP where it is separated out and reprocessed into three streams; uranium, plutonium and highly radio-active liquid waste effluent.

The feed clarification cell is one of the cells within THORP. It is known at Cell 220 and is part of the head end chemical plant. Tanks within this cell accept the dissolver product liquor from upstream plants. Every litre of product liquor contains about 250 grams of nuclear fuel, mostly being uranium. There are, of course, many vessels within the feed clarification cell. It is literally an enormous building. They include centrifuge tanks, the centrifuges, diverters and principally what my Lord is concerned with; two head end accountancy tanks and three buffer storage tanks. They hold the accounted clarified liquor prior to feeding forward into chemical separation. Each of the accountancy tanks holds 23,000 litres and is suspended from the roof of the cell. The liquor in the tanks is sampled for isotopic content and weighed, which enabled an accurate account of the amount of uranium and plutonium.

My Lord will no doubt have seen the photographs behind tab 4. If I might simply hold up *this* photo and indicate that the feed clarification cell is at about *this* area of the Sellafield site and I think most usefully directly behind that is a schematic of the cell which, I hope, contains all the relevant information. As I say, the feed clarification cell is very substantial, both in size and in construction. It is designed to contain the high radiation levels from the material process within the cell. It is 119 feet long, 68 feet high and at a maximum 47 feet wide. The walls are constructed of a special, extremely dense, concrete containing byritees[?] and is approximately one and a half metres thick. That equates to a much greater depth of ordinary concrete.

The floor of the cell is clad with stainless steel, as are the walls of the cell from the floor to a height of around one and half metres. This cladding, together with the substantial wall and roof thicknesses, form a secondary containment, in order to contain any leaks from the many tanks, and long lengths of high quality pipe work within the feed clarification cell. The cell is divided into two areas by a small wall which is at the same height as the cladding. One floor area is known as the feed clarification Area and is commonly referred to as the Feed Clari. The accountancy tanks and the buffer storage tanks are in the other floor area known as the Buffer Area. Each of the four areas slopes down into a stainless gully running around the edges of the floor and these gullies run into two sump areas, one each side of the small wall. The sumps are at low points in the cell floor cladding to collect leaked liquor and they provide both the means of detecting leaks from the tanks and pipe work and they allow recovery of any product back to safe primary containment. Within each sump is a level detection system known as pneumercator and a means of emptying the sumps called an ejector.

The sumps should always be primed with about 30 centimetres depth of clean acid in order for the pneumercators to work and to avoid potential cross-contamination of the feed clarification cell ventilation systems through exposure of the feed pipe to the ejector. Pneumercator is a commonly used system to measure depth of liquor. It is installed so that any changes in level as a result of leakage into the sump can be identified and will initiate an alarm in the control room. The numerator control comprises two pipes. One is open to the feed clarification cell atmosphere, while the other is at the bottom of the sump and pressurised air is pumped via a motor meter which is a floating bobbin in a glass tube and that measures the air flow down each pipe. Difference in air pressure between the open pipe and the pressure of air required to pass through the depth of the liquid in the bottom of the sump is measured by a pressure transducer. That sends a signal to the control room desk. The signal is translated into a depth and displayed in metres and a display in the THORP control room informs the operators at the plant and its status provides high, low, high/high and low/low alarms. Too high a level in a sump may increase the potential for a criticality, although I make it clear in this instance there was no risk of a criticality. Too low a level poses a risk of cross-contamination between ventilation systems. The air supply is regulated by a control that should always be set to a minimum of 300.

According to the THORP safety case, the vessels and pipe work in the feed clarification cell and Accountancy Cell are of welded construction and are fabricated to a high standard of integrity and thus a major leak on to the cell floor is regarded as unlikely. Nevertheless, if such an event were to occur, and it did occur in this case, the operator should be alerted to the situation by the sump alarm.

In terms of the hazards that are posed by a loss of primary containment, the pipe work and the accountancy tanks are the primary containment of this highly radio-active liquor. Any loss from this containment would result in liquor spilling on to the floor of the feed clarification cell building. The last line of defence between the liquor and the building's foundations was the stainless steel feed clarification cell cladding. That secondary containment formed by the cladding was designed to catch leaked liquor, not to store leaked liquor for a prolonged period of time. The store foundations, although extremely substantial, are porous. Any leak through the floor would result in highly radio-active liquor seeping into the ground and in such circumstances could possibly be detected over the course of time by the sampling of the ground through boreholes.

My Lord may have seen the THORP safety case behind tab 26 in file 2, but that states that leaks of dissolved product liquor in the feed clarification cell would be detected and recovered certainly within a few days. Examination of the result of a sample taken from the buffer side sump on 28 August 2004 demonstrates that the leak from the pipe work of this liquor had begun prior to that time. It is not until June 2005 that recovery from the floor of the bulk of the liquor was accomplished. It is right that to date borehole testing of the ground around the feed clarification cell has not produced any evidence of an actual leak to ground. Calculations based on values within the THORP safety case indicate that losing the line of defence afforded by the pipe work significantly increased the likelihood of a leak to the ground from one expressed as having a probability of occurring once in every 40,000 years to one occurring once in 250 years. It is right still a very remote possibility but my Lord will see the odds have been reduced by more than a hundred times.

Mr Finsey[?] is a specialist Inspector of Health and Safety in critical safety and radiological protection and he estimated the consequence to workers and public from a leak to ground. He estimated that the most affected person, ie a person who lives next to the site and lives off the land, could not have received a level of radiation sufficient to cause a possible serious health effect, nor one above the maximum stated as the legal limit for doses to public from normal operations.

Can I turn then to criticality and danger; a criticality accident occurs when a nuclear chain reaction is accidentally allowed to occur in fissile material. This releases neutron radiation which poses a great hazard to personnel and equipment. The purpose of nuclear criticality safety is to prevent a nuclear chain reaction in operations with fissile material outside a nuclear reactor.

Can I turn to paragraph 35. Mr Finsey, the same expert, has considered this incident that occurred at THORP and gives his opinion that for a number of reasons a criticality would not have been credible. He does, however, point out that the existing safety case for the accountancy tanks considers uranium enrichment of up to 4 per cent. It is right that administrative controls on blending limited this enrichment at THORP to 1.6 per cent and historical data shows that enrichment levels have never exceeded 1.6 per cent. Again I repeat, so in relation to this incident the conclusion is there was no risk from criticality.

In short then, dealing with risk, it is not alleged that anyone was harmed as a result of this incident. Nor that there was the possibility of exposure to increased radiation levels. All indications suggest that none of the liquor escaped from the cell and it is not alleged that there was a possibility of a criticality. It has been estimated that the consequences of any leak to ground as a result of this incident would not have caused any health effect to the public. My Lord may have seen the mitigation statement. Can I reassure my Lord that there really is no issue between the prosecution and the defence in this respect. The HSE's position, as they have set out, is there was no possibility in this incident of a criticality. The company's position is slightly at odds with the HSE in that Mr Finsey's view is that there may have been some circumstances where criticality could have been a possibility. The company's position is that there were no circumstances where it could have been a possibility. And in relation to the leak to ground, all parties are agreed there is no evidence of any leak to ground. The HSE cannot say there is no possibility of such a leak to ground occurring, but simply that there is no evidence and no indication that such leak has occurred and had such a leak occurred it would not have caused any health effect to the public.

My Lord, then moving to the International Nuclear Event Scale, that scale is devised as a means internationally for promptly communicating to the public in consistent terms the safety significance of events reported at nuclear installation. Behind tab 31 is the chart. The scale is intended as a means of putting events into proper perspective by providing a common understanding among the nuclear community, the media and the public of the significance of events. By way of example, the 1979 accident at Three Mile Island in the United States resulted in a severely damaged reactor core and an off site release of radio-activity that was very limited. That event is classified as level 5 based on the on site impact. The 1973 accident at the Windscale, which is now Sellafield Re-Processing Plant, involved a release of radio-active material into a plant operating area as a result of an exo-thermic reaction in a process vessel. That incident is classified as level 4 based on the on site impact.

This particular incident of the loss from containment at THORP was categorised by the company as level 3 on the International Nuclear Events Scale. That my Lord will see is termed a serious incident and there are broad criteria to support that level 3. Those include in which a further failure of safety systems could lead to accident conditions or a situation in which safety systems would be unable to prevent an accident if certain initiators were to occur.

The detailed guidance gives an example of a level 3 incident as one specifically concerned with non-reactors as involving events resulting in the release of a few thousand terrabekkles[?] of activity into a secondary containment where the material can be returned to a satisfactory storage area. And it is for that reason that this incident was classed as a serious incident on level 3 of the scale.

Following this incident the THORP reprocessing plant was shut down. It remains shut to this day. The company, once it had made this discovery, used the installed sump ejector system to transfer the spilled liquor in batches into the buffer storage tanks. Lifting of liquor from the floor began on 23 May and continued to 14 June 2005 and in between ejection steps the in cell wash ring system was used to lightly spray diluted nitric acid around the walls of the cell stainless steel liner to try and flush off any sediment that had settled.

On completion of the liquor removal, there remained a thin layer of silt, presumed to be highly radio-active, on the cell floor. The buffer cell sump was left primed with dilute nitric acid and with the sump level monitor communicator operational. The cell is thus currently safe with all the mobile leaked material within the primary containment of the buffer storage tanks.

A proposal for how to continue to process this material, which is contaminated with iron constituents from corroded steel components within the cell, has now been developed but is not yet underway.

Can I invite my Lord's attention to the photographs and perhaps assist with a little explanation which will allow me, I think, very much to shorten matters. The schematic of the cell ...

MR JUSTICE OPENSHAW: Sorry, I missed the page.

MR MATTHEWS: I am sorry, behind divider 4 and it is page 4 of divider 4. The process moves from right to left on the picture. The stream flows *this* way. My Lord will see the two accountancy tanks. The important one is in red and an enlarged view of the fractured pipe, which is the only pipe put in in this schematic, that went to that accountancy tank. The buffer tanks are on the other side. *This* is the bonded wall my Lord sees and the other side of the bonded wall are various other vessels. *That* is the feed clari side and *this* side with the accountancy tanks and the buffer tanks is the buffer sump side. And my Lord sees towards the top of the schematic the cell side and I hope that the colours are clear.

MR JUSTICE OPENSHAW: Yes.

MR MATTHEWS: Really effectively, it works like a cup and the liquid drains into the cup, any that is collected on that floor, and there is the pipes that go in for the part of the numerator system.

If my Lord looks on in the bundle, the purpose of the next schematic is really to give an idea of the mild steel supporting around those buffer accountancy tanks. They do not support the weight of the tanks. They are effectively only used if and when the process of accountancy is undertaken to affect the weigh of the tanks. But they are made from mild steel. My Lord sees the stainless steel rods coming out from the top of the tanks. They are effectively what support those tanks.

If my Lord then looks through, the next photograph gives a very good view and was taken by the camera inserted after the discovery. That is the view of the pipe that sheared off from the top of that accountancy tank. Then perhaps the most dramatic picture my Lord sees; that is taken from the same camera and is the area by that sump and my Lord sees in the inset an old photograph, I think taken from 1994, of what the sump and the steel cladding looked like and the arrows in each photograph indicate the same point. So my Lord gets an idea of the level of the liquid. At its shallowest depth the leaked liquor was 24 centimetres in depth approximately, but at its deepest point something approaching two foot. And if I tell my Lord that the diameter of that sump is 60 centimetres my Lord can have an idea from the inset photograph of the level that that leaked liquor is at. Then perhaps very briefly the other photographs -

MR JUSTICE OPENSHAW: The cladding, the secondary containment, I think was 1.5 metres high, was it?

MR MATTHEWS: Yes, 1.5 metres high. The next photograph is instructive because my Lord sees the cladding on the floor. Those are the stainless steel panels and the welds where they have been welded. It almost looks like tiling. Then of course the next photo the arrow marks the same spot giving my Lord an idea of the depth and similarly the photograph thereafter.

Can I draw my Lord's attention to *this* photograph which is, as it were, the before photograph showing that mild steel support framework in its virgin state. Then the next photograph I hope gives my Lord a good idea of the effect -

MR JUSTICE OPENSHAW: You have got much better copies than me. I have only got laser copies and it is never quite the same.

MR MATTHEWS: Can I pass my Lord my photographs. With that explanation they speak for themselves. My Lord will see that the nitric acid has corroded the mild steel framework.

MR JUSTICE OPENSHAW: Thank you.

MR MATTHEWS: It has not affected the buffer tanks, other than to cause some staining. They have not and will not corrode.

MR JUSTICE OPENSHAW: Sorry, just repeat that point.

MR MATTHEWS: In the schematic I draw my Lord's attention to the mild steel framework that is only used when -

MR JUSTICE OPENSHAW: Yes.

MR MATTHEWS: Because that is made of mild steel that has corroded, having been in contact with the nitric acid substantially.

MR JUSTICE OPENSHAW: Which photograph is that? You probably cannot tell because I have got yours.

MR MATTHEWS: I think from recollection 12 shows it in its virgin state and the photograph thereafter really shows the metal eaten away.

MR JUSTICE OPENSHAW: Yes, I understand. Thank you.

MR MATTHEWS: Can I briefly – on the shipper receiver difference and that is at paragraph 41, that my Lord will have read and no doubt understood is an accountancy measure. It is used for security purposes. It is a calculation at the end of each reprocessing campaign and it is the difference between the amount of uranium the customer has estimated to be in the fuel and sent to THORP and the amount of uranium that has effectively come out the other end. That accountancy is done via the accountancy tanks and the calculations used as an accurate measure of what has been fed forward to the chemical separation plant. It is not part of the plant safety monitoring system. It is a requirement of various European agreements on non-proliferation and safeguards and for the company to account to its customers. Nuclear accountancy is not identified, nor does it provide support to the company's safety case. That SRD figure, for short, is measured as a percentage and has an upper limit of 0.45 per cent above which the company's operational procedures require an internal investigation to be instigated. I think perhaps in tab 1 of file 2 my Lord can see the figures set out and on the second page of that one sees the figures for campaigns from 30 January 2005. The figure on the right hand column is expressed as a loss or a difference in grams, so the campaign that ended on 30 January 2005 resulted in 6,910,842 grams difference, which is a figure of 3.9 per cent. If my Lord then looks down to the campaign that ended on 29 March, one sees something like 8.3 tons. That is the 8.3 million grams and that was a difference of 10 per cent.

These figures did not become available to the company straight away. It took about six weeks to be calculated and so the 3.5 per cent figure was determined on 17 March 2005 and an internal investigation was initiated immediately. As a result of the numerator outputs failing to reveal elevated levels with the sumps, the investigation focused on administrative areas. In other words, checking the paperwork rather than the operation of the plant. That 3.5 per cent figure relates to the fuel that had been processed between 9 September 2004 and 30 January 2005.

At the beginning of 2005 it was noticed that the volume flows changed. The company, in other words, became aware that the accountancy tanks were taking more feed in order to fill up and calibration checks were made on what is called the constant volume feeder in order to confirm this was not the problem. And it appears to have been concluded that the cause was a discrepancy in the accuracy of the constant volume feeder.

Simultaneously the company became aware that approximately 8 per cent more dissolver batches were required to fill the buffer storage tanks and that, it was concluded, was due to uncertainty over the amount of dilutant being added during the process. Further SRD data became available on 13 April 2005 and that showed that the campaign from 30 January to 25 February 2005 had an SRD of 3.9 per cent and that is the one I have taken my Lord to on 30 January. Perhaps it is instructive to look back at earlier figures and see quite how different they were with grams no more than the hundred thousands and often in the tens of thousands.

So the campaign, as I say, that ran from 25 February 2005 to 29 March, that was reported on 15 April and that is the one that had this SRD figure of 10 per cent. On 14 April during the investigation into the initial elevated SRD figure, the company’s employees became aware of the existence of routine feed clari sump sample results that dated from November 2004 and February 2005 and they concluded that the problem was on the feed clari side of the cell. A meeting was held by THORP staff on 15 April to discuss the findings and by then that included the estimate that 83,000 litres containing 22,000 kilograms of uranium had been lost.

The company’s THORP Fuel Services Section oversees head end operations and a plan of action to insert cameras into the cell was drawn up for the work over the weekend of 16 to 17 April. The plan did not include the immediate shutting down of THORP operations, although it was acknowledged that liquor movements within the feed clarification cell would have to stop when the cameras were to be inserted into the cell. Over that weekend concerns were raised that this insertion of cameras was too great a task for weekend shift staff and the decision was made to defer the camera inspections until after the weekend. Preparation for the camera inspection resumed on Monday 18 April 2005.

The Crown do say that it was a remarkable decision to continue to keep THORP operational and re-processing fuel over that weekend, as I say, in the knowledge of the effectively missing 83,000 litres. Can I add that the company's own board of inquiry it appears criticised this decision by senior management and that was one of its findings.

In any event, on Monday 18 April the company's Nuclear Material Custodian performed a complicated summation of the volumes of liquor present in the tanks prior to ejection over the previous eight months. It is not a calculation routinely done. It is complex and not automated and is not reliably accurate, but that calculation confirmed the SRD data and as a result of this on 18 April the decision was finally taken to shut THORP down. The shots that my Lord has seen are from the camera inspections that took place on 19 April. Inspections that took place in the feed clarification site found no evidence of a leak or fracture. It was confirmed at about 2 pm on 20 April that the buffer side showed a fractured pipe, the pipe that my Lord has seen, and that there was staining due to leaked liquor on the side of the tank and, as I say, severe corrosion of cell support steelwork and this large volume of liquor on the floor of the buffer side of the cell. The Health and Safety Executive was notified at 5 pm on 20 April.

MR JUSTICE OPENSHAW: Can you just go through those dates again? The anomaly was first spotted because of the shipper receiver difference on -

MR MATTHEWS: Firstly, 13 April but the more significant, ie the 10 per cent figure, was 15 April, but by the 14th there is an investigation into the first figure, which is 3.9 per cent, and they have become aware of some sample results, that I will take my Lord to in due course, and conclude there is a problem. Then on 15 April they become aware that in fact 83,000 litres and that 10 per cent figure. And it is on the 18th, the Monday, that the plant is shut down.

On 22 April they carried out some investigations and an instrument mechanic discovered that the flow indication to the buffer sump numerator was showing that it was all correct. The initial movement of the needle valve controlling the air flow was as if the air flow was shut off or nearly shut and so the instrument mechanic simply returned the flow to the normal setting but he noticed that the rotor meter ball, the bobbin, was sticking in a position that indicated the flow was in the operational range, even if the air flow was much lower than this and it seems simply tapping the side of the rotor meter cured the fault. My Lord will appreciate the rotor meter is remote from the feed clarification cell. There is one pipe in the cell and the air pressure indicator is somewhere remote and, as I say, simply tapping that cured the fault and as soon as that instrument returned to operation it showed that the sump level was 1.8 metres. Clearly that instrument had not been in good working order.

A sump sample was then taken on 26 April and the results showed that the liquor on the floor was dissolved product liquor. That 83,000 litres of liquor lost from primary containment had collected on the buffer side. It was over three times the liquid volume of a single of those accountancy tanks and we ask my Lord to bear in mind that the amount of liquor required to raise the level in that buffer sump from the operational 30 centimetre to the higher arm level of 40 centimetre was only 30 litres.

Can I summarise the operation, the fractured pipe and the operation of the accountancy tanks really in a few lines. There is absolutely no dispute that this incident was caused by that pipe shearing away from the tank and what would have occurred is that it would have formed, as it were, a fracture before it sheared off over a period of time. Initially then the breach area would have been small and it would only grow a complete guillotine failure in the later stages. There has been consideration of how the tanks were designed and commissioned and changes to the way they were operated. Effectively what occurs is they are agitated on the steel rods and it appears over a period of time a decision was made to agitate them half full and the Crown would say, and I think the company accepts, that it does not appear that the possible effects of this change was properly considered. By agitating them in that way that has placed far more stress on the joins of the pipe to the top of the buffer tanks. I think that summarises that section of the matter.

Can I turn then to Licence Condition 34 and my Lord may feel that Condition 34 is perhaps central to the licence conditions. It is entitled “Leakage and escape of radio-active material and radio-active waste”. It provides:

1. The licensee shall ensure, so far as reasonably practicable, that radio-active material and radio-active waste on the site is at all times adequately controlled or contained so that it cannot leak or otherwise escape from such control or containment.
2. Notwithstanding paragraph 1 of this condition, the licensee shall ensure, so far as is reasonably practicable, that no such leak or escape of radio-active material or radio-active waste can occur without being detected and that any such leak or escape is then notified, recorded, investigated and reported in accordance with arrangements made under other licence conditions.

The company’s arrangements for addressing this nuclear site licence condition are in file 2, tab 17. I think my Lord does not need to refer to it. In paragraph 3.1 that document provides a definition of leak or escape which states “Leak or escape means a discharge or a loss of control of a radio-active substance beyond its intended containment and in a quantity which is readily detectable” and at paragraph 4.2.2 states that “In such circumstances at least one barrier will remain intact following any leakage or escape" and clearly that is what occurred here.

It is the Crown's case that in breach of this licence condition the company failed over a period of some eight months to ensure, so far as was reasonably practicable, that radio-active liquor in the pipe work feeding nozzle N5 of accountancy tank B did not leak or otherwise escape and during this time the leak grew from a few litres containing a few kilograms of uranium to one involving many thousands of litres with many thousands of kilograms of uranium. It is the Crown's case that in breach of the licence condition and over at least the same period of time the company failed to ensure, so far as was reasonably practicable, that such a leak could occur without being detected.

The company's own hazard analysis of leakage to ground from area 200, this area, recognises that the cell area has an engineered means of leak detection and an engineered means of leakage recovery back into the primary containment. Now that means the numerator is designated as safety related equipment. Other documents consider the criticality safety assessment of the accountancy tanks and then specifically considered the potential for the leakage of liquor. The document recognises the apparent high standard of the construction of the vessels and pipe work in the cell and thus regards a major leak as unlikely. However, in order to safeguard against the potential for liquor leakage resulting in gradual accumulation of plutonium and uranium two safety measures have been identified.

The first of these is an operating instruction and the second is that sump numerator which again is designated safety related equipment. Operator instruction 0491 contains the actions to be taken in response to a high or high alarm and to a low and low sump level alarm in the feed carrying the buffer sumps. Can I take my Lord to that document behind tab 19. The first page to note is page 593. It seems it is headed "Operating instruction" and it is concerned with safety requirements and plant safety case requirements. Indented we see:

> "In order to prevent a build up of plutonium in cell 220 sumps, if there is an unexpected level rise in either cell 220 sump a sample must be taken and analysed for plutonium as soon as reasonably practicable."

At 598 identified at number 24 and 25 are the operator instructions concerned with the responses to high level alarms in the buffer storage sump and responses to low level alarms in the buffer storage. If my Lord very briefly to turns to page 622, we have that operation 24 and the arrangements include at 24.3:

> "Arrange with the auto sampler to have an ad hoc sample taken from the sump."

Then at 624, operation 25 states "L2596". That is the buffer sump numerator, so response to low and low alarms, low/low alarms in accountancy and buffer storage sump. If my Lord looks at 25.2 one has to return the sump to the normal operating level of 300 millimetres, add wash acid from the wash cabinet.

So in other words, if there is a low alarm or a low/low alarm then the sump numerator has to be returned to its normal level and there are operating instructions for routine level monitoring of the sumps and actions to be taken for sampling the sumps in the event of the level of the sump numerator approaching or exceeding high level.

Again, there behind tab 16 specifically an operator instructions dealing with the operation of these sumps. Perhaps the first thing to note at page 271 again it is reiterated other safety precautions, both sumps should be maintained at a level above the low level alarm set point. Then at 276 – and perhaps this is more important – my Lord sees at page 276:

> "Operator instruction level monitoring for the two sumps:
>
> 1.1 Once per shift check the level indication on L2596."

That is the buffer sump numerator and L2584, that is the feed clarification numerator, or whenever a cell wash down or sump emptying operation is to be undertaken. Then over the page:

> "If the level indicator is approaching or exceeds the high position, then sample the sump contents ready for transfer as described in operation 2."

So a sample has to be taken. So at paragraph 73 the operational arrangements require routine samples to be taken every three months and analysed for the presence of uranium. That sump should only contain fresh acid unless a leak has occurred from a pipe or vessel and it is the Crown's case that these samples were rarely taken from the buffer sump. There were only eight successful efforts made out of the 22 routine sample dates, notwithstanding that the samples had been requested every three months. Following the requests that were made the head end chemical plant operators were not extracting liquor and this resulted in a nil volume being shown in the sampling bottle.

Another operator instruction required if such a nil volume or a failure to [inaudible] sample occurred, that the staff in auto-sampling had to request a repeat sample. This, it appears, they did but, as I say, no such samples were taken.

Set out in the following paragraphs are various extracts from statements of operators at the THORP Head End plant. Each of them confirm that they were not aware of the result of the sample taking exercise. So if it resulted in a nil volume sample, they simply would not be aware. One describes how "If there was a nil volume sample the procedure should be repeated, but I have not been aware of any nil volume samples. I have no access to the sample results". My Lord can see those sample results set out. The routine buffer sample taken on 28 August 2004 detected 50 grams per litre of uranium within the sump. This was the first routine sump sample found to contain any levels of uranium. It is the Crown's case that this was the first indication of the existence of leak and it demonstrates that this leak had occurred prior to 28 August 2004. The previous routine sump sample to be obtained from the buffer sump was as far back as 2 December 2003. That showed the presence of no uranium, but no routine samples were obtained for 1 March or 30 May, despite the requisite requests that they be obtained.

At paragraph 77 one of the manufacturing team leaders or the shift team manager, who has worked at Sellafield since 1985 and had been in his present post for six years, he acted as a duly authorised person and as a safe system of work controller for the Head End plant. He was also the radiological protection supervisor and as the area controller his role included responsibility for the whole of THORP under emergency arrangements. He also acted as the control room supervisor of operations in personnel. He describes how sump level monitoring was carried out via the operators and states how the response to these low sump level alarms is not a significant concern. Low level sump alarms, if they are not affecting the cell ventilation, would generally be left for a period of time before requiring action. My Lord, part of the reason of taking you to the operating instruction is that demonstrates that was contrary to that operator instruction.

He goes on to explain the priming of a sump is a crude operation. It can easily result in a high level alarm being generated. It is very difficult to balance a sump between the low and high level alarms at the first attempt. It can take several hours. He did state that sump high level alarm would prompt immediate action by the operator, who would inform a supervisor. He went on to describe that:

> "During production shifts numerous sample results are reported to me from various areas of the plant, the Head End chemical plant. The sample results come to me on a computer screen. Typically on a production shift 50 or more lines of sample results will arrive. These results cover more than one day of results, eg if a sample was analysed over a fortnight period this result may come in at the top of the list of sample results which could then require scrolling through several screens of data. Due to the space between sampling, three months, a routine buffer sample result can easily be missed, eg if I am not at the desk at the time that the result appears on the computer you would not necessarily go looking for it. The sump samples are prompted automatically to be taken but the results are reported without prompting and these results appear amongst the mass of other sample results. There are instance when the computer is not available and under those circumstances sample results are reported by fax. This results in many faxes accumulating over a short period."

He relates how on Friday (it should be) 27 August 2004 he was the shift team manager at the Head End chemical plant. During the course of that night a buffer area sump result was faxed, it appears, to the THORP general areas as that computer system was not operating. That is the result that showed the presence of 50 grams of uranium in the sump instead of fresh nitric acid. The shift manager claims that he never received the result but says if he had received the result then he would have been prompted to contact his line manager.

What is clear is somebody on that night shift requested a second sample of sump liquor to be taken. It is the Crown's case that the defendant company simply did not react effectively to this sump sample result. It appears that someone within the company received the result and requested that a second sample be obtained. That appears to be the only occasion that a second sample has ever been requested following a successful sample being obtained from the feed clarification cell sump and the HSE investigations discovered no evidence revealing the identity of who requested the second sample.

That second sample failed to obtain a volume of liquor. Then a routine sample was requested from each of the two sumps on 26 November 2004. The feed clari side detected 9 grams of uranium.

MR JUSTICE OPENSHAW: Sorry, 26 November? I thought it was 8 November, but perhaps I am wrong.

MR MATTHEWS: I could be wrong. I will check tab 29.

MR JUSTICE OPENSHAW: It does not really matter. Is this November anyway?

MR MATTHEWS: In short, the buffer sump was not successful. It failed to obtain a volume. That 9 grams in the feed clari side is likely to have been present as a result of what was ejected from the August 2004 buffer sump sample.

Another THORP Head End chemical shift team manager describes his understanding of how the safety case refers to the buffer cell sump in respect of unexpected occurrences and the potential to accumulate plutonium. He states an indication of a plutonium content above 3.5 grams per litre shows there is a cause for concern as material is reaching the cell sump where it should not be. Such arisings must be notified to the site nuclear safety liaison officer before any action is taken. He can remember how in December 2004 that buffer sump was in low alarm. He correctly says that:

> "If the sump goes into low alarm normal procedures apply and the sump should be re-primed. This had been attempted to recover the situation but failed. I was not able to do anything on my shift as we were operating short handed, so there was insufficient resource to put someone on plant."

He describes how he would get about 2,000 alarms a day and a low alarm in the buffer cell sump would not be seen as a high priority because a lot of alarms come up during normal operation that do not indicate there is a problem but arise, for example, because the plant has changed states. And he says that alarms were not routinely logged and he was unaware of any log that would record repriming of the sumps with fresh acid.

The logs do show that repairs to that buffer sump indicator were attempted throughout December 2004. The output was in low alarm and unsuccessful attempts were made to raise the low level. At one point on 9 December 2004 the deliberate addition of liquor was attempted and verified by staff hearing the sump fill up. However, the numerator output was observed not to have arisen. Again others simply repeat how they would be asked to take a sample, they would press the requisite button effectively but would not know whether it resulted in a nil result. He, that other worker at the control desk, relates he was unable to reprime the buffer sump in 2004. He claims to have informed his manager. My Lord will recollect that that is the numerator that is effectively found at the end to have the air turned down very low and is rectified by a tap.

On 6 January 2005 banging noises were reported coming from the feed clarification cell. They were investigated by the company and it was concluded that this was simple normal pipe working creaking, but records reveal the temperature within the buffer sump started to rise from 15 January 2005 and it appears to the HSE that that temperature rise was due to an increased leakage weight into the sump.

The level of liquor within the operational sump, the feed clari sump, also began to rise on 15 January 2005 and that appears to have been due to leaked liquor splashing or running off into that side of the cell. So it appears that significant liquor loss from the system on to the feed clarification cell had begun in early January 2005 and my Lord will recollect that the campaign that ended on 30 January had resulted in a loss of 7,000 kilograms of fuel. That was on the cell floor from that date and is an amount that equates to over 20,000 litres of liquor. However, at that time the buffer sump numerator was only reading its normal level of 30 centimetres or about 83 litres.

On 24 February a routine sample was requested from the two sumps. This time the feed clarification cell detected 60 grams per litre of uranium. The buffer sump sample again failed and was not reported and the Crown say on this occasion that level of uranium in the feed clarification side sump was almost certain to have been due to leaked liquor splashing or running off into the feed clari side and the company entirely failed to perceive the importance of this result and wholly failed to take any action as a result.

Can I turn then to Licence Condition 24. Much of this has perhaps been covered in referring my Lord to operating instructions, but the Condition provides:

1. The licensee shall ensure that all operations which may affect safety are carried out in accordance with written instructions, the operating instructions.
2. The licensee shall ensure that operating instructions include any instructions necessary in the interests of safety and any instructions necessary to ensure that any operating rules are implemented.

I take my Lord to that operating instruction concerned with the operation of the sumps and, in short, examination of the data that has been obtained from the company reveals significant extended periods during the previous five years prior to the discovery of the leak when the buffer sump level has been recorded below low alarm level. The company failed to carry out the operation in accordance with this operating instruction over this prolonged period. And again, my Lord has seen once per shift check the level indication on pneumercators. Put shortly, this operation was not carried out routinely in accordance with the instruction, again, over a period of five years. Again I have taken my Lord to that operation 1.4: “If the level indicator is approaching or exceeds the high position then sample the sump contents” and my Lord may have notice in bold at that point it is stated “**This is to comply with operating instruction 3.1.5 on another document**”. That instruction states how “If there is an unexpected level rise in either cell 220 sump the sample must be taken and analysed for the plutonium content as soon as reasonably practicable.” And that other document is in fact the criticality safety assessment for the sumps.

In summary, that feed clari sump started to show the increase in level from mid-January 2005. That level went through the high alarm on 14 March 2005 and through the high/high alarm on 23 March 2005. The output of the numerator shows that the rate of level rise slowed from 27 March 2005. That would be because by now the sump would have been full, a depth of .6 of a metre, and the level would have been slowed by the increase of the surface area as the liquor flooded the cell floor. In breach of the company’s operating instructions the sump was simply drained on 30 March 2005 without any sample being requested and with no explanation appearing in any operational log.

It is the Crown’s case that the failure to carry out these operations had a very significant impact on the failure to detect the leak and the failure recognise that the numerator was not in good working order.

Which brings me to Licence Condition 27. Again, my Lord may think an important condition - safety mechanisms, devices and circuits and states:

> “The licensee shall ensure that the plant is not operated, inspected, maintained or tested unless suitable and sufficient safety mechanisms, devices and circuits are properly connected and in good working order.”

Examination of the historical records from the buffer sump numerator show the depth of the liquor in the sump reveal how the system was not in good working order, again, over prolonged periods dating back to 2000. There are a significant number of prolonged occasions when the numerator was in an alarm state, was showing a zero reading and was producing erratic results. Between 1 July 2004 and 22 March 2005 the instrument system had raised over 100 low or low/low alarms and it is the Crown’s case that the plant operators were aware of this state of affairs as documented attempts were made, as I have described, to remedy the abnormal output. The nature of these results provides a very strong indicator that this buffer sump numerator was seriously malfunctioning and was not in good working order over what was a sustained period of time.

MR JUSTICE OPENSHAW: Five years perhaps.

MR MATTHEWS: Yes. I have not troubled you with this, but effectively it is produced from the company's computer and it is the -

MR JUSTICE OPENSHAW: It was giving anomalous readings over a long period.

MR MATTHEWS: It is the trend figures. It is trending the readings, the blue line being the buffer sump, the pink (which may be more difficult to see) being the feed clarification sump.

Can I move to paragraph 109. Perhaps it is obvious but Mr Jennings, one of the superintending inspectors of Health and Safety, he has examined that data obtained from the company. He points out how the sumps are designed to hold any leakage from the tanks or pipes until the source of the leak can be identified and isolated and how to detect the leaks each bond[?] is provided with a liquid level sensor, as we know, which gives sufficient warning through alarms in the control room of a leak so actions can be taken to avoid harm of effects that could arise. At paragraph 112 his analysis of the data shows a very distinct contrast, as I have shown on those graphs, between the buffer sump and the feed clari sump and as my Lord is aware from early 2000 it is distinctly different, the buffer sump. It is not working stably, it is out of line with expectations and, apart from times when the device was taken out of service over the five year period, the feed clarification side was working correctly throughout and the measurements make sense against what we know of how the plant was operating.

At 113 the buffer sump indicators, wild fluctuation with the mean level below the low alarm for 85 per cent of the operating period in that five years and it was often falling well below the lowest alarm rate. In his opinion it is clear that good evidence had been available to the company for 63 months of even a serious incident of malfunction. The most plausible reason was serious problems with the liquor level control in the buffer tank area. And he says the significant difference between the performance of the two instruments was a very strong indicator that it was seriously malfunctioning and not in good working order and the evidence for this was available to the company over a five year period and I stress that that graph is effectively produced through the company's results and the company's computer.

Which brings us to the 1998 incident because back in 1998 pipe work in the Head End dissolver cell had eroded through and leaked a relatively small quantity of dissolvable product liquor into the sump. There was a management investigation and a report made 28 recommendations concerning future recommendations. Two of them are particularly important. One stated that the four production support managers should ensure that where relevant and appropriate procedures are put in place requiring that all cell sump analysis results are recorded and trended by shift team managers as soon as practicable following receipt. Another stated that the THORP production support managers should ensure, where relevant and appropriate, procedures are put in place requiring that cell sump analysis result trends are reviewed by production support personnel on a regular basis. That is exactly what these are.

It must be, the Crown say, that these recommendations were directly related to and transferable to what was discovered following this investigation. 98 was a similar but less serious event and it should have resulted in the recommended arrangements being put in place to improve leak detection and monitoring in respect of Head End. It appears the company has no formal record of how or to what extent THORP Head End implemented the 1998 recommendations, but it is the view of the HSE that few of the older recommendations had been effectively implemented otherwise, had they, this leak would have been detected much earlier.

I do not doubt with the first part of the summary, I think having opened the case in detail, my Lord has the facts. Can I turn simply to paragraph 125. As a result of breaches, put simply the company lost its ability to detect leaks into the feed clarification cell and leaks from the cell and the company was reliant upon the last line of defence against the leak to ground of highly radio-active dissolvable product liquor which occurred during normal operation and, as I have stressed, over a prolonged period of time. And this substantial quantity, 83,000 litres, remained undetected for months. Again, I stress there is no evidence of a leak to ground from the incident and no person was put at risk or harm, none the less the probability of a leak to ground, as I have explained, increased significantly. These were thus serious offences. They amount to a significant departure from the relevant safety standard over a long period of time and a failure to comply with important conditions which I stress are concerned with safety attached to a licence to operate the most hazardous undertaking in the United Kingdom.

My Lord, I have set out, as we are enjoined to do, the relevant sentencing factors, but can I make this caveat; this is not a prosecution of a breach of the general duties under Section 2 or 3. It is not concerned with the risk in the sense of possibility of danger and very much the gravamen is the failure to comply with the conditions which are necessary in the interests of safety which I say are part of a commissioning regime that allows this defendant to engage in this hazardous activity and that licence is the primary means which the State regulates the safety of nuclear installations. It is also the foundation for public confidence in such safety. So to the extent that it is relevant I have set out the factors. Clearly the degree of risk and extent of danger it is not alleged that persons were exposed to danger as a result of the breaches and I think I have repeated more than once why we say the breaches are grave and where that gravity stems from. The Crown does point to a failure to heed warnings from the 1998 report in the way I have explained and the company does have a number of relevant previous convictions and to assist my Lord I have given something my Lord has not had before the briefest facts to support, behind tab 5, the previous convictions. If I can ask -

MR JUSTICE OPENSHAW: Thank you.

MR MATTHEWS: I am grateful. Thank you very much. I do not know if my Lord will be assisted by me reading out the previous convictions. Simply can I summarise them. One in July 1990 for the same offence. Pleaded guilty to a breach of Section 4.6 of the Nuclear Installations Act and relating to the transfer of fuel. The penalty imposed a fine of £1,000 and costs of £4,600. Then in 93 four breaches of licence conditions. Fined again in the Magistrates Courts £1,500 for each offence and £10,000 costs. In 1995 a breach of Section 3 of the Act and five counts of breaching licence conditions. That related to an internal fuel flask being transported without water in the magazine. A £15,000 fine for the Section 3 offence and five fines of £3,000 plus costs. 12 April 1996 a breach of Section 3; a sub-contractor was contaminated with radio-active material, which I think sounds perhaps more dramatic than it was, but for that offence the company was fined £25,000 and costs of £16,000. 2 February 2000 an offence contrary to Section 2.1, which I am afraid I have not provided particulars for, but it involved spilled nitric acid, not radio-active material, in which an employee was injured. This Crown Court a £20,000 fine. Then lastly, in October 2000 charges under the Ionising Radiation Regulations 1999, fines of £3,000, £3,000, £4,000 and £14,000. Lastly, 6 March, again the Ionising Regulations and a breach of Section 3 relating to the storage of radio-active material, a £9,000 fine for the Section 3 and two £3,000 fines. It is right to say that in none of the previous matters had there been loss of containment.

I have also provided principle sentencing authorities which I am sure my Lord is familiar with. And I hope I will be forgiven for saying that the paradigm shift that occurred in 1999 with Howe - Milford Haven case simply assists in dealing with public authorities and public bodies and I think provided welcome guidance for that particular conundrum which no doubt my Lord has read. And Jarvis Facilities similarly perhaps the important point from that case is the relevance of a public element where a company is engaged in activities that have a public impact, that is a factor to be taken into account. And I think perhaps most helpfully Balfour Beatty Rail Infrastructure Services Limited this year, the present Lord Chief Justice really reiterated a summary of the guidance from Howe and onwards at paragraph 22, set out 13 points which I think helpfully summarise all the relevant guidance and then perhaps added something to that at paragraph 40 under “Discussion” endorsing the guidance by the previous decisions set out in those 13 propositions. Only one of these propositions, number 10, deals expressly with the objects of the sentence, namely to achieve a safe environment for the public and to bring the message home, not only to those who manage a corporate defendant but to those who own it as shareholders. And then his Lordship spelt out Section 1.42 of the Criminal Justice Act and the purposes of sentencing and said how most of them could be applied in the case of the company, although a notion of the reform and rehabilitation of an offender provides some difficulty.

Then his Lordship went on to consider principally Section 3, as I say, the general duties of the Act and the nature of systemic failures and failures that are simply due to perhaps a single act of inadvertence on the part of a junior manager and said how in the latter cases a deterrent sentence was neither appropriate nor possible. Where the consequences of an individual's shortcomings have been serious the fine should reflect this but it should be smaller by an order of magnitude than the fine for a breach of duty that consists of a systemic failure. I know my Lord has been provided with a copy of the Transco decision in the Court of Appeal which was a case that I appeared in and that was perhaps an unusual, if not unique, case where the fault really was a single manager who simply took the wrong decision with disastrous consequences and that was the basis of the allegation. And again, the Lord Chief Justice a few weeks before the Balfour Beatty case considered the issue of the relevance of a company's financial status and the information to be provided to the court and no doubt my Lord will have seen that.

My Lord, can I move away then from the guidance and I think address you simply on the question of costs, which I am happy to say are agreed by the company and so can I give my Lord the figure which is £67,959.48. That is £67,959.48 and that, of course, includes investigation costs.

My Lord, unless I can assist further -

MR JUSTICE OPENSHAW: No, you have been most helpful. Thank you.

MR MONAGHAN: My Lord, I trust that your Lordship has received the defence response to my learned friend's prosecution opening.

MR JUSTICE OPENSHAW: Yes, I have and I have read it with care. It is extremely detailed and helpful and I am grateful to you for it.

MR MONAGHAN: Just as my learned friend indicated, I do not propose to go through every aspect of that seriatim. I doubt that would be particularly of assistance to your Lordship. There are matters none the less which it is necessary to deal with in some little detail but I hope to be relatively brief.

MR JUSTICE OPENSHAW: It is an important matter, you should take as long as is necessary.

MR MONAGHAN: Thank you, my Lord. Can I first of all simply say that it is right that that defence document is somewhat lengthy. It was intended to ensure that all significant points, whether they were facts or interpretation of facts, or aspects of the mitigation generally, were dealt with. There may well be a number of points, factual in particular, which your Lordship ultimately concludes do not bear particularly, or even at all, on the question sentence. One of those, perhaps a good example of that, is the fact that on the question of criticality there is a difference of opinion between the defendant and the prosecuting authority as to whether in different circumstances to this, hypothetical circumstances which have never arisen, the possibility of a criticality might exist. We have in effect agreed to differ because it seems to us all that the reality is that all parties are of the view that there was no possibility of a criticality, that is an uncontrolled nuclear reaction, in this case. All parties equally seem to agree that there would be no possibility of such a criticality in the vast majority of situations that could possibly arise in the THORP reprocessing plant. There is what I might, I suppose, call a grey area somewhere at the other end of the spectrum where if certain theoretical conditions arose – and as I say they never have – there is a difference of opinion as to whether a criticality might potentially be possible. But that seems, with respect, to be so far removed from the situation with which your Lordship is dealing that it does not seem, with respect, to have any bearing on these matters or this incident or to be relevant to sentence.

MR JUSTICE OPENSHAW: I agree.

MR MONAGHAN: None the less, there have been certain factual differences or differences in interpretation which the defendant company, perhaps understandably, was unhappy about ignoring, even when it was felt that ultimately they may not affect your Lordship's view and therefore the document is perhaps somewhat [inaudible] than it otherwise would have been.

That said, may I deal firstly with the preliminary, though none the less important, aspects of the mitigation and there is certainly no contention about. My learned friend has been kind and fair enough to allude to them in the course of his opening. The first of those is, of course, a guilty plea at the first opportunity. The second is the full cooperation that was given by the defendant company once the investigation of this matter by the Health and Safety Executive, and in particular the Nuclear Installation Inspectorate, the NII, had begun.

It has already been the subject of some allusion by my learned friend that the defendant company carried out its own board of inquiry. That was a full and wide ranging inquiry into what had gone on. Particular reference was made by my learned friend to the fact that the board of inquiry criticised the fact that the plant had been left to operate over the weekend within that short period that there was reference to in April when the insertion of the cameras because of logistical difficulties had to be put off from the Friday until the Monday. So it is clear that the board of inquiry that the defendant company set up pulled no punches and acted in no way to justify that which it felt ought to be criticised. And that is indicative of the level of cooperation and the level of seriousness with which the defendant company views these matters.

There is, of course – it has not been suggested but it is appropriate that it be said for the record because it is a matter within the various aggravating mitigating features set out in the authorities – there is, of course, no question of corners being cut or matters not done in order to save money. That was the case in the case of Howe, the seminal sentencing authority which your Lordship has. It is not the case here.

A factor to which the court must have regard, following on from those same sentencing authorities, is the company's reaction in the sense of steps taken to put matters in place to resolve the difficulties and, one would hope, to ensure that a recurrence of the same is not likely or possible. Those steps which were taken by the British Nuclear Group Sellafield Limited are set out in considerable detail at paragraph 60 onwards, which begins on page 13 of the defence document. I do not believe that it is necessary to go through those word for word. As, in effect, an overview it is right that increased numbers of operation meetings have been introduced, along with reviews, amendments of maintenance arrangements and other matters, all of which are designed to increase communications within the plant, as it is clear that a lack of communication in one sense underlies the difficulty that arose with the sump and numerator matters.

In addition, there have been insulated cameras, re-assessment of safety issues, significant investment into certain matters which in some ways are peripheral. One of them is, for instance, the [inaudible] of condensation – condensate forming within the sumps. That is mentioned because your Lordship may have seen that at one stage it was thought that the increase in condensation within one of the sumps was the cause of a particular reading and a necessity to empty the sump. So it is clear that there has been a very comprehensive review and the other thing that it seems could usefully be done from a technical and an organisational point of view done to – in response to these matters by way of resolving the difficulties which led to this incident occurring.

I do not want – I say I do not want, I do not believe that it is necessary unless your Lordship requires it - and I know that your Lordship has read the document in detail and carefully – to go through any of those particular individual details of that aspect of that piece of mitigation, but your Lordship sees in summary that a great deal has been done in response and that is a significant mitigating feature.

As to the record, it is right that there are convictions recorded against the defendant company. It is equally right that there is nothing of this sort and so far as these matters are concerned one matter at THORP - which again is perhaps less serious than its bald description makes it sound of some low level contamination of a contractor. THORP is a large complicated and potentially very hazardous operation. It is in effect to the company's credit that there has been no history of incidents here. There has been nothing at all of this sort and I would ask your Lordship to conclude that this is not a record which reflects badly for sentencing purposes upon this defendant.

My learned friend has alluded to the fact that this is not a Section 3 prosecution but of course most of the authorities that have been produced are and in the context of my learned friend's prosecution case statement and his opening to your Lordship it has been thought appropriate to deal with and refer to matters such as the overall seriousness of the breach and the level by which this company has fallen below the required standards. Now, it is a significant plank of the defendant's mitigation which we submit is of very considerable importance that there is an absence of risk in this case; risk of criticality, risk of contamination and risk of environmental impact. And so far as the last is concerned, it perhaps bears noting that in the Milford Haven case, which my learned friend referred to towards the end of his opening, the failure, in effect the negligence by the defendant company, was limited. The environmental -

MR JUSTICE OPENSHAW: Yes, but that was a straight liability case.

MR MONAGHAN: It was a strict liability case. The fine was considerable. The environmental impact was immense and it might well be regarded in this way; that the considerable fine reflected an enormous environmental impact that had occurred.

MR JUSTICE OPENSHAW: Yes, but an absence of fault, so I do not myself think that that was very helpful.

MR MATTHEWS: Well, perhaps it is not helpful in overall terms. It is none the less, as I say, accepted by the prosecution that these risks were all absent. If I might deal with them individually, but I hope briefly, criticality is an uncontrolled nuclear reaction and the defence say that it cannot be stressed -

MR JUSTICE OPENSHAW: I agree with you on criticality.

MR MONAGHAN: Yes, there is no possibility of any criticality at any stage in this incident, at any stage in any process, the defence say, with the caveat that there is some minor disagreement for the potential circumstances far removed from this.

The question of contamination which, as my learned friend has called long term damage, as described in his opening, is equally one where the defence say there is no risk. The reality is that all of the liquor that leaked from the fractured pipe was contained within this cell. Your Lordship has heard and seen photographs and plans of the cladding made in stainless steel to a height of approximately – and I think your Lordship clarified this with my learned friend – 1.5 metres in height. It is the nature of stainless steel that it is not affected by nitric acid. I anticipate that when these parts of the installation were designed that of course is one specific reason for the materials being chosen.

MR JUSTICE OPENSHAW: Yes, but the welds are vulnerable.

MR MONAGHAN: I am not sure if vulnerable is fair, in all fairness.

MR JUSTICE OPENSHAW: All right, but there is a potential weakness at the welds.

MR MONAGHAN: In theory, yes. It is right, however, that the welds are of the highest integrity imaginable. They were tested with the approval of the Nuclear Installations Inspectorate by various methods, various technical methods which were the limit of that which was technologically possible when the installation occurred. It is slightly odd, I think, that x-ray is referred to in the prosecution's documentation because x-raying, because of the nature of these welds, I am instructed, would simply not have been physically possible. Air box testing and other technologically advanced tests established to everybody's satisfaction at the time of the installation that there were no breaches, no holes, no loss in any way of the integrity where the welds had occurred. There has been no incident or occurrence since the installation that could be pointed to as something which is likely to affect that integrity. That is one factor. In addition to that there have been careful and complex calculations carried out by the defendant company based on measurements of volume and separately upon measurements of mass. The calculations which have been carried out show, certainly in the case of the mass calculations, relatively narrow margins of error that there has been no loss. That is consistent with the defendant company's findings in relation to the ground testing via boreholes which shows no increase attributable to this.

And the combination of the nature of the construction of the cladding, its being of the highest integrity to begin with and there having been no occurrence which could be said to be likely to affect that, plus the boreholes and the measurements and calculations, the combined effect of those matters is such that the defendant company is satisfied that there has been no leak. That in turn is consistent with the concession made on behalf of the prosecuting authority by my learned friend that there is no evidence of any leak to ground. The defendant company would say that when one looks at the design parameters, it is consistent with the various purposes within the design of this cell and consistent with the cell's purpose or purposes in avoiding the risk of any leak to ground, contamination or environmental damage. And I say this for this reason; as your Lordship will have read, the point of the cladding is in effect, within the context of its design, so that in the event of a – it is not a phrase I would often use – worst case scenario perhaps, a traumatic, catastrophic failure of the vessels in the feed clarification cell caused by potentially some sort of seismic event or similar and, as your Lordship sees, these are matters which had to be considered in the design and construction of this feed clarification cell. In the case of such a catastrophic failure the contents of the vessels would be deposited into the vessel formed by the cladding within the base of this feed clarification cell. It is there to contain that and it is axiomatic that it would take some not inconsiderable time in the case of such a traumatic catastrophic failure to find somewhere to put the dissolver liquor which had been deposited into the base of the cell in those circumstances, simply because there is no other part of the reprocessing plant which operates as spare capacity sufficient to evacuate that amount of liquor into. It follows that in reality the liquor would have to remain for potentially a significant period within its secondary containment, containment designed to hold it and avoid contamination and environmental impact until alternative arrangements were made. Although these were not the circumstances anticipated, that secondary containment has done the job it was intended for. It has minimised risk. It has avoided contamination and environmental impact. In short, it was not designed so that part of its normal function would be to hold dissolver liquor for any period of time, but it was designed so that it could do so if circumstances arose in which that happened. So it is slightly incorrect for it to be suggested that it was never part of its function.

As to the – I think it is referred to in my learned friend's addendum – the question of any agitation or cooling, that of course is part of the clarification process. The holding of this liquor is not part of the clarification process. It is simply holding until it can be removed.

Perhaps moving on from that slightly, as to the question of risk, it is important to note that the concession by my learned friend within my learned friend's case statement goes this far; that if there had been a leak to ground, for which there is no evidence, it would not have been sufficient to take the level over the maximum legal limit for [inaudible] to the public from normal operation. It follows – and I say again that this is very significant – there is no risk to health from contamination, there is no risk to environmental impact and we have already said that there is no risk of criticality.

I am sorry if I have taken a little while to go through those questions of risk or hazard. It seems to me to be necessary because it is something upon which the question of the seriousness of the breach, to some extent, hinges. I say that because in the Transco case – and this is at paragraph 36 of the judgment which your Lordship will find at tab 3 of the defence bundle -

MR JUSTICE OPENSHAW: Yes, I have got the case. What paragraph?

MR MONAGHAN: I am sorry, I have written down the wrong paragraph number. May I come back to that in a moment?

MR JUSTICE OPENSHAW: Yes, I do not think 60 exists.

MR MONAGHAN: No, it does not. I shall find the appropriate number and refer your Lordship to it in a moment.

The gravamen of the point that I wish to make is their Lordships defined seriousness as an amalgam of consequence and culpability. (It is 26. I am grateful to my learned friend) The defence say that that seems to be, when one looks at other aspects of matters which come within the criminal calendar, that that seems to be a not unreasonable way of their Lordships to assess it.

Consequence and culpability ought to be considered by your Lordship in assessing the seriousness of the matters here. Although – and it is referred to elsewhere – consequence may be to some extent a matter of chance, one sees an analogy with some other aspects of the criminal calendar and I have particularly cases causing death by dangerous driving in mind, where equally the fact of the death can be a matter of chance but it is a serious aggravating feature. In the case that I have just referred to in Transco the consequence was the death of one man, the unfortunate Mr Brady, and not inconsequential injury to others. So whilst my learned friend seeks to some extent to differentiate Transco from the instant case, it is right that consequence is a factor within the question of seriousness.

As to culpability, that is to say the other constituent part of seriousness, that clearly must include the question of risk and I say that because it is clear from the case of Jarvis, which your Lordship has already been taken to in tab 5 of the prosecution bundle, that the most important factor within the learned trial judge's assessment of the factors in sentencing appears to have been the element of risk involved and even though on appeal their Lordships felt that the learned judge had estimated those risks a little too high – though it is right that an actual derailment of a train had occurred of course – they reduced the sentence on appeal. But what that makes clear, in my respectful submission, is that risk is an element of culpability as well as consequence, which must be relevant to the question of seriousness. In this case, although there were failings in relation to the sampling and numerator – and I will come to those, if I may in a moment – it is right that so far as consequence is concerned there is nothing which the prosecution can point to which has been a relevant consequence of this incident.

As to risk, which clearly forms part of the other constituent element of [inaudible] ability, there is no risk of criticality. There was in reality no risk of contamination and no risk of environmental impact. So that is a very significant part and a very significant area when the question of the overall seriousness which is relevant to the appropriate level of fine that your Lordship ultimately sets, where the matters that can be put forward are very much in favour of this defendant. I would ask your Lordship to have regard to those in coming to the ultimate conclusion that your Lordship does.

Can I say something about the numerator and the sampling. It is right that there have been difficulties with the numerator over a lengthy period. It is not right that those difficulties had gone unnoticed or that they had not been acted upon in any way. It is clear that there had been numerous attempts to resolve whatever the fault was with the numerator which caused it to give regular inaccurate readings. It must follow from the circumstances which ultimately pertained that those efforts to repair the numerator and resolve the problem had failed. It would -

MR JUSTICE OPENSHAW: No-one had previously tapped it? It was not -

MR MONAGHAN: Well, I do not think it is that simple, with respect, my Lord. It was tap – the bobbin had become stuck. It was also linked to the adjustment of the air flow going through. The air flow going through had been set to a lower level. It is not possible to discern from this distance in time why that was done or who it was done by. It would seem that some adjustment at some stage had led to the conclusion that the numerator was now functioning properly. The reality is that that adjustment would seem to have prevented the numerator from changing its reading and showing the high reading. When the adjustment of the air flow was put back to what it should have been, the bobbin was stuck and when tapped it went to its correct level. That may be a little bit of a red herring because it really seems to have been the adjustment of the air flow which led to a particular reading being given, but not thereafter altering because of the reduction in the air flow so that looking at it – and if I have understood correctly, even tapping it with that air flow adjusted down, as it should not have been, would not have caused the correct reading to become apparent. Why that was done, as I say, is impossible to see at this distance. What does appear to have been the case is thereafter, because of the way it had been adjusted, that pneumercator carried on showing a steady but inaccurate reading. That was certainly one of the factors which influenced the conclusion that the discrepancy must be in the figures.

There had been difficulties on occasion with the calculation of the shipper receiver difference. It is, as my learned friend has alluded to, a complex calculation which takes a very considerable length of time, some six weeks even with the benefit of computers. Mistakes, it seems, are not wholly unknown and have been detected in the past by re-checking. It seems to have been the view held by some that the figures that were obtained from the shipper receiver difference were likely to have been caused by accounting error. That seems to have been behind the decision to leave the plant running over the weekend. And I am talking here, of course, about that very short period of time when figures became clearly apparent and action was in fact taken over a short period. That chronology seems to be this; 13 April, figures obtained showing the earlier campaign shipper receiver difference of 3.9 per cent; 14 April, the discovery of the sample results from November 2004 and February 2005 which seemed to show a discrepancy in the levels of uranium that were such that they were not consistent with the sumps being in their normal state. That in turn – and I believe this is referred to within the defence case statement – is not a clear cut and simple issue because there had previously been difficulties caused by contamination at the laboratory end with the result that there had been samples which had been believed to have been contaminated, which would indicate some sort of leak. No leak was found, subsequent samples were normal and it was ascertained by a process of elimination that there had been some contamination at the laboratory. None the less we have the 13th the first figures, 14th the sample results, 15h the figures from the later campaign showing a 10 per cent shipper receiver difference and on the same day a meeting where the decision was made that cameras should go in and see what was going on. So we are then talking about three days there. The cameras actually went in on the 18h. By the 18h – and this is also part of my learned friend's opening – further calculations had concluded that the shipper receiver difference was accurate. That in effect, in itself, would have been sufficient to illustrate the fact that there was a problem, that that problem did not lie in the accounting and it therefore lay within the fuel cell itself. It is fair to say that this incident could not have gone on beyond 18 April because at that stage it was not possible for there to be any conclusion other than that there was problem within the feed clarification cell.

It follows that, although there had been difficulties with the gauge in particular which had led to the incorrect and erroneous belief that things were normal and supported the view that the difficulty must be in the [inaudible] once the figures came in for the shipper receiver difference – and these are things in April going back to before Christmas. This is the first opportunity that there is to look at them. We are talking five days for consideration, reaction, re-calculation and for the cameras to go in [inaudible].

My learned friend's observation is somewhat surprising that it went on over the weekend. In retrospect, it did but not a helpful decision perhaps. But that must be seen in the context of the risk, the consequences, the fact that when the cameras were put into the feed clarification cell the liquor was roughly some 10 centimetres in depth. That is 10 centimetres up the 150 centimetre metal cladding [inaudible]. And steps immediately began to deal with the problem; the washing, the ejection and the shutting down of the THORP reprocessing plant.

So when your Lordship comes in due course to assess the overall seriousness, the primary difficulty here comes from, it seems, one of certainly well over a thousand instruments to develop the fault that had been the subject of attempted repairs. Therefore – and I am sorry that I have to say this again, but for reasons which are not clear had been dealt with in a way that made it look as though repair had been successful when it in fact had not, but which led to a belief that the level was appropriate. And indeed led to that belief being maintained until the shipper receiver difference was received, calculated, re-checked because there were understandable concerns that it may not be the shipper receiver difference, especially given that the faulty numerator was still giving a normal reading, and then stopped. It is quite right that that machinery, that one out of 12 or 13 hundred gauges, should have been more carefully dealt with, that there should have been better communication to allow that difficulty with the numerator to have been tied up with the samples, at least one of which seems to have been overlooked and a number of which seem to have been the subject of nil samples. The nil sampling difficulty, as referred to within the defence case statement, the process is, I think one of the witnesses said, rather crude. It sometimes means that what captures the sample is not in exactly the right spot at the right time. It does not mean that nobody has tried to do it. It does not mean that the implement has not gone to the right place and tried to pass on that which should have been received. There is a difficulty here with communication, I think, which again is one of the matters has been referred to in terms of the steps that have been taken by the defendant company since this incident. But if we fall back again, it seems, on to the fact that we have got a nil reading but the other safety measures, including the gauges, are indicating that it is in fact a sump with an appropriate level within it, when my learned friend makes the point that the operator instructions - and there are several, although the first one, I think, came up at page 593 – unexpected rise in level requires a sample to be taken and the difficulty is because this numerator seems to have been for some period in its position where having been adjusted in this attempt to repair and it did nothing of the sort, it was showing a normal reading, there was no unexpected rise detected and therefore no trigger for that specific, rather than the periodic sump sample to be taken. I have already explained, by reference to the matters in the defence statement, how it is that the steps taken since have been put in place with a view to preventing that from happening in the future.

In summary, when one looks at the question of seriousness, my submission is that first of all it would be a mistake to equate length of time, length of breach directly with seriousness of breach without anything further. It may be that a short breach, a breach which lasted a very short time, is serious and a breach that lasts a long time is serious. A breach of whatever licence or requirement there is upon an undertaking, an employer, etc. is not of necessity serious because it lasts a long time. These are matters which unfortunately, because of the relatively minor nature of the equipment – and I say that in that way because it is one of many, it is a small item, it is not as simple as a motor car fuel pump perhaps, but it is not the most complicated machinery in the THORP reprocessing plant either. That perhaps is equally one reason why it may have been dealt with in the way that it was, but one must put that into the context of the risk and consequences that flow there from, which I have dealt with at length.

It is the defence submission that when one looks at those questions of risk, culpability and consequence and the overall circumstances of this incident, which are set out in length in the defence case statement to which I have referred to at some length, the seriousness is not as high as perhaps the Crown's case would initially suggest, particularly given the lack of consequences or indeed risk. The defence would say that this is a matter which certainly ought to be put below the Transco case which is in the defence bundle in terms of its seriousness and in terms of its place in the hierarchy of things. There are no reported cases that my learned friend or I have been able to find which are directly on the point. This is certainly not a rail disaster case. It is not, unlike any of the sentencing authorities that your Lordship has, a case where injury has been caused or there has been a risk of injury or a cause of huge environmental impact. The defence submission would be that because of the absence of both risk and consequence it falls somewhat below.

I am sorry, my Lord, I seem to have gone slightly longer than I had planned. I do not really have very much more. I am quite happy to conclude now or later as your Lordship pleases.

MR JUSTICE OPENSHAW: I think if you conclude now it would be very convenient.

MR MONAGHAN: I am grateful to your Lordship of course. There are some minor matters which might be worthy of at least allusion. There is some criticism of the defendant for not responding to some banging noises that were heard on 6 January 2005. When that is put into its proper context there are all sorts of noises which occur, sometimes expected, sometimes unexpectedly, in any plant. It is paragraph 46 of the defence document. There are often noises caused by expansion and contraction of metal, heat, cold and various mechanical processes.

MR MATTHEWS: My Lord, can I say it is certainly not meant to be a criticism, just relating the fact.

MR MONAGHAN: Well, lest it be thought that it is a criticism -

MR JUSTICE OPENSHAW: Well, you can forget about it.

MR MONAGHAN: I shall. The 1998 incident led to some recommendations being made. There is perhaps a distinction which can be made and I have sought at paragraph 50 and 51 of the defence document -

MR JUSTICE OPENSHAW: The difference between disregarding warnings and failing to heed advice.

MR MONAGHAN: Well, in effect that is certainly the point to some extent, my Lord, yes. There were different matters that had gone on in 1998. It is unfortunate that there has been very little written record of what was done. That is not helpful, nor is it something that will happen again. There is an indication that a significant number of the recommendations were dealt with but some, particularly relating to cell sump analysis reports, do not seem to have been implemented throughout and that is something that the defence concede within the document that has been provided. But there was not perhaps inadequate monitoring so much as the discovery that nil samples had been taken and nothing done about it. The one exception – and as I say in the document too few attempts at re-sampling, with the one exception of the single sample that seems to have gone astray after being sent as a fax. None the less, as I say, that seems to have been against the background of other safety measures, in particular the numerator reading normal. The submission that the defence would make in those circumstances is that that is not properly a case to be seen as a failure to heed warnings. That ultimately is a matter for your Lordship of course.

In short, the seriousness of this matter, the defence would say, comes from three factors; the consequences, the element of risk within culpability which is clearly described in Jarvis and the nature of the breaches themselves. The first two I have dealt with at some length and I simply renew my submissions that they are at the very lowest level, no risk and no consequences of contamination or of environmental impact. The nature of the incidents themselves in reality amount to one gauge which should have been repaired but was dealt with in a way that made it look as though it had been repaired when it had not and sadly, as I say, I have no explanation for that, and a lack of re-sampling when the nil volume samples that seemed to make up the vast majority of the samples over a period had been brought out of the sampling process. That must be seen against the fact that once what acted as a fall back position, the information from the shipper receiver difference, was brought to the knowledge of the defendant, we have a period of three days inclusive, the Wednesday, the Thursday and the Friday, between the receipt of the first set of results and the decision that at least that part of the process has to stop so the cameras can go in and investigate and in fact a five day period before that actually happened and THORP re-processing plant was then shut down. The defence would say, when everything is taken as a whole that those matters which form the actual failings are not of the most serious, that the risk is nil, the consequences were nil and therefore this is a matter which falls into place in the hierarchy certainly below the matters which have been presented to your Lordship as sentencing authorities.

I do not seek to say anything about the finances of the defendant company to your Lordship. I think there was reference also in the Transco case to it being sufficient in some cases for a large public company simply to indicate that it was capable of paying the fine and I do not seek to deal with the question of finances any further.

I do not know if I can usefully assist your Lordship any further. Would your Lordship excuse my back just for one moment to ensure that there is nothing that those instructing me [inaudible] -

MR JUSTICE OPENSHAW: Surely.

MR MONAGHAN: [Sotto voce conversation] I am pleased to say that there is not. Thank you, my Lord.

MR JUSTICE OPENSHAW: There is nothing you want to -

MR MONAGHAN: No, thank you, my Lord.

MR JUSTICE OPENSHAW: No? Thank you both very much indeed. I will pass sentence at two o'clock.

[Luncheon adjournment]

SENTENCE

MR JUSTICE OPENSHAW: The defendant British Nuclear Group Sellafield PLC has been committed to this court for sentence by Whitehaven Magistrates Court on 8 June of this year, following its pleas of guilty to three offences contrary to Section 4.6 of Nuclear Installations Act 1965 as amended. They are accordingly liable for the penalties provided by Section 33 of the Health and Safety at Work Act 1974 which permits an unlimited fine.

The prosecution have opened this case from a carefully prepared statement of case which was circulated in advance. The defence have also put their mitigation into writing. It would serve no useful purpose for me just to repeat what they have already said. I shall confine myself therefore to identifying what seemed to me to be the relevant considerations to sentence.

I have read each of the authorities put before me. The general principles of sentencing in Health and Safety cases are most helpfully set out in the judgment of the Court of Appeal Criminal Division in the well known case of F Howe and Son Engineering Limited [1999] 2 Cr.App.R. [Sentencing[?]] at page 37. These principles were recently re-stated by MacKay, J. in Balfour Beatty Rail Infrastructure Services Limited in terms specifically approved by the Lord Chief Justice, giving judgment on the appeal in that case, reported at neutral citation[?] [2006] EWCA Crim. 1586.

There has been in recent years an increasing recognition of the seriousness of health and safety offences, however the infinite variety of circumstances makes it impossible to lay down any practical term or scale of penalties. Each case depends on its own circumstances, which I now seek to identify.

By reason of its huge scale, its nature and its complexity Sellafield on the West Cumbrian coast is the most significant and potentially the most hazardous nuclear site in this country. Its principle business is now re-processing spent nuclear fuel from home and abroad. Since 1 April 2005 the site has been managed and operated by the defendants.

Having regard to the unique dangers presented by nuclear material, the storage processing and disposal of nuclear waste is strictly regulated by the Health and Safety Executive, who are required by Section 4 of the Nuclear Installations Act to impose such conditions on the nuclear site licence as they deem necessary to secure the public's safety. Compliance with the terms of the licence is therefore of the greatest importance.

This case concerns the processes carried out within the THORP unit at Sellafield, THORP being an acronym for Thermal Oxide Re-Processing Plant. The operation of the plant has already been outlined by Mr Matthews and, as I have said, it is unnecessary for me to repeat what he has already said. I will, however, give a summary. It is considerably over-simplified but it explains the principle points of the process.

The used nuclear fuel is dissolved in concentrated nitric acid producing dissolver product liquor which is itself highly radio-active. The liquor, as I shall call it, is then variously treated and processed in a variety of different containers. One such container is the so-called accountancy tank in the fuel clarification cell. This was the primary containment which was designed and built on a massive scale to prevent any escape of radio-active material. There was a secondary containment in that the floors and walls were covered in thick five grade stainless steel cladding to a height of one and a half metres because it tended to hold and contain any leaks or spills. There was a gulley running round the floor draining into a sump. This was part filled with nitric acid. There was a device for measuring the amount of liquid in the sump called a numerator which had attached a sump alarm which was intended to alert the defendants to any increase of depth of liquids or liquor in the sump from which the existence of leaks or spillages could be inferred.

The stainless steel cladding was intended as a failsafe device. It was not intended for long term storage of the liquor. Although stainless steel is entirely resistant to acid and the specification and workmanship was to the highest standards attainable by technology, there is, as the prosecution have pointed out, always the theoretical potential for weakness at the welds. Furthermore, the sump itself has no proper means for control of temperature, nor is it possible to move liquids around when in the sump without this movement or agitation, as it is called. Any liquor present might crystallize and would then be more difficult to remove. Nor is it easy to remove so much liquor once it has entered the sump. Indeed it took some months to do so in this case. Furthermore, and perhaps most importantly, there is no absolutely secure secondary containment of the sump itself. It was surrounded by heavy duty concrete of quite extraordinary density and although that was not technically porous it would contain any escaped liquor for a long time, but there was, as I have put it, no absolutely secure secondary containment of the sump.

There were a number of security checks to ensure that all was well. All customers, called shippers, supplying nuclear fuel for reprocessing are required by contract to provide a detailed estimate of the amount of uranium which they expect to be recovered from the fuel which they have supplied. After each process the amount of uranium actually recovered is measured and the difference, the so-called shipper receiver difference or SRD, between what has been recovered and what should have been recovered is calculated. It is a highly complex exercise in advanced mathematics and even with powerful computers it takes many weeks to complete. Using this method an anomaly was spotted in the shipper receiver difference on 13 or 14 April 2005.

The defendants then initiated an investigation. A meeting of senior THORP management was held the next day, which was a Friday. Production at the plant continued over the weekend. It should have been shut down at once but in the scale of an eight month failure to detect the leak a couple of days seems to me to have made no practical difference to what happened. On the Monday a camera was inserted. Over the course of the next few days various images were taken and on 20 April a leak was found in a pipe feeding from the top of the accountancy tank. There was plainly visible in the photographs extensive corrosion of the mild steel work which supported the tank and extensive pooling of liquor on the floor within the secondary containment of the stainless steel cladding. That same day, as was their duty, the defendants informed the Health and Safety Executive of what had happened.

Investigations by the defendants and by the Nuclear Installations Inspectorate of the Health and Safety Executive showed that the leak had started as long ago as 28 August 2004 and had remained undetected for at least eight months. During that time fully 83,000 litres of the radio-active liquor had spilled, which liquor contained 22,000 kilograms of nuclear fuel, mostly uranium, with 160 kilograms of plutonium. Considered in isolation these statistics would be shocking indeed but I accept that they should be seen in the context of all the other relevant circumstances of the case.

The Inspectorate found a number of breaches of the licence, which are the basis of this prosecution. I will deal with each in turn later.

Again, I am conscious that my description is an over-simplification of an immensely complex process, but some summary is plainly necessary.

It was always intended that the liquor in the accountancy tanks would need, from time to time, to be stirred or agitated. The original plans provided for the tanks to be agitated only when full. When the tanks are full the movement of the liquor within the tank is slight, with the result that there is very little lateral pressure on the tank and very little lateral movement of it. It was, to all intents and purposes, held immobile but in order to overcome another quite separate and unrelated problem identified some years ago, which resulted from the risk of crystallization of the liquor if it was left unagitated, a change was made to the process by which agitation would happen regularly and not just when the tanks were full. Agitation of half tanks resulted in a more significant movement of the liquor within the tanks. This created lateral pressure which in turn created lateral movement. No change should have been made to one part of the process without a most detailed examination of the impact that such a change would have on the other parts of the process. This was not done or, if it was done, it failed properly to identify the altered loads upon the mountings of the tank. As a result, the risks to the pipe work for unforeseen whereas they were or should have been foreseeable by skilled examination. Over a long time lateral movement set up stresses in the pipe work attached to the tank. Gradually metal fatigue set in leading first to a leak and then eventually to complete rupture of the pipe work, as shown in the photographs taken on 20 April.

As a result, liquor escaped. It is self evident that no such leak should ever have taken place. This leak is a breach of Licence Condition 34 which prohibits leakage or escape of radio-active material.

Furthermore, it is obvious that the defendants should have had in place a system which could detect leaks on such a scale over these eight months. I have already explained how there was a device which measured the level of liquor or liquid in the sump. This was the numerator. Examination showed that a floating bobbin, the moving part of the numerator, was sticking in one position thereby giving a false reading. Indeed, an analysis of readings over a five year period showed wild and unaccountable fluctuations which are now obviously only explicable on the basis of a malfunction of that device over that full period. An unsuccessful attempt was made to fix it in December 2004 and possibly before also, but the attempt failed, was not renewed and the failure of that attempt was not properly recorded.

The failure of the numerator over that long period is, it seems to me, a serious matter and so it was that the rising levels in the sump went undetected. This failure is a breach of Licence Condition 27.

More than that, the numerator was often in a state of low alarm. The defendants say that there were, from various parts of the process, hundreds of such alarms. Such a system is failing properly to identify and isolate significant risks. There was, as the Nuclear Safety Directorate accurately put it, a culture of tolerating alarms, so the alarm was not effective. It did not detect or warn of particular failures which should have been apparent in this case.

There was another check which could and indeed should have detected this fault. The sump, as I have said, was part filled with concentrated nitric acid. Following the leak of the radio-active material the pure nitric acid in the sump would have been contaminated by the radio-active material. The change in the chemical and physical composition of the acid in the sump, and indeed in the radio-activity levels, should have been measured. Samples should have been taken every three months. For a variety of reasons the checks were ineffective.

Mr Matthews has carefully taken me through these cumulative failings. A routine sump sample taken on 28 August 2004 showed excess levels of uranium. As the prosecution point out, plainly the leak had already sprung by that date, which does indeed allow the commencement to be dated. The significance of this finding was not appreciated by the defendants at that time, at least it was not appreciated at a proper level of seniority.

A second sample was ordered but that could not be analysed since insufficient liquid was obtained. No-one ordered another effective sample to be taken. A further routine sample was taken in November 2004. That also detected excess uranium but no action was taken or, at any rate, the significance of the reading was not appreciated and the same goes for a routine test on 24 February 2005. I might add that during the same period a rising temperature within the sump was noticed. That now seems plainly to have been attributable to the leak but not such conclusion was drawn at the time.

These are, as I put it, cumulative failures. Various explanations have been put forward. Sometimes there is a defect in the sampling process and insufficient material for analysis was obtained or the sample was taken from the wrong place or in the mass of material provided on the operators’ computer screens the readings did not come to the attention of anyone who understood their significance. For whatever reason, the rising levels of radio-active material in the sump went unnoticed. The explanations put forward are inadequate and unsatisfactory and do not begin to excuse what amounts to a series of serious and culpable failures.

It is to me obvious that one way or another this leak of radio-active material from the fractured pipe should have been detected soon after it happened, certainly within weeks, probably within days. That it went undetected for fully eight months is a serious failing deserving of condemnation.

Those breaches of their operating instructions in relation to allowing too much fluid to gather in the sump and failing properly to monitor the levels of fluid in the sump, failing properly to take samples and failing properly to act upon such analysis as was provided are cumulative failures amounting to a breach of Licence Condition 24.

It is relevant to note that in 1998 a small leak had been detected in pipe work leading to a similar accountancy tank. At that time the company undertook a major review of safety procedures and a series of recommendations were made; to strengthen the system, recording the numerator readings, monitoring the sump levels, taking samples and ensuring that the resultant analyses were considered at a suitably senior level within the company and any relevant trend regularly monitored and reviewed so that any necessary action could be identified and taken. It is plain that although some of these recommendations were implemented others were not. If they had been the leak would have been detected much earlier. In my judgment a failure to follow safety procedures which were recommended by the company’s own safety experts is plainly a relevant factor in this case and it does go to aggravate these matters.

I ought to say something of the previous convictions of this company and of its predecessors. In the half century or so of nuclear operations at Windscale and Sellafield some breaches of statutory duty have, from time to time, resulted. Some were a long time ago. Some plainly were not serious, being dealt with at the Magistrates Court with very modest fines. It is true that there have been no previous convictions relating to the THORP plant which has been operating for 10 years and more, but there have been significant breaches of safety before, notably the two cases which led to appearances before this Crown Court in 1996 and in the year 2000. I do not think that in the light of these convictions the defendants can reasonably claim to have a good safety record so as to amount to substantial mitigation.

I turn then to such mitigation as there is. I accept, of course, that once the leak was found the defendants have done all they can to co-operate with the investigation. They have always accepted responsibility for what happened. They entered pleas of guilty at the Magistrates Court at the earliest opportunity. Furthermore, the defendants have accepted and implemented each of the 55 recommendations which the Health and Safety Executive have made in their report following this incident.

I move on to consider the consequences of these faults and failings. I accept that on any realistic basis there was no danger whatsoever of the nuclear material reaching the point of criticality. More than that, there is no evidence of escape of radio-active material from the cell, neither into the atmosphere nor into the ground. No-one was injured. No-one was exposed to any radio-active material. The liquor was held within the stainless steel cladding. The system within the feed clarification failed the secondary containment, the failsafe system worked. All this I accept.

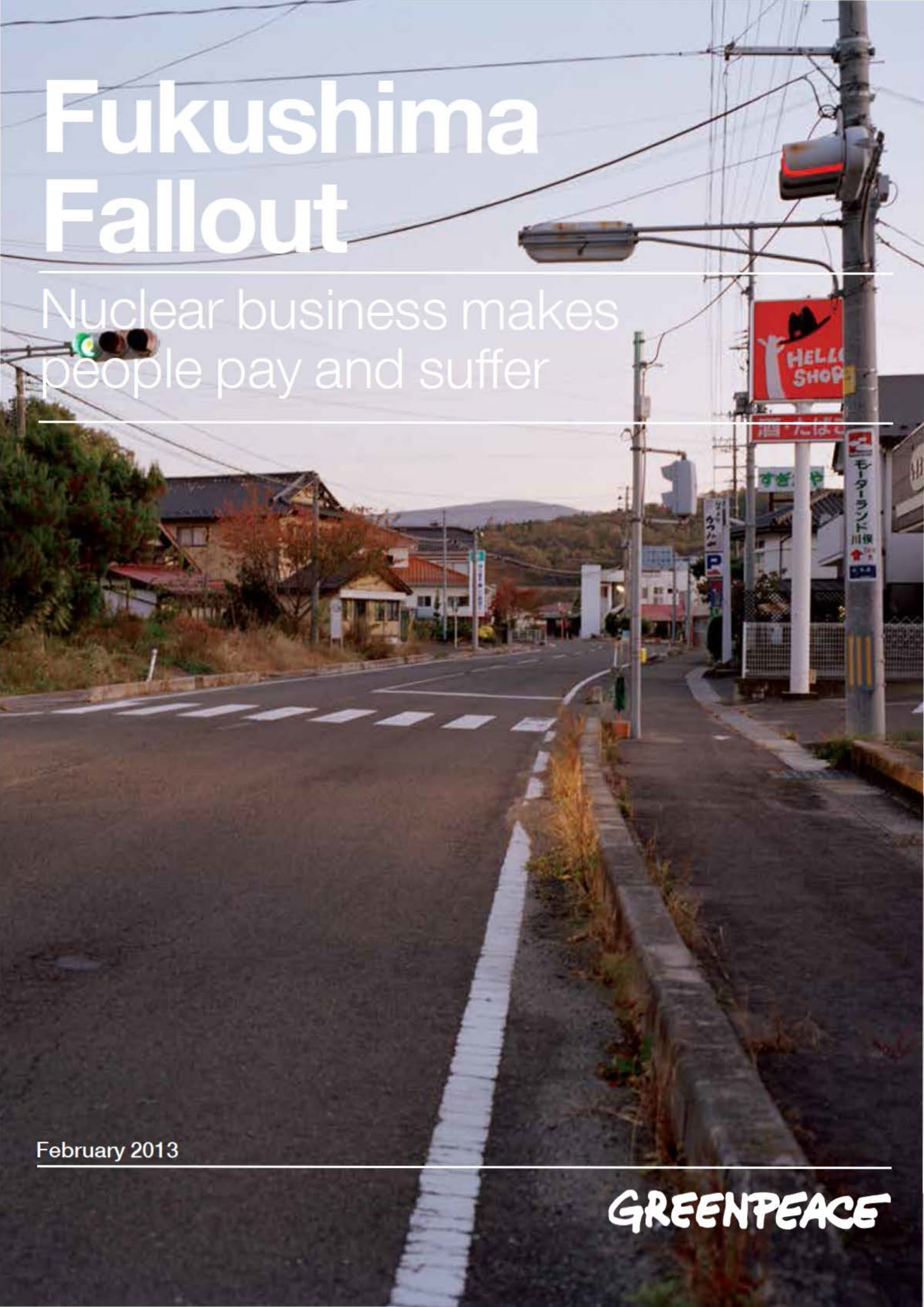
Therefore, say the defence, since no harm resulted this is not a serious case. I reject that submission. The licence provides for two systems to protect the public against accidental exposure to radiation and one of those systems failed. That failure went undetected for fully eight months. Appreciating, as I do, that seriousness is a combination of harm and culpability I accept the prosecution's essential conclusion set out at paragraph 126 of their case statement in these terms; that these were serious offences, the breaches amount to a significant departure from the relevant safety standard over a prolonged period of time and a failure to comply with important conditions concerned with safety attached to a licence to operate the most hazardous nuclear undertaking in the United Kingdom.

A fine must, of course, balance the gravity of the offending against the means of the offending company. It must mark public disquiet at the offence. It must be sufficient to ensure that health and safety issues are driven up the board room agenda and serve as an ever present reminder to all levels of management and indeed across the factory floor that health and safety issues matter and achieving public safety is a matter of paramount importance.

I turn now to identify what seems to me to be another relevant consideration discernible in the authorities. In particular in Jarvis Facilities [2005] 1 Crim.App.R. Sentencing[?] 247, the court is entitled to take a severe view of breaches of health and safety at work where the defendant is undertaking a public responsibility. In this case these defendants are entrusted with this uniquely hazardous material. They have a public duty imposed by statute to act in accordance with the terms of their licence. It is not an answer to these breaches of duty to say that their failsafe systems were effective or that no-one was in fact injured or put at risk. The fact is that the defendants did not properly discharge their public duty and as a result public confidence will be seriously damaged. As was pointed out in Milford Haven Port Authority [2000] 2 Crim.App.R. Sentencing[?], public bodies are not immune from appropriate criminal sanctions. Indeed the policy of Parliament would be frustrated if such an idea gained currency. No doubt the court should not impose a penalty which is so large as to hinder the authority from the proper performance of its public duty, but having identified that pitfall I shall endeavour to avoid it.

For all these reasons I have no doubt that the defendants are guilty of serious faults and failings and this must be marked by a significant fine. Taking into account all the matters to which I have referred, I think that after a trial a proper fine would be three quarters of a million pounds. I give credit of one third for an early plea. That will result in a fine of half a million pounds. That will be allocated between the various charges as follows; Charge 1, breach of Condition 27, there will be a fine of £300,000; Charge 2 and Charge 3, alleging respectively breaches of Conditions 34 and 24, there will be a fine of £100,000 on each, making half a million pounds in all.

There will be an order that the defendants pay the whole of the prosecution costs in the sum of £67,959.48. I think strictly I should make an order that it is payable within 28 days.



Fukushima Fallout

Nuclear business makes people pay and suffer

February 2013

GREENPEACE

Contents

Executive summary 4

Chapter 1: 10
Fukushima two years later: Lives still in limbo
by **Dr David McNeill**

Chapter 2: 22
Summary and analysis of international nuclear liability
by **Antony Froggatt**

Chapter 3: 38
The nuclear power plant supply chain
by **Professor Stephen Thomas**

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Cover image: Empty roads run through the southeastern part of Kawamata, as most residents were evacuated due to radioactive contamination.© Robert Knoth / Greenpeace

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Image: Kindergarten toys, waiting for Greenpeace to carry out radiation level testing.

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Governments have created a system that protects the benefits of companies while those who suffer from nuclear disasters end up paying the costs.

The nuclear industry evades responsibility for its failures.

Image: Aerial view of the Fukushima Daiichi nuclear plant following the 2011 disaster.

Executive summary

From the beginning of the use of nuclear power to produce electricity 60 years ago, the nuclear industry has been protected from paying the full costs of its failures. Governments have created a system that protects the profits of companies while those who suffer from nuclear disasters end up paying the costs.

The disaster at the Fukushima Daiichi nuclear power plant in March 2011 proves again that industry profits and people pay. Almost two years after the release of massive amounts of radiation from the Fukushima nuclear disaster, hundreds of thousands of people are still exposed to the long-term radioactive contamination caused by the accident. The daily lives of victims are disrupted. They have lost their homes, their jobs, their businesses, their farms, their communities, and a way of life they enjoyed.

They are still unable to get fair and timely compensation. Yet at the same time, the nuclear industry continues to evade its responsibilities for the disaster. It is business as usual: nuclear companies are still operating as always by creating nuclear risks.

How is it possible that, apart from the now nationalised Fukushima operator TEPCO, the nuclear industry is not paying for the multibillions in damages of Fukushima? How is it possible that companies, such as GE and Hitachi, that got large contracts by building, supplying and servicing the Fukushima nuclear power plant, can simply continue their business as if nothing happened?

It has become painfully clear that systemic flaws in the nuclear sector make the suffering of victims worse. Many of them survive in improvised conditions, unable to return home or to rebuild their lives elsewhere.

Why does this happen? The nuclear industry and governments have designed a nuclear liability system that protects the industry, and forces people to pick up the bill for its mistakes and disasters. To safeguard the public from nuclear risks, the system needs to be fundamentally reformed to hold the entire nuclear industry fully accountable for its actions and failures.

In February 2012, Greenpeace released *Lessons from Fukushima*, a report that uncovered the key causes of the Fukushima accident, which lie in institutional failures of governments, regulators, and the nuclear industry. These included: failure to acknowledge nuclear risks, failure to enforce appropriate nuclear safety standards, failure to protect the public in an emergency situation, and failure to ensure appropriate compensation for the victims.

This new Greenpeace report demonstrates how **the nuclear sector evades responsibility for its failures**. The nuclear industry is unlike any other industry: it is not required to fully compensate its victims for the effects of its large, long-lasting, and trans-boundary disasters.

In this report, the current status of compensation for victims of the Fukushima disaster is analysed as an example of the serious problems due to lack of accountability for nuclear accidents. The report also looks into the role of nuclear suppliers in the failure of the Fukushima reactors.

In addition, this report addresses two main protections for the industry:

- Liability conventions and national laws limit the total amount of compensation available and protect nuclear suppliers, the companies that profit from the construction and operation of reactors, from any liability. This caps the funds available for victims at a fraction of real costs and removes incentives for supplier companies to take measures to reduce nuclear risks.
- The complexity of and multiple layers in the nuclear supply chain exacerbate the lack of accountability for nuclear suppliers. Even though hundreds of different suppliers are providing components and services that are critical for reactor safety, these companies cannot be held accountable in case of problems.

Fukushima two years later – people left in limbo

Chapter 1 of this report details the **struggle of nuclear victims for fair compensation**. Author Dr David McNeil, (Japan correspondent and co-author of *Strong in the Rain: Surviving Japan's Earthquake, Tsunami and Fukushima Nuclear Disaster*) evaluates the ongoing human consequences of the Fukushima accident. Victims and witnesses tell stories about the multiple problems with the compensation process. As Mrs Kameya (68) states: "People think we will get a lot of money when something like this happens but they're wrong."

In the wake of the disaster, the 160,000 involuntary and tens of thousands of voluntary evacuees fled from the radioactively contaminated zone. For them, starting a new life seems almost impossible and the compensation process is complicating, not easing people's lives.

People are left in limbo, stuck between past and future. The problems with the compensation process are manifold: the processing of claims is delayed, and the monthly payments are not enough to ensure people a living, let alone enough to set up a new life. Not everyone is eligible for compensation, and the lucky ones only get a fraction of the value of their lost homes. There has not yet been a single payment that fully compensates anyone for the loss of a house and property.

The compensation scheme is set up in a way that compensation is first paid with government-backed financing. But TEPCO's nationalisation in June 2012 makes it clear that eventually ordinary Japanese people will pay the bill for Fukushima. The utility's demand on the state-backed Nuclear Damage Liability Facilitation Fund for compensation payments mounted to ¥3.24 trillion ($36.5bn US dollars) by December 2012. At the same time, the Japanese government injected ¥1tn (about $12.5bn at 2012 exchange rates) into the utility in May 2012 to save it from bankruptcy, which totalled an estimated ¥3.5tn in public money to the utility since the Fukushima disaster began.

Nuclear suppliers escape responsibility

Chapter 1 also investigates the **role of the nuclear supplier companies** in the Fukushima reactors. The Fukushima Daiichi nuclear power plant consisted of six reactors, with units 1 to 5 based on the flawed Mark I design by the US company General Electric (GE). GE supplied the reactors for units 1, 2, and 6, and two Japanese companies supplied the others — Toshiba provided units 3 and 5, and Hitachi unit 4.

All suppliers that were involved in the Fukushima nuclear power plants, including GE, Hitachi and Toshiba, are currently exempted from responsibility for the March 11 disaster. In contrast, many are even **profiting from the disaster**. GE, Hitachi and Toshiba, along with many other suppliers, are currently involved in the clean up, which includes decommissioning the Fukushima reactors and decontamination of radioactively contaminated areas.

A report by the independent investigation commission of the National Diet of Japan says that reactor Unit 1 of the Fukushima power plant was purchased by TEPCO under a "turnkey" contract for construction "that placed all responsibility" on GE. Fukushima Unit 1 was the first Mark I reactor ever built, and experienced numerous difficulties. The seismic design criteria in Japan were stricter than for the original design, but incorporation of the Japanese specifications was problematic and ad hoc reinforcements were made during construction.

In the 1970s, GE engineer Dale G Bridenbaugh publicly questioned whether GE's Mark I reactor would stand up to a loss-of-coolant accident. The Diet report adds that the Mark I containment vessels at Fukushima were reinforced in the 1980s, "but the reinforcement did not cover severe accidents of this scale." The report concludes that during the Fukushima accident, the pressure inside the containment vessels substantially exceeded their designed capacity, up to almost twice the capacity in the case of Unit 1.

Former GE employees recall how TEPCO elected to overrule its own engineers and follow GE's original construction design and put the plant's emergency diesel generators and batteries in the basement of the turbine buildings, with devastating consequences during the accident. Former Hitachi engineer turned whistleblower Mitsuhiko Tanaka helped build the reactor pressure vessel for Fukushima reactor Unit 4. In the final stages of construction, the vessel's integrity was dangerously compromised, legally obliging Hitachi to scrap it. Facing bankruptcy, the company covered up the defect and the vessel was installed at Fukushima.

In September 1989, the US Nuclear Regulatory Commission (NRC) encouraged owners of Mark I reactors to install hardened vents to prevent catastrophic failure of the containment in case of an accident. These vents would enable controlled reduction of pressure. During the Fukushima accident, the hardened vents proved ineffective, and the absence of filters exacerbated the radioactive releases.

Nuclear liability conventions protect the industry, not the people

The nuclear industry is granted **unparalleled and unfair privileges**. In contrast to many other risk-involving industries, nuclear liability conventions have been established with the intent to protect the nuclear industry – this includes operators, suppliers as well as investors. The current agreements do not ensure that victims receive full and timely compensation in the event of a major accident.

In Chapter 2, Antony Froggatt (independent consultant, Senior Research Fellow at Chatham House, UK) gives an overview of the existing international nuclear liability conventions, and maps the impact of these problematic rules, such as capping total compensation, excluding suppliers from accountability, and allowing operators not to have sufficient financial security to cover the damages.

The core problems of nuclear liability are:

- The objectives of international liability conventions are competing, if not mutually exclusive. First, they limit the extent of possible compensation claims, creating an economic environment that allowed the nascent nuclear industry to flourish. Secondly, they are supposed to grant victims access to full and timely compensation in the event of an accident.
- Only the operator of a nuclear power plant can be held responsible for paying for damages. Nuclear suppliers, who build and service plants, do not have to pay anything.
- The total amount of compensation available is limited, but these limits are well below the true cost of a nuclear accident.
- Definitions of nuclear damage do not cover all damages caused by a nuclear disaster.
- Potential victims in other countries can only sue for compensation in the country where the nuclear accident happened, **not** in their own courts.

The experiences of the Fukushima disaster show that even the Japanese liability regime is highly inadequate and unjust, despite the legal requirement of unlimited liability for an operator. The financial extent of the damage is generally far beyond what an operator can pay. Since the Japanese law excludes supplier accountability, the magnitude of funds provided by the nuclear industry is restricted to a very small fraction of the costs of Fukushima.

It is clear that holding only the operator responsible for a nuclear accident: "minimises the burden upon the nuclear industry as a whole, as the various persons who contribute to the operation of a nuclear installation, such as suppliers and carriers, do not require insurance coverage additional to that held by the operator"[1], as was pointed out by OECD's Nuclear Energy Agency in 1993. This needs to be changed; **people must be the first priority**, not the benefits of the nuclear industry.

Making nuclear suppliers pay for their mistakes would not only benefit the potential victims by making more funds available, but would also increase accountability and transparency and create incentives for the companies across the nuclear supply chain to prevent failures.

There are only a few exceptions to the protection of the nuclear supplier industry. Recognising the fundamental unfairness, India adopted a nuclear law that allows nuclear operators to seek recourse in the event of "wilful act or gross negligence on the part of the supplier". Also the existing laws in both Russia and South Korea allow operators to recover damages from suppliers in the event of negligence.

Chernobyl and Fukushima are examples of how costly nuclear accidents can be, with estimated damages in the order of several hundreds of billions of euros. These figures deeply contrast with what the industry is currently required to pay (between €0.3-1.5bn).

To create a system that is fairer and puts people ahead of business, the following must happen:

- No limits to the total amount of compensation.
- Hold the whole nuclear industry, including suppliers, accountable.
- Ensure adequate financial coverage by companies. A major nuclear accident would almost certainly bankrupt any private utility.
- Allow people to recover all damages caused by a nuclear disaster.
- Increase transparency into costs and liability insurances.

Nuclear supply chain lacks accountability and transparency

In Chapter 3, Professor Stephen Thomas (professor at the University of Greenwich Business School, UK, working in the area of energy policy) explores the involvement of suppliers throughout the lifetime of a nuclear reactor, and their responsibilities in terms of nuclear risks. Risks of nuclear accidents are not only caused by the reactor operation, but also by design choices, construction quality, and maintenance, which are of critical importance.

The cause of a significant accident at a nuclear power plant is seldom clear cut, and may involve a combination of design, construction, operation, and maintenance errors. By comparison, it is usually relatively easy to apportion primary responsibility for, say a car or airplane accident, to design construction, operator or maintenance error.

A nuclear power plant is unique in terms of complexity, safety requirements, plant lifetime, costs and on-site construction work.

The supply chain for a nuclear power plant is very complex and in many cases non-transparent. The owner/operator of a plant carries final responsibility, but design, construction and maintenance include many different parties through many layers of contracting and subcontracting. Different suppliers are responsible for implementing elements critical for a plant's safety, but currently these suppliers ultimately cannot be held accountable in case of an accident.

This lack of accountability is further enabled by a lack of transparency regarding contracts and company relationships. This situation creates major challenges in ensuring sufficient quality control on critical safety features. It is often unclear (at least to the outside world) who carries the final responsibility in case problems were to occur with certain equipment or designs.

Many of those further down the supply chain will exit the business long before the end of the life of the plant, as was the case with the Dutch supplier of the flawed pressure vessels for the Belgian Tihange 2 and Doel 3 plants. In the case of the Fukushima disaster, even though it is known that certain design features caused serious problems during the course of the accident, those responsible for the design and engineering are not being held accountable.

Lessons to be learned

We learned from Fukushima that nuclear power can never be safe. The nuclear industry, largely protected from the financial liability for the Fukushima accident, continues to do business, while the Fukushima victims still lack proper compensation and support. Would things be different if the next big nuclear disaster happened in your country? You would likely be facing the very same problems.

We have to phase out dangerous nuclear power entirely, and do so as soon as possible. Yet, if there is another major nuclear accident, people could be given better protection if we hold the nuclear industry fully accountable and liable. We need to learn the lessons from Fukushima, and change the system in order to **make all companies in the nuclear industry responsible for the risks they create**.

More importantly, we have to use this critical moment to finally switch to a safe and affordable supply of electricity — renewable energy. Mature, robust and affordable renewable energy technologies are available and up to the task of replacing hazardous nuclear reactors. Over the last five years, 22 times more new power generating capacity based on wind and solar was built (281,000MW) compared to nuclear (11,750 MW).[2] Wind and solar plants alone, built in just one single year of 2012, are capable of generating as much electricity as 20 large nuclear reactors. This is where the opportunity stands for a future free of nuclear hazards.

1 NEA (1993), "NEA Issue Brief: An analysis of principal ipal nuclear issues International nuclear third party liability, No. 4 - 1st revision", Nuclear Energy Agency November 1993, accessed November 2012 http //www.oecd-nea org/brief/brief-04-1 html

2 IAEA/PRIS (http://pris.iaea org/public); Global Wind Energy Outlook 2012, GWEA (http //www.gwec.net/wp-content/uploads/2012/11/GWEO_2012_lowRes.pdf); Global Market Outlook for Photovoltaics until 2016, EPIA (http://www epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiapublications/Global-Market-Outlook-2016.pdf&t=1359035167&hash=390c31d6e803e7c10b066e9ef72271831cf54c0d)

Image: Ms Satsuki keda and her sons were evacuated from their farm in Iitate, 40km northwest of the Fukushima nuclear plant. The farm had been run by the family for nine generations.

The Fukushima nuclear disaster is a story about how the system fails to support people.

#1

Fukushima two years later: Lives still in limbo

by Dr David McNeill

Dr David McNeill is the Japan correspondent for *The Chronicle of Higher Education* and writes for *The Independent* and *Irish Times* newspapers. He is the co-author of *Strong in the Rain: Surviving Japan's Earthquake, Tsunami and Fukushima Nuclear Disaster*.

1.1 Introduction

The story about liability following the Fukushima nuclear disaster is really a story about people. It's a story about how the system, that is supposed to help people after such a disaster, fails to support them. It's a story about how bureaucracies — government and company — play by rules that at minimum are terribly frustrating for people, and at their worst are an impediment to getting help.

Nearly two years after the disaster, people are still desperate for the help they deserve. The victims are ignored, left to fend for themselves, and waiting and waiting for compensation and fair treatment. Some have resigned to getting little. Others are fighting the system. This story of the flaws in the system that is supposed to help people is likely to be repeated with any nuclear disaster anywhere in the world.

1.2 Stuck between past and future

Yukiko Kameya (68) was one of the 7,400 people living in Futaba town, Fukushima Prefecture, when the 11 March 2011 earthquake and tsunami struck, crippling the nearby Fukushima Daiichi nuclear plant.

"There was no information afterwards at all," she says, recalling how public safety officials told her the following freezing cold morning that "it was possible" that some radiation has escaped.

She fled with her husband, first to Namie, about seven kilometres away, then to the Tokyo suburbs. Almost two years later, she is still there. Like 160,000 nuclear refugees ordered to evacuate and tens of thousands of people who voluntarily left Fukushima Prefecture, she lives in temporary housing and has yet to be fully compensated for the loss of her old life.[1]

Four months after being forced to abandon her home and all she owned, in July 2011, the owner and operator of the Fukushima reactors, Tokyo Electric Power (TEPCO), sent the first of its payments. A total of ¥1.6m (about $18,000 US dollars) was deposited in Kameya's account[2], including ¥1m in "temporary" compensation. When she called TEPCO, she was told that that money was an "advance" and would have to be reimbursed from future payments. "It wasn't compensation," she says. "That's when I started to fight them." While those advance payments are common practice as the total damage is being determined, this terminology continues to confuse victims of the catastrophe.

Mrs. Kameya and her husband subsequently received ¥100,000 a month ($ 1,130) for "mental distress" for the first nine months (March – November 2011), plus living expenses, after submitting a complex application form. The original "advance" was subtracted from that payment. Late in 2011, she made another claim, patiently filing hundreds of receipts for petrol, taxi fares, clothes and even household utensils.

Last February, fed up with the compensation process, she hired a lawyer and demanded compensation of ¥350,000 a month ($4,000) for daily expenses. She says many of her Futaba neighbours are doing the same. "I accepted their way twice but I can't do that anymore." TEPCO has told her that they "cannot" pay ¥350,000.[3]

Like most of the refugees, she has calculated her own one-off round figure to reboot her life and cut all ties to TEPCO, the government and the endless paperwork: ¥20m (about $225,000). "It doesn't matter what the government says, we'll never go home. Most of us accept that." If awarded the money, Mrs. Kameya says she would move to Saitama (in Tokyo's northern suburbs), buy a small house and live out the rest of her life. But like many other victims, she is doubtful that the current compensation scheme will help her to set up a new life.

Other nuclear refugees are also losing hope. Hitoshi Sega ran a small restaurant near the power plant and now works as a public school cook in Iwaki city, about 40km south of the stricken plant. He has yet to be compensated for his lost business, since compensation for substantial assets is still in the assessment stage. Others have stopped claiming expenses, like Fumitaka Naito, who bought a farm in Iitate village in 2009. Iitate village, 40km northwest of the Fukushima nuclear plant, was initially designated outside the 20km compulsory evacuation zone, but later ordered to evacuate because of high levels of radioactive contamination.[4] He says TEPCO will only pay him an average of ¥14,000 to take a monthly trip home. "The money does not even pay for my gas."

And some do not know if they will ever get any compensation for their lost livelihoods, like Farmer Katsuzo Shoji. He was told to leave Iitate Village in April 2011 and still lives with his wife in temporary housing in Date, 40km from his contaminated home. Both have given up any thought of returning home. Shoji and his wife live on ¥100,000 a month from TEPCO, and have begun selling vegetables from a rented allotment. He has no idea when, how and how much he will get compensated for his house, farm, crops, and slaughtered animals. "What could it be worth now?" he asks – even though the basis for compensation will be what everything was worth before the accident occurred. "Even if we were allowed to return, nobody would buy my food."[5] And so on.

The questions of victims illustrate how TEPCO's complicated compensation process is making life more difficult for those affected by the accident. Many of the tens of thousands who were either ordered to flee or who fled voluntarily from the contaminated zone around the Daiichi plant in March and April 2011 tell similar stories. They note multiple problems with the compensation process: delayed processing of claims; monthly payments too small to ensure a living, let alone start new lives; application forms too difficult to complete. Refugees in the appeal process have started to demand multiple times the amount TEPCO allocated to them. There has not yet been a single payment for assets and the housing evaluations are regarded as too low. The amount of potential demands for compensation has forced TEPCO to lengthen Japan's standard three-year legal time limit for claims.[6] The initial criticism focused on TEPCO's complicated application forms. In order to file claims for damages, victims needed to read through a 156-page instruction manual and fill out an application form extending to 60 pages. Now the forms have been simplified.[7] TEPCO's constant response to ongoing criticism of the process is "We are doing our best."[8]

The compensation scheme has been set up in such a way that compensation is first paid with government-backed financing.[9] This "Governmental Supporting Scheme for the Damages Caused by Nuclear Accident" was created in May 2011, and aims "to enhance governmental support for TEPCO to realise smooth compensation procedures for nuclear accident victims."[10]

In September 2011, Japan's government set up a new public-private agency, the Nuclear Damage Liability Facilitation Fund, to keep TEPCO on life support and oversee compensation, from a mix of public cash, bank loans (underwritten by the government), government-backed bonds and money from Japan's 10 electric power companies.[11] TEPCO has steadily increased its demands on the Fund to over ¥3tn (roughly $34bn), and more is expected. The cost of dealing with the accident forced the government to nationalise TEPCO in June 2012, "the biggest state intervention into a private, non-bank asset since America's 2009 bail-out of General Motors," said *The Economist*.[12] The utility's nationalisation makes it clear: ordinary Japanese people will pay the final bill for the Fukushima disaster.

1.3 "Permanent" compensation plan

In July 2012, a year and a half after the triple meltdown at Fukushima, TEPCO drew up its long-awaited plan on "permanent compensation", mainly for the assets of approximately 160,000 people ordered to evacuate.[13] The utility would pay fixed-asset prices for property but in most cases only "for the period during which the property is unusable."[14] The compensation scheme is based on a complex and disputed government system that divides the contaminated evacuated areas into three zones based on annual radiation levels of more than 50, 20-50mSv or less than 20mSv.

The government says that areas showing annual readings of less than 20mSv of radiation are "being prepared" for the evacuees' return.[15] What this means is that decontamination of these areas, designated *Hinan shiji kaijo kuiki* ("areas that will have the ban lifted") is "progressing", and is expected to finish in years or in some cases even months. In the meantime, evacuees can request two years' worth of compensation (a total of ¥2.4m) in advance. The government assumption that lies at the heart of this policy – that decontaminated areas can become habitable again – could keep many refugees' lives in a state of limbo for a long time. There are serious concerns about the efficiency of the decontamination efforts and the ability to make the areas safe to live in.[16,17] Former residents from these "less contaminated" areas can claim only for the use of their land, houses or businesses, not for the market value of their property. Many have protested this designation.[18]

For areas deemed "uninhabitable for at least five years" (over 50mSv), TEPCO announced that it would pay mandatory evacuees for the full cost of relocating and for fixed assets, but here again the calculation formula is mired in controversy. TEPCO uses local government taxation records to determine fixed-asset base prices, resulting in evaluations that are much too low, say many refugees. For example, Masumi Kowata (57), from Okuma, a town in Fukushima Prefecture, just 5km from the crippled plant, has been offered only ¥700,000 ($8,000) for her 180-year-old, 300m^2 house. She wants a real estate agent to assess the property, which she believes was worth at least eight times that amount before the accident, but she cannot persuade anyone to visit the contaminated zone.[19] Such stories are rife. Many thousands of evacuees have outstanding loans on land that was valued much higher than the property is worth today.[20] If the current value is used to determine the maximum compensation, these people will not be able to pay for the outstanding property loan, let alone pay for rebuilding their lives elsewhere.

The stage is set for multiple lawsuits that will drag on for years, says Yasushi Tadano, a Tokyo-based lawyer who launched a class-action compensation lawsuit against TEPCO in December 2012.[21] "The victims of this disaster often had large houses, rice fields, livestock and land and most had to move from that into small urban apartments or temporary housing," he points out. "The amount of compensation being offered is totally insufficient." He says lawyers will be asking for the difference between the government-assessed property values and the amount of money needed to build the same houses elsewhere.

Like many elderly refugees, Kowata says her health has been worsened by the stress of evacuation. Her husband has suffered kidney failure since the disaster. To pay for the costs of treatment, they have filed a compensation claim with TEPCO of ¥370,000 a month for the period between 11 March 2011 and November 2012, insisting that his condition is related to the enormous stress of the last two years. She has not received a penny from the company. But Kowata says she is lucky, since she is one of the small percentage of victims who were insured for the earthquake. So, she is receiving money from her private insurance company for the damage caused by the earthquake. While this covers her daily living expenses, it does not include the health treatment. "Many of the old people around here cannot even fill out the compensation form," she says.

TEPCO says it employs 12,200 people to directly process such compensation claims, including 3,500 of its own staff. But it cannot or will not answer the most crucial questions: Exactly how many people have applied for permanent compensation? What are the likely grounds for refusal or approval? How many refugees from the most contaminated areas are eligible for full compensation?[22] Off the record, company sources say most people who apply will get something but that few are likely to be completely satisfied.

Refugees who disagree with TEPCO's compensation scheme and have the energy to fight can take their complaints to the government-run Centre for Dispute Resolution for Compensating Damages from the Nuclear Power Plant Incident.[23] Established in September 2011 to ease the expected burden of lawsuits on public courts, the Centre has handled over 5,000 claims. About a quarter have been "settled", meaning disputes over living expenses (but not assets) have been resolved.[24] According to people close to the compensation issue, however, a growing number of refugees are bypassing both TEPCO and the Centre and negotiating directly with the aid of lawyers.

1.4 TEPCO's response

TEPCO has steadily increased its demands on the state-backed Nuclear Damage Liability Facilitation Fund, from an initial ¥1tn in October 2011, to a total amount of ¥3.24tn ($36.5bn) by December 2012. TEPCO made its latest demand of an additional ¥697bn for the Fund on 27 December. It is almost certainly not the last claim. The lawyer and head of the Japanese Bar Association, Yuichi Kaido previously told Greenpeace that the reported figure of ¥4tn in final compensation costs has "absolutely no basis in reality", meaning it is a completely unrealistic assessment of eventual compensation claims. TEPCO blames the rise on additional "compensation according to the redefined evacuation zone", additional "compensation for voluntary evacuees" and the "extended compensation calculation period", among other factors.[25] "If our current funds do not cover claims, we will apply to the Liability Fund for more," says TEPCO's compensation spokesperson Hiroki Kawamata.

The utility says that, by the end of 2012, it had paid out a total of ¥1,662.9bn in compensation to 160,000 "forcibly evacuated" refugees and to "voluntary evacuees," and to former or current residents mainly in Fukushima Prefecture who have been "inconvenienced" by the disaster.[26] It says women who were pregnant or families with young children in the prefecture at the time of the accident have received about ¥400,000 each; others have received one-off payments of ¥80,000.[27] Whether these payments are conditional on waiving future claims for illnesses caused by exposure to radiation, and mental distress, remains unclear. TEPCO said on one occasion that people cannot file future compensation for further illnesses arising from the accident, if they accept one-off payments now. On another occasion, TEPCO stated that it "does not in principle" rule out future claims.

TEPCO says a typical family of two adults and one dependent in the most heavily contaminated zone will receive a one-off payment of about ¥57m ($643,000).[28] That figure includes the loss of the use of their house and ¥6m per victim for "psychological damage" over the five-year evacuation. But the company admits that it has yet to pay a penny of compensation for fixed assets. "It has taken time to ask local governments to estimate the cost of assets," explains TEPCO's Kawamata.[29] He says payment will start "within the year."

Legally, Japan has a three-year time limit on applications for compensation, a limitation clearly designed to help shareholders, says Tadano, and which is in any case unworkable. "Sixty-seven years after the bombing of Hiroshima and Nagasaki there are still people who claim their health has been harmed. Three years is clearly not long enough."[30] TEPCO President Naomi Hirose has been forced to agree. He is also likely mindful of comparisons with Chernobyl, where victims who missed a deadline for applications were shut out of the compensation process. "We do not intend at all to say 'that's it' after three years ... We hope not to create concerns among the people affected," Hirose told Fukushima Governor Yuhei Sato during a January 2013 visit to Fukushima Prefecture.[31]

Japan's Act on Compensation for Nuclear Damage (1961) obliges TEPCO and other nuclear utilities to arrange private insurance of roughly ¥120bn per site – now accepted as woefully inadequate, as the total costs of an accident would be much higher. Compensation and decontamination alone are currently estimated at ¥10tn ($113bn) by TEPCO officials, double the estimate of a few months ago.[32] Although modelled on the US Price-Anderson Nuclear Industries Indemnity Act, the Japanese legislation has a difference, it places unlimited liability on a utility that causes an accident.[33] If, however, liability exceeds the financial security amount, the government could support the utility if necessary.[34] In the event of a "grave natural disaster of exceptional character," the company may be exempted from liability altogether. Where this exoneration applies, the government shall take "the necessary measures to relieve victims and to prevent the damage from spreading".[35] Although TEPCO has not invoked this clause, the company has been nationalised, in effect transferring liability to the public.

In May 2012, the Japanese government injected ¥1tn (about $12.5bn at 2012 exchange rates) into the utility, "the biggest state intervention into a private non-bank asset since America's 2009 bail-out of General Motors," said *The Economist*.[36] The injection capped an estimated ¥3.5tn in public money given to the utility since the Fukushima disaster began. On 27 June, shareholders in the company officially accepted its nationalisation, giving the government majority control.[37] The government backing allows TEPCO to continue as a limited company with shares traded on the stock exchange, while preventing it from going bankrupt.

1.5 Suppliers escape liability

What about the liability of suppliers to the Fukushima plant? Ever since the Japanese nuclear programme began in 1955, Japan has pursued a familiar industrial strategy of mimicking foreign technology (mainly US, British and French), while incubating its own domestic manufacturers and suppliers.[38] By 2011, this strategy had made Japan into one of the world's leading nuclear powers, led by Toshiba, Hitachi and Mitsubishi Heavy Industries. Construction giant Kajima, which helped build the Fukushima plant and many others, has also benefitted from this strategy.[39]

In 1957, Japan's White Paper on Nuclear Energy set out the nation's long-term goals of developing 7,000 megawatts (MW) of nuclear power by 1975. Electricity utilities were persuaded to invest in the Japan Atomic Power Company. The aim was to use 90% of domestic components and human resources.[40] Mitsubishi Atomic Power Industries and Sumitomo Atomic Energy Industries were inaugurated in 1958 and 1959, respectively, to develop nuclear technology. Toshiba and Hitachi began the same in the 1960s. Universities and manufacturers began training engineers in the 1960s.

The suppliers involved in the Fukushima disaster continue in business, and in some cases profit from the disaster.

Image: Public protest in Shibuya against the government's nuclear energy policies, and the restarting of nuclear plants.

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In 1963, Japanese manufacturers began partially constructing a Boiling Water Reactor (BWR) designed by General Electric (GE)-Ebasco. The decisions on what technology to use depended on commercial ties between US and Japanese companies. For example, Hitachi and Toshiba used technologies provided by GE, and Mitsubishi Heavy Industries (MHI) relied on Westinghouse. US firms quickly began to lag in investment and after the 1979 Three Mile Accident, which effectively froze US nuclear development; they fell well behind their Japanese competitors. In the words of former Hitachi engineer-turned whistleblower Mitsuhiko Tanaka, “the student became the teacher.”[41]

Tanaka’s experience illustrates the stakes, and risks in the then fledging industry. In the early 1970s, he helped build the 20 metre tall reactor pressure vessel inside the Fukushima Unit 4 at a huge foundry in Kure City, Hiroshima run by Babcock-Hitachi (the same foundry used to build the gun turrets for the world’s biggest battleship, the *Yamato*). In the final stages of making the $250m vessel, a blast furnace warped the metal, dangerously compromising its integrity and legally obliging the company to scrap it. The vessel is still at the core of Fukushima Daiichi Unit 4.[42]

Facing bankruptcy, Hitachi covered up the defect with Tanaka’s help, he says. “I suspect there are many more engineers like me in Japan.” The vessel was part of the Unit 4 reactor of the Fukushima Daiichi plant. GE supplied the reactors for Units 1, 2, and 6, and Toshiba for Units 3 and 5 (all six were GE designs). Tanaka left the company in 1977 to become a science writer and put the incident out his mind until he had a crisis of conscience watching the 1986 Chernobyl nuclear disaster unfold on TV. After he went public with his knowledge, Hitachi threatened him, he says. “They said: ‘Think about your family.’” Japan’s nuclear authorities released a statement a day later insisting there was no problem. “And that was the end of it,” recalls Mr. Tanaka.[43] Nobody pursued Hitachi for this cover-up he points out.

Kei Sugaoka, a Japanese engineer who worked at the Unit 1 site, and Katsunobu Onda, author of *Tepco: The Dark Empire*, questioned the integrity of the reactor after the 11 March quake, but before the tsunami.[44] The Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company (or the Diet Commission on the Fukushima Disaster), concluded that it was “impossible to limit the direct cause of the accident to the tsunami” without further evidence.[45]

The Diet Commission report notes that Unit 1 of the Fukushima Daiichi Nuclear Power Plant was purchased by TEPCO under a “turnkey” contract for construction in December 1966 “that placed all responsibility” on GE. The report says TEPCO chose GE not just because of the company’s technical achievements but also because they believed it would be cheaper to adopt a design of an already commissioned GE reactor in Spain, but Fukushima Unit 1 ended up being built first. “Instead of having the Spanish experience available to draw on, the Fukushima plant became the first facility to experience numerous difficulties.”[46]

The problems included seismic design standards that were stricter than for the original design of the Spanish reactor, entailing piecemeal modifications of supporting structures. Working inside the cramped Unit 1 containment vessel was considered particularly problematic. “The major problem here was whether the Japanese design specifications for anti-seismic design at the time were incorporated appropriately in the product design package from GE,” says the report, citing a former TEPCO vice-president, Ryo Ikegame, who worked at the Daiichi plant during installation. “According to Ikegame, they were not, and he indicated that ad hoc reinforcements were made during the construction.”[47]

In the 1970s, GE engineer Dale G Bridenbaugh publicly questioned whether the GE Mark I reactor used in Fukushima Units 1-5 would stand up to a loss-of-coolant accident.[48] The Diet report adds that Mark I containment vessels in Japan were reinforced against dynamic loads in case of loss-of-coolant in the 1980s, “but the reinforcement did not cover severe accidents of this scale.”[49] The series of reinforcements implemented included enhancing pipe penetration points where the strength margin was small, and adding parts to mitigate the dynamic loads. The report concludes that during the accident, the pressure inside the containment vessels substantially exceeded their designed capacity, up to almost twice the capacity in the case of Unit 1.[50] "We should also note that the MARK I type PCVs [pressure containment vessels] at the Fukushima Daiichi plant is smaller in volume than the improved version of MARK I, which contributed to the fast rise in pressure." In November 1987, Japan's NISA (Nuclear and Industrial Safety Agency) began an evaluation of the Mark I reactors to consider how much stress they could take before a loss-of-coolant accident would occur. The results of that evaluation have not been made public.

Another problem inherent to the Mark I reactor design is the occurrence of cyclical waves on the water surface of the reactor pressure-suppression pool during earthquakes.[51] The pool is meant to condense steam in case of an accident. When earthquake motion causes cyclical waves (called "sloshing"), the water surface in the suppression chamber shifts. As a result, the tips of "downcomer" pipes, through which steam is released into the water, could be exposed, releasing steam into the gaseous space of the suppression chamber. This causes the designed function of suppression to fail, resulting in over-pressure. Compared to other reactor designs, the Mark I type has the highest possibility of downcomer exposure. The Diet report recommends a "thorough study" on this problem.

From the start, former GE employees recall how TEPCO elected to overrule its own engineers and follow GE's original construction design by putting the plant's emergency diesel generators and batteries in the basement of the turbine buildings, with devastating results on 11 March 2011.[52]

Throughout the operation of Mark I reactors at Fukushima Daiichi, a steady stream of allegations emerged suggesting that problems were fixed *ad hoc*, or in some cases not at all, with the collusion of original suppliers and maintenance companies. Onda has spoken to a TEPCO engineer who said often piping would not match up to the blueprints.[53] In that case, the only solution was to use heavy machinery to pull the pipes close enough together to weld them shut.[54] Inspection of piping was often cursory and the backs of the pipes, which were hard to reach, were ignored. Repair jobs were rushed; no one wanted to be exposed to nuclear radiation longer than necessary.[55]

In September 1989 the US Nuclear Regulatory Commission (NRC) encouraged owners of nuclear plants with GE Mark I and II containment designs to install hardened (pressure-resistant) vents.[56] The NRC viewed controlled venting (release of radioactive gases to reduce pressure) as preferable to catastrophic failure of the containment. However, the NRC did not order the installation, but left the decision up to the reactor operators. Only after Fukushima has the NRC ordered that all GE Mark I and II reactors install reliable hardened vents.[57] But the NRC has not yet required that those vents be filtered, while most nuclear plants outside the US and Japan have included filters to reduce the release of radioactive contaminants. In January 2013, the commissioner of the new Japanese Nuclear Regulation Authority said that all Japanese BWR's will be required to install filters in their ventilation systems before they will be allowed to restart.[58]

Some engineers have called the installation of vents in the original flawed design a "Band-Aid fix" that failed at Fukushima.[59] In Japan, the hardened vents were eventually installed in the 90s, but filters were never installed even though the inefficiency of the existing filter system in Fukushima-type reactors was known and the technology was available.[60] During the Fukushima accident, the existing filtering system could not be used due to raised water levels in the containment vessel of the reactor. Also the hardened vents proved ineffective, as no manual operations were described for power loss situations.

According to Tanaka, there is a fundamental contradiction at the heart of pressure vessels: they are designed to keep radiation in during an emergency, but the same emergency can generate such pressures that an explosion is a risk. It was TEPCO's responsibility to install filters but it didn't, he says, because of their prohibitive cost.[61] During the Fukushima accident, then Prime Minister Naoto Kan famously had to order the Daiichi vents to be opened by hand on 12 March 2011.[62] In the end, venting in Unit 1 eventually succeeded, but venting in Unit 2 failed and in 3 only partially succeeded, according to Tanaka.

There are currently 10 Mark I-type reactors remaining in Japan, and 17 very similar GE Mark II reactors.[63] According to Tanaka, each one is the equivalent of a ticking time bomb. Not only are the companies involved in building, installing or maintaining these reactors all currently exempted from responsibility for the 11 March disaster, they are profiting from it, says lawyer Tadano. Toshiba and Hitachi lead the decommissioning of the Daiichi plant and Kajima is in charge of decontamination. The TEPCO group of companies is heavily involved in the clean up[64], which includes decommissioning of the Fukushima Daiichi plant and decontamination.

1.6 Conclusion

Thousands of nuclear refugees from the world's worst nuclear disaster since Chernobyl report multiple problems, including:

- Delays in processing their claims
- Inadequate amounts being offered
- Unclear procedures about waiving of future claims
- Not a single payment yet for lost or damaged assets
- Current three-year legal limit for claims

The suppliers and companies involved in the disaster, however, continue in business and in some cases profit from the disaster, backed by public money.

Japan's nuclear accident law limits liability to TEPCO, blocking victims from going after its suppliers. There is no mechanism in the law either for targeting executives of TEPCO or any of the suppliers. Then Prime Minister Yoshihiko Noda waived responsibility for the disaster last year when he said "no individual" is to blame and that everyone has to "share the pain."[65] The Diet commission report took the same approach, blaming "culture".[66] Over half of the TEPCO board has since taken lucrative post-TEPCO positions elsewhere.[67]

Kameya says the disaster has taught her to fight for her rights, and stay tightlipped. "If I say how much I'm getting, or demanding, people will say, 'Why are you getting so much?' People think we will get a lot of money when something like this happens, but they're wrong, and it will probably take five or ten years to be compensated."

"I asked a TEPCO guy, 'If you had to run for your life and became a refugee, could you live like this, saving every receipt for food, gasoline and clothes?' He didn't answer me."

1 Personal interview, Tokyo, 28 December 2012

2 All currency conversions are approximate and were done around 22 January 2013, unless otherwise indicated.

3 Personal interview, Ibid.

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5 Personal interview, 3 January 2013

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9 Tokyo Electric Power Company (TEPCO). 2011. Annual Report 2011. pp.6 http://www tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2011-e pdf

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18 See Jiji, Ibid.

19 Personal interview, 10 January 2013.

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21 Personal interview, 10 January 2013

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24 Personal interview with Hiroki Kawamata. TEPCO Compensation spokesperson, and Yoshikazu Nagai, corporate relations, 10 January 2013

25 Summary of amounts claimed and press release can be found here: http://www tepco.co.jp/en/press/corp-com/release/2012/1223937_1870 html (Accessed 12 January 2013)

26 TEPCO personal interview, Ibid.

27 Personal interview, 11 January 2013. Interim Guideline of the Funso Sinsakai dated 6 December 2011. http://www.mext.go jp/b_menu/shingi/chousa/kaihatu/016/index.htm

28 "TEPCO may start lump-sum compensation in August," The Daily Yomiuri, 26 July 2012. Available online at: http://www.yomiuri co jp/dy/national/T120725005729.html. The compensation scheme assumes a140m^2 house valued at ¥8 61m built in 2007 on a 300m^2 housing lot valued at ¥3m.

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30 According to the recent OECD/NEA report, Japan's Compensation Act does not set a time limit on rights to claim compensation for nuclear damage. While Japan's Civil Code provides the terms for the extinction of rights to claim the general tort liability, a recent examination found that the 20-year time limit to claim compensation "would not substantially bar claims" by victims of late injuries. See: OECD/NEA (2012). Japan's Compensation System for Nuclear Damages. Legal Affairs 2012, pg. 19.

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66 See Gerald Curtis, "Stop blaming Fukushima on Japan's culture," The Financial Times, 10 July 2012. http://www ft com/intl/cms/s/0/6cecbfb2-c9b4-11e1-a5e2-00144feabdc0 html (17 January 2013).

67 Willacy, M. 2012. "Fukushima plant directors resign with golden parachutes," ABC News, 27 June 2012. http://www.abc.net.au/pm/content/2012/s3534291.htm

The current nuclear liability conventions are intended to protect the nuclear industry, and do not offer sufficient compensation to victims.

Image: A Greenpeace sign indicates a radioactive hot spot in a storm water drain between houses in Watari, approximately 60km from the Fukushima Daiichi nuclear plant.

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#2

Summary and analysis of international nuclear liability

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2.1 Introduction

Nuclear power stations, as with all businesses, can damage the health and safety of their workers and, under more extreme circumstances, the general public and the wider environment. However, given the nature of the technology and fuel, nuclear power also has the potential for accidents that could lead to large and long-term trans-boundary impacts. This potential was recognised right at the start of the civil nuclear industry and international agreements were sought, both to enable potential victims to rapidly have access to compensation and to limit the extent to which the industry could be exposed to possible compensation claims.

At the heart of the problems around the approach to creating an international nuclear liability regime are competing objectives. To introduce a comprehensive liability regime it would be necessary for states that operate nuclear facilities, states involved in the supply of nuclear materials or services for these programmes and all other states that might be affected by a nuclear accident to be under the umbrella of the same liability and compensation regime. Currently, that is not the case.

For a liability and compensation regime to be attractive to states seeking to maintain or increase their nuclear power programmes, the requirements imposed by a liability and compensation regime must not be too burdensome[1]. Therefore, the signatories to the current conventions agree to a number of conditions such as: narrow definitions of nuclear damage and the length of time that compensation can be sought; that claims for compensation are channelled solely towards the operator; and that limits can be set on the total amount of compensation available. However, conversely, in order to be attractive for a state without nuclear power plants, liability and compensation conventions must offer sufficient compensation, and a regime must not introduce unacceptable restrictions or burdens for those seeking to obtain compensation for losses incurred. For such states, becoming party to one of the nuclear-liability conventions currently is not an attractive proposition.

The current nuclear liability conventions are unlike those of many other industries, as they are intended to protect the nuclear industry, and do not offer sufficient compensation to victims. This chapter gives an overview of the existing international nuclear liability conventions, and analyses the impacts of specific issues, such as capping the compensation available, and channelling of liability solely to the operator. In the conclusions, directions are given for the reform of domestic legislation on nuclear liability.

2.2 Overview of liability regimes[2]

2.2.1 International

There are two basic international legal frameworks contributing to the attempt to put in place the basis for an international regime on nuclear liability: Firstly, the Organisation for Economic Co-operation and Development's (OECD) 1960 Convention on Third Party Liability in the Field of Nuclear Energy (Paris Convention), and the associated "Brussels Supplementary Convention"[3] of 1963, and secondly, the International Atomic Energy Agency's (IAEA) 1963 Convention on Civil Liability for Nuclear Damage (Vienna Convention)[4]. The Vienna and Paris liability conventions are also linked by a Joint Protocol, adopted in 1988[5]. Despite this, however, only about half the world's 438 operational reactors are located in states that are contracting parties to one of the nuclear liability conventions[6], as many countries such as the US and Japan have not become part of either convention. All countries that operate nuclear power plants also have their own legal frameworks, which are not always fully compatible with the international conventions.

Negotiated at the time when the nuclear power industry was in its infancy, the Vienna and Paris Conventions had two primary goals: first, to create an economic environment where the nascent nuclear industry could flourish; and second, to ensure that clear procedures and some compensation would be available in the event of an accident. The first aim would be achieved by removing legal and financial uncertainties over potentially enormous liability claims that could arise in the event of an accident. For the industry, it was clear that nuclear power would only be viable if there were some financial protection for companies involved in the supply chain, as well as for investors who were placing their financial resources in a potentially dangerous and litigiously expensive sector.

While there are some differences in detail, the Vienna and Paris Conventions have features in common. In particular they:

- Allow limitations to be placed on the amount, duration and types of damage for which nuclear operators are liable;
- Impose a restrictive definition of nuclear damage[7];
- Require insurance or other surety to be obtained by the operator;
- Channel liability exclusively to the operator of the nuclear installation;
- Impose strict liability on a nuclear operator, regardless of fault, but subject to exceptions;
- Grant exclusive jurisdiction to the courts of one country for any given incident, normally the country in whose territory the incident occurs.

The accident at the Chernobyl nuclear power station in Ukraine in 1986 revealed a number of deficiencies in the international liability conventions. Most striking was that, compared with the damage caused by the Chernobyl accident, it was obvious that the liability ceilings were inadequate and that not all of the damage caused by Chernobyl was covered by the definition of damage applicable under either Convention. There were also problems with the limits on the time in which claims for compensation could be brought, the claims procedures, and the limitations on which courts had jurisdiction to hear claims. An international liability regime was not the only international framework that was seen to be lacking, and following Chernobyl efforts were made by the international community to modernise a number of conventions, including those on nuclear safety standards, on notification of the international community and on radioactive waste management.

On nuclear liability, as an interim step to creating a single treaty with global adherence, three steps have been taken. Firstly, the parties to both the Vienna and Paris Conventions adopted the 1988 Joint Protocol, which entered into force in 1992. The Joint Protocol created a "bridge" between the two conventions, effectively expanding their geographical scope. Doing so ensured that only one of the two conventions would be exclusively applicable to a nuclear accident. Secondly, some of the elements of the existing conventions were revised. The process of negotiating amendments to the Vienna Convention began in 1990 and concluded in 1997. Work then began officially in 1997 on revisions to the Paris Convention and in 1999 for the Brussels Supplementary Convention.[8] The revisions to the Vienna and Paris/Brussels Conventions increase the amount of compensation available (see Table 1), expand the time periods during which claims might be made and expand the range of damage covered by the conventions. The new liability and compensation amounts required under the revised Paris Convention would be at least €700m ($920m US dollars) and total compensation available under the revised Brussels Supplementary Convention would be €1,500m. Nonetheless, the overall amounts remain low when compared with the costs of the Chernobyl or Fukushima accidents. For Chernobyl, a large number of studies estimate the costs at between $75bn and $360bn (with considerable variation in exchanges rates). For Fukushima preliminary estimates from the Japanese Centre for Economic Research (JCER) suggested that the total costs would be in the range of ¥5,700-20,000bn (€48bn-169bn). Further, setting fixed compensation sums is not only arbitrary (in the absence of genuinely robust estimates of probable damage) but it is also unlikely to be valid over the longer term.

Finally, a new Convention on Supplementary Compensation (CSC)[9] was adopted in 1997 and is intended to be a free-standing instrument that may be adhered to by all states irrespective of whether or not they are Party to either of the existing nuclear liability conventions. Its objective is to provide additional compensation for nuclear damage beyond that established by the existing conventions and national legislation. Furthermore, it aims at broadening the number of countries within an international convention.
As a result, the industry would be protected from compensation claims outside these regimes. The CSC fixes the first tier of compensation at 300 million Special Drawing Rights (SDRs)[10] (roughly equivalent to €300m). If the operator is unable to meet this, the state in which the reactor is installed is required to make public funds available to cover the difference. If claims for compensation for nuclear damage exceed 300 million SDRs, the CSC requires that its member countries contribute to an international fund to provide additional compensation[11,12].

Table 1: Summary table showing liability and compensation amounts for different conventions (millions of euros (€)).

Convention	Operator liability & Installation state	Total combined contributions from Other States party	Total minimum compensation available	Number of Parties
Paris, 1960	€6 to €18	-	€6 to €18	15
Brussels, 1963	€202	€149	€357	12
Paris, 2004	€700	-	€700	3
Brussels, 2004	€1200	€300	€1500	3
Vienna, 1963	€50	-	€50	38
Vienna, 1997	€357	-	€357	10
CSC*, 1997	€357	Depends	€713	4

Source: International Atomic Energy Agency and Nuclear Energy Agency 2012

Although there are unifying features, the nuclear liability conventions do not provide a single comprehensive and unified international legal regime for nuclear accidents. As has been seen above, different countries belong to a variety of international agreements.

The goal of ensuring broad participation in the improved international conventions has not been achieved. As of May 2012, six countries have ratified the 1997 Vienna Convention; with a further four parties to this convention.[13] This was enough to bring the Joint Protocol to amend the Vienna Convention into force in 2003, but the lack of wide adoption remains problematic. There has also been a delay in the ratification of the revised Paris Convention and the revised Brussels Supplementary Convention.[14] In order for the Protocol amending the Paris Convention to enter into force it must be ratified by two-thirds of the Contracting Parties. For EU Member States, this was supposed to have taken place simultaneously by the end of 2006[15], but it has not yet been done. It is suggested that this will occur and that it will enter into force at the beginning of 2014[16].

For the Protocol amending the Brussels Convention, ratification by all contracting parties is required. Only four countries out of 15 (Argentina, Morocco, Romania and the US) have ratified the CSC[17], however, the CSC is set to enter into force on the 90th day after date of ratification by at least five states that have a minimum of 400,000 units of installed nuclear capacity (ie MWt -thermal[18])[19]. Although only four countries have ratified the convention, press reports suggest that Japan is now considering joining the convention[20]. (For a summary list of which countries have ratified each convention, see Table 2.) What is remarkable is that nearly 27 years after Chernobyl, 16 years after the adoption of the CSC, and nine years after the adoption of the 2004 Protocols to amend the Paris/Brussels convention, those enhancements have not entered into force. As a result, the situation has not changed significantly since the Chernobyl accident of 26 April 1986[21].

During the negotiations to revise the Vienna and Paris Conventions, representatives of the nuclear insurance industry stated that some of the proposed amendments would be problematic. In particular, the nuclear insurance industry was concerned that there was:

- insufficient private insurance market capacity to insure nuclear operators against raised liability amounts;
- an unwillingness of the market to cover extended/extinction periods during which an operator would be liable; and
- a difficulty in that private insurance could not cover all the categories included in the expanded definition of damage[22], such as damage to the environment.

The problems with private insurance can be seen to be, at least partly, a financial question. The UK government laid out the current difficulties in its 2007 consultation paper on the revision of the liability limit, when it said: “To the extent that commercial cover cannot be secured for all aspects of the new operator liabilities, the Government will explore the alternative options available – including providing cover from public funds in return for a charge”[23]. Already this has occurred as in the Netherlands the maximum liability is in line with the revised Paris Convention; however, under Dutch law a lower amount may be set for “low-risk” installations by ministerial order. So far, five installations have lower requirements, of between €22.5m and €45m. Furthermore, if an operator cannot obtain the financial security required by the Convention or it is only obtainable at “unreasonable cost”, the minister may enter into contracts on behalf of the state[24].

2.2.2 National[25]

A number of countries have only domestic nuclear liability laws (e.g. Japan), therefore, the extent of the potential compensation to victims and the requirements on the operators are dependent on these national laws. In the event of an accident in a nuclear facility in one of these countries, the requirements and terms of the international conventions would not be applicable.

Some countries that do not have commercial nuclear power, but may have nuclear research reactors, also have national liability regimes. One of the most prominent is Austria, which is also active in its opposition to the use of nuclear power in neighbouring countries. In 1995 its parliament adopted a resolution in which the government was asked to revise its nuclear liability law. This led to a law in 1998 that was "in sharp contrast to the basic principles of international law", in that liability was unlimited, legal channelling to the operator was largely eliminated, including a broadened definition of nuclear damage, and Austrian courts were given jurisdiction, if the damage occurs in Austria, regardless of the cause[26]. Even as revised, the levels of compensation are relatively low when compared to the likely costs of a serious accident (see section 2.3). By becoming a party to an international convention, a non-nuclear-power-generating state might actually restrict its possibilities for obtaining legal remedies in the event of an accident[27]. This is why the Austrian parliament's 1995 resolution specifically ordered the government not to present the Paris Convention for ratification until essential improvements, namely the elimination of legal channelling, were made[28].

2.3 Capping of nuclear liability vs costs of nuclear accidents

One of the key elements of the international liability conventions is to justify national legislation by putting in place a ceiling on the costs that a nuclear operator must pay in the event of a nuclear accident that has impacts that require compensation to third parties. The limits put in place under the international conventions are in fact the minimum that a utility is liable for, but in most cases this has been taken to be the maximum. Only in a few cases does national legislation go beyond that required by the conventions, for example in Germany, Japan, and Switzerland, there is no limit on the liability of an operator[29,30].

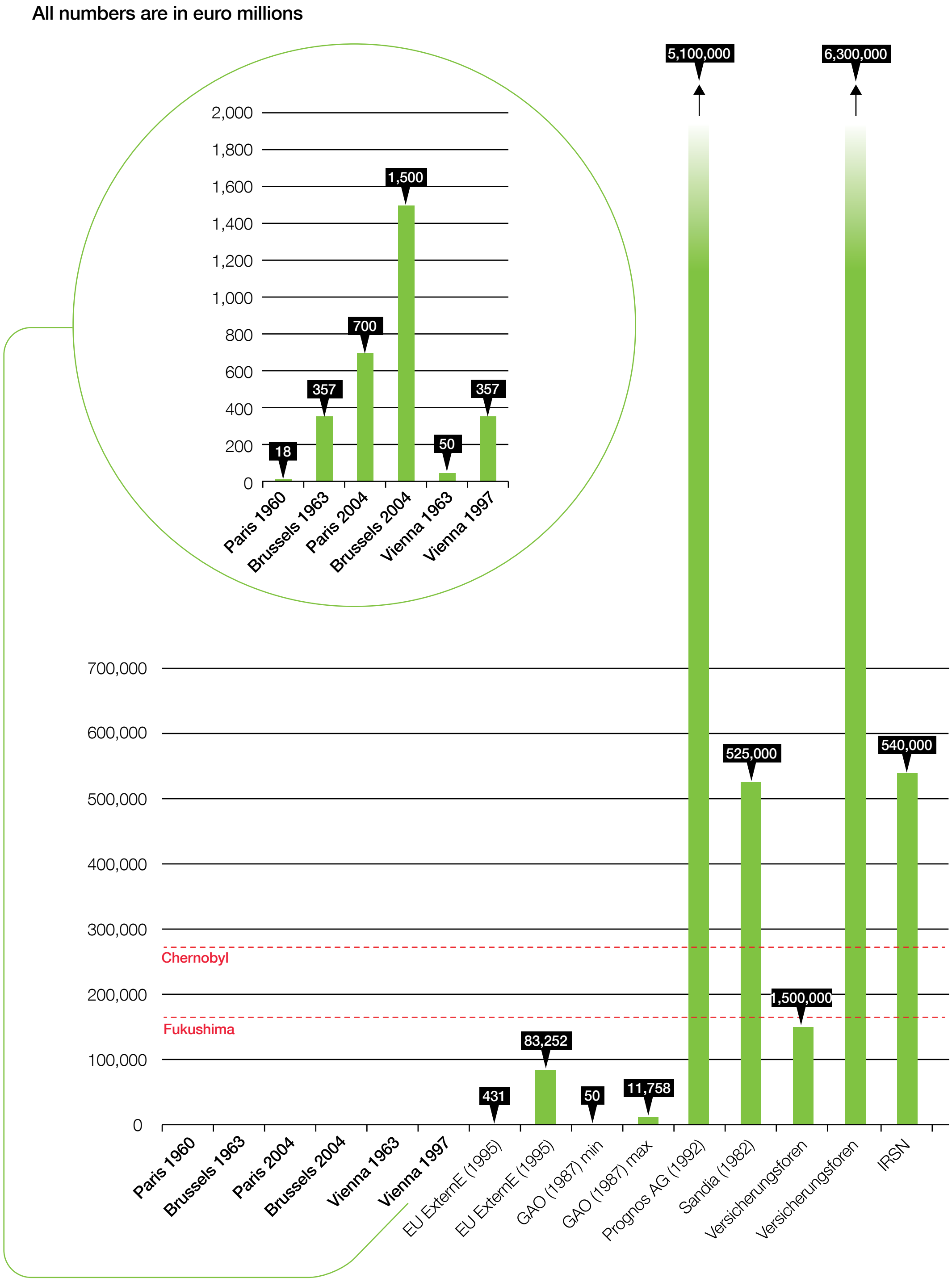
As noted in Table 1, the minimum requirements range between the different regimes, from €350m to €1.5bn. Even in an unlimited civil liability regime, the practical limits to the capacity of the nuclear insurance market and the assets of an operator (and, where these are also the object of channelling: suppliers and financiers) together impose a constraint on the magnitude of the funds that may be raised to compensate victims. In practice, the channelling of liability exclusively to the operator restricts the scale of the accessible funds to a very small fraction of the possible costs of a serious nuclear accident. Many nuclear countries have recognised this state of affairs and provide for guarantees of supplementary compensation for domestic victims using public funds. This is the case, for instance, in Germany and Switzerland (which have unlimited operator liability) as well as in the UK and France (which impose relatively low limits on operator liability).

However, these are insignificant in comparison to the differences between these thresholds and the theoretical costs of a large-scale accident, as can be seen in Figure 1.

In addition to the estimated cost of actual accidents, a number of theoretical assessments of accidents exist, including:

- The 1995 study by the EU ExternE project considered four reactor accident scenarios, which led to cost estimates for damage ranging from €431m to €83,252m.[31] It should be noted that these cost estimates exclude decontamination, although it is acknowledged that these costs "can rapidly be very high", and that that there are major limitations to the economic evaluation[32], arising from:
  - Uncertainties on the impact (evaluation of source term, difficulties to estimate the environmental impacts due to the long-term contamination, uncertainties on the radiation health effects, etc.);
  - Uncertainties on the efficiency of countermeasures;
  - Economic evaluation of some social consequences is nearly impossible.

Fig 1: Comparison of liability amounts in international conventions vs estimated costs of accidents.



Source: Greenpeace 2012. Note: The high estimates for the costs of Chernobyl and Fukushima are used as a reference (Chernobyl: €270bn, Fukushima: €169bn). The costs of the Fukushima accident are based on preliminary estimates.

- Following the Chernobyl accident, in 1987, the US General Accounting Office (GAO) conducted an analysis of the off-site financial consequences of a major nuclear accident for all 119 nuclear power plants then operating in the US. The estimates ranged per accident between a low of $67m US dollars (€50m) to a high of $15,536m (€11,758m).[33]
- An assessment conducted by Prognos AG in 1992 for the federal German government estimated the worst case accident scenario for the Biblis-PWR power station at $6.8tn (€5,100bn).[34]
- The so-called "Sandia Report" from 1982 concluded that a very large accident could cause damages in the order of $695bn (€525bn).[35]
- A study undertaken by Versicherungsforen Leipzig, for the German renewable energy sector in 2011, following Fukushima, assumed a cost range for a nuclear accident in Germany of between €150bn and €6.3tn.[36]
- The Institut de Radioprotection et de Sûreté Nucléaire (IRSN), which is the French public safety authority's Technical Support Organisation (TSO) on nuclear and radiation risks, in its November 2012 report on a major accident in France, suggested that the cost could exceed €540bn. This figure includes the cost of clean-up and compensation, loss of electricity, and the impact on the image of products, leading to a reduction in value. The leader of the study, Patrick Momal was quoted as suggesting that it would be an "unmanageable European catastrophe". He suggested that it could be costlier than that of Fukushima due to the higher population density and the fact that many power plants are inland.[37]

The actual costs associated with the Chernobyl accident are difficult to assess, and range from $75bn-$360bn (although exchanges rates vary considerably). An early estimate put the minimum near-term costs of the Chernobyl accident to be in the neighbourhood of $15bn, with longer-term costs of $75bn–$150bn.[38] A 1990 report prepared by Yuri Koryakin, the then chief economist of the Research and Development Institute of Power Engineering of the Soviet Union, estimated that the costs from 1986 through to 2000 for the former Soviet Republics of Belarus, Russia, and Ukraine, would be 170bn-215bn roubles (at the then official exchange rate this would be equivalent to $283bn-$358bn)[39]. The Belarus government estimated the total economic damage caused between 1986 and 2015 would be $235bn (1992 June prices)[40]. Another estimate suggests overall economic costs in Ukraine alone of $130bn[41]. In part due to the changing political situation in the region in the early 1990s and the changing currencies and exchange rates, it is impossible to put a precise figure on the cost of the Chernobyl accident. However, what seems clear is that it was the most costly nuclear accident to date, with costs in the order of hundreds of billions of dollars US, a figure which far exceeds most legislative requirements.

The final costs of the Fukushima accident are also unclear given the uncertainties over the number of affected people and the future for evacuated areas and their populations. An early estimate by the Japanese Centre for Economic Research suggested that the total costs would be in the range of ¥5,700bn-¥20,000bn (€48bn-€169bn). The estimated cost was broken down into three cost components: compensation for the purchase of land ¥4,300bn (€36bn); compensation for lack of income ¥630bn (€5.3bn); and the costs of decommissioning and decontamination between ¥740bn-¥15,000bn (€6.3bn-€127bn)[42].

In April 2012, in its annual report, TEPCO stated that the company was committed to providing prompt compensation for those affected by the accident in accordance with the 1961 Nuclear Damage Compensation Act. Based on guidelines from the Committee for Adjustment of Compensation for Nuclear Damages Disputes of 5 August 2011, TEPCO has assumed that the initial cost of compensation amounts to ¥2,644bn (€22bn)[43]. This includes ¥1,174bn (€10bn) for individual compensation, ¥986bn (€8bn) for businesses, plus ¥484bn (€4bn) for other expenses[44]. Of this, TEPCO will be responsible for nuclear damages amounting to ¥2,524bn (€21bn) after deducting ¥120bn it received in compensation pursuant to the provision of 1961 Nuclear Damage Compensation Act[45].

However, the ¥2,644bn is not the final figure, and annual payments are also expected, with ¥161bn (€1.4bn) allocated in the company accounts for further compensation in the first quarter of FY 2012[46]. It is noted by TEPCO that: "The Company records the estimated amount as far as reasonable estimation is possible at this moment, although the estimated compensation amounts might vary depending on the extent of accuracy of reference data and agreements with the victims from now on."[47] In November 2012, TEPCO officials suggested the costs of compensation and decontamination could reach ¥10tn (€85bn)[48].

The Committee for Adjustment of Compensation for Nuclear Damages Disputes estimated that the total costs of decommissioning the six units at Fukushima Daiichi would be around €13bn. However, the Commission was unable to determine and did not include the costs of decontamination[49].

To put these figures into context, according to the Japanese Cabinet Office's report released three months after the nuclear accident, the total estimated loss to tangible (direct) assets from the earthquake and tsunami, not including those arising out of the nuclear accident, was around ¥16.9tn (€143bn), which represents around 3.3% of GDP. While the insured loss stemming from the earthquake and tsunami is estimated at ¥3,000bn (€25bn), possibly making it the world's second most costly insurance loss since the 1970s[50].

2.4 Economic impact of capping liability

Actual experience and numerous studies have shown that the compensation required in the event of an accident with large-scale, off-site releases far exceeds even the revised limits of the international conventions. Therefore, in an age of increasing awareness of the consequences of environmental damage and a market economy, the concept of creating an artificial ceiling on the amount of compensation that utilities are required to pay out is unjustified.

As the compensation costs of accidents with off-site consequences exceed by orders of magnitude the liability requirements on the utilities in the international conventions, it might be assumed that the conventions were unfit for purpose and need to be adjusted to reflect the greater possible compensation claim. However, in fact it has the reverse impact: the conventions are successful in protecting an operator from damage claims.

The third-party liability ceilings placed upon nuclear operators by national legislation reduce their insurance premiums. Little data is publicly available on the actual costs of individual utilities for their third-party insurance liability and the specific details of the liability cover, and there is certainly no published comparison. However, *ad hoc* country data is available and includes:

- In the US, the Nuclear Regulatory Commission (NRC) requires all licensees of nuclear power plants to show proof that they have the primary and secondary insurance coverage mandated by the Price-Anderson Act. Licensees obtain their primary insurance through American Nuclear Insurers. The average annual premium for a single-unit reactor site is $830,000 (€630,000)[51].
- In 2011 in Canada, Ontario Power Generation Ltd paid $809,626 Canadian dollar (€623,000) for its nuclear liability, which covered 10 units at two power stations[52].
- The total insurance costs in the UK are estimated in a study commissioned by the Department of Energy and Climate Change (DECC) to be £10,000 per annum per MW of installed generating capacity. DECC's conclusion was that: "this demonstrates that total insurance costs, of which nuclear third party liability is only one element (other elements includes non-nuclear third party cover, business interruption, machinery breakdown, construction risks, crime etc.) are a very small proportion of the costs of electricity generation from nuclear plant"[53].

The studies cited below present data on the economic impact of increasing or removing the ceilings on liability. Some also present the costs for requiring private insurance.

A brief analysis published in 2003 suggested that if Electricité de France (EDF), the main French electric utility, were required to fully insure its power plants with private insurance but using the current internationally agreed limit on liabilities of approximately €420m, it would increase EDF's insurance premiums from €c0.0017/kWh[54], to €c0.019/kWh, thus adding around 0.8% to the cost of generation. However, if there were no ceiling in place and an operator had to cover a significant off-site release of radiation, it would increase the insurance premiums to €c5.0/kWh, thus tripling the current total generating costs[55].

A more comprehensive analysis, undertaken by Versicherungsforen Leipzig, looked at the insurance costs in Germany. This both highlighted the variables and costs associated with a cost-reflective insurance regime, and concluded that the insurance premium would increase the cost by a range of around €0.14 to €67.3/kWh[56].

The JCER study suggests that, if the anticipated costs for Fukushima (¥5.7tn-¥20tn, €48bn-€169bn) were required to be met by all of TEPCO's reactors operating for a 10-year period, it would add ¥6.8-¥23.9/kWh (€0.06-€0.22/kWh), while, if the cost were allocated to all nuclear power plants, it would add between ¥2.0-¥6.9/kWh (€0.02-€0.06/kWh), compared to quoted nuclear generating cost of around ¥6/kWh[57] (€0.05/kWh).

The UK Government undertook an assessment on extending the liability cover required by nuclear operators to meet the new requirements of the revised Paris Convention. Following discussions with the industry, DECC suggested: "that meeting the proposed changes to the regime, namely that operators will now be liable for 6 categories of damage instead of three (consequential economic loss is already covered), including personal injury now extended to 30 years, and that the level of liability will increase substantially from £140m to €1,200m. The estimates provided by industry suggest there would be an increase in insurance premium costs from 2 to 10 times the current levels, averaging 7.5 times current costs"[58].

2.5 Liability channelling

The Vienna Convention states (Article II, Par 5): "Except as otherwise provided in this Convention, no person other than the operator shall be liable for nuclear damage."

The major regimes all act to channel liability exclusively towards the operator and no other parties involved in the construction and maintenance of a nuclear installation may be held liable for any damages. The Vienna Convention provides for very limited rights of recourse of the operator towards any third party. Basically, according to its Article X, the operator shall have a right of recourse only "if this is expressly provided for by a contract in writing". Consequently, if a claim for damages is filed directly against such a third party, such claim should be basically dismissed by the court[59].

The justification for the channelling of liability onto the operator is that it simplifies and, therefore, expedites actions for damages brought by victims. It is further said that channelling also "secures as far as possible a fair and equal treatment of all potential victims, and is therefore also advantageous for every single victim"[60]. However, as the Nuclear Energy Agency points out, it also "minimises the burden upon the nuclear industry as a whole, as the various persons who contribute to the operation of a nuclear installation, such as suppliers and carriers, do not require insurance coverage additional to that held by the operator"[61].

The ability to seek compensation recourse with parties other than the operator in the event of an accident would not only benefit the potential victims, but would also increase accountability and transparency and help ensure an adequate safety culture is adhered to across the supply chain. Furthermore, the channelling of liability restricts the number of avenues open to potential victims to seek recourse, and, with a large number of claims and limited funds available, may mean that those affected are unable to receive adequate compensation.

A liability regime and in some cases being a signatory to the international conventions are often a requirement for foreign participation in nuclear projects. For example, the European Bank for Reconstruction and Development, one of the few International Financial Institutions to lend for nuclear power, has a requirement that the government in which the project is located must have acceded to the Vienna Convention and have corresponding national legislation[62]. The US Export Credit Agency[63] only requires that "the host country must have a regime acceptable to ExIm Bank governing liability for nuclear damage"[64], rather than becoming party to a specific convention.

However, not all national regimes recognise the necessity for channelling liability. India's new nuclear law, of 2011, specifically allows nuclear operators to seek recourse in the event of "wilful act or gross negligence on the part of the supplier", while the existing laws in both Russia and South Korea allow operators to recover damages from suppliers in the event of negligence[65].

In other, non-nuclear, sectors the legal and economic ramifications are not restricted to the operator, as has been seen in the case of the *Deepwater Horizon* oil spill, where affected parties have sought compensation not only from BP, the operator of the rig, but also from the rig owner, Transocean, and from Halliburton, the supplier of cement for the well[66].

2.6 Other areas of contention

There are a number of gaps and restrictions in the current national and international liability regimes. One of the most important relates to the environment. The revised conventions have changed the scope of liability and include loss of life or personal injury, loss of or damage to property, economic losses, loss of income, cost of preventative measures and the cost of measures of reinstatement of impaired environment. On this last point, however, it has been noted that "almost all forms of environmental liability are currently uninsurable"[67]. This is said to be for a number of reasons, including that there is not direct economic interest in the environment, and it is, therefore, impossible to provide an "insurable interest"[68].

As well as issues around the definitions of damage, problems remain in the current conventions relating to the length of time that claims can be made. The 1963 Vienna Convention states (Article VI) that: "Rights of compensation under this Convention shall be extinguished if an action is not brought within ten years from the date of the nuclear incident." This was revised in the Joint Protocol so that in respect to loss of life and personal injury claims may be made 30 years from the date of a nuclear incident, and, with respect to other damage, 10 years from the date of the nuclear incident. The extension of loss of life and personal injury claim periods reflects the latency period of many radiation-induced illnesses; however, restricting all other potential claims to 10 years does not reflect the extent of possible secondary effects of radiation in the wider environment. However, even this revision is an area of concern for insurers as the industry's "loss history from so called 'long-tail' liability insurance (i.e. where insurance exposure is not extinguished after a period of a few years) has been poor and it continues to be a challenging environment"[69] as it can potentially require compensation decades after incidents which increases the economic risks.

The international conventions also act to make the courts in whose territory the nuclear accident occurred have exclusive jurisdiction. This, therefore, restricts the ability of potential victims in other countries to seek recourse in their own courts. This is one reason why "there is a clear perception among non-nuclear states that the Paris and Brussels conventions are balanced in favour of the nuclear industry"[70].

The ability to seek compensation recourse with parties other than the operator would also increase accountability and transparency, and help ensure an adequate safety culture.

Image: Greenpeace checks radiation levels in Iitate village, 40km from the Fukushima nuclear plant. Greenpeace has been conducting ongoing radiation monitoring in the Fukushima region since the disaster in 2011 to monitor and assess the ongoing threat to the population and environment.

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2.7 Conclusion

The current national and international nuclear liability laws and conventions do not ensure that victims receive full and timely compensation, and that all liabilities are indeed covered in the event of a major accident.

The liability regimes do not ensure that utilities are able to meet their economic responsibilities to compensate and to "clean up" in the event of a major accident. Rather, the current regimes primarily serve to protect the industry – this includes operators as well as nuclear suppliers – and are discriminatory against potential victims and the environment.

The experiences of Fukushima, as well as academic studies, show that even the Japanese liability regime is highly inadequate and unjust, despite the unlimited and strict liability to the operator, primarily given the operator's limited financial security compared to the financial extent of the damage. This is explained in more detail in Chapter 1.

Following the Chernobyl nuclear accident, the reform of the international nuclear liability regimes was begun, but more than 25 years later very little progress has been made. What is remarkable is that nearly 27 years after Chernobyl, 16 years after the adoption of the CSC and nine years after the adoption of the 2004 Protocols to amend the Paris/Brussels conventions, those enhancements have not entered into force. As a result, the situation has not changed significantly.[71] Most importantly, only about half of the world's nuclear power plants are operating in states that are parties to one of the nuclear liability conventions. Furthermore, many of the proposed deficiencies acknowledged at the time of Chernobyl have not been addressed; as only the revised Vienna Convention has entered into force, with all other conventions remaining as they were prior to 1986. The full implications of this situation have not been adequately highlighted following Fukushima, in part due to limited transboundary contamination resulting from Japan's geographical isolation.

National governments, parliaments and nuclear operators should seek to reform their domestic legislation to include the following factors:

- The current ceilings on compensation to third parties affected by nuclear accidents, facilitated by the international regimes, will restrict potential victims and those affected by the accident gaining the necessary compensation and should be removed.
- The channeling of liability solely towards the operator is unnecessary and unreasonable. The ability to seek compensation recourse in the event of an accident would not only benefit the potential victims, but would also increase accountability and transparency in such an event and would help ensure an adequate safety culture was adhered too across the supply chain.
- Increase transparency into the costs and scope of utilities and nuclear companies nuclear liability insurance. This would enable comparison, both within the nuclear industry and between hazardous industries.
- Ensure adequate financial coverage. The lack of adequate financial coverage is a significant distortion of the electricity market. Other energy sources are required to make additional payments or pay higher taxes for the pollution or environmental damage they cause, for example for the costs of their emissions. Without state intervention, even large and previously financially viable utilities, such as TEPCO, would be unable to survive a major nuclear accident. A major nuclear accident, as a result of the extensive loss of confidence, revenues and reputation, would almost certainly bankrupt any private utility.
- There is a growing recognition that the financial impact of off-site radiological releases goes beyond those areas actually directly affected. In particular, the complex nature of manufacturing processes can mean that loss of a particular industrial plant has much wider economic implications due to disruption of components in supply chains. Furthermore, restrictions on agriculture produce or a fall in their value has been seen to occur well beyond the areas of initial contamination.

Table 2: Signatories on international conventions and their operator liability and financial security limits

Country	Paris Convention	Brussels Supplementary Convention	Vienna Convention	Protocol Amending Vienna Convention	Joint Protocol	Convention On Supplementary Compensation	Operator Liability	Financial Security Limited
Argentina			X	X		X	54.9	54.9
Armenia			X				-	Not Specified
Belarus			X	X			Unlimited	Not Specified
Belgium	X	X					297	324
Bolivia			X				Unlimited	Not Specified
Bosnia-Herzegovina							Unlimited	Not Specified
Brazil			X				USD 160 million	USD 160 million
Bulgaria			X		X		49	49
Cameroon			X		X		Unlimited	Not Specified
Chile			X		X		51	51
Croatia			X		X		44	44
Cuba			X				Unlimited	Not Specified
Czech Republic			X		X		307	307
Denmark	X	X			X		65	65
Egypt			X		X		Unlimited	Not Specified
Estonia			X		X		Unlimited	Not Specified
Finland	X	X			X		191	191
France	X	X					91	91
Germany	X	X			X		Unlimited	2,500
Greece	X				X		16	Not Specified
Hungary			X		X		109	109
India						x	252	Not Specified
Italy	X	X			X		5	5
Japan							Unlimited	920
Korea							325	30
Latvia			X	X	X		6	6
Lebanon			X				Unlimited	Not Specified
Lithuania			X		X		5	5
Macedonia			X				Unlimited	Not Specified
Mexico			X				Unlimited	Not Specified
Moldova			X				Unlimited	Not Specified
Montenegro			X				Unlimited	Not Specified
Morocco			X	X		X	Unlimited	Not Specified
Netherlands	X	X			X		340	340
Niger			X				Unlimited	Not Specified
Nigeria			X				Unlimited	Not Specified
Norway	X	X			X		65	65
Peru			X				Unlimited	Not Specified
Philippines			X				3	Case by case
Portugal	X						16	Not Specified
Poland			X	X			164	164
Romania			X	X	X	X	164	164
Russia			X				Unlimited	Not Specified
Serbia			X				Unlimited	Not Specified
Slovak Republic			X		X		75	75
Slovenia	X	X			X		164	164
Sweden	X	X			X		326	326
Switzerland	X						Unlimited	661
Turkey	X				X		16	Not Specified
Ukraine			X		X		164	164
United Kingdom	X	X					156	156
United States						X	11,900	300
Uruguay			X				Unlimited	Not Specified

Source: NEA (2011). Nuclear Operator Liability Amounts and Financial Security Limits. As of June 2011.
Amounts in € million, unless otherwise indicated.

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3 "Convention Supplementary to the Paris Convention of 29th July 1960 on Third Party Liability in the Field of Nuclear Energy". http //www.iaea.org/Publications/Documents/Treaties/parisconv html

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5 "The Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention", September 1988. The Joint Protocol entered into force on 27 April 1992. http://www iaea org/Publications/Documents/Infcircs/Others/inf402 shtml

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7 Nuclear damage" means -

loss of life, any personal injury or any loss of, or damage to, property which arises out of or results from the radioactive properties or a combination of radioactive properties with toxic, explosive or other hazardous properties of nuclear fuel or radioactive products or waste in, or of nuclear material coming from, originating in, or sent to, a nuclear installation;

any other loss or damage so arising or resulting if and to the extent that the law of the competent court so provides; and

if the law of the Installation State so provides, loss of life, any personal injury or any loss of, or damage to, property which arises out of or results from other ionizing radiation emitted by any other source of radiation inside a nuclear installation.

8 "The 1997 Protocol to Amend the 1963 Vienna Convention", see

http //www.iaea org/Publications/Documents/Infcircs/1998/infcirc566.pdf;

the 2004 Protocol to Amend the 1960 Paris Convention see

http //www.oecd-nea.org/law/paris_convention.pdf; and

the 2004 Protocol to amend the 1963 Brussels Supplementary Supplementary Convention, see

http //www.oecd-nea.org/law/brussels-supplementary-convention-protocol.html

9 "1998 Convention on Supplementary Compensation for Nuclear Damage", see

http //www.iaea org/Publications/Documents/Infcircs/1998/infcirc567.pdf

10 The SDR is an international reserve asset, created by the IMF in 1969 to supplement its member countries' official reserves. Its value is based on a basket of four key international currencies, and SDRs can be exchanged for freely usable currencies. (for more explanation see: http //www.imf org/external/np/exr/facts/sdr htm

11 McRae, B. (2007) "The Convention on Supplementary Compensation for Nuclear Damage: Catalyst for a Global Nuclear Liability Regime", Nuclear Law Bulletin No. 79 (June 2007)

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13 IAEA (2012), "Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage", 29 May 2012. http //www.iaea.org/Publications/Documents/Conventions/protamend_status.pdf

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16 Burges Salmon (2012), "Revised Energy Bill Published", Nuclear Law Newsletter, Burges Salmon, December 2012 http://www.burges-salmon.com/Sectors/energy_and_utilities/nuclear/Publications/Nuclear_Law_December_2012.pdf

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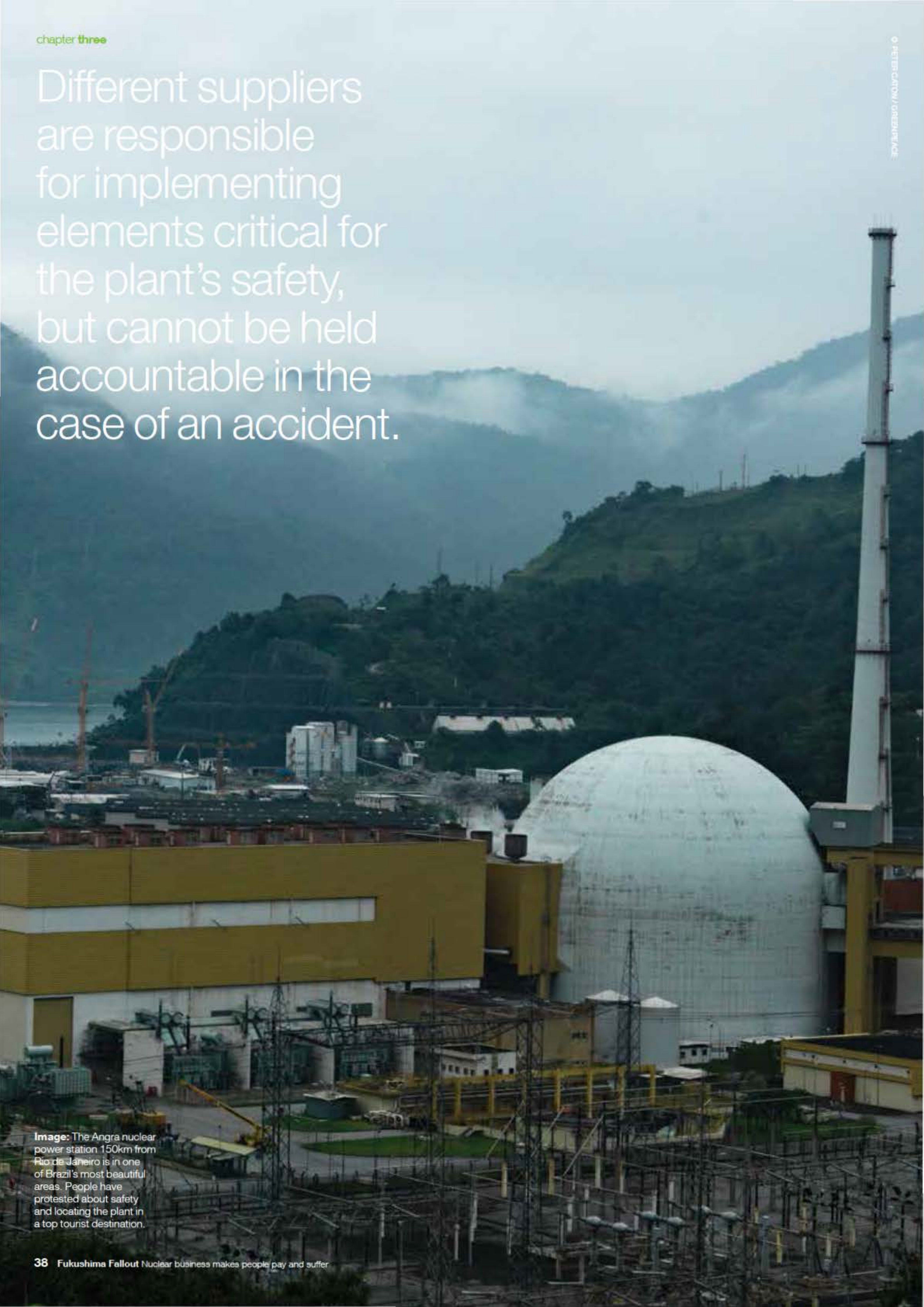

Different suppliers are responsible for implementing elements critical for the plant's safety, but cannot be held accountable in the case of an accident.

Image: The Angra nuclear power station 150km from Rio de Janeiro is in one of Brazil's most beautiful areas. People have protested about safety and locating the plant in a top tourist destination.

#3

The nuclear power plant supply chain

by Professor Stephen Thomas

Professor Stephen Thomas is Director of Research at the Business School of the University of Greenwich, UK, and he has carried out research on energy policy and particularly nuclear power for more than 30 years.

3.1 Introduction

This chapter examines the supply chain for each of the three main elements – construction, operation and maintenance, and decommissioning – of the life cycle of a nuclear power plant. It covers mainly the construction phase, which is the most complex, and also covers the operating phase, which is somewhat simpler. These are the reactor life cycle phases most likely to result in damages and liability issues in the near future that could be traced back to the suppliers of the equipment, materials and services. The decommissioning phase and long-term waste disposal are covered only briefly (see Box 1) because there is little commercial experience of decommissioning and the field of companies involved is not well established. Also decommissioning and waste disposal are less likely to result in short-term damage and liability issues, even though waste disposal in particular can cause damages for future generations.

A nuclear power plant is, on a number of criteria, very different to any other piece of industrial equipment. Its unique features include:

- **Safety requirements**. A failure at any stage in the life cycle of a nuclear power plant from start of construction to completion of decommissioning could have catastrophic consequences far beyond the bounds of the plant.
- **Cost**. The cost of a new nuclear power plant is in the order $10bn US dollars. The cost of decommissioning a plant is not well established because there is little if any representative experience of fully decommissioning a full-size commercial plant, and many of the key operations required – for example, robotic cutting up of highly contaminated materials – have not been demonstrated.
- **Plant lifetime**. The time from start of construction (typically 5-10 years to reach commercial operation), through operation (typically expected to be 40-60 years) to completion of decommissioning (expected to be up to 100 years from end of operation to release of site for unrestricted use) could be in excess of 150 years. In addition, the highly radioactive waste produced in a nuclear power plant will need to be safeguarded for hundreds of thousands of years.
- **Complexity**. A nuclear power plant comprises a vast number of components and materials, many of which are critical for safety and reliability. Many parts of the plant are difficult to access once the plant has been commissioned, and checking build quality or making modifications may be effectively impossible.

Box 1

Decommissioning

Decommissioning is the least proven of the three stages in the life cycle of a nuclear power plant. It is conventionally divided into three phases with periods of surveillance and storage in between.

Phase 1 mainly involves the removal of the spent fuel, which is dealt with under the second (O&M) stage. This is an operation that has been carried out throughout the life of the plant and is, therefore, technologically well proven. Once the fuel has been removed, the vast majority of the radioactivity has been removed from the plant and the plant no longer needs to be staffed as for an operating reactor because there is no longer any risk of a criticality. There is, therefore, an incentive to complete this operation quickly. Even though the vast majority of the radioactivity is in the fuel, the remaining structure is very hazardous and exposure to it would be damaging to health.

Phase 2 involves the removal of the uncontaminated structures, leaving mainly the reactor. This is essentially a normal demolition job and is not therefore technologically novel. There is no particular incentive to carry out the job quickly, although once it is done, the remaining plant is much cheaper and easier to monitor because the contaminated components can be sealed off and made largely inaccessible.

Phase 3 involves the cutting up and disposal of the contaminated structures. It is likely to require robotic techniques, not yet proven, and will generate a significant quantity of radioactive waste. There is little representative experience of phase 3, involving a full-size reactor that has completed a full operating life (those retired early will be much less contaminated and, therefore, easier to decommission).

The International Atomic Energy Agency identifies three strategies for decommissioning: immediate dismantling; “safestor” (enclosure for several decades prior to phase 3); and entombment.[1] The third, which involves covering over the plant, does not appear to be an option that any country has adopted.

In Europe, France, UK, Italy and Spain have not started phase 3 at any of their retired plants. Only Germany has experience of phase 3, mainly at the five reactors in former East Germany at the Greifswald site.

In the US, 22 commercial reactors have been retired and of these 12 are using the ‘safestor’ approach and, therefore, have no experience of phase 3. Of the 10 going for immediate dismantling, only seven are commercial-size reactors (>100MW) and most of these had not operated for a full life, so commercial experience is minimal.[2]

- **Need for user skills**. The reliability and safety of a nuclear power plant depends crucially on the user (i.e. the operator) providing exceptionally high-quality skills for operations and maintenance, and for managing contractors involved in construction, maintenance and decommissioning.
- **Large amount of site work**. Most of the cost of construction of a nuclear power plant is incurred at the site, and relatively little in the more controlled environment of a factory. This provides a particular challenge for the management of the construction process.

The utility (owner/operator) bears ultimate responsibility for a plant. International conventions (the Paris and Vienna Conventions and the Paris/Brussels protocol) channel liability for third-party damage to the operator of a plant, and limit the liability of the operator to an amount (on the order of $1bn) that is very small in comparison with the potential costs of a major accident.[3] In general, under these conventions suppliers responsible for design, construction and maintenance of a nuclear plant cannot be held liable for damages arising from their work.

Only in India has supplier liability been a particular issue of debate, resulting in the Civil Liability for Nuclear Damage Act, 2010. The Act places responsibility for any nuclear accident with the operator and limits total liability to 300 million Special Drawing Rights (SDR) (about €300m). However, the Act allows the operator to have legal recourse to the supplier for up to 80 years after a plant starts up if the "nuclear incident has resulted as a consequence of an act of a supplier or his employee, which includes supply of equipment or material with patent or latent defects [or] sub-standard services". This potential supplier liability may mean orders for nuclear power plants for India from foreign suppliers will not be commercially feasible.[4]

Details of the nuclear liability conventions and laws and their implications on the nuclear sector are covered in Chapter 2[5]. It is clear that the current nuclear liability conventions protect the industry by excluding supplier liability from the financial consequences of a nuclear accident, and by limiting liability for operators. No other industry enjoys this level of protection from the consequences of its actions.

This chapter explores the involvement of suppliers throughout the lifetime of a nuclear reactor, and their responsibilities in terms of nuclear risks. Risks of nuclear accidents are not only caused by the reactor operation, but design choices and construction quality are also of critical importance. For example, as was clearly demonstrated by the Fukushima disaster, the characteristics of a nuclear site need to be accurately assessed so the plant can be designed and built to resist any credible conditions such as earthquakes, flooding etc.

3.2 Construction

The construction of a nuclear power plant can be divided into three main categories of activity:

- design, engineering and procurement;
- supply of equipment (e.g. the reactor vessel), raw materials (e.g. steel and concrete) and basic goods (e.g. cabling and pipework); and
- management and execution of on-site construction (civil engineering).

A breakdown of the construction cost of a nuclear power plant, a Pressurised Water Reactor (PWR), is shown in Table 3. The PWR is the most widely used design in the world. This example relates to a Russian PWR reactor design called VVER. Different technologies, such as the other main design, the Boiling Water Reactor (BWR), will have a somewhat different breakdown of costs, as will other vendors' designs of a PWR, but this breakdown will be reasonably representative of other designs and vendors. What exactly is included in each category is not clear. For example, it is not clear what category architect engineering falls into: design of the overall design, excluding the nuclear steam-supply system[6] (NSSS), or the supply of the reactor vessel. However, the key points are that the design and supply of the NSSS represents only a small fraction, about 15%, of the cost of a plant. The cost is dominated by on-site engineering, such as construction, cabling, and installation.

Nuclear Engineering International's Yearbook provides a somewhat different breakdown of the elements, and for each reactor, names the supplier of the service. Table 4 illustrates the diversity of arrangements for a range of nuclear power plants. It shows five plants ordered in different eras, in different countries and under different procurement philosophies. The owner is generally the operator of the plant. Where a plant is owned by more than one company, one is designated as the operator of the plant or a special company is set up to operate the plant (e.g. Borssele, the Netherlands). The main contractor is normally known as the vendor and these are well-known names with a long history in the nuclear sector. However, sometimes ownership

Table 3: Cost breakdown of a nuclear power plant

Activity	% of plant cost	Possible supplier
Reactor design	?	Vendor
NSSS supply	15	Vendor, specialist suppliers
Architect engineering	?	Vendor, architect engineer, utility
Civil engineering	50	Civil engineer, utility
Electrical equipment	9	Specialist supplier
Turbine generator	6	Specialist supplier
Valves	6	Specialist supplier
Instrumentation & control	6	Vendor, specialist supplier
Other equipment	5	Specialist suppliers
Cooling	3	Specialist suppliers
Fuel	?	Vendor, specialist supplier

Source: S Boyarkin 'Presentation to the 7th Energy Forum' Eastern Institute, Sopot, Nov 29-30, 2012

Table 4: Suppliers of services for selected nuclear power plants.

	Fukushima 1	Columbia	Shin Kori 4	Dampierre 1	Borssele	Doel 3
Country	Japan	USA	Korea	France	Netherlands	Belgium
Year of order	1966	1971	2007	1973	1969	1974
Commercial operation	1971	1984	2014	1980	1973	1982
Owner	Tokyo Electric	Energy NW	KHNP	EDF	Essent/Delta	Electrabel
Operator	Tokyo Electric	Energy NW	KHNP	EDF	EPZ	Electrabel
Main contractor	GE	GE	Doosan	Framatome	KWU	Framaceco
Architect engineer	GE	Burns & Roe	KOPEC	EDF	KWU	Tractebel
Reactor system	GE Getsco	GE	Doosan	Framatome	KWU	Framaceco
Reactor vessel	IHI GE Getsco	CB&I	Doosan	Framatome	RDM	COP/Fram
Core internals	GE	GE	Doosan	Framatome Creusot	Borsig	Fram/ACE
First fuel	GE	GE	KNF	FBFC/Fram	KWU	FBFC/Fram
Steam raising	GE, Getsco	GE	Not known	Framatome	Balcke	COP
Turbine generator	GE	Westinghouse	Doosan	Alsthom	Siemens	Alsthom/ ACEC
Civil engineering	GE, Getsco	Bechtel	Not known	GCMB	Bredero	AMGC

Source: Nuclear Engineering International (2011). World nuclear energy handbook. Global Trade Media.

changes and capabilities move. For example, the main contractor for Doel 3 (Belgium) was formed by a consortium of Framatome (France, later known as Areva), ACEC and Cockerill. Neither of the latter two companies now exists in anything like their form when the plant was ordered.

A series of five plants ordered by the Washington Public Power Supply System became so notorious for cost overruns that only one of the five plants – the Columbia power plant – was actually completed. The owner's philosophy was dominated by competition considerations and all activities possible were put out to competitive tender. By comparison, the Korean plant, Shin Kori 4, was supplied by a much tighter supply chain, dominated by the utility, Korean Hydro & Nuclear Power Company (KHNP) and the main equipment supplier and vendor, Doosan with other services supplied by Korean "national champion" companies such as Korean Nuclear Fuel (KNF) and Korean Power Engineering Company (KOPEC). A similarly concentrated picture would apply for plants built in France. In the Netherlands, the Borssele plant was supplied by KWU (Germany), a company dominated by Siemens, which specialised in design rather than equipment supply, with the notable exception of the turbine generator. The Doel plant was ordered before the French nuclear power plant supply industry had been fully established so the equipment and services came from a wide range of suppliers, most of which do not now exist in anything like their form then.

3.2.1 Design, engineering and procurement

The design, procurement and engineering activities can be split into three roles: the reactor vendor, the architect engineer (A-E), and the engineering, procurement and construction (EPC) contractor. The boundaries between these roles are sometimes blurred, and there is overlap between the set of companies involved. For example, a reactor vendor like Mitsubishi could carry out all three activities, while Bechtel could be the A-E and the EPC contractor. The supply of the first fuel charge is conventionally included in the construction cost, but the suppliers are the same as those involved in supplying new fuel during the life of the plant and are considered in the Operations and Maintenance (O&M) section.

3.2.1.1 Vendors

The vendor market in its current form was largely set by 2006 when the Westinghouse (based in US) nuclear division was taken over by Toshiba (Japan). The world market, which by then was, and remains, extremely small, was dominated by three established companies with markets in the West: Toshiba, supplying PWR and BWR technology; Areva (France), supplying PWR and, potentially BWR technology; and Hitachi-GE supplying BWR technology. Three further suppliers, Atomstroyexport (ASE, Russia), supplying VVER (the Russian version of the PWR) technology; China, supplying PWRs; and Korea, supplying PWRs are now an increasing presence on the world market. Atomic Energy of Canada Ltd (AECL), now privatised and owned by the Canadian company SNC Lavalin, and Mitsubishi continue to offer plants but with limited chance of success. India supplies its home market with scaled-up versions of the Canadian-designed CANDU reactor it imported in the 1960s, but there appears no prospect of it being able to export these designs. China is the most complex and potentially the most significant of the new suppliers, and it is dealt with separately. Table 5 gives an overview of the designs available and their status.

Toshiba

In 2006, Toshiba bought the Westinghouse reactor division from British Nuclear Fuels Limited, a publicly owned nuclear company. By then, Westinghouse included the reactor supply divisions of Combustion Engineering (US) and ABB (Switzerland/Germany/Sweden), which was formed from the merger of the reactor divisions of Brown Boveri and Asea. Up to that time Toshiba (and its Japanese competitor Hitachi) had BWR technology licences with GE, and orders for Japan were split between Hitachi and Toshiba. Another design, Advanced Boiling Water Reactor (ABWR) technology, was jointly developed by GE, Hitachi and Toshiba. Toshiba ended its licence agreement with GE, and is now offering ABWR technology in competition with Hitachi-GE.

Toshiba's ABWR has been chosen for the US South Texas project, although it is unlikely that this project will proceed. The ABWR received approval from the US regulator, the Nuclear Regulatory Commission (NRC), in 1997, which expired in 2012. Toshiba applied for the approval to be renewed in 2010, and has submitted proposed design modifications so that the design meets current standards, but approval has not been given yet. In January 2013, there was no NRC target date for completion of this review.

The other main design Toshiba offers apart from the ABWR is the AP1000, already under construction in China (two each at Haiyang and Sanmen) since 2009, and first concrete is expected in 2013 for reactors in the US (two each at Vogtle and Summer).

In December 2012, Toshiba announced it was seeking to sell a 36% stake in its Westinghouse division. It was reported that three companies, including Chicago Bridge and Iron Company (CBI) — a Dutch-owned company based in the US — were interested in purchasing a 20% stake, and three other companies were interested in a 16% stake. Toshiba was reported to be expecting ultimately to retain only a 51% stake in Westinghouse.[7]

Areva

Areva NP was formed in 2002 from the nuclear divisions of Framatome and Siemens. Framatome was by then part of the Areva group, largely owned (92%) by the French government. Areva (66%) and Siemens (34%) merged their reactor supply businesses to form a joint venture, Areva NP. In 2009, Siemens announced its intention to withdraw from this joint venture and Areva NP is now wholly owned by Areva. It offers the European Pressurised water Reactor (EPR), the Atmea1 design (in a joint venture with Mitsubishi, Atmea) and potentially, the ACPR1000 in joint venture with CGNPC (China). It is also offering a BWR design, Kerena, although this is not available for purchase yet.

Table 5: Current Generation III/III+ designs on offer.*

Vendor	Design	Sales	Generic review
Toshiba/Westinghouse (Japan/US)	AP1000 (PWR)	USA (2), China (4)	US complete 12/11. UK process suspended
Toshiba/Westinghouse (Japan)	ABWR (BWR)	Earlier model to Japan (4)	US approval expired 2012. Renewal applied for 10/10. No completion date specified
Hitachi GE (Japan/US)	ESBWR (BWR)	-	US awaiting final rule-making
Hitachi GE (Japan/US)	ABWR (BWR)	Earlier model to Japan (2), Taiwan (2)	US approval expired 2012. Renewal applied for 12/10. No completion date specified
Areva (France)	EPR (PWR)	Finland (1), France (1), China (2)	UK approval 2013 US approval 2014
Areva (France)	ATMEA1 (PWR)	-	Not started
Areva (France)	Kerena (BWR)	-	Not started
ASE (Russia)	AES-92	India (2)	Not known
ASE (Russia)	AES-2006	Russia (5), Turkey (4), Vietnam (4)	Not known
Mitsubishi (Japan)	APWR	-	US approval 2015
Korea	AP1400	Korea (3), UAE (4)	Not started
AECL	Enhanced Candu 6	-	Not started

Source: Author's research.

** The nuclear industry has been developing nuclear technology for decades. Generation III and III+ designs are allegedly improvements on the Generation II deisgn, but the distinction from Generation II is arbitrary. Generation II, the most common design, was developed in the 70s and 80s, Generation I in the 50s and 60s.*

Box 2

The UAE nuclear order from Korea

In December 2009, the UAE ordered from Korea four nuclear reactors using AP1400 technology, beating opposition from consortia led by EDF (including GDF Suez, Areva, Total) with the EPR and GE-Hitachi (ABWR).[14] The contract is with the Korea Electric Power Corp (KEPCO) to build and operate the plants, the first coming on line in 2017 and the last by 2020. KEPCO will provide design, construction and maintenance for the nuclear reactor and will subcontract some of the work to equipment suppliers such as Hyundai, Doosan and Samsung. The terms of the deal and what is included are not clear although the contract is reported to be worth $20.4bn US dollars. The Korean bid was reported to be $16bn lower than the French bid, and the GE-Hitachi bid was reported to be significantly higher than the French bid.[15] It appears not to be a whole project "turnkey" (fixed price) deal. Korean companies will hold an equity stake in a joint venture with UAE public companies, which will operate the plants after their completion. Construction work on the first of these at the Barakh site started in July 2012.

Other export markets Korea has competed in, so far unsuccessfully, include Turkey and Jordan. The design being built in Korea and UAE, without a "core-catcher" and a "double containment", probably would not be licensable in Europe. Areva was particularly bitter about losing the tender to a design it claimed had much lower safety standards than their EPR. Their then CEO, Anne Lauvergeon, likened the APR1400 to "a car without seat belts and airbags".[16] Nevertheless, UAE's newly formed Federal Authority for Nuclear Regulation (FANR) has required changes to the reference design (the South Korean plants Shin Kori-3 and -4) to reflect the lessons from Fukushima. It had not been determined by September 2012 who would pay these extra costs.[17]

Some of the finance for the UAE project came from the US ExIm bank on the basis of the benefits to the Westinghouse company (owned by Toshiba), now owner of the technology licence following the absorption of the Combustion Engineering nuclear division into the Westinghouse reactor business, even though this is now owned by Toshiba. Westinghouse will provide the reactor coolant pumps, reactor components, controls, engineering services, and training.[18] The ExIm bank provided a $2bn direct loan to the Barakah One Company of the UAE to underwrite the export of American equipment and expertise. There is a lack of clarity over the ownership of Barakah One.[19] The partners in the project are KEPCO and Emirates Nuclear Energy Corporation (ENEC). KEPCO is entitled to take a share of ownership in the Barakah plant but, by September 2012, it was not clear whether they had taken one.

Hitachi-GE

After the take-over of Westinghouse by Toshiba and its emergence as a competing supplier of BWR technology, GE and Hitachi set up joint ventures in 2007. GE-Hitachi, 60% GE, 40% Hitachi, covers its US operations and Hitachi-GE, 80% Hitachi, 20% GE, for the rest of the world[8]. Both joint ventures market their BWR designs, the Economic Simplified Boiling Water Reactor (ESBWR) and the ABWR.

The ESBWR is a passive-safety design that was reportedly near completion of its regulatory review in the US in 2012. However, there was a delay and it is not clear when final approval will be given.[9] While there was some interest among US utilities, none of them appear likely to proceed and one switched to the older ABWR design supplied by Toshiba.

The ABWR received approval in 1997 from the US regulator, the NRC, which expired in 2012. Like Toshiba, Hitachi-GE applied for the approval to be renewed in 2010, and has submitted proposed design modifications so that the design meets current standards, but approval has not been given yet. In January 2013, there was no NRC target date for completion of this review. Hitachi-GE was chosen as the preferred supplier for a reactor to be built in Lithuania, but an order now seems unlikely after a referendum on nuclear power in October 2012 came down decisively against it.[10] In 2012, Hitachi-GE bought Horizon, a joint venture set up by two German utilities, RWE and EON, to build nuclear power plants in the UK.[11]

KEPCO/Doosan

After buying plants from Westinghouse, Framatome and AECL, the Korean nuclear industry (made up of the utility, Korean Electric Power Company and the equipment supplier Doosan) began to take a larger part in nuclear orders for Korea using Combustion Engineering technology. Initially they used an old design, System 80, which evolved into their OPR (Optimised Power Reactor) of 1,000 megawatts (MW) with 12 orders for Korea. The later Combustion Engineering System 80+ design received generic approval from the NRC, US regulatory authority, in 1997 (this expired in 2012) and the Korean nuclear industry bought a technology licence for this design from Westinghouse.

For the future, the most important Korean design is the AP1400 derived, under licence from Combustion Engineering, from the System 80+ design. The licence now resides with Toshiba/Westinghouse, although they are no longer marketing the design. Construction work in Korea on the first two units of this design (Shin-Kori 3 & 4) started in 2009. Construction on a third (Shin-Ulchin) started in 2012. Korea emerged as a potentially significant exporter of nuclear technology with its winning of a competitive tender in UAE in 2009 (see Box 2). In 2010, Korea claimed it would submit the AP1400 to the US NRC for generic design review in 2012.[12] By November 2012, the target date for submission was March 2013.[13]

AtomStroyExport (ASE)

After nearly two decades of limited marketing effort following the Chernobyl disaster, the Russian nuclear industry began to compete aggressively in export markets with its VVER technology, buoyed by the resumption of ordering in Russia. Since 2007, construction of seven new reactors has started in Russia, five using ASE's latest design, AES-2006, and two using an earlier design. For some markets, such as Jordan, it is offering the earlier AES-92, already built in India (Kudankulam) which was awaiting commercial operation in January 2013.

Atomic Energy of Canada Ltd (AECL)

Atomic Energy of Canada Ltd continued to win a trickle of orders for its CANDU reactors from 1980 onwards, for example in China and Korea, although both countries seem to have abandoned further orders of the CANDU. With no orders for its home market for 30 years and limited future prospects, AECL, previously owned by the Canadian federal government, was sold to the Canadian engineering company SNC Lavalin for a minimal amount ($15m Canadian dollars) in 2011.

While it still appears in bidding lists, for example to Jordan and Romania, the prospects of further orders are limited and the technologies it offers are based on designs first offered more than 35 years ago. It appears to have abandoned or at least put on ice its new generation designs, the ACR700 and ACR1000.

Mitsubishi

After the purchase of the Westinghouse reactor business by its Japanese competitor, Toshiba, in 2006, continuing a relationship with Westinghouse was not viable for Mitsubishi and it began to market reactors independently, initially its APWR design. This had been under development since 1980 but promises of orders for Japan had not been fulfilled. Two planned orders (Tsuruga) have been continually delayed and may not proceed after the Fukushima disaster. Further modifications were undertaken and the APWR (1,700MW) began the process of generic review by the NRC in 2007. In 2012, the NRC was forecasting completion of the review in 2015, but the one US utility, Luminant, interested in the design is not close to ordering the two units (Callaway) it plans.[20] The joint venture, Atmea, between Mitsubishi Heavy Industries and Areva was announced in 2007, when they stated that a 1,000MW design, to be called Atmea1, would be developed using technology from both companies. By 2012, there was some interest in this design from markets such as Jordan, Turkey and Argentina, but the detailed design work had not started in 2012 and the design has not started a generic review anywhere yet. Until such a review is complete, exporting will be difficult.

China[21]

China is potentially the most important new vendor to emerge on the world reactor market. After nearly two decades of ambitious forecasts of nuclear ordering not being achieved, China began to order large volumes of plant in 2008. From 2008-10, construction was started on 25 units. Of these, 19 were supplied by Chinese vendors, 15 using the CPR1000 design and two using the similar CNP1000 design and two using the smaller CNP600 design. It also imported four reactors from Toshiba/Westinghouse (AP1000) and two from Areva (EPR), with strong technology-transfer provisions. Its older CNP300 and CNP600 designs appear to still be available. Construction was started on two export orders to Pakistan for the CNP300 design in 2011 and construction on two CNP600 reactors in China was started in 2010.

Table 6: Chinese-designed reactors

Vendor	Design	Intellectual property	Sales	Markets	Status
CGN	CPR1000	Licensed from Areva	18	China	Still available
CGN	ACPR1000	Joint development with Areva?	0	China +	Not licensed
CNNC	CNP300	Indigenous	5	Pakistan, China	Still available
CNNC	ACP300	Indigenous	0	China +	Not licensed
CNNC	CNP600	Indigenous	6	China	Still available
CNNC	ACP600	Indigenous	0	China +	Not licensed
CNNC	CNP1000	Licensed from Areva	2	China	Development stopped
CNNC	ACP1000	Indigenous	0	China +	Not licensed
SNPTC	CAP1400	Joint development with Westinghouse	0	China +	Not licensed

Source: Author's research.

The construction and operating phases of a reactor are most likely to result in damages that could be traced back to suppliers.

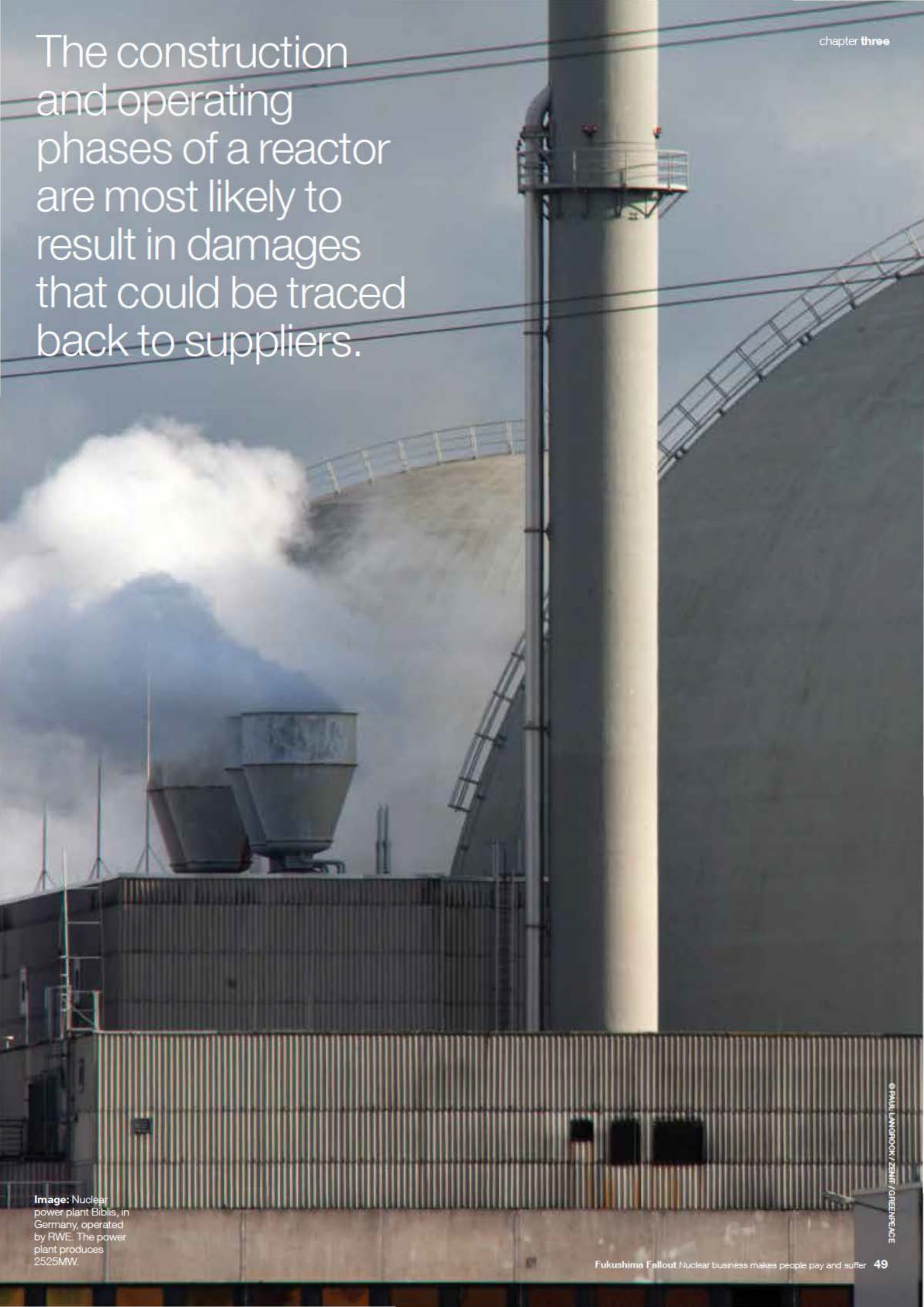

Image: Nuclear power plant Biblis, in Germany, operated by RWE. The power plant produces 2525MW.

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There is considerable development, not covered here, of fuel-cycle activities and Chinese companies have been active buying uranium resources, for example, in Kazakhstan. The programme to develop high-temperature reactors in China (using the German pebble bed design) was resumed in January 2013 after a delay following the Fukushima disaster with start of construction of a 200MW demonstration plant at Shidao Bay but this design is some way from commercial deployment.[22]

Fast-reactor designs are also being developed but do not appear to be close to commercial deployment, or a high priority, and are also not discussed further. For the future, the most relevant designs are Chinese designed PWRs, the AP1000 and the EPR. Table 6 shows the status of the designs already built and proposed for China.

The future world market for vendors

The so-called "nuclear renaissance", first talked about more than a decade ago, was expected to see a revival of nuclear ordering in the West, based on new reactor designs offered by the traditional Western vendors, for example, Areva's EPR, Westinghouse's AP1000 and GE's ESBWR. This surge of orders in the West has not happened and the reactor market, in terms of vendors and designs, is dramatically different to that of only a decade ago. The main changes include:

- Increased control of the main vendors by Japanese companies. Westinghouse was taken over by Toshiba; Toshiba has split from GE and is now competing against it for BWRs; Hitachi seems to dominate the joint ventures with GE for sales of BWRs; Mitsubishi is trying to establish itself as a frontline vendor through its APWR and through its Atmea joint venture with Areva;
- Before the Fukushima disaster, Japan seemed poised to make a major effort for the first time to enter the international market with much stronger coordination and support from the Japanese government, for example, with loan guarantees. If this support is not maintained, it is not clear how successful Japanese companies will be in winning exports;
- China, with its complete supply chain, has emerged as a potentially important vendor although, until China resumes ordering reactors following its halt on orders after the Fukushima nuclear disaster, it will not be clear which technology/technologies will be offered. The options include: the EPR and AP1000 under licence, the CAP1400 jointly with Westinghouse; a 1,000MW design, yet to be defined jointly developed with Areva[23]; or indigenous designs, the ACP1000 and ACPR1000;
- Korea has emerged as a global vendor of nuclear power plants with the winning of a large order for its AP1400 for UAE;
- Russia has moved outside its traditional markets of Eastern Europe and former Soviet Republics to markets in developing countriess, such as Vietnam. It would also like to get a foothold in the West, for example, via entry to the UK market;
- India remains a potentially large market for reactors and has a reactor supply industry but seems a long way from being able to compete on international markets.

Shifting of roles

A key issue in reactor orders is the availability of finance and it is now clear that, unless there is a strong and credible guarantee that full cost recovery from consumers will be possible, reactor orders will only be possible with state, or state-backed finance. Vendors seem, for the first time, willing to take equity stakes in reactors. Examples include Russian companies in Turkey, Hitachi-GE in Lithuania, Chinese companies in the UK, Areva in the UK and Korean companies in the UAE. This further blurs the line between operators and suppliers, raising additional questions about who carries responsibility and could be held liable in case of accidents. It remains to be seen whether vendor ownership of operating plants is a viable business model. As was demonstrated by the collapse of British Energy in 2002, when a fall in the wholesale electricity price led to it reportedly losing £2m a day,[24] electricity generation is a huge cash flow business and if a project goes badly, even a large vendor would be in serious difficulties.

In Russia, the Turkish Akkuyu project for four reactors of Russian design will be a Build-Own-Operate (BOO) deal, the first time this model has been used for a nuclear plant. The company that will own the plant is a Russian consortium dominated by the Russian reactor supply company, Rosatom (92.85%) with minor holdings from Inter RAO (the Russian utility) and AtomStroyExport.[25]

The Russian consortium is arranging financing of the project, backed by a 15-year Power Purchase Agreement (PPA) with Turkey's state electricity wholesaler Tetas, for around half the total output — 70% of the first two Akkuyu units and 30% of the second two. The power is to be sold at a weighted average price of $123.5/MWh, with a ceiling of $153/MWh.[26] If construction costs overrun or if operating costs are higher than expected, the Russian owners could lose large amounts of money. Where PPAs become uneconomic, the plant owners have typically tried to renegotiate the terms, shifting the risk to consumers.

In Lithuania, Hitachi-GE was expecting to take 20% of the Visaginas plant comprising one ABWR. Lithuania was expected to take 38% and Latvian (22%) and Estonian (20%) were expected to take the rest of the equity.[27] However, a referendum in October 2012 before the agreement was finalised was decisively against the project, and there seems little prospect it will now go ahead. It is therefore not clear whether the proposed model was viable.

In the UK, Hitachi-GE bought Horizon, a joint venture set up by two German utilities, RWE and E.ON, to build nuclear power plants in October 2012.[28] However, before Hitachi-GE can build in the UK, the ABWR will have to go through the UK's Generic Design Assessment process, likely to take about five years. So it is too early to say what the form of Hitachi-GE's involvement in the UK would be. Russian and Chinese companies and Areva were also reported to have bid for Horizon.[29]

3.2.1.2 Architect engineering

The role of architect engineering (A-E) is particularly prominent in the US where, in the past, utilities have not had the size and capability to design power plants of all types, and used specialist architect engineers to integrate the elements of a nuclear power plant into an overall design. Most utilities had long-term relationships with their favoured A-E, which in turn might tend to use the same equipment vendor, and nuclear power plants were built using the same model. Some of the larger utilities, like the Tennessee Valley Authority (TVA), did their own A-E but for those that did not, about a dozen A-Es were involved in the US nuclear power programme.[30] Some of these are still active, such as Bechtel, while others have exited the business, for example Stone & Webster.

The lack of standardisation among US plants and cost overruns are often blamed on the A-E, which generally has no incentive to use standardised designs and in some cases, simply produced poor designs.

In some cases, the vendor takes this role, for example Siemens or Areva, while in others the utility takes the role, for example EDF. One of the factors behind the problems at the Olkiluoto plant in Finland (see 3.2.4) is often said to be Areva's inexperience in this role[31].

3.2.1.3 Engineering, procurement, construction (EPC) contractors[32]

The EPC role of overall project management has become more prominent as attempts are made to introduce nuclear power into markets in smaller or less developed countries where the utility may have limited capability and the industrial base is not very strong. An effective EPC contractor is likely to need strong skills in project and construction management in the nuclear industry and from other complex projects, as well as good skills in procurement to ensure the complex supply chain is well managed.

The field of companies involved in EPC include utilities such as Korean Hydro and Nuclear Power Co (not only for plants to be owned by themselves), architect-engineers such as Bechtel, specialist nuclear companies such as AtomTechnoProm and nuclear vendors, although this is not common.

3.2.2 Equipment and materials supply[33]

The World Nuclear Association (WNA) portrays the supply chain as a pyramid with six tiers and it gives two examples of this chain.[34] From the bottom, these tiers are:

- Raw material suppliers and miners (e.g. silver, zinc etc);
- Processors/fabricators (e.g. alloys);
- Sub-component suppliers/distributors (e.g. control rods and heavy forgings);
- Original equipment manufacturers (e.g. rod cluster control assembly);
- System integrators (e.g. reactor pressure vessel and steam generator);
- Technology vendor, supplier of the nuclear steam-supply system (NSSS).

A nuclear power plant contains millions of items, each with its own supply chain.

The major discrete items of equipment in a nuclear power plant are: the turbine generator; the reactor pressure vessel; the containment structure; the reactor internals and reactor pumps; and valves. All these items must be specifically designed for nuclear power plants.[35] The discrete items of equipment can be divided into three categories according to how safety-relevant they are, and to how specific they are to a particular reactor design:

- Nuclear industry-grade components specific to the reactor design (e.g. the reactor pressure vessel);
- Nuclear industry-grade components not specific to the design (some valves and pumps); and
- Commercial-grade components (e.g. the turbine generator).

The nuclear industry-grade components specific to the reactor design are nearly all in the nuclear island — the reactor area where systems producing heat, through nuclear reaction, deliver heated water to the conventional island, where electricity is produced. The nuclear industry-grade components not specific to the design are found in the nuclear island, the conventional island and in the balance of the plant. The commercial-grade components are mostly in the conventional island and the balance of the plant, although there are important items, such as cranes and electrical power systems, in the nuclear island. This means that major systems comprise items of differing grade, supplied by many different suppliers.

Items of safety significance generally have to be produced in a facility that has been certified as meeting the required standards by a credible authority. For example, in the US, facilities have to be given approval by the American Society of Mechanical Engineers (ASME). Setting up production facilities was, therefore, a major commitment for a component supplier.

In the main period of nuclear ordering in the 1970s in the US and from 1975-85 in France, vendors and suppliers had a sufficient volume of orders to set up production-line facilities, but as ordering rates have fallen, components have to increasingly be fabricated on a one-off basis, increasing their cost. Regulation and certification by, for example ASME, should ensure the quality is equivalent.

Design-specific nuclear industry-grade components will generally have to be produced in production facilities designed to produce that specific item. When designs change, the facilities supplying the equipment likely will also change. This means that even when there is a large and reasonably assured design for nuclear power plants, as for example in China, the supply chain may still not be adequate if the design to be used has not been decided. If the design changes, the supplier will have to make major investments in production facilities.[36] For US, European and Japanese vendors, where it is not clear there is a substantial market for any of their designs, it will be a major risk for equipment suppliers to invest in production facilities.

3.2.2.1 The nuclear reactor

The reactor itself is a hugely complicated piece of equipment whose supply is the sole responsibility of the vendor, who will sub-contract individual parts to specialist contractors. It comprises a reactor pressure vessel, its internal structures (such as the reactor core shield) and immediate auxiliary hardware (such as the driving mechanism for control rods). The reactor is surrounded by other vital devices and components, such as primary cooling pipes, coolant pumps, pressuriser, injector of boron, and in most designs also steam generators that separate the primary circuit from a secondary one.

3.2.2.2 The reactor vessel

The reactor vessel is perhaps the most extreme example of a nuclear-specific component (see Box 3). Production requires highly specialised skills and facilities, in particular ultra-heavy forging presses. In 2012, there was reported to be only one supplier, Japan Steel Works, which had a capacity of three vessels a year (see Box 3), to supply the pressure vessel for an EPR. The World Nuclear Association[43] reported there were nine specialist steel-supplier companies with facilities able to produce large forgings, in Japan, China, Russia, Korea, France, Germany, India, Czech Republic and the UK.

There is then a second field of about 20 largely different companies that use these forgings to produce the pressure vessels. Some of these are different divisions of a reactor vendor (e.g. Areva and Mitsubishi Heavy Industries), while some are specialist companies, such as Babcock & Wilcox (US).

3.2.2.3 The containment

The secondary containment is a reinforced structure that envelops the reactor and other parts of the NSSS, in order to protect them from external events but also to contain any radiation leaks that may occur from the primary circuit. It is an airtight chamber, often composed of single or double pre-pressed (or reinforced) thick concrete walls and ceiling, integrally attached to the reactor's basemat. For better air tightness, the secondary containment often has a steel liner on its internal surface. It is supplied and built as a part of the civil engineering work at the nuclear power plant, though it has to meet very high industrial standards.

The containment usually also has accompanying devices, such as spraying systems to suppress the internal pressure, and hydrogen re-combiners to prevent accumulation and explosion of hydrogen, in the case of a major accident. The containment also needs to have a number of penetrations to allow the piping carrying steam to reach the conventional parts of the power plant, as well as enabling access for staff, machinery (exchange of fuel or components) and electric cables. Additional pieces of equipment are supplied to keep those penetrations airtight.

Each reactor design has a separate supply chain comprising a large number of companies of various types. The WNA gives examples of six of the companies involved in the supply of the containment structure for Areva. These include three French companies (e.g. Bouygues Construction), a Swiss company (VSL International), a German company (Babcock Noell Nuclear Gmbh) and a Chinese company (SEPCO).

3.2.2.4 Steam generators

Steam generators are required in PWRs in which the reactor coolant water goes through a secondary circuit (the steam generators) in which the steam to drive the turbines is produced. In BWRs, the reactor coolant water drives the turbines directly. Steam generators also require large forgings, for example, the four steam generators in an EPR weigh about 500 tonnes each. The WNA lists about 16 suppliers, with considerable overlap between suppliers of steam generators and the suppliers of containment vessels.

Unlike the reactor vessel, which is a life-limiting component – in other words, if the vessel is not serviceable, replacing it is not an option – steam generators can be replaced and because these have not proved as durable as expected, there is a substantial market in replacement steam generators. These can be supplied by the original equipment supplier or by a competing company. Suppliers listed by WNA include:[44]

Box 3

The reactor pressure vessel

Complexity of manufacture

The reactor pressure vessel is one of the most safety-sensitive components in a PWR. If the integrity of the reactor vessel cannot be guaranteed, the safety of the plant is in serious doubt because the assumption is that if there is a flaw in the vessel it will rupture before it leaks, so there will be no advance warning.

The issues in 2012 surrounding the pressure vessels supplied by Rotterdamse Droogdok Maatschappij (RDM) illustrate the complexity of the issues. In 2012, inspections at the Doel 3 plant revealed thousands of cracks in the pressure vessel. The reactor was closed pending investigations into the extent and severity of the cracks and the future of the 21 reactors worldwide with reactor vessels supplied by RDM.[37] Similar flaws were found in Tihange-2 whose pressure vessel was also supplied by RDM.[38] These were a very diverse set of reactors ranging in size from about 50MW to 1,300MW, using three different technologies and from about 6 different vendors. By December 2012, it was still not decided whether Doel 3 and Tihange-2 would be allowed to go back into service. The vessel was supplied by RDM which had met the ASME (American Society of Mechanical Engineers) requirements of the day.[39] However, the manufacture of the vessel was more complicated than that. It was reported that[40]: "In the case of Doel 3, the raw materials for the reactor shells was supplied by Krupp, the forging by RDM, the cladding and assembling by Cockerill for the lower part (two core shells, transition ring and bottom plate) and by Framatome (now Areva NP) for the upper part comprising the RPV head, nozzle shell, and the final assembly."

It is believed the cracks were created during the manufacturing process, but it is far from clear at time of writing who was responsible for the errors that caused them. They were only revealed because of the use of a new ultrasonic sensor so it may not be possible to determine when these flaws occurred.

Specialised facilities

In recent years, there has been considerable publicity about bottlenecks in the supply chain because the dearth of orders has led to closure of many of the certified manufacturing facilities. Of particular concern is the manufacture of the pressure vessel, for which only one supplier, Japan Steel Works (JSW) has the facilities to produce the ultra large forgings needed to produce a reactor vessel in one piece for the very largest reactors, such as the Areva EPR. The alternative of welding together a vessel made up of several parts is usually seen as less desirable.[41] The capacity of JSW was only three vessels per year. Despite the obvious risk of a bottleneck, no other company was willing to make the investment of $900m US dollars in a 14,000 tonne steel press. JSW built another one that came on-line in 2010.[42] Plans by Doosan (Korea) and Sheffield Steelmasters (UK), which has a 30-year-old press of 13,000 tonnes, to build similar presses did not materialise. However, the global re-evaluation of nuclear power following on from Fukushima has meant that orders have dried up and the second JSW press might not have been justified.

- China: China First Heavy Industries, Dongfang Electric Corporation, Dongfang Heavy Equipment Limited, Harbin Boiler Company;
- Korea: Hyundai Heavy Industries, Doosan;
- Areva (France);
- Babcock-Hitachi KK (Japan);
- AtomEnergoMash (Russia);
- DCD Dobryl (South Africa); and
- ENSA (Spain).

Tubing for steam generators is supplied by another set of companies including: Vallourec and Vanatome (France); Alfa Laval (Sweden); Armatury (Russia); Larsen & Toubro (India); Sandvik (Sweden); and Sumitomo (Japan).

3.2.2.5 Pumps and valves

Pumps and valves are found in many systems of a nuclear power plant, in some cases in safety-related areas. A typical PWR or BWR has about 5,000 valves and 200 pumps. The WNA lists more than a dozen suppliers of the more specialised types of pumps. Some are specialist pump companies (e.g. Curtiss-Wright), while others are divisions of diversified companies that include reactor vendor divisions, e.g. Areva and Mitsubishi. The main pump suppliers include: AtomEnergoMash, HMS Pumps (Russia); Areva (France); Dongfang Electric Corporation and Shanghai Electric Heavy Industry Group (China); and Mitsubishi and EBARA (Japan).

Specialist valves and actuators (motors that drive valves) are supplied by specialist companies including some that also supply pumps (e.g. Flowserve). The WNA lists 16 suppliers of valves and actuators including: Arako spol s.r.o. (Russia), AUMA (Germany), Armatury (Russia), Larsen & Toubro (India) and Samshin Ltd (Korea).

3.2.2.6 Turbine generators

The turbine generators, that convert energy into electricity, have traditionally been the major item in a thermal power station, and they remain a major item of expenditure for a nuclear power plant. Many of the original nuclear vendors were suppliers of turbine generators for fossil-fired plants, e.g. Siemens, GE and Westinghouse.

There about a dozen suppliers of turbines for large reactors and several of these also supply the reactor. These include: Dongfang Electric Corporation, Harbin Electric and Shanghai Electrical (China); Bharat Heavy Electricals, and Larsen & Toubro (India); OMZ and AtomEnergoMash (Russia); Alstom (France); Doosan (Korea); Mitsubishi (Japan); Siemens (Germany).

3.2.2.7 Raw materials and small components

Large amounts of raw materials such as steel and concrete, with stringent specifications, are required in the construction of a nuclear power plant. In recent years, there have been serious problems at the construction sites of the Olkiluoto (Finland) and Flamanville (France) EPR plants because of poor quality control in the pouring of the concrete base-mat.[45]

A typical PWR or BWR includes 210km of piping and 2,000km of cabling with varying functions and specifications. This is mostly nuclear industry-grade non-specific or commercial-grade and is, therefore, open to a large number of potential suppliers. Responsibility for ensuring the quality of the materials and components varies according to how the project is carried out, but lies broadly with the company carrying out the EPC (engineering, procurement and construction) functions.

3.2.3 Civil engineering

As Table 3 illustrates, the on-site installation and construction represents by far the largest element of the cost of a nuclear power plant, and is notoriously the most difficult cost element to control because of the large number of sub-contracts involved, and because a construction site is much more difficult to manage than the more controllable environment of a factory. The companies involved are large engineering companies, not particularly dependent on the nuclear industry, with experience in large projects, such as rail links and other types of power plants. In recent years, companies such as Kajima (Japan), Daewoo and Samsung (Korea) and Bouygues (France) have taken this role. Their contribution and in particular their quality control is crucial to the overall quality of the plant.

3.2.4 Problems in the construction phase

Few nuclear projects are built to time and cost, and many substantially overrun their forecast construction time and cost. These problems were well illustrated by the severe problems with the construction of an Areva-supplied EPR at the Olkiluoto site in Finland.

Problems at Olkiluoto have occurred since the project began in 2004. The main concerns are about the strength of concrete, welding quality, delays in engineering design, supplier inexperience and poor control over subcontractors[46]. The problems continue, pushing the expected completion date to 2014 from the original 2009.[47] The costs have more than doubled to about €8.5bn from the original estimate of €3.2bn.[48]

In Korea in 2012, it was discovered that more than 5,000 small components installed at units 5 and 6 of the Yeonggwang plant were certified with forged safety documents. The plants had already entered service and were shut down for nearly two months while investigations took place and these parts were replaced.[49] Korea's high level of dependence on nuclear power meant the closure of these plants jeopardised the security of electricity supply in Korea.

3.3 Operations and maintenance (O&M)

The supply chain for the O&M phase is somewhat simpler than for the construction phase but more difficult to define. It involves: the day-to-day operation; routine maintenance, usually on an annual basis; repair and replacement of failed equipment, sometimes during routine maintenance and sometimes, if the failure is safety related or serious, in an unplanned outage; supply of new fuel; and dealing with spent fuel.

Unlike construction where the activities and equipment needed are largely predictable and predetermined, not all the activities and purchases for the O&M phase are predictable. Refuelling and some routine maintenance are relatively predictable but some operations such as a non-routine repair or replacement will be determined by the plant's operating history, and repairs may have to be planned and carried out by methods designed specifically for the plant. This makes the field of companies involved in the O&M phase more difficult to define.

3.3.1 Operation

This is invariably the responsibility of the owner/operator (utility), which must satisfy the national regulator that the operators are suitably qualified and competent. For the future, if the arrangements proposed for Turkey, the UAE and perhaps Vietnam are followed elsewhere, the operator may be a foreign company, and suppliers themselves may have a share and thus be co-owners of the operator.

In most countries, reactors are owned and operated by a single large utility (e.g. France, Czech Republic, Hungary, Korea, Brazil, Mexico and Belgium) or a small number of large utilities (for example, Japan, Germany, Spain and Sweden). In the US, there are a large number of utilities owning nuclear power plants ranging from very large utilities, for example the Tennessee Valley Authority (TVA), to very small utilities for which a single reactor represents a large proportion of their total assets. There has been some consolidation of ownership. For example, PECO (Philadelphia), which owned (or owned majority shares in) six nuclear reactors merged in 2002 with Unicom, which owned 10 nuclear power plants to form Exelon. Exelon took over a number of other nuclear plants in the US and merged with another utility, Constellation, in 2012, making it the largest nuclear power plant owner in the US with about 19GW of installed nuclear capacity.[50] The new company is also called Exelon.

Generally, the largest utilities, especially those with strong government backing, are more heavily involved in the supply chain. For example, the French utility EDF carries out its own architect engineering and is heavily involved in the design process for the nuclear steam-supply system (NSSS). Smaller utilities are more likely to sub-contract activities in the O&M phase.

3.3.2 Routine maintenance

This is usually carried out during a refuelling outage which takes place at 1-2 year intervals. It is often carried out by the utility but can be carried out by specialist contractors, including the vendor and equipment suppliers.

3.3.3 Equipment repair and replacement

Depending on the complexity of the operation, this may be carried out by the utility, for simpler repairs, or for complex operations (e.g. replacement of the steam generators) by specialist companies, including the original equipment supplier. The contractor may be selected by competitive tender.

3.3.4 Problems in the operating phase

If O&M is not carried out to the highest standards, there can be severe or potentially severe consequences. The Browns Ferry (US) fire of 1975, when an electrician's candle disabled the safety systems for the three reactors on site, was close to causing a major accident.[51] The investigation by the President's Inquiry into the Three Mile Island (US) accident (the Kemeny Commission)[52], which resulted in a meltdown of much of the fuel, found the accident was the result of a complex combination of equipment failure and human issues.

The Davis Besse (US) plant came close to a serious accident because maintenance procedures had not identified cracking and thinning of the reactor vessel head.[53] Had the vessel head failed, there would have been a serious loss-of-coolant accident.

3.3.5 Supply of fuel

Supply of fuel is itself at the end of a supply chain. This includes: mining and processing of uranium; converting the uranium to uranium hexafluoride; enrichment to increase the percentage of the "fertile uranium isotope from 0.7% to about 3.5%"; reconversion, and mechanical processing to manufacture the fuel rods. This supply chain is not elaborated in detail here but most of the elements have their own issues. All will leave facilities that at the end of their life will need careful decommissioning.

Image: In Finland, the construction of the Olkiluoto 3 reactor is well over budget and years past its original completion date.

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The cause of a significant accident at a nuclear plant may involve a combination of design, construction, and operator or maintenance errors.

Mining is a massively disruptive process involving the removal of large quantities of rock and soil and leaves a waste stream, tailings, which if not handled carefully can pollute ground water.[54] The main uranium-producing countries are Canada, Russia, Namibia, Australia, Kazakhstan and it is produced by mining companies such as RTZ (multinational), Cameco (Canada), Areva (France), ARMZ (Russia), Kazatomprom (Kazakhstan) and BHP (Australia). Conversion to uranium hexafluoride is carried out by a large number of companies, including mining companies (Cameco), diversified nuclear companies (Areva) and specialist companies.

Enrichment involves extremely expensive facilities and uses huge quantities of energy. It is also a militarily sensitive technology as it can produce weapons grade materials. The main global suppliers are Eurodif (France), Urenco (UK, Netherlands, Germany), Minatom (Russia), JNFL (Japan) and USEC (US).

Fuel fabrication and supply is sometimes carried out by a division of the reactor vendor, e.g. Westinghouse, or by a specialist company, e.g. TVEL (Russia). Only a handful of the countries with nuclear power plants have domestic fuel-fabrication plants. The main ones are: Canada (GE); France (Areva); Germany (Siemens); Japan (MNF – Mitsubishi and NFI – Toshiba); Korea (KNFC); Russia (Mashinostroitelny); UK (NDA); and the US (GE, Siemens, Westinghouse, Areva).

While in principle the delivery of nuclear fuel is a service that can be switched to alternative suppliers, in practice this is highly impractical and complicated. Fuel rods and their assemblies are highly specific for each of the reactor designs, and it may take a number of years before an alternative supplier develops and fine-tunes fuel rods suitable to a given reactor. In reality, operators are therefore stuck with one fuel supplier over the lifetime of their reactor.

There have been a number of scandals on the supply of nuclear fuel. In 1999, it was discovered that British Nuclear Fuels (BNFL) had falsified quality-assurance data for fuel containing plutonium (so-called Mixed Oxide or MOX fuel) shipped to Japan.[55] BNFL was forced to take back this fuel.

The Czech Temelin nuclear plant provides a good example of the difficulties of switching fuel supplier. In 2006, the Czech utility was forced to turn back to its original Russian fuel supplier for its Russian-designed reactor because of concerns about the rigidity of the Westinghouse-supplied fuel, which was deforming and preventing correct insertion of the control rods.[56]

3.3.6 Spent fuel

Spent fuel removed from a reactor generates large amounts of decay/residual heat and, therefore, needs to be actively cooled for several years until this heat generation has decayed sufficiently so that the risk of a meltdown (in case of cooling failure) no longer exists.

After the initial cool-down period (typically 3-5 years), spent fuel is stored onsite at interim storage, transported to a central interim storage elsewhere, or sent to reprocessing facilities. There are three main ways in which spent-fuel storage can be carried out:

- Initial storage in wet spent-fuel pools that are built onsite, in the vicinity of the reactors. Most western reactor designs situate the pools outside of the containment, in an auxiliary building, while Russian designs locate the pools inside the containment. The pools and their cooling systems are an integral part of the reactor design, construction and supply; they often share the same power backup systems, water supply systems, and ultimate heat sinks with nuclear reactor islands. Hence, suppliers of reactors are also involved in spent-fuel storage.

Box 4

Final disposal of spent fuel

There are two main options for dealing with spent fuel: direct disposal, or reprocessing. Direct disposal in a high-level waste repository is the preferred option for most reactor owners. No high-level waste – a category that includes spent nuclear fuel – final repository, where the waste must be isolated from the environment for about 250,000 years, has been constructed yet and it may be decades before any such facility exists. Until then, the costs and the technology will remain unproven. The field of companies offering this service is undeveloped but given the extraordinary safety requirements, such companies will inevitably be closely associated and often fully owned by government.

Spent-fuel direct disposal has not been demonstrated anywhere yet and most countries that are expecting to follow this route are many years away from even selecting a site.

Reprocessing on a commercial basis is only carried out in three countries: France (La Hague), UK (Sellafield) and Russia (Chelyabinsk and Krasnoyarsk). These facilities are owned by the national governments. Japan has almost completed a large reprocessing plant, Rokkasho. The plant is reported to have been 99% complete since 2007, but its start-up has continually been delayed (19 times by October 2012) and, by then, its projected start date was October 2013.[61] Its owner, Japan Nuclear Fuel Limited, is mainly owned by the 10 privately owned, major Japanese electric utilities. Other countries, such as India, have smaller facilities but these are not open to international customers, and they may have dual military/civil purposes.

- After the initial cool-down period, the interim storage of spent fuel can continue to be based on pools filled with water – i.e. wet storage. This practice is linked to most of the Russian-designed nuclear power plants. One of the suppliers of those interim wet storage systems (pools) is Skoda JS.[57]
- Interim storage can also be in dry casks. The fuel is stored in heavy, self-sufficient containers that need no additional, active cooling, or the presence of water. Thus they can be stored under open air, or at shallow underground facilities. There are several companies producing the casks, such as Gesellschaft fur Nuklear-Service (Germany), Holtec Intl, NAC Intl. and Areva-Transnuclear NUHOMS. Skoda JS also obtained a licence to fabricate the German-designed dry storage casks.

Spent fuel is expected to either be reprocessed or disposed of directly (see Box 4). Reprocessing is particularly contentious because it is a hazardous process, and because it produces separated plutonium, which represents a major weapons-proliferation risk. Direct disposal raises fewer proliferation concerns but the requirement to identify sites and package the waste, which also applies to waste from reprocessing, so that there can be near certainty that the material will remain isolated from the environment for the several hundred thousand years it will take for the material to cease to be hazardous.

Spent or partially used fuel that is not in the reactor may represent a significant hazard as was demonstrated at the Fukushima disaster.[58] A less widely publicised accident occurred at the Paks plant (Hungary) in 2003. Here, fuel assemblies were removed from the reactor for cleaning in a cleaning tank.[59] The cooling system proved inadequate and the 30 fuel assemblies in the tank were all damaged, some severely, leading to the release of some radioactive material. The accident was blamed on the supplier of the tank, Areva (France), who paid compensation reported to be $4.5m. The plant (Unit 2 of the four-unit site) was off-line for more than three years.[60] The loss of income from the lost output for those three years will have far exceeded the compensation paid.

3.4 Conclusions

A nuclear power plant has several unique features: complexity; extent of and potential cost of accidents; importance of user skills; lifetime; cost; and the importance of site construction work. This means that the cause of a significant accident at a nuclear power plant is seldom clear-cut and may involve a combination of design, construction, operation and maintenance errors.

By comparison, it is usually relatively easy to apportion primary responsibility for, say a car accident to design, construction, operator or maintenance error.

In addition, international conventions and national laws limit (in the case of operators) or absolve (in the case of suppliers) from the financial consequences of accidents caused by their errors in a way that applies to no other industrial activity. Without this level of insulation from the consequences of any accidents, it is clear no commercial company could justify owning or supplying a nuclear power plant.

The supply chain for a nuclear power plant is very complex and in many cases non-transparent. The owner/operator of a plant carries final responsibility, but design, construction and maintenance include many different parties through many layers of contracting and subcontracting. Different suppliers are responsible for implementing elements critical for the plant's safety, but these suppliers ultimately cannot be held accountable in case of an accident.

This lack of accountability is further enabled by lack of transparency regarding contracts and company relationships. This situation creates major challenges in ensuring sufficient quality control on critical safety features. It is often unclear (at least to the outside world) who carries the final responsibility in case problems were to occur with certain equipment or designs.

Many of those further down the supply chain will exit the business long before the end of the life of the plant, as was the case with RDM, the supplier of the flawed pressure vessels for the Belgian Tihange 2 and Doel 3 plants. In the case of the Fukushima disaster, even though it is known that certain design features caused serious problems during the course of the accident[62], those responsible for the design and engineering are not being held accountable.

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5 Antony Froggatt, see Chapter 2 of this report.

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29 Agence France Presse 'France's Areva to bid for British nuclear plant venture' 7 July 2012

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32 For a detailed review of the role of the EPC contractor, see World Nuclear Association (2012) 'The World Nuclear Supply Chain Outlook 2030' World Nuclear Association.

33 For more details, see World Nuclear Association (2012) The World Nuclear Supply Chain Outlook 2030' World Nuclear Association.

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People must be the first priority, not the benefits of the nuclear industry.

Image: A Greenpeace radiation expert checks contamination levels at a house in Watari, approximately 60km from the Fukushima Daiichi nuclear plant.

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Committee on Radioactive Waste Management

FINAL

CoRWM's Radioactive Waste and Materials Inventory – July 2005

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Contents

1 Introduction 1
2 Methodology for Preparing the CoRWM Inventory 4
3 Categories of Radioactive Waste and `Other Materials' 6
4 Criteria for Defining Radioactive Materials as Waste 10
5 CoRWM Baseline Inventory 12
6 CoRWM Baseline Inventory - Uncertainties And Assumptions 20
7 Summary and Example Scenarios 33
8 Conclusions 42
References 44
Appendix A Current QA arrangements for checking inventory data 46
Appendix B Questions we are asking all stakeholders if they can answer 48

Glossary

ABWR	Advanced Boiling-Water Reactor
AEA	Atomic Energy Agency
AGR	Advanced Gas-cooled Reactor
AWE	Atomic Weapons Establishment
BE	British Energy
BNFL	British Nuclear Fuels Limited
CfA	Conditions for Acceptance
CoRWM	Committee on Radioactive Waste Management
Defra	Department of the Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
EPR	European Pressurised-Water Reactor
HLW	High Level Waste
ILW	Intermediate Level Waste
JET	Joint European Torus
LLW	Low Level Waste
LMU	Liabilities Management Unit
MoD	Ministry of Defence
MOX	Mixed Oxide Fuel
NDA	Nuclear Decommissioning Authority
NGO	Non-Governmental Organisation
NII	Nuclear Installations Inspectorate
NORM	Naturally Occurring Radioactive Materials
OCNS	Office for Civil Nuclear Security
PBMR	Pebble Bed Modular Reactor
PWR	Pressurised Water Reactor
QA	Quality Assurance
RWMAC	Radioactive Waste Management Advisory Committee
RWI	Radioactive Waste Inventory
SGHWR	Steam Generating Heavy Water Reactor
TBq	Terabecquerel (10^{12} becquerels)
THORP	Thermal Oxide Reprocessing Plant
UKAEA	United Kingdom Atomic Energy Authority
VLLW	Very Low Level Waste
WAGR	Windscale Advanced Gas-cooled Reactor

1 Introduction

(a) Terms of reference

1.1 The Inventory Working Group (IWG) terms of reference were established in the context of CoRWM's objective, namely to:

- Recommend to Ministers the best option, or combination of options, for managing the UK's solid radioactive waste that can provide a long-term solution, providing protection for people and the environment.

1.2 The Committee's priority task is to recommend what should be done with the wastes now in storage or likely to arise in the future for which no long-term management strategy currently exists – that is:

- High level waste (HLW);
- Intermediate level waste (ILW); and
- Low level waste (LLW) unsuitable for disposal at Drigg.

1.3 The specific terms of reference of IWG are to:

- Identify, on the basis of engaging with the public and stakeholders, the inventory on which CoRWM will make its recommendations on the long-term waste management options.

(b) Aims and coverage of the inventory

1.4 IWG was established by CoRWM to determine the inventory of radioactive wastes, including some radioactive materials (uranium, plutonium and spent nuclear fuel) not currently classed as waste but which may need to be managed as wastes in the long-term. In order for potential solutions to be assessed, we need to know the amounts of the wastes, in terms of both volume and radioactivity; the form of the wastes and any associated technical difficulties; the current location of the wastes; and any special considerations that apply, such as security.

1.5 In practice, we aim to identify the range of possible inventories in order to measure their different impacts on the long-term management options we are identifying. Key questions relating to the range of inventories include the extent to which the inventory would be altered if further nuclear power stations were build, if uranium, plutonium and spent fuel were to be managed as wastes, and if uranium and plutonium were to be burned as fuels in existing or new UK reactors.

1.6 We use the term "inventory" to describe the types and amounts of wastes that the UK has to manage. Many of these wastes are currently included in the UK Radioactive Waste Inventory (RWI), which is used to help the UK meet its international obligations under the:

- Euratom Community Plan of Action in the field of Radioactive Waste; and

- The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

1.7 United Kingdom Nirex Ltd (Nirex) and Defra co-sponsor and co-manage the preparation of the UK RWI. We have used information from the draft 2004 UK RWI [1], which contains data on radioactive wastes in the UK that existed at 1 April 2004 and those projected to arise after that date. This inventory supersedes the previous 2001 UK RWI [2]. It is anticipated that the 2004 UK RWI data will be approved for publication in June/July 2005, with the reports released into the public domain in October/November 2005. Because we are using draft 2004 UK RWI data, it may be the case that our report differs from the published 2004 UK RWI.

1.8 In using the data we have taken account of the quality assurance (QA) arrangements for compiling the UK RWI. Appendix A outlines the current QA arrangements for checking UK RWI data.

1.9 We also recognise the fact that the storage of radioactive wastes and materials on nuclear sites are subject to inspection by the UK Nuclear Installations Inspectorate (NII) (whose Licence Conditions require operators to have adequate records of materials and wastes), and the Office for Civil Nuclear Security (OCNS) (who are responsible for regulating the security of such materials). Also, EURATOM carries out inspection of fissile materials (such as uranium and plutonium), except for materials in the ownership of the Ministry of Defence (MoD).

1.10 The current UK RWI does not include radioactive materials, although it does include small quantities of lightly irradiated research reactor fuel and uranium residues already declared as wastes by their owners. The stakeholders we consulted generally supported recommendations made by the Radioactive Waste Management Advisory Committee (RWMAC) that the UK RWI should be expanded to cover a wider range of radioactive wastes and radioactive materials. Radioactive wastes that are not currently covered comprehensively by the UK RWI include spent sealed sources, very low level waste, and low activity waste from the decommissioning and clean up of nuclear sites. Radioactive materials that are currently not included in the UK RWI are separated stocks of uranium and plutonium, spent fuel, and Naturally Occurring Radioactive Materials (NORM).

1.11 In reaching our conclusions, we have made wide use of the Nirex report *Identification and description of UK radioactive wastes and materials potentially requiring long-term management* [3], in addition to feedback from the waste and material owners.

1.12 The quantities of radioactive wastes and materials requiring long-term management that are within our remit are presented in Section 5 of the report. We refer to this as CoRWM's Baseline Inventory. For the sake of completeness we also make note of other radioactive wastes and materials generated in the UK, including those that will be returned overseas.

1.13 At points throughout the report, we highlight (using a different font) where uncertainties occur that could affect radioactive waste and material volumes, activities and forms, as well as where they may be located. These uncertainties and there implications are presented in Section 6 of the report.

1.14 This report is an updated version of our preliminary report on the inventory [4]. The preliminary report was issued for consultation during the first stage of public and stakeholder engagement. The feedback we received has been documented elsewhere [5]. We have taken account of this feedback in the preparation of this report. In particular we have identified short-lived ILW that may be suitable for near surface disposal. We have also included information on spent sealed radioactive sources (SSRSs), considered alternatives to our nuclear power station new build scenario, and have highlighted the key radionuclides and the physical and chemical properties of the wastes that may need to be considered by CoRWM with regard to the safe handling, storage, transport and long-term management. Furthermore, we have taken the opportunity to update the inventory where more recent information is available. In particular we have made use of draft 2004 UK RWI data.

1.15 In parallel with the work of CoRWM, the Government is reviewing LLW management policy. With many nuclear sites and facilities moving into their decommissioning phase, and with the Nuclear Decommissioning Authority (NDA) now established to deal with this, it is recognised that a very large volume of LLW will arise during the next few decades. The anticipated amount of LLW could potentially fill the Drigg disposal facility a number of times over. Consequently the policy review will consider whether the limited disposal capacity remaining at Drigg should be taken up with large quantities of low activity waste from decommissioning, or whether there are alternative, more cost-effective, ways in which such waste might be more appropriately but equally safely managed. Furthermore, it will consider whether it is appropriate to excavate what could be very large volumes of contaminated ground containing very low levels of radioactivity in order to transport them over potentially large distances for burial at some other location. The Government intends that the review will identify a new policy framework to cover the future management of LLW.

2 Methodology for Preparing the CoRWM Inventory

(a) Preliminary inventory

2.1 We set out to gather information, identify the assumptions used and the areas of uncertainty. As part of this, we wrote to a range of stakeholders that had identifiable interests in the materials and wastes seeking answers to questions about the inventory. The questions were substantially the same in each case so that the process is clear and transparent to the public and stakeholders. The final list of questions used is given in Appendix B. In line with our commitment to transparency, all the questions we posed, and the responses we received, are accessible via the CoRWM secretariat to anyone who wishes to see them.

2.2 We asked the following bodies to be involved:

Non-Governmental Organisations (NGOs); regulatory bodies; local government; citizens' groups in areas where waste is currently managed; *all of which have interests either in environmental issues (including public and worker exposure to radiation, both historic and prospective) or in issues of proliferation*.

Nirex and Electrowatt-Ekono (UK) Ltd, *respectively the co-sponsor (with Defra) and the contractor for the UK RWI and which hold much of the inventory data*.

British Energy (BE); British Nuclear Fuels plc (BNFL); the United Kingdom Atomic Energy Authority (UKAEA); Urenco; GE Healthcare (formerly Amersham plc), *which are civil users of radioactive materials and produce radioactive waste*.

The Liabilities Management Unit (LMU) and the Energy Bill team within the Department of Trade and Industry (DTI). *LMU was the forerunner of the NDA, which is responsible for substantial amounts of the UK's civil radioactive waste, together with accompanying liabilities.*

The DTI, *which is responsible for energy policy*.

The MoD and the Atomic Weapons Establishment (AWE), *which are the major non-civil users of radioactive materials and produce most defence wastes.*

2.3 There are three key overarching questions that our questionnaire sought to address:

a) Are there any concerns over the adequacy (including the scope) of the current UK Radioactive Waste <u>Inventory</u> (RWI)?
b) What <u>criteria</u> should be used for deciding how much of the three categories of radioactive materials (Plutonium, Uranium and spent fuel) should be treated as waste?
c) Are there <u>scenarios</u> (such as changes in decommissioning or energy policy) where the waste inventory could change significantly?

2.4 We held discussions with many of the stakeholders to explore their responses on waste and to consider the status of Uranium, Plutonium and spent fuel, including the criteria for their possible reclassification.

2.5 We followed the "guiding principles" which CoRWM has agreed should govern its work. The statement of guiding principles can be viewed on the CoRWM website (www.corwm.org.uk). We also followed the CoRWM *Publication Scheme* and *Statement of Policy on Transparency* which are also on the website.

2.6 Our preliminary report on the inventory [4] was issued for consultation during the first stage of public and stakeholder engagement.

(b) July 2005 Inventory

2.7 We have taken account of the feedback from the first stage of public and stakeholder engagement [5]. This has identified a number of headline issues on the inventory where we have undertaken further investigations and analysis. We have also made some presentational changes to the report with the aim of improving its clarity and readability.

2.8 We have made use of the 2004 UK RWI information (draft status), which was not available when we prepared our preliminary report.

2.9 The July 2005 inventory report will be issued to the July plenary of CoRWM.

3 Categories of Radioactive Waste and `Other Materials'

3.1 Radioactivity is the spontaneous disintegration of unstable atomic nuclei, with loss of energy through emission of a charged particle and/or gamma radiation. Radioactive atoms are also known as radionuclides, and materials are said to be radioactive if they contain or are contaminated with radionuclides. Almost all materials are, strictly speaking, radioactive, because they contain traces of naturally occurring radionuclides. Radionuclides can also be man-made; most are produced in nuclear reactors.

3.2 All radioactivity reduces naturally over time. This is called radioactive decay. The rate of decay is measured with reference to the constant 'half-life' of the radiation emitted. This is the length of time taken for the radiation to fall by a half. Half-lives of radionuclides vary considerably. Those with shorter half-lives will decay to trace levels in a few years or less. Those with long half-lives will decay only very slowly, often over many thousands or millions of years.

3.3 Material that has no further use, and that incorporates or is contaminated by radioactivity above certain levels defined in UK legislation, is known as radioactive waste [6]. Radioactivity is potentially harmful to people and the environment. This means that radioactive waste cannot simply be thrown away, but must be managed in a way that will ensure safety, which for radioactivity that decays very slowly will extend long into the future.

3.4 Radioactive waste is likely to be created whenever radioactive materials are used, for example in the generation of electricity in nuclear power stations and from the associated production and processing of the fuel, from the use of radioactive materials in medicine, industry and research, and from military nuclear programmes. Figure 3.1 shows the sites of the major radioactive waste producers in the UK (there are no major producers in Northern Ireland).

3.5 Radioactive wastes cover a wide range, from those that contain high concentrations of radioactive materials to general industrial and medical wastes that are only lightly contaminated with radioactivity. In the UK radioactive wastes are categorised in terms of the nature and quantity of radioactivity they contain, and their heat generating capacity, into high level waste, intermediate level waste, low level waste and very low level waste.

3.6 **High level waste (HLW).** HLW is highly radioactive. The radioactivity generates a great deal of heat. This has to be taken into account when storing it or designing facilities for its management in the long term. It is mainly the liquid waste product of reprocessed spent nuclear fuel after the uranium and plutonium have been separated out. The Nuclear Installations Inspectorate (NII) requires that HLW be transformed from a liquid form to a passively safe solid form. In order to achieve this, HLW is concentrated, mixed with molten glass, and put it in storage in 150 litre payload stainless steel containers. By 2015, the majority of the HLW should have been treated in this way [7]. The vitrified HLW is currently stored for a period of at least 50 years to allow for the heat-emitting radionuclides to decay to levels that would facilitate long-term management [8].

3.7 **Intermediate level waste (ILW).** ILW is less radioactive than HLW, and does not generate sufficient heat for this to be taken into account in the design of facilities for its management. ILW is much more varied than HLW. Major components include metal items such as nuclear fuel cladding and nuclear reactor components, graphite from reactor cores, and sludges from the treatment of radioactive liquid effluents. ILW is stored in tanks, vaults and drums, with most waste requiring concrete to shield operators from the radiation. In time ILW will be retrieved, and packaged by immobilising the wastes in cement-based materials within 500 litre stainless steel drums, or for large items in higher capacity steel or concrete boxes.

3.8 **Low level waste (LLW).** LLW is less radioactive than ILW. Currently LLW consists largely of contaminated redundant equipment, protective clothing and packaging. Soil, concrete and steel items such as ducting, piping and reinforcement from decommissioning nuclear facilities will dominate future arisings. Most LLW can be sent for disposal at the Drigg facility in Cumbria where suitable waste is first supercompacted, and waste is packaged in large metal containers, which are placed in an engineered vault a few metres below the surface. Drigg is expected to be full by 2050. Some LLW cannot go to Drigg because its radionuclide activity content or its physical/chemical properties (e.g. flammability) do not satisfy the site acceptance criteria. There are uncertainties over the future management of this "non-Driggable" LLW, since if the wastes were not processed they would have to be managed as if they were ILW. However, one option would be to treat the wastes chemically so that they meet the Drigg acceptance criteria for physical and chemical properties (assuming that they also meet the radionuclide limits). This would involve characterisation of each waste, identifying a suitable treatment process, and comparing the cost of this process with the cost of managing the waste as ILW. The process and cost would be waste dependent.

3.9 **Very low level waste (VLLW).** VLLW is waste with a very low radioactivity content. It is uniquely defined in terms of low volumes because it is intended that this category of waste is disposed of with domestic refuse at landfill sites, and the typical volume of a domestic dustbin is of the order of $0.1m^3$. Hence reference is made to “dustbin disposal”, which is primarily aimed at wastes from “small users”, that is organisations that do not belong to the nuclear sector such as hospitals and educational establishments.

3.10 Although not a category of radioactive waste defined in UK legislation, we use the term **Low activity wastes** to distinguish wastes from the nuclear sector that fall within the radioactivity range of VLLW but which are of high volume and so inconsistent with “dustbin disposal”. Such wastes (also referred to as site clearance wastes) will be produced as demolition rubble and soil when nuclear power stations and other nuclear facilities are decommissioned over the next century. A small proportion of this waste is transported to designated landfill sites, but most remains in-situ. Owing to the anticipated high volumes of future site clearance waste, the Government is reviewing the scale of, and arrangements for dealing with, these wastes.

3.11 In other countries the classification systems for radioactive wastes vary in approach and application. Many are related to the management routes available. The principal difference is the use in other countries of categories of transitional waste that will decay in a relatively short period of storage to a lower waste category [9]. In this regard wastes in the ILW and LLW categories are designated as either short-lived or long-lived.

3.12 Not all radioactive material in the UK is currently classified as waste. This is because it may have a future use and therefore a value to its owners. For example, the UK's stock of plutonium could be used as fuel for nuclear power stations, and so is not declared as waste at the moment. But, if it is not to be used as fuel, it may have to be managed as waste in the future. This report considers what volumes and radioactivities would be involved if materials like this did need to be managed as wastes.

3.13 There are a number of radioactive materials that may have to be managed in the same way as radioactive wastes. These are plutonium, uranium, spent fuel and NORM.

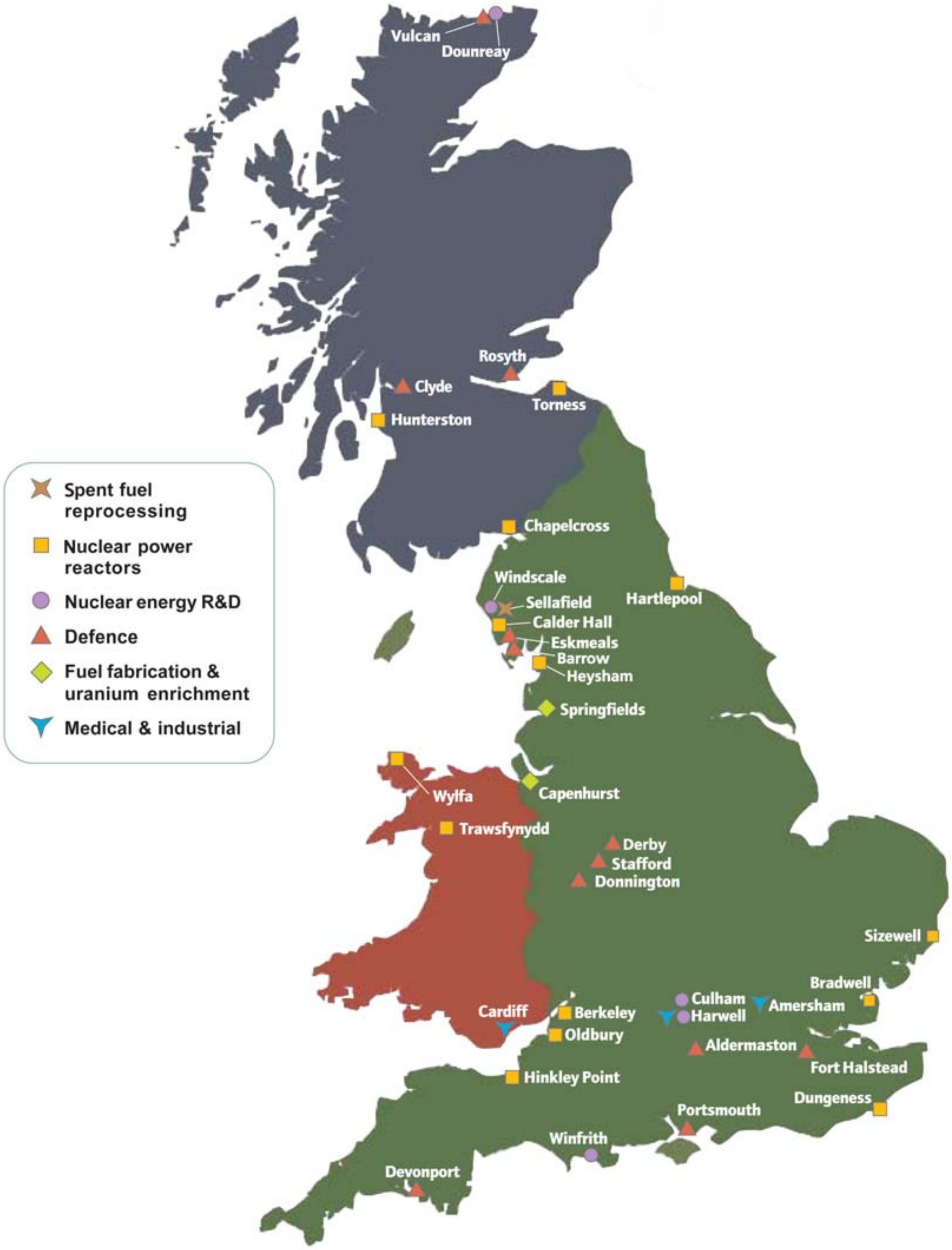
3.14 **Plutonium** is mostly created as a by-product of the use of uranium fuel in nuclear reactors. It is contained within spent fuel when it is removed from a reactor, but can be extracted by reprocessing. Plutonium is used in the manufacture of some reactor fuels and it is used in nuclear weapons - hence the terms *reactor grade* and *weapons grade* plutonium.

3.15 **Uranium** is found naturally, and is also a product of spent fuel reprocessing. It has similar uses to plutonium. Less radioactive uranium (called depleted uranium) has more commonplace uses, such as counterweights in aircraft.

3.16 **Spent fuel** is nuclear fuel that has been used to power nuclear reactors. It can be reprocessed (to separate out plutonium and "unburnt" uranium) or managed in some other way - by storing it, or by packaging it and placing it directly in a repository as is planned in the USA, Finland, Germany and Sweden.

3.17 **Naturally Occurring Radioactive Materials (NORM)** are substances that contain the primordial radioactive elements uranium and thorium, and their radioactive decay products. The majority of NORM arises from industrial processes. These processes may enhance the concentrations of radioactivity. In the UK, NORM streams arise in the electricity generating (coal fired), metal mining and processing, oil and gas extraction, and water treatment industries.

Figure 3.1 Map to show sites of radioactive waste production



4 Criteria for Defining Radioactive Materials as Waste

4.1 Materials are generally regarded as waste if no further use for them is foreseen. Current UK policy in relation to reprocessing spent fuel or holding it in long-term storage pending some form of disposal is that the decision is up to the commercial judgement of the owner.

4.2 A number of criteria for reclassifying radioactive materials as wastes were suggested by stakeholders – ones relating to the likelihood of future use as an energy source, as well as those relating to safety, cost, technical feasibility, security and proliferation, and timing.

4.3 Plutonium could be the source of a nuclear chain reaction when it is in a concentrated form. This is called "criticality". There is also the possibility that it could fall into the hands of terrorists. These safety and security risks mean that much thought is given to the intentions, arrangements and organisation for plutonium. Feasible alternatives for the management of plutonium include using it in Mixed Oxide (MOX) fuel (i.e. fuel comprised of plutonium and uranium oxides), burning it in an inert matrix containing thorium or zirconium to prevent the production of more plutonium during irradiation, or immobilising it in a stable matrix or as a low specification MOX mixture.

4.4 The National Stakeholder Dialogue Plutonium Working Group concluded that, of the immobilisation options, use of a ceramic form offers the most promising solution [10]. This offers a management option that provides dilution to ensure long-term safety, but also makes it more difficult to extract the plutonium for use in weapons. For the purposes of estimating potential quantities, we have assumed a dilution factor of 1:10 in a ceramic matrix.

4.5 The Plutonium Working Group also concluded that the addition of a radiation barrier (e.g., the encasement of the immobilised plutonium product in vitrified high level waste) was of questionable benefit for assuring the security of the product as long as thorough attention was given to the other physical and institutional aspects of security [10].

4.6 The Plutonium Working Group has stated that, in its opinion, the disposition of plutonium (whether by immobilisation or reactor burning or both) should commence within a 25-year timeframe, and BNFL has agreed with this recommendation. The Working Group did not seek to reach a conclusion on whether immobilisation is to be preferred to a reactor based approach. However, it did recommend a programme of work to enable the benefits and disadvantages of the two strategies to be fully assessed. Until this is carried out, there will be a considerable element of uncertainty as to the contribution of plutonium to the inventory.

4.7 BE reported that although reprocessed uranium can be used to manufacture fuel for the existing Advanced Gas Cooled Reactors (AGRs) and the Pressurised Water Reactor (PWR) at Sizewell B, it has no short term plan for its utilisation because the prevailing market price for uranium is low. Use of the reprocessed uranium would become economic if uranium prices rise and BE therefore regards its reprocessed uranium stock as a hedge against this eventuality. BE also noted that plutonium could, in principle, be used in the manufacture of mixed oxide fuel (MOX) for Sizewell B and AGRs, although the commercial case (mainly in terms of the higher cost of the fuel, and the cost of plant modifications particularly in the case of the AGRs) makes it unattractive. New nuclear power stations, depending on design, could also use MOX fuel, but at today's uranium prices, burning MOX fuel in light water reactors would be uneconomic. Thus existing stocks of plutonium would only be used if uranium prices rose, MOX fuel were used as a plutonium management tool, or the fast reactor programme was resumed. Thus, there are various uncertainties, technical as well as economic, regarding the use of uranium and plutonium in both existing and new reactors [11, 12].

4.8 Several overseas countries use plutonium as MOX fuel in their reactors. Use of plutonium in MOX fuel for overseas reactors is most likely when (a) an economic case can be made, or (b) the reactor is specifically a MOX fuel type.

4.9 The current BNFL view for plutonium is that it is a valuable energy resource and that this generation should not deny its use to future generations by declaring it a waste and conditioning/packaging it as a waste form. However, BNFL notes that about 5% of existing plutonium stocks are likely to require extensive chemical treatment to allow it to be used as fuel, potentially making this route uneconomic [13]. The company currently has work programmes in place to consider three fundamental options for plutonium – safe storage, utilisation in reactors and immobilisation. BNFL notes that issues for uranium are similar to those for plutonium, with the added complication that about half the inventory is stored in gaseous form [13].

4.10 In the light of the uncertainties that apply to uranium and plutonium, CoRWM has been asked to address the possibility that uranium and plutonium could be declared and treated as wastes. We also consider the alternative possibility that uranium and plutonium may be recycled as an energy source, with consequent generation of wastes from that process. This will allow us to comparison the implications of these possibilities on the inventory and, ultimately, on the long-term options we are considering.

4.11 BNFL plans to reprocess existing holdings and all anticipated future arisings of spent Magnox fuel - a total of about 8,000tU at April 2004 [1]. However, BNFL is having to establish contingencies should it not be able to do so. This introduces an uncertainty in the possibility of having to manage some Magnox fuel directly in the future.

4.12 BE has no current plans to reprocess the spent fuel from its PWR at Sizewell B (about 1,200tU lifetime arisings). Spent fuel is being stored at the station. Also, a substantial quantity, approximately 3,500tU, of spent AGR fuel is not covered by current reprocessing contracts [1]. This fuel will be stored at Sellafield. There remains uncertainty should current plans be revised, and either or both of these quantities of spent fuel are reprocessed.

5 CoRWM Baseline Inventory

(a) *Radioactive wastes*

5.1 Information on radioactive wastes is taken from the 2004 UK RWI (draft status) unless otherwise indicated. The main assumptions on which the volumes of future waste arisings are estimated are:

1. All operating Magnox reactor stations are shut down by 2010.
2. AGR stations operate for 25, 30 or 35 years, with the last shutdown in 2023.
3. Sizewell B PWR operates for 40 years and is shutdown in 2035.
4. Final stage decommissioning for all UK power stations is deferred, for up to 112 years after shutdown.
5. Final stage decommissioning and site clearance at all UK power stations is completed by 2128.
6. No new nuclear power stations are constructed.
7. Magnox fuel reprocessing continues until 2012, with a total of 55,000tU reprocessed.
8. Oxide fuel reprocessing in Thorp continues until 2011, with about 5,000tU AGR fuel, 4,500tU overseas LWR fuel, plus much smaller quantities of WAGR and SGHWR fuel, reprocessed.
9. An estimated 3,500tU AGR fuel and 1,200tU Sizewell B PWR fuel is not reprocessed.
10. Decommissioning of reprocessing and other plant at Sellafield is completed by about 2120.

5.2 The quantity of AGR fuel assumed to be reprocessed is 600tU less, and so the quantity of spent fuel that may need to be managed as waste is 600tU more, than in our preliminary report on the inventory. We have therefore had to recalculate the quantities of separated plutonium and uranium, which are not given in the UK RWI.

5.3 A proportion of the waste arising in the Thorp and Magnox reprocessing plants at Sellafield results from reprocessing overseas spent fuel. All overseas reprocessing contracts signed since 1976 include a provision to return packaged wastes back to the country of origin. UK Government policy is that these wastes should be returned. Waste substitution is the process whereby an additional amount of HLW would be returned that is equivalent in radiological terms (but smaller in volume) to the ILW and LLW that would otherwise be returned. LLW substitution has been part of Government policy has a number of years.

5.4 Since we issued our preliminary report on the inventory, the Government has accepted that for ILW (as for LLW) its policy on overseas wastes can be implemented by substitution arrangements that ensure broad environmental neutrality for the UK. Therefore our baseline inventory assumes both ILW and LLW substitution.

High Level Waste

5.5 HLW produced in the UK has accumulated since the early 1950s from the reprocessing of spent nuclear fuel at Sellafield. Sellafield has two reprocessing facilities – the Magnox Reprocessing Plant and the Thermal Oxide Reprocessing Plant (Thorp). BNFL anticipates that all spent fuel from the continuing operation of the UK's Magnox power stations will be reprocessed, and that the plant will continue to operate until 2012. For Thorp, BNFL anticipates that all spent fuel covered by current contractual commitments will have been reprocessed by 2011, with total plant lifetime throughputs of about 5,000tU AGR fuel, about 4,500tU overseas LWR fuel plus small quantities of WAGR and SGHWR fuel. This excludes about 3,500tU AGR fuel forecast to arise over power station lifetimes. It is currently assumed by BNFL that this spent fuel will be held in long-term storage.

5.6 HLW at Sellafield is comprised mainly of fission products. There is an initial steep decline in activity in the first 12-24 months or so following reprocessing, as short-lived nuclides (principally Ru106, Ce144 and Pm147) decay. HLW contains approximately 95% of the radioactivity in all UK radioactive waste.

5.7 In the 2004 UK RWI raffinate from reprocessing spent PFR fuel at Dounreay has been reclassified as ILW by UKAEA on the grounds that the heat output is now considerably below the threshold of about 2kW/h for HLW as defined by the IAEA [14]. UKAEA has consulted with stakeholders on its proposal for reclassification and management of PFR raffinate.

5.8 The 2004 UK RWI reports the following HLW volumes at Sellafield:

HLW	Waste at 1.4.2004 (m^3)	When all waste at 1.4.2004 and future arisings are packaged	
		Conditioned volume (m^3)	Packaged volume (m^3)
Liquid waste	1,890	-	-
Vitrified waste	456	1,340	1,750

The conditioned volume is the volume of the glass product resulting from waste vitrification. The packaged volume is the volume of the glass product plus the stainless steel containers in which the waste is packaged.

5.9 Of the total packaged volume, the 2004 UK RWI reports that about $400m^3$ is from reprocessing spent fuel for overseas customers and is contracted to be returned to these customers. With ILW substitution, a further $60m^3$ of HLW would be subject to return, based on the guideline assumption of 15% extra HLW volume returned to overseas customers [19]. Hence $1{,}290m^3$ is designated as UK HLW.

5.10 The radioactivity of all HLW (UK and overseas) at 1 April 2004 is about 75,000,000TBq. The radioactivity will peak at about 110,000,000TBq when all planned spent fuel reprocessing has been completed. Thereafter radioactive decay will result in a fall in radioactivity.

Intermediate Level Waste

5.11 ILW is accumulated in stores the UK. Most of the ILW in the UK is produced and owned by BNFL, UKAEA, BE and MoD. Much smaller amounts of ILW are produced and held by GE Healthcare, and by small users such as AEA Technology and hospitals. In April 2005 the NDA took over responsibility for the civil sector wastes produced by BNFL and UKAEA. Some uncertainty is inevitable regarding the approach that the NDA will take to ILW storage - for example, possible consolidation of interim storage at a smaller number of sites. It is not expected that this uncertainty in approach will significantly change the volumes in the ILW inventory.

5.12 There is no central storage facility for ILW in the UK. Most ILW is stored at the site of production, although some small users make use of ILW storage facilities at Harwell and Sellafield.

5.13 Until the 1990s there was a presumption in favour of not treating or conditioning the raw ILW, so as not to foreclose disposal options. However since 1990 increasing quantities of ILW arisings at Sellafield have been conditioned by immobilising the wastes in cement, and at other sites progress is being made to retrieve historic wastes from storage facilities for conditioning.

5.14 The 2004 UK RWI reports the following ILW volume at 1 April 2004 and once all existing holdings and future arisings have been packaged. The table below lists the UK nuclear sites that generate most ILW:

ILW Site	Waste at 1.4.2004 (m^3)	When all waste at 1.4.2004 and future arisings are packaged	
		Conditioned volume (m^3)	Packaged volume (m^3)
BNFL sites:			
Sellafield	57,500	124,000	150,000
Magnox power stations	11,000	53,600	98,100
BE sites:			
AGR power stations	2,430	30,600	56,800
Sizewell B PWR station	24	892	1,430
UKAEA sites:			
Dounreay	3,770	11,900	13,900
Harwell	2,130	3,380	5,020
Windscale	692	4,600	6,140
MoD sites:			
Aldermaston	3,630	7,260	8,430
Devonport/Rosyth	574	3,460	5,830
Other sites	750	2,310	2,350
Total	**82,500**	**242,000**	**348,000**

About 70% of current ILW is held at Sellafield. However, in terms of the total quantity of waste projected, Sellafield accounts for about 43% of all ILW (packaged volume), the eleven Magnox power station sites account for 28% and the seven AGR power station sites account for 16%. Dounreay is the next largest contributor with 4%. Future arisings of ILW are 242,000m^3 (packaged volume) representing about 70% of the baseline ILW inventory. However, only a small fraction of this waste – about 30,000m^3 - is from continuing operations and so potentially avoidable should facilities be shut down immediately. The majority of the waste already exists contained within nuclear reactors and other facilities, and will only arise when these are shut down and decommissioned.

5.15 Of the total packaged volume, the 2004 UK RWI reports that about 5,000m^3 is from reprocessing spent fuel for overseas customers and is contracted to be returned to these customers. However the baseline inventory assumes ILW substitution, where the waste would remain in the UK for management.

5.16 The radioactivity of ILW at 1 April 2004 is about 4,500,000TBq. The radioactivity of ILW will peak at about 4,600,000TBq when all planned spent fuel reprocessing has been completed. Thereafter radioactive decay will result in a fall in total radioactivity even though further ILW will arise.

5.17 The material composition of unconditioned ILW (current holdings plus future arisings) is:

- Metals (32%);
- Graphite (30%);
- Sludges, flocs & liquids (14%);
- Concrete, cement & rubble (13%);
- Others including organic materials (11%).

Conditioned waste contains between 40% and 80% immobilising matrix, depending on the type of waste.

5.18 Radioactive decay will have little effect on the management options for some ILW (notably that arising from spent fuel reprocessing) because is contaminated with uranium and plutonium. Most operational wastes at UK power stations are contaminated with fission products (some with half-lives of around 30 years or more), so storage for several hundred years would be required to gain significant benefit from radioactive decay. A study based on the 2001 UK RWI has indicated that ILW volumes would reduce by about 10% within 30 years from decay to LLW. The reduction would be about 20% after 300 years, but there would very little recategorisation of waste thereafter [15]. The 2004 UK RWI includes a number of ILW streams that waste producers plan to either decay store (because they are contaminated with short-lived radionuclides such as Co60 or H3) or decontaminate so that they are suitable for disposal as LLW at Drigg. These streams amount to a total packaged volume of 19,000m^3.

Low Level waste (non-Drigg)

5.19 The UK has a national disposal facility for Low Level Waste (LLW), located at Drigg in Cumbria. Drigg operates acceptance criteria for LLW. Non-compliant LLW (which we term *non-Drigg LLW*) is currently stored at the site of arising. Drigg is expected to be full by 2050, although its closure date is uncertain for a variety of reasons, pending the outcome of the regulatory review of the site post-closure safety case. A replacement facility for Drigg is likely to be required to deal with LLW arisings during the second half of this century and beyond. The uncertainty in the closure date for Drigg will not affect the volume of LLW in the UK.

5.20 The 2004 UK RWI reports the following volumes for non-Drigg LLW for which there is no alternative disposal route.

Non-Drigg LLW Site	**Waste at 1.4.2004 (m^3)**	**When all waste at 1.4.2004 and future arisings are packaged**	
		Conditioned volume (m^3)	**Packaged volume (m^3)**
BNFL sites:			
Magnox power stations	-	24,600	29,300
BE sites:			
AGR power stations	-	5,810	6,940
UKAEA sites:			
Harwell	57	114	133
Winfrith	352	562	652
Other sites	16	105	131
Total	**425**	**31,200**	**37,200**

Nearly all non-Drigg LLW will be generated at the Magnox and AGR power station sites. These wastes are reactor graphite from final stage decommissioning, which contain concentrations of carbon 14 (C14) above limits imposed at Drigg. These wastes are forecast to arise after the 2050 date when Drigg is expected to close.

5.21 The radioactivity of non-Drigg LLW is several orders of magnitude lower than HLW and ILW.

Low Level waste (Drigg)

5.22 LLW that meets Drigg's acceptance criteria is not within our remit. This waste is being considered in the parallel Government review of LLW management policy. The 2004 UK RWI includes a conditioned volume of about 2,000,000m^3 (equivalent packaged volume about 2,480,000m^3) that either meets the Drigg CfA or has a current disposal route to landfill. Nearly all of the waste is forecast future arisings, with approximately half from Sellafield, major contributions from Magnox power stations and Aldermaston, and smaller contributions from Dounreay and AGR power stations. Approximately 85% of all future arisings are from decommissioning and site clean up, the majority arising after 2050 when Drigg is scheduled to close.

Low activity wastes (Site clearance wastes)

5.23 This category of radioactive waste is not within our remit. It is being considered in the parallel Government review of LLW management policy. The 2004 UK RWI separately identifies low activity waste from decommissioning at Dounreay (53,6000m^3 conditioned volume; 67,000m^3 packaged volume) as well as including contaminated land and decommissioning rubble in LLW estimates (see paragraph 5.19). There are considerable uncertainties in estimates of the volume of site clearance wastes due to the current lack of definition of far-term site decommissioning and clean up plans. The fact that much characterisation work remains to be carried out makes estimation of waste volumes somewhat speculative. Furthermore the benefit of decontamination that might allow waste volume to be below the lower threshold level for radioactive waste must be considered against the cost. However, it is recognised that the total quantity of such waste could be significantly higher than that in the 2004 UK RWI - it has been reported that the volume of contaminated ground for remediation at Sellafield could be 18,000,000m^3 [13]. This volume indicates that there is no solution for dealing with site clean up wastes by any current management route. This figure of site wastes is significantly higher than that of the combined HLW/ILW/LLW inventory.

(b) Other materials

Plutonium

5.24 Separated civil plutonium is held mainly as unirradiated plutonium oxide at Sellafield with a small amount in other unirradiated forms and fuel residues. Plutonium is also contained in irradiated spent fuel at civil reactor sites and at reprocessing plants. Holdings of military plutonium are classified but are much less than civilian stocks - MoD has declared a figure of slightly less than five tonnes to be surplus to its requirements [16].

5.25 Plutonium is generally measured in tonnes of heavy metal (tHM). The volume has been determined using a density value of 11.5 tonnes per cubic metre [3].

5.26 Holdings of civil plutonium are published annually by the DTI. The latest published figures [17] show stocks of unirradiated plutonium total 96.3 tonnes (approximately 8m^3). A further 37 tonnes are estimated to be present in spent fuel at reactor sites and reprocessing plants.

5.27 The BNFL National Stakeholder Dialogue Plutonium Working Group has reported on the management of separated plutonium [10]. The Working Group estimate a final inventory of 142 tonnes of separated plutonium (approximately 12m^3), with 37 tonnes owned by overseas customers. It is UK policy that the plutonium would be returned to overseas customers. This would leave a UK plutonium stockpile of 105 tonnes. However for our baseline inventory we have reduced this figure to 102 tonnes (approximately 9m^3) because it is now assumed that less AGR fuel will be reprocessed (see

8s 5.2 and 6.58). Uncertainties exist about the closure dates for the Magnox stations and about how much AGR fuel will be reprocessed that could, potentially, impact on the plutonium inventory.

5.28 Should all plutonium be declared as waste and immobilised, the National Stakeholder Dialogue Plutonium Working Group has reported that the use of a ceramic waste form offers the most promising solution [10]. Based on a dilution factor in the ceramic matrix of 1:10 dilution factor and a packaging regime described by Nirex [3], conditioned and packaged volumes would be approximately 120m^3 and 4,450m^3 respectively for the total of UK and overseas plutonium.

Uranium

5.29 Uranium comes in various forms - it is found naturally and can be processed to give highly enriched, low enriched and depleted uranium (these forms having different concentrations of U235). Natural uranium is the basic feed material of the nuclear fuel cycle, and is used for Magnox reactor fuel. Low enriched uranium is used for AGR and PWR fuel, typically at a U235 content of between 3 and 5%. The principal uses of highly enriched uranium (HEU) (U235 content greater than 20%) are for submarine reactor fuel and nuclear weapons. Depleted uranium (in the form of uranium hexafluoride) is a by-product of uranium enrichment, and it is recovered from reprocessing natural and low enrichment fuels. Depleted uranium represents about 96% of the reprocessing product in volume after plutonium has been separated out, and HLW removed. In the UK uranium enrichment is undertaken at Urenco's Capenhurst facilities.

5.30 Holdings of civil uranium are published annually by the DTI. The latest published figures [17] show stocks of depleted, natural and low enriched uranium (DNLU) of 85,000 tonnes and stocks of HEU of 1,546kg. Military uranium stocks have been reported as about 15,000 tonnes DNLU and 21.9 tonnes HEU [3].

5.31 Nirex has estimated a final inventory of about 153,000 tonnes DNLU, with a corresponding packaged volume after treatment of 74,200m^3 [3]. These rounded figures remain valid for the revised assumption for AGR fuel reprocessed (see paragraph 5.2). Nirex has also calculated a final inventory of 23.5 tonnes HEU, with a corresponding packaged volume of about 750m^3 based on the same packaging regime as that assumed for plutonium [3].

Spent fuel

5.32 UK stocks of non-reprocessed spent fuel consist of arisings from Magnox and AGR stations and from the Sizewell B PWR station, along with smaller quantities of specialist fuel from research and prototype reactors.

5.33 There are no plans to reprocess about 4,700tU of UK-owned spent fuel, consisting of some 3,500 tHM of AGR fuel and 1,200tU of Sizewell B PWR fuel. Nirex has presented information on projected volumes should spent fuel be declared as waste and packaged [3]. It is assumed that the AGR fuel would be dismantled, as at present, and that the graphite separately packaged as ILW. We have adjusted the packaged volumes for AGR spent fuel to account for the additional 600tU now forecast. We have also revised the packaged volume of Sizewell B PWR spent fuel so that this is consistent with the latest SKB disposal concept [14].

Spent fuel	Quantity (tU)	Packaged volume (m^3)
Sizewell B PWR	1,200	2,740
AGR fuel dismantled	3,500	5,410
AGR graphite (ILW) (1)		5,120
Total	**4,700**	**13,270**

(1) This will be included with other ILW in the baseline inventory.

Uncertainties exist about how much AGR fuel will be reprocessed that could, potentially, impact on the spent fuel inventory. There may also be small quantities of specialised fuel from UK research reactors, in addition to those already declared as wastes and reported in the 2004 UK RWI. However quantities and radioactivities are likely to be very small in comparison [3].

5.34 Non-reprocessed spent fuel that is declared as a waste will have to be managed directly (i.e., not reprocessed). But there are issues concerning the volume of spent fuel that may have to be managed directly (derived from uncertainties about the lifetime of the Magnox stations and the Magnox reprocessing plant, and about the extent to which AGR fuel will be reprocessed.

NORM

5.35 This category of radioactive material is not within our remit. In the UK the significant NORM streams and annual productions (in tonnes) are [18]:

- Coal ash (from electricity production) 6,200,000
- Oil and gas industry scale and sludge 2,000
- Water treatment sludge 1,430,000
- Metal mining and processing residues 6,200,000

6 CoRWM Baseline Inventory - Uncertainties And Assumptions

(a) Radioactive wastes

6.1 The baseline inventory of radioactive wastes is that given in the 2004 UK RWI. Current holdings of radioactive waste can be accounted for with a high degree of confidence, as they exist and can be measured. On the other hand the 2004 UK RWI is based on assumptions as to the nature and scale of future activities, timetables for facilities operation and decommissioning, as well as on waste conditioning and packaging assumptions. In general there is reasonable confidence in estimates of future arisings from operations over the next 5 years. Uncertainty increases the further that operational waste arisings are projected into the future. The greatest uncertainty rests with future arisings of waste from facilities decommissioning and site clean up.

6.2 In this section, we present some of the uncertainties in these assumptions, and the potential impact in terms of changes to waste quantities etc. these might have on our baseline inventory, and therefore on particular waste management options.

6.3 There are a number of key factors that might impact on the radioactive waste inventory. These are:

1. Future spent fuel reprocessing
2. Waste substitution arrangements
3. Lifetimes of existing nuclear power stations
4. New build nuclear power stations
5. Decay storage and decontamination
6. Early decommissioning and site clean up
7. Categorisation of ILW into short and long-lived wastes
8. Segregation of waste on production
9. Spent sealed radioactive sources (SSRSs)
10. Waste processing, conditioning and packaging.

We address these factors in turn.

Future Reprocessing

6.4 At 1 April 2004 a total of about 47,000tU spent Magnox fuel and 5,000tU spent oxide fuel had been reprocessed at Sellafield. A further 8,000tU Magnox fuel and 4,500tU oxide fuel were projected for reprocessing. In addition 3,500tU of AGR fuel and 1,200tU of fuel from Sizewell B will be placed into long-term storage. Uncertainties in the baseline inventory arise from any potential changes to these assumptions.

6.5 The remaining operating Magnox station current projected closure dates are Dungeness A (2006), Sizewell A (2006), Oldbury (2008) and Wylfa (2010). Under current plans the remaining spent fuel would be reprocessed by 2012/13. In the event of early reprocessing plant closure, the amount of Magnox fuel remaining could be estimated from the current Magnox fuel inventory, the rate of processing and the rate of spent fuel production. However if Magnox reprocessing had to stop, it is assumed that the Magnox reactors themselves would also have to close. This is because the uranium metal contained in spent Magnox fuel, and its magnesium alloy cladding, are highly reactive materials. When stored under water, as is the case at all Magnox stations other than Wylfa, Magnox spent fuel undergoes corrosion, initially of the magnesium alloy cladding and subsequently of the uranium metal fuel. Once corrosion has started, reprocessing is inevitable to transform it into materials that are ultimately suitable for long-term management. Even if spent Magnox fuel were dry stored, it would need to be in a carefully controlled environment, and a suitable conditioning process developed.

6.6 The precise closure date for Thorp is governed by how much AGR and overseas LWR fuel will be reprocessed. We have assumed that existing contractual obligations for the reprocessing of overseas LWR fuel would be met. The uncertainty therefore is dependent on decisions taken on the treatment of future AGR spent fuel.

6.7 If the 3,500tU AGR fuel currently planned to be stored were to be reprocessed the following estimated packaged waste volumes would be generated [1]:

250m^3	HLW
7,000m^3	ILW
10,000m^3	LLW (Driggable)

The HLW and ILW represent approximately 15% and 2% respectively of the baseline inventory packaged volumes.

6.8 If the 1,200tU Sizewell B fuel were to be reprocessed the following estimated packaged waste volumes would be generated [1]:

90m^3	HLW
2,000m^3	ILW
5,000m^3	LLW (Driggable)

The HLW and ILW represent approximately 5% and <1% respectively of the baseline inventory packaged volumes.

6.9 At 1 April 2004 Thorp had reprocessed a total of 5,000tU spent fuel [1]. The 2004 UK RWI does not report how much of this is AGR fuel. It is therefore difficult to estimate the impact that early plant closure would have on the amount of unreprocessed spent AGR spent. For the purposes of estimating the uncertainty we have assumed that early closure could potentially double the amount of spent AGR fuel requiring long-term management.

Waste substitution arrangements

6.10 Our baseline inventory assumes that there will be waste substitution (see paragraphs 5.3 and 5.4). Waste substitution is the process whereby an additional amount of HLW from reprocessing spent fuel would be returned to overseas customers that is equivalent in radiological terms (but smaller in volume) to the ILW and LLW that would otherwise be returned.

6.11 Uncertainty is limited to whether or not waste substitution takes place. If ILW substitution does not, about 5,000m^3 of packaged ILW would be returned (see paragraph 5.15) in place of the additional 60m^3 of HLW (see paragraph 5.9). A further 25,000m^3 of packaged LLW will be produced from reprocessing overseas spent fuel, but as this can be disposed to Drigg it is outside our remit.

6.12 The principle supporting waste substitution is one of radiological neutrality. Therefore there should be no effect on the baseline inventory in terms of radioactivity.

Lifetime of existing nuclear power stations

6.13 Market conditions or technical and safety issues could result in revised lifetimes. The lifetimes of the remaining operational Magnox stations in the 2004 UK RWI correspond with the latest dates for end of generation announced by BNFL. Consequently, uncertainty is limited to earlier closure. In the case of British Energy's AGR stations and the Sizewell B PWR station, possible alternatives to lifetime assumptions (25, 30, 35 or 40 years depending on the station) are early closure or extended operation.

6.14 To illustrate the impact of power station lifetime changes, the 2004 UK RWI gives estimated waste volumes from one year's station operation (see below). The figures do not include wastes from reprocessing discharged fuel.

Waste type	Station	Volume arising (m^3)	When all waste has been packaged	
			Packaged volume (m^3)	Conditioned volume (m^3)
ILW	Magnox (1)	34	64	45
	AGR (2)	23	62	41
	PWR (3)	8.1	17	12
LLW	Magnox (1)	34	39	31
	AGR (2)	54	59	48
	PWR (3)	25	80	65

(1) Average annual arisings for period 2004-2008 at operating stations.

(2) Average annual arising for period 2004-2009 at AGR stations.

(3) Average annual arising for period 2004-2009 at Sizewell B.

6.15 For example, should all 7 AGR stations operate for an additional 5 years, the total additional packaged ILW volume would be 2,170m^3, i.e. <1% of the baseline inventory volume. An additional 2,065m^3 packaged LLW would be produced - it is expected that the LLW would be disposed to Drigg. An additional 1,300tU spent fuel would also be produced. Should Sizewell B operate for an additional 10 years, the total additional packaged ILW volume would be only 170m^3. An additional 800m^3 packaged LLW would be produced, but it is expected that this would be disposed to Drigg. An additional 300tU spent fuel would also be produced.

New build nuclear power stations

6.16 There are no current plans to construct further nuclear power stations in the UK. However BNFL and BE continue to assess the feasibility of new reactor designs to replace existing reactors. To assess the impact of a new build programme of nuclear power stations, we have considered a number of alternative reactor designs:

- Advance Passive (AP1000) – an advanced PWR designed by BNFL-Westinghouse;
- European Pressurised Water Reactor (EPR) –an advanced PWR designed by Framatome ANP;
- Advanced Boiling Water Reactor (ABWR) – an evolution of the General Electric BWR design;
- Pebble Bed Modular Reactor (PBMR) - a high temperature helium-cooled reactor.

6.17 We have focussed on the scale of programme put forward by BNFL and BE in their submissions to the Government Energy Policy Review in 2001. This programme is 10GW installed, to maintain nuclear generating capacity at about 25% of UK electricity output. BNFL has proposed that 10 AP1000 reactors be built within the next 20 years to achieve this. Our objective is to assess the impact of BNFL's proposal on the baseline inventory and compare it with possible alternatives. We make no comment on licensing issues, costs and timescales.

6.18 The AP1000 reactor is capable of burning MOX fuel, and so would represent an option – if so desired – for reducing the UK's stockpile of plutonium. BNFL estimate that two AP1000 reactors could consume the projected UK stockpile over a 20-year period.

6.19 BNFL has estimated the following quantity of spent fuel and total operational and decommissioning wastes (packaged volumes) from a programme of 10 new AP1000 PWRs with an operating lifetime of 60 years [13] as follows:

14,000tU	spent fuel
9,000m^3	ILW
80,000m^3	LLW

6.20 We have assumed that the spent fuel would not be reprocessed to recover uranium and plutonium, but would be packaged directly. It has been estimated that this would give a packaged volume of 31,900m^3 [18] using the latest SKB disposal concept [20]. It is likely that all LLW would meet Drigg's CfA for disposal.

6.21 The effect of the additional 9,000m^3 of ILW is relatively small when compared with the ILW volume in the baseline inventory – it represents about 2.5% of the total.

6.22 A comparison of waste volumes for a 10GW installed programme with alternative reactor types has been undertaken [18]. The results of this comparison are given in the table below.

Reactor type	Spent fuel (tHM)	Packaged volume (m^3)		
		Fuel in SKB canisters (m^3)	ILW	LLW
AP1000	14,000	31,900	9,000	80,000
EPR	9,200	21,000	13,000	100,000
ABWR	15,400	31,500	187,000	
PBMR	6,200	130,000 (1)	10,800 (moderator and other plant) (1)	

(1) Unpackaged volume.

For the PBMR operational wastes are difficult to asses, but might be less than for the water-cooled reactors because the PBMR is an entirely dry system. Wastes from decommissioning the PBMR vessel and associated shielding cannot be assessed from the sparse design information currently available.

Decay storage and decontamination

6.23 The UK definition of HLW states that these are wastes " in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities." The definition does not include specific levels of heat output, but NII guidance [21] refers to IAEA guidance [22], which classifies HLW as radioactive waste that has a heat output exceeding about 2kW/m^3. A study based on the 2001 UK RWI has indicated that within 50 years about 95% of the HLW volume will have a heat output below this threshold [15]. We would anticipate a very similar outcome using 2004 RWI data. Hence by using the IAEA criterion, the UK's HLW would be reduced to less than 100m^3 (packaged volume), with the majority reclassified as ILW. However, this would not affect total radioactivity, and the ILW would still remain significantly radioactive for periods in excess of this time.

6.24 There a number of ILW streams in the 2004 UK RWI that waste producers plan to decay store or decontaminate, so that the waste can be disposed as LLW at Drigg. The major components are Magnox and LWR pond furniture at Sellafield, desiccants and some catalysts at AGR power stations, short-lived ILW from decommissioned submarines and redundant pond skips at Magnox power stations. Their total packaged waste volume is 19,000m^3 [18]. This represents about 5.5% of the ILW baseline inventory.

6.25 A further 1,830m^3 (packaged volume) of contaminated solid ILW in the 2004 UK RWI that might be amenable for decontamination have been identified [18]. However, these wastes add less than 10% to the 19,000m^3 identified by waste producers.

6.26 Large quantities of contaminated ILW from facilities decommissioning will arise in the future at many sites. Decontamination of these wastes could reduce significantly the overall ILW volume, but decisions on whether or not decontamination is carried out will depend on technical feasibility, radiological impact and economics.

6.27 A study carried out by EEUK for Defra & Nirex based on the 2001 UK RWI [9] shows that after 120 years (when all waste is forecast to have arisen) 19% of ILW has decayed to LLW. At 300 years a further 2% only has decayed to LLW.

Early decommissioning and site clean up

6.28 Most future waste arisings in the 2004 UK RWI are from facilities decommissioning at Sellafield and final stage decommissioning at Magnox and AGR power stations. We have analysed the potential impact of early decommissioning on the baseline ILW inventory.

6.29 For the Magnox and AGR power stations, it is assumed that construction a high integrity, low maintenance structure or "safe store" for the reactor containment building, and the subsequent period of "Care and Maintenance", would be omitted. Final stage decommissioning and site clearance would continue directly after the removal of non-radioactive plant and structures external to the reactor area. This would bring forward final stage decommissioning and site clean up by between about 60 and 95 years for Magnox stations and about 75 years for AGR stations. The implications are that some LLW might be reclassified as ILW.

6.30 For AGR stations, some reactor mild reactor LLW streams have been identified where the activity exceeds the upper LLW limit when extrapolated backward by 80 years. The total packaged volume of these streams is 8,790m^3, which represents about 2.5% of the total baseline ILW inventory.

6.31 It is expected that the impact of early clean-up of Magnox stations will be of the same order of magnitude in terms of overall impact on the baseline inventory.

6.32 In the 2004 UK RWI it is forecast that all decommissioning work at Sellafield will be completed by 2120. We have addressed the issue of uncertainty in the ILW inventory by assuming that completion of decommissioning is brought forward to 2040. Analysis of decommissioning waste stream data in the 2004 UK RWI indicates that although LLW stream activities will be higher, because much of the waste will arise earlier, the increased activities are not expected to exceed LLW limits. Our conclusion is that the impact on the baseline ILW inventory will be minimal.

Categorisation into short and long-lived wastes

6.33 One of the proposed waste management options that CoRWM has short-listed in its 2nd consultation exercise is the near surface disposal of short-lived wastes. One of the advantages of this option is the potential to allow future decommissioning wastes to be managed at existing sites, removing the need to transport large volumes to central or regional facilities. Because near surface disposal is suited to short-lived wastes whose radioactivity falls to low levels over a few hundreds of years, it would not be suitable for wastes that contain a mix of short and long-lived radioactivity, such as the wastes from spent fuel reprocessing, unless this radioactivity was at a low level initially. A study has been carried out to identify ILW that could be designated as short-lived under international classification systems, and that therefore might be suitable for disposal at a near-surface facility [18].

6.34 The UK does not classify radioactive wastes as short and long-lived. Our analysis has been based on the EU radioactive waste classification system [23], which is itself based on the IAEA classification scheme [22]. The EU system states that the short-lived low and intermediate level waste category includes radioactive waste with nuclides half-life less than or equal to those of Cs137 and Sr90 (around 30 years) with a restricted alpha long-lived radionuclide concentration (limitation of long-lived alpha emitting radionuclides to an overall average of 400 Bq/g in the total waste volume).

6.35 The result of applying the EU classification system to ILW in the 2004 UK RWI is that only a small volume of ILW (2,320m^3 in terms of conditioned volume) can be classified as short-lived. A breakdown of this conditioned volume (and the equivalent packaged volume) into sites and regions is shown in the table below. The main component of the short-lived waste is pond skips at Magnox power stations (1,050m^3 conditioned volume; 1,310m^3 packaged volume). However BNFL is proposing to decontaminate pond skips and dispose of them to Drigg as LLW. Other significant components include ion exchange material at Trawsfynydd and tritium contaminated items at Cardiff and Culham. There are only 420m^3 of decommissioning ILW that can be classified as short-lived; these are from uranium and plutonium facilities at Dounreay and Aldermaston, and from JET at Culham. There is no short-lived ILW from decommissioning nuclear power stations.

		Waste at 1.4.2004 and future arisings	
Site	**Region**	**Conditioned Volume**	**Packaged Volume**
Bradwell	East of England	43	54
Sizewell	East of England	209	261
East of England Total		**252**	**315**
Chapelcross	North West	0.2	0.3
Sellafield	North West	22	26
North West Total		**22**	**26**
Torness	Scotland	24	25
Dounreay	Scotland	290	337
Scotland Total		**314**	**362**
Amersham	South East	57	72
Harwell	South East	0.1	0.1
Culham	South East	135	160
AWE Aldermaston	South East	199	237
HMNB Portsmouth	South East	0	0
Dungeness A	South East	171	213
South East Total		**562**	**682**
Winfrith	South West	23	27
Hinkley Point A	South West	454	566
Berkeley Centre	South West	2	2
South West Total		**479**	**594**
Cardiff	Wales	186	216
Trawsfynydd	Wales	300	1,400
Wales Total		**486**	**1,620**
Oldbury	West Midlands	203	253
West Midlands Total		**203**	**253**
Overall Total		**2,320**	**3,850**

6.36 The principal reason why there is such a small volume of short-lived ILW is that there are very few ILW streams in the 2004 UK RWI that do not contain radionuclides with half-lives of greater than 30 years.

6.37 In practice any new proposed UK near surface disposal facility would have conditions for acceptance that impose waste concentration limits on both alpha and beta/gamma radionuclides, as Drigg does today. Therefore in determining what ILW streams might be suitable for near surface disposal we have utilised the CfA for the Drigg site, and we have examined how much additional ILW volume might be accommodated in a near surface disposal facility should the CfA be less onerous than those imposed at Drigg. We have also examined the ILW radionuclide activity data in order to determine which radionuclide activity concentrations would restrict or prevent near surface disposal of ILW.

6.38 Drigg imposes limits on waste stream radionuclide concentrations (specific activity trigger levels) and on waste stream radionuclide activities (total activity trigger levels) averaged over the lifetime of a waste stream. Applying these limits to ILW in the 2004 UK RWI gives a conditioned waste volume of 1,170m^3 that meets all radionuclide trigger levels. This volume comprises about 660m^3 from Magnox power stations, and consists mainly of miscellaneous contaminated items and pond skips. BNFL has reported in the 2004 UK RWI that it plans to decontaminate pond skips so they can be disposed to Drigg as LLW.

6.39 The Drigg LLW disposal site also imposes conditions regarding the physical and chemical composition of wastes consigned for disposal. We have analysed the material composition of ILW in the 2004 UK RWI, and our conclusion is that only a very small volume of waste meeting the radioactivity limits would be restricted because of their material composition.

Segregation of waste on production

6.40 One of the uncertainties in determining the volumes of waste suitable for near surface disposal is the ease or difficulty of segregating short and long-lived wastes from the mix of radioactive wastes that are produced. In the UK most existing nuclear facilities have been shut down or are nearing the ends of their operational lives. As a result, most operational waste reported in the 2004 UK RWI has already been produced, is held in stores, and, if amenable, would require sorting to segregate short and long-lived waste items. In contrast most facilities decommissioning waste in the UK will arise in the future, so in principle practices could be implemented to segregate short and long-lived wastes when they are produced.

6.41 To a large extent wastes that are suitable for near surface disposal in the UK are already segregated – as a LLW fraction. However we have identified a number of ILW streams in the 2004 UK RWI that have the potential for segregation into ILW and LLW fractions (see table below).

Site / ILW stream type	Conditioned volume (m^3)	Packaged volume (m^3)
AWE Aldermaston / PCM	6,330	7,340
AWE Aldermaston / sea disposal packages	200	240
Harwell & Winfrith / sea disposal packages	1,180	1,370
Total	**7,710**	**8,950**

6.42 Operational and decommissioning PCM wastes at Aldermaston are classified as ILW in the 2004 UK RWI until they can be accurately classified as either ILW or LLW. AWE intends to size reduce and repackage ILW sea disposal packages. Some of the waste will be reclassified as LLW. A small number of sea disposal packages at Harwell and Winfrith may be segregated as LLW after detailed inventory investigation. Furthermore a waste management strategy is being developed for the ILW packages – waste may be removed, in which case the bulk of the concrete/mild steel containers may be segregated as LLW. We will assume a nominal 50% by volume (about 4,500m^3) of these wastes are LLW as a basis for quantifying uncertainty.

6.43 It may be the case that other ILW streams in the 2004 UK RWI contain components that could be segregated and routed to near surface disposal. However, our analysis of ILW in the 2004 UK RWI, and what proportion of this could be designated as short-lived and be potentially suitable for near surface disposal, suggests that the impact of waste segregation would likely be very modest.

Spent sealed radioactive sources (SSRSs)

6.44 There are uncertainties regarding the number of SSRSs that might come forward as radioactive waste. Sealed radioactive sources (SSRSs) are widely used in industry, medicine and research. The UK has a large and complex market for sealed radioactive sources. There is one major manufacturer, two organisations that recycle sources, importer/distributors and up to 6,000 registrations issued for the use of sources (although many may no longer be in use). Some SSRSs can be recycled into new sources, or stored to allow their decay and disposal. Others however remain as ILW for long periods.

6.45 The nuclear industry uses SSRSs, and has facilities for storing redundant ILW sources. These wastes are included in the UK RWI. SSRSs produced by the non-nuclear industry (small users) that fall into the ILW category are mostly relatively short-lived. Special arrangements are required for their storage. UKAEA and GE Healthcare operate storage facilities at Harwell and Amersham respectively, and these wastes are included in the UK RWI. However large numbers of sources are retained on small user premises under registrations, and these are not included in the UK RWI. Nirex has reported an estimate of $<1m^3$ for the volume of recovered redundant sources [3], but in view of the large uncertainties it has been suggested that it would be prudent to increase this estimate by a factor of 10, and assume a volume of $<10m^3$ [18].

6.46 It has been suggested that for Co60 sources the total radioactivity could be comparable with the Co60 radioactivity in ILW (about 2,300,000TBq). Also the radioactivities of individual sources may be as high as 2,000 TBq, and therefore significant decay storage may be required [18].

Waste processing, conditioning and packaging

6.47 Assumptions on how waste will be conditioned and packaged in the future will determine conditioned and packaged volumes for long-term management. For certain wastes there are uncertainties in the nature of the conditioning process that will be adopted, the degree of volume change on conditioning, and the type of container used to package the waste. These uncertainties will be greater for future decommissioning wastes, where site operators and the NDA will need to decide on waste processing. Changes to processing and conditioning methods could significantly affect the baseline ILW inventory.

6.48 An example of the possible impact of changes in waste processing technologies can be illustrated by considering the fate of metal waste arisings. The 2004 UK RWI includes over 60,000 tonnes of ferrous metals in operational and decommissioning ILW. Future management strategies may include for example, melting, decontamination or size reduction, all of which could have an impact on the total volumes of these wastes. However, additional facilities may be required which would require management and decommissioning themselves.

6.49 Treatment processes offer significant benefit in terms of minimising the volumes of some wastes for long-term management. For example, large amounts of contaminated ferrous metals from decommissioning could be melted to separate out ILW, leaving LLW suitable for disposal at Drigg and potentially very low active metal suitable for recycling.

6.50 There are uncertainties regarding the approach that the NDA will take to ILW storage - for example, possible consolidation of ILW interim storage at a smaller number of sites. It is not expected that this uncertainty in approach will significantly change the ILW inventory.

(b) Other materials

Plutonium and uranium

6.51 Uncertainties that could potentially impact on the inventories held in the UK include the closure dates for the Magnox reprocessing plant and the operational Magnox stations; the quantity of AGR fuel reprocessed and the return of the 37 tonnes of overseas plutonium to its owners.

6.52 Early closure of the Magnox reprocessing plant or of Magnox power stations will not have any significant affect on the plutonium and uranium inventory, as there remains at most a total of only 10 years of further generation.

6.53 It is reported that each tonne of spent AGR fuel contains about 5.2kg of plutonium and 969kg of uranium [3]. Consequently an additional 18.2 tonnes of plutonium and about 3,390 tonnes of uranium should arise if the 3,500tU balance of AGR fuel is reprocessed. Also, each tonne of spent Sizewell B PWR fuel contains about 12kg of plutonium and 937kg of uranium [24]. Consequently an additional 14 tonnes of plutonium and about 1,120 tonnes of uranium should arise should the forecast total 1,200tU of fuel be reprocessed.

6.54 There are three fundamental options for plutonium management: safe storage in a suitable form, utilisation in reactors and immobilisation. However the choice of option will have little impact on the overall UK waste inventory volume.

6.55 If the waste is maintained in storage in its present powered form, its volume represents only a very small fraction of HLW and ILW volumes. However it is recognised that continued storage of separated plutonium in powder form is not acceptable in the longer term (i.e. beyond 25 years) [10].

6.56 If plutonium were to be treated and packaged as a waste, the estimated total packaged volume of 4,450m^3 would represent increases of about 160% and 13% in the HLW and ILW packaged volumes.

6.57 The use of plutonium as MOX fuel in UK reactors is covered in paragraph 4.7. If all plutonium were to be used as fuel in current and future nuclear reactors, this would have an impact on the radioactive waste inventory. The impact of new nuclear power station build, necessary if all plutonium (and potentially some recovered uranium) were to be used as fuel in the UK, is discussed in paragraphs 6.16 – 6.22. BNFL notes that about 5% of existing plutonium stocks are likely to require extensive chemical treatment to allow it to be used as fuel, potentially making this route uneconomic [13].

6.58 The burning of plutonium and uranium in MOX fuel would deplete the inventories of these materials, as well as affecting their chemical make up. It is reported that MOX fuel with an initial composition of 944kg U and 56kg Pu would with medium burnup (48GWd/tHM) in a PWR produce spent fuel containing 914kg U and 34kg Pu [24]. This is equivalent to 3% depletion in the amount of uranium and 40% depletion in the amount of plutonium.

6.59 The principal options for uranium management are conversion of UF_6 to solid oxide and either utilisation in reactors or packaging as waste. However a 10GW installed new build programme of AP1000 reactors would only utilise 14,000tHM as fuel so the choice of option will have little impact on the overall UK waste inventory volume. Any alternative water-cooled reactor type will not change the outcome to any significant extent.

Spent fuel

6.60 There are issues concerning the volume of spent fuel that may have to be managed directly (i.e., not reprocessed) derived from uncertainties regarding:

1 The extent to which AGR fuel will be reprocessed,
2 The extent to which Sizewell B PWR fuel will be reprocessed,
3 The extent of lifetime extensions to existing nuclear power stations
4 The impact of any new nuclear power station build,
5 The packaging method for spent fuel.

6.61 Items 1 & 2 are covered in paragraph 5.33, item 3 in paragraph 6.15, and item 4 in paragraphs 6.16 – 6.22. Five-year lifetime extensions to the AGRs and the Sizewell B PWR would increase the quantity of spent from about 4,700tU to about 6,300tU, and the volume of packaged waste from 8,150m^3 to about 9,470m^3. The impact of new nuclear power station build would, depending on the reactor type and the assumptions made, increase the quantity of spent fuel to be managed from about 4,700tU to, at most, about 20,000tHM, and the volume of packaged waste from 8,150m^3 to about 40,000m^3.

7 Summary and Example Scenarios

(a) Summary of Baseline Inventory and Uncertainties

7.1 In the this section of the report we have brought together the information on our baseline inventory presented in Section 5 and on the uncertainties in the inventory presented in Section 6 and summarised this for each radioactive waste and material within our remit. Table 7.1 provides further information on radioactive wastes and materials produced in the UK, and the anticipated quantities by category based on current assumptions. It shows whether these wastes and materials are included in the 2004 UK RWI, and if a long-term management solution currently exists.

High Level Waste (HLW)

Inventory and uncertainties	**Approximate change in HLW**	
	Packaged volume (m^3)	**Packaged volume (%)**
2004 UK RWI	1,750	
Overseas HLW	- 460	
Baseline	**1,290**	**100**
Early closure of Magnox reprocessing	Up to - 160	Up to - 12
Early closure of Thorp	Up to - 250	Up to - 19
Reprocess additional 3,500tU AGR fuel	+ 250	+ 19
Reprocess 1,200tU PWR fuel	+ 90	+ 7
ILW substitution not implemented	+ 60	+ 5

Intermediate Level Waste (ILW)

Inventory and uncertainties	Approximate change in ILW	
	Packaged volume (m^3)	Packaged volume (%)
2004 UK RWI	348,000 (1)	
Graphite from 3,500tU spent AGR fuel	- 5,120	
Baseline inventory	**353,000 (1)**	**100**
Early closure of Magnox reprocessing	Up to - 7,900	Up to - 2
Early closure of Thorp	Up to - 1,880	Up to - 0.5
Reprocess additional 3,500tU AGR fuel	+ 7,000	+ 2.0
Reprocess 1,200tU PWR fuel	+ 2,000	+ 0.6
ILW substitution not implemented	- 5,000	- 1
Early closure of Magnox stations	Up to - 900	- <1
Life extension to AGRs (+ 5 yrs)	+ 2,170	+ 1
Life extension to AGRs (SF graphite)	+ 1,930	
Life extension to Sizewell B (+ 10 yrs)	+ 170	+ <0.1
New build nuclear power stations	+ 9,000	+ 3
Decay/decontamination (producer plans)	- 19,000	- 5
Waste segregation	- 4,500	- 1
Early power station decommissioning	+ 17,580	+ 5
Unaccounted SSRSs	+ <10	- <0.01

(1) Rounded

7.2 The baseline inventory includes a packaged volume of 3,850m^3 that can be designated as short-lived ILW and potentially suitable for near surface disposal.

Low Level Waste (LLW) non-Drigg

7.3 There are uncertainties over the future management of "non-Drigg" LLW since if the waste is not processed to make it suitable for Drigg disposal it would need to be managed in the same way as ILW. The "non-Drigg" LLW inventory (37,200m^3 packaged volume) represents about 8% of the baseline inventory. Non-Drigg LLW could be sent to Drigg for disposal if it were treated to ensure that it meets the Drigg CfA. Nearly all non-Drigg LLW is reactor graphite containing C14 above the limits imposed at Drigg. While we do not rule out future treatment, the nature of the waste would make this difficult.

7.4 Reactor graphite arises as ILW and LLW during final stage decommissioning of Magnox and AGR power stations. While the total quantity of graphite should be known accurately, there will be an uncertainty in the relative volumes of ILW and LLW.

Plutonium

Inventory and uncertainties	Approximate change in plutonium	
	Packaged volume (m^3)	Packaged volume (%)
Total inventory	4,450	
Overseas plutonium	- 1,180	
Baseline inventory	**3,270**	**100**
Early closure of Magnox reprocessing	Up to - 640	Up to - 20
Early closure of Thorp	Up to - 580	Up to - 18
Reprocess additional 3,500tU AGR fuel	+ 580	+ 18
Reprocess 1,200tU PWR fuel	+ 450	+ 14
Use of plutonium in fuel for new build	- 3,270	- 100

Uranium

Inventory and uncertainties	Approximate change in uranium	
	Packaged volume (m^3)	Packaged volume (%)
Baseline inventory	**74,950**	**100**
Early closure of Magnox reprocessing	Up to – 3,390	Up to - 5
Early closure of Thorp	Up to –1,660	Up to - 2
Reprocess additional 3,500tU AGR fuel	+ 1,660	+ 2
Reprocess 1,200tU PWR fuel	+ 550	+ 0.7
Use of uranium in fuel for new reactors	- 6,840	- 9

Spent fuel

Inventory and uncertainties	Approximate change in spent fuel	
	Packaged volume (m^3)	Packaged volume (%)
Baseline inventory	**8,150**	**100**
Reprocess additional 3,500tU AGR fuel	- 5,410	- 66
Reprocess 1,200tU PWR fuel	- 2,740	- 34
Life extension to AGRs (+ 5 yrs) (1)	+ 840	+ 10
Life extension to Sizewell B (+ 10 yrs) (1)	+ 680	+ 8
New build reactors (10 x AP1000)	+31,900	+ 390

(1) No reprocessing of spent fuel.

(b) Example Scenarios

7.5 Section 7.2 presents the volumes and radioactivities for the baseline inventory. Section 7.3 presents four alternative scenarios to illustrate the impact on the baseline inventory of uncertainties in the quantities of radioactive wastes and materials.

Table 7.1. Total volumes of radioactive materials and wastes in packaged form

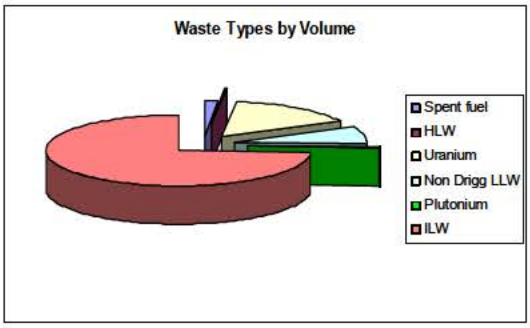
	Included in UK RWI	Long term management options	Eventual projected volume (m^3) at about 2120				
			2004 UK RWI As reported [1]	2004 UK RWI When all conditioned	Unconditioned	Conditioned	Packaged
Materials not declared as waste							
Plutonium [2]	No	No	-	-	12 (139 t)	120	4,450
Spent fuel[3]	No	No	-	-	(4,700 tU)		13,270
DNL Uranium[4]	No	No	-	-	(153,000 tU)		74,200
HE Uranium[5]	No	No	-	-	1 (24 tU)		750
Higher activity wastes							
HLW[6]	Yes	No	2,490	1,340	Not applicable	1,340	1,750
ILW[7]	Yes	No	217,000	242,000	217,000	242,000	348,000
Lower activity wastes within CoRWM's remit							
Non Drigg LLW[8]	Yes	No	26,300	31,200	26,300	31,200	37,200
Lower activity wastes not within CoRWM's remit							
Drigg LLW [9]	Yes	Yes	2,030,000	2,000,000	2,030,000	2,000,000	2,480,000
Site Clean Up Wastes (VLLW)[10]	No	No	-	-			18,000,000

[1] 2004 UK RWI includes unconditioned and conditioned wastes.
2 The volume of plutonium, which will be held in the UK in its original unconditioned form, is estimated to be approximately 12 cubic metres. This is based on a final inventory of 142 tonnes (37 tonnes of which are owned by overseas customers) at a density of 11.5t/m^3 [10]. If all AGR fuel were reprocessed there would be an additional 18.2 tonnes (1.6m^3) of plutonium.
[3] Comprises 3,500tU AGR fuel and 1,200tU Sizewell B PWR fuel. The packaged volume includes the dismantled fuels (8,150m^3) and AGR graphite overpacked in disposal canisters as ILW (5,120m^3) [3].
[4] Depleted Natural and Low enriched Uranium. Final inventory and packaged volume is taken from Reference 2.
[5] Highly Enriched Uranium. Final inventory and packaged volume is taken from Reference 3.
[6] HLW figures are taken from the 2004 UK RWI (draft unapproved) [1]. 400m^3 of the final packaged volume is attributable to reprocessing of fuel from overseas and is subject to return of waste provisions. A further 60m^3 would be returned with ILW substitution.
[7] ILW figures are taken from the 2004 UK RWI (draft unapproved) [1].
[8] Non-Drigg LLW figures are taken from the 2004 UK RWI (draft unapproved) [1]. These exclude all LLLW suitable for disposal at Drigg or with a current alternative disposal route.
[9] It is estimated that a replacement facility for Drigg will be needed after 2050. Figures are taken from the 2004 UK RWI (draft unapproved) [1]. Figures do not include naturally occurring radioactive materials (NORM), which have an estimated annual arising of about 18 million cubic metres.
[10] The RWMAC report [25] refers to a BNFL Study '*Contaminated Ground Remediation Strategies for Sellafield*'. Arisings predicted for Sellafield site only – VLLW or Very Low Level Waste, this value is also given in BNFL's response to CoRWM.

7.2 CoRWM Baseline Inventory

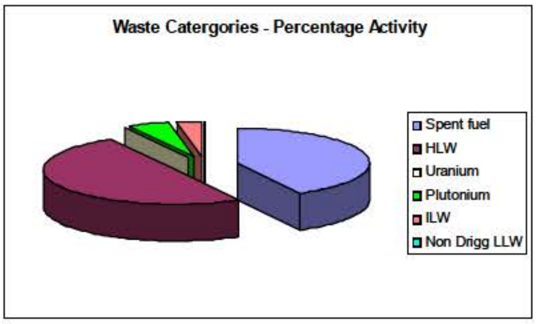
The contributions by volume of each waste and material type in the form in which they could be packaged, are as follows:

	Contribution (%)	Volume (m^3)
Spent fuel	1.7	8,150
HLW	0.3	1,290
Uranium	15.7	74,950
Non-Drigg LLW	7.8	37,200
Plutonium	0.7	3,270
ILW	73.9	353,000
Total	**100**	**477,860**



The contribution to total radioactivity of radioactive wastes and materials is illustrated below at an indicative date of 2040, based on reported activity data [1, 19]. The total radioactivity at this date is about 78,000,000 TBq. This radioactivity and the relative contributions of the wastes and materials will change over time. It demonstrates that over 90% of radioactivity is associated with HLW and spent fuels. If the wastes only are considered the contributions are: HLW (96%), ILW (4%), Non-Drigg LLW (<0.001%). The total radioactivity is about 41,000,000 TBq.

	Contribution %
Spent fuel	42
HLW	50
Uranium	<0.01
Non-Drigg LLW	<0.001
Plutonium	5
ILW	3
Total	**100**



7.3 Alternative Scenarios

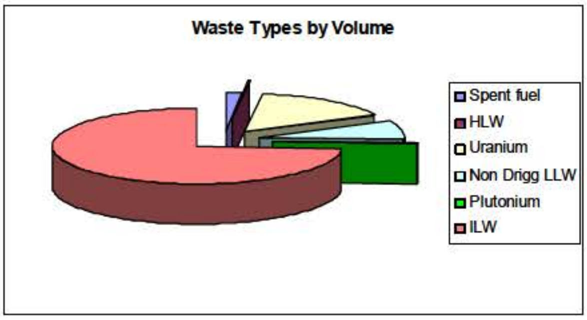
We present a number of alternative scenarios to illustrate the range of uncertainties in the baseline inventory. The contributions by volume of each waste and material type in the form in which they could be packaged are as follows:

Scenario 1: No substitution of ILW

HLW, ILW and plutonium from the reprocessing of spent fuel from overseas reactors are returned, i.e. HLW is not substituted for ILW. The volume of HLW for management in the UK would increase by 60m^3 and the volume of ILW decrease by about 5,000m^3. The total inventory volume is about 1% less than the baseline inventory.

The principle supporting waste substitution is one of radiological neutrality. Therefore there should be no effect on radioactivity.

	Contribution (%)	Volume (m^3)
Spent fuel	1.7	8,150
HLW	0.3	1,350
Uranium	15.8	74,950
Non-Drigg LLW	7.9	37,200
Plutonium	0.7	3,270
ILW	73.6	348,000
Total	**100**	**472,920**

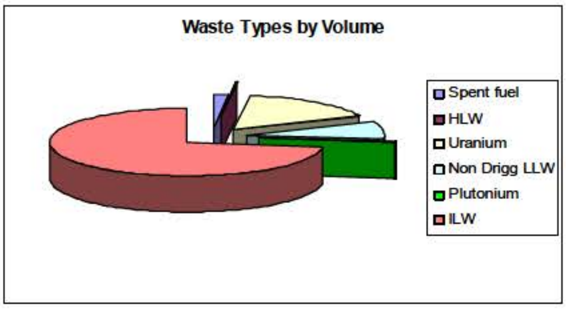


Scenario 2: Decontamination, decay storage and segregation of ILW

This scenario examines the impact of waste producer plans to decontaminate or decay store suitable ILW streams so that they may be disposed of to Drigg as LLW, or to segregate components of certain ILW streams so that they may be disposed of to Drigg as LLW. For this latter category we have assumed that 50% of the waste volume could be classified as LLW. The result of decontamination, decay storage and segregation of ILW is to reduce the ILW inventory volume by 23,500m^3 (about 7%) and the total inventory volume by about 5%,

The effect on the baseline inventory in terms of radioactivity would be minimal.

	Contribution (%)	Volume (m^3)
Spent fuel	1.8	8,150
HLW	0.3	1,290
Uranium	16.5	74,950
Non-Drigg LLW	8.2	37,200
Plutonium	0.7	3,270
ILW	72.5	329,500
Total	**100**	**454,360**

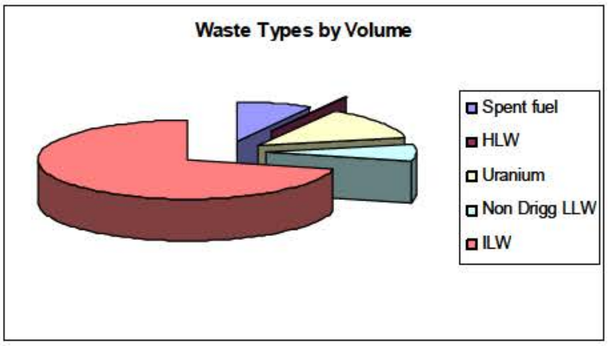


Scenario 3: Life extensions for existing AGR power stations and for Sizewell B, plus a programme of new nuclear power stations

We have assumed that existing AGR stations would operate for a further 5 years and Sizewell B for a further 10 years. This would mean that the AGRs operated for 30, 35 or 40 years, and Sizewell B operated for 50 years. We have assumed a new build programme of 10 AP1000 reactors in the UK. The outcome would be similar for alternative designs of water-cooled reactor we have considered, but considerably different for a design such as the PBMR. We have assumed that the new programme of reactors would use MOX fuel sufficient to utilise the stockpile of plutonium in the UK. (It is recognized that about 5% of the plutonium stockpile would require extensive chemical treatment before use and so may be packaged, in which case the volume of plutonium would be about 230m^3) It is also assumed that uranium for the fuel will come from the UK stockpile.

The result of power station life extensions and new build is to increase the total inventory volume by 36,580m^3 (about 8%). The effect on the baseline inventory in terms of radioactivity would be more significant because of the additional spent fuel produced.

	Contribution (%)	Volume (m^3)
Spent fuel	8.1	41,570
HLW	0.3	1,290
Uranium	13.2	68,110
Non-Drigg LLW	7.2	37,200
Plutonium	0	0
ILW	71.2	366,270
Total	**100**	**514,440**

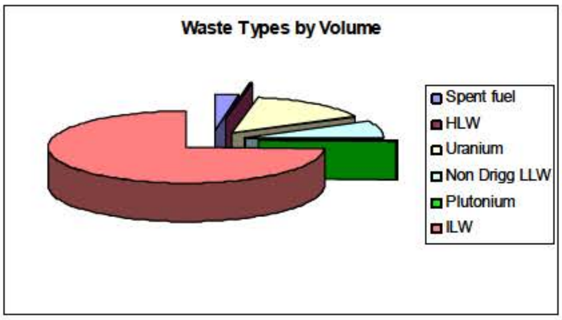


Scenario 4: Early closure of reprocessing plants and early power station decommissioning

This scenario examines the impact of bringing forward the closure of spent fuel reprocessing and the decommissioning of the UK's nuclear power stations. We assume that spent fuel reprocessing plants would be closed early, thereby increasing the amount of spent fuel for future management but reducing the amounts of HLW, ILW, plutonium and uranium. For the Magnox programme we assume that power stations would close immediately, but that all remaining spent fuel would be reprocessed. Early decommissioning would increase the proportion of waste falling into the ILW category.

The result of power early plant closures and decommissioning is to increase the total inventory volume by 5,630m^3 (about 1%). The effect on the baseline inventory in terms of radioactivity would also be minimal.

	Contribution (%)	Volume (m^3)
Spent fuel	2.8	13,560
HLW	0.2	880
Uranium	14.5	69,900
Non-Drigg LLW	7.7	37,200
Plutonium	0.4	2,050
ILW	74.4	359,900
Total	**100**	**483,490**



8 Conclusions

(a) Background

8.1 The aim of this report is to update the radioactive waste and material inventory on which CoRWM will, within the next two years, make its recommendations on how the UK's higher activity radioactive wastes, and other materials that may be declared as wastes in the future, should be managed over the long term.

8.2 We have made use of the latest information on radioactive wastes in the 2004 UK RWI. However this is draft information yet to be approved for publication. Consequently, elements of CoRWM's inventory may differ from the published 2004 UK RWI, but this is unlikely to be significant.

8.3 We have taken account of feedback received on our preliminary inventory report during the first stage of public and stakeholder engagement. In particular we have identified short-lived ILW that may be suitable for near surface disposal and considered alternatives to our nuclear power station new build scenario.

8.4 We have examined the implications of uranium and plutonium being declared and treated as wastes, as well as these materials being recycled as an energy source in nuclear reactors with the consequent generation of waste.

(b) Findings

8.5 We have determined the baseline inventory (on the basis of the six categories of radioactive materials and wastes - uranium, plutonium, spent fuel, HLW, ILW and non-Drigg LLW - that fall within our remit) at 477,860m^3 in packaged form.

8.6 The contribution to radioactivity in the baseline inventory is mostly from HLW and spent fuel.

8.7 Our findings, based on the range of uncertainties we have identified and the example scenarios we have presented to illustrate these uncertainties, are that the extent to which the baseline inventory is likely to vary in volume terms is less than 10%.

8.8 The greatest impact on the baseline inventory would be from a programme of ten new build nuclear power stations. The amount of spent fuel that would need to be managed would be about five times greater, assuming that the fuel were not reprocessed, and the total radioactivity would be similarly greater. Use of the UK stockpile of plutonium in MOX fuel would affect both the amount of plutonium in the total inventory as well as its chemical form.

8.9 If plutonium and uranium were declared wastes, whilst having very small impact on total waste inventory, they would represent a further waste stream which would require specific management recognizing the materials own particular characteristics with respect to safety (including criticality) and security.

8.10 Should ILW substitution not be implemented, this would have only a very minor impact on the inventory volume.

8.11 Only a small proportion of ILW (about 1% by volume) can be categorised as short-lived and so potentially suitable for near surface disposal.

8.12 The 2004 UK RWI contains ILW streams for which waste producers have plans to decontaminate, decay store or segregate LLW components so that wastes can be disposed of to Drigg. Further analysis of the 2004 UK RWI data has suggested that the impact of further waste segregation would likely be very modest.

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Appendix A Current QA arrangements for checking inventory data [1]

1. Introduction

1.1 A meeting was held on 23 March 2004 between members of CoRWM's Inventory Working Group (IWG) and Nirex. At that meeting it was agreed that Nirex would prepare a short note on the Quality Assurance (QA) arrangements in place for checking data provided by waste producers for publication in the UK Radioactive Waste Inventory.

1.2 Nirex, as producer of the Inventory, reviews and challenges the data provided by waste producers. However, the current situation is that the waste producers are ultimately responsible for the published data on their own wastes.

2. General arrangements

2.1 Nirex is responsible for the provision of the Inventory to DEFRA, under a written agreement with DEFRA. Nirex is certified to ISO 9001 this is audited by LRQA on a 6 monthly basis.

2.2 Nirex defines a Technical Specification for work required from a contractor to assist in the preparation of the UK Radioactive Waste Inventory. Nirex currently contracts Electrowatt Ekono UK Limited (EEUK) to collate the data for the Inventory and to interface with the waste producers in the collection of data.

2.3 EEUK is also certified to ISO 9001. EEUK, in turn, is required by Nirex to review the QA arrangements in place for each waste producer who provides data. The aim is to ensure that all major waste producers have appropriate procedures and quality plans in place.

2.4 Waste producers, operating nuclear facilities, must adhere to the conditions of their site licenses. These include a condition on Quality Assurance and the need to have an appropriate Quality Management System (QMS) in place. Data submitted by waste producers should be produced, checked and verified under an appropriate QMS.

3. Detailed arrangements

3.1 Nirex conducts audits of the EEUK on a periodic basis.

3.2 EEUK is required to review the data submitted by waste producers and to undertake:

- Checks of data (see 3.3. below);
- Identification and resolution of data quality issues with waste producers (e.g. mass balance queries);
- Return of data to waste producers as necessary, for the waste producers to check and approve their data submission in accordance with their own QMS.

3.3 EEUK carry out checks, as specified by Nirex, which include:

- Comparison with previous inventory data;
- Checks for consistency and completeness;
- Comparisons with data for other waste streams of a similar type at the same or other sites;
- Evaluation of the adequacy of the data.

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[1] Appendix 1 of Nirex response PCD 445355

3.4 Priorities for the improvement of data are defined by Nirex/EEUK and brought to the attention of the individual waste producers. However, it is up to the waste producers whether or not they act upon this information.

3.5 The data provided by the waste producers is provided under their own QMS. The waste producers are currently responsible for the quality of data and are accountable to UK regulators for verifying the data (The site licence requires waste producers to hold an inventory of radioactive materials on site). The waste producers are also responsible for the categorisation of their waste streams.

3.6 Nirex is currently reviewing the above arrangements with a view to introducing near real-time inventory reporting. Part of this exercise is to consider the implications on the quality of data provided.

4. Other reviews

4.1 Nirex has conducted a number of top-down reviews, based on knowledge of total quantities of radionuclides generated from the known quantity of irradiated fuel. From this, the total quantity of all radionuclides can be estimated and these totals can be compared with the total activity reported in the inventory.

4.2 Nirex also carries out reviews after the data has been published as part of its Letter of Comfort assessment process, such as:

- Data improvements. (See Appendix 2 for an example of how the quality of Inventory data for chlorine-36 has been improved).
- On receipt of packaging proposals Nirex undertake a “nature and quantities” study. At this point, the waste producer’s data, submitted as part of the Inventory, can be updated with more comprehensive data.
- Data recording assessments.

Appendix B Questions we are asking all stakeholders if they can answer

Do you have any concerns over the adequacy (including the scope) of the current UK Radioactive Waste Inventory (RWI)?

What criteria do you consider that CoRWM should use in recommending what proportion, if any, of the existing and future arisings of spent nuclear fuel, plutonium and uranium from reprocessing should be managed as if they were radioactive waste?

Are there scenarios (such as changes in energy policy) where the waste inventory could change significantly?

Under one or other of these headings, further questions include:

- Do you believe the 2001 UK RWI includes all relevant wastes?
- Are the assumptions used (mainly by the waste producers and owners) to determine the inventory of wastes still valid?
- What are the implications of radioactive decay (of both wastes and materials) on the inventory in the long term?
- What are the implications of "substitution" and UK import/export policy for radioactive wastes?
- Are there practicable uses for uranium, plutonium and spent fuel in the nuclear fuel cycle and elsewhere?
- What is the technical significance of uranium, plutonium and spent fuel to volumes/management options?
- Are the risks associated with uranium, plutonium and spent fuel outweighed by their possible/potential use?
- What are the implications for the inventory of future decisions on energy?

Research Report

Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations

Independent Report for Greenpeace UK • 1st March 2011 • Issue 1

Publication Disclaimer

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Executive Summary

The Coalition Government has sensibly proposed to revise the spent fuel disposal pricing basis from a *Fixed Unit Price* to what is effectively a *Variable Unit Price with Maximum Price Cap.* This more flexible arrangement is now called the *Waste Transfer Price* (WTP).

The Waste Transfer Price will increase over time as the final outturn costs of actually siting, building and operating the government's deep Geological Disposal Facility (GDF) are better understood.The Coalition Government has also proposed that the Waste Transfer Price should be deferred for a period up to 30 years after the start of nuclear reactor generation.

The variable unit pricing and the 30 year deferral period are important new principles introduced by the Coalition Government which potentially make spent fuel disposal pricing much fairer for taxpayers. The major advantage is that the government will have a very good idea of the actual costs of disposal by the end of the 2050 Deferral Period, because the government's Geological Disposal Facility (GDF) is planned to be fully operational by 2040. By 2050 the government will know the true outturn capital cost of siting and constructing the repository and will also have had 10 years practical operating experience running the repository.

However subsidy problems arise from DECC setting the level of the *Expected Price* and the *Price Cap* which appear to be too low. To help like-for-like comparison between FUPSIM and DECC cost calculations, we have used DECC's generic 1.35 GWe reactor assumptions. All calculations have been checked using a Hewlett Packard HP-12C Financial Calculator.

There are two potential *indirect subsidies* to energy companies for spent fuel disposal. The subsidies are indirect because the NDA would suffer the losses, not energy companies.

- **Maximum Price Cap**. Is the spent fuel disposal Price Cap (978 £k/tU) high enough to cover the government's costs, based on what we know about nuclear cost escalation trends?
- **Unit Disposal Cost**. Has the marginal cost to the government of spent fuel disposal (193 £k/tU) been underestimated compared with conservative modelling predictions?

Based on our Fixed Unit Price Simulation (FUPSIM) modelling analysis:

- **Price Cap Subsidy**. If the NDA repository experiences future nuclear cost escalation at the NDA's usual historic rate of 4.5% (above inflation) then actual unit costs of disposal will rise eventually exceeding the Price Cap by 2047. The disposal price paid by the energy utility will not fully cover the NDA's disposal costs, and so the NDA will require a government subsidy to make up the shortfall. The subsidy is around £131 million for a 40 year PWR but becomes significantly worse at around £1,127 million for a 60 year PWR.

- **Disposal Cost Underestimation Subsidy**. DECC may have underestimated the NDA's true disposal costs by 280 £k/tU, the difference between FUPSIM (473 £k/tU) and DECC estimates (193 £k/tU). The underestimation will mean that the NDA will not fully recover all of its disposal costs for new build reactor fuel, and so the NDA will require an indirect government subsidy to make up the shortfall. The subsidy will be around £296 million for a 40 year PWR and proportionally larger at £445 million for a 60 year PWR.

- **Overall Subsidy**. The total subsidy is of the order of £427 million (39% of the Capped Disposal Price) for a 40 year 1.35 GWe PWR. For a 60 year 1.35 GWe PWR the total subsidy is significantly worse of the order of £1,572 million (95% of the Capped Disposal Price), arising mainly because of the very severe effects of nuclear cost escalation on NDA losses.

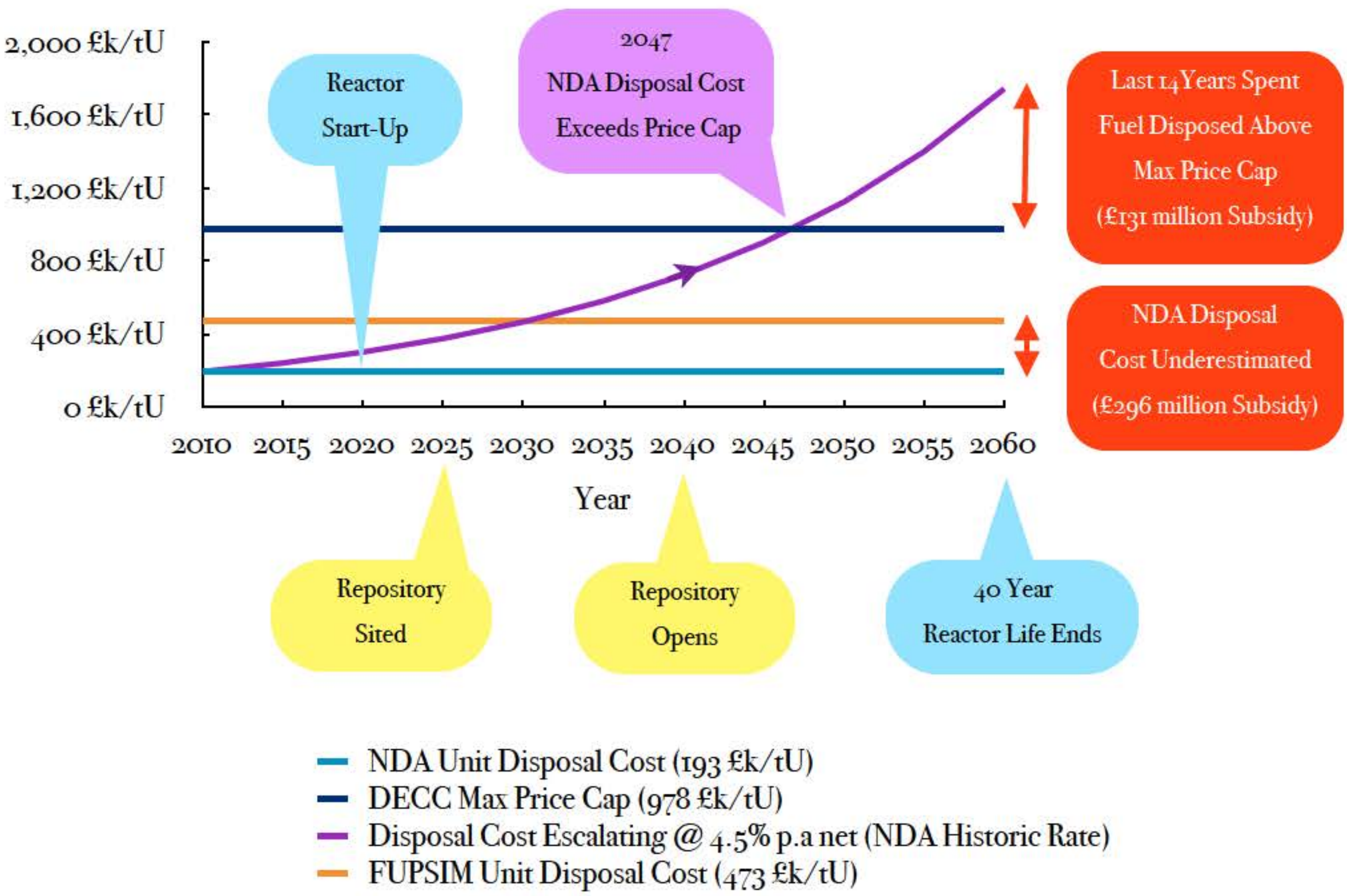
NDA Subsidies Needed to Recover Full Costs of Spent Fuel Disposal (Per Reactor)

DECC 1.35 GWe PWR	DECC 'Expected Price' Spent Fuel Disposal	DECC 'Capped Price' Spent Fuel Disposal	Estimated NDA Subsidies Needed	Comment
40 year lifetime	£670 million Price Paid By Energy Utility	£1,104 million Max Price Paid By Energy Utility	£131 million Price Cap Subsidy £296 million Disposal Cost Underestimation Subsidy **£427 million** **Total Gov Subsidy**	**39% government subsidy** needed by NDA on top of the Capped Price paid by energy utilities

DECC 1.35 GWe PWR	DECC 'Expected Price' Spent Fuel Disposal	DECC 'Capped Price' Spent Fuel Disposal	Estimated NDA Subsidies Needed	Comment
60 year lifetime	£1,005 million Price Paid By Energy Utility	£1,656 million Max Price Paid By Energy Utility	£1,127 million Price Cap Subsidy £445 million Disposal Cost Under-estimation Subsidy **£1,572 million** **Total Gov Subsidy**	**95% government subsidy** needed by NDA on top of the Capped Price paid by energy utilities

Based on 10 reactor fleet. Subsidy per reactor will be higher if fewer reactors are built. The Total Subsidy is in fact slightly underestimated here because the Disposal Cost Subsidy will also affect the Price Cap Subsidy but we have calculated the two subsidies separately.

Price Cap Subsidy and Disposal Cost Underestimation Subsidy (Per Reactor)



We have also observed two interesting pricing anomalies:

- **Futures Market for Nuclear Waste.** An unintended consequence of setting fixed government price caps on nuclear waste disposal is the possible emergence of a tradable futures market. The combination of high NDA nuclear cost escalation combined with low DECC price capping may result in an unusual situation when the GDF repository first opens in 2040. Because of cost escalation the capped price for spent fuel disposal set for an energy company may already be cheaper than the through-the-door-price for new disposal customers entering the market. The Disposal Price would reach the Price Cap by 2036 (assuming 4.5% nuclear escalation), well before the 30 year price-setting Deferral Period ends in 2050. As a result, market players may trade spent fuel disposal capacity contracts with each other for a profit. This suggests that the DECC Price Cap has probably been set too low.
- **New Build Reactor Fuel Disposal is Half the Cost of Existing Reactor Fuel Disposal.** In DECC's pricing model we understand that new PWR nuclear reactor spent fuel disposal is half the cost of disposing of AGR spent fuel from Britain's existing reactor fleet. In other words PWR fuel disposal is half the cost of AGR fuel disposal on the same per-tonne basis. Presentationally this may perhaps give the appearance of favouring new nuclear build and so raises questions of balance and fairness in the pricing method. There are also technical and operational reasons why the pricing differential might not be valid in the real world.

There are two straightforward solutions to solve the subsidy issues identified in this Report:

- **Remove the Price Cap**. This would avoid most of the subsidy difficulties. We suggest that variable spent fuel disposal prices should be set based on the NDA's actual costs, indexed for both *NDA cost escalation* and *CPI price inflation*. At present DECC disposal prices would be indexed for inflation only but not nuclear cost escalation which causes most of the difficulty. Fully variable spent fuel disposal prices are better than Capped Prices since they guarantee that the taxpayer will be repaid in full without any public subsidy.
- **Set a Single Price for AGR, PWR and MOX Spent Fuel**. Most of the differences between FUPSIM and DECC unit cost modelling arise because of the way that DECC calculates lower disposal costs for PWR spent fuels. Setting one uniform (per-tonne uranium) disposal price for all major spent fuel types (AGR, PWR, MOX) would make more sense.

Table of Contents

1. Policy Background 9

2. Purpose of this Updated Research Report 9

3. DECC Generic 1.35GWe PWR Used in FUPSIM 9

4. Report Author 10

5. Downloading and Running FUPSIM 10

6. Coalition Government's Revised Spent Fuel Disposal Pricing 10

7. Potential Subsidies 12

8. NDA Nuclear Cost Escalation 12

9. Price Cap Subsidy 14

10. Futures Market from Price Cap and Deferral Period 19

11. Reliability of DECC and FUPSIM Modelling 21

12. Spent Fuel Disposal Costs for Different Reactor Fleet Sizes 25

13. Disposal Cost Underestimation Subsidy for Large Fleet 28

14. Disposal Cost Underestimation Subsidy for Small Fleet 31

15. Bibliography 33

1. Policy Background

In March 2010 the previous Labour Government consulted on proposals to set a Fixed Unit Price (FUP) for the disposal of radioactive wastes from new nuclear power stations that might be built in the UK.[1] In December 2010 the new Coalition Government published improved and more flexible proposals to set a Waste Transfer Price (WTP) for nuclear waste disposal.[2] The WTP consultation process must be seen within the wider background of the Coalition Government's objectives both to reduce the UK national deficit through better public spending controls and also to offer no direct subsidies for new nuclear power station development.[3]

2. Purpose of this Updated Research Report

Jackson Consulting was previously commissioned by Greenpeace to develop an interactive computer simulation of spent fuel disposal pricing called FUPSIM. The FUPSIM model and Research Report was published in June 2010.[4] Jackson Consulting has been commissioned by Greenpeace to briefly reassess the Coalition Government's new pricing proposals using FUPSIM and identify any potential subsidies that might favour nuclear energy development.

This updated Research Report is intended to be provide a realistic and impartial appraisal of spent fuel disposal pricing. The views expressed and conclusions reached are solely those of Jackson Consulting and do not necessarily represent those of Greenpeace.

3. DECC Generic 1.35GWe PWR Used in FUPSIM

To help like-for-like comparison between FUPSIM and DECC calculations, we have used DECC's generic reactor modelling assumptions as far as possible based on a 1.35GWe PWR reactor operating for 40 years lifetime, generation start-up 2020, end of generation 2060, average Load Factor 90%, with a lifetime generating output of 424,000 GWh over 40 years.

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[1] Department of Energy and Climate Change. *Consultation on a Methodology to Determine a Fixed Unit Price for Waste Disposal and Updated Cost Estimates for Nuclear Decommissioning, Waste Management and Waste Disposal*. 25th March 2010.

[2] Department of Energy and Climate Change. *Consultation on an Updated Waste Transfer Pricing Methodology for the Disposal of Higher Activity Waste from New Nuclear Power Stations*. 7th December 2010.

[3] Conservative Party. *Conservative Liberal Democrat Coalition Negotiations. Agreements Reached*. 11th May 2010.

[4] Greenpeace UK. *Fixed Unit Price Simulation For Disposal of Spent Fuel from New Nuclear Power Stations in the UK*. Research Report by Jackson Consulting. 15th June 2010.

4. Report Author

This Research Report was written by Ian Jackson, an independent nuclear consultant and currently an Associate Fellow in the Energy, Environment and Development Programme of the Royal Institute of International Affairs, Chatham House. Ian Jackson is the author of *Nukenomics: The Commercialisation of Britain's Nuclear Industry* (2008).

5. Downloading and Running FUPSIM

FUPSIM is a free-to-use fully interactive research simulation of nuclear reactor spent fuel disposal pricing using the state-of-the-art *Wolfram Mathematica* graphical computational programming engine. The FUPSIM model runs on Wolfram's *Mathematica Player* which may be freely downloaded for any Windows, Apple Mac or Linux computer.

Users must first download and install the free Wolfram Mathematica Player 7 here:

http://www.wolfram.com/products/player/

The FUPSIM model and User Guide is available as a free download here:

http://www.jacksonconsult.com/fupsim.html

6. Coalition Government's Revised Spent Fuel Disposal Pricing

The Coalition Government has sensibly proposed to revise the spent fuel disposal pricing basis from a *Fixed Unit Price* to what is effectively a *Variable Unit Price with Maximum Price Cap.* This more flexible arrangement is now called the *Waste Transfer Price* (WTP). The Waste Transfer Price will almost certainly increase over time as the final outturn costs of actually siting, building and operating the government's deep Geological Disposal Facility (GDF) are better understood. At present we can only have a hazy idea about what these life-cycle costs might be, although the current planning estimate by the Nuclear Decommissioning Authority (NDA) is £12.2 billion (undiscounted). The government has also very sensibly proposed that the Waste Transfer Price should be deferred for a period up to 30 years after the start of nuclear reactor generation. Assuming Britain's fleet of new nuclear reactors starts up around 2020 then the Waste Transfer Price would be deferred until 2050. The *Final Price* paid by an energy utility company will depend on the (variable) Waste Transfer Price at 2050, subject to an agreed maximum Price Cap set by the Secretary of State today.

The variable unit pricing and the 30 year deferral period are important new principles introduced by the Coalition Government which potentially make spent fuel disposal pricing much fairer for taxpayers. The major advantage is that the government will have a very good idea of the actual costs of disposal by the end of the 2050 Deferral Period, because the government's Geological Disposal Facility (GDF) is planned to be fully operational by 2040. By 2050 the government will know the true outturn capital cost of siting and constructing the repository and will also have had 10 years practical operating experience running the repository.

Table 1
DECC's Proposed Spent Fuel Disposal Pricing

Waste Transfer Price	Estimate	Comment
Unit Disposal Cost (Base Cost)	193 £k/tU	DECC estimate of the minimum unit cost today for disposing of one tonne of uranium spent fuel in the NDA's Geological Disposal Facility (GDF).
Combined Risk Premium and Risk Fee Cost	119 £k/tU	DECC estimate of combined Risk Premium and Risk Fee (62% overall) to compensate the government for taking on the risk that future disposal costs will escalate above the Price Cap after the Final Price is set.
Utility Disposal Price	312 £k/tU (1.6 x Base Cost)	DECC estimate today of the future price paid by the energy utility company to government to dispose of one tonne of uranium spent fuel in the NDA's Geological Disposal Facility (GDF).
Max Price Cap	978 £k/tU (5.1 x Base Cost)	DECC maximum price cap that the energy utility would pay to government for disposal of one tonne of uranium spent fuel. DECC estimate there is a 99% probability that the actual disposal cost will be below the Price Cap, and a 1% probability that the actual disposal cost will exceed the Price Cap.

Source: DECC Waste Transfer Price Consultation Document at Page 6. Costs are undiscounted and expressed in March 2008 prices. The most recent full lifecycle evaluation of GDF costs was £12,157 million (undiscounted) at 31st March 2008 [NDA 2008].

7. Potential Subsidies

The Oxford English Dictionary defines a subsidy as "a sum of money granted from public funds to help an industry or business keep the price of a commodity or service low". In practice *direct subsidies* paid in cash by government to an industry are rare. Instead governments usually prefer *indirect subsidies,* for example through artificially low pricing deals where a publicly funded body does not recover its full costs for providing a service to industry.

There are two potential indirect subsidies to energy companies for spent fuel disposal:

- **Maximum Price Cap**. Is the spent fuel disposal Price Cap (978 £k/tU) high enough to cover the government's costs, based on what we know about nuclear cost escalation trends?
- **Unit Disposal Cost**. Has the marginal cost to the government of spent fuel disposal (193 £k/tU) been underestimated compared with conservative modelling predictions? FUPSIM uses a well known power law scaling relationship to calculate per-tonne costs.[5]

8. NDA Nuclear Cost Escalation

Nuclear projects, especially unique first-of-a-kind (FOAK) facilities, have historically suffered from significant cost escalation well above national inflation rates. Nuclear cost escalation might mean that the actual unit costs of disposal in the future may exceed the Price Cap today. Public taxpayers would therefore subsidise any financial shortfall between the capped price paid by the energy utility and the actual cost of disposal in the Geological Disposal Facility. The NDA is a good comparison benchmark for likely cost escalation because the NDA itself has responsibility for developing the government's Geological Disposal Facility.

Since the NDA was created in April 2005 its nuclear liabilities have escalated significantly, increasing 34% (£21. billion) in 4 years from £62.7 billion (2005/6 FY) to £83.8 billion today (2009/10 FY). This rise has been nearly continuous each year and suggests that NDA nuclear cost escalation has been approximately 4.5% annually, over and above the UK average inflation rate of 3.0% during the same 4 year period (YE 31 March 2006 to YE 31 March 2010)[6]. This sustained growth in NDA nuclear liabilities is shown in Graph 1 overleaf.

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[5] FUPSIM is based on the six tenths rule of cost estimation. See for example Chapter 20 of the US Department of Energy *Cost Estimating Guide* DOE G 430.1-1 (28 March 1997).

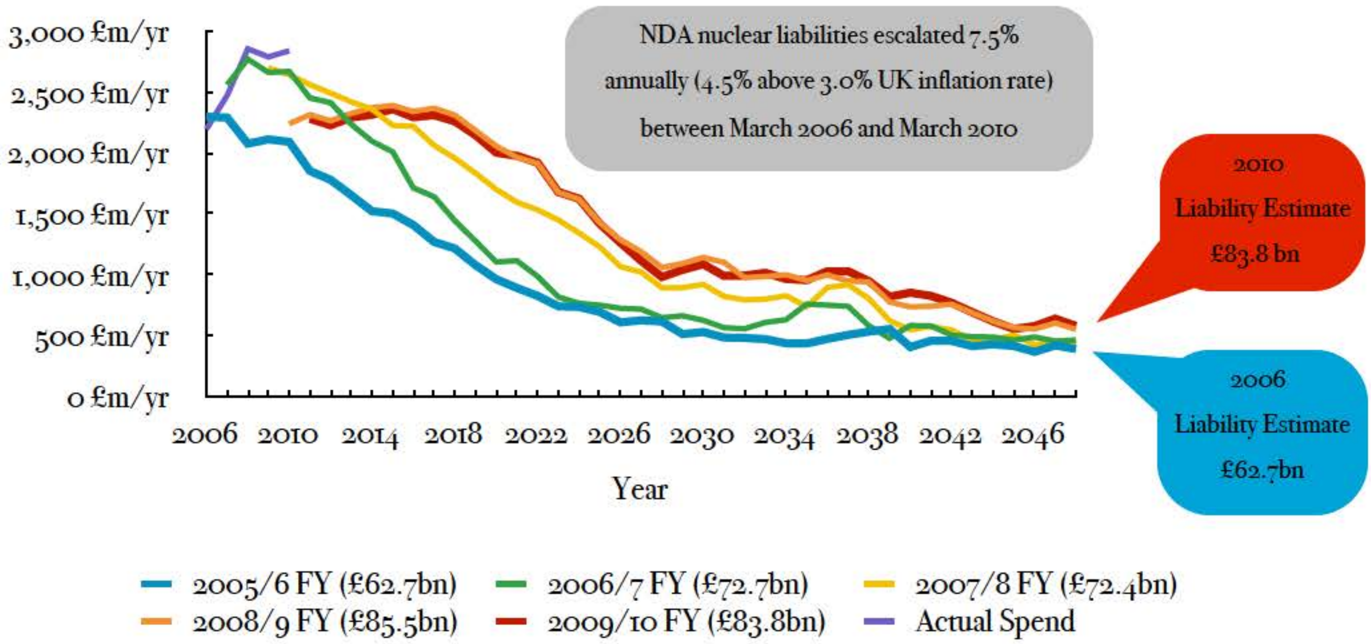
[6] Bank of England inflation calculator. UK inflation from 2005 to 2010 averaged 3.0% per annum. http://www.bankofengland.co.uk/education/inflation/calculator/flash/index.htm

NDA nuclear liability escalation trends are especially suggestive because they share key similarities with a GDF; the lifecycle costs are spread over similar very long timescales of at least 100 years into the future; and capital construction costs are a relatively small component (25%) of the overall lifecycle costs, which are dominated by facility running costs (75%).

There is some evidence that NDA cost escalation has peaked and is now slowing, because the past two years estimates are very similar (see the red and orange lines in Graph 1 below). However actual spending each year (shown by the purple line) has generally been higher than forecasted in previous years liability assessments. Overall the medium term trend does appear to be a gradual rise upwards at about 4.5% net annual cost escalation (above inflation). This level of cost escalation is fairly typical for nuclear projects and in fact similar to American experience developing the spent fuel repository at Yucca Mountain in New Mexico, USA.

Graph 1

4.5% Net Annual Cost Escalation in Nuclear Decommissioning Authority Liabilities



Source: NDA Annual Report & Accounts 2005/6 through to 2009/10. Spending and liability forecast data kindly provided by the NDA under the Freedom of Information Act.

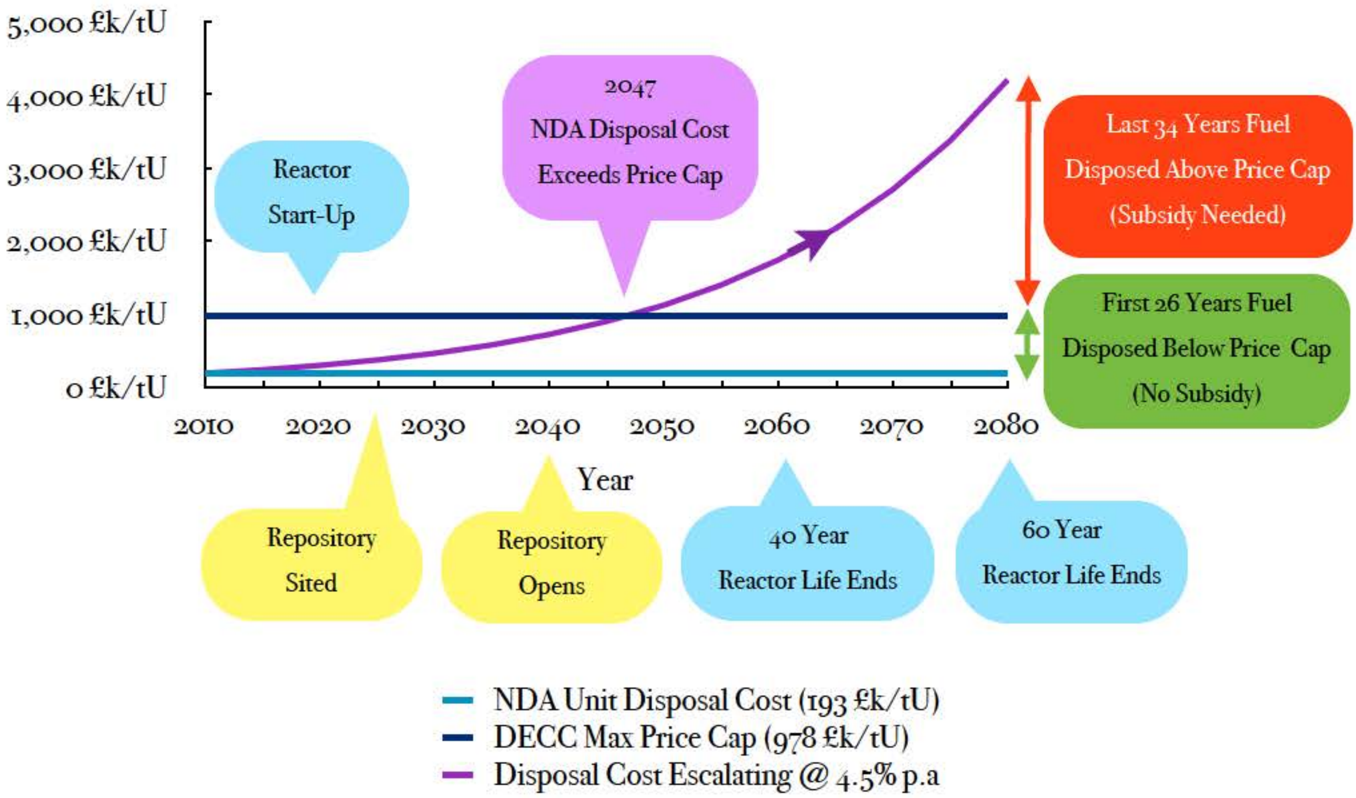
Note: For ease of display, Graph 1 shows a window of annual spending forecasts from 2006 to 2050 but total NDA lifecycle liabilities (currently £83.8bn) extend until 2135.

9. Price Cap Subsidy

DECC estimates the NDA's unit cost of spent fuel disposal to be 193 £k/tU in 2008 prices. This is the minimum unit cost (or base cost) that the NDA must be paid to fully recover its expenses for siting, building, operating and eventually closing the GDF disposal facility.

If the NDA repository experiences nuclear cost escalation at the NDA's usual historic rate of 4.5% (above inflation) then actual unit costs of disposal in the future will eventually exceed the Price Cap. The disposal price paid by the energy utility will not fully cover the NDA's disposal costs, and so the NDA will require a government subsidy to make up the shortfall. The subsidy is around **£131 million for a 40 year PWR** or **£1,127 million for a 60 year PWR**.

Graph 2
The Effect of 4.5% Nuclear Cost Escalation on the NDA's Spent Fuel Unit Disposal Costs, Compared with DECC's Unit Disposal Price Cap



Assuming the GDF experiences the NDA's 4.5% per annum net cost escalation then:

- **First 26 years of 40 year PWR lifetime (2020 - 2046)**. For the first 26 years of PWR reactor operation the NDA's actual disposal cost is below the DECC Price Cap. The Price of spent fuel disposal paid by energy companies will gradually increase but no public subsidy will be needed because the NDA will fully recover all of its actual disposal costs.

- **Last 14 years of 40 year PWR lifetime (2047 - 2060)**. For the final 14 years of PWR reactor operation the NDA's actual disposal cost will rise *above* the DECC Price Cap. Because the Final Price of spent fuel disposal paid by energy companies will remain fixed at the Price Cap, the NDA will not fully recover all of its actual disposal costs. The NDA will make a yearly loss which will gradually become worse over time (because of the effects of escalation). The government will therefore need to pay the NDA to cover these losses, making-up the shortfall. This provides an indirect subsidy of **£131 million** to the energy company.

- **Last 34 years of 60 year PWR lifetime (2047 - 2080)**. In reality both the AP1000 and EPR reactors planned to be built in the UK have 60 year design lifetimes. If the lifetime of the PWR is extended to 60 years then for the final 34 years of PWR reactor operation the NDA's actual disposal cost will be significantly above the DECC Price Cap. Under these circumstances the NDA would make a severe **£1,127 million** loss requiring a subsidy.

Table 2
NDA Subsidies Needed From Setting a Price Cap on Spent Fuel Disposal

DECC 1.35 GWe PWR	DECC 'Expected Price' Spent Fuel Disposal	DECC 'Capped Price' Spent Fuel Disposal	Additional NDA Subsidy Needed	Comment
40 year lifetime	£670 million Energy Utility	£1,104 million Energy Utility	**£131 million Government**	Government subsidy is 12% on top of the max Capped Price paid by energy utilities
60 year lifetime	£1,005 million Energy Utility	£1,656 million Energy Utility	**£1,127 million Government**	Government subsidy is 68% on top of the max Capped Price paid by energy utilities

Source: The total Expected Price and Capped Price are given in the DECC Waste Transfer Price Consultation Document at Page 6. (These include a small contribution from ILW). The size of the NDA Subsidy required as actual disposal costs escalate above the Price Cap is calculated in Table 3 and Table 4 below. All calculations are approximate.

Table 3
Subsidy Needed From Setting a Price Cap on Spent Fuel Disposal

Generic 1.35GWe, 40-Year PWR Reactor, 2020 - 2060

Date	NDA Unit Cost of Disposal (£k/tU)	DECC Price Cap on Disposal (£k/tU)	NDA Loss (£k/tU)	PWR Fuel Discharged (tU/yr)	Subsidy Needed (£k)
2010	**193**	**978**	**0**	**0**	**0**
2046	941	978	0	26.5	0
2047	984	978	-6	26.5	159
2048	1,028	978	-50	26.5	1,325
2049	1,074	978	-96	26.5	2,544
2050	1,123	978	-145	26.5	3,843
2051	1,173	978	-195	26.5	5,168
2052	1,226	978	-248	26.5	6,572
2053	1,281	978	-303	26.5	8,030
2054	1,339	978	-361	26.5	9,567
2055	1,399	978	-421	26.5	11,157
2056	1,462	978	-484	26.5	12,826
2057	1,528	978	-550	26.5	14,575
2058	1,596	978	-618	26.5	16,377
2059	1,668	978	-690	26.5	18,285
2060	1,743	978	-765	26.5	20,273
				Total Subsidy	**£131 million**

Note: Assumes actual NDA Unit Cost of Disposal (£k/tU) escalates at the NDA's historic nuclear escalation rate of 4.5% per annum net (above inflation). FUPSIM estimates that DECC's Generic 1.35 GWe PWR will discharge 1060 tU over 40 years (26.5 tU/yr). NDA cost escalation calculations performed on an HP 12C Financial Calculator.

Table 4
Subsidy Needed From Setting a Price Cap on Spent Fuel Disposal

Generic 1.35GWe, 60-Year PWR Reactor, 2020 - 2080

Date	NDA Unit Cost of Disposal (£k/tU)	DECC Price Cap on Disposal (£k/tU)	NDA Loss (£k/tU)	PWR Fuel Discharged (tU/yr)	Subsidy Needed (£k)
2010	**193**	**978**	**0**	**0**	**0**
2046	941	978	0	26.5	0
2047	984	978	-6	26.5	159
2048	1,028	978	-50	26.5	1,325
2049	1,074	978	-96	26.5	2,544
2050	1,123	978	-145	26.5	3,843
2051	1,173	978	-195	26.5	5,168
2052	1,226	978	-248	26.5	6,572
2053	1,281	978	-303	26.5	8,030
2054	1,339	978	-361	26.5	9,567
2055	1,399	978	-421	26.5	11,157
2056	1,462	978	-484	26.5	12,826
2057	1,528	978	-550	26.5	14,575
2058	1,596	978	-618	26.5	16,377
2059	1,668	978	-690	26.5	18,285
2060	1,743	978	-765	26.5	20,273
2061	1,822	978	-844	26.5	22,366
2062	1,904	978	-926	26.5	24,539
2063	1,989	978	-1,011	26.5	26,792
2064	2,079	978	-1,101	26.5	29,177
2065	2,172	978	-1,194	26.5	31,641

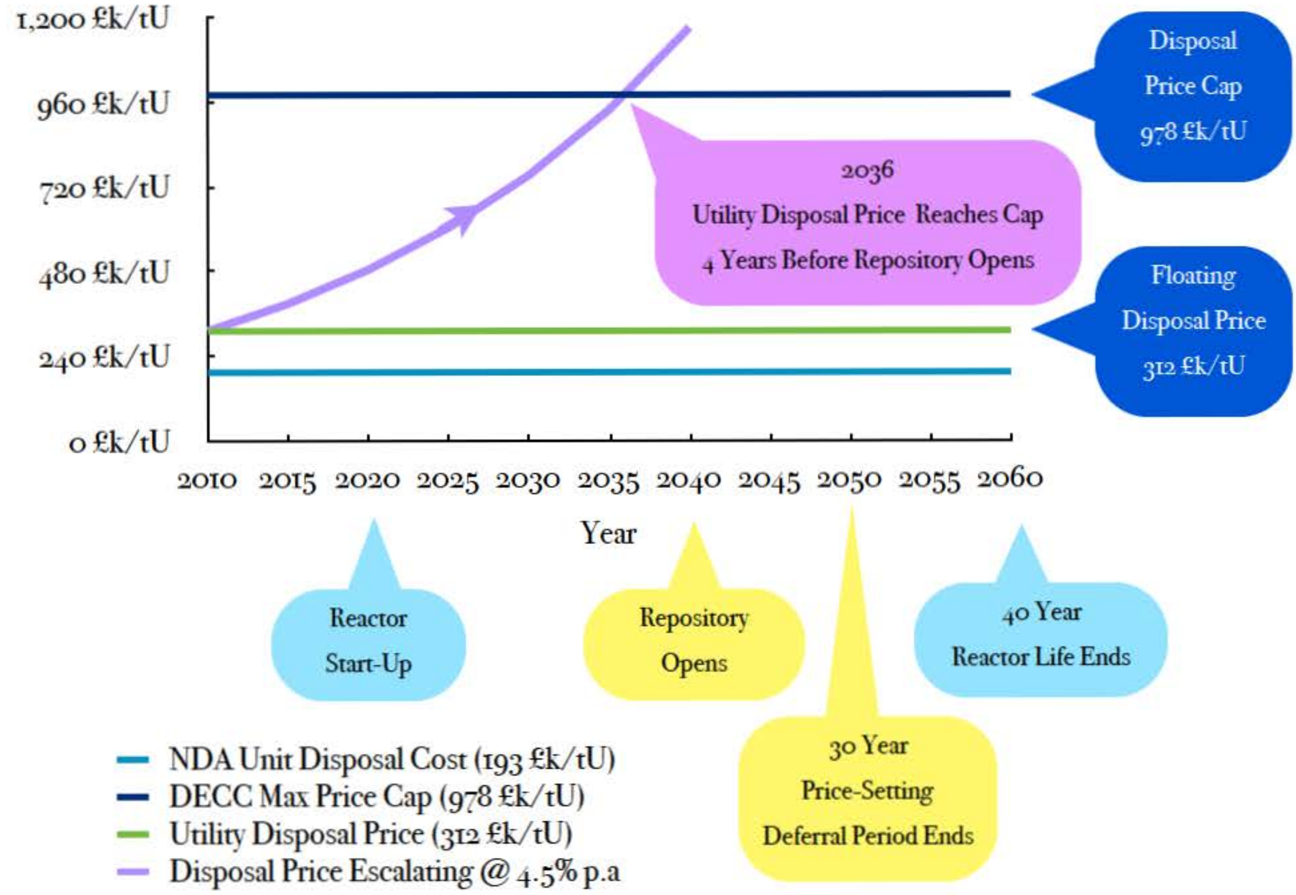
Date	NDA Unit Cost of Disposal (£k/tU)	DECC Price Cap on Disposal (£k/tU)	NDA Loss (£k/tU)	PWR Fuel Discharged (tU/yr)	Subsidy Needed (£k)
2066	2,270	978	-1,292	26.5	34,238
2067	2,372	978	-1,394	26.5	36,941
2068	2,479	978	-1,501	26.5	39,777
2069	2,591	978	-1,613	26.5	42,745
2070	2,707	978	-1,729	26.5	45,819
2071	2,829	978	-1,851	26.5	49,052
2072	2,956	978	-1,978	26.5	52,417
2073	3,089	978	-2,111	26.5	55,942
2074	3,228	978	-2,250	26.5	59,625
2075	3,374	978	-2,396	26.5	63,494
2076	3,526	978	-2,548	26.5	67,522
2077	3,684	978	-2,706	26.5	71,709
2078	3,850	978	-2,872	26.5	76,108
2079	4,023	978	-3,045	26.5	80,693
2080	4,204	978	-3,226	26.5	85,489
				Total Subsidy	**£1,127 million**

Note: Assumes actual NDA Unit Cost of Disposal (£k/tU) escalates at the NDA's historic nuclear escalation rate of 4.5% per annum net (above inflation). FUPSIM estimates that DECC's Generic 1.35 GWe PWR will discharge 1590 tU over 60 years (26.5 tU/yr). NDA cost escalation calculations performed on an HP 12C Financial Calculator.

10. Futures Market from Price Cap and Deferral Period

The combination of NDA nuclear cost escalation combined with DECC price capping may also result in a strange situation when the GDF repository first opens in 2040. Because of cost escalation the capped price for spent fuel disposal paid by an energy company may already be cheaper than the through-the-door-price for new customers entering the market. And in fact the Disposal Price would reach the Price Cap by 2036 (assuming 4.5% nuclear escalation), well before the 30 year price-setting Deferral Period ends in 2050. Overall this suggests that the DECC Price Cap has probably been set too low.

Graph 3
The Effect of 4.5% NDA Nuclear Cost Escalation on the Spent Fuel Disposal Price Actually Paid By Energy Utilities



The NDA's Strategy Director warned in May 2010 that this price difference might inadvertently create a *futures market* in radioactive waste disposal.[7] A futures market is a trading market where participants buy and sell future contracts for delivery or supply of a service (such as radioactive waste disposal for example) on some specified future date.

The 312 £k/tU Disposal Price charged by DECC (which is about 62% higher than the NDA's 193 £k/tU unit cost) will escalate reaching the maximum Price Cap by 2036, some 4 years *before* the repository first opens in 2040. This means that early contracts for spent fuel disposal will be cheaper than the normal NDA door price paid by later repository customers.

A market trader (such as a new energy company) could then buy the right to dispose of a certain amount of spent fuel (from another energy company trader) at slightly below the future door price. This is basically a system of tradable futures contracts. It would also encourage energy companies to sign disposal contracts with DECC early on for rather more disposal capacity than perhaps needed, so that this might be sold for a profit later to new market players. An energy company trader might also choose to sell their disposal allowance if they did something else with the spent fuel instead such as transfer it to a store or reprocess it.

The creation of a futures market in spent fuel disposal is not necessarily a bad thing. It might even result in much better spent fuel management strategies to reduce disposal volumes and so maximise trading profits from selling spare disposal capacity. But it does serve to illustrate the unintended consequences of setting fixed government price caps on nuclear services. The possible emergence of a futures market strongly suggests that the Price Cap is too low.

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[7] Nuclear Decommissioning Authority. *Nuclear Decommissioning Authority Response to Fixed Unit Price Consultation*. Dr Adrian Simper (Strategy Director). May 2010. The NDA was concerned that awarding a disposal capacity contract at fixed price (now capped price) might give the energy utility an asset if the future price has been underestimated. The energy utility could then sell their disposal capacity allowance later for a profit. The NDA Strategy Director was clearly well aware and mindful of the NDA's 4.5% cost escalation trajectory.

11. Reliability of DECC and FUPSIM Modelling

We are grateful to DECC for providing helpful comments on the FUPSIM model.[8] This has improved our understanding of how DECC models disposal costs and the key sensitivities.

The total cost of a GDF repository is very sensitive to the total quantity of spent fuel it contains. For example the NDA's historic legacy of spent fuel represents only 2% of the total volume of waste in a repository but is responsible for around 50% of the gross repository cost. This makes it difficult to reliably model unit disposal costs because even small changes in the spent fuel inventory can significantly increase the total lifecycle cost of the repository.

Table 5
2007 MRWS Waste Inventory[9] and 2005 Nirex Repository Cost Estimates[10]

Nuclear Waste	Packaged Volume (m3)	Packaged Volume (%)	NIREX Repository Cost (£m 2003)	NIREX Unit Cost (£k/tU)
Spent Fuel HLW	11,200 1,400	2.3% 0.3%	Single SF/HLW GDF £5,035m	952 £k/tU
ILW Others	364,000 100,300	76.3% 21.1%	Shared SF/HLW/ILW/O GDF £10,100m	952 £k/tU
	476,900	100%		

Note: The average unit cost of spent fuel disposal was approximately = £5035m/(3,500tU AGR + 1,200tU PWR) x 11,200 m3 / (11,200 m3 + 1,400 m3) = £0.952m/tU to dispose of the CoRWM inventory of 3,500tU AGR + 1,200tU PWR = 4,700tU [NIREX, 2005][CoRWM,2006]. The latest DECC legacy spent fuel inventory has now increased to 7,000tU AGR + 1,200tU PWR = 8,200tU [DECC, 2010].

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8 Department of Energy and Climate Change. *OND Analysis of Independent Report for Greenpeace by Jackson Consulting: Fixed Unit Price Simulation for Disposal of Spent Fuel from Nuclear Power Stations in the UK (FUPSIM)*. Internal Note to File. November 2010.

9 Department for Environment, Food and Rural Affairs. *Managing Radioactive Waste Safely: A Framework for Implementing Geological Disposal*. Cm7386. June 2008.

10 NIREX. *Summary Note for CoRWM on Cost Estimates for CoRWM Option 7 (Deep Geological Disposal) and Option 9 (Phased Deep Geological Disposal)*. NIREX Technical Note 484432. September 2005.

The development of a brand new first-of-a-kind (FOAK) Geological Disposal Facility will be a difficult technical challenge. A fully costed and Peer Reviewed site-specific development and construction plan has yet to be prepared. Britain has not yet selected its disposal site nor disposal technology although the reference concept is KBS-3V, a system involving the disposal of spent fuel within copper canisters. KBS-3V looks a promising option but recently the NDA has investigated different alternative spent fuel packaging and repository emplacement arrangements.[11] It is interesting that this technical management review was triggered by the need to reduce 160-year spent fuel cooling and storage times at proposed nuclear reactor build sites. Feedback from public meetings strongly opposed this during the 2010 Nuclear National Policy Statement (Nuclear NPS) consultation process for siting new reactors.[12] A solution has been proposed involving the judicious mixing of different ages of irradiated PWR spent fuel which might cut on-site storage times to around 50 years. In future the Site Licence Company (SLC) responsible for construction and operation of the GDF repository will probably drive further innovations and improvements in radioactive waste management. For example the US consortia running other nuclear sites in the UK have already introduced new operational innovations with the aim of improving efficiency and reducing costs.

In the light of this uncertainty, FUPSIM uses a conservative approach to calculate unit disposal costs for new nuclear reactors by scaling upwards from known NDA costs based on the total mass of legacy AGR and PWR uranium fuels needing disposal. The method involves a mathematical power law which is well known in process cost estimation.[13] The method is conservative because it assumes that one tonne of uranium AGR fuel will be packaged and disposed in much the same way as one tonne of uranium PWR fuel. Both fuels contain the same one tonne mass of uranium, the only difference is the physical geometry of the fuel rod assembly and its outer cladding. AGR fuel rods sit within a circular honeycomb structure whereas PWR fuel rods sit within a very long and square shaped fuel assembly grid.

To make the most efficient use of repository space it is likely that AGR spent fuel assemblies would be size-reduced in some way (by stripping off the outer cladding), then treated and encapsulated before emplacement in a copper canister. This general approach to waste optimi-

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[11] Nuclear Decommissioning Authority. *Feasibility Studies Exploring Options for Storage, Transport and Disposal of Spent Fuel from New Nuclear Power Stations.* November 2010.

[12] Department of Energy and Climate Change. *The Government Response to the Consultation on the Draft National Policy Statements for Energy Infrastructure.* October 2010.

[13] FUPSIM is based on the six tenths rule of cost estimation. See for example Chapter 20 of the US Department of Energy *Cost Estimating Guide* DOE G 430.1-1 (28 March 1997).

sation is now standard practice in the waste management sector. The only major operational constraints are radiation dose to workers handing the fuel and the risks of criticality if too many spent fuel rods are deliberately squeezed together during size reduction. Furthermore the NDA will now probably employ complex mixing of both long and short-cooled spent fuel together, increasing the operational radiological hazard dealing with canisters.

Together these factors mean that an *NDA Spent Fuel Packaging Plant* [14] is likely to be built with sufficient robotic capability for remote handling spent fuels, size reduction and packing in a copper canister. Some of the necessary technology for remote handling and size reduction of spent fuel is already used at THORP to strip and reprocess AGR spent fuels.

Because of the likely convergence of similar handling and treatment techniques for both AGR and PWR spent fuels explained above, the most conservative approach to model disposal costs is to assume similar unit costs for both AGR and PWR spent fuels. The FUPSIM model takes this approach, avoiding complications from differing fuel and canister geometries.

However DECC treats the unit disposal costs from legacy AGR spent fuel and new PWR spent fuel separately, with new PWR spent fuel being about half the cost of AGR spent fuel. The difference arises because DECC models costs based on the volume of a copper disposal canister. DECC assumes that the capacity of a copper canister is just over 1 tonne for uranium AGR spent fuel but 2.06 tonnes for uranium PWR spent fuel. Because AGR fuel assemblies are rather bulky, fewer will fit inside a disposal canister. This is a reasonable calculation approach but it does mean that the costs of expanding a repository to dispose of PWR fuel from new nuclear reactors will become very much cheaper. This is because DECC assumes relatively inefficient packing of bulky AGR fuels but highly efficient packing of PWR fuels.

In practice both AGR and PWR spent fuels ought to have very similar disposal footprints per tonne of uranium, provided that they have been properly size-reduced in a packaging plant to remove their excess cladding. Robotic size reduction is easier for AGR fuels because the assemblies are fairly short (about 1 metre in length) and their outer graphite cladding shell can be easily removed. Moreover AGR spent fuel rods can be size reduced and compressed together with fewer criticality risks because the enrichment of AGR fuel is lower than PWR fuel. These operational practices should significantly improve the canister packing efficiency and make overall AGR disposal costs broadly similar to that for PWR spent fuel.

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[14] A £500m Centralised Spent Fuel Packing Plant has recently been proposed as an option and provisionally costed in the NDA's *Spent Fuel Feasibility Study* (November 2010).

Another problem with DECC modelling is that high burn-up (65GWd/tU) PWR spent fuel assemblies radiate more heat than standard burn-up AGR spent fuels (35 GWd/tU). In order to accommodate high burn-up spent fuels, fewer PWR fuel assemblies per storage canister might be necessary to maintain a repository temperature limit of 100 degrees C. However the NDA's judicious mixing strategy combining both short and long-cooled PWR spent fuel assemblies within a single canister might exacerbate this temperature control problem. (Judicious mixing is a political solution to help avoid 160-year spent fuel storage on reactor sites). A copper canister has an assumed capacity of 4 PWR spent fuel bundles (2.06 tU/can) but it is possible that this might need to be reduced in some cases to make judicious mixing work better (for example down to 3 bundles at 1.55 tU/can). Judicious mixing could perhaps reduce the PWR packing efficiency down towards a similar level as AGR fuel (1.0 tU) making overall AGR canister disposal costs broadly similar to that for PWR spent fuel.

In summary, both the likely operational impact of optimised size reduction of AGR fuels and judicious mixing of PWR fuels strongly suggests that the more prudent approach to modelling disposal costs is to assume similar unit costs for both AGR and PWR spent fuels. This is the conservative approach used in the FUPSIM model which we believe is the better way forward given the significant technical uncertainties dealing with AGR and PWR spent fuels.

Table 6
Summary of Reasons Why DECC Should Not Assume New Build PWR Fuel is Half the Disposal Cost of Legacy AGR Fuel

FUPSIM Reasons For Similar Disposal Cost 1tU AGR =1tU PWR	DECC Reasons For Half Disposal Cost 1tU AGR = 2.06 tU PWR
• Conservative given operational uncertainties. • UK has not selected final disposal technology. • No site-specific fully-costed GDF build plan. • Alternative SF packing arrangements possible. • NDA Spent Fuel Packaging Plant is planned. • Standardised packing treatment regimes likely. • Size reduction to remove AGR cladding possible, improving packing efficiency similar to PWR. • Compression of low enriched AGR bundles possible, improving packing efficiency similar to PWR. • NDA judicious mixing strategy may reduce packing efficiency of mixed cooled PWR fuels. • Fewer PWR assemblies per storage canister might be necessary to maintain GDF temperature limit.	• KBS-3V is reference disposal concept at present. • Assume direct disposal of AGR and PWR fuel assemblies without significant pre-treatment. • 4 PWR spent fuel bundles (2.06 tU) fit in canister. • Fewer AGR spent fuel assemblies (1 tU) fit in copper canister (without size reduction).

12. Spent Fuel Disposal Costs for Different Reactor Fleet Sizes

The Labour Government's 2008 *White Paper on Nuclear Power* stated that "operators of new nuclear power stations will be obliged to meet their *full share* of waste management costs".[15] This is an important principle affecting cost calculations. FUPSIM calculates the cost for an NDA legacy repository (£bn) and the extra cost for a bigger repository to dispose of extra spent fuel (£bn) from new nuclear build. FUPSIM calculates the *marginal* cost (£m/tU) of increasing the repository size which is just the basic minimum unit cost of the extra spent fuel space. FUPSIM also calculates the *full share* cost (£m/tU) of increasing the NDA repository size which combines or spreads the unit cost of disposal of both new and legacy spent fuel together. FUPSIM displays both marginal and full share results.

If just a few new reactors are built then it is much more expensive to dispose of reactor fuel. But as the size of a new build reactor fleet increases then unit disposal costs drop. The unit costs are lower because larger repositories have better economies of scale than small ones. Put another way, unit costs are cheaper as more radwaste is added to the repository, up to a certain point limited by the maximum radiological capacity of the disposal site.[16] DECC has assumed a large 10 reactor fleet which significantly dilutes unit costs by 28%. A 10 reactor fleet is about the largest fleet size that could all be accommodated within a single repository.

FUPSIM was designed to simulate waste disposal liabilities and costs for any size of new nuclear power station built in the UK up to a total site generating capacity of 4GWe. For example FUPSIM can model various Single and Twin AP1000 and EPR reactor combinations that might be built on any of the 8 disposal sites in the Nuclear National Policy Statement (NPS).

FUPSIM models the full share costs of slightly expanding the NDA's Geological Disposal Facility (GDF) to accept spent fuel waste from any single new nuclear power station up to 4GWe. However FUPSIM was not designed to model costs from the entire new UK reactor fleet, which will probably range from between 1 and 10 new build reactor units by 2025. The Nuclear National Policy Statement is based on new reactors being fully deployable by 2025.

As the NDA repository expands with new nuclear build fuel added, Spent Fuel Unit Disposal Costs may be approximated through iterations of the *six-tenths rule* cost estimating formulae:

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[15] Department for Business, Enterprise and Regulatory Reform. *Meeting the Energy Challenge: A White Paper on Nuclear Power*.Cm7296. January 2008. See pages 152 - 153.

[16] The radiological capacity of a GDF repository site is a radiation risk based upper limit on the total radioactive inventory and is intended to reduce the risk of death to members of the public from radiation exposure to less than one chance in one million per year (10^{-6} p.a.)

$$\mathbf{CB = CA \times (SB/SA)^{SF}}$$

Cost B (CB), Cost A (CA), Size B (SB),
Size A (SA), Scale Factor (SF = 0.6)

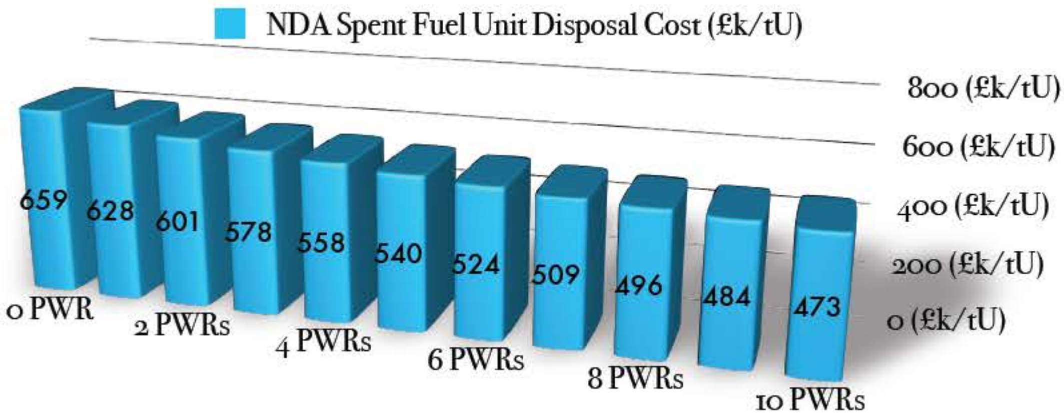
Table 7
Reduction in NDA Spent Fuel Unit Disposal Costs as Reactor Fleet Size Increases

1.35 GWe PWR Fleet Size	Spent Fuel Discharged (tU)	SIZE A Old Repository Inventory (tU)	SIZE B New Repository Inventory (tU)	COST A Old Spent Fuel Repository Cost Segment (£m)	COST B New Spent Fuel Repository Cost Segment (£m)	Shared Spent Fuel Unit Disposal Cost (£k/tU)
0	0	8,200	-	£5,404m	-	659
1	**1,060**	**8,200**	**9,260**	**£5,404m**	**£5,813m**	**628**
2	1,060	9,260	10,320	£5,813m	£6,204m	601
3	1,060	10,320	11,380	£6,204m	£6,579m	578
4	1,060	11,380	12,440	£6,579m	£6,940m	558
5	1,060	12,440	13,500	£6,940m	£7,289m	540
6	1,060	13,500	14,560	£7,289m	£7,627m	524
7	1,060	14,560	15,620	£7,627m	£7,955m	509
8	1,060	15,620	16,680	£7,955m	£8,275m	496
9	1,060	16,680	17,740	£8,275m	£8,587m	484
10	**1,060**	**17,740**	**18,800**	**£8,587m**	**£8,891m**	**473**

Note: The Spent Fuel and HLW proportion of the GDF repository cost is approximately 50% of the NDA gross lifecycle cost = £12,157m / 2 = £6,079m. The Spent Fuel cost segment is then split in proportion to the volume of SF packaged waste = £6,079 x 11,200 m3 SF / (11,200 m3 SF + 1,400 m3 HLW) = £5,404m. This is approximately the cost segment for disposal of the NDA's historic legacy of 8,200 tU Spent Fuel, without any new build fuel. The MRWS packaged waste volumes are given in Table 5 [MRWS, 2007].
Cost scaling margin of error using the six-tenths rule power law is typically +/- 20%.

Graph 4

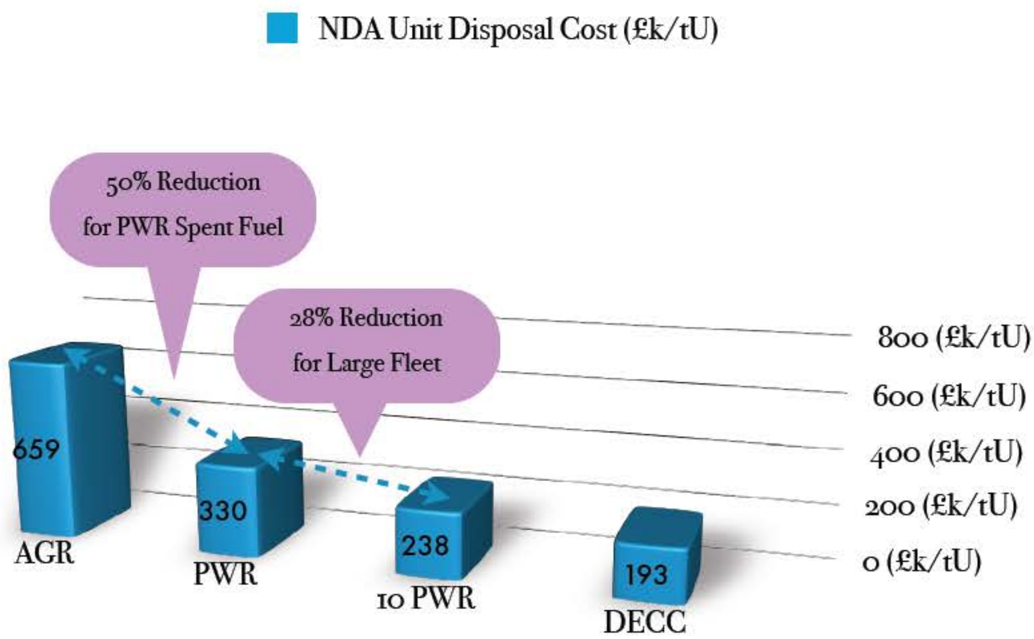
Reduction in NDA Spent Fuel Unit Disposal Costs as Reactor Fleet Size Increases



Note: FUPSIM modelled based on DECC's Generic 1.35GWe PWR reactor operating for 40 year lifetime, discharging 1060 tU. Calculations are shown in Table 7. A 10 PWR Fleet reduces unit disposal costs by 28% (from 659 £k/tU down to 473 £k/tU).

Graph 5

How DECC Calculates Low Unit Disposal Costs for New Build Spent Fuel



Note: Using this calculation method there is good agreement between FUPSIM's estimate of DECC unit cost (238 £k/tU) and DECC's stated unit cost (193 £k/tU) which is within FUPSIM's +/- 20% margin of error.

13. Disposal Cost Underestimation Subsidy for Large Fleet

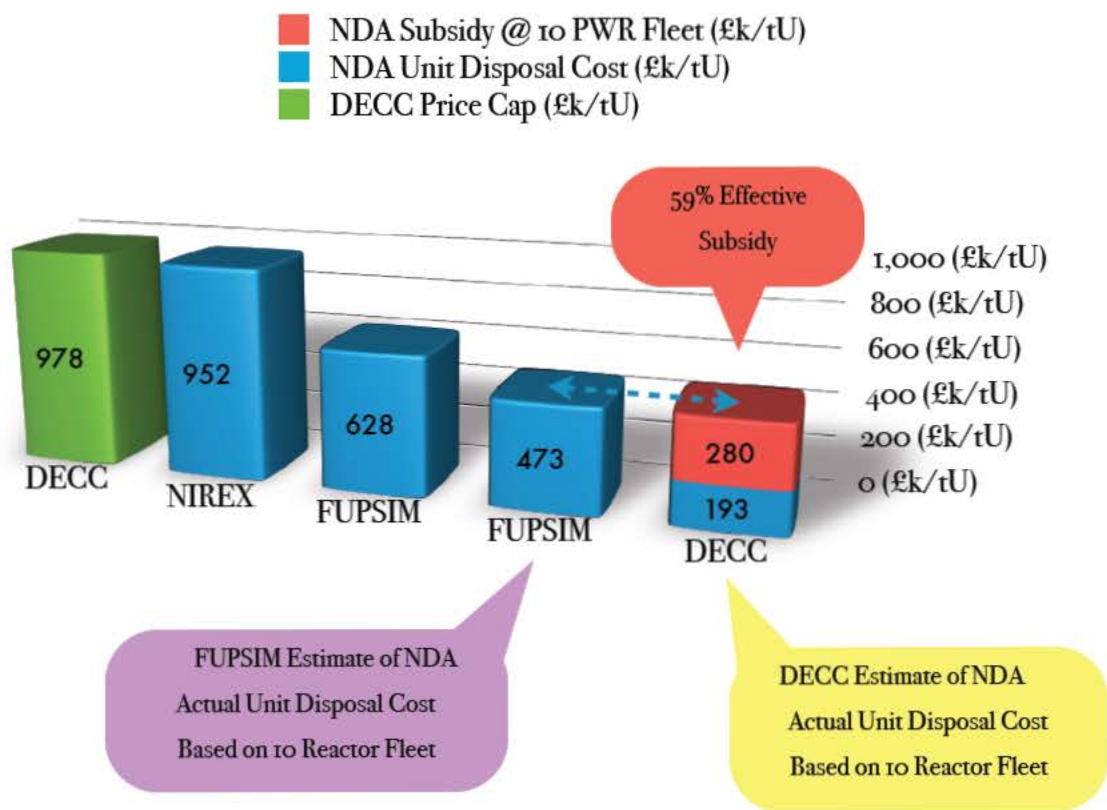
All computer models are a simplification of the real world. Both the FUPSIM simulation and DECC parametric models are approximate and will probably not be entirely correct. The best approach is to look at a range of unit cost predictions and make a sensible judgement. Table 8 and Graph 6 below show a range of modelled Unit Costs and the Price Cap for comparison.

Table 8
Range of Predictions for NDA Unit Costs of Spent Fuel Disposal
(The minimum unit cost needed to fully recover the NDA's actual disposal costs)

DECC Price Cap (£k/tU)	NIREX (£k/tU)	FUPSIM 1 PWR (£k/tU)	FUPSIM 10 PWR (£k/tU)	DECC Base Cost (£k/tU)
978	952	628	473	193

Note: FUPSIM unit cost estimates are given in Table 7 and Graph 4 based on DECC's 1.35GWe PWR with 40 year generating period. The NIREX estimate is in Table 5.

Graph 6
Range of Predictions for NDA Unit Costs of Spent Fuel Disposal



It is important to note that these are the minimum actual *Unit Costs* of spent fuel disposal not floating *Unit Prices* charged by DECC, which are set slightly higher subject to a maximum Price Cap. NIREX spent fuel disposal unit cost estimates are at the high end of the cost range, FUPSIM is towards the middle and DECC unit costs are at the bottom of the range.

DECC has assumed a large 10 reactor fleet which significantly dilutes unit costs. A 10 reactor fleet is about the largest fleet size that could all be accommodated in a single GDF. To calculate the subsidy from possible underestimation of NDA actual disposal costs it is fairest to compare the 10 reactor FUPSIM Unit Cost with the DECC Unit Cost (on like-for-like basis).

If FUPSIM modelling is correct then DECC may have underestimated the NDA's true disposal costs by 280 £k/tU (473 £k/tU - 193 £k/tU = 280 £k/tU). The underestimation will mean that the NDA will not fully recover all of its disposal costs for new build reactor fuel, and so the NDA will require an indirect government subsidy to make up the shortfall. The subsidy will be around **£296 million for a 40 year PWR** or **£445 million for a 60 year PWR**.

Table 9
NDA Subsidies Needed From Underestimating Actual NDA Disposal Costs of Spent Fuel
(Subsidy Per Reactor, Based on a 10 PWR Reactor Fleet)

DECC 1.35 GWe PWR	DECC 'Expected Price' Spent Fuel Disposal	DECC 'Capped Price' Spent Fuel Disposal	Additional NDA Subsidy Needed	Comment
40 year lifetime	£670 million Energy Utility	£1,104 million Energy Utility	**£296 million Government**	Government subsidy is 27% on top of the max Capped Price paid by energy utilities
60 year lifetime	£1,005 million Energy Utility	£1,656 million Energy Utility	**£445 million Government**	Government subsidy is 27% on top of the max Capped Price paid by energy utilities

Source: The total Expected Price and Capped Price are given in the DECC Waste Transfer Price Consultation Document at Page 6. (These include a small contribution from ILW). The size of the NDA Subsidy required is calculated in Table 10 below.

Table 10
Subsidy From Underestimating Actual NDA Unit Disposal Costs of Spent Fuel
(Subsidy Per Reactor, Based on a 10 PWR Reactor Fleet)

Generic 1.35GWe PWR, 40-Year and 60-Year Generation

Model	NDA Unit Cost (£k/tU)	PWR Fuel Discharged 40 Years (tU)	NDA Disposal Cost (£m)	PWR Fuel Discharged 60 Years (tU)	NDA Disposal Cost (£m)
DECC	193	1060	£205m	1590	£307m
FUPSIM	473	1060	£501m	1590	£752m
Loss	-280	**Subsidy**	**£296 million**	**Subsidy**	**£445 million**

Note: FUPSIM estimates that DECC's Generic 1.35 GWe PWR will discharge 1060 tU over 40 years and 1590 tU over 60 years (26.5 tU/yr).
FUPSIM Unit Disposal Cost of 473 £k/tU @ 10 PWRs is calculated in Table 7.

14. Disposal Cost Underestimation Subsidy for Small Fleet

DECC's cost modelling assumes that 10 new nuclear reactors will be built and all their spent fuel disposed in the NDA's Geological Disposal Facility (GDF). However if just a few new reactors are built then it becomes much more expensive to dispose of spent fuel. Put another way the unit costs of disposal (£k/tU) are much higher for small reactor fleets (See Graph 4).

Another possibility is that utilities do build a large reactor fleet but decide not to dispose of all of their spent fuel in the NDA repository for strategic reasons. For example uranium reactor fuel might be supplied from abroad and returned to the country of origin (take back).

In the worst case, if the UK nuclear renaissance fails to materialise and only one new 1.35GWe PWR is actually constructed,[17] then the unit disposal cost rises to 628£k/tU (see Table 7). In this case DECC may have significantly underestimated the NDA's true disposal costs by 435 £k/tU (628 £k/tU - 193 £k/tU = 435 £k/tU). The underestimation will mean that the NDA will not fully recover all of its disposal costs for new build reactor fuel, and so the NDA will require an indirect government subsidy to make up the shortfall. The subsidy will be around **£461 million for a 40 year PWR** or **£692 million for a 60 year PWR**.

Table 11
NDA Subsidies Needed From Underestimating Actual NDA Disposal Costs of Spent Fuel (Subsidy Per Reactor, Based on a 1 PWR Reactor Fleet)

DECC 1.35 GWe PWR	DECC 'Expected Price' Spent Fuel Disposal	DECC 'Capped Price' Spent Fuel Disposal	Additional NDA Subsidy Needed	Comment
40 year lifetime	£670 million Energy Utility	£1,104 million Energy Utility	**£461 million Government**	Government subsidy is 42% on top of the max Capped Price paid by energy utilities
60 year lifetime	£1,005 million Energy Utility	£1,656 million Energy Utility	**£692 million Government**	Government subsidy is 42% on top of the max Capped Price paid by energy utilities

Source: The total Expected Price and Capped Price are given in the DECC Waste Transfer Price Consultation Document at Page 6. (These include a small contribution from ILW). The size of the NDA Subsidy required is calculated in Table 12 below.

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[17] EDF Energy's business plans seem the most advanced at present, with proposals for a twin 1650 MWe EPR at Hinkley Point C (3.3GWe) and subsequently a Twin EPR at Sizewell C.

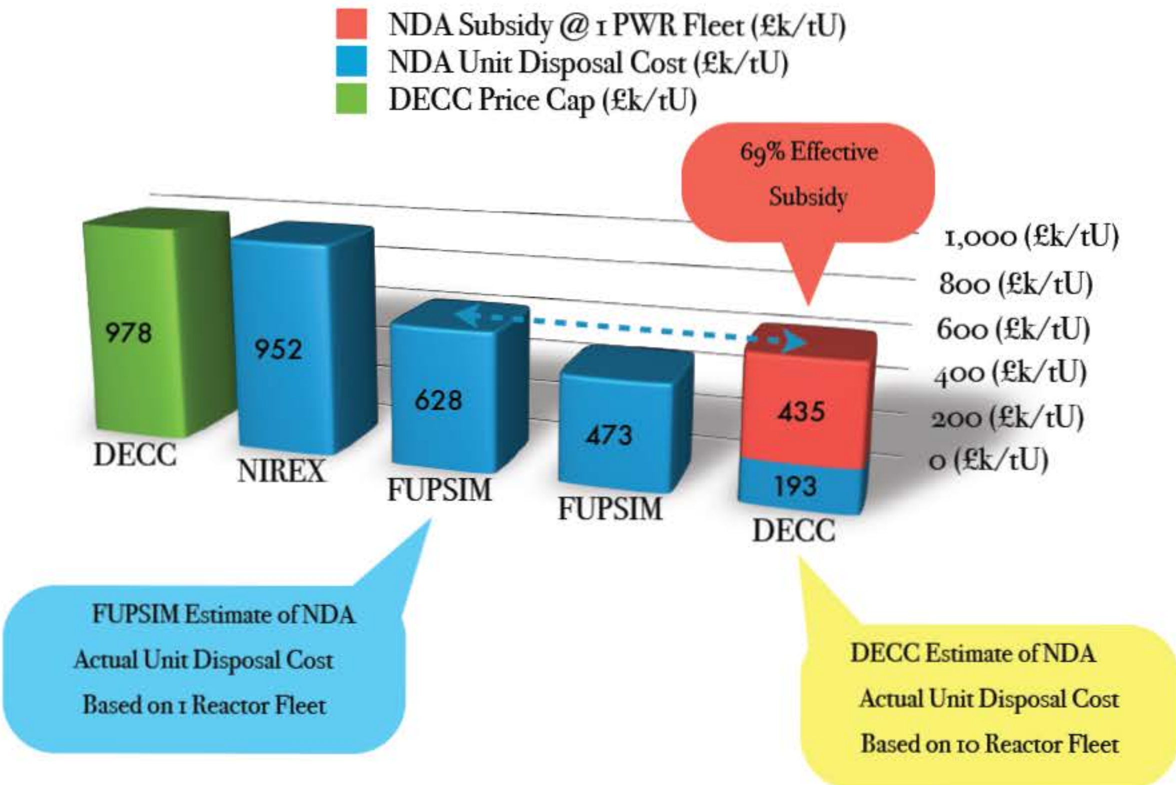
Table 12
Subsidy From Underestimating Actual NDA Unit Disposal Costs of Spent Fuel (Subsidy Per Reactor, Based on a 1 PWR Reactor Fleet)

Generic 1.35GWe PWR, 40-Year and 60-Year Generation

Model	NDA Unit Cost (£k/tU)	PWR Fuel Discharged 40 Years (tU)	NDA Disposal Cost (£m)	PWR Fuel Discharged 60 Years (tU)	NDA Disposal Cost (£m)
DECC	193	1060	£205m	1590	£307m
FUPSIM	628	1060	£666m	1590	£999m
Loss	-435	**Subsidy**	**£461 million**	**Subsidy**	**£692 million**

Note: FUPSIM estimates that DECC's Generic 1.35 GWe PWR will discharge 1060 tU over 40 years and 1590 tU over 60 years (26.5 tU/yr).
FUPSIM Unit Disposal Cost of 628 £k/tU @ 1 PWR is calculated in Table 7.

Graph 7
Range of Predictions for NDA Unit Costs of Spent Fuel Disposal



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GREENPEACE

March 2011

Response to
Funded Decommissioning Programme Guidance
and
Waste Transfer Price consultations

We welcome the opportunity to comment on DECC's C*onsultation on revised Funded Decommissioning Programme Guidance for New Nuclear Power Stations (noted as the FDP)* [i] and the *Consultation on an updated Waste Transfer Pricing Methodology for the disposal of higher activity waste from new nuclear power stations (noted as the WTP)* [ii]

In discussing the proposals contained in the consultations, we do not mean Greenpeace agrees with proposals to build new reactors.

Summary

Main points are that:

Subsidy/taxpayer risk

- the change from a 'fixed unit' price to a maximum cap under the 'Waste Transfer Price' (WTP) for what operators will expect to pay for disposal still implies a subsidy to new build operators.
- leaving a period of 30 years - after operations - to settle a Final Price for disposal assumes too much about reactor lives (and relies too much on industry expectations for generation) and risks leaving waste management and disposal underfunded. There should be no cap on waste disposal costs.
- in order to accommodate the many uncertainties around disposal, but to facilitate new build, and provide 'certainty' to investors, the Government's proposals unjustifiably and unfairly lean too much in favour of nuclear investment.
- it is assumed that monies will be accumulated, and companies will remain viable and solvent, over the timescale necessary to see completion of a FDP – a period of many decades and long after revenues from power generation may have ceased - and the completion of the Decommissioning and Waste Management Plan (DWMP) and Funding Arrangements Plan (FAP). This flies in the face of the experience in the UK, for example it is less that 10 years ago that the main nuclear power generator in UK was formally insolvent and had to be bailed out by the taxpayer both as an emergency measure and in the long term.

Omissions from consideration

- the Government continues to rely on what it calls successful completion of processes connected with new build and ignores the fact that they are still subject to significant uncertainty, in particular uncertainties over siting, establishing and operating a geological disposal facility (GDF) in order to make plans and determine costs. The Government should recognised, throughout, that there are still no finalised proposals for a disposal facility.
- the proposed changes to the Secretary of State's (SoS) powers to modify a Funded Decommissioning Programme (FDP) - to 'fetter' his powers are not dealt with in the consultation even though they could have far reaching implications.

- the WTP consultation does not properly discuss outstanding and unresolved problems of waste and spent fuel management and encapsulation and funding for these.
- the consultation does not fully explain how the FDP processes might impact on other relevant process e.g. Managing Radioactive Waste Safely (MRWS) process
- there is no mention of the relevance to the revised Paris and Brussels conventions on accident liability, and how measures for proposed legislative changes (which will incur financial costs) could have implications for spent fuel and waste management and disposal.
- the consultation does not address the introduction of new elements to new build in other current consultations, such as proposals to use plutonium-uranium (MOX) fuel. This is not discussed but has wide implications.

Secrecy

- it is unacceptable that the agreements, which will have practical and financial implications for over 100 years, will remain closed to public input or Parliamentary scrutiny until after they are decided on. Agreements, and any modifications to them which impact on the funding, or the practical arrangements concerning decommissioning, waste and spent fuel management and disposal, must be open for public information and participation and Parliament scrutiny.
- key information on cost modeling has not been made public

A public consultation?

As with every other consultation on nuclear matters, these two come with their own series of very complex proposals as well as being held within a mix of other complex but inter-related consultations. Consultations such as that on the six energy National Policy Statements (which closed in January), the consultations on plutonium disposition and that on international liability (accident) conventions and changes to UK legislation, as well as that on Electricity Market Reform, all overlap with these consultations in terms of timing. This makes it impossible for the informed consultee properly and fully to respond.

Each of the other consultations, and the matters they consider, have an impact on the rationale for the FDP and WTP consultations or have a direct impact on the result to be achieved e.g. the proposals to possibly change the legislation on insurance cover in the event of an accident to also include nuclear waste repositories as well as reactors.

To understand and appreciate the breadth and impact of the proposals in this consultation, also requires an understanding of the debates around the Energy Act 2008, as well as subsequent relevant consultations.

On this we note the previous documents on these matters:

- Funded Decommissioning Programme Guidance, 2008,
- three pre-consultation papers on the Fixed Unit Price (2009); and
- the consultation on Fixed Unit Price (2010).

There are also legislative changes proposed or being made which appear to be relevant to the current consultations.[iii]

In addition, all the responses and other material submitted in reply to the earlier consultations need to be considered.

It is highly unlikely members of the public, NGOs or local authorities with interests in the matters the consultations cover - in particular in localities where there may be new reactors and where the decisions made following these consultations will have practical impacts - will be able to find the time and necessary expertise to comment on these documents?

It is suggested that the Government should bring together in one document all the proposals which affect each other so that the public concerned can be fully consulted.

Greenpeace has already provided much comment and evidence on this matter to official processes, such as:

- memos and made submissions for the hearings on the Energy Bill 2008,
- evidence to the Public Bill Committee hearings on the bill -
- a response to the FDP consultation in 2008[iv] ; and
- responses to the 2010 consultation on Fixed Unit Price.[v]

This response is made as a series of comments on key issues raised in the current consultations. Greenpeace refers DECC to previous submissions it has made on this issue and asks that they be taken into account along with this document.

Parametric cost model. The NDA parametric model has not been released, making it virtually impossible to fully check the basis for the methodology in the paper.

Greenpeace has asked if DECC will release the NDA's Parametric Cost Model - which is the basis for all costings in the WTP consultation.[vi] DECC said the model is primarily for internal use and "not really user friendly", but the NDA is prepared to demonstrate it - if people go to the NDA offices at Harwell. DECC informed Greenpeace that a demonstration has already been run for some of the utilities. How can it be considered a public consultation if people have to go through such arrangements to see the financial model?

It is not acceptable in a public consultation that essential information is, effectively, being withheld from scrutiny by all interested parties due to the failure of DECC and the NDA (both of which are well funded) to find a method of releasing the information.

Greenpeace asks that this information, essentially for proper consultation, be made available to the public in a readily accessible form.

What's included in an FDP – according to the draft guidance?

We note that, according to the draft guidance, it is proposed an FDP covers the:

- the Decommissioning and Waste Management Plan (DWMP) which will set out details of the steps to be taken in relation to what are called “technical matters” and the estimates of costs likely to be incurred in connection with the “designated technical matters” (1.8 FDP); and
- the Funding Arrangements Plan (FAP) should set out details of any security to be provided ....in connection with meeting the estimated costs of carrying out the plans (as set out in the DWMP) for the decommissioning of the site and for the management and disposal of waste arisings (i.e. the designated technical matters)

(1.9 FDP).

The FDP notes: *The DWMP is therefore intended to cover all technical matters (including designated technical matters) whereas the contents of the FAP should relate only to designated technical matters.* [vii]

We note (FDP) that:
2b.6 The technical matters are the steps set out in the DWMP relating to the decommissioning of the power station, cleaning up of the site, and waste management and disposal activities. The requirement that these be set out is intended to meet the overall objective of the FDP that operators make prudent provision for the full costs of decommissioning their installations; and their full share of safely and securely managing and disposing their waste, and that in doing so the risk of recourse to public funds is remote at all times. (our emphasis) [viii]

We also note, on (2b.8 FDP) this indicates which activities will be designated technical matters under the Energy Act and that (2b.9, FDP): *The key difference between the technical matters and the designated technical matters is that the cost of non-designated technical matters are to be met by the operator from operational expenditure, while the costs of designated technical matters must be provided for in the independent Fund which operators will be expected to set up.* (our emphasis)

The above are key in terms of understanding the timing and the relation of all the activities (and plans which concern them) which are to be covered by an FDP and what funds have to be accumulated and under what mechanisms (as per the draft guidance).

Firstly, it is understood the FDP has to be in place before any 'nuclear safety related' work (on a reactor) i.e. any work which is regulated by the NII as being essential to nuclear safety.

Secondly, it is important to consider what has to be in the DWMP presented to the SoS for his agreement prior to key construction milestones – and what will be *known* at that time. The processes (and progress) on the GDF are important to an FDP as this will have to be agreed before reactor construction. Yet a GDF will not be established (if at all) for some decades. In addition, it will be subject to a completely separate process i.e. Managing Radioactive Waste Safely (MRWS) – as well as being subject to a different set of planning and regulatory procedures from those which govern the FDP process.

In relation to this, we note (2b.12 FDP) that the SoS expects the DWMP to be divided into three principal phases and there are a number of elements that an approvable DWMP would "also be likely to include." These are, among other things:

• *A clear timeline showing key milestones and giving scheduling assumptions in each of the three phases of the Base Case as defined below.*

• *A summary of the key assumptions underpinning the operator's DWMP. In particular the operator should provide details of any assumptions that differ from the Base Case, with an explanation of reasons for any proposed deviation from the Base Case.*

• *An explanation as to how the assumptions and parameters underpinning the DWMP are expected to evolve over time as the new nuclear power station operates and draws near to* *closure.*

It is not made clear exactly what 'key milestones' are to be shown (i.e. which activities) and how the public/local communities around sites will be notified of any changes from the base case, as per the guidance. If, for example, the milestones include actual disposal - which will not be certain (at the very least) for some decades - it brings into question how a DWMP can include milestones - unless these are accepted as being no more than expectations rather than achievable outcomes. Greenpeace finds this part of the guidance unhelpful and incomplete at best and at worst creates the impression of there being more certainty over disposal than in fact there might be (depending on what a DWMP might list as 'milestones.'

Alongside the FDP, the Government will agree with operators a process on determining waste disposal costs and the funds needed for waste and spent fuel management. [ix] This will also include the terms on which the Government will accept title and liability for the wastes and spent fuel. Thus, under an FDP, dates for transfer of wastes and spent fuel (based on uncertain disposal timelines) and costs (also based on uncertain disposal timelines) will be offered *before* reactor construction and also before key activities are finalised and real costs known. This is clearly unfeasible.

Oversight, modifications and SoS powers

There is too much flexibility built into the FDP process (33 FDP). The level of flexibility allows operators to move from the base case - which creates uncertainty for on-site operations and local communities around both reactors or possible GDF sites.

We note (1.17 FDP) that: *The FDP must be durable so that the arrangements set out in the FDP remain applicable for the generating lifetime of the station, throughout decommissioning and until the operator has satisfied all of its obligations under the FDP.*

How this can be done before a disposal route - let alone agreement on a possible 100 years of spent fuel storage (and encapsulation) - is decided? Overall this indicates that a number of modifications will be needed to the FDPs over time to accommodate the many - and potentially significant - changes which are likely to take place (all without public input and Parliamentary oversight).[x]

Greenpeace asks DECC to ensure the guidance does not include anything which is liable to mislead the public or other into thinking that there are solutions where, in fact, none exist.

In the FDP there is an emphasis on plans for the DWMP. However, given the lack of direct instructions on this, from the regulators and the Government, it is reasonable to ask just how much reliance can be placed on such plans.

The lack of clear directions (as opposed to guidance) almost appears designed to maximise the possibility of modifications to the FDP, yet at the same time the Government is intending to pass legislative amendments which will constrain the power of the SoS to make future amendments - and all this before the first reactor application has gone to the IPC or the NII/EA have provided the reactors (and essential plant such as spent fuel stores) under the Generic Design Assessment process.

The Base Case presents the generic case and leaves too much of the specific (2b.16-.

2b.18 FDP) to the closed discussions around the agreement. This favours the industry over public interest in disclosure of information and leaves much to be dealt with through modifications to agreements behind closed doors.

Public and Parliament

In a meeting with Greenpeace (1st February 2010) DECC said the Government will 'encourage' industry to put as much as possible into the public domain, commercial confidentiality and security notwithstanding. DECC confirmed the FDPs - the agreements - would only be published after they have been finalised between industry and Government.

The Government is asked to reconsider any preliminary decision that is made following this consultation. It should insist that any nuclear operator publicly releases, immediately after an FDP is finalised, the terms and conditions of an FDP. There is a public right to know (under the Aarhus Convention) the details of any agreements which will impact on the environment and which, in this case, will also have the potential for long lasting impacts.

The responsibility to publish an FDP - or a redacted version - seems to rest with the companies. What responsibility does the Government have, on behalf of the taxpayer, to publish an FDP? There is no indication of how notification of an FDP decision will be made public or whether it will be accompanied by details of the FDP. No statutory deadline is given for publication of an FDP by the SoS. Neither consultation mentions precisely how the companies will publish details of the contract will be published.

To place such weight on commercial considerations rather than in the legitimate public interest in the environment is unlawful and undemocratic.

DECC has not explained how the discussions would tie in, or otherwise, with the Managing Radioactive Waste Safely (MRWS) Process and which the FDP will have an impact on. [xi]

DECC was asked also if there was, for example, any possibility of input from the public or local authorities to an FDP e.g. to ensure that there are compensation (aka benefits) packages, for reactor-site storage of spent fuel for 100 years (as some councils have indicated they would like to see. Such discussion as there is on benefits packages relates only to a GDF site (see 2.2.37 WTP). DECC said that any community benefits and reactor sites and spent fuel stores would be decided under any overall development package with operators, and not within the FDP process.

Powers of the SoS

On Modification of an FDP, the document notes:

1.28 In determining whether (and if so, on what terms) to propose a modification to the FDP, the Secretary of State will have regard to the matters set out in this Guidance; in particular whether the modification is a necessary, appropriate or proportionate means to ensure that the Objective is met and the Guiding Factors are complied with.

The Energy Bill 2011 will make amendments to the primary legislation concerning FDPs for new nuclear plants. The changes to the Energy Act 2008 are said to be necessary to provide certainty for new nuclear build investors, but according to DECC they will also '*fetter the Secretary of State's discretion over the exercise of the power to propose modifications to the FDP.'* [xii]

It is not clear from the above if the changes safeguard the interests of the nuclear industry, rather than add further protection for the public purse.

The DECC briefing [xiii] on the amendments (8th December 2010) notes they are:

To ensure that there is an appropriate balance between the Secretary of State's powers to protect the taxpayer and the operator's need for clarity and certainty over how those powers will be exercised.

Yet the proposed legislative change is referred to only once in the current consultation on the revised FDP notes:

7. During the period of this consultation the Government is considering amending the Secretary of State's power under the Energy Act 2008 to modify an operator's FDP to ensure that there is an appropriate balance between the Secretary of State's powers to protect the taxpayer and the operator's need for clarity over how those powers will be exercised. This Guidance might need to be updated if those amendments are passed.

As noted, the amendments, if passed, could lead to further changes to the guidance. It is not clear if the guidance (already on its second round of consultation) would then be subject to further consultation. In Greenpeace's view is there must be public consultation.

No worked example of the impacts of the amendments is given in the impact assessment on the amendments. [xiv] If passed the amendments could lead to further changes to the Guidance. The amendments referred to in the consultation should have been clearly spelt out so the implications could have been examined; as it is the amendments and accompanying documents are poorly explained. Anyone commenting on the consultation would have a lot of extra research to do in order to be able to appreciate what is happening regarding these amendments, all while the consultation is taking place.

The amendments are being progressed even though it is acknowledged there are uncertainties over the full policy impact of the changes. It is not at all clear why this is being done now, as it is not expected that an FDP will be agreed between Government and industry for at a year.

The timing of an FDP - and what has to be in it - is very relevant to the lack of resolution around decommissioning and nuclear waste funding and the practicalities of waste and spent fuel management and disposal. These issues will likely remain unresolved for many decades. In this context, proposals to limit the discretion of the SoS to exercise powers to modify an FDP appear extremely premature and could impact significantly on the Government's negotiating power when it comes to agreeing or modifying FDPs with industry.

It would be ill advised to make changes to the Energy Act 2008 at this time when there is a public consultation the FDP guidance. The consultation is inadequate as it does not fully take into account the proposed changes to legislation and the powers of the SoS to modify an FDP, which is of particular concern when there are so many unknown factors on waste management and disposal.

DECC has told Greenpeace that despite the impression given, legislation still 'enables' the SoS to modify FDPs. We note that DECC said that in return for the amendments - which bind the SoS - the FDP will have to be more robust. While Greenpeace welcomes the opportunity to meet with DECC to discuss these matters, a full understanding of the impact of the amendments should have been in the consultation and not something gained through a meeting.

<u>Waste transfer price, cap/price setting and deferral</u>

Consultation question 1 asks: *Do you agree or disagree that the level of the Waste Transfer Price should be subject to a Cap and that in return for setting a Cap the Government should charge a Risk Fee? What are your reasons?*

Greenpeace does not agree with a cap on waste disposal costs.

This is because the main reason behind setting a maximum cap which operators can expect to pay is to give certainty to new build investors (3.1.5 WTP), whereas no certainty is being provided for the taxpayer that the public purse will not eventually have to pay towards waste and spent fuel management and disposal. The claim that: *the Government's objective is to ensure the safe disposal of ILW and spent fuel from new nuclear power stations without cost to the taxpayer and to facilitate investment through providing cost certainty (para 3.1.7 WTP)* is just that - a claim. There is no guarantee this objective will be met, particularly if there is a price cap.

The removal of uncertainty and risk from the operators is a disguised subsidy and could be unlawful.

The history of this suggests that the Government has been caught between reassuring parliament and the public that there is to be no subsidy for nuclear power while wishing to meet the industry's demands for financial help.

Initially the Government proposed (October 2008): *2.9 The Government would expect to set a fixed unit price based on the operator's projected full share of waste disposal costs at the time when the approvals for the station are given, <u>prior to construction</u> of the station.* (our emphasis) [xv]

The introduction of a 'capped' price - as opposed to a Fixed Unit Price (along with the proposed 30 years deferral period before setting a Final Price) - is a significant change to the proposals.[xvi]

A 'cap' - to be set at the <u>outset</u> - the maximum the operator can expect to pay (1.14 WTP) raises many questions. Although it is recognised there would be some adjustments to funding arrangements over time for operators accumulate the monies up to the capped price (if necessary) from the very beginning operators will know there is an absolute limit on their costs.

That there is to be a cap plus risk premium is tacit acknowledgment of the risks of cost escalation. The cap and risk premium could however be exceeded. The benefit of doubt is given to the operators under the Government's proposals, with the risk (of subsidy) staying with the taxpayer. How can it be that certainty is given to the private nuclear sector and not the taxpayer instead?

In relation to this, it is noted (1.14 WTP) that: *The March consultation said that in seeking a deferral the operator would be accepting the risk that a Price set at a later date could be higher than the Price on offer at the outset, if estimated costs escalate sufficiently in the intervening period. Having considered the responses to the consultation, the Government's view is that it will be difficult for an operator to accept such a risk, given that there is very little the operator can do to manage and mitigate it. In contrast, <u>the Government does have capacity to manage risks around waste disposal costs, as these</u>*

costs will be heavily influenced by the manner in which the Government implements geological disposal. Therefore the Government's view is that it is reasonable for nuclear operators to have some certainty over their maximum exposure to these risks from the outset. [xvii] (our emphasis).

The risk to disposal and costs should remain with the operator and not be removed by the Government which cannot guarantee - regardless of the various mechanisms proposed - that the cap will not be exceeded. This means monies should be accrued for waste and spent fuel management and disposal by the operator but no cap set on them.

The SoS will set a Final Price, even in the event of there being no GDF after the deferral period (3.3.61-3.3.62 WTP). This raises the same questions as those around the 'unknowns' which would arise earlier in the process when an expected price is offered (1.12 and 1.24 WTP). That is because whenever a Final Price is set it still amounts to a limit on unknown levels of cost - and thus risks subsidy. Is it not clear how the SoS can determine a cap alongside a Default Date (3.3.64 WTP) as this will depend on the status of any proposals on disposal at that time. What if no plans for a GDF are in progress when a Final Price is set?

On 1.1.4 WTP (see above) the Government, may be able to 'manage' or 'influence' some risks, but it cannot control them all. For example, it cannot guarantee it will find a volunteer community, *with* the right geology, which will take *all* legacy *and* new build wastes. Minutes of meetings of Government officials reveal, in discussing project plans on geological disposal, their thinking on this matter: *Considering the draft project plan as set out October 08, it was noted that overdue tasks are those dependant (sic) on the local community, over which Government has no direct control.*' [xviii] (This information was only released following a Freedom of Information request).

Despite the obvious problems, government appears to be willing to accept claims (2.2.28 WTP) that the costs risks are extensively within its control.

Quite how the Government will seek to control local authorities, the voting public, the money markets (so funds accumulate the necessary amount of money), independent specialists assessing geological suitability, security threats and many, many other aspects of the disposal process which are 'outside of its direct control' remains to be seen.

How it will seek to control the whole disposal process in the future, so it can be sure of the price offered (when the FDP agreements are made and the cap offered), is not clear? If it cannot guarantee it can control all of this, then a cap should not be given.

Indeed, we note (3.3.72 WTP): *The best available waste disposal cost estimate is the current best estimate derived by NDA for their reference scenario. This is a single value base estimate rather than a distribution, as a detailed line-by-line assessment of the risks and uncertainties around this estimate cannot meaningfully be produced at this stage, in the absence of a site and final design for a GDF.* (our emphasis)

We note the geological suitability of the only areas currently under consideration in the MRWS process (Allerdale and Copeland) is being questioned by experts in this field. Indeed, the suitability of the whole Cumbria region as suitable for geological disposal is being challenged. [xix] This demonstrates the shaky basis for the Government's assumptions.

On *Handling Uncertainty in cost estimates* (3.3.95-3.3.102 WTP) the issue of the level of uncertainty comes up yet again - particularly with reference to the fact that it is the intention to set the cap at the outset (e.g. 3.3.85-3.3.88 WTP).

Can DECC really decide on a risk fee high enough to cover all eventualities which may lead to an increase in costs over the cap, but which is low enough to not deter investors? This problem is acknowledged to a degree (3.3.107 WTP) but the proposals to set a cap continue forward with no discussion on when the whole policy (let alone agreements and contracts) might be revisited in the light of new information down the line if things do not go as planned?

It is clear the intention is to make decisions in the short term (1-2 years) regardless of major, unresolved issues which exist now and may not be resolved for decades. In the meantime new reactors - producing highly radioactive spent fuel - will have been built.

Despite criticisms made of the assumptions regarding costs in the March 2010 consultation, the Government has not changed its analysis of risks and uncertainty. (3.3.87 WTP).[xx] This flies in the face of the facts.

On (2b.26 FDP), we note the Base Case sticks to an assumed 40 year operating life for a reactor, which at first seems sensible based on what companies may need to accrue in terms of funding for waste costs. However, it then goes on to note that the current reactor vendors are proposing 60 years operating lives for reactors - and that plans can subsequently be changed to accommodate any extensions in operating life. Why has the Government not set the operating life to the average operating life now which is around 25-30 years(although an operating life 40 years may be achieved).[xxi]. The Government should at least set a deferral date which is realistic in terms of the average life of a reactor in order to safeguard against the Final Price being fixed too late? (see also 3.3.6 WTP).

Costs, volume/weight, fuel mixing and storage

Volume and weight as unit cost basis
On the pricing for the disposal of spent fuel and ILW we note the Government has moved from its proposed per kilowatt hour for spent fuel to a 'simpler' cost per tonne of uranium (weight) for spent fuel (2.2.53 WTP).

The volume/weight measure does not adequately factor in the problems with the heat-generating capacity of new build spent fuel - which is it recognised is a factor in both the management *and* the disposal of new build fuel. Using weight/volume alone is a clumsy measurement and although probably very helpful to the new build industry does not recognise the problems of new build fuel - which will be exacerbated further still if MOX is used.

Radioactive inventory
Using volume/weight as a basis for disposal costs is not enough. The unit costs should take into account the radioactive inventory of spent fuel (it does not have to be based on a specific isotope). This would recognise that new build spent fuel (i.e. based on a 10GW programme) would contain three-fold the amount of radioactivity as all legacy wastes and nuclear materials (from the past 50 years of activity) combined. [xxii]

This could be relevant, at the very least, to the issue of any compensation package for the communities considering a GDF. Or is it DECC's intention to foreclose discussion on this by deciding on the WTP units and measures well before the discussions on inventory and compensation take place through the MRWS process?

Fuel Mixing
The issue of radioactive inventory (and heat generation) is clearly an issue which is why the NDA has said a 'judicious mix of short and long cooled fuel' ([xxiii]) would possibly shorten storage time before disposal to 50 years, from the original 100 years (to help in reducing storage costs and time and possibly disposal costs also).

Questions naturally arise over the mixing of long-cooled and short-cooled fuel mixing and how it might be achieved? Could legacy spent fuel be used to enable 'quicker' disposal for new build fuel, but at the risk of leaving legacy wastes above ground for longer? If this did happen what impact it might have on costs in terms of subsidy? The consultation does not state either whether operators will be allowed to swap fuel to achieve shorter storage times pre-disposal.

If fuel mixing does not take place as planned then both the variable costs of contributions to a GDF may change for new build operators due to the proportion of space required (and other factors).

If it is found however that the long and short cooled fuels cannot be mixed - the disposal (and costs) become more of an issue then the Final Price will be affected. Using tonnes of uranium as a unit may be simpler for the industry, but leaves the risk of increased costs in terms of , storage times (at reactors sites or off-site) and encapsulation etc to be addressed as well as practicalities of spacing and disposal in a GDF. On this we note a recent presentation an MRWS meeting which raised concerns over potentially significant environmental impacts arising from the heat generation of new build spent fuel in a GDF. [xxiv](. With regard to this, it is important to be mindful also of the potential worker exposure in handling higher burn up fuels, and the possible environmental impacts of encapsulation (or other handling or conditioning) of the spent fuel.

On the potential health and environmental implications of spent fuel management and disposal the consultation makes no mention of when the Justification process will be applied to the above ground works and/or GDF (either together or separately).

Whose fuel gets to share the legacy GDF?

When it met with DECC, Greenpeace asked DECC if it would give preference to different operators based on a) when they built the reactors and/or b) when they applied for an FDP or WTP? DECC acknowledged the consultation is 'silent' on this matter. We note 3.3.16 WTP that operators may want to set a final price before the end of the deferral period? (We also note a new Cap may be set for each new operator applying for a WTP (4.2.4 WTP).

On this we note that in a 2009 pre-consultation paper it was recognised the first new build operators entrants would likely be disadvantaged in the setting of a 'fixed unit price' as the earlier they applied, the more risks attached, as there were more uncertainties.[xxv]

How will DECC deal with any jockeying for position on a final price and disposal timeline for different operators? Whose waste gets to share a legacy-new build GDF - and therefore how soon spent fuel is sent for disposal - is not an incidental matter as it will have very real implications for communities living around reactor sites or possible GDF(s) and what might happen in their localities.

How might the possibilities pan out in terms of the order in which operators will apply for a Final Price? What if operator X builds a reactor later than operator Y, but applies for the final price before operator Y? Operator X does this so it can benefit from the cost sharing which will come from using a legacy-new build waste repository. However, Operator Y (and others) may have built their reactors earlier than X, but have deferred in applying for a Final Price until later than X hoping for the greater cost certainty promised by the Government. In doing so they also risk having to pay much more if their spent fuel has to go into a second (new build waste only) repository.

Assumed Disposal Date

It is Greenpeace's view that the Expected Assumed Disposal Date (3.3.19 WTP) or the date the Assumed Disposal Date is given (3.3.109-3.3.111 WTP)[xxvi] might be subject to more delay than is anticipated. The whole process risks setting dates - and raising expectations - too far in advance of objectives becoming reality. Similarly, giving an indicative timing of when title and liability might transfer to the Government for waste and spent fuel (when the waste contract is initially agreed 3.1.2 WTP) is very relevant. That this might be reviewed later does not detract from the fact that the contractual obligations will in all likelihood be used to put pressure on communities - none of whom will have had a say in the FDP negotiations - to agree to a GDF.

MOX spent fuel

The Base Case (page 45 FDP) assumes the new reactors will use uranium or uranium oxide fuel, yet at the same time this consultation is taking place DECC has published a consultation giving the Government's preferred option (for the disposition of the UK's plutonium stockpile) as reuse in MOX fuel.[xxvii] The use of MOX fuel could have many practical and financial implications which these consultations do not address.

The potential use of MOX fuel, which is more radioactive than new build fuel, could massively complicate any future FDPs or modifications to them (and the Waste Transfer Price).

The NDA has not produced a timeline for storage and disposal of MOX spent fuel as part of the Government's consultation on plutonium.[xxviii] Given this, the consultation on the WTP should be done again running MOX fuel through the model. And the Government should re-consult on the result.

Geological disposal facility - when and if

Throughout both the consultation documents there are references either to disposal or a GDF. The FDP (2b.14) asks operators for information about the predicted spent fuel inventory for the site and its relevant characteristics as this will have a direct bearing on the costs of waste management and disposal.

This gives the impression matters will be settled, via the FDP process, before reactor construction begins but before other crucial processes, e.g. the MRWS process, have run their course.

As DECC will be aware this is not the case, nor can it be in the context of this consultation.

In (2b.25 and 2b.26 FDP - pre-generation) on what an operator must provide information on (and which is to be consistent with information put before the Infrastructure Planning Commission - IPC) the consultation states that: *An approvable FDP will require the operator to demonstrate that a credible disposal route for the ILW and spent fuel has been identified. The Base Case assumes that this will be in a Geological Disposal Facility (GDF) that the Government will construct to dispose of higher activity radioactive wastes.* (our emphasis).

How will the timing of an FDP agreed impact on the MRWS process, surely the FDP process will pre-empt it? Also, if the first FDP is to be negotiated from mid-2011, how can any operator 'demonstrate' a 'credible disposal route'? Also, it is not clear what will happen if the IPC is not properly informed of operator plans.

On matters concerning timing, and what is achievable (and which relate to costs), we note: *(FDP) 2a.13: The purpose of the quinquennial report, which is a detailed and comprehensive analysis, is to ensure that the FDP is up to date. For the DWMP this is to ensure that the plans for the decommissioning of the site and for the management and disposal of waste arisings are realistic, clearly defined and achievable and that the corresponding cost estimates are robust (set out in Part 1 of this Guidance).* (our emphasis)

Further, (FDP) 2b.3: *The aim of the DWMP is to demonstrate that the decommissioning of the nuclear power station and management and disposal of waste can be undertaken in a way which is prudent and consistent with the requirements and expectations of the safety, security and environmental regulators. By forming part of the FDP required to be approved by the Secretary of State, it is designed to ensure that a plan for these activities, based on established techniques and steps, is prepared prior to the construction of the nuclear power station. It is also designed to ensure that accurate and up to date estimates of the costs of decommissioning and waste management and disposal are provided, to demonstrate that prudent provision will be made to meet these costs.* (our emphasis)

Again, it is asked how an operator can possible present a DWMP which will be able to 'demonstrate' that the disposal of waste 'can be undertaken' - and how can this be done not only before the construction of reactors (estimated to begin around 2013) but also when there is no known GDF site (and the geology is not known) and the first new build spent fuel disposal is not planned until 2130 at the earliest.[xxix]

It is also noted that it has been estimated it will take up to 2185, at least, to get all spent nuclear fuel from a (10 reactor) new build programme into a GDF. This is based on a reactor starting operations in 2020, closing after 60 years (and assuming no shortening of the original estimated time for cooling spent fuel i.e. it stays in storage for 100 years). [xxx]

Estimating an Expected Assumed Disposal Date as part of the initial agreement with the operators - as well as giving a capped price - lacks credibility given all the issues to be resolved over the next 90-170 years.

Nowhere near enough consideration is given to whether a second GDF may be needed (e.g. 2.2.41 WTP). Page 45 and 46 (FDP) assumes both ILW and spent fuel from new build will be disposed on in a GDF: whether even one eventuates, let alone a second one is build, is not honestly debated. Yet suggestions by Government in other documents - that at least a 16GW new build programme is likely - and desirable - strongly suggest a second

GDF would be required.[xxxi] This should be acknowledged in the consultation: it is too late, on this important matter, to leave the need for a further GDF until later.

There have also been suggestions that the above-ground works for the first GDF, could service a second GDF - this brings this discussion (once again) back to the MRWS process and the considerations been made through that process which are sidelined by the FDP and WTP consultations. It seems that this consultation has not taken into account the existence or product of other consultations.

There is too much reliance on a GDF siting-process going to plan (e.g. 3.2.3, 3.2.5 WTP) and the Government's ability to manage costs around disposal (3.2.8 WTP). Yet, the process as set out by the NDA on how geological disposal will be implemented (e.g. 3.2.12 WTP) cannot be guaranteed. We also note the recent comments from the Energy and Climate Change committee on its concerns over the uncertainty surrounding disposal.[xxxii]

The decision to further extend the deferral period to 30 years for setting the final price for waste disposal - based on the assumption this will happen after the first legacy waste emplacement around 2040 (and costs are more certain) is a massive gamble which could go wrong. Or, that a final price could be set (around 2025) once a site is selected, but before the first waste emplacement (3.3.14 WTP) is also based on the Government's over-reliance on the progress of disposal and its 'commitment' to this happening (3.3.15 WTP). All of this is at odds with the volunteer approach under the MRWS process and thus creates a false impression of the risks involved.

The process of agreeing an FDP looks very likely to tie the communities - particularly those living around a potential GDF - into agreements which will have been finalised well before they have considered key issues (e.g. on inventory). They will have had no say in these matters. No information is given on how the contractual arrangements of an FDP will impact on any agreements yet to be considered under the later stages of the MRWS process between the site developer and any new build operators wishing to either store waste and spent fuel near a GDF or dispose of it *and* the communities they are meant to negotiate with.

<u>Costs for spent fuel management and encapsulation</u>

A lump sum is to be paid from the Independent Fund if waste transfers to the Government: *FDP 2b.27 In the event that the operator expects its waste to transfer to Government before the Assumed Disposal Date, the operator's DWMP should clearly set out those steps expected to take place after the Transfer Date and the cost of those steps. The operator's plan should also contain an estimate of the Lump Sum Payment, including an allowance for a commensurate risk premium, to ensure that the Payment is sufficient to cover all waste management costs incurred between the Transfer Date and the Assumed Disposal Date. (see also 3.3.18 WTP)*

Again, it is too soon to be making such a commitment as, if the ADD is wrong, it could entail significant extra costs not covered by the risk premium attached.

If the lump sum is to be transferred after decommissioning of the reactor takes place which, from the last consultation we assume to be around 20 years (after electricity generation ceases). This may be overly optimistic. [xxxiii] It has not been explained sufficiently in any document (concerning this matter) why the Government is assuming there will be no care and maintenance period post-generation but pre-decommissioning (page 42, FDP).

The FDP (2b.36) states: *At present there is uncertainty over these waste management costs but this should reduce over time. By the Transfer Date it should be possible to estimate these costs with a much higher degree of confidence. Notwithstanding this, under this approach the Government would expect the operator's provision to be based on a conservative, evidence-based, estimate of the waste management costs and would expect the Lump Sum Payment to include a commensurate risk premium to compensate the taxpayer for taking on the risk of subsequent cost escalation.*

This may seem reasonable, yet only last March (nine months before the current consultation) it was noted, on encapsulation (which is an essential part of the pre-disposal process to be covered by the lump sum) that one approach would be for the Government to expand the scope of the Fixed Unit Price to cover these costs but that: *This would require the Government to estimate these costs, together with their attendant level of uncertainty. However this uncertainty is considerable, particularly around the costs of encapsulation, and hence the additional risk premium would be large.*[xxxiv]

No evidence has been presented to justify the lessening of concerns (or omission of them) over storage and encapsulation costs from those which appeared in the March 2010 consultation. The Government should consult on the basis of the best evidence available to them and not on the basis of unwarranted assumptions.

We acknowledge the Base Case assumes that spent fuel storage and encapsulation takes place at reactor sites, but also see no evidence to back up claims that: *However in the event that regional or central facilities were available for either storage or encapsulation of spent fuel that should lead to significant reductions in waste management costs. (2b.32 FDP)*

On the issue of shared facilities for legacy and new build wastes and potential subsidy, (2.2.17 WTP) the Government's response (2.2.23 WTP) is inadequate and downplays real concerns - without providing any evidence - that subsidy could arise to new build through sharing facilities.

On the Summary *of principal costs streams and how they will be met*. Under the section on Spent Fuel (page 51, FDP) the ordering is that encapsulation of spent fuel for disposal comes *after* the transport of spent fuel for disposal. If the base case is - first and foremost - encapsulation at reactor sites, then the Guidance should reflect this and have these two reversed and placed in order of which they are expected to take happen.

OTHER/GENERAL POINTS

The guidance should be more prescriptive. The non-prescriptive guidance and then the powers to modify the FDP (coupled with constraint of SoS powers) and the vagaries over Final Price, as well as the 'flexibility' on many unresolved issues, favours the nuclear industry to the potential detriment of the taxpayer.

On EU state aid law the WTP paper states (3.1.6): *The Government's approach to taking title to and liability for ILW and spent fuel will be subject to ensuring compliance with EU State Aid law.*

No explanation is given as to how exactly the Government will demonstrate its measures do comply with EU State Aid Law; Greenpeace assumes that the Commission, which is the sole arbiter on this issue, will be asked to approve any scheme in advance and that the Government accepts that, without this approval, subsidy is plainly unlawful.

On the Funding Arrangements Plan (para 2c. 9 FDP) we note: *Any structure proposed must be demonstrably capable of accumulating and receiving sufficient funds to meet the plans as set out in the DWMP for the designated technical matters.*

Given the timescales involved it is not unreasonable to ask how - over a possible 160 years for spent fuel storage (covering that created from when the reactor first goes critical to when a GDF may be able to received the final spent fuel) the Government can guarantee that all relevant funding is in place in the case of insolvency (2c.11-2c.12 FDP). Within recent years both individual nuclear companies (e.g. British Energy) have gone bankrupt and other major financial institutions have gone to the wall (sometimes very quickly, quicker than an annual or quinquennial review would have spotted).

What certainty can there be that the organisation holding the funds for the DWMP will be 'safe' over the time period required? Of course, the Government will say it will ensure this via the FDP arrangements, but given such agreements are secret, how will the public and Parliament really be able to establish the safety of such funds?

Notification/credit rating: On the final dot point in (2a.20 FDP) and the requirement to notify the SoS of: *'Change in the credit rating of the operator, the Fund or of any entity providing a guarantee or other credit support under the FDP. '*

This seems particularly lame given the experience with British Energy. As a number of reports have since concluded, not enough was done to head-off BE's looming bankruptcy before it had to appeal to the taxpayer for a bailout. Yet it was known by the Government and the Shareholder Executive the company was in trouble.

On this, we ask if there will be protection for the taxpayer in having a schedule for the title and liability - and transfer of wastes and spent fuel - in batches to ensure that the Government does not agree - in advance of funds being available - to take *all* the spent fuel from a reactor or even a fleet of reactors? We are aware the Government is the 'last resort' in the absolute failure of any institution with practical or financial obligations for waste and spent fuel, but the onus should remain with the operator and associated companies (which may be overseas) to fund these liabilities.

Will there be a clause in the contracts which will enforce the necessary funding to be paid by associated companies overseas (or another Government's, as in the case of EDF which is majority owned by the French state) if a portion of the spent fuel costs has be to recovered - in the event a UK-based operator goes bankrupt?.

On Contributions to the Fund. On this we note (2c.38 FDP) that: *Payments to the Fund should be viewed as an essential matter during operation which must be serviced before debt and/or other costs as appropriate.*

The Shareholder Executive was, it is understood, meant to do a similar job on monitoring British Energy's viability, but took its payment of shareholders as a sign of the company's financial well-being (although there were not the powers to actually stop BE paying dividends to shareholders before its waste liabilities). The National Audit Office explains the problem in BE's case. [xxxv] On this also note the conclusions of the Public Accounts Committee on the Restructuring of British Energy in July 20078[xxxvi]

It is to be hoped the current administration has learnt from the failures over BE, but it might still be relevant if those who advised on BE are also advising on the FDP and WTP issues. This is not a Department with a good record on nuclear liabilities.

On Investment Strategy (2c.47-2c.53 FDP), we refer to Greenpeace's earlier submission (June 2010) where it was noted that: *The financial engineering (in the fixed unit price consultation is) designed to pay for disposal of spent fuel relies upon accrued interest funding around 70% of the total disposal cost. The energy utility would typically pay around 30% of the disposal cost over a 60 year period but then rely upon compound interest earned during the next 50 - 100 years to make up the shortfall. The arrangement transfers most funding risk to the stock market.*

Combining the risks of the nuclear waste management process and the financial markets (and possible returns on investments over 100 years) - when coupled with DECC's record on nuclear liabilities - indicates the potential financial problems around managing nuclear liabilities are massive.

Even with the best intention, the combination of different factors - variability in the FDPs over time, risks on waste and spent fuel management and disposal (which are practical, financial and political), the flexibility to operators proposals, the SoS powers (and how these are to be constrained), the potential problems with investment returns, disbursement of funds, the viability of the operators and associated companies - could either together or separately create many problems

On investment returns (2.2.34 WTP) states: *Over the many decades in which these funds are expected to operate, the Government considers it reasonable for an operator to plan on the basis that real terms growth in investments will be achieved. However it is important to note that the risks around fund performance lie with the operator not the Government.* (our emphasis)

Given the recent financial crisis this is a brave or perhaps foolish claim. The consultation gives the impression of certainty for investment, yet (4.5.11 WTP) goes on to note: *The performance of an operator's independent Fund will depend on a number of factors, including the Fund's investment strategy and the performance of the economy over time. It is impossible to project fund performance over the very long timescales involved here. Moreover, given the long timeframes involved, even small variations in assumed fund performance can have a very large impact on the estimated level of payments into the Fund.*

Linked to this is the issue of modification of an FDP (2a.43) *Modifications may include changes to the DWMP, for example to account for technical or operational changes to the nuclear power station which have had an effect on the cost estimates for the designated technical matters. Modifications may also include changes to the FAP, for example to reflect changes to contribution schedules in respect of the Fund to take account of changes to cost estimates set out in the DWMP or to reflect investment returns.* (our emphasis)

As noted earlier, there is too much reliance on the expectations of how much of the funds will come from accrued interest on investment returns. As with the issue of credit rating, we ask how a potentially significant down-turn in fortunes (which can happen very quickly) will be conveyed to the SoS and acted on - and acted on it time.

We note (2c.64-2c.66 FDP) on the guidance on Sufficiency of Fund and (2c.67-2c.72 FDP) Protection against an insufficient Fund. Again, there are questions over whether the Government will have the necessary powers - and be able to act in time - to reduce the risk of insufficient funds (particularly in the event of a major technical failure or terrorist act) and also whether it will be able to act to ensure 'associated companies' will step in if the operators fails to provide sufficient funds.

On reporting requirements, we note (footnote para 2a.6) that: The Government has proposed text for the Nuclear Decommissioning and Waste Handling (Finance and Fees) Regulations 2010 (the proposed Regulations) and expects to lay them in the House subject to parliamentary approval in time for them to come into effect on 6 April 2011. It seems odd to have already passed these before this consultation takes place as it assumes there will be no changes needed, regardless of the outcome of the consultation.

Variable costs
We note that apportioning Fixed Costs will be based on Variable Costs which cannot be provided at present (3.3.30 WTP). Variable costs are also assumed to be linked to 'demand' for disposal. This also relates to when a Final Price is set and whether it is at the GDF site selection stage or post-first waste emplacement (3.3.52 WTP). We note the consultation (3.3.77 WTP) acknowledges there could still be uncertainties around the variable costs even after the Final Price is set.

Fixed cost contribution
On fixed price contributions to the cost of a GDF from new build operators. We note: *(2.2.43 WTP) The starting point for the calculation of the Fixed Costs is expected to be at or around the time that the first price is requested by a prospective new nuclear operator. It therefore excludes all design and other costs incurred before that point. The consultation noted that there are categories of possible costs excluded from the current cost estimate but which might need to be added in later, such as the cost of community benefits associated with a GDF and the need to maintain institutional control for the facility post closure. To the extent that such costs are incurred or expected to be incurred as part of the GDF project, a new nuclear power station operator will be expected to pay their full share of these costs.* our emphasis *(see also estimating waste disposal costs 3.3.25, 3.3.32-3.3.39 WTP)*

It has been estimated that costs to date, to establish a repository, undertake R&D on various waste forms etc., is around £1bn. The Government is now saying that new build operators will not pay any of those costs. It will doubtless be argued that those costs would have been incurred for legacy wastes anyway. If there is a GDF and if it involves new build wastes then all development costs should be shared with new build operators as not including all the costs to date will constitute a subsidy to new build.

Fixed costs - (3.3.32-3.3.39 WTP) another 'unknown' is the size of any new build fleet - therefore ignoring certain earlier costs (see paragraph above) might benefit a few operators e.g. depending on the maximum inventory allowed for the GDF, fuel mixing and other criteria, but not others who may use a second GDF. The costs (based on a generic reactor) rather than the supposed commitment by pro-new build companies - to a 16GW programme - ignores the extent to which the waste and spent fuel inventory could drive a second GDF and who benefits. There should be worked examples using a 10GW, 16GW or even 20GW programme to give an idea of the potential impact overall - for either one or two GDFs.

Definitions in the paper differ from those used by CoRWM (e.g. disposal is not defined in either the FDP or WTP) and the EA in GRA papers. Given proposals on retrievability and reversibility, which will probably be discussed under the MRWS process, this could lead to confusion as to the actual outcome expected by all parties on these issues. Indeed, in this consultation, as with other Government and agency documents, common definitions and meanings are not shared.

The term 'waste transfer price' now covers both the earlier Fixed Unit Price element for disposal costs and the 'lump sum' for ILW and spent fuel management (and encapsulation) once title and liability passes from the operator to the NDA. WTP is defined (page 87) as: *the price paid by an operator of a new nuclear power station in return for the Government taking title to and liability for their ILW and spent fuel.*

WTP now joins together a price (for disposal) which will be capped at the very outset when an FDP is agreed, with the 'lump sum' which will not be capped i.e. the operators will have to accrue funds over the life of the reactor and then adjust the amount in the fund to cover estimated costs just before the monies are handed over. The change in name may seem small, but might it also indicate potential policy drift whereby the storage/encapsulation costs eventually becomes part of a 'fixed' price.

Liability/insurance cover

The consultation does not discuss how liability cover will be provided for spent fuel stores on site after generation has ceased but before the title and liability pass to the NDA. For the estimated 20 years to decommission the reactor (after which title and liability for spent fuel will pass to the NDA) the spent fuel stores will be the single biggest hazard on site. Insurance cover for this should be specifically stipulated as part of the FDP package. We also note the consultation on the changes to the UK liability laws are taking place at the same time as this consultation.

On the Base Case - working assumptions list. We challenge the idea that dose limits will be those in currently in use. Future generations may wish to impose the more stringent Basic Safety Objectives as in the NII SAPS (see GP Justification response, Feb 2009, pages 7-9). [xxxvii]

We also note (page 47 FDP) that LLW will be disposed of at the LLWR in Cumbria or 'a successor facility.' As with the higher activity wastes, the question arises as to what will happen if there is no new national disposal facility for LLW?

Conclusions

The consultation has presented inadequate information.

Some of the information is misleading. This is the particularly the case for all the references to future waste disposal which seem to assume problems have already been overcome.

The proposals are a disguised form of subsidy.

The proposals to keep the future agreements and arrangements from public view and scrutiny are undemocratic and unlawful.

The process undermines the voluntarism approach around the siting of a GDF and key issues concerning it such as the inventory of wastes to be disposed of.

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i Consultation on revised Funded Decommissioning Programme Guidance for New Nuclear Power Stations http://www.decc.gov.uk/assets/decc/Consultations/fdp-guidance-new-nuclear/985-consultation-revised-fdp-guide.pdf

ii Waste Transfer Price document: http://www.decc.gov.uk/assets/decc/Consultations/nuclear-waste-transfer-pricing/984-consultation-waste-transfer-pricing-method.pdf

iii e.g. *The Nuclear Decommissioning and Waste Handling (Designated Technical Matters) Order 2010 (SI 2010/2850)* came into effect on 30 November 2010.

iv http://webarchive.nationalarchives.gov.uk/20090103073128/http://www.berr.gov.uk/files/file48074.pdf

v Greenpeace response to consultation questions, June 2010 C:\Documents and Settings\Jean\Local Settings\Temporary Internet and Jackson consulting report on fixed unit price cost modeling Files\Content.IE5\M1O7SZ4L\674-nuclear-decommissioning-cons-responses[1].zip http://www.greenpeace.org.uk/files/pdfs/nuclear/gpuk-fupsim-report.pdf

vi (3.3.90 WTP) *The detailed cost estimate resulted from a rigorous process in 2007/08 that included bottom up estimates with costs and prices included from tender information, quotations, relevant industry data and current salary levels. (3.3.90 WTP)*

vii See Page 20 The Energy Act 2008 Consultation on The Financing of Nuclear Decommissioning and Waste Handling Regulations Designated technical matters
http://www.legislation.gov.uk/ukpga/2008/32/section/45

viii See also FDP *2b.7 Some of the technical matters are designated technical matters. These are defined in the Energy Act as being the steps that need to be taken to decommission the installation and clean up the site (which includes the management and disposal of waste) after the nuclear power station has finally ceased generation. The Act also envisages that certain steps undertaken during the generating life of the station may also be specified as designated technical matters by Order.*

ix WTP *3.1.2 Alongside the approval of an operator's FDP, the Government will expect to enter into a contract with the operator regarding the terms on which the Government will take title to and liability for the operator's spent fuel and ILW (the "Waste Contract"). In particular, this agreement will need to set out how the price that will be charged for this waste transfer will be determined (the "Final Price"). The Final Price will be set at a level consistent with the Government's policy that operators of new nuclear power stations should meet their full share of waste management costs.*

x I It is not clear in terms of reference to 'transparency' and 'good industry practice' (e.g. para 3.3.46 and 3.3.55, 3.3.68 WTP), who the details of agreements will be made known to.

xi WTP 3.3.11 notes there will be independent oversight on the pricing and review, but not public or Parliamentary oversight.

xii http://www.decc.gov.uk/assets/decc/legislation/energybill/544-energy-security-bill-brief-nuclear-operato.pdf

xiii ibid

xiv http://www.decc.gov.uk/assets/decc/legislation/energybill/993-energy-bill-2011-ia-nuclear-operators.pdf. The relevant section of the proposed Energy Bill 2011 is http://www.publications.parliament.uk/pa/ld201011/ldbills/033/11033.72-77.html#j121.

xv Pre-Consultation Paper No1: on a methodology to determine how the fixed costs of building a geological disposal facility should be apportioned and share between operators of new nuclear power stations. DECC. October 2008.

xvi *4.1.3 (WTP) As with the figures in the March consultation, the figures given here are for the purposes of illustration and should not be taken as representing the level of the Cap, Risk Fee or Expected Price that will actually be set for an operator of a new nuclear power station.*

xvii We note WTP, *3.3.85 The Cap will be determined by the Secretary of State at the outset and the Government will guarantee that the Final Price will not be higher than the Cap. In return for this guarantee the Final Price will include a Risk Fee. The Cap and the Risk Fee will be indexed for inflation. The Cap will be set at a level that reflects the Government's current analysis of risk and uncertainty around waste disposal costs and gives a very high level of confidence that actual cost will not exceed the Cap.*

xviii Minutes, Geological Disposal Implementation Board, 2 March 2009.

xix http://www.davidsmythe.org/nuclear/cumbria%20bgs%20exclusion%20report%20review%20for%20website.pdf

xx Paragraph 3.2.18 (WTP) is also very relevant to whole pricing system - e.g. the expected Price at the end of the Deferral Period (3.3.8-3.39 WTP) is based on uncertainty.

xxi http://www.choosenuclearfree.net/energy/nuclear-power-and-climate-change/nuclear-power-%E2%80%93-a-slow-response-to-an-urgent-problem/

xxii CoRWM (17th January 2006) Inventory Summary Information , Doc 1531 http://www.corwm.org.uk/Pages/Archived%20Publications/Tier%202%20(6)%20-%20Reporting/Tier%203%20-%20CoRWM%20inventory/1531%20-%20Inventory%20summary%20information,%20including%20new%20build%20(the%20One%20Pager).doc

xxiii Page iv, http://www.nda.gov.uk/documents/upload/Geological-Disposal-Feasibility-studies-exploring-options-for-spent-fuel-from-new-nuclear-power-stations-November-2010.pdf

xxiv Prof. Stuart Hazeldine, presentation to MRWS Partnership meeting on Thursday, 3rd March.

xxv Para 3.2.2 OND Pre-consultation discussion paper No. 3: Establishing a fixed unit price for the disposal of intermediate level waste and spent fuel from new nuclear power stations – a worked example May 2009

xxvi *3.3.19 The Assumed Disposal Date will be determined alongside the Final Price, and an Expected Assumed Disposal Date will be provided to the operator alongside an Expected Price. In the event that the Final Price is set before GDF Site Selection, the Default Pricing Mechanism will also determine the Assumed Disposal Date.*

xxvii http://www.decc.gov.uk/en/content/cms/consultations/plutonium/plutonium.aspx

xxviii http://www.nda.gov.uk/documents/upload/Plutonium-Credible-Options-Analysis-redacted-2010.pdf

xxix see also 2b.4: Under the Energy Act, as one of a number of approvals to build a new nuclear power station, operators will be required to submit an FDP to the Secretary of State for approval. The Energy Act requires such operators to provide to the Secretary of State details of their plans for managing and disposing of all wastes.

xxx The arrangements for the management and disposal of waste from new nuclear power stations, page 13, para 52 http://data.energynpsconsultation.decc.gov.uk/documents/wasteassessment.pdf

xxxi Page 16, 9.0 http://www.westcumbriamrws.org.uk/documents/94-Inventory_critique_Pete_Roche.pdf

xxxii Paras 70-72 http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/231/23106.htm#a16

xxxiii Section 5, para 5.3.25 http://www.decc.gov.uk/assets/decc/Consultations/nuclearfixedunitprice/1_20100324145948_e_@@_ConsultationonFixedUnitPricemethodologyandupdatedcostestimates.pdf

On Phase 3 (2b-30-2b.32 FDP) after the end of electricity generation, it is noted that:

Decommissioning ends when all station buildings and facilities have been removed and the site has been remediated in accordance with relevant legal and licensing requirements.

xxxiv *ibid see.3.2.28*

xxxv See page 52 http://www.nao.org.uk/publications/0506/restructuring_of_british_energ.aspx

xxxvi http://www.publications.parliament.uk/pa/cm200607/cmselect/cmpubacc/892/892.pdf

xxxvii http://www.greenpeace.org.uk/files/pdfs/nuclear/GPUKJustificationResponse.pdf