REACTOR DECOMMISSIONING STRATEGY: A NEW START FOR BNFL

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ABSTRACT

The key points of BNFL Magnox Electric's revised waste management and reactor decommissioning strategy for the reactor sites are:

- Reactors will be defuelled as soon as practicable after shutdown.
- Predominantly Caesium contaminated plant will be dismantled when it is no longer needed.
- Cobalt contaminated plant such as boilers will remain in position until the reactors are dismantled, but appropriate decontamination technology will be regularly reviewed.
- All buildings except the reactor buildings will be dismantled as soon as practicable after they are no longer needed.
- Operational ILW, except some activated components, will be retrieved and packaged during the Care and Maintenance preparation period. All wastes will be stored on site, and handled in the long term in accordance with Government policy.
- Reactor buildings and their residual contents will be placed in a passive safe storage Care and Maintenance condition in a manner appropriate for the site.
- Contaminated land will be managed to maintain public safety.
- The reactors will be finally dismantled in a sequenced programme with a start date and duration to be decided at the appropriate time in the light of circumstances prevalent at that time.
- Currently, the Company is considering a sequenced programme across all sites, notionally beginning around 100 years from station shutdown, leading to a range of deferral periods.
- For provisioning purposes, the Company has costed a strategy involving reactor dismantling deferrals ranging from 85 to about 105 years in order to demonstrate prudent provisioning to meet its liabilities. A risk provision to reflect the potential for shorter deferral periods is included in the cost estimates.
- The end point for reactor decommissioning is site clearance and delicensing, based on the assumption that a reasonably practicable interpretation of the "no danger" clause in the Nuclear Installations Act 1965 (as amended) can be developed.

In line with Government policy, and taking account of all relevant factors, this strategy will be subject to ongoing review and development and may be modified in the light of changed circumstances in the future.

BACKGROUND

BNFL owns 26 reactors in the UK, the earliest of which was commissioned in 1952. These are all of the first generation Magnox type: carbon dioxide cooled, graphite moderated and fuelled by natural uranium enclosed in magnesium alloy cans. Of the 26 reactors, eight are now finally shutdown and six are defuelled. The other 18 are all operational. A recent announcement by the Company established that the other units will all be closed by 2009: this has inevitably brought reactor decommissioning into even sharper focus in the UK.

The UK has fuel reprocessing facilities, but no disposal route for any of the activated materials associated with a reactor dismantling operation[1]. Magnox reactors are considerably larger than LWRs, typically having 22m diameter, 2000te carbon steel pressure vessels which contain 2000te of graphite and a further 1000te of other carbon steel components. Reactor dismantling is a complex on-site task, very different from the processes, which have been employed, for example, for the Trojan plant in the US.

BNFL is committed to an ongoing process to monitor and review the Company's decommissioning and waste management strategies. These reviews take account of:

- experience gained in implementing waste management and decommissioning programmes both in the UK and abroad,
- developments in technology,
- views of a wide range of Stakeholders including the UK Nuclear Installations Inspectorate (NII), Government Departments and the public.

The strategies have changed significantly over the past few years as a result of this ongoing review process.

UK Government Radioactive Waste Management Policy (Cm 2919, July 1995) requires all nuclear operators to draw up strategies for decommissioning their redundant plant. This Policy also requires the Health and Safety Executive[2] to review these strategies quinquennially[3] to ensure they remain soundly based as circumstances change. As part of this review it is usual for the UK licensees to produce a submission describing their waste and decommissioning strategy. It so happens that 2000 was a Quinquennial Review (QQR) year for Magnox Electric plc, the electricity generating subsidiary of BNFL. This paper, which aims to describe the Company's current waste management and decommissioning strategies for the Magnox reactor sites, is a summary of the Quinquennial Review submission, produced to assist the Regulator to fulfil its obligations under Government policy.

GUIDING PRINCIPLES

The following are among the principles used to provide guidance in developing strategies and plans for reactor decommissioning and waste management.

(a) The safety of the public and the workforce, together with the protection of the environment, are of paramount importance and will be considered ahead of all other factors.

(b) Strategies will maintain a flexible approach and avoid, where possible, the premature foreclosing of options.

(c) Radioactive wastes will not be unnecessarily created and, where they are created, the quantities for disposal will be minimised as far as is reasonably practicable.

(d) Decommissioning and waste management will be undertaken as soon as it is reasonably practicable to do so, taking account of all relevant factors[4], such that there is a systematic and progressive reduction in hazard.

(e) In particular, defuelling will commence as soon as reasonably practicable after the cessation of generation, so that the most active and potentially mobile radioactivity is removed on a relatively short timescale.[5]

(f) All radioactive materials remaining on the site following defuelling will be retained or placed in a passively safe state to minimise the need for maintenance, monitoring or other human intervention.

(g) Where any decommissioning or waste management work is to be deferred, appropriate records will be retained and maintained throughout the period.

(h) The sites will be managed to maintain a passively safe state, through deployment of appropriate suitably qualified and experienced resources, throughout any decommissioning deferral period.

(i) The sites will remain subject to nuclear site licences, and all the safety conditions and controls that this imposes, throughout any deferral period.

(j) The development of decommissioning and waste management strategies and plans will learn from experience.

(k) Decommissioning and waste management strategies will be developed to be cost effective and to minimise as far as is reasonably practicable the overall net present value costs.[6]

(l) The end point for decommissioning for the reactor sites is that they should eventually be de-licensed and made available for appropriate alternative use.

(m) A research and development programme will be maintained to ensure awareness of developments in technology.

(n) Solid waste arising from decommissioning sites will be packaged in a form, agreed in advance with UK Nirex Ltd[7], suitable for interim surface storage.

STRATEGY ASSUMPTIONS

The development of the Company's waste management and decommissioning strategies is based on the following set of assumptions:

- The end point for reactor site decommissioning is de-licensing, provided there is a reasonably practicable interpretation of the "no danger" clause in the Nuclear Installations Act, 1965, as amended (NIA65).[8]

- Strategies should reflect only currently available technologies.

- Strategies must optimise against all relevant factors as required by Government Policy.

- NII agrees there is an adequate safety case for deferment of reactor dismantling.

- The regulatory regime is unlikely to be static and safety case acceptance criteria will prudently be assumed to become even more stringent.

The validity and implications of these assumptions are subject to on-going assessment.

REACTOR SITE DECOMMISSIONING AND WASTE MANAGEMENT STRATEGY

To identify the preferred generic decommissioning and waste management strategy options, a systematic and transparent process has been applied to consider a comprehensive range of potential options against a wide range of relevant factors. The process is used to rank potential options in terms of their overall acceptability.

An important principle within the process is that safety and technical feasibility are considered first, followed by a range of other relevant factors including cost effectiveness.

Defuelling

The spent nuclear fuel held within the reactors and in the fuel cooling ponds at the time of shutdown is by far the most hazardous material on the site, comprising more than 99.9% of the total radioactivity. In order to meet the principle of systematic and progressive reduction in hazard, and therefore to increase the intrinsic safety of the site, the first and main task following shutdown is to defuel the reactors and cooling ponds, and to transfer all spent fuel off-site. Stocks of potentially hazardous materials, chemicals, gases and combustible materials that are no longer required (eg carbon dioxide, hydrogen, lubricating oils) will also be removed from the site. Work will also proceed to remove asbestos and other hazardous materials that may exist on the site, such as thermal insulation materials on pipework and plant.

Care and Maintenance Preparations

Prior to the period of care and maintenance, dismantling and preparatory work will be undertaken to remove both radioactive and non-radioactive plant and buildings. The specific details of what will or will not be dismantled in this period will be subject to a case-by-case assessment, and hence may vary from site to site. It is generically expected to include the dismantling, and the disposal of resulting wastes as appropriate, of all buildings except the reactor buildings.

For many of these plant and structures, such as radioactive effluent treatment plant and fuel cooling ponds, the dominant radionuclide is Caesium-137[9], which has a half-life of 30 years. In these particular plant and structures, the radioactivity is more mobile (because of the solubility of Caesium) and the integrity of the radioactivity containment may degrade more quickly with time. Although it would be feasible to retain these in a safe state and defer their dismantling the buildings are not, in general, so robustly constructed as the reactor buildings. Therefore, Caesium contaminated non-reactor buildings and plant will be dismantled during the Care and Maintenance Preparations period.

Some partial dismantling and de-planting may occur on and within the reactor buildings but the major plant items such as the reactors, the reactor biological shields, the main gas ducts, the boilers, and possibly some fuelling machinery, will not be dismantled. These will be stored for a potentially extended period prior to their eventual dismantling. The dominant radionuclide associated with plant and structures in the reactor buildings comes from Cobalt-60. This has a half-life of 5.3 years, much shorter than Caesium-137, which means substantial reductions in radiation dose rates occur over any deferral periods. Furthermore, the plant and structures in the reactor buildings are substantial[10], robust structures within which the radioactivity is either naturally immobile or fully contained in high integrity vessels. They can therefore readily be retained in a passively safe state, presenting minimal hazard to the public and workers, for an extended period following shutdown.

Appropriate work will be performed on and within the reactor buildings to put them into a passively safe and secure state for the period of quiescent Care and Maintenance that follows. This will be done on a timescale and in a manner most appropriate for each individual site. The buildings and their contents will be appropriately prepared to ensure the containment of radioactivity and to prevent inadvertent human intrusion. The reactor building structures and external cladding will be maintained, refurbished or replaced as necessary to ensure they remain weather-proof and to minimise any potential for water ingress. Any necessary equipment and samples will be installed to enable appropriate monitoring of conditions within the reactor buildings, to enable confirmation of the continuing safe status of the plant, structures and radioactivity containment.

All work undertaken in the Care and Maintenance Preparations period will be subject to safety assessments, as well as environmental impact assessment under Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999[11] and Article 37[12] of the Euratom Treaty, as appropriate.

Care and Maintenance

Following the Care and Maintenance Preparations period, reactor sites will remain in a quiescent Care and Maintenance state for a prolonged period, to allow the benefits associated with radioactive decay to be gained. During this period, no significant dismantling work will be carried out but the site will continue to be managed, monitored and maintained to ensure it is retained in a passively safe and secure state.

During the Care and Maintenance period, safety is assured and public exposure is prevented by the immobility of the radioactivity within the reactors. The greatest inventory of radioactivity is within activated solid materials[13], and is not readily available to be released to the environment. The remaining buildings will have been modified, as appropriate, to comply with the principles of passive safety. The majority of the radioactive material is in solid form and will be multiply contained within the typically 100mm thick steel pressure vessel, the 1.5m thick reinforced concrete shields and the reactor building weather envelope. The inspection, monitoring and maintenance regime will be based on the requirements of the safety case and relevant legislation.

The robust nature of the modified reactor buildings and storage facilities will ensure minimal need for human intervention during this period. Nonetheless regular visits will be made to the sites by trained and competent personnel to confirm the continuing security and safety of the sites and to perform any necessary maintenance and monitoring work. It is expected that these regular visits and inspections will be sufficient to monitor the site and that there will be no continuous human presence or supervision on the sites. However, it is intended that there will be appropriate security and condition monitoring installed on the sites, which will transmit data to a permanently manned off-site location, so as to enable appropriate and timely responses to be made to any unusual occurrences. The staff at this off-site location will form an experienced team to manage safety case production and maintenance, manage records and maintain learning from experience, in addition to deploying resources on-site as required.

Safety Assessment for the Care and Maintenance Period

A detailed safety assessment has been prepared for the Care and Maintenance period to give confidence in the Company's decommissioning strategy. The assessment has been produced specifically for Trawsfynydd in Wales. Key points include:

- A reactor inventory calculated from measured elemental concentrations and confirmed by extensive dose rate measurements and sampling inside the reactor bioshield.

- Comprehensive and systematic hazard identification, validated by three independent studies, which addressed over 400 potential hazards.

- Hazard analysis which included:

    - degradation of the plant and structure
    - fires
    - explosions
    - impacts
    - human intrusion

- Acceptance criteria assumed to be ten times lower[14] than currently used.

In overview the safety assessment demonstrates:

- Small residual radioactive inventory following defuelling with the vast majority locked into large section activated structures.

- Multiple containment of the more radioactive components.

- Integrity of the plant and structures by weatherproofing, ongoing monitoring, inspection and repair.

- Only standing water can credibly cause corrosion leading to a structural problem.

- Low risk to the public in the event of failure of the safety management system.

- The largest potential doses to the public are associated with and assessed as:

- Large commercial aircraft crash and fire[15]: <25mSv.

- Failure of the safety management system (including failure of NII to monitor and control compliance with the Site License Conditions): 1-3mSv.

- Deliberate human intrusion into the reactor buildings: <1mSv.

Law and the legal instruments that are available to the Regulator reinforce the continued assurance of safety. As with all other decommissioning periods, this period will also be subject to the conditions and controls associated with the relevant Nuclear Site Licence, including periodic review of safety cases.

Site Clearance

The final period of decommissioning involves the dismantling of the remaining structures, appropriate clearance of any residual radioactivity and de-licensing[16] of the site to make it available for re-use.

It is proposed that dismantling of the reactors be performed in a sequential programme, starting at one site and gaining experience before starting work on the next site. After dismantling reactors on several sites in this way, sites could be worked on in pairs, to reduce the length of the programme. The sequenced programme approach will allow the systematic build-up of suitable infrastructure and of dedicated and experienced resources. It is anticipated that the suitably qualified and experienced team maintained by the licensee to assure ongoing safety during the Care and Maintenance period will contribute to the larger dismantling teams, transferring experience and information as resources are built up.

The precise start date and duration of the dismantling programme will be decided at the appropriate time, in the light of prevailing circumstances, after review and consultation with stakeholders. In the meantime, the Company proposes to maintain a degree of flexibility over the deferral timescale to allow for uncertainties on such issues as changes in the regulatory regime and the availability of a deep waste repository. Currently, a sequenced programme across all sites is being considered, leading to a range of deferral periods notionally beginning around 100 years from station shutdown, subject to an adequate safety case being available. After periods of this order, the benefits from radioactive decay have largely been gained, such that worker doses will not significantly reduce further with time[17] and waste volumes and complexity of dismantling operations are minimised. For provisioning purposes, a strategy involving reactor dismantling deferrals ranging from 85 to about 105 years has been costed in order to demonstrate prudent provisioning to meet the Company's liabilities. A risk provision to reflect the potential for shorter deferral periods is included in the cost estimates.

Reactor Site Operational Intermediate Level Waste (ILW)

ILW is material with specific activity exceeding 12GBq/te $\beta\gamma$ or 4GBq/te α, but which is not heat generating. There is currently no disposal route for this waste in the UK. It is produced on the reactor sites during operations, and also during defuelling and the early part of the Care and Maintenance Preparations period. These waste streams are generally accumulated on the sites in their raw form within tanks and vaults. The management strategy for these wastes is to ensure passive safe storage as soon as possible after shutdown, to retrieve and encapsulate those not already in a passive safe state. Where operational ILW is to be encapsulated for disposal, packaging arrangements are agreed in advance with UK Nirex Ltd, confirming that the waste package should be acceptable for disposal.

There is an extensive ongoing development programme to ensure the wastes can be successfully encapsulated and that the waste package will be acceptable for long-term storage, and eventual disposal. All waste management work will be subject to appropriate safety cases being prepared and agreed.

Reactor Site Contaminated Ground

There is some radioactively contaminated ground on the reactor sites as a result of past spills and leaks. The extent and nature of contaminated ground varies between sites but the areas of contamination are largely known and the levels of radioactivity are generally low. Where it has not been appropriate to remove the contamination it has been managed and monitored *in situ* to ensure the safety of the public, workforce and environment. However, as sites move into the decommissioning phase, this approach is being reviewed to ensure continuing long-term safety.

Specific strategies and detailed plans for the individual sites are still being developed but the approach being taken to achieve this generally includes the following steps:

- Review of site records related to spills, leaks and contaminated ground management and monitoring.
- Review of existing hydro-geological information on the site.
- Detailed isotope dependent surface radioactivity measurements across the site.
- Borehole monitoring for radioactivity measurement and hydro-geological purposes.
- Review and development of appropriate technologies and options for ground contamination management and remediation.
- Identification of preferred options for management of contaminated ground.
- Development and maintenance of a land contamination safety case.

This work provides detailed information on the extent and nature of any contaminated ground, and the hydro-geological conditions, thus facilitating the development of strategies for the management of contaminated ground on the sites.

STRATEGY CHANGES

BNFL Magnox Electric's Waste and Decommissioning Strategy has changed over the past few years, reflecting the Company's experiences in managing its shutdown reactor sites and extensive discussions, debates and agreements with the NII. This section summarises the main changes.

- It had been assumed that only limited dismantling of radioactive plant and buildings would be undertaken in the period following defuelling. Other buildings, such as fuel cooling ponds and active effluent treatment plant as well as the reactor buildings, would be retained on site and not be dismantled for up to about 135 years following station shutdown. In the current strategy only dismantling of the reactor buildings will be deferred for a period to be decided in the light of prevalent circumstances, notionally around 100 years following station closure. This change in strategy will have a major impact on the number of buildings remaining on site and will remove all of the plant containing the longer half-life and more mobile radionuclide Caesium-137.

- Previous strategies assumed little work would be done on site to create the high integrity weather envelopes until about 30 years or so after station closure. In the current strategy the extent and timing of such work will be decided on a site-by-site basis.

- It was previously envisaged that operational ILW stored in raw form on the Magnox sites would be retrieved and packaged on a timescale concurrent with creating the weather envelope, when an ILW repository was expected to be available. In the current strategy most ILW will be retrieved as soon as practicable after station shutdown.

The primary aim, and outcome, of these strategy changes has been to reduce even more rapidly the minimal residual hazard on a defuelled decommissioned reactor site.

ALTERNATIVE OPTIONS

Although preferred options have been selected to develop the current strategies, other options are maintained should they be needed particularly for the management of operational ILW. The Company keeps an open mind in determining whether technological developments might enable improvements to be made to strategies and implementation plans. A continuing technical work programme is in place to investigate any promising technologies so that strategies can be reviewed and to ensure decisions are based on best information.

The Company is also committed to understanding stakeholder concerns, with work ongoing to discuss reactor decommissioning through a Stakeholder Dialogue process facilitated by the Environment Council.

CONCLUSIONS

The waste management and decommissioning strategies for the UK Magnox power stations have been reviewed and revised.

The current strategies:

- bring much more work forward into the period following station shutdown;

- allow flexibility in the timescale for dismantling the reactors so that account can be taken of changing circumstances;

- provision for dismantling the reactors starting 85 years from shutdown, in contrast with previous proposals to defer for up to 135 years.

- The principles guiding these changes include:

- keeping potential hazards to the public, workers and the environment to a minimum;

- reducing these residual hazards by waiting for radioactivity levels to fall naturally;
- whilst no ILW disposal facility is available, keeping waste on-site in buildings which were specially designed to prevent radioactive escaping;
- minimising the need for taxpayer money to pay for earlier reactor dismantling.

FOOTNOTES

1. Only waste with specific activity less than 12GBq/te $\beta\gamma$ or 4GBq/te α can currently be disposed in the UK. It is Government Policy that high specific activity material will eventually be disposed deep underground. At the present time no disposal site has been identified.
2. The Nuclear Installations Inspectorate is part of the Health and Safety Executive.
3. Quinquennially: every five years.
4. The requirement to take account of all reasonable factors is an inherent part of Government Policy, contained within Cm 2919.
5. Defuelling removes 99.97% of all the activity present on the site whilst the reactors were operating.
6. BNFL discounts its liabilities using a prudent discount rate of 2.5% per annum.
7. UK Nirex Ltd is the company set up by Government to provide a radioactive waste disposal route in the UK.
8. The Nuclear Installations Act allows a site license to be revoked only when "there is no danger from any ionising radiations from anything on the site". As yet there is no case law to interpret these words.
9. Cs-137 is the dominant isotope in Magnox fuel ponds (fuel pools) because the fuel is uranium metal unlike the ceramic fuel material used for LWRs. Any in-pond fuel failures therefore release soluble caesium and the pond becomes contaminated with this rather than Co-60, as would be the case for LWRs.
10. Magnox boilers (SGUs) typically weigh up to 1000te each. A Magnox site usually has 8 or 12 boiler units weighing in total some 10000te. These units are made of carbon steel and most of the tubes are finned; therefore they are not easily decontaminated.
11. EIA99 regulations require an environment impact assessment to be made for the decommissioning process, which has to be agreed by the NII before any work can start. The regulation requires the NII to consult widely and take account of all opinion before reaching a conclusion. It applies to all sites shut down before 19 November 1999. To date, no UK site has received clearance under this regulation.
12. Article 37 requires each European nation to demonstrate that its nuclear operations have negligible impact on any other EU nation. The Government, not the utility, submits the case.
13. Each Magnox reactor contains about 2000te of graphite and 5000te of carbon steel.
14. BNFL currently operates to a dose rate limit of 20mSv/a for its workforce. The decommissioning safety cases assume dose rate limits of 2mSv/a for the workforce.
15. It is not thermodynamically apparent that the fuel load of a fully laden military tanker would be sufficient to set the graphite moderator on fire. However, for the purposes of this assessment that assumption has been made.
16. As noted previously, the wording of the Nuclear Installations Act does not readily allow for delicensing. However, recent European legislation defines a Basic Safety Standard set at of the order of 10μSv/a, which could be used as an acceptance criterion in pathway analyses. This criterion is much lower than the 250μSv/a (25mrem/a) criterion used in the US.
17. Integrated worker dose rates inside a Magnox reactor pressure vessel (based on a defined engineering plan involving man access to set up and maintain dismantling equipment) fall to 2mSv/a after about 85 years from shutdown.