The Potential Benefits and Drawbacks of Deferring the Decommissioning and Dismantling of Nuclear Facilities.

D.G. Pomfret¹, R.S. Nash¹, P.B. Woollam²

¹BNFL, Waste Management & Decommissioning, Sellafield, Seascale, Cumbria, CA20 1PG, United Kingdom.
²BNFL, Reactor Decommissioning Unit, Berkeley Centre, Berkeley, Gloucester, GL13 9PB, United Kingdom.

INTRODUCTION

There is no doubt that Decommissioning and Dismantling (D&D) of redundant nuclear plants or sites at the end of operations is necessary. However, the timing of such work requires careful consideration and, in a world where political issues dominate, there may be a danger that safety and business drivers are ignored.

To develop the strategy for D&D, several factors have to be considered and addressed. No one factor should form the sole justification for the approach to be adopted. Safety in all its forms must be the primary consideration, but the strategy must take account of all relevant factors.

The over-riding principles should be:

- That D&D represents the systematic and progressive reduction of hazards ultimately leading to de-licensing of the site. The UK policy for this is stated in reference 1.
- The process of D&D should be undertaken as soon as reasonably possible, taking account of all relevant factors.
- Radioactive and Chemotoxic material remaining following cessation of operations should be managed in order to minimise the potential for harm to the public, workforce or the environment.
- Wastes produced during the decommissioning process must be managed to minimise the requirement for double handling, and be contained in a form suitable for ultimate disposal.

THE KEY ASSUMPTIONS

- The bulk inventory of a facility is removed during the operational phase whenever possible. For reactors, the de-fuelling process would remove 99.9% of the radioactivity.
- Post Operations Clean Out (POCO) is completed as soon as possible to remove any mobile radioactivity. This would be at an early stage of decommissioning.
- Natural radioactive decay leads to a progressive reduction in hazard; this should be taken into account when determining D&D strategies.
- A safety case can be made for the condition of the facility, and such safety cases are periodically reviewed throughout the lifetime of the facility.
- The safety cases are assessed against relevant deterministic and probabilistic safety and legislative criteria, and comply with national Government policies (current at the time these are prepared) to assure ongoing safety.
- If ongoing safety cannot be demonstrated, then appropriate remedial work to rectify the situation will be carried out. Ultimately, this could include the completion of D&D on an earlier time frame.
- Routes for the ultimate disposal of wastes will become available, and the waste streams can be made compatible with such routes. Plant should not be dismantled until waste disposal routes are available, unless there are overriding safety reasons to do so.
- Waste quantities will be minimised as far as reasonably possible, and the necessity to double handle waste packages will be avoided if possible.

THE DECOMMISSIONING STRATEGY DECISION PROCESS

The important elements associated with the early stages of decommissioning are presented in Figure 1. The transition from operations to decommissioning should include the removal of the bulk inventory and result in a significant decrease in hazard once this is complete. Further gains may be made once plant POCO is complete, and any residual potentially mobile activity has been removed. The overall strategy needs to be clear before commencement of the D&D process, this must ensure that the optimum safety solution is adopted.

The full safety of the plant must be addressed for the whole duration of the D&D process. Some essential factors must be considered to ensure safety. Time delays allow corrosion and leakage processes to increase, resulting in further difficulties for the decommissioning manager. There are benefits however, which can be gained through radioactive decay or dilution processes, these should not be ignored when defining the overall strategy.

The decision process can be divided into two stages; primary factors and secondary factors.
STAGE 1: PRIMARY FACTORS

These factors must be met in order to ensure safety. In this category four over-riding factors are considered. The failure of any factor would effectively prohibit any deferral options:

Structural Safety

The ability of the structure to meet the safety constraints to the end of any proposed programme of D&D is a fundamental strategy consideration. This means that any requirements for containment or shielding during the passive storage regime must not be compromised. This factor has to consider the safety aspects for both normal and fault conditions. Consideration must include the effects of all structures (old and new), but the “As low as reasonably practicable” (ALARP) approach may be applied to risk when judging old structures against modern standards. The potential for changes to the structure during the D&D operations must also be considered.

If structural inadequacies are identified, then remedial actions (e.g. erection of an overbuilding) should be considered. Where structural concerns remain, and further improvements are not possible, then early D&D may be the only option.

Environmental Safety

The impact of a facility on the environment cannot be ignored. Those plants which have (or potentially have) an adverse impact on the environment (e.g. uncontrolled leaks), must be addressed as soon as possible. It is imperative that releases to the environment, both radiological and non-radiological are prevented so far as is reasonably practicable. Normally the removal of the bulk inventory should minimise this concern to acceptable levels, but this may not always be the case.

In addition to the above, it is clear that all discharges to the environment must be managed within agreed authorisations. If the potential exists to fall outside such limits, then early D&D may be the only option.

In the UK, regulations require the provision of an Environmental Statement in support of nuclear reactor D&D projects, see Reference 2; this requirement is also defined in EEC legislation. This type of statement allows the D&D strategy, and its environmental impact to be declared publicly. An example of this is seen in Reference 3.

Radiological Safety

Two considerations apply regarding radiological safety:

○ The first is whether the dose rates after POCO has been completed, are at acceptably low levels to allow full decommissioning to proceed with minimal constraints. If this is the case, then no radiological benefit can be gained from fission product decay resulting from deferral.

○ The second is whether any radioactive daughter products will be generated which could result in greater difficulties than those associated with the parent isotope. Examples of this would be actinide decay chains such as 241Pu. The original isotope is primarily a beta emitter with a half-life of 12 years, whilst the daughter product 241Am is a gamma emitter (half-life 432 years). The soft radiation of the parent isotope is relatively easy to shield, but when daughter isotopes such as 241Am are produced, these may create significant problems from external dose.

Deferral may be an option where the time delay allows benefits to be gained through radioactive decay. If this is not the case then early D&D should be considered.

Conventional Safety

The ability of the plant infrastructure to survive to the end of its requirements in the D&D process must be considered. Generally the equipment in a plant can be maintained or replaced if necessary. Occasionally the safety of the facility may be compromised by corrosion etc. such that long term operation may become impractical.

An example would be the corrosion of access routes, which, in highly active areas or those with significant chemical problems, may prove very difficult to repair. These types of problem may significantly increase the complexity of the D&D task.

The effects of corrosion and the availability of services and downstream plants may restrict the options available and/or significantly increase the overall costs.
STAGE 2: SECONDARY FACTORS

The acceptability of Stage 1 will allow further consideration to be given to the D&D timescales. This further consideration should now use a balance of risk process to define the optimum time frames. The secondary factors listed below form part of the balance of risk process. These allow consideration to be given to the gains that could emerge by adopting the policy of deferred D&D. In this category seven factors are addressed:

Radioactive Decay

Radioactive materials exist either as a product of the process (e.g. reactor fuel) or as activated components due to neutron bombardment. Additionally some items become active as a result of being contaminated by contact with radioactive isotopes.

In general, the fuel and its cladding are not a key decommissioning issue, as this forms part of the process in the nuclear cycle. The effect of this fuel on its surroundings (e.g. by activation or contamination processes) may however, become significant problems for the decommissioning manager.

For reactors the main problem is gamma emitting radio-nuclides produced by activation of the construction materials of the reactor, especially the core, shielding and pressure vessel. In this context, the key isotopes produced are $^{60}$Co, $^{108}$Agm, $^{94}$Nb, with respective half-lives of 5.27y, 418y, and 20,000y. It is clear for the isotopes of both silver and niobium, that several thousands of years are required to benefit from radioactive decay and that other drivers would dominate the D&D strategy considerations. It is also clear that for the cobalt isotope, significant dose rate reductions can be achieved by deferral, but this does take 80-90 years to achieve useful reductions. Figure 2 shows the variation of dose rate with time for the most radioactive parts of a Magnox reactor, (this is mainly activated steelwork, with $^{60}$Co being the dominant radioactive isotope). This figure shows that significant dose rate reductions can be achieved (six orders of magnitude), but this levels off after a period of around 135 years.

A significant difference between Magnox reactors and PWR equivalents is the size of the activated components. A typical 200 MW Magnox reactor has a vessel diameter of around 20m and a total weight of around 5000t. By contrast, a 1,200 MW PWR has a vessel diameter of around 4.5m and a total weight of about 600t. The ability to move and dispose of the pressure vessel as a single item whilst possible for a PWR, is clearly not possible for a Magnox reactor. The strategy adopted for the different types of reactor may therefore vary in line with the physical constraints of the work.

For Magnox fuel storage ponds, the key issue is radioactivity either suspended or in solution in the pond liquor, or radioactive sludge. The dominant isotope is $^{137}$Cs with a half-life of 30.2y. The main problem to be tackled is contamination, and especially ingrafted contamination within the structural concrete (as most of these ponds in the UK are not lined). Normally removal of the surface layer can significantly reduce the radioactivity associated with the rest of the structure. Some benefit could be gained by deferral, but generally, this is small. Cleanup and treatment processes to address the contamination are preferable alternatives.

For Oxide fuel storage ponds (especially those lined with stainless steel), the issue is again gamma emitting radio-nuclides produced by activation of the construction materials. In these ponds, $^{60}$Co is typically of equal if not greater importance than $^{137}$Cs.

Looking at the above, it is clear that for the specific isotope $^{60}$Co, real benefit can be gained, simply by delaying the D&D. The benefits of deferral of D&D for $^{60}$Co is of double importance, both in terms of half-life regarding operator exposure, and because it is a higher energy gamma source. For other isotopes, a well planned and executed cleanup process at the early stages of D&D would prove more effective.

Inventory Conditioning

Inventory management is more generally an issue for chemical plants, especially when residual inventory remains at the end of the operations phase. Quite often, totally new processes have to be developed to recover these materials; therefore, the retrieval and clean-out stages often are the most demanding. At this stage, the condition of the inventory could be affected by two processes:

- **Dilution** of the specific activity may be possible for liquid inventories. This process allows removal of light particulates suspended in the liquor, and may reduce dissolved activity. To be able to dilute the specific activity of the liquors may significantly help with dose management, but it does demand a good treatment plant to minimise the impact on the environment. In some plants, the ability to introduce a layer of less active liquor above the main source terms could prove very advantageous. The ability to remove a significant part of the active inventory through dilution may simplify the overall D&D.


On its own, dilution does not provide significant gain, but it can prove effective as part of a dose management strategy. Reduction of the specific activity by dilution may be possible in some circumstances, but a full cost benefit analysis is required to ensure that genuine gains can be achieved. This is particularly true regarding volume and activity of waste produced and the impact on the environment.

- **Chemical reactions** (e.g. corrosion) may be on going processes in the inventory. The management of the waste stream into the right condition to suit downstream plants is an important consideration. In general, it is easier to handle either uncorroded or fully corroded material rather than partially corroded. The timing of the waste management strategy should take account of the potential effects of corrosion. If partially corroded material exists, then consideration could be given to delaying the retrieval and treatment processes to simplify the downstream impacts. This may be unadvisable if the corrosion reaction cannot be properly controlled, or difficulties are encountered in demonstrating safety.

The advantages of deferral to allow corrosion processes to take effect may be an option worthy of consideration, but difficulties in ensuring product quality may prove to be a handicap. The key disadvantage may relate to managing the risk at the parent plant. Many corrosion reactions such as Magnox/Water produce undesirable by-products (in this case Hydrogen is evolved giving a potential deflagration hazard, and heat which could adversely affect the containment structures).

**WASTE MANAGEMENT**

The important issue regarding wastes, is to ensure that the chosen option does not unnecessarily increase the volume produced. In the early years following operations, the dose rates at the plant may be high, and any wastes produced may be of a higher specific activity. To overcome the dose concerns, significant quantities of shielding may be required; this in turn inevitably becomes active waste by the end of the D&D process. The benefits of handling less active waste streams are inevitably lost if short-lived isotopes are not allowed sufficient time to decay away; consideration should be given to adopting long term storage strategies if these are appropriate.

The benefits of deferral include the potential that less waste is produced, and that some of the waste will be of a lower specific activity. Minimisation of waste produced has both environmental and financial benefits. Working with less active waste streams will give dose savings, could provide the most appropriate option in terms of “As Low As Reasonably Practicable” (ALARP) and “Best Practical Environmental Option” (BPEO), and again provide potential cost savings.

The potential disadvantages include a longer time at risk especially of producing secondary wastes (e.g. spillage resulting in contamination of the plant or to ground).

**STRATEGIC PLANNING BENEFITS**

This factor is important in the context of the full strategy up to and including ultimate disposal. If the final repository for waste is not available, then short-term options may be reliant on above ground storage. The lack of clear specifications for final disposal routes may result in unnecessarily restrictive specifications being applied to waste packages. It is clear that a real danger of ‘double handling’ exists, where uncertainty remains regarding the required waste package specifications. If a final repository route is not fully defined then, plants built to receive waste and convert this into suitable packages for long-term storage may be wrongly specified. At a future date, new facilities may become necessary to re-handle the waste packages, and these in turn will add to the total waste inventory when they need to be decommissioned.

There is a need for a clear, fully defined strategy up to and including ultimate disposal. This type of strategy must be able to accommodate the requirements of all the waste streams without foreclosing options too soon. There is also a need for agreement both nationally and internationally regarding the standards to be applied when developing the waste management strategy. It is unacceptable to both operators and paymasters to have to work in a climate of ever changing standards, especially when waste management strategies could extend over many decades.

The benefit of deferral in this case is that time can be allowed to prepare the strategy, and to build the final disposal repository before waste is packaged in an unsuitable form. The costs, in terms of both dose to operators and financial, could be significant if the wrong option is chosen.

The disadvantage could be the delay in converting waste into a stable package for long-term storage.
INFORMATION MANAGEMENT

The ability to ‘mothball’ a plant for a period prior to final D&D is reliant on the ability to retrieve knowledge, which may be lost with the passing of the original workforce. Extended periods of deferral will demand very good information archiving and retrieval systems, and detailed high quality information held by them. These systems must be maintained over the deferral period, and the technology must be retained to re-access this information. There will also be a need to educate operators in the future regarding the appropriate safeguards to be applied when completing the D&D activity.

In contrast, there could be an opportunity to employ new technology (which is currently non-existent) to address the legacy left by this generation. Future technologies may be able to deal with radioactive wastes without adding to the current problems. The ability to retain the appropriate records is an essential requirement to allow D&D to be completed at the end of any deferral period.

FINANCIAL PLANNING

All D&D liabilities are an integral part of the business, and the need to manage the finances to pay for this is clear. The most effective way to minimise these costs is to develop the optimum strategy that allows the costs of each activity to be controlled. It is clear that opportunities to re-use facilities, and to pass several waste streams through the same sentencing plant, allows scope for savings. Waste disposals will inevitably form a significant part of the overall costs, therefore minimisation of wastes produced is imperative; deferral will help with reducing these costs.

Liabilities management includes setting aside money, well in advance, to cover D&D costs. The longer the time that is available, then the greater is the opportunity to invest money and to discount costs, this results in lower cash flow demands. Conversely in many cases, the shorter the timeframe probably means lower overall costs (but with a higher component of cost having to come from the industry rather than investments). There may however be the potential for savings in the future if new technologies can be found which simplify the D&D process.

The process of discounting the costs of liabilities requires great care, in order to account for all of the potential costs and benefits. The discount rate is the difference between the growth of funds set aside, and the inflationary costs of carrying out the work and disposing of the wastes. It can reasonably be assumed that most factors can be predicted over a time frame of several decades, with the exception of new regulatory or political constraints.

In general (if money is set aside properly and invested effectively) the more time available before commencement of D&D, should mean a lower impact on industry costs. Deferral has potentially very significant financial benefits.

PUBLIC EXPECTATIONS

A number of political drivers exist which may influence the decision process when developing the D&D strategy. In some countries, such as Japan, land availability is scarce therefore the need to re-use land encourages early D&D. In other places, public opinion against nuclear power is resulting in the drive to close down and remove nuclear facilities at an early date. There is a need to manage public opinion and address their concerns and perceptions about the nuclear industry.

Public opinion and political decisions are more likely to influence D&D strategies than are technical and regulatory arguments. It is therefore imperative for the industry, world wide, to allay unfounded concerns. The nuclear D&D strategy must be seen to be the right approach, and must not be the cause of problems in the future.

Taking the time to plan, rather than rushing to meet some programmed deadline, must be the right way forward. Taking the time to bring on board the public and the politicians is also an important consideration. Deferral may well allow these issues to be properly managed.

SUMMARY

The potential benefits of deferral

The main benefits are:
• More time allows for better management of the risk (especially if the radiological inventory was minimised at plant closure).
• Extending the D&D programme allows dose reductions to take place, especially if short-lived isotopes are involved (i.e. half-lives up to a few years).
• More time allows for better optioneering and planning of the D&D processes.
• A longer time frame gives the opportunity to develop new or better technologies.
• With proper control, improved political strategies can be developed.
More time gives better opportunities for financial planning to take effect.
The concern of “Will there be enough money to fund D&D” can become “A little funding set aside early, and properly managed, can pay for D&D in the future”.

Savings in dose, impact on the environment, and money can be achieved through a well-managed deferred programme.

The potential drawbacks of deferral

An extended programme of D&D demands:
- The continued financial viability of the business owning the liability.
- The political will and the infrastructure to remain in place over a long period.
- Tied in to the above is the need to keep money available for a long time.
- Being able to retain and recover the relevant knowledge after a long period.
- Additionally the concerns regarding the security of the site and its inventory over a potentially long dormant period would need to be addressed.

The important considerations are whether the public perceptions, and regulatory and political climate would allow deferral even if the technical and safety justifications were made.

CONCLUSIONS

The costs of hasty D&D, without long term national and international planning, may outweigh the perceived benefits. There is a need to establish a regulatory framework that allows the development of the right approach for each type of facility. The industry needs to become more effective in addressing the concerns and requirements of all its stakeholders.

There are several steps towards developing the D&D strategy, and if safety is not compromised, then consideration should be given to all factors that affect this process. Part of the strategy decision process should be to consider whether short or long term deferral is a sensible option. The benefits in terms of safety, impact on the environment, and overall costs should not be overlooked.

REFERENCES

4. Interdisciplinary Science Reviews, 1998, Volume 23, No. 3. “How will we manage the waste from reactor decommissioning”.
Figure 1: Early stages in the Decommissioning and Dismantling Process

End of Normal Operations

Remove Bulk Inventory
  e.g. Reactor De-fuelling

Remove Mobile Radioactivity
  e.g. POCO or Washout

Review Primary Safety Factors:
  - Structural Integrity
  - Environmental Impact
  - Radiological Benefits / Costs
  - Conventional Safety Considerations

Adopt Appropriate D&D Timescale
Figure 2: Graph showing Dose rate vs. Time for a Magnox Reactor