SYSTEM APPROACH FOR THE MANAGEMENT OF RADIOACTIVE WASTE

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ABSTRACT

An integrated approach to Waste Management and Decommissioning, which takes account of the lifetime implications (safety, dose uptake, discharges and cost) is an important strategic process in forward planning. This type of approach is particularly relevant when making decisions concerning waste minimisation and segregation, packaging and surface storage of high and intermediate level waste in advance of the existence of disposal facilities. Such a systematic approach forms an integral part of a process which enables progress to be assessed and plans to be updated in response to changing demands upon business operations and can continually be applied to waste management policy and to optimise the detailed waste management plans.

1. Introduction

For almost 40 years British Nuclear Fuels Plc (BNFL) has been a leading force in the international nuclear industry providing an integrated nuclear fuel manufacturing and reprocessing service for power utilities. BNFL offers a range of services to the Nuclear Fuel Cycle from its five sites in the North West of England. These include reprocessing, waste treatment and disposal at Sellafield, electricity generation at Chapelcross and Calder Hall, fuel manufacture at Springfields, enrichment at Capenhurst and engineering design and central administration at Risley. The Company came into being in 1971 and prior to that date had been the Fuel Production arm of the United Kingdom Atomic Energy Authority. Some 14,000 people are employed by BNFL in the United Kingdom, with additional staff in offices in Japan, Korea, China, Germany, France and in the Company's USA subsidiary BNFL Inc. In addition the Company provides nuclear fuel transport services by a fleet of purpose built ships.

The BNFL policy for radioactive waste management is to minimise effluent discharges to the environment, to safely dispose of solid low level waste as it arises and to provide safe and cost effective methods for storing, treating and preparing for disposal of all other wastes.

UK practice, with its focus on reprocessing as the key irradiated fuel management strategy, has traditionally distinguished between waste treatment and waste disposal issues.

The distinction between treatment and disposal is perhaps clearer for UK utilities than in other countries, who do not have a domestic reprocessing option. In such instances the major focus is likely to be on the consideration of waste disposal rather than the additional consideration of process options. Nevertheless the Systems Approach can still provide major benefits as it is consistent with and links strategically to the assessment of other waste and irradiated fuel management options. Having a systematic approach to waste management issues enables such options as noted above to be readily assessed.

2. Definitions of Waste Categories

In the United Kingdom radioactive wastes are allocated into one of three categories:

(a) **High Level Waste (HLW)** or heat generating wastes are those in which the temperature may rise significantly as a result of their radioactivity. The design of storage or disposal facilities must therefore take this factor into account. In practice the HLW category is applied to the concentrated product from the primary separation stage of fuel reprocessing and to the immobilised glass product which results from the vitrification process to transform the concentrate into a form suitable for long term storage and ultimately disposal. UK Government Policy currently states that HLW will be stored for 50 years or more before disposal.

(b) Intermediate Level Waste (ILW) are those containing radioactivity above the levels set for low level waste, but which do not generate a significant amount of heat as a result of their radioactivity. ILW wastes are currently placed in surface stores. Investigation work is in hand to confirm the site suitability for a UK Deep Waste Repository, which will be operational in the early part of the next century.

(c) Low Level Waste (LLW) contain radioactive materials other than those acceptable for dustbin disposal (very low level), but not exceeding 4 Gbq/t (108 nCi/g) alpha or 12 Gbq/t (325 nCi/g) beta gamma. LLW is currently disposed of at BNFL's Drigg site near Sellafield.

It is recognised that many countries have differing waste classifications, and that organisations such as the IAEA have their own[1]. The physical characteristics of these wastes range from large redundant items of equipment, through fuel cladding debris to sludges and flocs produced from liquor treatment operations, with activity and dose rates covering a wide spectrum. Such variabilities do not affect the applicability of BNFL's systems approach to other contexts, once the implications of these definitions on the waste characterisation and inventory process have been identified.

3. Background to Waste Arisings in the UK

Many different waste types have been produced over the last 40 years from fuel reprocessing operations in UK. Reprocessing of irradiated nuclear fuel has been carried out at Sellafield since 1952, when reprocessing of fuel from the original UK air-cooled reactors began. In 1964 a second facility was commissioned to reprocess Magnox fuel from the UK Civil reactor programme. More than 35,000 tonnes of Magnox fuel have been reprocessed to date. The third generation reprocessing plant, the Thermal Oxide Reprocessing Plant (THORP) entered commercial operation in March 1994 and processes Oxide fuels from AGRs and LWRs. Contracts have been signed to cover the reprocessing of 7,000 tU in the first 10 years of operation and a significant amount of the available capacity in the second 10 years. During the commissioning period THORP operated very successfully and BNFL is confident that the plant will meet its future targets.

The reprocessing operations produce a range of radioactive wastes which will require treatment, storage and disposal. The treatment and disposal of these wastes has been and will continue to be dependent on both the physio-chemical nature of the waste and the concentration of the specific radionuclides present.

The reprocessing of fuel into the next century will generate additional ILW arisings and the successful management of these arisings, together with the retrieval and treatment of the stored ILW, is a major challenge facing BNFL. Recognising that the costs associated with managing such liabilities would be considerable a strategy review was initially carried out which identified future treatment requirements and integrated these with existing encapsulation and treatment capabilities in order to establish a comprehensive ILW management system and to optimise the site wide waste management and decommissioning operations over the next 30 to 40 years. The integrated routeing of the major waste streams is shown in Figure 1 for the Sellafield Site. Prior to the detailed examination of the waste streams it had been anticipated that the majority of arisings could be dealt with by a single major operational plant which comprised of conditioning processes for all waste streams. The development of the Integrated Waste Management Strategy highlighted that this solution was not only, technically complex, but did not consider the timescale for treatment, making the single plant solution not cost effective and operationally inefficient due to the periods when it would not be operating at full capacity as a result of the different timescales for waste retrieval and fresh waste arisings. The Systematic Approach allows the evaluation of different options to consider the timing of the treatment of different waste forms.

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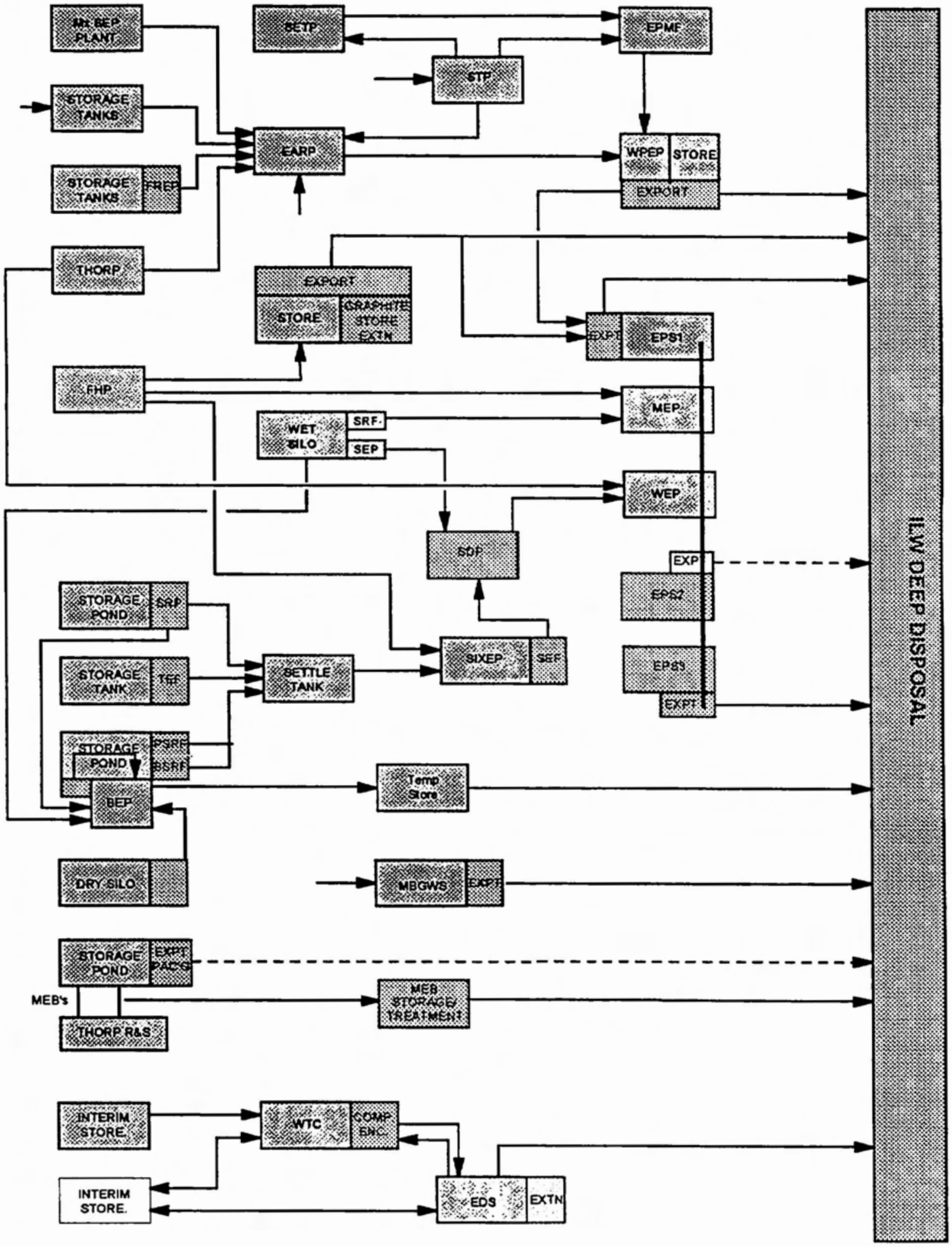
[1] New classifications were published in 1994 in IAEA Safety Guide 111-G-1.1 "Classification of radioactive waste"

Figure 1
Major Sellafield Waste Routeing



4. HLW Management

The highly active liquor arising from the primary separation stage of reprocessing is currently concentrated by evaporation and stored in a number of stainless steel tanks containing sufficient cooling coils to be able to remove the decay heat. There are approximately 1400 m^3 of such liquors in storage and reprocessing operations are likely to generate another 2300 m^3 by about the turn of the century. The Vitrification Plant which incorporates this liquor into glass began operations in 1990 and it is anticipated that this plant will reduce the backlog of liquor currently stored at such a rate that in 20 years time only limited volumes of highly active liquor will be held on site. In line with Government policy the vitrified product will be stored in a natural draught air-cooled store for at least 50 years, until its rate of heat generation reaches a level compatible with disposal in an appropriate repository.

5. LLW Management

BNFL owns and operates the principal UK solid low level waste disposal site at Drigg in West Cumbria, four miles south of Sellafield. The management strategy for LLW has been extensively developed in recent years, including increased emphasis of volume reduction and waste form specifications.

This development programme, to upgrade the site commenced in 1987 with the construction of a concrete vault to receive containerised waste. Prior to this date waste has been tumble tipped into trenches and progressively covered with earth and finally overlain with an impermeable clay 'cap'.

In parallel to these developments the waste form itself was reviewed with the conclusion that high force compaction offered the most benefits, ie by extending the operational life of the Drigg site, by reducing the waste volume prior to disposal, the compacted waste then being encapsulated by grout within a half height ISO freight container for disposal in the concrete vault, so providing a high integrity package which would insure against failure of the covering clay 'cap'.

To this end a High Force Compaction Plant, at Sellafield, and a Grouting Plant, at Drigg, have been constructed and commenced operations in 1994.

6. Scope of ILW Streams

Intermediate level waste (ILW) are safely stored at Sellafield in a range of different environments. These storage facilities take the form of 'wet' or 'dry' silos, tanks and ponds with a number of these structures dating from the commencement of reprocessing operations in the 1950's. Although a wide variety of ILW streams are generated during reprocessing operations, these can be grouped according to their origins or properties as follows.

Fuel Element Cladding Wastes: Comprising of essentially solid wastes such as leached cladding and end assembly fittings from oxide fuel (known as hulls) and Magnox fuel element debris (known as swarf). The Magnox wastes are currently stored in a number of pond and silo structures, containing waste in differing degrees of corrosion. For example a 'wet' silo typically contains corroded swarf, sludge and technical wastes in some compartments from earlier reprocessing operations and uncorroded swarf in others as a result of more recent operations. Storage pond facilities contain sludge in the pond itself and miscellaneous items of technical waste in skips within the pond.

Miscellaneous beta-gamma wastes (technical waste): any waste which is contaminated primarily with beta-gamma emitting isotopes, with very limited alpha emitting contamination, typically, contaminated maintenance scrap and fuel storage equipment.

Slurries: a variety of materials including ion-exchange materials, flocs from pond water and liquid effluent treatment, and sludges resulting from the corrosion of Magnox Swarf in water. The current storage of sludges has already been referred to above. Storage tanks currently provide containment for mixed aluminium and iron hydroxide flocs with a substantial alpha content.

Plutonium Contaminated Material (PCM): waste which is primarily contaminated with alpha emitting isotopes. This takes the form of drummed packages of small scale waste, larger items of equipment such as redundant gloveboxes in crates or used HEPA filters in stillages. PCM is currently stored in drummed form in Interim Storage facilities at Sellafield and Drigg. (Crated PCM will shortly be retrieved from Drigg and enclosures on the Sellafield site for transfer to Interim Stores).

As an indication of the scope of waste streams generated at Sellafield, there are more than 60 storage locations containing a total of approximately 40,000 m^3 of ILW at Sellafield. The reprocessing of Magnox and oxide fuel is estimated to add a further 15,000 m^3 of unconditioned ILW by about the turn of the century.

7. Intermediate Level Waste Management Strategy

Although storage of unconditioned wastes can be achieved within current safety requirements detailed technical assessments have shown that for the majority of ILW waste streams storage in an encapsulated form is both economically and radiologically preferable to any of the alternatives for the treatment of sludges, swarf and hulls. Therefore the decision was taken some years ago to carry out early treatment of wastes and investigation of alternative processes lead to cement encapsulation as the preferred waste form.

In formulating this approach a number of advantages associated with early encapsulation were identified, these were:

Safety: encapsulation increases the inherent safety of waste storage by reducing the mobility of activity. This is particularly true for slurries, sludges and solid waste stored under water. In the case of Magnox swarf encapsulation will also reduce the rate of degradation, compared to the past practice of storage under water which resulted in the corrosion of the swarf to produce a sludge.

Monitoring and Surveillance: encapsulated waste will require less monitoring and surveillance than raw waste.

Operational Exposure/Costs: overall operator dose uptake, will be significantly reduced if early encapsulation is adopted, largely because the number of handling operations is reduced. These reductions will also provide an overall cost benefit.

Decommissioning: the process of decommissioning an encapsulated product store containing drums which will be essentially free from external contamination will be relatively straightforward when compared to the decommissioning of raw waste store. This will reduce the decommissioning costs and the associated operator dose uptake.

It can be clearly seen that these factors, in combination, offer significant advantages for the encapsulation of wastes. These however must be weighed against the risk associated with early encapsulation.

The main risk associated with early encapsulation is that the encapsulated product will subsequently be found to require further treatment or packaging to meet the acceptance criteria of the Deep Waste Repository, when they are developed. If further treatment such as overpacking is required, then some of the advantages of early encapsulation will be negated. In developing the policy of early encapsulation of ILW, BNFL have identified the optimum matrix and investigated the influence of the matrix on the long term safety of a repository to minimise risk.

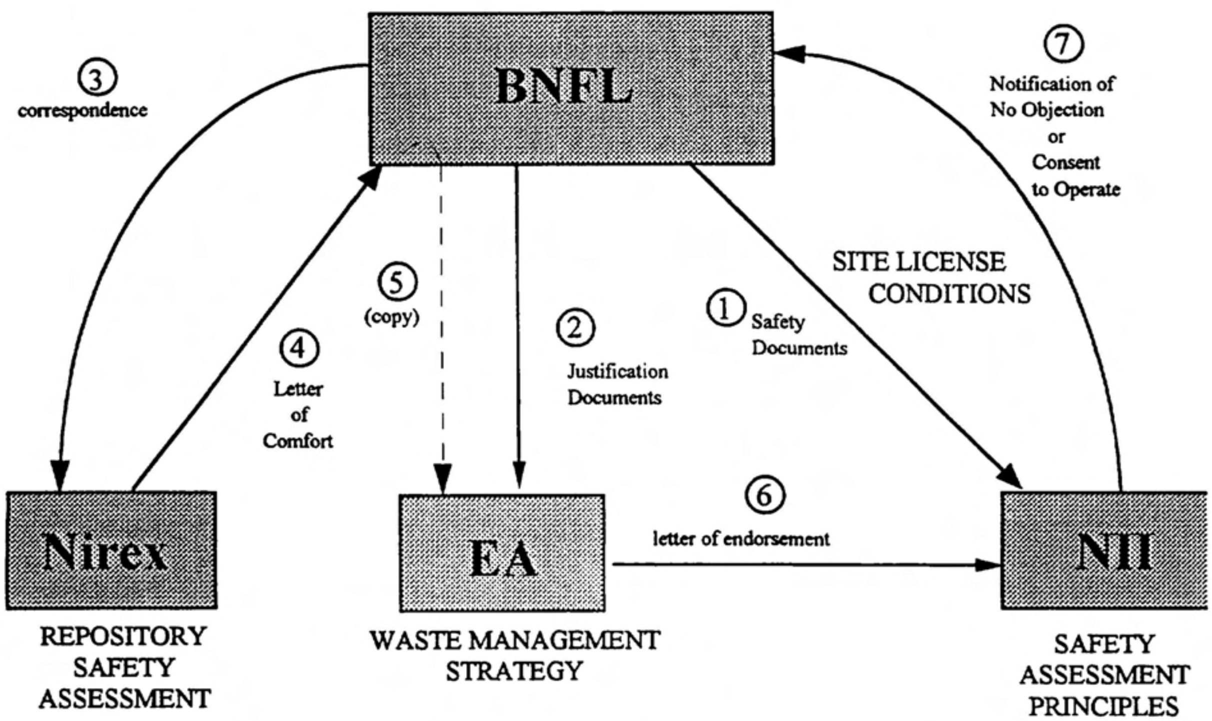
As part of the procedure for gaining statutory approval for the operation of a waste treatment plant the operator is required to justify the choice of waste treatment process to the Environment Agency, formerly Her Majesty's

Inspectorate of Pollution (HMIP), who are charged with ensuring the regulations set by the Department of the Environment are adhered to. The plant operator must demonstrate the acceptability of the process on a number of grounds including overall safety, suitability of the product for interim storage, transport and disposal, and the minimisation of the generation of secondary and decommissioning wastes. The Systems Approach clearly sets out these plans and how they fit into an overall strategy so aiding the Regulators understanding of the Operators intentions and the effects of such actions.

In order to demonstrate the suitability of the product for transport and disposal, the plant operator must, inter alia, secure the agreement of the UK body responsible for the development of a deep disposal facility for intermediate and low level waste, UK Nirex Ltd, that the product properties are compatible with the proposed transport and disposal facilities.

The interactions between BNFL, The Environmental Agency (EA), UK Nirex Ltd and the Nuclear Installations Inspectorate (NII) and the way the above requirements introduce to the Waste Management Process are illustrated in Figure 2.

Figure 2
Interactions for a Waste Management Process



BNFL has therefore developed its strategy to achieve the following objectives for the direct encapsulation of future arisings of ILW:

- No additional 'raw' waste storage facilities will be constructed
- Fresh waste will be conditioned for disposal as it arises
- Existing wastes will be retrieved for encapsulation on timescales determined by the condition of existing stores, encapsulation plant capacity and the availability of a disposal route

8. Implementation of Strategy

For those ILW streams that require encapsulation this takes place in three plants which are at Sellafield, in addition a fourth plant packages technical wastes which do not require encapsulation.

Magnox Encapsulation Plant (MEP): MEP has been built to encapsulate Magnox swarf and has been operational since 1990. The plant encapsulates not only fresh swarf, but also swarf retrieved from the silos in which it is currently stored.

Waste Encapsulation Plant (WEP): WEP treats wastes from THORP and other operations using a similar process to MEP for the encapsulation of hulls, whilst encapsulating THORP slurries using in-drum mixing. Subject to the provision of a suitable preparation plant WEP will also encapsulate other wastes including the sludge formed by the corrosion of Magnox swarf in water, currently stored in silos. WEP is now in operation.

Waste Packaging and Encapsulation Plant (WPEP): WPEP encapsulates the ferric floc produced by the Enhanced Actinide Removal Plant (EARP). This in turn receives slurries produced by mobilising the settled floc currently contained in storage tanks by agitation, but without dilution via the Floc Retrieval and Export Plant (FREP).

Waste Treatment Complex (WTC): WTC will process both crated and drummed PCM waste. The new facility will house a crate/filter breakdown and size reduction unit, the product of this unit being characterised waste in 200 litre drums. These drums will be combined with the backlog and current arisings feed of 200 litre drums and be supercompacted and grouted in 500 litre stainless steel drums, this being the package for final disposal.

Consistent with the overall objectives of applying a *continual* technical review to the overall waste management strategy as plants and processes are developed and integrated into the grand scheme, consideration of compaction for other ILW streams has also been examined. In this instance the process which has been considered involves the drying and high force compaction of sludges, arising from the corrosion of Magnox Swarf, retrieved from the 'older' wet silo storage building. The use of the compaction process will bring about a major reduction in the number of drums produced from the treatment plant when compared with the previously considered processes which relied upon the addition of fluids prior to encapsulation in WEP. Such a reduction in drummed arisings lead to several benefits.

- Less throughput and demand on existing encapsulation plants
- Greater flexibility in the operation of the encapsulation plants to deal with arisings from other plants
- The potential to shorten the operating life of the encapsulation plant so minimising the overall lifecycle costs

This compaction plant will also be able to receive resins from the Site Ion Exchange Plant which, in turn, will utilise some of the 'free' capacity of the encapsulation plant (WEP). In so doing providing an improvement in the operating efficiency which will benefit the overall lifetime costs of waste treatment.

This is an example of how the Systematic Approach can not only examine the technical needs for treatment of a waste stream, but also consider the timing, identify the optimum technical solution and timing for completion of the work to maintain operation by combined processes to benefit financial, managerial and operational requirements. It should also be noted that had the two processes been required on different timescales the more beneficial solution may have been to allow conditioning of the silo sludges to take place as quickly as possible and to design a smaller, possibly mobile encapsulation unit to treat the ion exchange resins at the appropriate time. In this way one would avoid the high operational costs of running a major plant beyond its period of maximum efficiency and therefore maximum benefit.

The Systems Approach helps to review such strategic decisions in good time to allow all options to be considered and a 'robust' forward plan which is able to accommodate changes and developments without major amendment formulated.

9. The Systems Approach

Once the objectives had been defined, a step by step approach leading to the required integrated waste management strategy was identified which would:

- Identify all radioactive wastes from known and anticipated operations
- Prepare technical plans to produce a robust long term waste management plan
- Identify the methods and costs of treating, storing, retrieving, transporting and disposing of the wastes
- Identify the liabilities arising from these costs both for BNFL and BNFL's customers
- Identifying a formal methodology for updating/reviewing the assessment annually

In order to achieve these requirements we have established a structured approach in four phases.

Phase 1. Identifying the waste and its location and characteristics, including volume, physical and chemical properties, the method of storage and the condition of the building in which it resides.

For future wastes, determining where the wastes will arise (in this case from reprocessing operations) and the quantity and potential types of fuel which might be reprocessed. This was followed by assessment of the potential waste volumes and characteristics expected from such a reprocessing programme.

Phase 2. Identifying waste groups comprising wastes with similar characteristics as noted under scope of ILW streams. Then reviewing the existing treatment routes to determine their ability to handle these wastes. Applicability being considered not only in terms of physical, chemical and radionuclide characteristics but also in terms of timescale constraints during which plants and waste are simultaneously available. The timing of when the different wastes should be treated is a major consideration and will allow optimisation of total lifetime costs. However the continued safety of historic waste storage must always be of paramount importance.

It is worthy of note that study of Technical waste streams during this phase concluded that the most practical option for this material was to pack and store ungrouted. No benefit could be seen for encapsulating the waste as the activity is not mobile and the levels of activity will have decayed substantially by the time deep disposal is available. These wastes are currently stored in 3.5 m^3 boxes within the Miscellaneous Beta Gamma Waste Store.

Phase 3. The third phase is an optioneering phase in which BNFL reviews all the options available for retrieving, handling and treating the wastes. This process involves contribution from operational staff, as well as the design team. Firstly by taking the global views of options, refining these to identify the plants necessary and progressively developing the detail of these facilities. Computer models are utilised to assist in this work, providing the models with functional and cost data, including current plant capacity, new plant capacity, facility annual operating costs, capital costs of new facilities etc. Simultaneously, BNFL defines the specific details of the overall process and develops specifications which address, at a minimum:

- Waste container sizes and availability
- Capability of the plants to handle the number and sizes of containers
- Logistics, including ability to transport and handle the wastes

The Waste Routeing Diagram (Figure 1) in schematic form shows the inter-relationship of the waste streams with the plants the waste is being recovered from, those which are carrying out treatment and conditioning, those providing storage and the final disposal route.

Phase 4. The final phase involves detailed development and design work for the new facilities and includes the feedback of operating experience in order to validate or modify existing assessments.

10. The International Context

The systems approach to radioactive waste management developed within BNFL can be applied without adjustment to the basic methodology, to a variety of international conditions.

For example, in the former Soviet Union and Central/Eastern Europe, there has been little opportunity for the co-ordination of waste management policy and strategy, leading to a situation characterised by a lack of effective waste characterisation and inventory and waste management. In such economies there is a need for cost-effective characterisation, inventory, retrieval, treatment and repackaging, and storage or ultimate disposal. Advice could be provided on implementing suitable QA and regulatory systems. Such assistance must not only be cost-effective, but must also meet the requirements of the donor agencies and their associated regulatory organisations.

In the European Economic Area, competition between reprocessing carried out in the United Kingdom and France, and direct disposal proposed in Sweden, Finland and Germany, as alternative irradiated fuel management strategies is likely to become more intense. BNFL's systems approach cannot only be utilised to ensure that the economics of reprocessing are optimised, but can also be extended to include spent fuel intended for either long term interim storage or for direct disposal as an additional waste form. This is of value not only to reprocessors but also to utilities seeking to keep their waste management options open.

Both the above benefits come into play in North America. In Canada, the disposal of spent fuel from Candu reactors (which currently is not reprocessed), can be modelled as any other fuel which is potentially destined for direct disposal.

In the United States, the situation is more complex. There is great potential for characterisation, retrieval and treatment business on Department of Energy sites, which have been operating since the Second World War and the opportunity for controlling overall lifetime costs by use of the Systems Approach.

In the civil nuclear programme, the ongoing moratorium on reprocessing and the political indecision on an alternative strategy is leading to intense at-reactor fuel storage problems. Suggestions are being made that limited reprocessing may be allowed to alleviate the problem. The paramount need however is for a framework which will allow for the development of a cost effective strategy, allowing for all irradiated fuel management options, including direct disposal, which meets political and regulatory sensitivities.

The Japanese nuclear industry is taking a two track approach. The first is a traditional one, of building a domestic reprocessing and waste management facility. The Japanese resource balance is such that the political commitment to nuclear power and to reprocessing is perhaps one of the strongest in the world, and evidence is such that considerations of business and financial strategy have suffered as a result. Subject to the necessary cultural adjustments, the existing systems approach should be readily replicable to the Japanese context, thus helping to instil a more balanced political and business strategy into the programme.

The other track is one being followed in many other countries. Considerable investment is being made into research projects directed at partitioning and transmutation as an alternative technology for actinide management. Once the process implications and associated costs have been identified, such radically different waste management philosophies should be capable of being readily incorporated into the existing systems framework as an alternative but equally valid option. (Similar comments apply to the proposed Russian approach of partitioning minor actinides for potential industrial use).

11. Conclusions

BNFL has completed six annual reviews of its Waste Management Strategy and is now progressing the detailed definition and optimisation, construction and operation of facilities required to meet this strategy and is confident that the overall achievement of its long term objectives will be met. The use of this approach has benefited the Company in that it is able to prioritise key issues in this area, and to be able to demonstrate to the Regulatory bodies that the matter of waste management is being addressed in a fully integrated manner.

Although developed for the UK context, the BNFL approach can be seen as being valid in a range of international situations, for customers with differing requirements yet demanding an integrated approach to their needs, balancing technical and business considerations. In addition this approach is consistent with and links strategically to the assessment of other waste and irradiated fuel management options. The management of irradiated fuel is to many utilities a commercial decision. Interim storage, in either wet or dry stores, is not a final solution, but can provide an interim measure enabling a delay in making a decision between recycling and direct disposal. BNFL believes recycling to be the most effective spent fuel management route and reprocessing and subsequent management processes are proven and internationally established techniques. Having a Systematic Approach to waste management issues enables such options as noted above to be readily assessed to achieve the optimum solution, not only in technical terms, but also in optimising and reducing overall lifetime costs.