ENCAPSULATION OF INTERMEDIATE LEVEL WASTES BY BNFL

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ABSTRACT

Intermediate level wastes (ILW) arise from fuel fabrication and reprocessing operations at the Sellafield site of British Nuclear Fuels plc (BNFL). At present the waste is stored in bulk without pretreatment. BNFL is constructing facilities to encapsulate and package such wastes in a cement-based matrix. The encapsulated wastes will be stored in an easily retrieved manner, and will be in a form suitable for public sector transport and eventual disposal. A wide variety of intermediate level waste streams have been identified as being suitable for encapsulation; mainly fuel cladding debris from Magnox and oxide fuel reprocessing and slurries, flocs, and ion exchange material from effluent treatment. The scope of the encapsulation facilities, the programme and cost for their provisioning, together with a description of the Magnox swarf encapsulation process are presented. The development programme in support of the project, the choice of container and the product quality assurance requirements are also discussed.

BACKGROUND

Reprocessing of irradiated nuclear fuel has been undertaken at Sellafield since 1952 when the first reprocessing plant was commissioned. A second facility was brought on-stream in 1964, primarily to reprocess the irradiated uranium metal resulting from the UK civil Magnox reactor programme. To date, in excess of 25,000 tonnes of Magnox fuel arising from both UK and overseas nuclear power stations have been processed in the plant and it is expected that it will continue to operate until around the turn of the century.

Additional facilities are being built at Sellafield to reprocess irradiated oxide fuels from advanced gas-cooled reactors (AGRs) and light water reators (LWRs). THORP (Thermal Oxide Reprocessing Plant) is due to start up in the early 1990s with a committed throughput of 6,000 tonnes, of which about two-thirds will come from overseas.

The generation of nuclear energy, like all complex industrial activities, results in the formation of waste materials. In discussing the treatment of wastes it is convenient to categorize the various types. The following classification is used in the UK:

1) High level heat generating wastes (HLW) which are those wastes in which the temperature may rise significantly as a result of their radioactivity. This factor has to be taken into account in designing storage or disposal facilities.

2) Low level wastes (LLW), which are wastes containing radioactive materials other than those acceptable for dustbin disposal (very low level), but not exceeding 4 G Bq/t alpha or 12 G Bq/t beta/gamma.

3) Intermediate level wastes (ILW) which are wastes with radioactivity exceeding the boundaries for low level waste, but which do not require heat generation to be taken into account in the design of storage or disposal facilities.

In practice the high level waste classification is applied to the concentrated waste product from the first extraction stage of a reprocessing plant. Thus to be consistent this classification is adopted by BNFL in grouping its waste arisings although BNFL's intermediate level wastes include certain streams in which heat generation cannot be ignored in store and repository design. However, the heat generation rates from these wastes are very much less than from HLW.

Reprocessing operations give rise to a variety of ILW streams. These may be summarized as:

1) Fuel element cladding mechanically removed from Magnox fuel elements prior to dissolution. (Magnox swarf).

2) Fuel element hulls and assembly fittings remaining after the dissolution of oxide fuel.

3) Slurries and flocs resulting directly from reprocessing operations and the treatment of effluents.

4) Technological waste, which refers to a wide variety of waste produced from plant operations and maintenance (typically filters and scrap engineering components).

5) Plutonium Contaminated Material (PCM) which is a generic term (similar to TRU waste) covering materials which range from soft shreddable items, such as PVC bags, gloves, through to large non-combustible items such as redundant glove boxes; all having varying degrees of plutonium contamination, but very little beta/gamma activity.

BNFL's strategy is to encapsulate existing waste and fresh arisings in a cement based matrix with the resulting solidified wastes being held on site in engineered retrievable stores until such time as a suitable disposal route is available.

The present encapsulation proposals are limited to categories 1 to 3; technological waste will be stored unencapsulated in a retrievable form pending the outcome of development work in support of its disposal in an encapsulated form. BNFL is negotiating with the Legislative Authorities with regard to the encapsulation of PCM in a separate facility.

The implementation of the above strategy requires the provision of an encapsulation facility with sufficient capacity to treat fresh waste as it arises and also retrieved waste from existing stores.

Existing storage capacity for Magnox swarf will be fully utilised in 1990 which determines the date by which encapsulation facilities must be available. Facilities for encapsulating ILW from THORP will be required in 1992. The timescale for the retrieval of existing stored (unconditioned) wastes for encapsulation will be determined by a number of factors including:

- the capacity available for encapsulation;
- the physical state of existing storage facilities;
- the availability of an appropriate disposal route.

PHASING OF ENCAPSULATION FACILITIES

The Medium Active Solid Waste Encapsulation Plant (MASWEP) project will be completed in several phases:

Phase I: (to be operational in 1990)	The first encapsulation plant (EP1) which will encapsulate Magnox swarf; the first product store (EPS1) and a Services Building (EPSB1).
Phase II: (to be operational in 1992)	The second encapsulation plant (EP2) which will encapsulate ILW from THORP and flocs from an effluent treatment plant; a second Services Building(EPSB2).
Phase III: (to be operational in 1997)	A Sludge Preparation Plant (SPP) which will prepare sludges etc for encapsulation in EP2.

Additional Storage Modules will be provided as required by the encapsulation programme.

CONTAINER SIZE

A fundamental requirement of an encapsulation strategy which is to proceed in advance of a suitable disposal site, is the use of an appropriate container. The purpose of a container is to provide secondary protection of the waste (after the matrix) to minimise the risk of any spread of active material during on-site handling and storage operations, and, subsequently, during off-site transport and disposal.

After a careful evaluation of container sizes ranging from 200 liters to 2,000 liters it was decided to standardize on a nominal 500 liter drum. This decision was based on a number of factors including:

1) Magnox swarf is already transferred for (unconditioned) storage in a flasked container of about 450 liter capacity; metering and dispensing of such a material poses significant problems;

2) the need to guarantee uniform mixing, within the container, of cement powders into a range of slurries/flocs/ion exchange materials;

3) the need to restrict wasteform centerline temperature increases resulting from activity content and the setting exotherm and thus to avoid impairing 'product' quality;

4) a reasonable shape and weight to allow reliable handling and transfer operations during encapsulation and afterwards (the overall weight of a filled 500 liter drum is up to about 1,500 kg);

5) acceptance by UK Nirex Ltd of such a container as a standard package;

6) overall cost including drum fabrication, storage, transport and disposal.

PLANT CAPACITIES

EP1 will be a single line plant designed to be capable of processing up to 6m^3/day of Magnox swarf and generating up to 13 product drums/day.

EP2 will be a two line plant designed to be capable of processing THORP hulls and slurries, flocs from liquid effluent treatment and other wastes in the future found to be compatible with the processes. It will also process Magnox swarf in the event of an EP1 outage. It will generate up to 30 product drums/day.

EP1 and EP2 will both generate encapsulated products contained in stainless steel drums of nominal capacity 500 liters.

The exact scope of SPP has still to be determined.

About 30,000m^3 of ILW (including 6,000m^3 of PCM) have arisen from operations at Sellafield over the last thirty years.

The total volume of wastes arising from reprocessing operations up to the end of the present Magnox program which will eventually be encapsulated in EP1 and EP2 amounts to about 40,000m^3. A total of about 90,000 drums of encapsulated product will be produced.

EPS1, the first product store module will have a storage capacity for 11,000 drums. It is estimated that if a permanent disposal route is not available by the end of the century, up to six storage modules could be required to store the encapsulated products generated by this date.

The Services Buildings will provide such facilities as changerooms, inactive services (steam, water, compressed air, electricity) to meet plant requirements, and will house such facilities as plant data recording, model rooms, offices, etc.

PROJECT COSTS

Phase I of the MASWEP project will cost about $300M (January 1986 Money Values).

The total project including Phases II and III and recovery of the wastes from the existing stores has a budget cost of about $1,000M (January 1986 Money Values).

DEVELOPMENT

Development work in support of the MASWEP project has been divided into four main categories:

Feed Characterization and Simulation
Process/Instrumentation Development
Product Evaluation
Safety Studies

The Feed Characterization and Simulation Programme provides detailed information on the physical, chemical and radiochemical characteristics of wastes to be encapsulated in MASWEP. based on the information obtained, a range of simulants has been defined for use in Process Development and Safety Studies.

Active samples of Magnox swarf were taken from the decanning plant over a 4 year period (1981-1985) and the subsequent characterization is now virtually complete. Additionally, inactive swarf samples were taken from the new Fuel handling Plant during commissioning. The range of characterization data includes:

- bulk swarf density;
- physical size distribution, both of the cladding material and the associated fuel, but with particular emphasis on the finer material;
- settling characteristics of fine material;
- radionuclide content of solids;
- radionuclide content of liquor (in contact with the swarf);
- definition of inactve simulants.

For other waste streams, similar characterisation data is being provided following sampling of historic stocks of wastes. Rheological properties are investigated for slurry and floc type wastes. However for oxide fuel reprocessing wastes, in the absence of full scale plant operations, data are generated from pilot plant operations and obtained from international programs.

The process development programme includes inactive investigation of all the process stages including storage to provide data for design and to confirm the performance of prototype equipment. The process development programme for Magnox swarf encapsulation commenced in mid 1985 and will be substantially complete in mid 1987.

Items studied in detail include:

- Drum Filling with Magnox swarf and Dewatering;
- Encapsulation Grout Preparation and Infilling;
- Curing at different temperatures;
- Drum Decontamination;
- Liquid Effluent Treatment;
- Product Drum Corrosion, Ventilation, Fabrication and Identification;
- Store Ventilation Including Product Cooling;
- Stack Sampling and Dispersion Characteristics.

The product evaluation programme was instigated in 1982 with joint BNFL/Department of Environment funding to investigate the properties of a variety of matrix/waste formulations and to enable the most suitable to be specified.

One of the main problems in development work in the nuclear field is that it is rarely possible to carry out full scale active work. Hence other experimental arrangements have to be made such that reliable extrapolation can be made. Thus the Product Evaluation programme was sub-divided into

1) small scale non-active;
2) full scale non-active;
3) small scale active.

With the large number of different types of wastes to be examined, it was decided that each waste form would be studied in four phases:

Phase 1

1) Defining the waste form.
2) Indication of special characteristics.
3) Identification of possible treatments and encapsulation matrices.
4) Waste characterisation.
5) Simulation of active waste.

Phase 2

1) Practical investigation of potential encapsulation matrices identified in Phase 1. Typically these have included:

inorganic cements;

polymers;

polymer modified cements.

2) Comparison of the most promising matrices. Limited product evaluation tests including physical stability, thermal stability, leach testing, mechanical strength and radiation stability are performed on small scale samples in order to identify the preferred formulation(s) for Phase 3 studies.

3) An indication of waste pre-treatments that may be required.

Phase 3

A systematic evaluation of the product properties of the selected process(es) from Phase 2 Studies with the reference formulation. The practical studies cover a wide range of product properties over the initial few months during which the matrix is hydrating. Five areas are evaluated:

- physical properties;
- physical/chemical stability;
- thermal properties;
- radiation stability;
- leaching behaviour.

Longer term assessments are carried out in those areas where the properties of the hydrated product may continue to change. The practical studies are supported by mathematical modelling thus enabling the long term behaviour during storage and disposal to be predicted with a high degree of confidence.

The detailed database of information generated on the preferred option will be used for its justification and the analysis of its suitability for storage, transport and disposal.

Phase 4

Multicomponent program covering the following aspects of the product:

- identification of the acceptable waste/cement formulation envelope and determination of the associated product properties;
- provision of data to support the product quality assurance regime;
- provision of additional generic data to support safety arguments;
- provision of additional information requested by authorising bodies or other interested parties.

Phase 2 studies have been carried out for the major ILW streams and a Blast Furnace Slag/Ordinary Portland Cement formulation has been selected as the preferred encapsulant for ILW. Important benefits associated with the use of cement when compared to alternative matrices include:

1) Cement is suitable for encapsulating wastes ranging in composition from dry solids to wet sludges.

2) Cement is composed of thermodynamically stable hydrated salts with well documented physical and chemical properties.

3) Cement has excellent thermal stability due to the low thermal conductivity and non-flammable nature of the material.

4) Because of its high pH and sorptive capacity cement has excellent properties for actinide retention, both in the short term and in the disposal environment. This benefit is considered to far outweigh cement's poorer, although satisfactory, performance in relation to the retention of shorter lived fission products.

Phase 3 studies for Magnox swarf have shown that BFS/OPC is an excellent encapsulating medium. The product properties have been shown to meet all the essential criteria required for the waste management phases from storage through to ultimate disposal. In addition the product properties under abnormal conditions for example resulting from a high temperature environment have confirmed the choice of inorganic cement as the best encapsulation matrix for all the ILW so far assessed.

Phase 4 studies for Magnox swarf have shown that the range of acceptable product formulations to be broad. Testing of the product properties at the extremes of the acceptable formulation envelope has shown little difference in the encapsulated waste characteristics when compared with the reference product formulation.

Development work in support of the safety case for Magnox swarf encapsulation commenced in early 1985 and is substantially complete. Topics studied in detail include:

The possibility of a Magnox swarf fire on exposure to air, its consequences, and methods of prevention including the use of inert gases.

Aerosol generation during processing and accident conditions, eg dropping a package.

The possibility of a hydrogen deflagration at the various process stations or during storage.

The possibility and consequences of dropping a product drum during on-site transport and store charging, store emptying and off site transport to a permanent disposal site.

The behaviour of the product in a major fire, as a result of accident during off-site transport.

The main safety case in support of Magnox swarf encapsulation has been submitted to the Nuclear Installations Inspectorate and the Department of Environment in several stages over the past two years. Permission to construct all the Building and Civil work has been received. Permission to install the plant is anticipated to be received in mid 1987.

PROCESS DESCRIPTION

For the encapsulation of Magnox swarf, Zircaloy/stainless steel hulls and other bulk solid wastes, an in-drum grouting process is employed, which involves the addition of a pre-mixed cement grout to a container of waste. The method is termed vibrogrouting. The BFS/OPC grout is sufficiently fluid to be easily pumped to the grouting station.

The in-drum mixing process is similar except that there is no dewatering stage; dry cement powder is added to the slurry/floc.

The Magnox Swarf encapsulation process to be employed in EP1 comprises the following stages:

Swarf Receipt:	The Magnox swarf is received in bottom opening transport flasks which each house water filled bins of Magnox swarf. On average one bin per 1100Kg(u) decanned is received. The contents of up to 13 flasks per day can be processed in EP1. Up to 8 flasks can be stored in EP1.
Drum Filling:	The flask is moved to the Tipping Station. The bin is lowered into the tipping chute and the contents tipped into a waiting encapsulation drum. One drum receives the entire contents of a swarf bin.
Dewatering/Grouting:	The drum is transported to the Dewatering/Grouting station. The drum ullage is inerted using Argon to prevent any possibility of fire following dewatering prior to encapsulation. The water is ejected from the drum and discharged for treatment. The cement grout, formulated from Blast Furnace Slag (BFS), Ordinary Portland Cement (OPC), and water, is added whilst the drum is vibrated to remove the argon.
24 Hour Curing:	Within a short period of time the drum is transported to the Curing Area where the grout is allowed to set for 24 hours to enable it to gain sufficient strength for subsequent movements.
Capping:	After the 24 hour cure period the drum is moved to the Capping Station where a self-levelling grout, formulated from Pulverised Fuel Ash, OPC and water, is added. The purpose of the cap is to immobilise the loose activity which may be present on the surface of the initial grout addition, and to minimise the ullage space in the top of the drum.
24 Hour Curing:	The drum is left for 24 hours to allow the cap to set to enable it to gain sufficient strength for subsequent movements.
Lidding:	The drum is transported to the Lidding Station where a flanged lid is bolted to the drum.
Decontamination:	The drum is transported to the Decontamination Station, where the drum is washed with high pressure water to remove loose surface contamination.
Monitoring:	The drum is transported to the Monitoring Station where the drum is remotely swabbed to establish the residual contamination levels.

When the drum has been monitored it is placed in a stillage capable of holding four drums. The stillage is then transported underground to the product store for storage in an array of 14 x 14 x 16 high.

In order to maintain a controlled temperature to minimise hydrogen evolution the store is forced cooled by a recycle air ventilation system. A proportion of the air is extracted, filtered and discharged from a 70m high stack together with aerial effluents from EP1.

All liquid effluents from the process are treated to remove solids and then piped to the central site treatment and disposal facilities.

ENCAPSULATED PRODUCT QUALITY ASSURANCE

The approach to this important aspect of plant design and operating philosophy has been constrained by the obvious difficulty in making physical checks on the finished product, ie the encapsulated waste package. There are two main areas of concern:

Activity Content

There is no existing equipment capable of providing, with any worthwhile accuracy, the nuclide inventory of drums of cemented wastes of the type described in this paper, although such measurements may be possible in the future.

Assessments of activity content of the encapsulated waste will therefore be based on measurements taken on the wastes before encapsulation. For example the measurements taken by the High Resolution Gamma Spectrometry (HRGS) equipment to assess fuel residue at the Magnox fuel decanning caves will be used to provide an accurate assessment of the activity associated with a given identified batch of Magnox swarf. This will be cross-referenced to the uniquely identified encapsulated product drum.

Product Quality

Similarly it has not been possible to identify other than a few very basic measurements (eg weighing) which could be practically made on the product. It is possible however to envisage how product quality can be assessed and assured based on various in-process measurements coupled with a quality control plan and an adequate data base derived from both small scale active and full scale inactive encapsulation.

BNFL is establishing the detailed QA requirements in consultation with its overseas customers, the Nuclear Installations Inspectorate and the UK Authorising Departments.