MONITORED RETRIEVABLE STORAGE AT SELLAFIELD

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ABSTRACT

This paper describes the Monitored retrievable storage facilities constructed by BNFL at its Sellafield site.The paper first describes the different waste streams handled by BNFL and the overall routing of these waste streams.The criteria which affect store design are discussed.The paper then goes on to describe each store together with the waste characteristics which have shaped the design.Stores ranging from highly active vitrified waste stores and intermediate level waste stores to drum stores for plutonium contaminated material are described.

INTRODUCTION

Storage of nuclear waste is one of the most interesting challenges facing the nuclear industry. This is not necessarily because it involves the solving of any great technical problems, though this can be the case with some waste types. It is because store design involves the engineer in the fundamental issues of the profession, that is the necessity to produce a cost effective product through a thorough understanding of the product requirements and of the marketplace. As a company deeply involved with the design, construction and operation of all types of nuclear plant BNFL is in a unique position to understand both the marketplace and the product requirements. This paper will describe some of the stores which BNFL has constructed to meet these requirements. However before describing these stores the paper will first look at the nuclear industry in the United Kingdom to give a background to stores development.

THE NUCLEAR INDUSTRY IN THE UNITED KINGDOM

The nuclear electricity generating industry in the United Kingdom is one of the oldest in the world. The world's first commercial Nuclear power station "Calder Hall" was opened in 1956 in the north west of England at a site now known as Sellafield. Calder Hall used non-enriched Uranium metal as fuel and this basic design of fuel was used for the first phase of nuclear power stations in the UK. These power stations are known as the Magnox reactors, named after the magnesium alloy used to clad the uranium fuel rod. A total of 26 reactors of this type were built at various sites around the country and have operated successfully over a period of over 25 years.

While the Magnox power stations were operating successfully Britain was developing a new generation of more efficient nuclear reactors. These new reactors were developed from the Magnox reactors but use enriched uranium dioxide fuel. This takes advantage of developments not just in reactor design but also in fuel enrichment technology. These reactors are known as the Advanced Gas Cooled reactors. There are 14 reactors of this type now successfully operating in the UK.

The widespread adoption of the Pressurized Water Reactor have demonstrated the reliability and cost effectiveness of this type of reactor. The UK has now commenced a program of reactor construction based on the PWR. This decision has been further influenced by the wide base of experience now available in the use of this technology. There is just one PWR under construction in Britain, however with the opportunities created by the privatization of the electricity supply industry BNFL is itself investigating the feasibility of constructing and operating reactors of this type.

THE ROLE OF BRITISH NUCLEAR FUELS

British Nuclear Fuels provides a total nuclear fuel service from fuel production, enrichment and fabrication to spent fuel reprocessing, nuclear waste storage. This service is provided to both the United Kingdom electricity generating industry and to overseas customers. It's reprocessing operations are based at Sellafield. BNFL also operates commercial reactors of the MAGNOX type at their Calder Hall and Chapel Cross sites.

Reprocessing of any spent nuclear fuel gives rise to various types of intermediate and high level wastes. Due to the different reactor and fuel types used in the UK there are several more waste streams to be handled than would be the case in an industry based on a single reactor type. Until recently at Sellafield all of these waste streams have been handled by the safe but temporary method of storing them in tanks or silos. Now, with the continued expansion of operations at the site and the filling of the original tanks and silos BNFL has adopted a policy of converting all wastes to a solid form suitable for final underground disposal.

As part of the policy of solidification BNFL has designed and constructed a series of dry stores for the interim storage of this waste. The wastes will be held in the stores until a final repository is available. Each storage facility has been specifically designed to meet the requirements of individual waste types or groups of similar waste types. The stores operate within stringent safety requirements and have been designed to allow full retrieval of the waste under a wide variety of accident and extreme environmental conditions. The capacity of each of the stores has been selected to hold all of their respective waste product arising until the repository is available. Before going on to describe the range of stores BNFL has constructed it is necessary to briefly describe the waste streams and their individual storage requirements.

Spent nuclear fuel arrives at Sellafield from the customers' reactors by rail. It is unloaded and temporarily stored underwater in ponds awaiting reprocessing. The fuel falls into three distinct categories, Magnox, AGR and LWR. First the fuel from the Magnox reactors is decanned removing the magnesium alloy casing. The magnox swarf, as it is known is taken by shielded flask to another plant for encapsulation and then for interim storage in the Encapsulated Product Store.

Secondly, fuel from the Advanced Gas Cooled Reactors is dismantled by first removing the outer graphite sleeve, which is crushed and drummed without encapsulation and taken to the Graphite Store. The fuel pins are then removed from the assembly leaving the supporting grids tubes and braces which are drummed without encapsulation and stored in the Stainless Steel Store.

Thirdly fuel from the pressurized water and boiling water reactors together with the fuel pins from the advanced gas cooled reactors is cut into small pieces to allow the uranium oxide fuel to be dissolved. The zirconium or stainless steel residue is taken by shielded flask to an encapsulation plant and then for interim storage in the Encapsulated Product Store. After chemical reprocessing of the dissolved fuel, highly active fission product wastes are at first stored in liquid form before being piped to the Windscale Vitrification Plant for solidification in a glass matrix followed by interim storage in the Vitrified Product Store.

Low activity liquid effluents generated at various stages during reprocessing are treated prior to discharge to sea. One of these treatment plants removes actinides by precipitation thereby generating a solid waste floc. This floc is encapsulated and stored in the Waste Packaging and Encapsulation Plant Store. Miscellaneous intermediate level solid waste from all operating plants at Sellafield which are too active to be disposed of by low level land fill operations are sorted and packaged for storage in the Miscellaneous Beta Gamma Waste Store.

Items of solid waste which have become contaminated with plutonium or other alpha emitting materials are taken for packaging and storage in the Engineered Drum Store.

All other materials which have been used within the active plants at Sellafield but which are not deemed active enough to be stored in either the miscellaneous beta gamma waste store or the engineered drum store are routinely taken for low level disposal in specially engineered trenches operated by BNFL.

STORAGE DESIGN CRITERIA

The stores mentioned above vary considerably in detail design, however, with the exception of the low level store they all contain significant quantities of radioactive material and consequently have much in common.

Two basic requirements of any store are to maintain the stored product in a safe and stable condition and to operate within required safety standards. These basic requirements must be met in a store design which is commercially attractive to the operating company. In order to fulfil this task it is of paramount importance to understand the storage characteristics and physical behavior of the product to be stored. As an operating company BNFL are in a unique position to understand these requirements and therefore to optimize the design of a store to suit the waste requirements. Some of the more important product characteristics are:-

- Waste package surface Dose rate
- Waste package surface contamination
- Heat output
- Maximum allowable product temperature
- Gaseous emissions
- Package strength
- Activity content

These parameters vary greatly from one waste type to another. For instance, highly active vitrified waste has a surface dose rate of up to 4500 Gy/hour and a heat output of 2.5kW per container, whereas encapsulated waste from liquid effluent treatment plants typically has a surface dose rate of only 0.1 Gy/hour and zero heat rating. Clearly these two stores will have greatly differing storage criteria which will considerably effect the design and hence the cost of the store.

ENCAPSULATED PRODUCT STORE

Two encapsulation plants are currently being constructed and commissioned at Sellafield. These plants are designed to receive magnox, stainless steel and zirconium fuel cladding from which the spent fuel has been dissolved prior to reprocessing and to encapsulate it in a cement matrix. The two streams, magnox and zirconium or stainless steel cladding are processed in separate plants due to the differing nature of the waste. The wastes are however encapsulated into identical Nirex standard 500 litre drums and will be stored in the same store, the Encapsulated product store.

The principle characteristic of the waste which has dictated the store design is the corrosion of the encapsulated Magnox waste. Magnox fuel cladding is an alloy of of magnesium which after encapsulation can corrode within the cement matrix releasing small quantities of hydrogen. To keep the hydrogen concentrations within controlled limits corrosion is minimized by maintaining the temperature of the cement matrix below 35°C. This criterion has dictated the principle design requirement of the store ventilation system which is to use chilled air for the cooling of the waste drums. The use of chilled air has in turn dictated the use of stainless steel throughout the internal store structure in order to ensure a design life of fifty years.

The Encapsulated Product Store has been designed for a capacity of 12544 drums stored in stillage each of 4 drums. The stillage are stacked 16 high in a 14 by 14 matrix formed by a stainless steel stillage support structure. The store is ventilated to remove fission product decay heat and the hydrogen generated by corrosion of the Magnox fuel cladding and by radiolytic action on the concrete matrix. The cooling air is filtered prior to discharge from a high level stack.

The store has been constructed to be seismic resistant to a one in ten thousand year earthquake and the structure will allow full retrieval of stillage after such an earthquake.

GRAPHITE STORE

The Graphite store receives drums from the Advanced Gas Cooled Reactor fuel dismantling facility. The graphite being the moderator which has been removed from the fuel assembly prior to dismantling. The graphite is loaded into drums without encapsulation.

The principle characteristic of the drums of graphite is its surface dose rate. The dose is sufficiently low to enable an open construction of store provided that adequate precautions are taken to protect operating personnel during loading operations. The drums are not heat generating and do not release hydrogen or other gasses.

Experience in the design of pond handling equipment enabled BNFL to recognize the opportunity to use a similar type of equipment in the handling of this relatively low level intermediate level waste. The AGR graphite store has proved extremely successful. First in minimizing operator dose uptake despite being of open construction. Secondly it accrues all the benefits of low construction costs associated with an open store.

The store has a capacity of 4880 drums which are stacked in a freestanding manner in one of the 16 storage bays. The drums are stacked 5 high within a bay. Each bay is capped by a series of removable roof slabs which are handled by the drum placement crane. The store is not ventilated.

The store is not designed to be earthquake resistant, the drums are allowed to topple over as a result of the earthquake, and recovery equipment is provided to retrieve the drums from such a condition. This philosophy has been acceptable due to the low activity content of the store together with the inherently stable non heat generating nature of the waste.

The store is equipped with closed circuit television equipment to enable the inspection of any part of the store or any stack of drums. For more detailed inspection drums may be removed and returned to the receipt cell which is equipped with CCTV, windows, manipulators, turntables etc.

The store is not instrumented in any way other than the normal environmental monitoring due to the relatively benign nature of the waste.

STAINLESS STEEL STORE

The Stainless Steel store receives drums from the Advanced Gas Cooled Reactor fuel dismantling facility. The stainless steel consists of the grids, tubes and braces which are used to support the fuel pins in the fuel assembly.

The drums are much more radioactive than the graphite drums. They generate small quantities of heat but do not release hydrogen or other gasses. The major challenge in the design and construction of this store was in the economical construction of a relatively small storage vault. The stainless steel waste is not a large heat emitter and recognition of this has allowed BNFL to construct the store of simple and cheap reinforced concrete sections.

The store has a capacity of 680 drums which are stacked five high inside separate precast concrete tubes arranged in a hexagonal array set in a concrete monolith. Each tube is capped by a removable concrete roof plug. The plugs and drums are handled by a flask and gamma gate system which can be moved from one storage tube to another by means of an electric overhead travelling crane. The store is ventilated by forced convection and the air is filtered prior to discharge via an outlet stack.

The drum handling machinery is provided with CCTV equipment to enable close inspection of the drums, though like the Graphite store, drums can be removed for a more thorough inspection if necessary. Whilst temperature monitoring of each storage channel is not necessary a number of thermocouples have been fitted which monitor the overall temperature of the storage matrix.

WASTE PACKAGING AND ENCAPSULATION PLANT STORE

The Waste packaging and encapsulation plant store will store drums of encapsulated ferric oxide floc generated by the Enhanced actinide removal plant and maintenance waste solids from the Low active effluent treatment plants.

The principle characteristic of the waste arising from the EARP facility is its relatively low radiation levels, which has enabled the store to be built without formally meeting seismic requirements. Seismic design and construction without doubt contributes greatly to the cost of any plant or storage facility, the recognition that seismic design was not necessary was an important achievement. The waste generates small quantities of hydrogen.

The WPEP store is in many ways a development of the AGR stainless steel store although of much larger capacity. It uses a precast cast concrete drum support matrix which can be regarded as a development of the concrete tubes used in the AGR store. One interesting feature of the store is that bulk concrete shielding has been reduced by placing the more active drums in the center of the store surrounded by drums of lower activity at the periphery of the store.

The drums are stacked 15 high in the spaces formed by a matrix of concrete columns. Each channel is capped by a concrete plug. The plugs and the drums are handled using a shielded "bell" which is moved around the charge floor by an electric overhead travelling crane. The storage vault is ventilated by using conventional fans and filters.

Drums can be retrieved for inspection at any time using the shielding bell. Other than the normal environmental monitoring no other form of inspection or monitoring is required.

MISCELLANEOUS BETA/GAMMA WASTE STORE

The Miscellaneous Beta/Gamma Waste Store is designed to accept waste from the adjacent waste packaging plant. The waste consists of miscellaneous items of process plant and can take many forms, from broken pumps or valves to used filters. The waste is packaged in concrete lined carbon steel boxes each having a capacity of 3.5 cubic meters. The waste releases small quantities of hydrogen generated by the radiolysis of any organic materials within the box.

The storage vault has a capacity of 1734 boxes arranged in a series of aisles. The boxes are moved along the aisles by way of a ground level rail mounted bogie system and are stacked three high without any form of external support. Each aisle is long enough to accommodate 34 stacks of boxes. There are 18 aisles in the vault although 1 of these is left empty to allow box retrieval.

It has been shown during shake table tests that a stack of 3 boxes will not topple or move appreciably out of position during the Design Base Earthquake. The storage vault is ventilated in order to remove hydrogen. The store environment is monitored for excessive humidity and dehumidifiers will operate at preset levels in order to minimize corrosion of the carbon steel boxes. The storage vault can be viewed by CCTV inserted into the vault through any one of a number of purposely provided penetrations through the concrete shielding.

Boxes can be retrieved at any time for inspection in the adjacent waste packaging plant. They can if necessary be opened and the contents removed for more detailed inspection or retreatment.

ENGINEERED DRUM STORE

The engineered drum store is currently under construction at Sellafield, it stores materials arising from reprocessing operations which have become contaminated with plutonium or other alpha emitting materials. The waste does not have high surface dose rates but containment must be of a high order due to its plutonium content. The waste does not generate heat or hydrogen.

Waste packaged in 200, 400, or 500 litre drums can be stored. The store design provides for rapid inspection and emergency retrieval or emplacement of any drum within the store in 15 minutes. It is intended that up to 1% of the drums within the store will be inspected and assayed annually. Visual monitoring of all drums will be carried out on a routine basis by means of a remotely controlled tractor unit incorporating a closed circuit television system.

Drums are handled by means of a manually driven shielded fork lift truck. Any drum suspected of deterioration will be retrieved by the truck and transferred to a repackaging facility.

Vitrified Product Store

The vitrified product store stores vitrified highly active waste arising from reprocessing operations. The waste is stored in specially designed 150 litre stainless steel containers. It generates large amounts of fission product heat and has a *very high surface* dose rate. The waste does not release hydrogen.

The store is ventilated by natural convection to remove fission product heat. Cooling air passes directly through the store and is not filtered prior to release to atmosphere.

The containers are stored in closed "thimble tubes" to maintain segregation between the cooling air and the containers thus allowing the use of a once through natural convection system without filtration. It has been constructed in a series of 4 identical vaults each containing 200 thimble tubes in a 10 by 20 array. Each thimble tube can contain up to 10 product containers giving a total vault capacity of 2000 containers. Each vault is equipped with its own inlet duct and exhaust stack and thus forms a self contained easily repeatable storage module.

Conditions within the store are continuously monitored by a surveillance computer connected to a comprehensive array of instrumentation. The surveillance system maintains records and trend data to demonstrate that the vitrified product has been stored in a manner consistent with the requirements to maintain good product quality.

The store has been designed to have a 50 year operational life. The selection of materials, methods of construction etc have therefore been most important. To demonstrate that design life is being achieved the store has been equipped with a corrosion monitoring system together with a closed circuit television system for remote viewing of all significant internal store features. The system is radiation tolerant and capable of operating in the elevated temperatures of the store environment.

The thermohydraulic performance of the store was carefully modelled before construction began in order to demonstrate the inherent safety of the design. This computer modelling has been backed up by use of a full scale test rig actually installed in one of the storage vaults in VPS. Very close agreement was found between the computer model and the temperatures measured in the test rig. In addition to the normal operation modelling great emphasis was placed on the performance of the store during and after total or partial loss of cooling accidents, including earthquakes and aircraft impacts.

FUTURE DEVELOPMENTS

The stores described above have been constructed and are operating successfully at the Sellafield site. Each store was originally designed to accommodate all the waste arising from reprocessing until the year 1995 at which time a final underground repository was expected to be available. However due to political reasons the repository is not now expected to be available until the year 2005. It will therefore be necessary for BNFL to construct further interim stores. As a result of the delayed repository availability BNFL are conducting a review of the various stores currently operating with the intention of rationalizing store design to just one or two designs capable of storing a wide variety of waste types. It is not expected that a single store design could provide cost effective storage for all waste streams, however it is quite feasible that one type of store could be used for intermediate wastes and another for high level wastes.

One type of store not mentioned above is a dry store for spent fuel. At present BNFL does not operate any dry fuel stores, using pond storage exclusively due to the safety and technical problems associated with the original MAGNOX fuel. However the long term storage of oxide fuel in a dry store environment is attractive and BNFL are currently investigating the modifications required to the Vitrified Product Store which would be necessary to adapt it to dry fuel storage. Preliminary work indicates that though there are essential differences in the physical dimensions between vitrified waste containers and spent fuel the VPS is eminently suitable for commercial dry fuel storage.

In conclusion BNFL's long standing experience in nuclear fuel reprocessing and in the handling of various waste streams has resulted in the construction of a whole range of monitored, retrievable dry stores. Each store is a cost effective solution to its particular interim storage problem. Changing circumstances, and in particular the delayed availability of a long term repository may result in the development of more universal store designs. It is certain however that as a commercially aware company BNFL will continue to use the most cost effective solution to the challenge of nuclear waste storage.