REPROCESSING AND WASTE MANAGEMENT IN THE UK

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ABSTRACT

This paper surveys progress in irradiated fuel reprocessing and waste management at the BNFL Sellafield Site. Magnox fuel reprocessing is reviewed and oxide fuel reprocessing, due to commence in the early 1990s is compared with existing practices. Both fuel types will be reprocessed, in parallel. The paper describes how Magnox fuel reprocessing will be sustained by recent additions of new plant and shows how waste management downstream of reprocessing, will be integrated across the Sellafield Site.

MAGNOX FUEL REPROCESSING

Present Magnox fuel reprocessing operations have evolved from concepts developed in the late 1940's and first brought into service in the early 1950's. The aim was to introduce simplicity and reliability. Fuel elements were transported and handled under water; light metal alloy cladding was removed mechanically under water; metal fuel was dissolved in nitric acid; uranium, plutonium and fission products were chemically separated in plant designed to obviate the need for maintenance. Solid wastes were retained in wet or dry silos as appropriate. Highly active liquid wastes were concentrated and stored in tanks (typically 150 m^3) provided with cooling and monitoring services. Intermediate level liquid wastes were stored to allow decay of short lived activity, principally ruthenium and zirconium/ niobium, before final treatment and discharge in combination with low active liquid wastes. The treatment process relied on adsorption of activity on a precipitated floc blanket, with discharge of the clarified liquor. Spent fuel storage pond liquid effluents were initially discharged without treatment apart from gravity separation of suspended solids. These process concepts served for reprocessing fuel for over a decade while throughput and fuel irradiation remained modest.

The second reprocessing plant retained these concepts: it was sized to accommodate Magnox fuel discharged from the first program of commercial nuclear power stations in the UK and was commissioned in 1964. The nominal design basis was 1500 t(U) per year at an irradiation of 3000 MWD/t(U) and a minimum of 90 days cooling. Over the past two decades the average irradiation has increased to about 5000 MWD/t(U). To date more than 25,000 t(U) has been handled through this plant and its predecessor.

Experience has shown how sensitive the central reprocessing operation is to the availability and performance of its peripheral facilities, even when the underlying concepts are simple and well understood after years of operation. Notwithstanding the difficulties inseparable from the operation of a large chemical plant complex, activity discharges from Sellafield to the environment (Fig. 1 and 2) have at all times been within authorized limits laid down by Regulatory Bodies, and the results of environmental monitoring studies undertaken by both BNFL and independent bodies, published annually, show that radiation dose uptake by critical population groups has remained well within internationally recommended limits.

Nevertheless the climate of opinion has moved steadily to apply increased pressure for greater plant reliability, lower activity discharges from the site as a whole and hence lower environmental impact to critical groups and the population in general, whilst at the same time improving the already high standards of workforce safety.

Against this background it has been necessary to consider how the Magnox fuel reprocessing operation may be safely sustained for the remainder of the Magnox power generation programme, now expected to last until the turn of the century following a detailed and favourable review of the technical and economic viability of the Magnox stations. In addition it has been necessary to consider how the Magnox reprocessing plants will interact with oxide fuel reprocessing when it commences in the early 1990s, particularly in respect of the management of wastes and effluents.

REINFORCEMENT TO SUSTAIN MAGNOX REPROCESSING

Figure 3 shows in block form the complex of fuel receipt, reprocessing and waste treatment plants now in operation. Three major facilities have recently been added at a capital cost of about $700M. Together with detailed changes in plant operation and the re-routing of some effluent streams within the site, these plants provide for increased reliability at the critical spent fuel handling and decanning stage, and greatly reduce activity discharges.

The Fuel Handling Plant (FHP) replaces the spent fuel storage pond and decanning bays commissioned in the early 1960's. Events which occurred during the mid 1970's left a backlog of corroded fuel. The handling and decanning of this fuel in elderly plant and equipment requiring excessive mechanical maintenance entailed undesirably high operator radiation uptake. Following these events it was decided that a new complex of fuel storage ponds and decanning plant

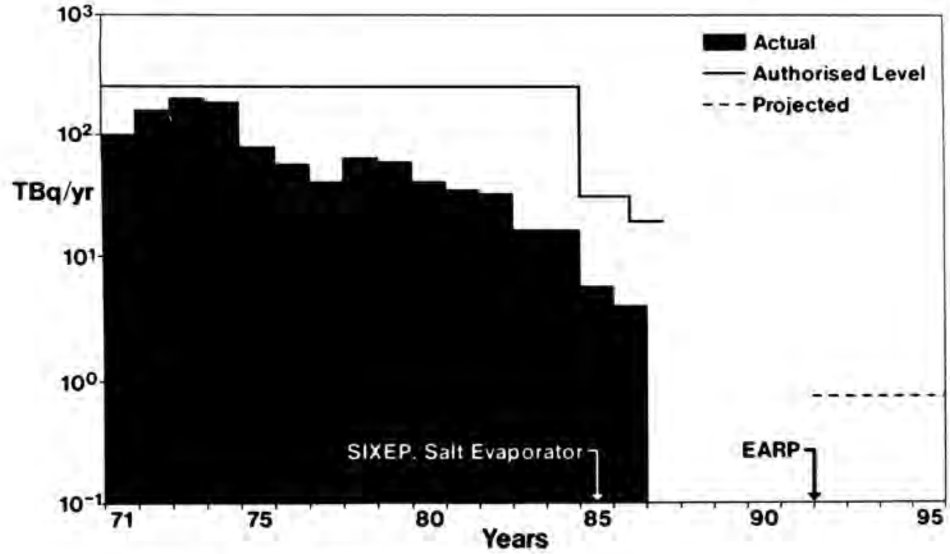

Fig. 1. Total Alpha Discharges.

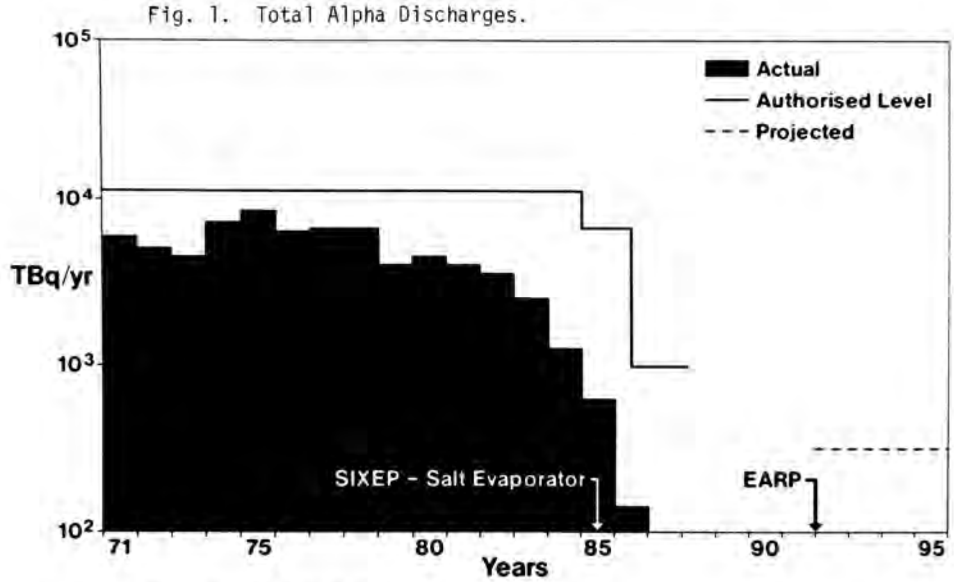

Fig. 2. Total Beta Discharges.

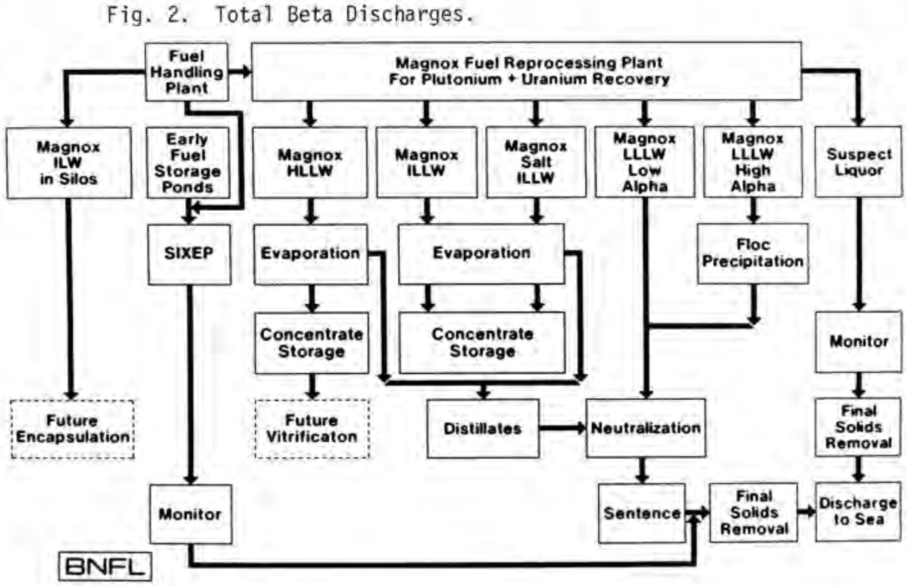

Fig. 3. Current Magnox Reprocessing Complex.

should be provided and that fuel handling within this complex should be automated. Three storage ponds are provided in a closed, ventilated, building some 300 metres long. Each pond is mounted on plinths and the design concept allows man-access to the interspace beneath the ponds for inspection and remedial work should this prove necessary (Figs. 4 and 5). Fuel handling into the ponds, and from the ponds to decanners, is automated as is the decanning operation itself. Provision is made for remote maintenance of pond and decanner equipment. Although the prime impetus for creating the new Fuel Handling Plant arose from Magnox fuel considerations, one of the ponds will be dedicated to the storage of AGR fuel elements as received. A major extension to the FHP, which is being commissioned and due to start active operations in the immediate future, will enable AGR fuel elements to be dismantled. Graphite sleeves and stainless steel grids and braces will be segregated from the fuel pins which will be repacked in containers for more economical storage (factor 3 volume reduction) whilst awaiting reprocessing. The graphite and stainless steel ILW will be stored in a dry store. Eventually they will be encapsulated in cement. The cost of the AGR fuel dismantling and waste storage facility is about $150M.

The SIXEP ion exchange plant project, commissioned in May 1985, provides a permanent facility for treating spent fuel storage pond liquid effluent. This replaces the submerged zeolite skips introduced as a temporary measure during the 1970's principally to reduce the discharge of caesium. The plant consists of three main process stages; sand filtration, pH reduction by counterflow contact with carbon dioxide and ion exchange using a material which is a naturally occurring zeolite called clinoptilolite (Fig. 6). The design decontamination factors for caesium and strontium were 200 and 500 respectively. In practice, the performance for caesium and strontium has exceeded flowsheet expectations and plant availability has been above 90%.

The third facility provided in support of Magnox fuel reprocessing is the Salt Evaporator, commissioned in 1985. The reprocessing plant generates "salt-bearing" effluents from solvent washing operations. These contain modest levels of short lived activity (ruthenium, zirconium/niobium) and long lived activity (caesium, strontium, actinides) and have hitherto been discharged, albeit at activity levels within authorised limits. The Salt Evaporator enables the salt feeds to be concentrated and held in store along with "salt-free" concentrate until a new Enhanced Actinide Removal Plant (EARP) is commissioned in the early 1990s.

The introduction of SIXEP and the Salt Evaporator during 1985 more than halved the alpha and beta discharges to sea compared with 1984. (Further reduction of beta discharges resulted in 1986 with SIXEP operating over a full year instead of only 7 months.)

	Alpha discharges		Beta discharges	
	Ci	TBq	Ci	TBq
1984	367	13.6	32160	1191
1985	154	5.7	15850	587

The provision of the SIXEP and Salt Evaporator Plants demonstrates that BNFL is responding to the requirement placed upon the Company by Regulatory Bodies to use Best Practicable Means to reduce to a minimum activity discharges and radiation uptake by critical population groups and the public at large. It is pertinent to relate the quantities discharged to the total amounts of activity handled, taking as a basis a throughput of 1400 t(U) of Magnox fuel irradiated to 5000 MWD/t(U) and cooled for 180 days before reprocessing. The table below compares the total activity input with that discharged.

	Activity Input (TBq)	Activity discharged(1) (TBq)	Proportion of Activity discharged
Total alpha	0.9×10^5	8	1 part in 10^4
Total beta	1.9×10^7	8.2×10^2	1 part in 2.10^4

Note (1) 1985 data

Future Reductions in Liquid Effluent Discharges

The reductions already achieved have been illustrated in Figs. 1 and 2, which show how annual activity discharge has become a progressively smaller fraction of the Authorised Limit. Nevertheless there is public pressure for discharges to be reduced further. This received additional impetus from the November 1983 incident at Sellafield in which ruthenium activity was discharged to sea during the Reprocessing Plant shut down for wash-out and maintenance.

Following this incident the Company agreed with Regulatory Bodies that discharges of free solvent and particulates should be prevented and that permitted limits for activity discharges should be expressed on a shorter time-base. The Sellafield site discharge authorisation has been amended accordingly. At the same time the Company published its commitment to reduce annual discharges from Sellafield to 0.75 TBq(20 Ci) alpha and 300 TBq(8000 Ci) beta, and these may be compared to the activity input to Magnox and Oxide Fuel reprocessing in parallel (see Table on next page).

Against the background of these commitments the entire provisioning for LA effluent discharges from Sellafield has been carefully reviewed, noting that streams which would at one time have contributed an insignificant proportion of a larger total will in future become relatively more important. It is proposed to construct an Enhanced Actinide Removal Plant (EARP) for operation from the early 1990s. This plant will utilise the soluble iron content of an existing Magnox plant effluent to create, after neutralisation, a ferric floc on which alpha activity is preferentially adsorbed. Development has confirmed that alpha decontamination factors greater than 100 may be obtained. Factors greater than 1000 are achievable on medium active and Salt Evaporator concentrates, which will be treated in this plant after storage to allow decay of short lived fission product activity. A modest performance in strontium and ruthenium activity removal is also expected. Current capital estimates for EARP are about $300M.

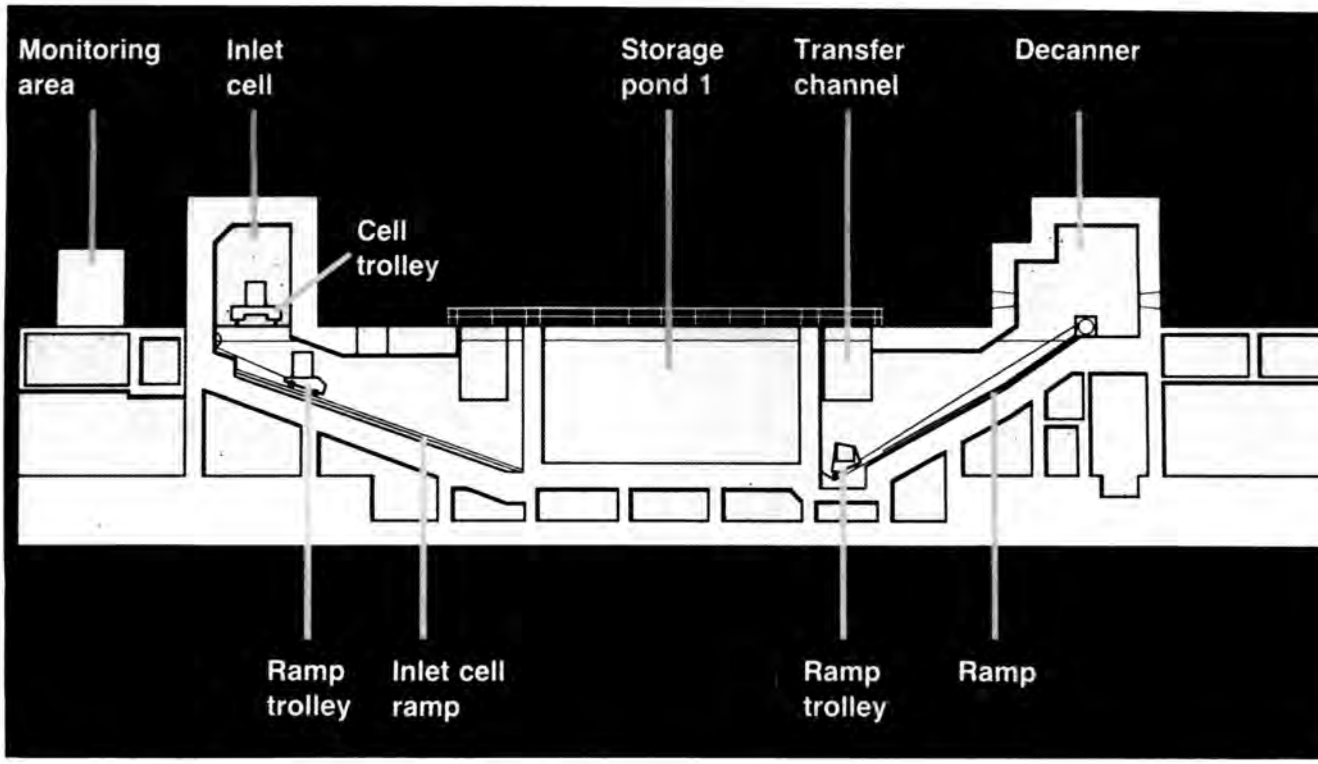

Fig. 4. Section Through Fuel Handling Plant.

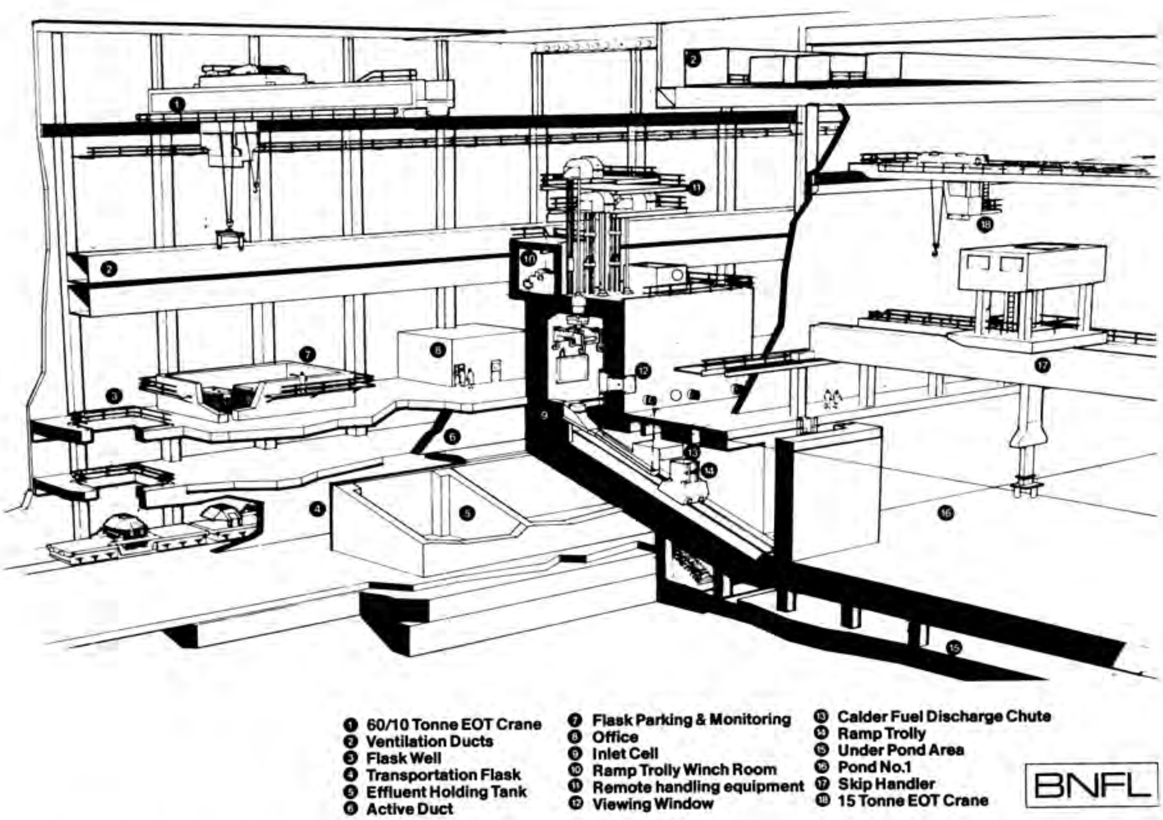

Fig. 5. Pictorial View.

	Activity Input			Activity discharge	Proportion of Activity discharged
	Oxide fuel(1)	Magnox(2)	Total		
	(TBq)	(TBq)	(TBq)	(TBq)	
Total alpha	1.4×10^5	0.9×10^5	2.3×10^5	0.75	1 part in 3.10^5
Total beta	1.5×10^7	1.9×10^7	3.4×10^7	300	1 part in 10^5

Notes (1)600 t(U) oxide fuel per year comprising 200 t(U) AGR fuel and 400 t(U) LWR fuel, each cooled for 5 years.

(2)1400 t(U) Magnox fuel per year, 5000 MWD/t(U), cooled 180 days

Figure 7 is a simplified block diagram showing the inter-relation between EARP and other Sellafield facilities.

Alongside this investment, schemes are being developed to combine low active liquid effluents so that solids and free solvent may be retained. An additional consideration is the selection of streams needing to be held and monitored before discharge, noting that time is required for analytical checks and that ability to recycle to upstream facilities is required. Schemes are also in hand for the disposal of degraded solvent removed from service in reprocessing plants plus solvent retained in traps on LA effluents. All solids removed from LA effluents before discharge will be candidates for immobilisation in cement analogous to those discussed later in respect of the major ILW arisings. The additional capital estimate for LA effluent streams is about $350M. Such provisioning should allay public misgivings about liquid effluent discharges from fuel reprocessing at Sellafield and provide for safe and reliable operation until well after the turn of the century.

OXIDE FUEL REPROCESSING IN THORP

Some aspects of oxide fuel reprocessing technology, notably whole element shearing and fuel leaching, were demonstrated in the early 1970's when about 100 t(U) of oxide fuel (AGR & LWR) was processed through the original reprocessing plant, which had been modified for this purpose. The experience resulting from this, encouraged the Company to seek contracts for reprocessing fuel from domestic and oveseas customers in a purpose-built plant, known since the mid 1970's as THORP (Thermal Oxide Reprocessing Plant). Permission to proceed with this venture was granted following the Windscale Public Inquiry in 1977 and subsequent Parliamentary approval.

This plant is committed to reprocess 6000 t(U) of oxide fuel in its first 10 years of operation commencing in the early 1990s. Two thirds of this total will be LWR fuel of overseas origin and the remainder will be AGR fuel from UK Generating Boards. The design life of the plant is 25 years and it is expected that additional commercial orders will be obtained for reprocessing in the period after the turn of the century. The capital estimate for THORP is about $1850M and additional expenditure will be incurred on fuel receipt and storage ($135M), pipebridges ($75M), plus waste treatment plants to service both Magnox and oxide fuel reprocessing.

The technology to be employed in THORP is consistent with the underlying philosophy adopted for all reprocessing plants at Sellafield in that the principal items of "wet chemistry" plant are designed to obviate the need for routine maintenance. Conversely the head end plant is designed to allow remote disassembly, decontamination and maintenance or replacement of the whole-element shear and other mechanical items. There are additional and significant physical differences between THORP and its Magnox precursor reflecting fundamental flowsheet changes designed to minimise activity in effluents other than the highly active. The effect of these changes is that, notwithstanding the increase in actinide and fission product input to THORP compared to Magnox, the activity discharges attributable to THORP in effluents discharged to sea is a minor portion of the total (see Table).

The most significant flowsheet change is the adoption of "salt-free" reagents in THORP, to effect plutonium/uranium separation compared with ferrous sulphamate reductant in the existing Magnox fuel process. The result is to produce "salt-free" medium active effluents which will be concentrated by evaporation and then combined with highly active

	Agreed limit on total Sellafield activity discharge post 1991	Activity attributable to THORP(1)
	(TBq)	(TBq)
Alpha activity	0.75	0.1
Beta activity	300	22

Note (1) Design basis: reference PWR fuel at 600t(U) per year

raffinate destined ultimately for vitrification. The present THORP flowsheet utilises salt bearing reagents for solvent washing, as does the Magnox fuel process, and these will be concentrated in the Salt Evaporator plant referred to earlier. However, development is in hand aimed at the feasibility of eliminating residual salt bearing streams, offering the prospect of containment of all but very low active effluents.

The physical differences between THORP and Magnox plants at the head end are whole element shearing and batch leaching of oxide fuel compared

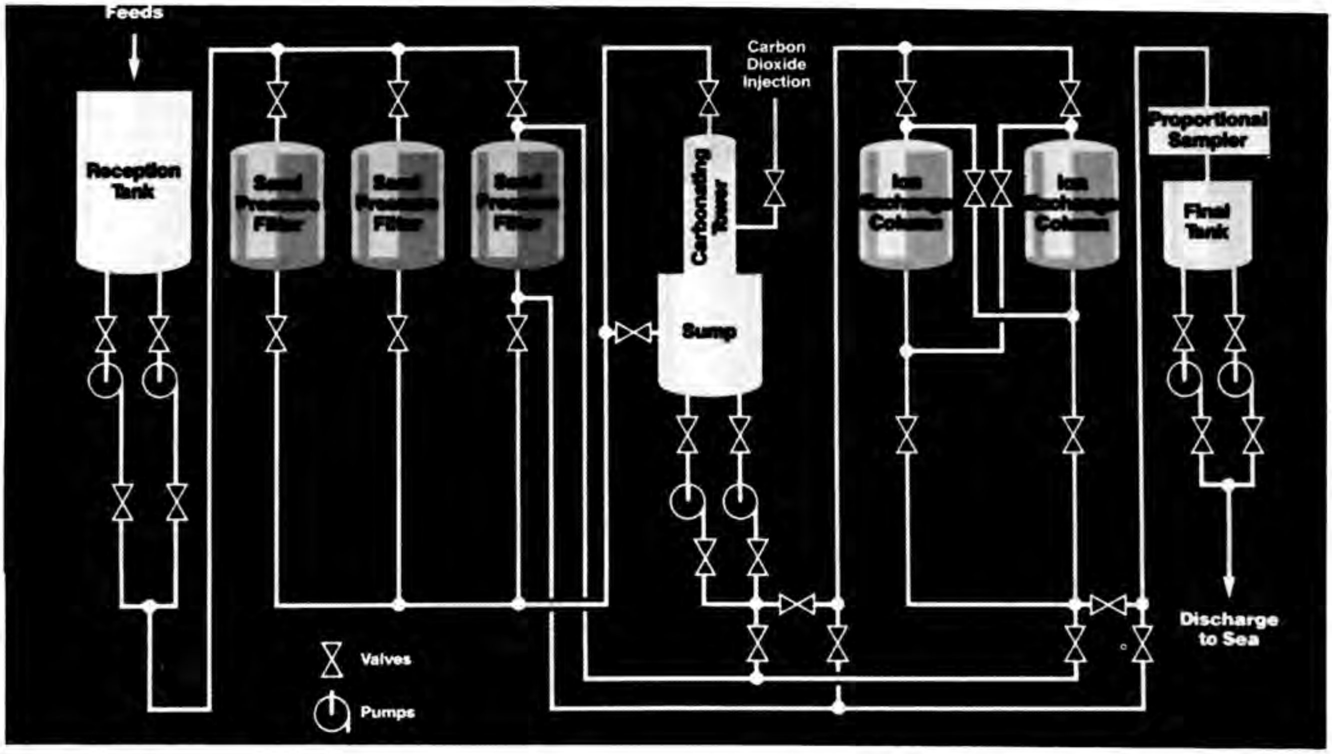

Fig. 6. The SIXEP Process.

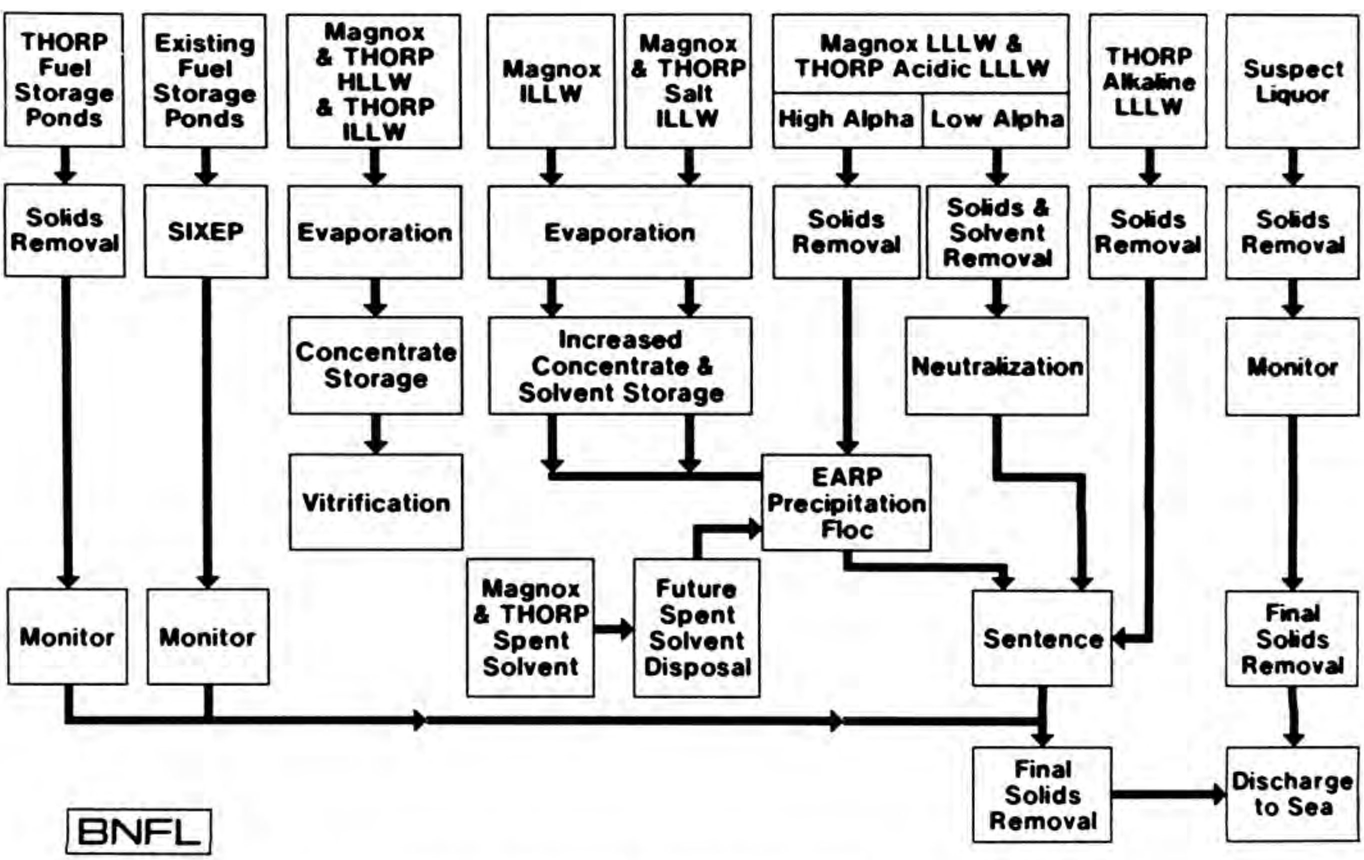

Fig. 7. Liquid Waste Treatment System Proposed for 1992.

to Magnox fuel decanning and continuous dissolution of metal fuel. THORP will incorporate a centrifuge to remove insoluble fission product alloys from highly active dissolver liquor (not present in significant quantities in dissolved Magnox fuel liquor). In THORP Uranium/plutonium co-decontamination, separation and purification will be undertaken in pulsed plate columns rather than in mixer settlers. This change permits plant design to avoid criticality (a potential hazard from residual enriched uranium as well as from the enhanced plutonium throughput) and serves to minimise liquor volumes, residence times and radiation damage to organic solvent, thus minimising potential plutonium losses in some effluents.

Conversion of THORP plutonium nitrate to plutonium oxide product will utilise the oxalate precipitation, filtration, calcination route in continuous (rather than batch) operated equipment representing evolutionary development of plant which is now in use for Magnox plutonium.

The THORP fuel receipt building is weathertight; storage pond construction and hydrostatic testing have been completed, services installation has commenced, and active operation is projected for 1988.

Foundation work for the THORP Head End and Chemical Separation has been completed and building and civil work is in progress. Contracts have been placed for major items of mechanical and chemical plant. Operation is anticipated to commence in 1992.

WASTE TREATMENT

The principle additional Waste Treatment Plants that are being designed and constructed to service Magnox and Oxide fuel reprocesing are the Vitrification Plant (WVP) for highly active liquors; the Medium Active Solid Waste Encapsulation Plants (MASWEP) for intermediate level solid wastes, and the Waste Treatment Complex (WTC) for Plutonium Contaminated Material.

Vitrification of HA Liquid Waste

Almost all of the original fission product activity in fuel, and much of the actinide activity (excluding plutonium) ends up in the highly active raffinate from the first solvent extraction cycle. Practice to date has been to concentrate this liquor in simple submerged coil evaporators and store the highly active concentrate in tanks provided with cooling facilities to remove fission product decay heat. It has long been recognised that phased provisioning of such tanks over the total (Magnox plus THORP) reprocessing period, and continuous surveillance of all tanks over an indefinite period thereafter, is not a permanent solution. Policy, endorsed by the UK Government, is to immobilise highly active liquid waste by vitrification, and to hold the contained waste monoliths in an engineered store for a period of at least 50 years during which time surveillance can be maintained until a repository for ultimate disposal of this waste is made available. The provisionings allow for the progressive emptying of the existing liquor storage tanks, leaving some of the later units as interim buffer storage between the reprocessing and vitrification operations.

The Windscale Vitrification Plant (WVP) embodies technology developed and applied at Marcoule (France). It comprises a continuous rotary calciner from which dry powder is discharged by gravity to a melting pot. Two batches of melt are poured into each preheated stainless steel container which is withdrawn when full, cooled, sealed by lid welding, decontaminated, inspected and transferred to store. The vitrification process introduces new technology to Sellafield in that there are items of moving and rotating high temperature plant in the main process line which will require maintenance and replacement. All items are therefore designed to be remotely replaceable. Design has been supported by the operation of a Full Scale Inactive Facility (FSIF), which replicates all major plant items. This has been provided to optimise the process, demonstrate operation and maintenance procedures, provide confidence in meeting plant capability, quantify the properties of the waste form, and to train process and maintenance staff.

Construction of WVP is well advanced. Shielded cells are being built within the completed outer shell. Two lines of plant and equipment are to be installed for completion in mid-1988 to allow at least one years inactive commissioning before active operation in the Autumn of 1989. The capital estimate for the plant and its asociated product store is about $300M.

The volume of highly active liquor concentrate now in store is about 1500m^3. When vitrified the equivalent volume of contained waste will be about up to 600m^3 in up to 4000 canisters. For the combined Magnox and oxide fuel reprocessing programmes to the end of the century the ultimate volume of vitrified waste will be up to 1500m^3 in up to 10,000 canisters. Containers will hold about 3×10^4 TBq(8×10^5 Ci) at the time of filling, irrespective of original fuel type.

During the period up to the end of 1989 the provision of additional facilities for highly active liquor evaporation and storage will be completed. This includes installation and connection of two more storage tanks (21 in total) and a third highly active liquor evaporator intended as a spare to the existing second evaporator at the end of the operational life of the first evaporator. A pipebridge is under construction from THORP to the highly active liquor evaporator/storage tank complex and from there to the vitrification plant. The capital estimate for the additional highly active liquor evaporation, storage and transport facilities is about $220M (including the connection of some earlier tanks, services rationalisation and provision of transfer tanks).

Management of Intermediate Level Waste (ILW)

The Company has been required by Regulatory Bodies to seek an alternative to the creation of additional wet silos for holding Magnox swarf arising from the decanning of spent Magnox fuel. The aim is to convert future arisings and (eventually) existing waste stocks to a stable waste form suitable for ultimate disposal after interim storage if necessary. Proposals for the encapsulation of Magnox swarf into cement monoliths have been developed by the Company and agreed by the Regulatory Bodies. A project is now under way for doing this, with the first phase due for active operation in 1990, comprising a single cement grouting line, a product store and services building. The Magnox swarf feed will be flasked directly from the new Fuel Handling Plant already described. Development in support of this project has included extensive product evaluation, and waste form disposal studies. These have confirmed that the cemented waste form will remain essentially monolithic for upwards of 100 years. Even based on pessimistic assumptions, estimates of the potential dose to the public which may result from leaching of the cemented waste in a repository by ground water, should this eventually reach drinking water supplies, will be at least three orders of magnitude below the UK regulatory limit of 10^{-4} Sv/yr.

Solid wastes arising from THORP include leached fuel cladding, centrifuge solids and other active solids in slurry form. Proposals to encapsulate these in cement have been accepted in principle by Regulatory Bodies and it is therefore intended to construct a second ILW encapsulation plant for THORP wastes and flocs from the Enhanced Actinide Removal Plant. This plant is being designed to provide facilities for grouting THORP hulls (and Magnox swarf if required), and for in-drum mixing of flocs and slurries. The plant will be constructed on a plot adjacent to the first ILW encapsulation plant and some services will be shared.

The capital estimate for the encapsulation plants with their associated product stores and service buildings totals about $1,000M including retrieval of existing wastes. Site preparations have been completed. Building and civil work for the first phase is well advanced and plant installation will commence in mid 1987 for active operation in 1990. Foundations for the second encapsulation plant are in the progress of being constructed with the plant required to be available for active operation to a timescale commensurate with THORP, i.e.,1992.

In the longer term it is intended to remove Magnox ILW from the existing suite of wet silos. Much of the swarf consigned to the earlier silo compartments is known to have corroded to a thick sludge. The timescale for removing and encapsulating this sludge depends on the development and demonstration of mechanical/hydraulic equipment for its remote retrieval. The alternative of in-situ chemical dissolution of the sludge, even using mild reagents, is judged to be unattractive for a combination of reasons, including potential adverse effects on the silo structure and the need to establish a processing route to segregate activity before disposing somehow of decontaminated Magnox-bearing liquor. It is proposed that silo sludge will be encapsulated in cement along with sludges to be retrieved from redundant Magnox ponds and spent clinoptilolite. Some $300M has been identified as global cost provisioning for retrieving and transferring such wastes.

In addition to the ILW streams discussed above, attention is being given to the treatment of miscellaneous plutonium-contaminated wastes (PCM). A substantial backlog of such waste is held in drums and crates in interim stores. They contain soft waste (lab coats, rubber gloves, PVC or other plastic wrapping, tissues) and hard wastes (items of equipment, glass bottles, glove boxes). By definition this material is not suitable for shallow land burial and currently it is not possible to cement the lightly contaminated material (less than one alpha curie per ton of waste) for disposal at sea. Projects are in hand to sort, shred and redrum soft waste in order to achieve an overall volume reduction and meet current standards for waste containment, and to sort and redrum items of hard waste with the same object. It is proposed eventually to grout the drummed waste in cement with a view to disposal in a deep repository alongside other ILW. Construction of the sorting, shredding, redrumming facility to meet the initial objectives is well advanced and space has been allocated for a drummed waste encapsulation line. A second, later phase of the project is now at the design and development stage. This will cater for large crated items of equipment which require size reduction in order to produce waste compatible with proposed disposal packages of standard size. Size reduction will be accomplished remotely, within alpha containment, using non-reactive plasma arc or laser cutting techniques. Both phases together constitute the Sellafield Waste Treatment Complex (WTC) and the combined capital estimate is about $90M.

Miscellaneous solid wastes other than Magnox or THORP ILW already discussed requires handling, sorting and interim storage before eventual encapsulation for disposal. A facility for this purpose is to be provided for active operation in 1989 at a cost of about $80M.

Consideration is also being given to the eventual treatment and disposal route to be recommended for articles known generically as "pond furniture". These comprise skips used for transport and storage of Magnox and AGR fuel, and multi-element bottles used for transport and storage of LWR fuel. It will not be possible to re-use some early examples of these items because they do not meet current standards. Methods of decontamination and size reduction are under examination.