THE DESIGN AND CONSTRUCTION OF THE WINDSCALE VITRIFICATION PLANT AND VITRIFIED PRODUCT STORE

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ABSTRACT

The paper describes the background of High Level Waste storage and vitrification development in the UK and its application to Reprocessing Operations at Sellafield.

The main stages in the vitrification process and associated maintenance facilities are described together with the layout of the Windscale Vitrification Plant (WVP) and associated Vitrified Product Store (VPS). The design and construction techniques employed for example, the use of Computer Aided Design and the effect of automatic pipe bending/orbital welding and the use of precast units for cell construction, are discussed and current construction progress is highlighted.

The vitrification process uses complex mechanical plant operating in high temperature and radiation fields. An extensive engineering and process development programme has been carried out. A full scale inactive facility (FSIF) has been constructed and the objectives and results from the operation of FSIF are presented. In addition to engineering and process development, a comprehensive programme of glass technology development has been carried out to establish maximum waste incorporation levels, reaction kinetic and product properties of the candidate glass formulations.

INTRODUCTION

The reprocessing of spent nuclear fuel at Sellafield by nitric acid dissolution and solvent extraction gives rise to a highly active liquid waste (HLW). This waste stream contains practically all of the fission products, neptunium and trans-plutonium elements present in the irradiated fuel as well as traces of plutonium and uranium. At present the HLW stream is concentrated by evaporation and is stored in specially designed stainless steel tanks. Although tank storage under properly chosen conditions is a proven safe technique, this cannot be the ultimate solution to highly active waste management. A tank storage system is costly, requires maintenance and surveillance over long periods of time and the waste remains in an inherently mobile form. It has been internationally recognised that conversion of the HLW to a solid form would give advantages in safety, economy, handling convenience and stability for both transportation and ultimate disposal.

BNFL will solidify the HLW at Sellafield using a borosilicate glass formulation. This particular form of solid was selected after a full comparison of the available processes, taking into account the availability of industrial scale technology which would enable the objective of implementation before the end of the present decade to be achieved. The Windscale Vitrification Plant (WVP) and associated Vitrified Product Store (VPS), currently under construction, will have the capacity not only to treat the arisings from the Magnox and THORP reprocessing plants but also to process the present backlog of stored HLW.

HLW STORAGE

The aqueous raffinate from the first extraction cycle of a fuel reprocessing plant has an original volume of up to 5 m^3/te of uranium. It is concentrated by evaporation typically to about 50 l/te U for Magnox and 150-250 l/te U for thermal oxide fuel waste. This concentrate and the residues of the evaporated raffinates from further extraction cycles or other reprocessing plants will be transferred to the solidification plant of the reprocessing site. The liquors, which contain suspended solids, are about 1.5M in nitric acid and have a specific activity level of typically 1600 Ci per liter.

THE WVP PROCESS

A number of vitrification processes have been developed however in late 1979 a detailed comparison of the HARVEST and AVM (Atelier de Vitrification de Marcoule) indicated that whereas both could be developed to an industrial scale, the latter could be developed more rapidly and would result in a smaller number of high active storage tanks. A decision was taken by BNFL in early 1980 to adopt the French process.

The WVP consists of two vitrification lines based on the continuous AVM process with some services common to both lines. Under the terms of a contract between BNFL and SGN (a subsidiary of Cogema), SGN is undertaking the design and procurement of the process equipment for the calcination and melting steps of the process. The main steps in the process are shown in Fig. 1 which consists of the following operations:

- HLW preparation
- Transfer feed to calciner
- HLW feed to calciner
- Calcination and associated off-gas treatment
- Melting and pouring
- Welding of container lid
- Decontamination and monitoring of product container
- Transfer container to store

The preparation of the HLW feed takes place in two high active storage tanks which are equipped to enable transfer of liquid to WVP. The HLW selected for a vitrification campaign is transferred to the appropriate tank and prepared for WVP by the addition of a controlled volume of lithium nitrate solution. Lithium nitrate is required to ensure adequate reactivity of the calcined HLW at the melting stage. The prepared feed is characterized by sampling and analysis before being fed forward to WVP.

The prepared HLW feed is transferred to WVP by pipebridge in batches of about 10 m^3 to the feed vessels in WVP. Two feed vessels are provided each capable of feeding either vitrification line.

A constant volume feeder is used to meter the flow of HLW to the calciner. Other feeds to the calciner are effluent recycle liquor from the dust scrubber, sugar solution to give good calcine granulometry, additional lithium nitrate and dilution water. Individual flow rates are selected to suit the HLW analysis and production rate for the line.

The calciner consists of a stainless steel tube inclined at a slight angle and rotated inside an electrical resistance heated furnace. The calciner is supported at each end by roller bearings and special air tight seals. As the HLW flows down the calciner it is successively evaporated, dried and partially denitrated. The dry powder produced (calcine) is continuously discharged by gravity directed into the melting pot. A loose bar (the rabblebar) is fitted inside the calciner to break up the particles and to help prevent the build up of material on the wall.

The primary off gas system comprises a dust scrubber column, a tube condenser and a bubble cap scrubber column for nitrogen oxide removal. This is followed by the secondary off gas comprising a scrubber column, electrostatic precipitators and high efficiency filters. The function of the off gas system is to reduce the nitrogen oxides and ratioactive emission of the effluent to below the authorised discharge limit.

The melter furnace is inductively heated and is controlled at a temperature of about 1100°C. Glass frit is fed in controlled batches to the lower end of the calciner where it falls by gravity with the calcine into the melter. The calcine and glass feed rates are such that, typically, 25 per cent w/w incorporation of the waste as oxides in the vitrified product is achieved. As the level of vitrified waste in the melter reaches a pre-determined point, an induction heated 'freeze valve' at the base of the melter is activated and the molten glass is cast into the product container placed beneath the molten. This pouring stage takes place approximately every eight hours and each product container can accommodate two pours from the melter.

Further development of the AVM calciner and melter has been carried out in France and improved capacity has been achieved. The calciner performance has been improved by 50% and the melter by 67%. This improved equipment is being installed in the two vitrification plants at La Hague. The first of which is known as AVH (Atelier de Vitrification de la Hague) and consists of three vitrification lines and is currently under construction. The second plant also consists of three lines but is at an earlier stage of construction. WVP will also use the improved AVH equipment.

The glass container (1.3m high by 0.42m diameter) holds about 150 litres of vitrified product and has a total weight of about 470 kg. The glass container is held in a pre-heat furnace to maintain a temperature of about 500°C before and during pouring. This minimises thermal shock on the glass and ensures that successive pours adhere to one another giving a cohesive single block of glass. After filling, the container is lowered from the pre heat furnace and is allowed to cool. A lid is then loosely fitted and the container and lid completely sealed by an automatic fusion welding technique. Here the container is placed in a decontamination vessel where high pressure water or dilute nitric

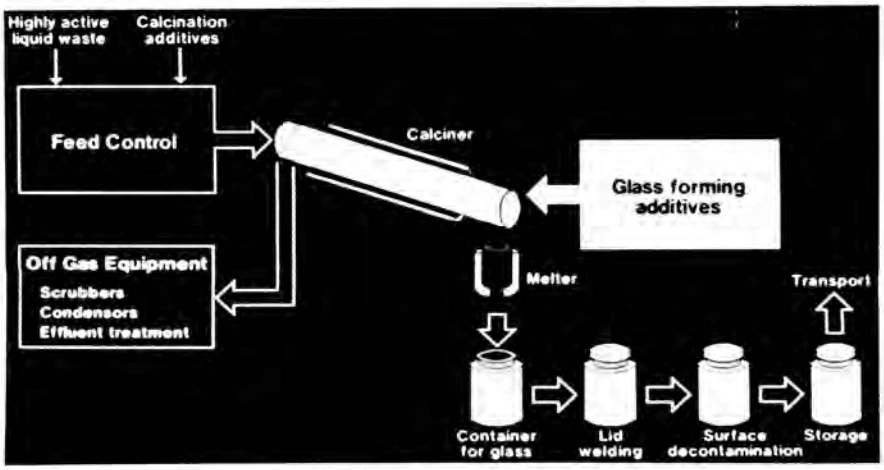

Fig. 1. WVP Process.

acid is used to remove loose contamination of the external surfaces. After decontamination the container is monitored and if sufficiently decontaminated is placed in a transfer flask and the flask transferred to the Vitrified Product Store which is adjacent to WVP.

The main process plant items will require periodic maintenance and replacement. Each vitrification line will have its own purpose-built maintenance facilities (the breakdown and maintenance cell). The HLW liquor feed metering equipment, the calciner, the melter pot and the primary off-gas treatment equipment are remotely replaceable by means of a bridge crane, special tools and master slave manipulators.

The maximum production rate of the two lines in WVP is equal to about 21 containers per week and the total annual output is expected to be 600 containers.

WVP LAYOUT

The layout of the two vitrification lines in WVP and shown in Figs. 2 and 3. The plant can conveniently be separated into cells containing the main process equipment as follows:

- HLW and effluent tanks cell which is a single cell serving either vitrification line and contains two $13m^3$ capacity feed vessels and two HA effluent tanks;
- two vitrification cells, each containing a HAL feed CVF, seal pot, confluent pot, calciner, melter and dust scrubber;
- A breakdown cell connected directly to each vitrification cell by a diaphragm door, to the pouring cell by trap door and to the decontamination cell by trap door. Equipment for the remote maintenance of equipment, dismantling, activity monitoring, cutting and packaging of waste is provided in each cell;
- a pouring cell connected to each vitrification cell which contains an elevating table to transfer empty product containers from a carousel to the pouring position under the melter. The container is filled from the melter through a diaphragm joint separating the vitrification and pouring cells. Lid placing, cooling stations and lid welding equipment is also provided;
- a decontamination cell common to both vitrification lines and contains a high pressure wash decontamination tank which traverses on rails from the post down facility from each pouring cell and each breakdown cell to a post up facility in the control cell;
- a common control cell containing a sealed product container post from the decontamination cell, a smear test machine to externally swab the container, a pneumatic swab transfer system to present the swab to an external monitoring system and a gamma gate located in the roof for flasking out product containers to the Vitrified Product Store.

In addition, a number of cells containing the LA effluent system, NOX scrubbers, Hoist parks/module change areas, secondary off-gas treatment equipment and filters are provided. The chemical plant is controlled from a central control room.

VITRIFIED PRODUCT STORE

The filled product containers are transferred by flask to the Vitrified Product Store (VPS) which is adjacent to WVP. In VPS the containers are stacked up to 10 high in stainless steel thimble tubes which are sealed at the base. The air flow removes heat from the outer surface of the thimble tube and since there is no direct contact with the containers it is intended to operate the store using natural convection and no filtration. VPS will consist of four compartments, the first of which will be equipped to operate with outlet air filtration (ie with fans) in order to demonstrate that very low activity discharges can be achieved with the store design.

A typical section through a VPS compartment is shown in Fig. 4. Each compartment has an air inlet at the base of one side and an air outlet directly opposite at the top of the other side. The channel assembly is supported above the base slab to provide an air inlet distribution manifold and will terminate below the charge floor to provide an outlet manifold. The cooling air thus flows horizontally into the compartment, vertically through the channel assembly, horizontally to the outlet duct prior to the discharge stack.

An export facility will be provided adjacent to the store to enable the product containers to be loaded into a suitable transport flask for the return of residues to overseas Containers.

WVP DESIGN AND CONSTRUCTION

The design of WVP has made extensive use of Computer Aided Design (CAD), in particular a Plant Design Management System (PDMS) which has lead to the production of a three dimensional electronic model of some sections of the process and services plant and pipwork. The principal benefits are to enable clashes check prior to fabrication and installation thus reducing abortive site work with related programme and cost penalties. Also PDMS enables detailed materials scheduling to facilitate materials provision. Additional consideration in HLW area was given to installation by means of access platforms and field weld location. Resulting from this CAD enabled outputs for pipe bending spools by a CNC bending machine. Design has also included provision for automatic (orbital) welding of pipework. Use is being made of the BNFL patented consumable socket ring for orbital welding.

The external building of WVP is a steel frame structure clad with panels consisting of an outer skin of folded aluminium and an inner skin of folded mild steel containing about 35mm of insulating material. This structure is approximately 64m long by 38m wide by 40m high and contains about 1500 te of structural steel. Suitable access routes for the subsequent construction and installation work are incorporated in the design and the subsequent construction work is served by four overhead cranes. The building shell was completed in August 1983 and the process cells are currently under construction within this shell.

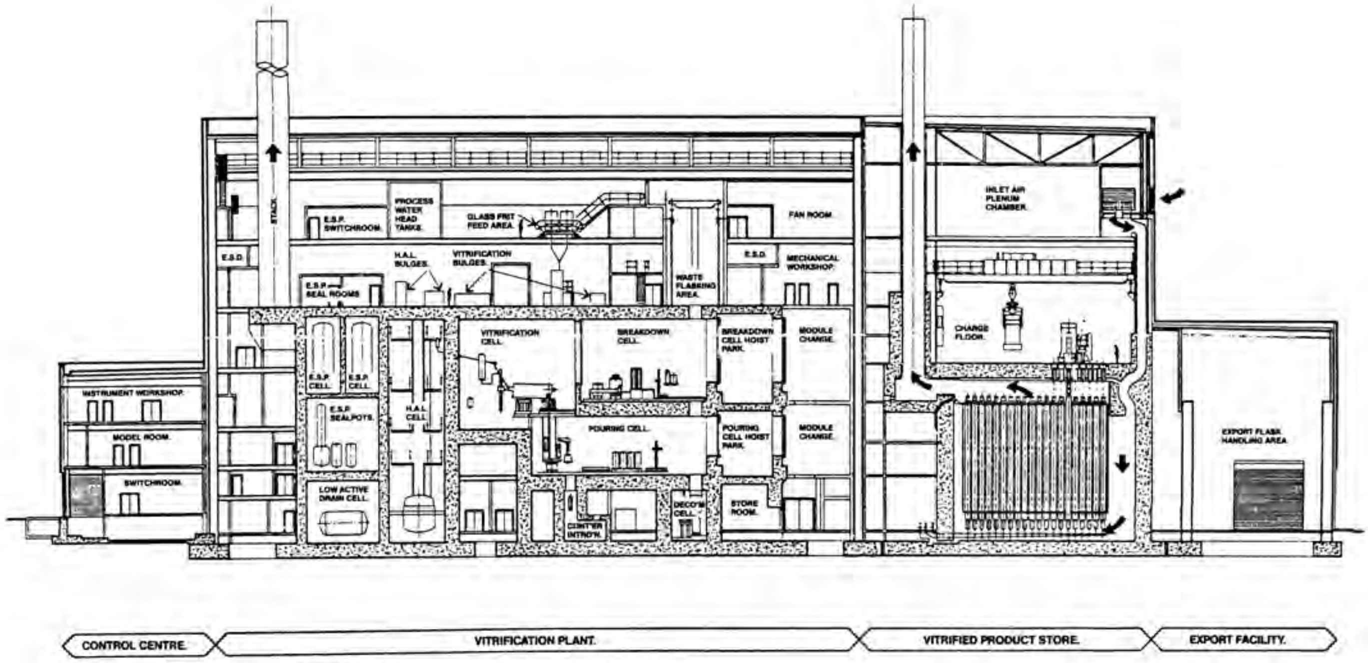

Fig. 2. Layout of Vitrification Lines in WVP-1.

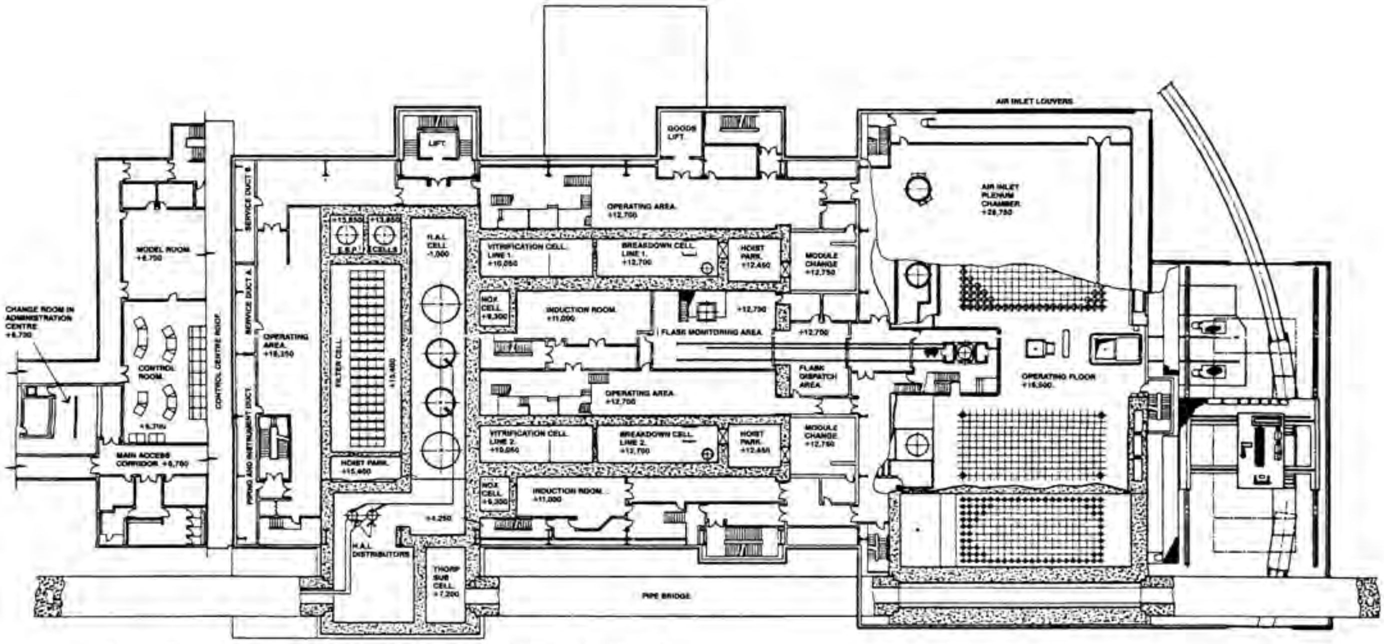

Fig. 3. Layout of Vitrification Lines in WVP-2.

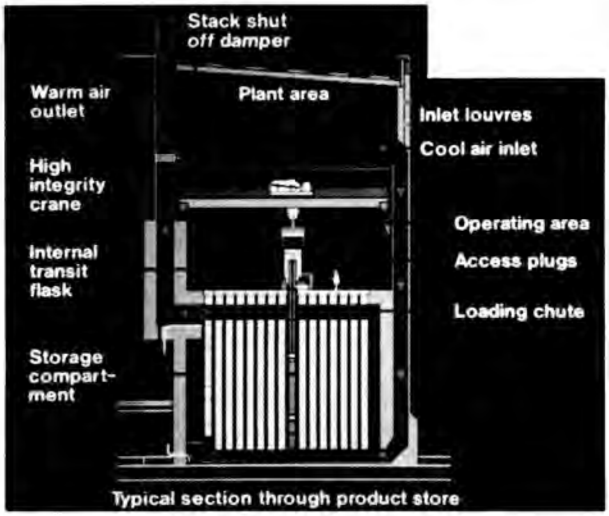

Fig. 4. Typical Section through Product Storage Compartment.

The main advantages of using a building shell is that the time lost due to bad weather is reduced to a minimum. This method of construction also enabled work on the site to commence about 12 months earlier than would otherwise be possible due to earlier definition of the outer envelope than the cells. The civil work programme is extended by using this construction method, however, this is more than compensated for by the earlier start of the mechanical work eg the installation of cell linings.

The cells are constructed using concrete precast units, fabricated off-site, which incorporate liner supports for the later installation of the stainless steel liners in the cells. The reinforcing necessary to meet the required seismic criteria is placed between the precast units when these have been correctly positioned. The remaining space is then filled with concrete or special heavy concretes (eg barytes or iron shot) according to the radiation shielding required. The panels are constructed from a small number of individual templates using different combinations and orientations. About 600 individual precast units will be used for the HLW feeding and vitrification cells in WVP. A total of about 3,000 te of structural steel is used for floors and secondary steelwork and 27,000 cubic metres of reinforced concrete will be used in the construction.

The major benefit from this construction method is the ability to construct the precast units off-site under carefully controlled conditions with good surface finish and precast liner supports. The limitations of the technique are that less space is available for the reinforcing steel in the structure and the requirement to specify design features, such as wall penetrations, at an earlier stage than for normal construction methods.

WVP DEVELOPMENT PROGRAM

The vitrification process requires the use of complex mechanical plant operating in high temperature and radiation fields. To this end the HLW feed metering equipment, calciner, melter primary oil gas system and all the container handling devices etc are designed to be remotely replaceable using remote couplings, a bridge crane, special tools and master slave manipulators.

The overall objectives of the engineering and process development programme are:

- to optimise the process for the vitrification of wastes;
- to demonstrate the procedures necessary for operation and maintenance of the vitrification plant;
- to provide sufficient data to assure the programmed start up of the vitrification plant and to give a high degree of confidence in achieving the design plant availability;
- to fully quantify the properties of residue (that is to say the complete package of waste in its sealed container);
- to train process and maintenance staff in the operations of the vitrification plant.

Implicit in these objectives is the complete replication, at full scale, of the main features of the plant. In 1981 BNFL placed contracts for the design and construction of a full scale inactive facility (FSIF); its construction was to be in two stages

- FSIF Phase 1 - a full scale replica of the highly active vitrification cell comprising all the incell items, pipework, control systems etc contained behind mock shielding walls and fitted with windows and manipulators for remote handling trials;
- FSIF Phase 2 - a full scale replication of all the product container handling equipment, again contained behind mock shielding walls fitted with manipulators and windows.

Construction and commissioning of FSIF Phase 1 and 2 is complete.

The objectives of the glass technology development programme are:

- to modify the well characterised Fingal and harvest glass formulations for use in the continuous WVP process;

- to establish the maximum waste incorporation levels, the manufacturing behaviour, reaction kinetics, viscosity and stability of the candidate glasses;

- to establish the limit for suitable glass formulation in the candidate glass and thereby define the flowsheet tolerances;

- to characterise the thermal stability of the glass after pouring;

- to provide a support service to FSIF operations.

A new suite of glass technology laboratories has been commissioned for the glass technology development work.

The product glass formulation must both satisfy the needs of the process and give the desired product qualities. Demands of the process include the ease of manufacture of the product, the aggressive nature of the molten product towards the melter crucible, the reaction kinetics in the melter, the ability to flow easily from the melter and to reform the freeze valve on completion of the pouring operation, and the degree of plant control necessary to produce consistently a product of acceptable quality. Product qualities required are primarily chemical, thermal and radiation stability.

The formulation of a candidate glass for the WVP is an evolutionary process from laboratory scale, through pilot scale to full scale application. The laboratory scale glass technology studies cover a wide range of basic development, selecting suitable glass formulations for the incorporation of both existing a future HLW and also the characterization of the glass product. Once the basic candidate glasses have been identified they are subjected to testing on the pilot scale melter where the availability of melt sizes up to 20 kg allows for the evaluation of scale-up effects. In conjunction with the melter studies the pilot scale calciner is used to optimise the flowsheet with regard to the nature and concentration of calcination additives. Calcines produced in the pilot scale calciner are also fed back into the laboratory studies to aid the glass selection. The results of these studies allow the selection of suitable candidate glasses for testing at full scale in the FSIF.

Once the full scale flowsheet has been produced based on lab and pilot scale it is tested in the FSIF and the product from the full scale equipment is compared with those produced under similar conditions at laboratory and pilot scale.

On completion of all the FSIF trials it is then possible to assess all the samples produced under various conditions and to formulate a product specification and to assign control values to the several operating parameters. The culmination of all this development work is the WVP flowsheet.

CONCLUSION

The construction of WVP is now proceeding well. At the time of writing (January 1987) the concrete cell work and the installation of the main vessels are complete. Pipework fabrication and installation is well underway and the electrical installation has commenced. Active start up is forecast for the autumn of 1989.