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VRTF: A NEW PACKAGE FOR THE TRANSPORT OF VITRIFIED RESIDUE WASTE FROM SELLAFIELD TO JAPAN

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ABSTRACT

High-level waste is generated as a product of the chemical process of reprocessing. Sellafield Ltd has stored such waste at Sellafield in liquid form for about 40 years. While most of the waste generated at Sellafield is a product of the UK nuclear industry, a quantity is generated as a result of reprocessing fuels from overseas customers and will be returned to the country of origin, such as Japan. The liquid waste, known as residue, has to be incorporated in a stable form to facilitate safe and convenient export. Sellafield Ltd operates a plant which vitrifies the residue in a stable glass matrix within special stainless steel containers. After a period in storage within Sellafield's Vitrified Product Store the activity and heat generated have decayed to acceptable levels. Containers will then be moved into the recently constructed Residue Export Facility, currently being commissioned. Within this facility, those containers selected for export will be cleaned, monitored then remotely loaded into a transport package.

Sellafield Ltd has designed and manufactured the Vitrified Residue Transport Flask (VRTF) to safely perform these transports of the vitrified residues to Japan. The package design is capable of carrying 21 vitrified residue containers whilst satisfying the stringent shielding requirements within the overall UK weight and size limitations, resulting in a package which is 2.5m in diameter, 6m in length and a laden weight of 113.5 tonnes. Originally licensed in 1993 as a type B(U)F against 1985 (Amended 1990) IAEA regulations, the design was fully reviewed to enable its relicense against 1996 regulations. The manufacture of the first package was completed in December 2006, and the package handling trials in the Japanese facilities performed during the summer of 2007.

INTRODUCTION - PURPOSE OF THE PACKAGE

The VRTF package (Figure 1) has been designed to transport consignments of 21 containers of vitrified residue from the Waste Vitrification Plant (WVP), Sellafield Ltd's production facility at Sellafield, to the base load customers' storage facilities. The primary use of the VRTF will be to return residues to Japan's storage facility at Rokkasho-Mura. In WVP, the molten residue is poured into stainless steel containers which are capped and seal welded after solidification (Figure 2) and moved into the Vitrified Product Store (VPS), where they may reside for several years. In due course, the containers which weigh approximately half a tonne each, are transferred from the product store into the Residue Export Facility (REF) where they are decontaminated by bead blasting, inspected for contamination, tested for activity release to assure leaktightness, then loaded into the VRT Flask, the subject of this report.

The flask was originally approved as Type B(U)F against the requirements of the 1985 (as amended 1990) IAEA Regulations for the Safe Transport of Radioactive Material. The VRTF was subsequently approved in March 2007 for B(U)F approval to 1996 (Revised) IAEA Regulations, Reference 1, which followed a review of the design in its entirety and reassessment of all major analyses. It is essential that the flask is compatible with the REF and other locations where it will be handled. To meet this requirement, the design has been 'harmonised' with the French (AREVA NC) design and a number of common operational features are incorporated. Weight and dimensional constraints imposed by the requirements for road, rail and sea transport have been accommodated within the design to ensure the flask is suitable for worldwide operations.

DESCRIPTION

The overall size of the package including the shock absorbers is 2.5m diameter and 6m long with a maximum loaded weight (without its transport frame and thermal guards) of 113. 5te. A schematic representation of the flask is shown in Figure 1.

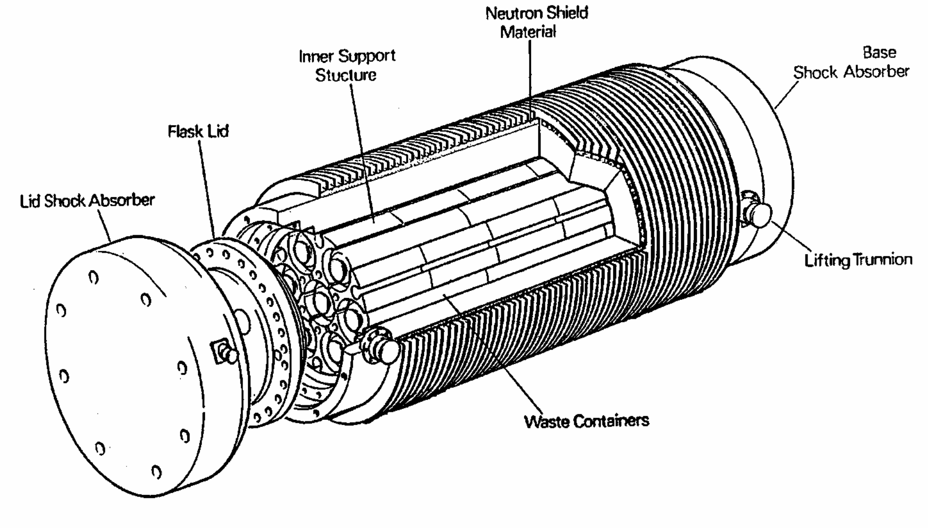

Figure 1: Schematic Representation of the VRT Flask

The main components of the package are:

- A cylindrical body with circumferential fins
- A lid bolted into a recess in the body
- An internal aluminium support structure (basket)
- Vitrified residue waste containers (contents)
- Lid and base shock absorbers

A general description of each of these components is given below:

Flask Body

A single monolithic thick walled forging design has been adopted. The flask has a shell external diameter of 2060mm and 310mm wall thickness, with a maximum diameter over the welded fins of 2500mm. The overall length is 5097mm without shock absorbers. When these are fitted, the length increases to 5935mm. The empty fabricated flask body weighs 85.6te. The cylindrical shell of the flask body is manufactured from carbon steel specified with enhanced low-temperature impact properties. At the bottom end of the cylinder a forged steel base of maximum thickness 325mm is welded using a full-penetration butt weld. Materials for the containment are selected for strength, both under pressure and impact, and resistance to fracture at low temperatures. Circumferential fins are attached to the outside of the flask body by fillet welding. Neutron shielding material is contained in sealed compartments at the fin roots and the flask base, trunnions and over the trunnion flanges. The flask body is provided externally with two pairs of stainless steel trunnions, which are used for supporting the flask in transport, and for lifting and tilting operations. Internally the cavity surface (bore) is sprayed with aluminium to enhance the heat transfer and provide corrosion resistance.

Flask Lid

The lid is manufactured from a stainless steel forging and incorporates a double 'O' ring sealing system. Both seals are manufactured from Viton. The inner seal provides the containment sealing while the outer is used to provide a testable interspace. The lid is bolted to the flask body using 36 bolts. Neutron shielding material is enclosed on the upper surface of the lid. A sealed orifice gives access through the lid to the flask cavity to allow the internal gas pressure to be set after loading. On the underside of the flask lid, flared spacers locate the lid ends of the waste containers and act as shock absorbers to protect the neck of the container against damage caused by 'shunting'.

Aluminium Support Structure

The internal support structure, or basket, consists of 30 identical aluminium segments, assembled in five layers of six (Figure 3), to form seven circular compartments. One compartment runs centrally along the flask's axis with the other six positioned radially around it. The segments are clamped against the flask wall to provide stability and optimum heat transmission, see figure 4 for segments fitted in position. All aluminium surfaces are hard anodised to give a hard wearing finish with an enhanced emissivity value. The system of clamps and axial spacers between the segments allows differential thermal expansion to take place without causing unacceptable distortion of the support structure. Aluminium was selected because it is lightweight, has a high thermal conductivity, is castable and minimises any damage to the containers.

Shock Absorbers

Shock absorbers are fitted at each end of the flask to protect it against end impacts. The lid shock absorber is constructed using pinewood with a stainless steel casing. The wood is held in place by a series of radial ribs to ensure the energy absorbing capability of the wood is fully utilised. The base shock absorber is manufactured in a similar way, but in this case the balsa wood is used as the energy absorbing media. Side impact protection is provided by the circumferential fins attached to the body, together with the enclosed neutron shielding compartments.

Figure 2: Vitrified Residue Waste Container

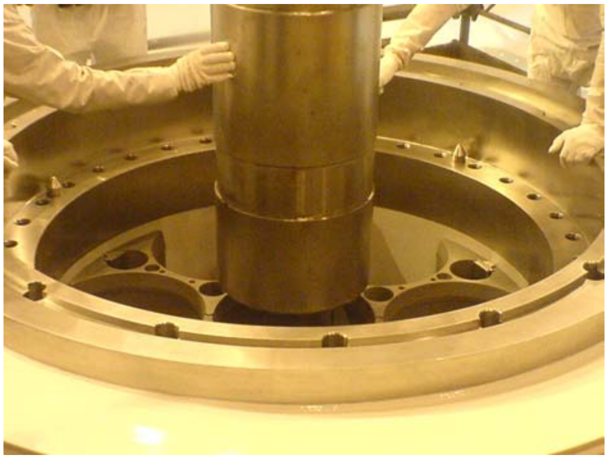

Figure 3: Segments Layer (prior to fitting at manufacture)

Figure 4: Segments and mandrel checking following fitting at manufacture

THERMAL DESIGN

The VRTF operates dry under all circumstances and, consequently, heat transfer from the contents to the flask body is affected principally by a combination of conduction and radiation. The heat radiates from the residue containers into the aluminium basket. Heat transfer is by radiation and air conduction across the narrow gap from the container to the segments and then by conduction into the flask walls. The heat is then conducted through the flask wall into the circumferential cooling fins, from where it is dissipated to the surrounding atmosphere. The fin geometry has been selected to give optimum heat dissipation capacity taking into account the combined effects of fin pitch, height and thickness.

The maximum decay heat load for the flask's contents defined in the UK licence will be 42 kW with the maximum decay heat load for an individual container not exceeding 2.5 kW. The Vitrified Residue can be stored for an indefinite period providing its temperature does not exceed 500°C. Consequently the flask's heat transfer systems are designed to ensure the residue never reaches this temperature when in normal transport or in long term storage. However, higher transient temperatures can be accommodated with temperatures up to 650°C and 750°C lasting for several weeks being acceptable for pessimistic accident conditions. The maximum calculated temperature under normal transport conditions is approximately 450°C. For the case of 2kW average heat load for all containers, the maximum waste temperature drops to approximately 400°C. The maximum accessible surface temperature at the fin tips is approximately 80°C (without insolation), which is below the Regulatory acceptable limit of 85°C. However, full side thermal guards may be fitted at the customers' request. The effects of a thermal accident, including consideration of the combustion of the shock absorber materials, have been considered with particular respect to the resulting temperatures of the lid and orifice seals, neutron shielding material, and the vitrified waste and its container. The maximum calculated temperature under a combination of the maximum flask heat load, highest individual central container heat load, an impact accident that causes the detachment of all segments and a fire accident with a week long "cooldown" is approximately 640°C for the residue. This temperature is below maximum allowable limits for short term transients. The neutron shield material does exceed operational limits; however, shielding assessments pessimistically assume total loss of the material in accident conditions.

MECHANICAL DESIGN

Stresses are generated throughout the flask's component parts by a combination of mechanical and thermal effects. The heavy-duty construction of the flask with its thick body shell and lid means that many of the stresses encountered are very low during normal transport and under accident conditions. Pressure within the flask will always be below 1 bara in normal operation, therefore pressure stresses are typically insignificant. Under thermal test (fire accident) conditions differential expansion occurs between the stainless steel and carbon steel components. A thermal stress analysis has been undertaken using finite element techniques to analyse transient temperature differentials, which give rise to thermal stresses and distortions. Distortions predicted in the lid seal area are applied to validate the seal performance.

IMPACT DESIGN

The ability of the flask to withstand the IAEA Regulatory Mechanical Tests is demonstrated by a combination of model testing and analysis. For the accident case where a 9 metre drop is combined with a 1 metre drop onto a rigidly mounted bar, the flask must be capable of retaining its radioactive contents and maintaining its shielding performance within prescribed limits. In addition, if the shock absorber is important for thermal protection, as with the lid shock absorber, then shock absorber retention shall be demonstrated. The wood filled shock absorbers fitted to each end of the flask and the external finned surfaces with enclosed neutron shielding material provide impact protection in the event of an accident. For accident conditions a series of 9m drops and 1m punch tests using ¼ scale models have been carried out supported by Finite

Element analysis. These demonstrate that containment is assured, the shock absorbers remain attached and the lid bolts remain elastic throughout the drop.

The main concern in terms of the flask's structural integrity is its behaviour when subjected to impact forces in a -40°C ambient temperature and with all components at –40°C i.e. an unloaded flask. To ensure that structural failure does not occur under such circumstances, materials which remain ductile at low temperatures have been carefully selected for the flask's vital components.

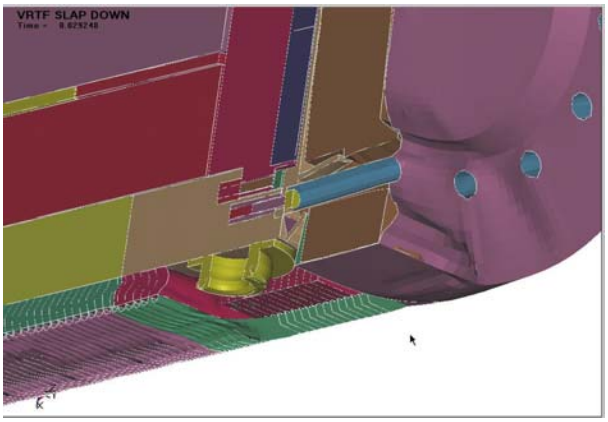

Figure 4. Side Drop – DYNA3D finite element analysis of lid end and shock absorber impact

Figure 5. ¼ Scale side drop and punch test of lid end and shock absorber impact

RADIATION SHIELDING DESIGN

One of the principal objectives of the shielding design is to achieve as far as practical a uniform dose profile around the flask whilst maintaining heat transfer performance and minimum laden weight. The quantity of residue in each container, the configuration of the 21 containers in the flask and the uniform activity of the residue, means that with the similar thicknesses of gamma and neutron shielding on the flask body and ends, a uniform dose profile is achieved. The gamma shielding is provided mainly by the thick steel shell of the flask whilst the neutron shielding is provided by a layer of enclosed boronated silicone rubber at the fin roots and at the ends of the flask. The maximum dose rates calculated are less than 47μSv/h at 2m from the surface and 828μSv/h at the trunnion surface, with both being less than half the Regulatory limits.

CRITICALITY DESIGN

The vitrified residue contains trace elements of fissile material and although the fissile content is very small, a criticality analysis has been performed to demonstrate that the flask's contents are safely sub-critical under all circumstances. Consequently the support structure does not contain any neutron poisons.

CONTAINMENT AND SEALS

The main containment is assured by the flask body and lid, which are bolted together using 36 high-tensile bolts. The joint between these components is sealed using a double elastomeric seal arrangement. The material selected, on the basis of its properties at the operating and thermal accident temperatures, is a specially formulate grade of Viton. The containment system is defined as:

- Flask body and welded base
- Flask lid, its inner lid seal and lid bolts
- Flask orifice plug and seal

The containment design intent is to ensure that under all normal conditions of transport the internal pressure remains sub-atmospheric thereby ensuring that there is no out-leakage from the flask and, therefore, no activity release. Normally the flask will operate with an internal pressure of less than 0.5 bara. After a transport period of one year followed be the regulatory accident the internal pressure is demonstrated to still be less than 1.0 bara. For the extreme condition of -40°C the seal in the flask remains effective albeit with an increased leakage. This increases the pressure rise in the cavity during the one week period at –40°C, but the cavity still remains below 1 bara. The lid seal is the most critical for long-term and accident behaviour. It has been predicted by calculation that even under the most severe accumulative conditions of thermal ageing, radiation dose, impact and thermal transient seal face separation; the seal compression will always exceed 10% - a UK Regulatory guide.

OPERATIONS AND COMMISSIONING

Operations

The VRTF is loaded at Sellafield within the purpose designed Residue Export Facility (REF). It is transported on site horizontally supported on its four trunnions. In REF, the flask is tilted to the vertical position and then lifted off the wagon using a vertical lifting beam attached to the trunnions at the lid end of the flask. Operations associated with the removal of the lid and the container loading of the flask is carried out remotely within REF. Once loaded, the flask undergoes pre-despatch leak testing, contamination and radiation checks. It is then transported to a temporary storage building to await offsite shipping. When transported off-site, the flask is placed horizontally on a railwagon where it is supported and secured by its four trunnions. The railwagon design is a flat bed requiring a purpose design transport frame. After Health Physics monitoring the flask is despatched from the building ready for onward shipment.

The VRTF is transported by rail from Sellafield to Barrow. It is then transferred, complete with its transport frame, onto a PNTL ship for the next leg of its journey to Japan. On arrival the ship goes directly to a port at the Rokkasho-Mura storage Repository where the flask is unloaded, complete with its transport frame on to a road vehicle and transferred directly into the Site. The empty flask is returned by the same route.

Commissioning

Following the manufacturer's functional trials of the first VRTF in December 2006, a commissioning programme was initiated to confirm the flask's operability at user ports, ships and facilities. The flask was transported to the International Nuclear Services ship terminal at Barrow in the United Kingdom. Ship fitting trials were performed successfully on PNTL's Pacific Sandpiper (Figures 6 and 7). The flask remained on the ship during a High Level Waste voyage to Japan, where it was successfully unloaded at the Mutso Ogawa terminal in March 2007 and transferred to Rokkasho Mura's nuclear site for storage. Full cold handling commissioning trials were performed in September 2007 within the High Level Waste storage facility. These trials simulated a full cycle of waste delivery, unloading and preparation for the empty return of the VRTF back to the UK. At the time of presentation of this paper, the VRTF is on route to the UK where further cold handling commissioning trials will be performed. On successful completion, active handling trial will be initiated in preparation for first use.

Figure 6: Transfer to PNTL Ship

Figure 7: VRTF within Ship's Hold

CONCLUSIONS

The Vitrified Residue Transport Flask (VRTF) has been successfully licensed to IAEA Regulations (ref 1) and issued with a B(U)F96 certificate by the United Kingdom Department for Transport. The flask will be used to transport high level waste, in the form of vitrified residue within stainless steel containers, from the United Kingdom to Japan. The first flask was manufactured in December 2006 and has undergone cold handling trials at UK and Japanese ports, and at the high level waste storage facility in Japan. Following commissioning trials in the UK, the flask will be used for subsequent waste transports.

ACKNOWLEDGMENTS

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REFERENCES

1. Regulations for the Safe transport of Radioactive Material, IAEA, TS-R-1, 1996 Edition.