DEVELOPMENT OF THE BNFL VITRIFIED RESIDUE TRANSPORT FLASK

Richard Gowing [1], Ian J Hunter [2], Anthony R Cory [2] and Masao Ohashi [3]

[1] **British Nuclear Fuels plc, Risley, UK**
[2] **Nuclear Transport Limited, Risley, UK**
[3] **Mitsubishi Heavy Industries Ltd., Tokyo, Japan.**

Introduction

The development and design by Nuclear Transport Limited (NTL) of the BNFL (British Nuclear Fuels plc) Vitrified Residue Flask for returning high-level waste to its country of origin has been described elsewhere (Gowing and Cory 1989) with the most recent and detailed account being given in 1991 at Bournemouth (Coulthart et al 1991). In this paper recent developments in the design, procurement and approval of the flask are described.

Design Summary

As shown in Figure 1, the flask body comprises a cylindrical shell and base manufactured from forged carbon manganese steel, with a stainless steel lid bolted into it. Silicon rubber neutron shielding is encapsulated in compartments at the flask ends and between the cooling fins. Removable shock absorbers are bolted to both ends, and two pairs of bolted trunnions are fitted for lifting and tie-down. The flask carries 21 vitrified residue containers in a support structure made up of 30 cast aluminium segments secured by a bolting system to the internal flask cavity. This assembled support structure forms seven circular channels to receive the vitrified residue containers.

Thermal Design

The Vitrified Residue Flask is designed to carry a heat load of 42 kW, whilst maintaining a fin-tip temperature of less than 85°C under IAEA regulatory conditions. The heat generated by the 21 residue containers is dissipated through an aluminium basket structure in the flask cavity to the flask wall. On the external surface of the flask, circumferential fins are welded at a pitch of 40mm to give an extended surface for heat transmission to atmosphere.

The internal aluminium basket structure comprises 30 separate segments arranged in 5 layers in the flask cavity. Each segment is clamped to the flask wall by 3 bolts; the outside radius of each segment is made slightly larger than the flask bore radius to ensure intimate contact when the attachment bolts are tensioned. The segments are cast in such a shape as to form seven circular channels to locate the residue containers. The segments are anodised to enhance heat transfer, increasing the surface emissivity values to around 0.9, and the internal surface of the flask is aluminised.

The external circumferential fins extend through a layer of neutron shielding material, which is effectively enclosed in compartments between the fins, having a radial height equal to some 60% of the fin depth. Hence only 40% of the fin depth is used as an extended surface for heat transfer; nevertheless this has been shown to be more than adequate. The fins are manufactured from carbon steel for efficiency, with a thickness of 6mm to reduce weight, and are finished with a high specification paint system.

In the early stages of design development it was appreciated that the flask internals represented a departure from established practice and would therefore require some practical development to prove viability. Initially a test rig was manufactured to demonstrate the effectiveness of the clamped connection during repeated heating and cooling cycles; it was considered essential to show that no significant reduction of clamping effectiveness was to be expected in service. Secondly, a further test rig was used to investigate heat transfer between the inner surface of the segment, adjacent to the residue container, and the flask wall, with specific attention given to temperature drop at the clamped boundary surfaces. These two trials, conducted at AEA Winfrith during 1987 gave confidence to proceed to the next phase of development, a full scale thermal test rig.

A full scale section of the flask internals, 2 segments deep, was constructed, clamped in a heavy steel cylinder representing the flask body. Cylindrical heaters simulating residue containers were introduced into the rig. The heat output of each heater was variable upto a maximum equivalent to a 2.5 kW residue container, to enable the effects of a wide range of heat loads and asymmetric heating scenarios to be investigated. An empty residue container was introduced and withdrawn from each of the channels in turn to demonstrate satisfactory clearance and low geometric distortion caused by asymmetric heating. The rig was instrumented with many thermocouples to obtain temperature data to verify thermal performance of the flask internals. This trial was successfully concluded at AEA Winfrith in 1988.

Complementary to practical tests, a full thermal analysis was carried out by NTL using the 'TAU' finite element code from the 'UNCLE' suite of programmes. The results of this analysis showed good agreement with the results of the rig trials, and gave confidence to proceed with all aspects of the flask concept as far as thermal design was concerned, towards detail design.

The external finned surface of the flask largely follows established practice with circumferential steel fins. There is an abundance of published data concerning this type of extended surface heat transfer, and it was considered that behaviour could be predicted with sufficient accuracy by theoretical analysis alone without resort to practical trials.

Leak Tightness

The development of firstly a case and secondly an analysis for leak tightness of the Vitrified Residue Flask has been a significant departure from established practice. In order to present a case for a dry flask carrying highly radioactive material, some considerable degree of original thought has been necessary.

The vitrified residue is contained within the flask in 21 stainless steel containers, sealed by automatic remote welding. Such is the nature of the filling process that these welds cannot be fully inspected and hence are not of guaranteed integrity. Whilst all indications from the Sellafield facility are that perfectly satisfactory welds are consistently being made, it was agreed that for the purposes of analysis an initial assumption would be that the weld was considered to have failed for all 21 containers. Hence all radioactive material present in the container plenum volumes is considered to be distributed throughout the flask cavity.

Initial supporting work included an analysis of the container plenum space by BNFL Safety Section, and a practical trial undertaken at Sellafield. It was decided to transport the flask at a reduced internal pressure, to give additional assurance that any anticipated leakage would be inwards. (A supplementary analysis has demonstrated satisfactory leak tightness is maintained even if the flask cavity is maintained at atmospheric pressure.)

The design brief for the flask specified that the requirement of a B(U) licence should be met, which required in turn that careful consideration be given to the flask sealing requirements at a temperature of -40°C. A number of materials were considered for 'O' ring seals, including silicone and

EPDM. When consideration of factors such as permeability and performance at higher temperatures was made, some of these materials were found to be less than ideal. In most respects Viton performs well, but undergoes a transition at -25°C below which its ability to seal effectively is much reduced. However, recent work (Burnay and Nelson, 1991) quantifies this reduction in performance, and it was found that at temperatures below -25°C down to -40°C, Viton could be shown to satisfy the leak tightness requirements of the Vitrified Residue Flask.

Assessment of radioactive material release showed that the only conditions for a positive release to atmosphere occurred when an atmospheric pressure of 0.25 bar absolute was considered; in this unlikely event, combined with the increased seal leakage at -40°C, activity release was shown to be well within regulatory limits.

As an extension of the main analysis, leak testing criteria were calculated for the flask, based on an SLR for the whole flask of 1×10^{-4} bar cc/sec. This determined pressure drop criteria for lid seal interspace and orifice interspace in the range of 0.09-0.25 bar/hour, figures considered easily measurable. Similar criteria were applied to the model flask to check containment integrity following impact testing.

The result of all work performed in support of the leak tightness case was to demonstrate that for all cases considered the requirements of IAEA Safety Series 6 were comfortably met. It is emphasised that many conservative factors have been applied in this assessment and that the conclusion is very much a 'worst case' consideration.

Impact Design

The Vitrified Residue Flask will be one of the largest and heaviest flasks operated by BNFL. In order to keep weight and dimensions within the limits which can be transported and handled with existing equipment, certain features have undergone a more extensive process of design optimisation than many smaller flasks. The development of impact limiters/shock absorbers and their attachment to the flask is a case in point.

The flask cavity diameter is larger than most fuel flasks, and due to the radiological characteristics of the contents the finned neutron shielding on the outside of the flask is extended almost to the flask ends. This has meant that the amount of external spigot engagement for the impact limiters/shock absorbers is minimal compared with fuel flasks, and that the flask trunnions have been pushed out to the extremities of the flask body. Impact limiter design and attachment has therefore departed somewhat from established practice, and some development work has been undertaken.

In the case of the flask base, the trunnion location is provided on an extended 'skirt' to the cylindrical body; this leaves a recessed base and the impact limiter is designed to be partially located in this recess. Hence an effective internal spigot location is provided to resist shearing forces. The impact limiter is retained by eight bolts to the body skirt. As the flask base contains no orifice, the duty of the base impact limiter is concerned mainly with limiting the deceleration of the flask contents in the event of an accident.

It is the lid end impact limiter which has accounted for the bulk of the design development work. Initially, the design followed established practice as far as possible, being a balsa filled stainless drum, with shear dowels added to compensate for the reduced overlap or engagement over the flask body. Eight bolts were used to retain the impact limiter.

Having established the preliminary design, a programme of impact testing using a quarter-scale model was agreed with the UK Competent Authority and with MHI. The programme was carried out at Nuclear Electric's Structural Test Centre in Cheddar, Somerset. In addition to model testing, a programme of analytical support was commenced by BNFL's Engineering Technology Support Group.

Early results proved encouraging, the flask passing the normal tests for lid, base and corner impacts during Spring 1991. The trunnion design was modified to promote collapse, and hence reduce the punching effect on a vulnerable area of the flask during the horizontal drop. Following this modification the horizontal drop was successfully carried out.

Discussions with MHI, confirmed by analysis, showed the potentially most damaging drop attitude to be an oblique corner drop, where the flask centre of gravity is not centred over the point of impact, and consequently a rotational force is induced. Having established a precise attitude, the test was conducted, during which the lid impact limiter was separated from the flask. Although the flask containment was subsequently found to be intact and the flask damage minimal, the loss of the shock absorber left the lid vent orifice vulnerable to punch impact, and the test was not considered a success.

Redesign of the impact limiter at that stage was limited to an improvement of the shear engagement to the flask, by providing an internal spigot. As flask damage had been minimal, the impact absorbing material itself was considered to be adequate. A new model shock absorber was made and the test performed again in September 1991. This time the impact limiter was retained in position, but with considerable damage to the attachment and the 'corner' of the flask body. Although the containment integrity of the flask was shown to be within acceptable levels, the extent of the damage was considered too great for the test to be considered successful.

The necessity for a more fundamental change in the lid impact limiter design was at that stage indicated. Discussions took place extensively between NTL, BNFL and MHI. By mid-October a revised design was established. The characteristics of this design were:

1. Pine wood replacing balsa as an infill material with greater energy absorbing potential.
2. Increased depth of shock absorber + 25%.
3. Further improvements to the internal spigot to increase shear resistance.
4. Attachment bolts increased from 8 to 16, of an improved design with greater resilience.

As the characteristics of the impact limiter were somewhat changed, it was decided to undertake a programme of three further tests, to include the lid face and corner drops. These tests were undertaken during the Spring of 1992 and were completely successful. The design of the flask was subsequently changed to reflect this development.

<u>Development of Neutron Shielding Material</u>

The Vitrified Residue Flask Design incorporates KSL (Kobe Steel Limited, KOBESH type neutron shielding material (Nodaka, 1992) in special compartments between the external circumferential fins, in the lid and in the base. Each compartment allows for expansion of the material but extensive thermal testing of the material over appropriate periods at expected operational temperatures has shown that the material decomposes to some extent discharging gaseous molecules. It has been shown in some operational cases that this could lead to high pressure generation in the compartments and so a need for pressure relief has been identified.

Shielding calculations of the flask have indicated adherence to dose rate criteria for 5% decomposition of the material and loss of hydrogen. However, thermal stability tests performed on the material over reasonable intervals of time have indicated that loss in neutron shielding performance over a typical flask life of 20 years due to gas release would be appreciably less than 5% at 150°C.

At this time consideration of different methods for introducing the neutron shielding material into the fin compartments is underway. Material pouring is favoured and trials will be performed for different flask orientations and damming arrangements in order to determine the most effective.

MHI Involvement and Collaboration

At an early stage of the project, BNFL recognised the need to form a technical collaboration with a Japanese organisation to enable the precise requirements of the Japanese licensing authorities to be both understood and complied with. Discussions with the Overseas Reprocessing Committee (ORC) representing the utilities commenced in 1988 and were followed by further meetings with MHI. BNFL concluded a contract with MHI for a formal check and review process prior to design submission to JMOT (Japanese Ministry of Transport) in 1993.

During the detail design phase of the flask, some changes to the design were instigated as a result of design review by MHI, mainly concerned with shielding details and improvements to impact performance. Japanese shielding requirements, for example, exceed those of the IAEA and have required considerable depth of analysis to be undertaken. MHI and ORC representatives witnessed the most critical of the impact tests conducted at Cheddar in order to provide if necessary a first-hand independent account to JMOT.

In addition, MHI have been involved with the demonstration testing at CRIEPI's Yokosuka site of a 'hybrid' flask incorporating features of the BNFL design and the French TN28V (Ito 1992, Kirchner 1992).

Conclusion: Approval, Procurement, Commissioning

The full application for Type B(U)F approval was submitted to the UK Department of Transport (DTp) in July 1991, and approval is expected shortly. DTp's assessors have witnessed the impact tests, and modifications resulting from these and from manufacturing trials with the externally similar Excellox 6 (Gowing & Purcell 1992) have been applied to update the submission. MHI have nearly completed their review and will, in conjunction with ORC, submit their adapted safety case with the completed UK approval to the Japanese authorities with a view to getting their approval about the end of 1993.

Tenders for the first flasks have now been invited and contracts are expected to be placed early in 1993 for delivery early 1995. Meanwhile the export facility at Sellafield is nearing completion, as is the receipt facility at Rokkasho-mura, ready for cold handling trials of the flask during 1995 and the first shipments of vitrified residues to their country of origin in early 1996.

References

BURNAY, S and NELSON K. Leakage of Transport Container Seals during Slow Thermal Cycling to 40°C. International Journal of Radioactive Material Transport, Vol 2 No 1/3, 91-96 (1991).

COULTHART D R, EMMISON J and CORY A R. The BNFL Vitrified Residue Transport and Storage Flask. Ibid Vol 2 No 1/3, 23-31 (1991).

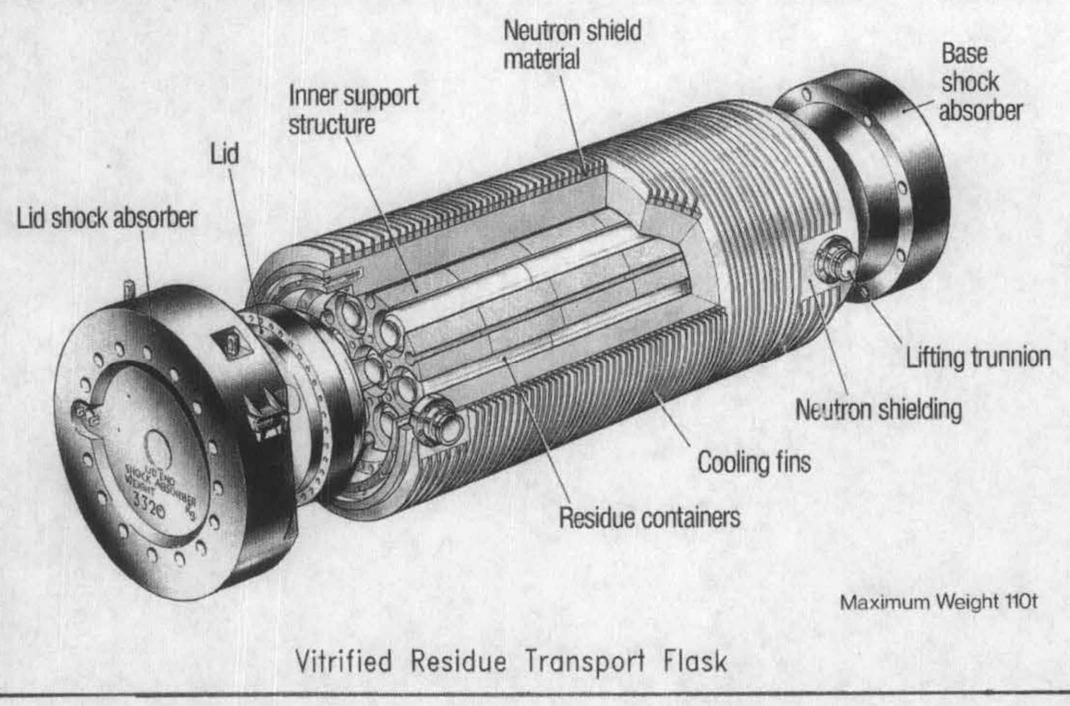
GOWING R and CORY A R. Developing a Flask for Vitrified Waste. Nuclear Engineering International, September 1989, 38-40.

GOWING R and PURCELL P C. Further Experience and Developments in the Transport of Spent Fuel. This Symposium, Paper 12-2, 1992.

NODAKA M., TANIUCHI H., YOHIMURA K., NAGAHAMA H. Neutron Shielding Material Applicable for Advanced transport Packaging. PATRAM '92. Poster Presentation Yokohama, Japan, 1992.

ITO C. Drop Test of Demonstration Test Cask for Transporting Vitrified High Level Radioactive Wastes. This Symposium Paper 34-4, 1992.

KIRCHNER B. Operational and Safety Aspect of the Vitrified Waste Packaging. This Symposium Paper 38-3, 1992.



Vitrified Residue Transport Flask

Session 14:

RISK ASSESSMENT-II

Chairman : F. Lange
Co-Chairman : S. F. Wang
Coordinator : K. Shirai