FURTHER EXPERIENCE AND DEVELOPMENTS IN THE TRANSPORT OF SPENT FUEL

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INTRODUCTION

At PATRAM '89 I described (Gowing 1989) the flasks used by British Nuclear Fuels plc (BNFL) and its subsidiary Pacific Nuclear Transport Limited (PNTL) for transporting spent LWR fuel from Japan to Sellafield and gave statistics on their use. In this paper the statistics will be updated and developments in operation and licensing reported.

Transport of spent fuel from Japan started in 1969 with the Magnox fuel from Japan's first nuclear power station. The special features of the flasks used for this are described and experience of their handling summarized.

To meet future requirements for the transport of spent LWR fuel of higher burnup and initial enrichment, new flasks are required and progress with the design, licensing and procurement of these is described.

EXCELLOX 3, 3B AND 4 FLASKS: FURTHER EXPERIENCE

Design: a recapitulation

The Excellox flasks in use have a welded carbon steel shell with circumferential cooling fins and a steel encased lead liner. Spent fuel is carried in a multi-element bottle (MEB) holding 5 or 7 PWR assemblies or 14 BWR assemblies. Neutron shielding is provided by the water inside the MEB and in the annuli between the MEB and liner and the liner and flask shell. Additional neutron shielding to compensate for the ullage is provided for BWR fuels by an external strapped on jabroc blanket and for PWR fuels by using a multi-chamber MEB, with the fuel chamber filled with water which expands into a separate ullage chamber. Further details are given in my 1989 PATRAM paper (Gowing 1989).

Spent Fuel Deliveries

PNTL's fleet of 3 Excellox 3 72 ton gross flasks (72 assemblies), 51 74 ton gross Excellox 3B flasks (14 BWR or 5 PWR assemblies) and 26 Excellox 4 92 ton gross flasks (7 PWR assemblies) have continued to give trouble-free service and to operate well within their design limits. To the end of August 1992 the total of deliveries using these flasks has risen to 10,129 fuel assemblies in 869 flask loads, comprising 8,382 BWR assemblies in 602 loads and 1,747 PWR assemblies in 267 loads, or about 2,250 tonnes of irradiated uranium in 3,500 tonnes of fuel assemblies, in the course of 19 years of incident free transport.

Radiation

Radiation levels from the flasks have continued to be low, well within the requirements of the local and international regulations. Since the flasks are licensed against the 1973 regulations a neutron quality factor (NQF) of 10 is applied.

A recent review has shown that all shipments so far would have satisfied the regulations if an NQF of 20 were applied, and further indicates that flasks loaded with fuels of full contract specification (up to 30 GWd/t average irradiation for BWR, 40 for PWR) would probably still comply. This demonstrates the conservatism of the original shielding calculations and confirms the continuing licensability of the flasks should these higher standards be applied to grandfathered packages.

Criticality

Shipment of fuel from Japan's first PWR required use of the Excellox 3B since the Excellox 4 normally used for PWR fuel is outside the handling capacity of that plant. The criticality case was based on an assumption (Clemson and Watmough 1989) that 4% of the fuel content would disintegrate in a flask impact to form a moderated suspension. However, it was found that this material could form a critical assembly in the unlikely event of its migrating into the unpoisoned separate ullage chamber of the MEB.

A review was set in hand to examine the 4% fuel breakup criterion, meanwhile as an expedient the dissolved boron present in the PWR pool water, with which the flask and bottle were filled when loading the fuel, was taken into account. Subject to stringent analytical and operational controls to confirm and maintain this boron in the package, this enabled the shipments to take place, meanwhile the review (Watmough 1992) of fuel breakup under impact conditions produced a figure which eliminated the critical mass in the unpoisoned chamber. The two PWR package designs for which we have approval are licensed to carry one leaky fuel assembly, containing not more than 5 leaky pins, per flask loaded with 5 or 7 assemblies.

A similar review is to be undertaken for BWR fuel, although the problem of a separate unpoisoned ullage chamber does not arise and nuclear safety is assured even though it is at present based on an old assumption of 10% fuel breakup at impact.

Gas Generation and Flask Pressurization

At PATRAM '89 I showed (Gowing 1989) how we had reviewed gas pressure and composition data to provide an acceptable maximum normal operating pressure (MNOP) OF 60 psi (414 kPa) gauge for the Excellox 4 PWR package. A similar review of BWR shipment data produced an MNOP of 85 psi (580 kPa) gauge. These MNOPs resulted in peak pressures well within the capacity of the flasks, and they were recognized by the UK competent authority's issue in October 1990 of certificates for all of these packages in which the former requirement for pressure measurement at intervals was deleted. This has enhanced the safety of the shipments by eliminating the breaking of containment and exposure to radiation inherent in these checks. Periodic monitoring of gas compositions and pressures in flasks and MEBs received at Sellafield has continued to confirm the validity of this assessment.

Leakage Assessment

At PATRAM '89 (Hunter et al. 1989) we described our attempts to reconcile our operational leak tests with the stringent requirements of the IAEA regulations and concluded that the adoption of a 2-tier assembly verification system (ANSI N 14.5, 1987) offered the most practical and sure way of demonstrating leaktightness. However, competent authorities proved reluctant to agree to such a system that did not depend on direct verification of an acceptable leak rate at each shipment.

The pressure drop method in routine use depends on pressurising the interspace between two seals. Any pressure loss during the test would be through the outer seal to the environment, and through the inner seal back into the flask, i.e., in parallel. The actual leak path for the flask is from the interior through the inner seal to the interspace, then through the outer seal to the environment, i.e., in series.

The reduction by a factor of 4 between the leak rate as measured with the seals in parallel and the actual situation with the seals in series has proved sufficient for the routine interspace pressure drop leak test to give a satisfactory demonstration of flask leaktightness.

Continuing Use

The Excellox 3, 3B and 4 flasks have recently received new Type B(M) Fissile approval certificates from the UK competent authority which are valid till mid 1995. These are for Package Design against the 1973 (As Amended) IAEA Regulations as permitted by Paragraph 714 of the 1985 Regulations.

With their continuing excellent performance and regular maintenance the flasks can be expected to remain in service with full approval to be available for other work on completion of the present spent fuel transport contracts in 1998.

TOKAI MAGNOX FLASK

Introduction

BNFL pioneered intercontinental spent fuel transport in 1969 with the shipment of Magnox fuel from Tokai No. 1 Power Station. The 12 flasks now in use were introduced in 1984 to replace the first set of Tokai flasks whose design was based very closely on those used by the CEGB (Central Electricity Generating Board, now Nuclear Electric) since the early 1960s.

Design

The present design of flask is shown in Figure 1. The only significant difference from the current Nuclear Electric design (Barnfield and Pannett 1992) which was introduced at the same time is the addition of extra shielding to the lid, to reduce the transport index to less than 10 in compliance with Japanese regulations. To thicken the steel lid where the extra shielding was needed would have increased the package weight and invalidated the CEGB's drop tests. The solution was to attach a balsa-in-steel shock absorber which provided the required extra shielding and at the same time compensated for its extra weight by its impact limiting properties. This shock absorber is bolted to the four corner lugs on the lid, one of the bolt holes having a lockable cover to prevent unauthorized access to the lid bolts.

Transport

To minimize corrosion of the Magnox cladding during the long sea voyage, these 50 ton flasks are carried in tanks in the ships' holds, in which water cooled to $22^{\circ}C$ is circulated.

Each tank is fitted with a lid to retain the cooling water, with an aperture by which periodic readings are taken of the flask pressure which is then vented to atmosphere via filters from the mast head. The upper removable decks of these holds carry Excellox flasks.

For rail transport between Barrow and Sellafield, the same 160 ton gross 8 axle wagons are used as for the Excellox flasks, fitted with a transport frame to hold two Magnox flasks.

__Experience in Use__

From the first shipment in 1969, to the recent delivery in August 1992, a total of 379 flask loads bearing nearly 1100 tonnes of uranium have been safely delivered to Sellafield. The routine pressure checks during the sea voyages have never shown any abnormal readings. Those taken on the latest voyage which arrived at Barrow on 27 July this year are typical, with a maximum recorded pressure of 7 lbf/in^2 (48 kPa).

The UK certificate of approval was recently renewed, still against the 1973 IAEA Regulations under the grandfathering provisions of the 1985 regulations, and it is envisaged that these flasks will continue in service on this basis for the remaining life of the Tokai power station.

NEW FLASKS: EXCELLOX 6 AND 7

__The need for new flasks__

The PNTL flasks referred to in the first part of this paper and similar flasks operated by Nuclear Transport Limited (NTL) are at present in use to carry spent UO2 fuel at assembly initial enrichments up to 3% (BWR), or 3.8% (PWR) with burnup up to 45 GWd/tU.

These fuel specifications are near the limit for the existing flasks, and to carry the high burnup and mixed oxide fuels now being irradiated a step change to the design has been found necessary. The Excellox 6 and 7 design resulting from this change is the subject of the remainder of this paper.

__Excellox 6 and 7 Flask design__

A full account of the development and design of the new Excellox flasks was given at the Bournemouth international conference in 1991 (Purcell and Coulthart 1991).

The new design (Figure 2) takes advantage of advances in forging and fabrication techniques to allow the adoption of a monolithic body with a forged carbon-steel shell providing all the gamma shielding. This thick shell allows the lid to be bolted directly into it, improving the strength and protection of the lid joint. Discarding the lead liner makes the flask easier to decontaminate and maintain, and the snug fit of the MEB transfers the ullage to the space between MEB and flask lid when the flask is standing vertical. This enables the water level valve to be placed securely under the protection of the lid shock absorber.

Balsa-in-steel shock absorbers enclose the lid and base ends and all penetrations, and the transport frame supports the flask by the four lifting trunnions. To cater for the wide range of fuels to be transported, the new flask has been designed in two lengths: Excellox 6 which can carry fuel assemblies up to 5.0m long and Excellox 7 for 4.5m fuel. The flasks have maximum loaded weights of 97 and 89 tonnes respectively and are thus compatible with the existing transport systems operated by PNTL and NTL. An extra pair of "secondary" trunnions is provided to fit BNFL's THORP receipt pond.

Neutron shielding formerly provided by the water annulus outside the lead liner is now effected by an exterior layer of boronated silicon rubber located between the cooling fins. This can be made thicker on the upper cylindrical surface to allow for the ullage, and it is thicker all round on the Excellox 7 which has to cater for a neutron quality factor (NQF) of 20 to meet Japanese requirements. This arrangement for shielding and fins allows for the transport of BWR fuels of up to 40 GWd/tU burnup, 35 MW/tU specific power and PWR fuels of up to 50 GWd/tU burnup, 40 MW/tU specific power with cooling periods from 12 months based on thermal loading of 40 kW for the Excellox 6 and 35 kW for the Excellox 7. The lower heat output for Excellox 7 is caused by the reduced area of fins projecting from the thicker neutron shield as well as the half meter shorter finned area of the flask.

Multi-Element Bottles

A new design concept of MEB will be used. This has a removable basket of slotted boronated stainless steel plates held together by a bolted spider and stainless steel bands, which can be dismantled and decontaminated then either reassembled for reuse or packed for disposal. The new design (Figure 3) allows increased pre-irradiation enrichment using the conventional rectilinear arrangement of fuel compartments, to cater for the maximum BWR enrichment, while a new arrangement with the compartments grouped radially around the centre allows for a major increase in enrichment for PWR fuels. These increases will also cater for the transport of MOX fuels.

Key fuel load parameters

	Excellox 6 PWR	Excellox 7 PWR	Excellox 7 PWR
Maximum enrichment (%)	4.5	4.5	3.8
Maximum fuel element length (m)	5.0	4.5	4.5
Maximum fuel element cross section (mm)	230	216	140
Maximum irradiation ($MW.d.tU^{-1}$)	50000	50000	40000
Maximum specific power ($MW.tU^{-1}$)	40	40	35
Maximum weight of uranium per assembly (kg)	551	458.4	200

Present Status: Development, Approval, Procurement

Package Design Safety reports have been prepared and full submissions made to the UK competent authority for approval of both flasks carrying PWR fuels and Excellox 7 carrying BWR fuels in rectilinear array MEBs as type B(U) Fissile, followed by supplementary submissions for radial PWR MEBs in both flasks. UK competent authority staff witnessed the programme of impact tests which were carried out on quarter-scale models of the heavier Excellox 6 in 1990, and at full scale on the new MEB structures, in both rectilinear and radial arrays. Following the impact tests in 1991-92 on the externally similar vitrified residue flask (see Gowing et al. 1992) the attachment of the shock absorbers to the lid and base of the flask was refined.

An initial order has been placed for three Excellox 6 flasks, for service early in 1994 to carry PWR spent fuel from Germany to Sellafield. The bodies have been machined and assembled from the forgings, and trials of fin welding have taken place, resulting in minor changes to the welding detail design. Consideration of the properties of the neutron shielding material (see Nodaka et al. 1992) has led to changes in the arrangements for thermal expansion and pressure relief in the fin compartments. Details are given in our paper on the Vitrified Residue Flask (Gowing et al. 1992).

Since the Excellox 6 and 7 designs have so much in common, the UK competent authority's staff have been assessing them together; approval of Excellox 6 with radial MEB is expected towards the end of 1992, to be followed closely by Excellox 7 and the other package make-ups submitted. The UK approval for Excellox 6 will be immediately submitted to the German and French competent authorities for Fissile validation, so that the necessary approvals are in place when the flasks enter service early in 1994. Meanwhile the Excellox 7 design is being reviewed by consultants in Japan in preparation for submission to the Japanese competent authorities for validation or approval.

Conclusion: new flasks

New flasks have been designed to carry the spent fuels arising during the next few years and into the next century. Procurement and approval of the first of these are well advanced in preparation for first service in early 1994.

SPENT FUEL TRANSPORT: CONCLUSION

More than 100 flasks in use by PNTL and NTL to transport spent fuel from Japan and continental Europe to Sellafield are continuing to give good service, and new flasks are being procured to service the more advanced fuels now beginning to be offered for transport.

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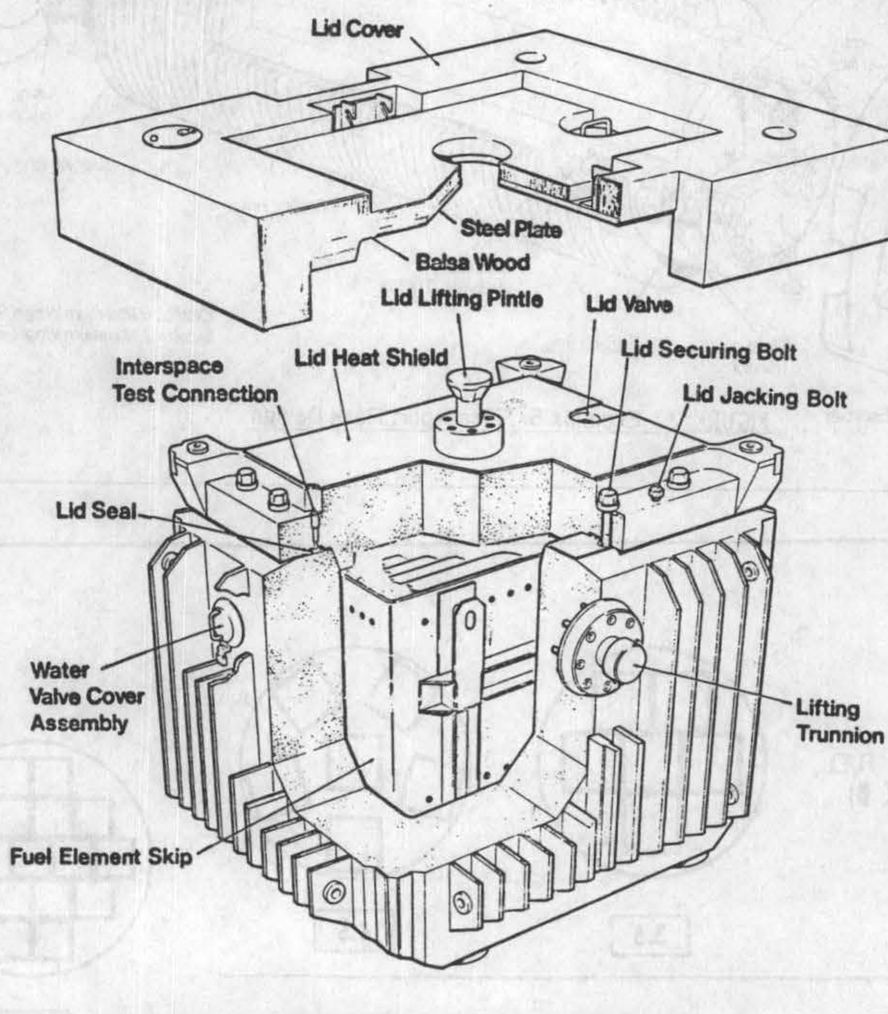

FIGURE 1. TOKAI MAGNOX FUEL FLASK

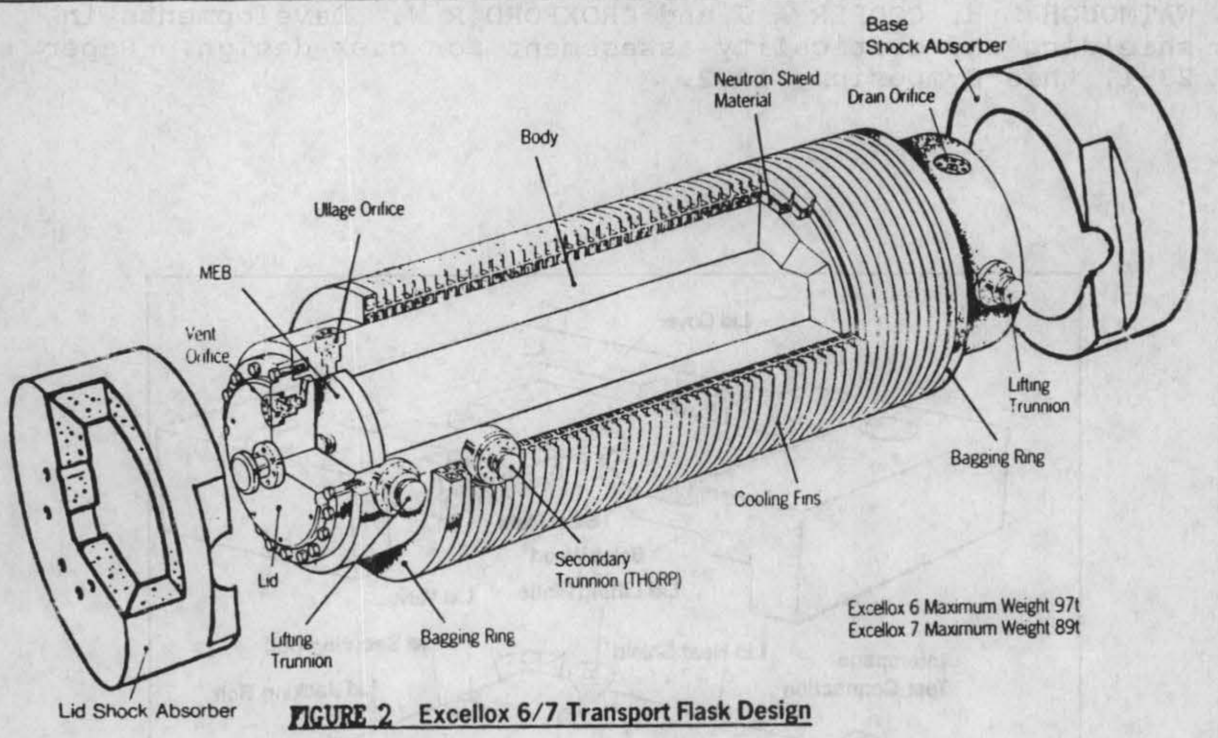

FIGURE 2 Excellox 6/7 Transport Flask Design

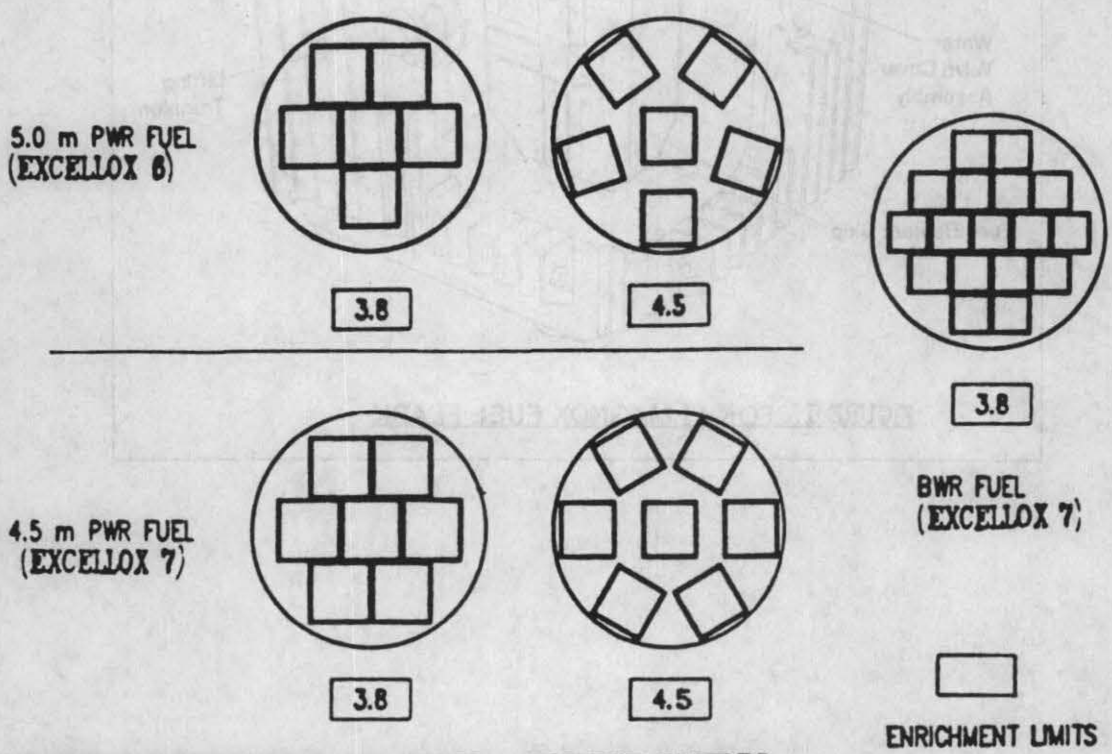

FIGURE 3 EXCELLOX 6 & 7 MULTI - ELEMENT BOTTLES.