Design of a New Air-Transportable Plutonium Container

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1. Introduction

Transport of Plutonium arising from reprocessing plants and the transport of fresh fuel, mixed plutonium and uranium oxide (MOX) and fast breeder reactor (FBR), to nuclear power plants plays an essential part in the nuclear fuel cycle.

Plutonium transport dates back to the beginning of the nuclear industry but with the development of reprocessing plants and the consequential increase of its production, plutonium transports have recently reached an era of industrial development characterised by BNFL's 1680 container which incorporates techniques specially designed to:

- prevent criticality
- provide adequate protection against radiation and thermal effects (gammas, neutrons)
- provide a high degree of containment
- allow automatic handling (for the reduction of exposure to personnel)
- guarantee high levels of physical protection

Though the size and shape of all packaging for the transport of plutonium in its many forms may vary, each is designed with two basic tenets in mind. Firstly that the plutonium is contained in an essentially leaktight vessel, and secondly that the containment vessel is protected, so that in the event of an accident the integrity of the containment vessel is maintained within regulatory limits.

The need for a new container to serve the Company's Thermal Oxide Reprocessing Plant (THORP) was identified in 1979. Two key requirements were that it should have the capability to be loaded remotely and strong enough to meet anticipated additional regulatory requirements. In 1983 the decision was taken to design the container to meet the US NUREG requirements so as not to restrict the container's use in international transports. Initially a 4-channel, 12-can design was considered but this proved to be too large and heavy for the envisaged transports and also the designers were of the opinion that the high impact test would be too demanding on such a container. Accordingly the 1680 design was adopted, the 4 channel, 8-can specification giving a payload of around 50kg plutonium dioxide. From an early stage in the development programme the 1680 was thus designed to meet the IAEA requirements and, with a shock absorber, to be inherently strong enough to meet the NUREG requirements.

2. Principal Factors Considered in the Design of the BNFL 1680 Container

2.1 Containment - Setting the Leak Rate Standard

The requirements of the IAEA regulations (1), with regard to the standards of leaktightness, are very onerous for plutonium. With the mixture of isotopes derived from reprocessing of LWR fuel, the regulations restrict the allowable leakage of plutonium dioxide to approximately 0.004 _g/h under normal conditions of transport, and to 3mg/week under accident conditions.

Using experimental correlations between the gaseous leakrate and the possible loss of particulate radioactive materials is the classical method for determining the level of leaktightness of the package containment vessel. In this scenario the value for the ratio of plutonium to gas assumed to be leaking (aerosol density) is most important. Experimental work (in this area) by Curren and Bond (2) and Yesso et al (3), led BNFL to pursue an alternative approach. This was to consider particle sizes in relation to the dimensions of the leak path, similar to the analysis used by Anderson (4), but defining a "critical crack" whose dimensions are chosen to coincide with the dimensions of the particle under consideration. From this, and using appropriate formulae, a gas flow can be deduced which, if not exceeded during testing, is proof that the system has no leak paths large enough for particles to escape. In the case of the BNFL welded storage can, this value is 1×10^{-5} bar cm^3 S^{-1}, and is a value accepted by the United Kingdom Competent Authority.

2.2 Development of the Containment Vessel

Stainless steel cans with welded lids are preferred by BNFL for transport and storage. The welding procedure is subject to a stringent quality assurance regime and the resultant standard is similar to that used in the manufacture of fast reactor fuel elements. The containment vessel currently used by BNFL is a 153mm dia can which has been tested to withstand high internal and external pressures. The lowest internal pressure at which failure occurred has been 2.5 MPa and the system has withstood external pressures of 5 MPa. In addition the containment vessel has been subjected, without loss of containment, to impacts in which the average decelerations exceeded 3000g. It is worthy of note that this is five times the average deceleration to which a "black box" flight recorder is tested (5).

Future internal packaging developments will lead to the replacement of the aluminium inner bottle in current use by a stainless steel screw-lid can which itself is sealed within a stainless steel cylinder. To achieve this packaging system BNFL has developed a novel method which utilises a laser cut and weld sequence. This cylinder replaces the polythene bag presently used for "bagging out" of a glove box and is nominally contamination-free. The associated outer can will have alpha-numeric identification characters engraved on the outer surface, and a series of grooves cut into the intermediate cylinder which can be read electronically, thereby enabling identification of the contents without having to remove the outer can. Prior to final welding the outer can will be helium filled and leak tested. The objective of this development work has produced a strong and demonstrably leaktight storage containment vessel and also reduced the amount of non contaminated waste for final disposal.

2.3 Criticality Considerations

The earliest designs of plutonium packagings were dictated by the features incorporated in the package to ensure a criticality incident would not occur. Compliance with the regulations regarding the safe transport of fissile materials was guaranteed by the provision of a suitable shield which incorporated a moderating material. Most of these packagings also used a material which had a large capture cross-section for thermal neutrons placed between the moderator and the fissile contents. BNFL's choice for the moderator material in the 1680 container was, as in previous designs, a hardwood, whose properties were well known and could be verified during the early stages of the development programme.

2.4 Designing for Thermal Resistance

An additional benefit derived from the use of wood as a shield is that it affords, provided it remains encased, a high degree of fire protection. The IAEA Regulations require a packaging to be subjected to a high temperature environment, averaging 800°C, for a period of 30 minutes and for the package to retain containment integrity and shielding. The amount by which the wood shielding is expected to be charred is a major design criterion. Results of experimental work(6), demonstrate that a 25mm loss in thickness can be expected to occur in a 75 - 100mm sample during the IAEA test. The NUREG 0360 fire test is more demanding and the results of the 1680 NUREG fire test is detailed later in the paper.

2.5 Designing for Energy Absorption

Wood being cellular material, has great ability to absorb the kinetic energy encountered in transport accidents. The thickness of wood required may be assessed by calculation once the relevant properties of the material have been established by a programme of tests.

2.6 Payload Demands

Plutonium dioxide derived from oxide fuel reprocessing has a higher heat output per kilogramme than the current Magnox type material. Thus the Company's older packagings are restricted in their payload because the current criticality clearances are reduced due to the high heat output. The payload design specification was that the 1680 container was to be able to transport large quantities, around 50kg of plutonium dioxide from the THORP reprocessing plant. The payload target has resulted in the dimensions of the 1680 container being approximately one metre long and one metre in diameter and weighing approximately 2.5 tonnes (See Appendix 1). The inner containment tubes are made from a very high strength stainless steel and carry eight of the THORP product cans. The 1680 package can dissipate over one kW of heat and remain within the temperature limits of the IAEA Regulations. Each of the four carrier tubes are sealed by a cap with an outer "Viton" ring and an inner metallic ring, which provides a verifiable containment boundary.

The package is designed to minimise dose levels, through the utilisation of timber shielding (a minimum of 200mm) and remote handling in both the vertical or horizontal mode during loading and unloading.

3. Experience in Testing of Plutonium Containers

Transport containers owned and operated by BNFL have been designed in accordance with the preceding section and, having been subjected to IAEA tests, have in most cases, only suffered superficial damage to the outer packaging of the containers. It was recognised by the Company that these packages were therefore capable of sustaining much greater damage, though recognising that the IAEA regulations are designed to ensure that the radiological consequences of the majority of potential accidents will be negligible.

In anticipation of public concern, BNFL embarked upon a series of trials in which packages were subjected to terminal or near-terminal velocity impact on to a hard concrete target. In 1973 a wood-cadmium design, the BNFL type 0675 container, was dropped from 610m and missed the target - symbolising the difficulty in this area of test work. The package impacted the hard earth adjacent to the target at 80ms^{-1} which was ascertained from detailed examination of high speed film. Only superficial damage to the outer container resulted and there was no loss of contents from the enclosed product cans. Two years later the tests were repeated using two similar containers and again one impacted the hard earth surrounding the target. Leaktesting of the cavity lid showed the cavity retained its integrity of 5 x 10^{-4} bar cm^{3} s^{-1}, and that the inner product cans were also leaktight. The second 0675 container struck the concrete target at 80ms^{-1} with estimated average impact decelerations of 2000g, though the lid and the seal were retained, 0.043grams were released from one of the inner product cans (representing 0.0007% of the total surrogate contents) which was retained in the cavity and not released to the environment.

More recently in 1984, a prototype design, the 1676 container, was released from a height of 1550m. The momentum of the package at 125ms^{-1} was so great that it penetrated the target (150mm concrete) and the hard underfill by approximately 370mm, with the average deceleration being calculated at over 2000g. Again, measurements confirmed no loss of contents occurred.

BNFL own and operate a fleet of 24 SAFKEG containers, designed by Croft Associates Ltd, and the Company to be consistent carried out in 1986 similar tests on two of the containers, the SAFKEG 2816C and 2816A, designed to carry the 153mm welded can and a 100mm rolled seam tin plate can respectively. The 2816C was released from 503m and impacted the target at approximately 75ms^{-1}, rebounded 6m into the air and came to rest 15m away from the point of impact. Although the average decelerations were approximately 2700g, both the inner product cans and the outer containment vessel were still leaktight to the IAEA criteria for normal conditions which was, in this case, 1 x 10^{-5} bar cm^{3} s^{-1}. The 2816A was released from 335m impacting the target at 61ms^{-1} with average decelerations of 1800g. The inner rolled seem tin plate cans were still leaktight to their pre-drop standard as was the outer containment vessel.

The experience gained from these trials was utilised in the 1680 container development programme and gave confidence to the design team that the container would meet the IAEA test criteria either by physical test or theoretical assessment. To meet the US NUREG 0360 Criteria (7), BNFL extended the development programme of the 1680 container. To carry out the high speed impact requirement of 130ms^{-1} for this series of tests, the BNFL project team designed an overpack shock absorber to supplement the strength of the package. In order to carry out a full scale impact test onto an unyielding target, it was necessary to find a suitable test facility which could accelerate a container weighing nearly 8 tonnes to speeds of up to 130ms^{-1}. The UK Ministry of Defence had a test facility at Pendine in South Wales, United Kingdom. The track at Pendine however, proved to be too small to carry an 8 tonne load and therefore it was decided to build a new track at Pendine for the tests. The possibility of using Sandia's facilities in the United States, which had been used for the original PAT 1 trials, was considered. However, the facility at Sandia did not have a sufficiently high target to package mass ratio and the cost of building a new one in the United States, together with the associated transport costs, did not make this option financially justifiable. There was also the added benefit with Pendine of having both design team and test facility in the same country. For the tests a standard rail track was laid on a solid concrete base for some 420m terminating at the target which initially weighed 600 - 700 tonnes. This target proved inadequate and a new target weighing some 3500 tonnes was constructed made of solid concrete abutment built into the side of a sand dune and capable of holding 1000 tonnes of sand.

Following a successful side-on impact at the prescribed speed, the full scale package was then subjected to the rest of the NRC criteria of crush, punch and slash tests, fire and immersion, and BNFL are satisfied with the results to date.

4. Risk Assessments

BNFL fully supports the belief that the safety argument for transport containers is that account should be taken of both the likelihood of an accident occurring severe enough to cause release of material and the consequences of any such release.

The accident rate for civil aircraft is low; for severe accidents which are defined as including at least 1 fatality and destruction of aircraft, the rate is about 10^{-6} per flight. International research(8) has shown that not all severe crashes will result in greater damage to the packages than those inflicted by the IAEA Type B tests. Estimates range from 1% to 10% of accidents. However, most packages greatly exceed the requirements of the IAEA tests, as shown by the tests detailed in Section 3, where even at very high impact speeds IAEA leaktightness is maintained and no real estimates of leakage of material over and above the IAEA requirement have been possible.

Despite the lack of actual release data, even if the very pessimistic assumptions of a release greater than that allowed for by the IAEA requirements are considered, there are further safety factors to be taken into account. Most plutonium powder is too coarse to be retained in the lung and hence large releases must be assumed before health effect models can predict the possibility of the development of cancers over the following 50 years. The consequences of the package being lost at sea can also be shown to be minimal, and Plutonium Dioxide is insoluble in water(9). However, the container would corrode eventually and even if plutonium were to be suspended in the sea water, it can be shown that the dilution effect of the water ensures that the effects on populations are minute.

5. Experience in Transport

BNFL does take pride in its enviable safety record for the transportation of plutonium by all modes, both domestically and internationally since 1952. In the United Kingdom BNFL has transported plutonium between nuclear installations by road using specially constructed vehicles incorporating the highest security standards. Since 1978 several tons of mixed oxide fuel assemblies for the Dounreay Prototype Fast Reactor (PFR) have been transported by air. In the last 16 years a total of over 4 tons of plutonium which has represented over 80 deliveries have been made to overseas destinations. The material has been in the form of plutonium dioxide powder for at least 90% of these transports with the remainder being fabricated plutonium fuel in various forms.

6. Conclusion

Plutonium transport has been safely and efficiently carried out by BNFL both nationally and internationally for the last 30 years. The transport operations have been carried out in accordance with national and international law which, to date, has been based on Regulations recommended by the International Atomic Energy Agency. This outstanding safety record is due to the design and development of the packaging and the rigorous checks that are carried out at every stage of the operation. BNFL are committed to the continuation of maintaining such transports in a safe, secure and cost effective manner.

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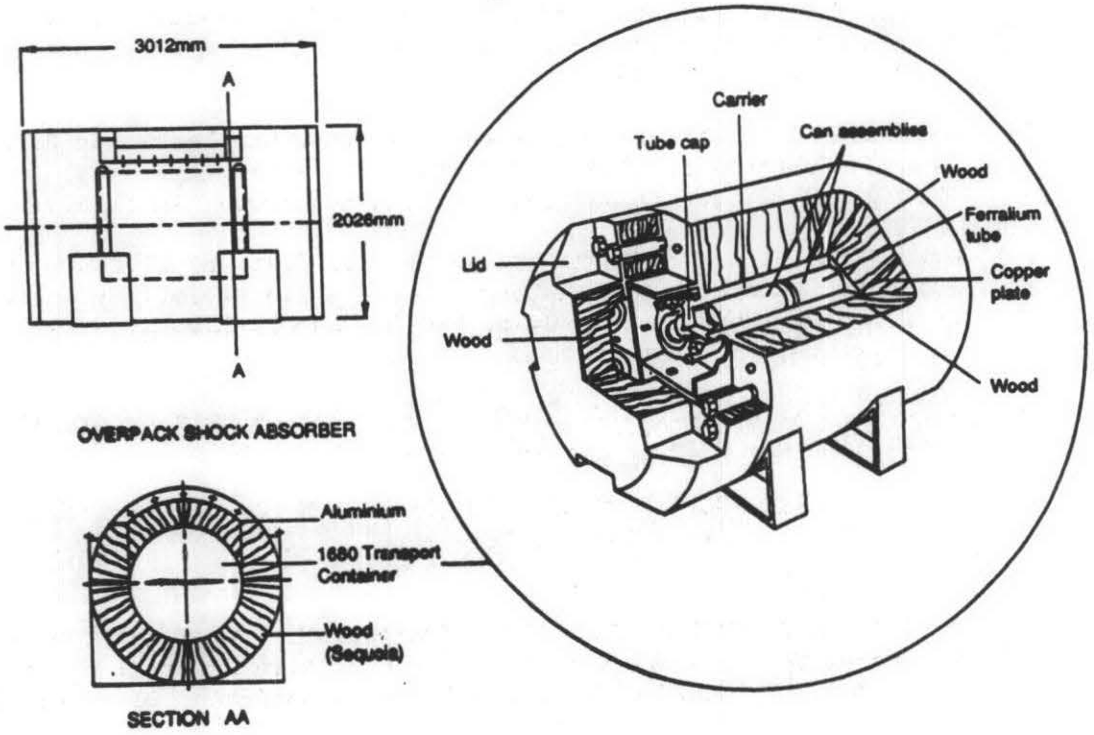
APPENDIX I



1680 Transport Package and Overpack Shock Absorber