ABSTRACT FOR PATRAM 2013

Title: - Impact of a double containment boundary requirement on small type B (U) package safety case

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Abstract

The United Kingdom (UK) Government has tasked the Nuclear Decommissioning Authority (NDA) with the decommissioning and clean up of the legacy of UK's civil nuclear sites. This task requires a well organised and flexible transport network to relocate radioactive material (RAM) from the producing site to intermediate and final storage facilities.

International Nuclear Services (INS), as a subsidiary company of the NDA, is supporting the Site Licence Companies that operate the various nuclear sites to establish, optimise and coordinate their RAM transport systems. This includes helping to ensure that each off-site move is performed in compliance with current legislation and to high safety standards, and that the transport system represents good value to the taxpayer.

There are many existing packages available to conduct these transports, but in some cases the nature of the material to be transported, safety benefits, and/or commercial benefits justify the development of a new package. When such a business case exists it is important that the new package has a high degree of flexibility. It needs to be adaptable to any receipt facility from the most simplistic to the most sophisticated and to be able to carry a wide range of types of radioactive material produced though the lifetime of operating plant.

The INS3578, a new package designed by INS, maximises content and enhances flexibility of use thanks to its double containment boundary and its unique shielding design. Loading capability and undemanding handling requirements present a real advantage in comparison to other package options.

The aim of this paper is to present the advantages of a double containment boundary, and to describe the impact of this design solution for a type B(U) licensed package safety case (i.e. mechanical/thermal behaviour, containment, activity release, shielding, etc). It also discusses how simplicity of operation and maintenance has been achieved.

Introduction

International Nuclear Services has been developing a new type B package to transport various materials such as PCM, waste, fissile material and unirradiated fuel elements encapsulated in welded stainless steel cans.

The INS3578 has been designed to maximise the payload transported per package for a wide range of contents within an established overall geometrical envelope imposed by existing export/import facilities in the UK.

The INS3578 feasibility study highlighted the requirement and the benefit of a double containment system (water barrier), preventing water ingress to the Inner Containment Vessel. Multiple high standard water barriers have already been used, for example, on various spent-fuel flasks to reduce fuel integrity justification. INS's new designs are using multiple water barriers to optimise package capability.

Multiple water barriers may be implemented by many different technical solutions such as:

- A single containment boundary package transporting RAM material loaded with testable watertight cans, or
- A single containment boundary equipped with two independent and testable lids, or
- Two fully independent and testable containment systems interacting like "Russian dolls"

The INS3578 has been designed with two independent Containment Vessels (CV) which remain leak tight when the package is subject to the IAEA tests (para. 682(b) of TSR 1-1). As designated containment boundaries, both CVs are manufactured and maintained with a high degree of quality control and are independently testable before each shipment.

This paper describes the INS3578 double containment boundary, discusses its impact on the Design Safety Report and highlights how potential operating and manufacturing challenges were overcome to ensure a commercially viable product.

INS3578 Key facts.

Overview
The INS3578 has been designed to transport solid fissile material, Plutonium Contaminated Material and other types of waste. The types of product considered can be summarised as PuO_2 powder, MOX residues and pellets, and waste forms in different cans and overpacks.

The following Table (Table 1) provides key parameters of the INS3578 package design.

Table 1: 3578 Design parameters

Parameter	units	INS3578
Overall height	mm	1000
Overall Diameter	mm	450
Weight	kg	292
Internal cavity height	mm	663
internal cavity diameter	mm	172
Loading capacity	kg	40
Max. Heat Load	W	170

Licensing
The INS3578 has been designed with a bounding design capability covering several transport opportunities within the UK. However, for the purpose of licensing, the package content will only cover the requirement of a subset of its capability. This will however require a B (U) licence application for Road, Rail and Sea.

Some of the materials considered require the security provisions of Category One transport, which implies the use of a High Security Vehicle (HSV).

The planned licence allows for the transport of 1 or 2 cans per package, 6 or 9 packages per Stillage (depending on the payload requirement), and 4 Stillages per ISO container or HSV.

This configuration should allow the transport of up to 72 cans per vehicle (ISO or HSV) with the 9 package stillage, which is up to a 50% increase in packing capacity per shipment in comparison to current assets. This offers an obvious advantage in the reduction of the total number of transport operations required.

INS3578 double containment system

The INS3578 double containment boundary is composed of 2 individual containment vessels; the Outer Containment Vessel (OCV) enveloping the Inner Containment Vessel (ICV). These containment vessels are mechanically connected by a robust bayonet closure system preventing mechanical impact between the ICV and the OCV Top Lid.

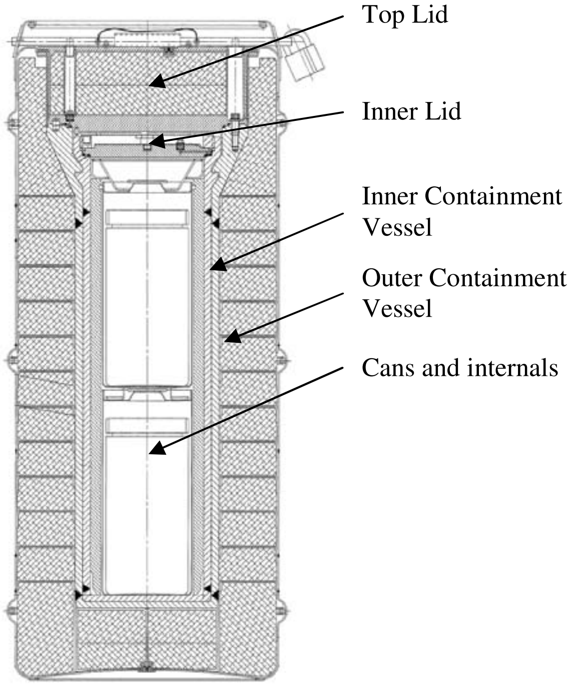


Figure 1, 2: 3578 Package design

The Inner containment vessel:

The ICV has been designed to be operated (i.e. loaded/unloaded, handled) within the package or independently, providing the maximum flexibility of use to any potential user.

Made from welded tube and plate, the ICV features a cavity of 663 mm height and 172 mm diameter. It is able to transport up to two cans of any established Sellafield Ltd product can design (See Table 2) and many other contents defined around the world such as product cans used by Areva on the LaHague finishing line.

Table 2: INS3578 contents examples

Cans type		Contents		Overall dimension	
		Type	Form	Max Diameter (mm)	Length (mm)
Overpacks	Type 1	PuO_2	Powder	Ø 167.4	329
Overpacks	Type 2	MOX	Residues/ pellets	Ø 117.5	252.3
Overpacks	Type 3	MAGNOX, MOX, SDR PuO2 Residues	Residues/ pellets	Ø 155.5	252
Overpacks	Type 5	Waste	Residues	Ø 155.5	313
Magnox Outer can		Waste	Ceramic	Ø 152.4	311.15
Magnox Outer can		PuO_2	Powder	Ø 152.4	311.15
Magnox Outer can		MOX	pellets	Ø 152.4	311.15
Thorp Outer can		PuO_2	Powder	Ø 133.18	311

Internals (components contained within the ICV excluding RAM material), such as liners, spacers or shock absorbers, guarantee the thermal and mechanical compatibility of each content type with the package design intent.

The ICV cavity is closed by the inner lid (Figure 4) and clamped with a M205 threaded retaining ring torqued to 300Nm. Specifically designed equipment will enable operators to achieve the required torque.
The ICV containment seal leak tightness is tested by a pressure drop method.

The outer containment vessel:
Made from welded tube and plate, the OCV features a cavity of 712mm height and 195 mm diameter capable of containing and securing a fully loaded ICV.

The ICV is secured by rotating by 15° when fitted in the Outer Containment Vessel and engaging its bayonet tangs (See Figure 3) to mating features on the OCV (see Figure 4). During the transport, inner containment vessel rotation is prevented, maintaining the bayonet system lock, by a locating pin attached to the OCV lid.

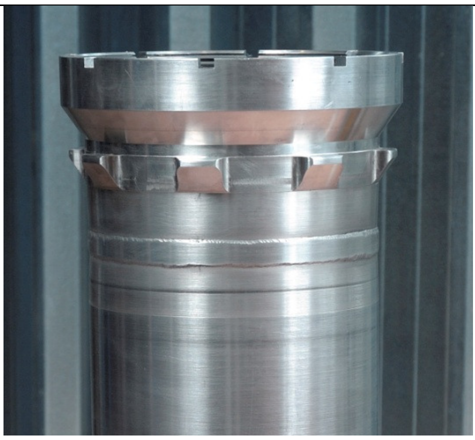
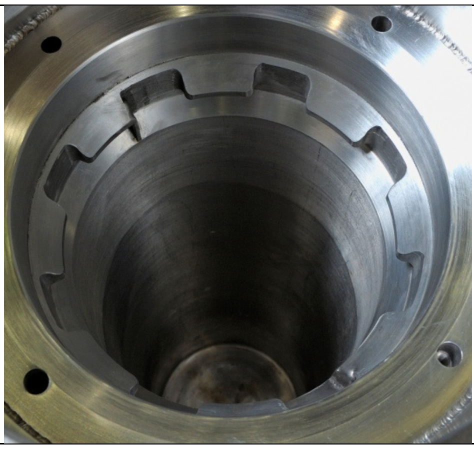
	

Figure 3: ICV bayonet tang	**Figure 3: OCV bayonet tang**

The Outer Containment Vessel forms the spine of the package structure and acts as a central column supporting shielding and shock absorber elements.

The outer containment boundary is completed and closed with the Outer Lid (Figure 5). This self shielded Lid is secured by 8 M10 bolts tightened to 60Nm. The containment seal leak tightness is tested by a pressure drop method. Access to the bolts and pressure test point are accommodated through the lid thickness.

Figure 5: ICV & OCV Lids

The Design Safety Report

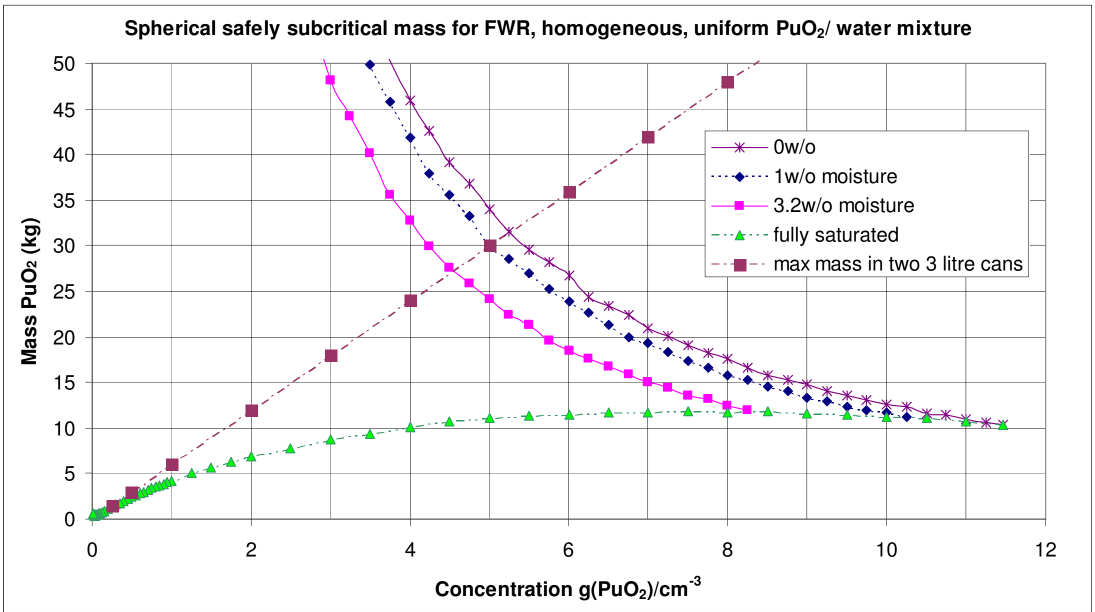
The design safety report aims to demonstrate that the package design maintains the containment of radioactive material, as required by the regulations (Ref.1) when exposed to various hazards related to the transport of dangerous goods in the public environment.

Developing a double containment boundary has a positive impact on various parts of the safety demonstration including:

- Criticality assessment,
- Shielding assessment,
- Thermal behaviour,
- Impact behaviour, and obviously
- Containment

The criticality and shielding assessment:

The INS3578 double containment boundary was primarily designed to optimise the payload transportable. Considered as a high quality double leak tight barrier, it prevents any water ingress within the inner containment vessel considerably improving the criticality safety limit. The effect of limiting the moderator content in the CV to that inherently associated with the fissile material can easily be demonstrated by the use of simple criticality handbook data. Figure 5 compares safely subcritical masses for a fully water saturated sphere of PuO2 with the equivalent data assuming a limited moderator content. For PuO2 powder systems, which typically have a density below 4g(PuO2)cm-3, the outcome is such that the mass that can be transported is dictated by can volumes, rather than criticality safety limits.



Data assumes 100w/o Pu-239/Pu and a safety criterion of $k+3\sigma \leq 0.94$.

Figure 6: Indicative Effect on Package Mass Limits of Moderator Content

The INS3578 shielding efficiency is principally due to the use of highly effective Neutron shielding: the CLP-NS (Cross Linked Polyethylene – Neutron Shielding).

Engineered for military submarine nuclear reactors, this lightweight neutron shielding material is capable of maintaining its efficiency (hydrogen content) at a continuous temperature of 150°C.

The second containment boundary structure provides the additional gamma radiation shielding required to transport aged neutron sources such as Plutonium and MOX pellets.
The package shielding efficiency is illustrated in Table 3 by comparing the INS3578 to an equivalent package (similar size) used on Sellafield site to transport similar products with the same reference isotopic.

Table3: Shielding comparison between the existing asset and the INS3578 using the same reference isotopic

		On site package (μSvh^{-1})*			INS3578 (μSvh^{-1})		
		Neutron	Gamma	Total	Neutron	Gamma	Total
Side	Contact	829.3	226.6	1055.9	216.9	84.3	301.2
	1m	41.0	11.9	52.9	11.0	4.4	15.4
	2m	12.4	3.6	16.0	3.3	1.4	4.7

* *Information provided by Sellafield Limited*

An improvement of a factor of three is generally observable. Noticeable reduction of gamma radiation is obvious illustrating the indirect impact of a double containment boundary.

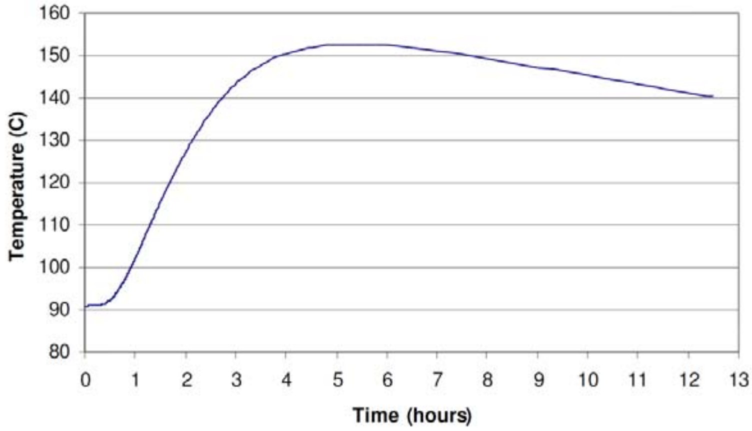
Further detail on the criticality and shielding assessment are available in Patram 2013 paper: Criticality and Dose Uptake Benefit from a New Package Design (Ref. 2).

The package thermal behaviours:
The development of the INS3578 concept has been delivered through research into the optimum thermal balance between the IAEA Normal Condition of Transport (NCT) and Accident Condition of Transport (ACT) thermal regulatory tests for a predefined package volume corresponding to the plant capability.

The high internal mass of the package provides substantial thermal inertia consequently relaxing the design margin required to optimise the insulating material conductivity. The optimum conductivity was obtained by varying the amount and the size of internal fins inserted between blocks of low conductivity CLP-NS material.

Figure 7 shows a seal temperature profile from the INS3578 OCV during a simulated IAEA fire

Figure 7: Temperature evolution of the OCV seals during an IAEA fire



The INS3578 detailed thermal assessment highlighted the benefit offered by this new design as described in Table 4.

Table 4: Thermal assessment summary

Heat load (W)	NCT		ACT	
	IAEA insolation, 38°C ambient		800°C fire	
	Max. Skin T°	Max. Inner T°	Max. Skin T°	Max. Inner T°
170	58 °C (Top)	94 °C (Side)	763 °C	146 °C
70	55 °C (Top)	65 °C (Side)	763 °C	118 °C

The INS3578 Normal condition of transport shows very low internal temperatures which minimises the effect of any thermal ageing on CLP-NS.

Ageing effects are limited by containing the material within a leak testable cavity, which isolates the shielding material from any sunlight and oxygen, the two agents responsible for polymer ageing.

The package mechanical behaviours:
The INS3578 mechanical behaviour has been assessed in detail and a prototype drop test completed in January 2013 (See Figure 8 and 9). Notwithstanding further IAEA drop tests are expected during the summer of 2013, there is now a clear understanding of the package mechanical behaviour against the IAEA requirements.

Lid edge damage

Base edge damage

Figure 8, 9: INS 3578 Damage from development phase drop test

The package overall dimensions, imposed by existing plant interfaces, prohibited the use of sacrificial shock absorbers. Mechanical protection was consequently built in to the structure immediately surrounding the OCV, using the CLP-NS mechanical properties to absorb impact energy.

At temperature, CLP-NS acts as a rigid elastomer in absorbing the energy from the impact. The surrounding metallic structure has been optimised to accommodate potential deformation and minimise the possibility of failures which may expose the shielding material to direct flame contact.

The double containment vessels (ICV + OCV) were robustly designed to accommodate significant acceleration generated by the IAEA mechanical test. As a result, very little plastic stress across the thickness of the containment wall is observable.

The bayonet system described earlier is designed to prevent the ICV interacting with the OCV Lid during an impact and consequently reduces any resulting seal surface deflection which may challenge the containment assessment. Having very little space to implement this locking device, it was decided to implement a rigid bayonet system preventing any significant plastic deformation. As a direct consequence, the bayonet tangs concentrate most of the plastic stress observable on the containment vessels. These plastic stresses are not considered challenging for the containment boundary efficiency as there is no observable failure and none of the peak stresses are transverse to the containment vessel thickness.

The inner containment vessel lid is protected from the package content by an internal shock absorber, mitigating any seal surface deflection resulting from the internals' own motion.
Positioned between the lid and the package content, the shock absorber is designed to absorb the kinetic energy for a defined temperature range within the space left available within the ICV cavity. This feature is consequently designed for a specific transport requirement and will be re-evaluated for any content change.

The containment assessment:
The implementation of a double containment boundary considerably improves the package capability to contain radioactive isotopes.

Both containment vessels are considered as robust independent containment boundaries with a unique leak path through the O-ring seals.

Any potential activity releases are minimised during shipment by:

- Achieving a pre-shipment leak test with a permissible leak rate of 1.25 x 10^{-6} Pa.m^3/s SLR
- Maintaining the seal temperature below 100°C which guarantees the seal compression set for a duration exceeding 18 months.
- Maintaining any residual seal surface opening due to IAEA mechanical test below 50µm (<<10% residual compression).
- Reducing the internal pressure by keeping the payload to a reasonable temperature which will minimise the radiolysis/thermolysis effect and any pressure due to thermal expansion.

Figure 10: INS 3578 OCV pressure drop test

As a result, any RAM material contained within the INS3578 will have to leak from a pressurised Inner Containment Vessel through two sets of efficient seals in order to reach the environment. Only the material which has managed to leak into the OCV cavity can subsequently be further released to the environment.

It is also interesting to highlight that the magnitude of any leak is directly related to the pressure differential across a seal system. The OCV pressure (relative to the ICV pressure) will define how much activity, incoming from the ICV, will be available and the OCV pressure (relative to atmosphere) will define the leak through the OCV seal system to the environment. This therefore establishes two critical parameters for future activity release calculations.

The Impact on the Package

As a double containment boundary, the INS3578 development had to address various preconceived ideas about its complexity. It was consequently highlighted at an early stage that loading/unloading, maintenance and manufacturing of the packages required additional care to overcome any difficulties. Consequently, this new user-friendly and economical RAM package presents a significant improvement in transport capacity.

INS3578 operations:
The 3578 design has combined simplicity and performance.

The potential additional operation requirement related to the second containment boundary was highlighted at an early stage. By combining the shock absorber and the shielding within the outer lid, the design promises to be quick and easy to operate and will protect operators from radiation during most of the manual operation.

Its flexible design allows any specific plant to fit the design to their process. It could be loaded:

- Remotely or manually
- Vertically or horizontally
- In one or two steps by removing (or not) the primary containment vessel from the main package

Maintenance requirement:
The INS3578 maintenance requirements were optimised to enhance the package availability when extensively used. Minor maintenances were replaced by increasing the pre-shipment checks and major maintenance (every 5 years) requirements. This generates a significant improvement on operating cost without compromising maintenance quality and safe use of this new asset.

As a direct impact, despite its double containment boundary, the INS3578 availability for transport activities was improved and the maintenance cost was considerably reduced.

Package manufacturing:
Recognising the additional manufacturing requirement generated by the double containment boundaries and fins assembly, INS decided to involve various manufacturers' right from the feasibility study throughout the design development. This relationship with the shop floor allows the optimisation of the package manufacturing cost and guarantees the best value. The various package features and detailed arrangement were designed for ease and economy of quantity production

Conclusion

INS is developing a new package design to transport PuO_2 powder, MOX residues and pellets, and waste forms in different cans and overpacks. The new design takes a large step forward and secures NDA transport capability in the future to support key decommissioning projects. The flexibility incorporated into the design also means that the package can readily be adapted for other customers' needs.

In addition to its enhanced payload, the INS3578 was designed to improve the packing density per shipment.

An optimised design and maintenance regime will enhance the package availability.

The Package detailed design has been completed in June 2013 with IAEA drop tests, a full fire test and licence application planned for later this year.

Through this project INS is supporting the NDA with its decommissioning mission, and is maintaining and developing RAM transport expertise on behalf of the estate.

Reference

Ref. 1: TS-R-1, Regulation for the Safe Transport of Radioactive Material, IAEA Safety Standards, 2009.

Ref.2: Criticality and Dose Uptake Benefit from New Package Design, PATRAM 2013, Dominic Winstanley (Sellafield Ltd), Ben Acker (INS)