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CONCEPTUAL DESIGN OF ROBUST SHIELDED BOX TRANSPORT CONTAINER TYPE B(U) PACKAGE DESIGN

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ABSTRACT

In recent years, a number of the organisations responsible for managing the clean-up of the UK's nuclear sites have adopted Robust Shielded Boxes (RSBs) for the packaging of higher activity waste (HAW). RSBs are thick-walled, ductile cast iron containers with a gross mass of up to 35 tonnes. They do not require remote handling and can use unshielded, personnel-accessible stores.

This paper focuses on the conceptual design of a reusable Type B(U) transport container for transport of RSBs. It presents the conceptual design development work, including the principal design features, options considered and the final conceptual design of Robust Shielded Box Transport Container (RSBTC).

To allow unrestricted transport upon the UK rail network the RSBTC design is required to be compatible with the mass and dimensional limits of the most constraining W6a rail gauge. Challenges were experienced in achieving this target due to the physical size of the RSBs and high payload mass of 35 tonnes, which represents a contents mass to RSBTC gross mass ratio of over one. These requirements presented significant challenges for the lid closure and impact limiter designs, requiring the inclusion of a high-capacity bolting arrangement and novel lid features to maintain containment and structural integrity in regulatory impact scenarios.

The RSBTC design has been developed to a conceptual level of detail and successfully demonstrates concept feasibility of a Type B(U) transport container design suitable for transporting two types of RSBs in compliance with the mass and dimensional constraints of the UK rail network.

INTRODUCTION

Since the late 1940s, the UK has accumulated radioactive waste, which is currently stored at more than 30 sites around the UK. Low Level Waste (LLW) is typically managed by treatment or disposal at the UK's LLW Repository, while Intermediate Level Waste (ILW) in England and Wales will be disposed of in a GDF[1]. RWM's mission is to deliver a GDF and provide radioactive waste management solutions [1].

Plans for the construction of a GDF in England and Wales are at an early stage. In order to have confidence that the conditioning and packaging of radioactive waste will result in waste packages that would be compatible with future disposal in a GDF, RWM has implemented a Disposability Assessment process [2]. This process considers the performance and safety of waste packages against a suite of waste packaging specifications [3], which set out the bounding package requirements anticipated for transport to and disposal within a GDF. A key aspect of the process is to consider the feasibility of safe, compliant transport of waste packages through the public domain to a GDF.

In recent years, a number of waste packagers have proposed the use of Robust Shielded Boxes (RSBs) for the packaging of ILW. RSBs are thick-walled (up to a few hundred millimetres), typically made from ductile cast iron, and have a gross mass of up to 35 tonnes; they are suitable for packaging of waste with a wide range of specific activities and fissile nuclide contents. Due to the shielding provided by their thick cast iron walls, RSBs do not typically require remote handling facilities and can use unshielded, personnel-accessible stores.

Some RSB designs are suitable for transport as Type IP-2 packages in their own right [4]. However, waste packagers are considering the use of RSBs for more active wastes to allow greater flexibility in waste management strategies. In recognition of this potential future use of RSBs, RWM has identified the need to explore the feasibility of a reusable Type B(U) transport container for transporting RSBs, compatible with unrestricted transport upon the UK rail network and with the planned infrastructure at a GDF.

This paper sets out the conceptual design of the Robust Shielded Box Transport Container (RSBTC) Figure 1, that fulfils the user and systems requirements developed at the outset of the project, focussing upon the RSBTC impact limiter and robust lid closure designs. Two further papers relating to the RSBTC have been selected for presentation at PATRAM 2019; one discusses the need for an RSBTC within the UK and its potential applications, setting out the key requirements and constraints [5], the other focuses specifically on the structural design and analyses to demonstrate the impact performance of the RSBTC [6].

[1] The Scottish Government Policy is that the long-term management of higher activity radioactive waste should be in near-surface facilities

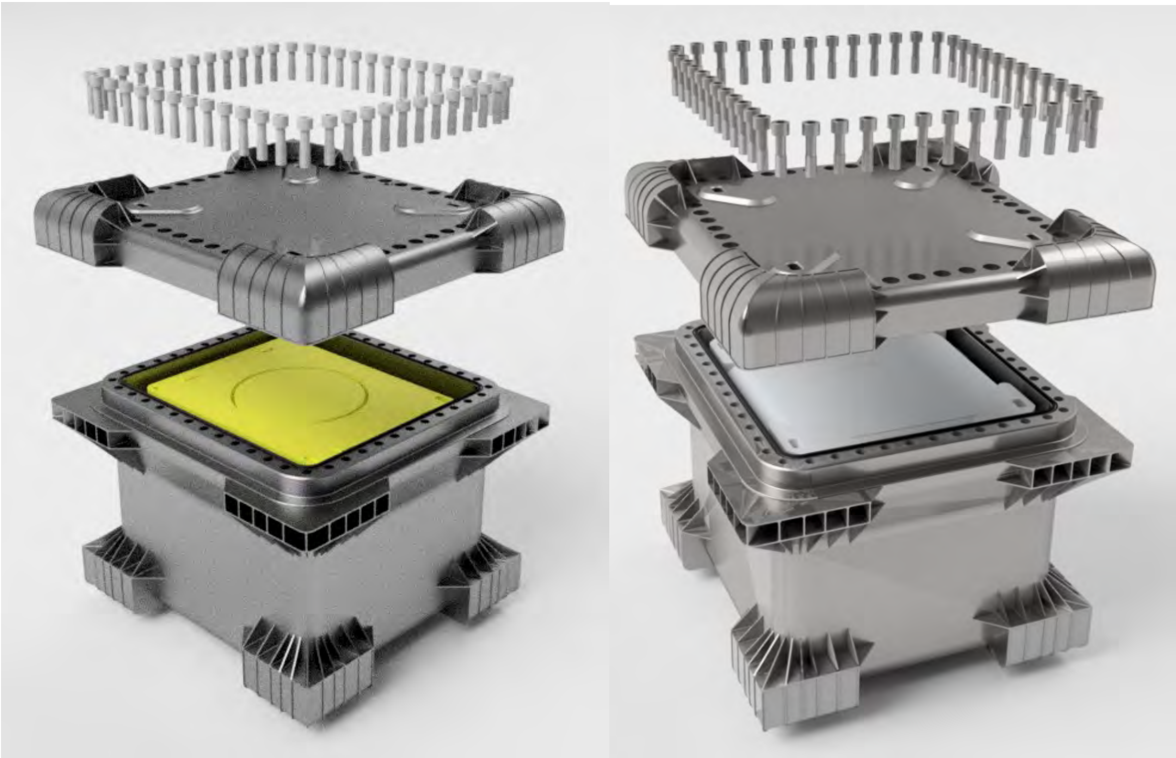


Figure 1. Conceptual design of the RSBTC

For the RSBTC conceptual design two RSBs were considered, a Magnox GNS Yellow Box® and a Sellafield Self Shielded Box (SSB). Schematic illustrations of these two designs of RSBs are shown in Figure 2. For the purpose of developing the RSBTC conceptual design, the SSB bounded the contents parameters in terms of both physical size and mass.

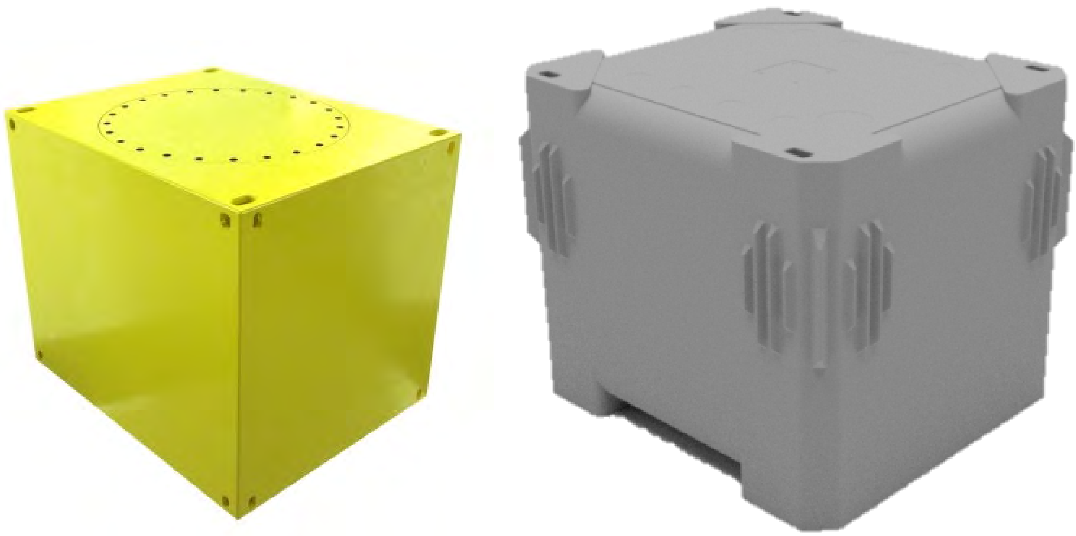


Figure 2. Schematic illustrations Magnox GNS Yellow Box® (left) and Sellafield Self Shielded Box (SSB) (right)

CONCEPT OPTIONS

The conceptual design of the RSBTC has been developed from an initial concept options workshop, where the principal features of the transport container design were evaluated against the defined set of requirements and the preferred options confirmed. The design features evaluated included:

- Overall shape and loading aperture;
- Impact performance and thermal performance;
- Lid fastening system and materials;
- Containment system and seal materials, including venting/purging;
- Transport container materials;
- Lifting features;
- Tie-down features;
- Internal features.

Principal design constraints and challenges

Significant design challenges arose from the gross mass and external dimensions of the RSBs and their impact upon the RSBTC design, in particular the requirement for compatibility with transport upon the UK rail network. These challenges were identified at the outset of the conceptual design and are summarised in Table 1.

Table 1. Principal challenges for the RSBTC conceptual design

Criteria	Challenges
Dimensions of RSBs The RSBTC needs to accommodate the largest SSB at length 2140mm, width 1940mm and height 1740mm but also accommodate the smaller GNS Yellow Box®	• Sets the minimum cavity dimensions required but also requires measures to accommodate the smaller GNS Yellow Box® • Sufficient clearance required for loading operations but conflicting requirement of a desire to minimise clearances for impact performance • Compliance of the RSBTC with UK W6a rail gauge restricts available space for impact limiters potentially requiring novel designs and features
High payload mass The RSBTC is required to accommodate RSBs with a gross mass of up to 35 tonnes	• High payload mass of the SSB presents significant challenges for the RSBTC lid closure design • Mass restrictions for Route Availability (RA) targets for rail transport restrict gross mass

Compatibility for rail transport

As input to the RSBTC conceptual design, a separate assessment [7] considered transport of the RSBTC upon several designs of rail wagon in operation upon the UK rail network, notably to assess and confirm:

- Dimensional compliance with the UK W6a rail gauge;
- The available space for the design of the RSBTC impact limiters;

- Permissible Gross Laden Weight (GLW) for a target Route Availability (RA) of RA8 (maximum load of 22.8 tonnes per axle);
- Permissible GLW for the threshold RA10 (maximum load of 25.4 tonnes per axle).

Reviewing the three wagon options, the WH Davies 4-axle well wagon design provided the most clearance for the impact limiter features due to the reduced deck height of the central well section and was selected as the preferred option. Figure 3 shows the RSBTC within the UK W6a rail gauge profile using the preferred WH Davies 4-axle well wagon design.

In the critical top corner zone this provided a clearance of 143mm in the most constrained lateral direction for the design of the impact limiters.

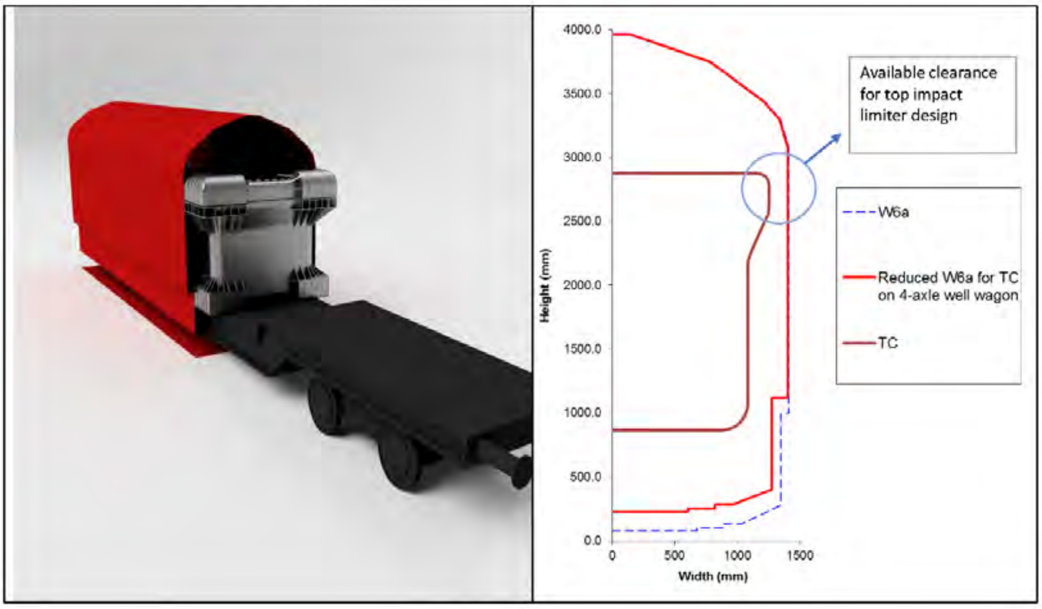


Figure 3 – RSBTC showing available space with W6a gauge profile

DEVELOPED CONCEPTUAL DESIGN

The RSBTC is a large cavity, top opening, bolted lid design of Type B transport container. The gross mass of the RSBTC when loaded with a 35 tonne SSB is 66.5 tonnes.

The RSBTC conceptual design considered the materials of construction, opting for durable 400 series stainless steel, using cast CA6NM for the body and forged F6NM material for the lid. The body has a flared top profile which provides a robust bolting flange accommodating 50-off M68 high tensile steel closure bolts. Impact limiters, in the form of deformable fins manufactured from 10 mm thick 1.4404 (316L) stainless steel plates are welded to the body and lid. The features of the RSBTC conceptual design are shown in Figure 4.

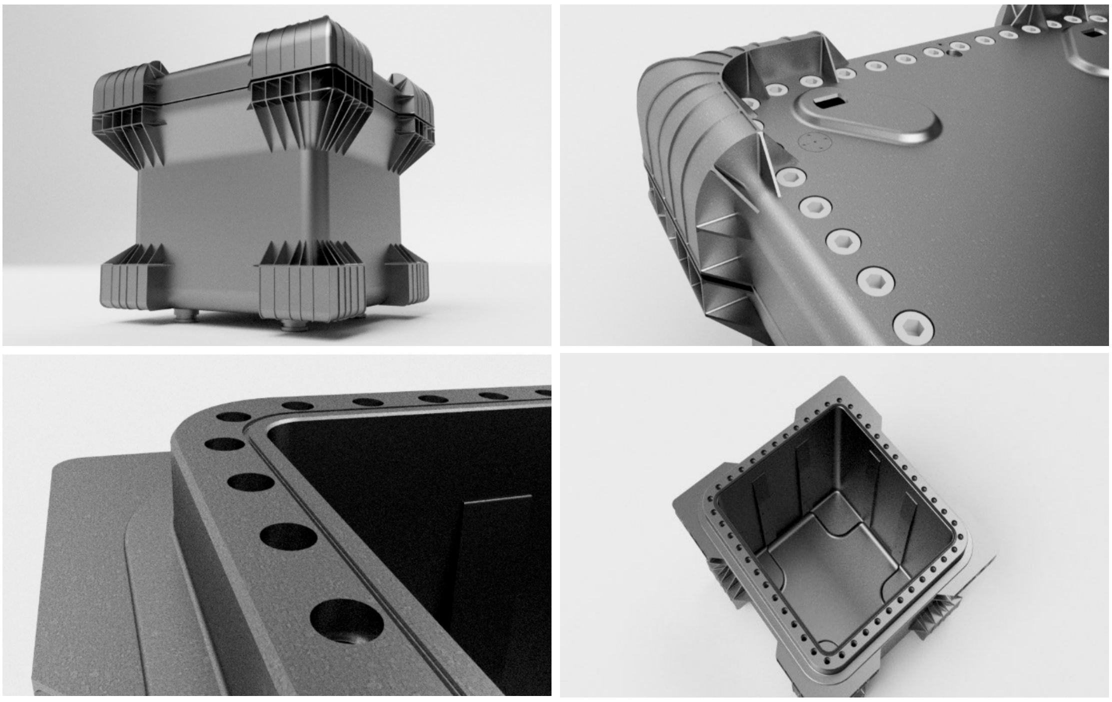


Figure 4 Features of the RSBTC conceptual design

Material section thicknesses are 100mm unless thickened for structural capacity, i.e. in the flared bolting flange and areas around the twistlock and feet locations. The 100mm section thickness has been assessed as suitable for manufacture by a leading UK manufacturer, Sheffield Forgemasters [8].

A cuboidal design was selected for the RSBTC on the basis that this represents the most efficient shape, both in terms of physical size and mass of the proposed contents.

A top opening design was selected for the conceptual design on the basis that it is the simplest and most efficient design in terms of size and mass. Top loading is also consistent with the other types of transport container designs developed by RWM, including the Standard Waste Transport Container (SWTC) and Large Waste Transport Container (LWTC) concept designs, as well as those operated by Magnox and Sellafield, such as the AGR and A2 fuel flasks. Maintaining consistency with established designs and concepts is also considered to simplify handling, loading and unloading operations at Magnox, Sellafield and at a GDF.

From the outset significant challenges arose for the closure design from the high payload SSB at 35 tonnes which results in a gross mass to contents mass ratio of approximately 1, coupled with the dimensional limitations of the W6a rail gauge which would constrain the size of the impact limiters in the critical corner zones.

Lid closure design

A bolted closure design was selected for consistency with existing designs, using the design philosophy of a larger number of smaller bolts being preferred for improved stress distribution and performance during impacts.

The final RSBTC conceptual design incorporates 50-off M68 high tensile steel grade 12.9 closure bolts. In compliance with structural design code BS 5950-1 [9] the bolt pitch spacing is nominally

2.5D. The total bolting capacity at 7200 Nm torque is 26.5 MN (2,700 tonnes). At this torque the induced stress in each closure bolt is 183 MPa, giving a FOS 6 on material 0.2% proof stress.

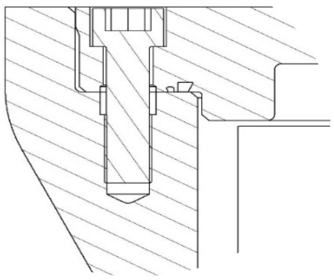
Design of lid-body connection for impact performance

Bolt protection during impacts is provided by inclusion of robust shear lips (spigots) and by recessing the bolts into the RSBTC lid. Spigots are useful in removing shear loads from the closure bolts during the regulatory impact scenarios (which comes from the sliding motion between the lid and body flanges) since shear loads are carried by the spigots, leaving the bolts to carry tension and a small amount of prying force only.

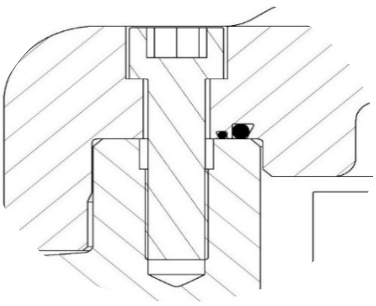
Two design schemes for the lid/body connection were considered (Figure 5). Concept 1 lid design protects the closure bolts by recessing the lid fully into the body and providing an inner spigot to remove bolt shear loads. Concept 2 lid design incorporates a robust double shear lip arrangement comprising of an outer and inner spigot. The design and location of the spigots are critical to the impact performance of the closure:

- The external spigot protects the closure bolts in the direction of the impact;
- The internal spigot protects the bolts on the opposite side by preventing the lid sliding along the body flange and by minimising lozenging of the body in corner and lid edge impacts.

Concept 2 lid was selected as the preferred design on the basis that the double shear lip configuration provides optimum shear protection of the closure bolts irrespective of the impact orientation. In addition, further shear protection of the bolts is provided by counter-boring the top section of the tapped holes in the body. This feature has been successfully employed on similar Croft designs, namely the Croft Self Shielded Box design No 4078 which was regulatory impact and fire tested at BAM.



Concept 1 Lid



Concept 2 Lid

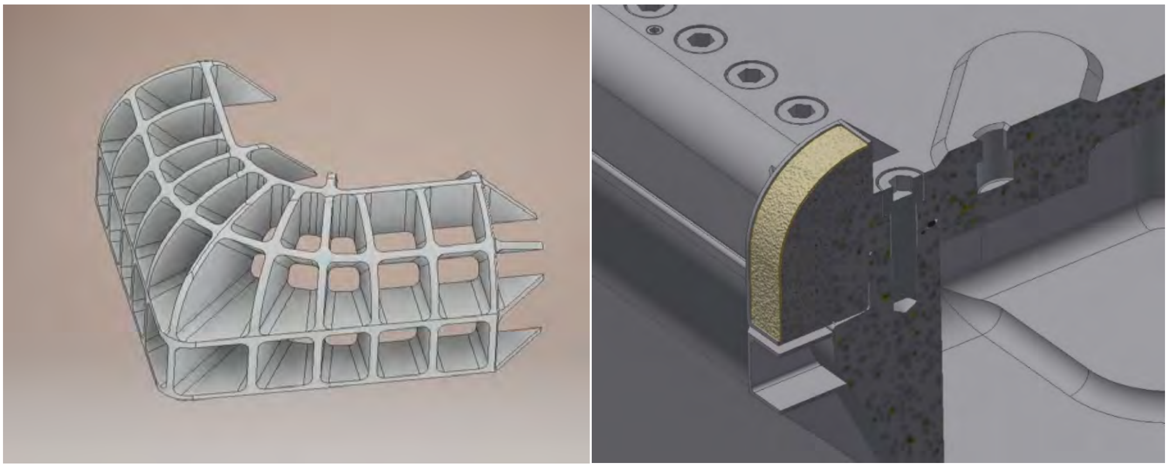
Figure 5 – Conceptual design of RSBTC lid

Imapct limiter design

The dimensional constraints of the UK W6a rail gauge proved a significant challenge for the RSBTC impact limiter design. Initial designs focused upon a cast or weld-on deformable ribbed lattice structure, which through an iterative process of finite element (FE) analysis was refined to enhance the RSBTC impact performance. The FE analysis and impact performance of the RSBTC design is presented in a separate PATRAM paper #1426 [6].

Challenges with the impact performance and concerns regarding the complexity of the initial ribbed design for manufacture led to the final simplified design. In the final design impact performance was achieved by removal of a number of the webs, replacing these with General Plastics FR3740 rigid polyurethane impact limiter foam ,inserted between the vertical ribs (fins) at the critical impact zones (Figure 6). Figure 7 shows the lid corner impact case when loaded with the bounding 35 tonne gross mass SSB.

The inclusion of the impact limiter foam provided a secondary benefit of enhanced thermal insulation at the corners minimising heat transfer into the lid and the seals. FE thermal analysis reported in [11] shows the maximum transient lid seal temperature reached is 251°C with the lid seal remaining above 200°C for approximately 200 minutes (3.4 hours). These values are below the excursion limits for the proposed fluoroelastomer seal materials [10].



Initial ribbed impact limiter design

Section through final impact limiter design

Figure 6 - Conceptual design of RSBTC impact limiters

The FE analysis confirmed no material failure in the body, lid or lid bolts of the RSBTC by assessing the maximum plastic strain with the material minimum elongation to failure. If the plastic strain exceeded the material minimum elongation to failure, a further judgement was made on whether the plastic strain occured under a compressive stress state, where material failure is less likely. The full impact analysis is reported in [11].

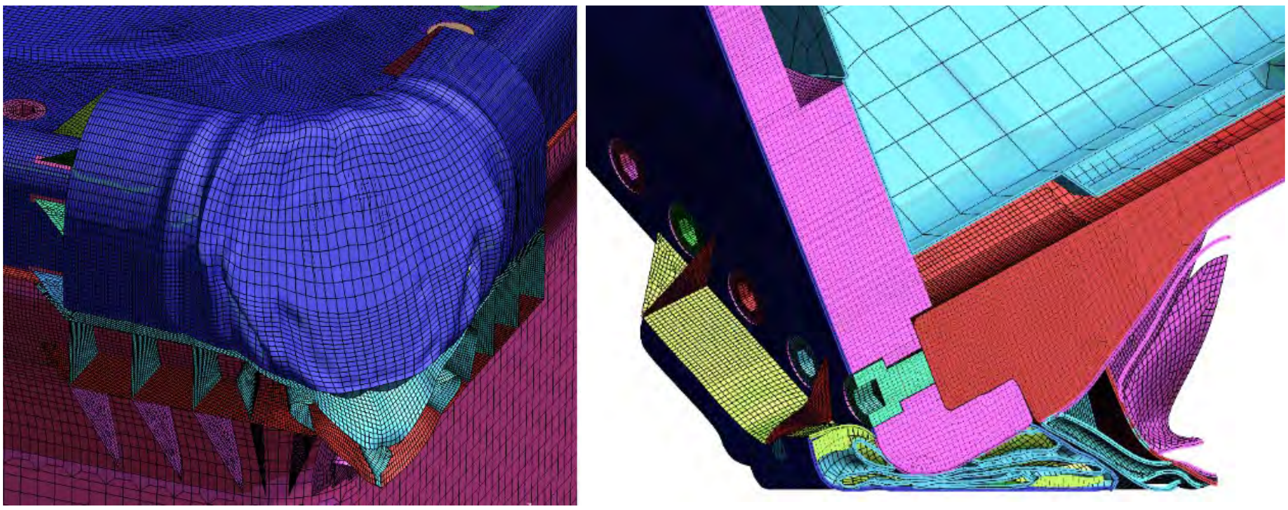


Figure 7 – Performance of RSBTC impact limiter design (9.3m corner impact)

Seal groove design and performance

A conventional double O-ring seal closure design was used to provide a 'small' interspace volume. This is beneficial operationally for the pre-shipment pressure drop leakage test since the interspace volume directly influences the required test duration for a given leakage rate. The RSBTC uses a 20 mm diameter inner containment seal and 10 mm diameter outer seal. Groove depths provide a nominal 25% of seal compression which is consistent with BS 4518 [12] design criteria for a static face seal application.

The seal compression of the inner containment seal (5 mm design compression) was utilised in the FE impact analysis to confirm that the transient lid-body gap during regulatory impact events remained within the seal compression limits with an appropriate margin of safety. For the purpose of establishing a target threshold for the impact FEA a value of retaining 10% of seal compression (i.e. 2 mm) was set which gives a maximum transient lid-body gap of 3 mm.

In all impact positions the maximum transient seal gap observed in the analysis was less than the threshold value and therefore containment integrity was maintained. The maximum lid gap observed in the analyses was 2.7 mm in the 9m flat side drop (short side). The residual lid to body gap after the impact event at this location was 1.7 mm [11].

The free void volume of the O-ring grooves has been calculated to confirm that sufficient volume is retained for seal expansion during the thermal transient in fire accidents. Based upon worst case tolerance effects the calculations confirm that when exposed to a 300˚C temperature excursion the maximum seal groove fill ratio is 0.94% for the 20mm diameter containment seal and 0.92% for the 10mm diameter outer seal. These values are compliant with published guidance from Sandia National Laboratory [13].

CONCLUSIONS

In support of current and future waste management strategies within the UK the RSBTC conceptual design was undertaken to establish feasibility of transporting either a Magnox GNS Yellow Box® or a Sellafield Self Shielded Box (SSB) within a Type B(U) transport container upon the UK rail network.

The RSBTC conceptual design has been developed to fulfil a defined set of user and system requirements, developed in the early stages of the project. A number of these requirements presented significant challenges for the RSBTC design due to the high payload mass and physical size of the contents (RSBs) coupled with the dimensional and mass constraints of the UK rail network.

To fulfil these requirements the RSBTC conceptual design adopted a high capacity lid bolting system and double shear lip flange design for impact performance in regulatory impacts. The impact limiter design was developed iteratively by FEA impact analysis to arrive at the final conceptual design which utilises deformable fins supplemented with crushable impact limiter foam at critical impact zones.

Detailed impact FEA has demonstrated performance of the RSBTC conceptual design in regulatory impacts, including confirmation that the transient and residual seal gaps remain within the established 10% seal compression target established at the outset of the conceptual design work.

The final RSBTC conceptual design has been assessed as dimensionally compliant with the most restrictive W6a rail gauge allowing unrestricted access upon the UK rail network. The gross laden weight of the RSBTC upon a 4 axle well type wagon is 91.5 tonnes giving an axle loading of 22.9 tonnes and a RA9. The RA8 target is achievable with minor mass reduction of 300kg.

ACKNOWLEDGEMENTS

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