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**DEVELOPMENT OF A LARGE WASTE TRANSPORT CONTAINER (LWTC) FOR DISPOSAL
OF LEGACY ILW TO A GEOLOGICAL DISPOSAL FACILITY IN THE UK**

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ABSTRACT

As a subsidiary of the UK's NDA, INS supports RWMD's (Radioactive Waste Management Directorate) strategic objectives by reviewing technical aspects of its transport strategy and in the provision of engineering services relating to RAM transport packaging designs.

Engineering support initially involved a design review of RWMD's Standard Waste Transport Container (SWTC-285) packaging, which subsequently led to conceptual studies into a similar purpose, but dimensionally larger and heavier transport package design. This research culminated in the development of the Large Waste Transport Container (LWTC) for rail transport on an 8 axle rail wagon with gross mass of 180 tonnes.

Central to the LWTC's design philosophy are its cuboid form and the large loading aperture which are respectively driven by payload geometry and operational requirements. This geometry and the high volume / mass of the design presented a number of technical challenges, particularly in respect of manufacturing and in satisfying the requirements of TS-R-1 when compared to conventional packages, which benefit from their typically cylindrical form and minimal containment openings.

In conjunction with a business case, which investigated the economic advantages for such a large capacity package, the project presented a number of critical technical risks that needed to be mitigated to assess the feasibility of this design. These include:

- Compliance with IAEA TS-R-1 Type B(U)F Accident Conditions of Transport (e.g. impact/thermal/shielding) requirements
- Operability at a Geological Disposal Facility in the UK
- Operability at the Sellafield Site
- Compatibility with RWMD waste packages for legacy Intermediate Level Waste (ILW)
- Manufactured using proven technologies
- Compatibility with UK rail network restrictions

This paper concentrates on the mitigation of these technical risks, specifically in terms of the LWTC external dimensions, shielding provision, manufacturing route and structural performance during Accident Conditions of Transport (ACT).

INTRODUCTION

On behalf of RWMD, INS Engineering completed a technical review of the Standard Waste Transport Container (SWTC) range of packages that are intended to be licensed as Type B(U)F designs (**Fig. 1**). These packages have identical external handling features with varying cavity geometry, depending upon the size and shielding requirements of the Intermediate Level Waste (ILW) content. The heaviest variant of the SWTC range, (the SWTC-285) was the primary subject of the INS review and shall be used to transport unshielded ILW waste packages to a Geological Disposal Facility (GDF). These packages are briefly described in **Table 1**.

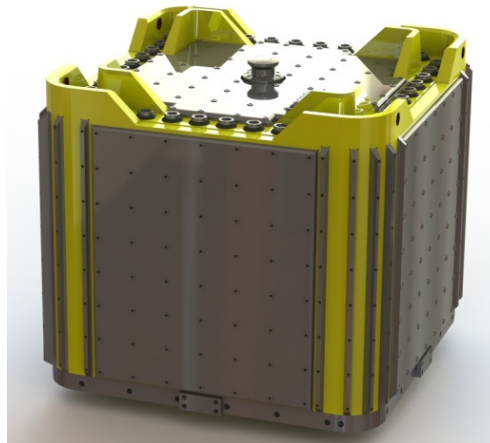





Fig.1: SWTC-285 transport package

Table 1: Standard unshielded ILW packages to be transported in the SWTC-285 to a GDF

Designation:	Description:	Dimensions (mm) & maximum mass (t)	Number required:
500 litre drum (4 off in a stillage) 	RWMD Specification: N/104 Generic container for operational ILW [1]	Ø800x 1200 2 t (per drum) 12 t (loaded stillage)	39,528
3m ³ Box 	RWMD Specification: N/104 Large container for Solid Wastes [1]	1720x1720x1200 12 t	39,585
3m ³ Drum 	RWMD Specification: N/104 Large container for in drum mixing and immobilisation of sludge wastefoms [1]	Ø 1720x1200 12 t	3,142

Following processing and interim storage at UK waste producer sites, packages will be transported to a GDF in the appropriate SWTC. On arrival, the loaded package is transferred into the GDF via either an access shaft or drift tunnel. The waste will then be removed from the transport package in an inlet cell and the SWTC returned to the surface, to be dispatched for further transports.

The capacity of the GDF package handling equipment was based on industry standard mining equipment [2]. These identified handling limits enabled the gross mass of the SWTC designs to be clarified, assuming that other transport equipment, e.g. drift tunnel bogies, need to also be considered as an integral part of a GDF delivery system. The limit also enabled a target mass for the public domain transport system to be identified, which would primarily be reliant on the UK rail network. These are shown in **Table 2**.

Table 2: SWTC 90t transport system

Item:	Maximum Mass (t)
SWTC-285	52 [1]
3m ³ Box/Drum	12 [1]
Standard 4 – axle Rail Wagon (22.5t rated axles)	26 [2]
Total : 90 t	

Subsequent to RWMDs adoption of these limits, a Site Licence Company (SLC) made enquires in respect of a GDF being able to import Multi-Purpose Containers (MPCs) that would significantly exceed the identified GDF equipment capacity. A re-assessment of mining technologies by RWMD indicated that this mass increase was within the lift envelope of market leading mine equipment. The results of this capacity review therefore provided potential to consider the transfer of other large mass items into a GDF.

One such opportunity was the assessment of a larger version of the SWTC, that could transport multiple numbers of the standard unshielded waste units described in **Table 1**, or a single, large capacity waste disposal unit. Such an oversized unit would support the disposal of larger decommissioning items, with limited or no size reduction. This could significantly reduce expenditure on complex and costly size reduction facilities on a number of UK decommissioning projects. As a comparison with the packages detailed in **Table 1**, this oversize unit could weigh as much as 34 t, with external dimensions of (l)3920 x (w)1770 x (h)1394mm. From this review of the GDF handling capacity, the Large Waste Transport Container (LWTC) concept was conceived (**Fig. 2**)[3].

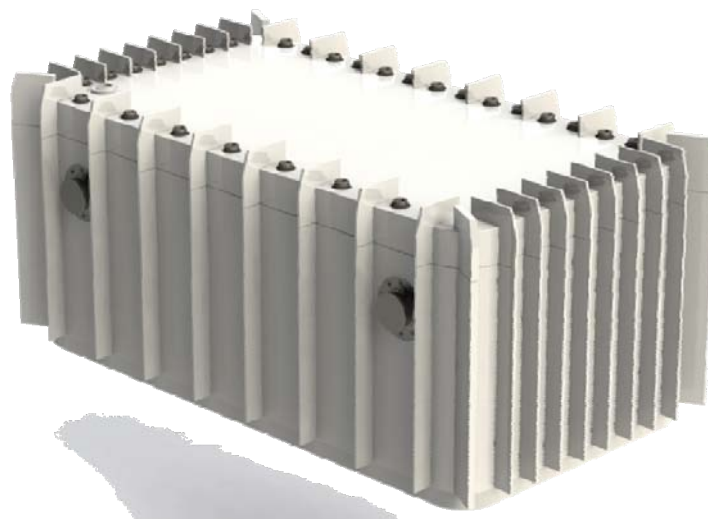


Fig. 2: The Large Waste Transport Container (LWTC)

As with any design, the LWTC is required to satisfy a number of technical requirements, the main aspects of which are outlined in **Fig. 3**. These presented technical challenges that need to be addressed in its development to ensure a substantiated solution is possible.

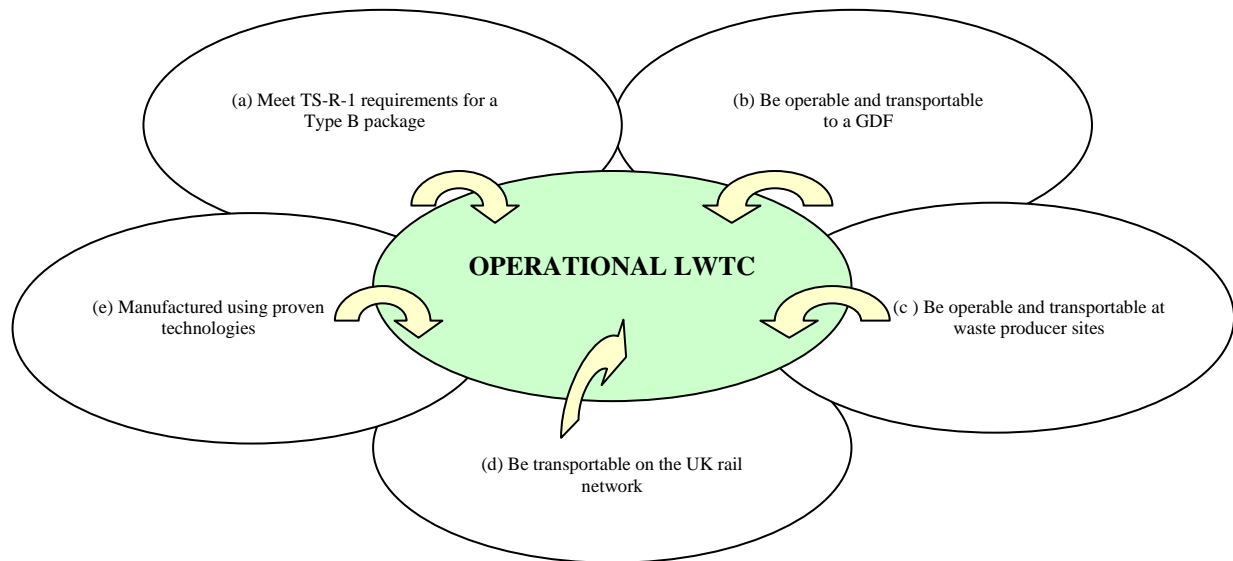


Fig.3: LWTC – Design challenges

SHIELDING REQUIREMENTS

A primary consideration of any transport package design is the ability to protect operational personnel and the public from the radioactive contents. Once the material type and thickness requirements are understood, meaningful studies can commence on manufacturing issues and subsequently, response to Accident Conditions of Transport (ACT) can be studied and developed. The increased geometry of the LWTC and the appreciable amount of time that had elapsed since the SWTC assessments were completed presented an opportunity to review shielding requirements using the latest ILW activity data for the UK. A study was completed that considered the shielding performance of the LWTC when transporting the waste streams identified in the UK Waste Inventory [4,5]. A range of package wall thicknesses were considered in order to determine what percentage of the overall conditioned volume could be transported in the LWTC, using the TS-R-1 dose limit targets.

Table 3: ILW shielding requirements

Percentage (%)	LWTC wall thickness when considering conditioned waste volume (mm)
50	25
60	40
70	65
80	115
90	155
100*	260

*Does not include waste stream 1C01

The shielding analysis studied theoretical LWTC steel wall thicknesses over a range from 25 to 300mm. The study showed that at approximately 260mm, all the waste streams (excluding one) could be transported within the LWTC at the planned operational target of 2040. The single waste stream that could not (failing to satisfy the 0.1 mSv h^{-1} at 1 m transport criterion, assuming non-exclusive use) is denoted in the inventory as 1C01. This waste stream is identified as a beta/gamma source, dominated by

^{60}Co with a very high specific activity (131 TBq m^{-3}). However, it also has a conditioned volume of only 0.12 m^3 , a fraction of the useable volume of an LWTC. It was therefore considered unduly pessimistic to include this as the upper limit for the shielding requirement and due to its limited volume, it was decided that it should be considered in isolation, possibly using alternative transport assets.

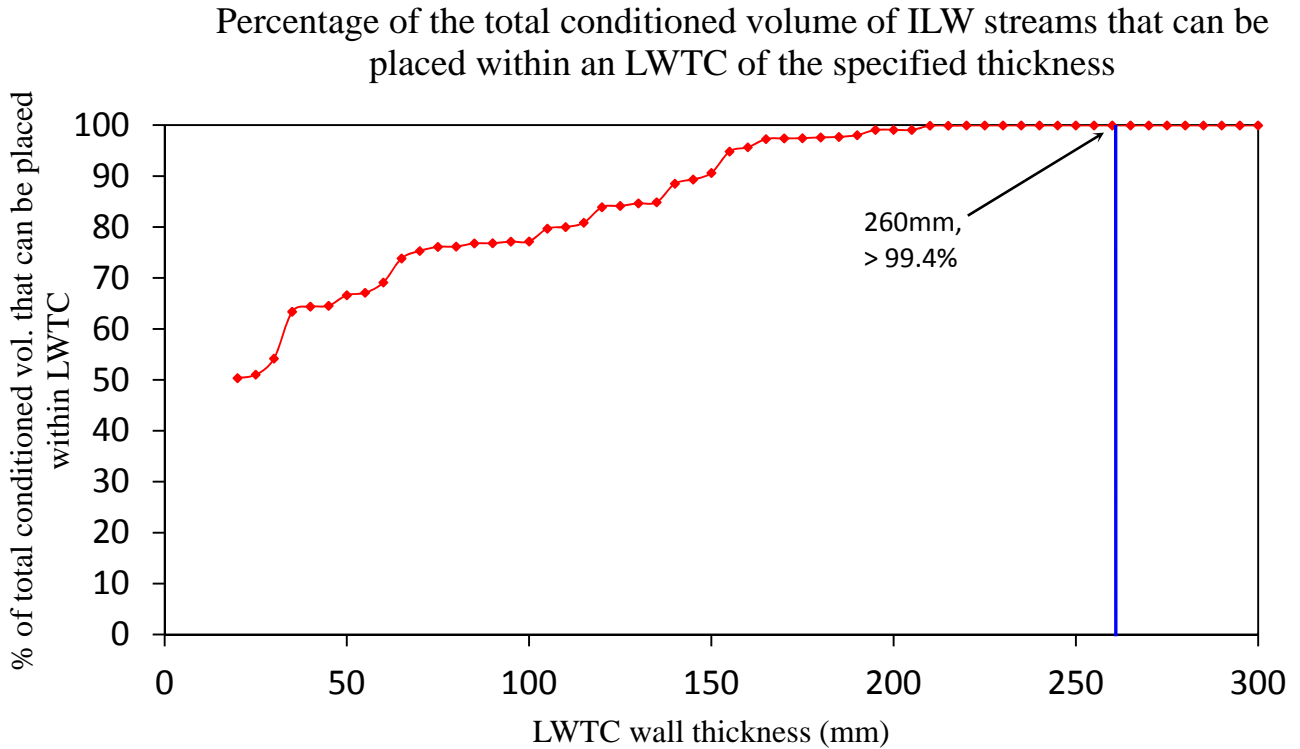


Fig. 4: LWTC wall ‘v’ % ILW for transport at 2040

Fig. 4 relates the LWTC wall thickness to the percentage of the UK ILW volume that can be transported. For example, 150mm of shielding is required to transport ~90% of the total conditioned volume of waste. Beyond this shielding gains in relation to wall thickness become increasingly limited, as is evident from the data points beyond 200mm.

As stated in [3] a requirement of the LWTC is the ability to transport all of the UK ILW waste streams. 260mm of steel was demonstrated to achieve this, (excluding 1C01) but it was noted that a significantly reduced wall of 150mm provided adequate shielding for 90% of the material. This indicates that an additional 110mm of steel is required to shield the upper 10% of higher activity material. However, the 260mm wall satisfied the specification requirement and it was judged that this amount of material would be required to provide the structural integrity required during both handling operations and to satisfy ACT assessments. Following clarification of the shielding requirements, the next stages were to understand the size/mass constraints for the design and to address manufacturing issues.

MASS AND GEOMETRY RESTRICTIONS

The LWTC will primarily be transported on the UK rail network. As the location of the GDF is not currently identified, the package must be able to operate on the most restrictive sections of this network, thus ensuring that the site location does not negatively impact the design. In respect of rail transport, there are two main issues that needed to be considered (i) width limitations on the package cross-section to ensure it does not exceed the most restrictive UK rail gauge and (ii) load ratings for the rail wagon axles. This required the rail wagon configuration and mass to be considered during the package design assessment process (**Fig. 5**).

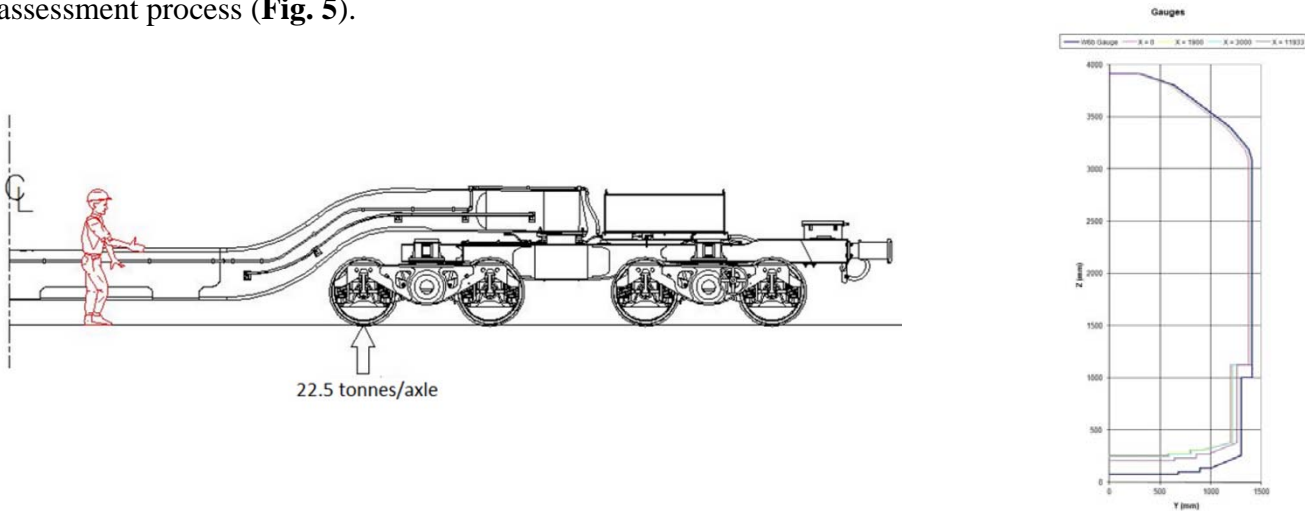


Fig. 5: KXA-C rail wagon and the UK W6b rail gauge

The NDA owns a number of high capacity, 8-axle rail wagons specifically for transporting large mass spent fuel and High Level Waste (HLW) packages. These wagons, designated KXA-C's, provided the design team with a baseline method of considering the rail restrictions during development of the LWTC. Each KXA-C wagon weighs 52.5t and is capable of carrying a 126.5t payload (180t gross) whilst satisfying the requirements of the most restrictive UK rail gauge. Taking account of the content geometry, required handling clearances and the shielding requirements, the cross-section of the LWTC was identified. Sweeping this section along the useable wagon bed, the LWTC maximum length and hence volume was identified, initially using 120t as the target loaded mass, with 6.5t of contingency (**Fig. 6**). This provided the maximum geometry and mass of the LWTC for subsequent manufacturing studies and analytical assessments.

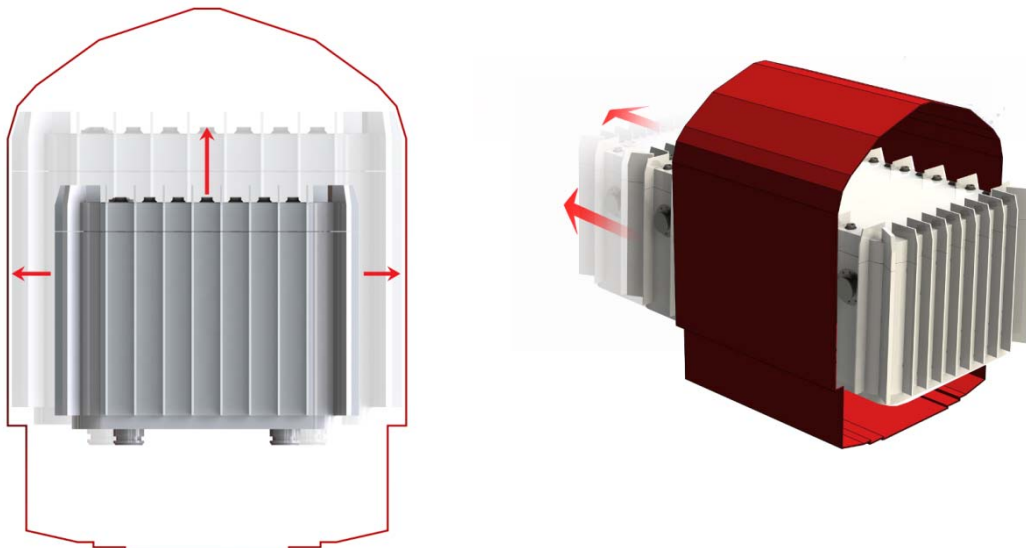


Fig. 6: Cross-section and length driving the LWTC gross mass in relation to rail gauge

Although the KXA-C wagon design has adequate carrying capacity for the LWTC, it is subject to restricted usage (50,000miles). This limit was imposed due to the wagon bed design fatigue life. In addition the wagon bed is longer than necessary for the LWTC and the package retention method is also different. A design variant specific for the LWTC provided the opportunity to improve the fatigue life, whilst ensuring the interface with the LWTC geometry was optimised. An assessment was undertaken and a design proposal developed. This study provided a wagon concept with an improved fatigue life that met the operational aspirations of the LWTC (Fig. 7) [6, 7].

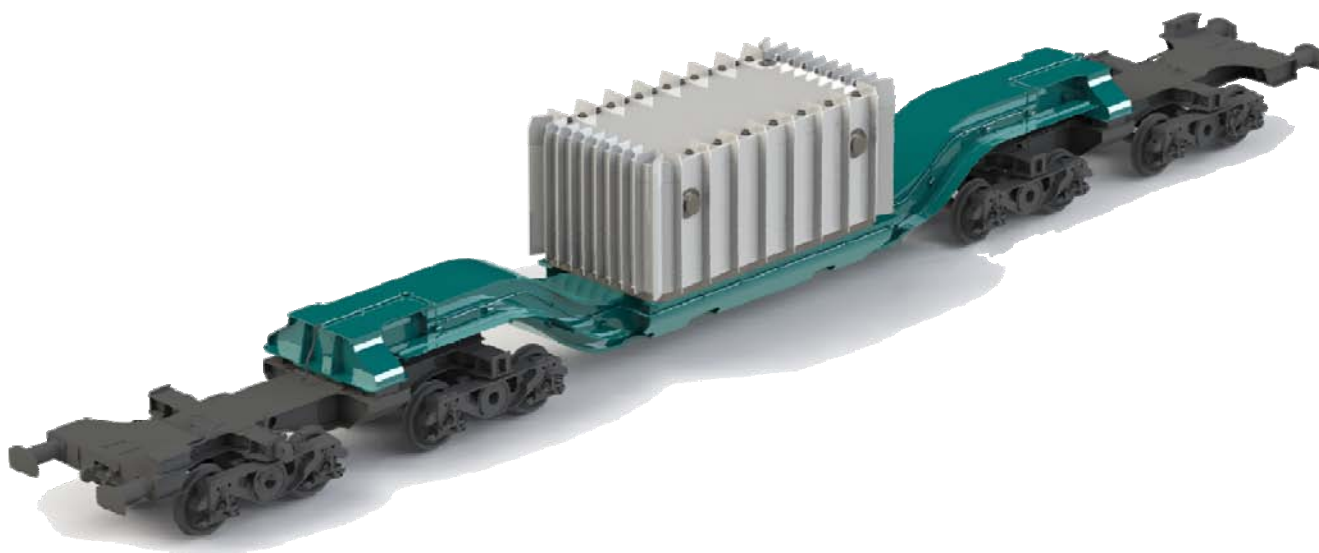


Fig. 7: LWTC concept rail wagon

MANUFACTURING

Materials used in the construction of Type B transport packages must possess substantiated mechanical properties at -40°C . This is a regulatory requirement [8] and guidance [9] explains how compliance can be demonstrated for various types of materials. The simplest approach and the one employed on the LWTC project was to identify “...materials which remain ductile and tough throughout the required service temperature range, including down to -40°C ...” [9]. Identifying such materials is relatively straightforward for package sub-components e.g. seals, bolts and trunnions, as suitable materials could be inferred from other Type B designs. However, the material of the LWTC body and lid components presented increased technical risks due to their novel (from a transport package perspective) size, mass and geometry. The response of these components at -40°C is particularly significant, as their monolithic structure suggested the potential for a containment breach if a flaw was to propagate through the material.

A specialist was employed to identify materials for these critical components. This included a review of suitable materials based on mechanical property requirements, manufacturing and inspection routes and the cost effectiveness of these processes. Subsequent studies [10, 11] which supported previous work by RWMD, identified a martensitic stainless steel as the most appropriate material for the given task. This material, GX3CrNi13-4 (CA6NM) provides the necessary mechanical properties, whilst also being suitable for a number of manufacturing routes. It is also heat treatable, has good corrosion resistance and importantly ultrasonic test methods can be employed with confidence, due to the small martensitic grain size. Using this material as a basis, the subsequent manufacturing assessments indicated that the most cost effective solution would be to cast both the body and lid components, with subsequent machining

providing suitable finishes for component attachments/seal faces, etc. Specialist software was used to understand how these high volume/mass sections would solidify during casting. This enabled optimisation of the casting header positions to ensure final solidification occurred in these volumes, rather than in the components (**Fig. 8**).

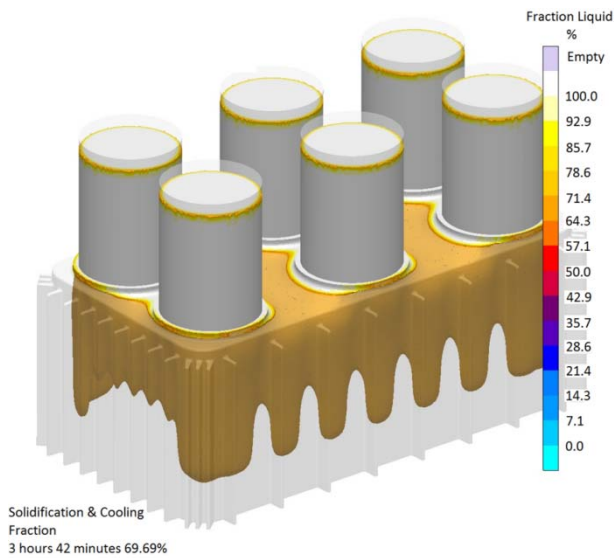


Fig. 8: Modelling of an inverted LWTC body being cast in CA6NM material



Fig. 9: 4 tonne corner section of LWTC body and sample material properties

To further underpin the identified manufacturing route and provide benchmark material data for the ongoing analytical studies, a 4t corner section of the LWTC body was cast in CA6NM material (**Fig. 9**) (**Table 4**). The manufacture of this sample also provided the opportunity to develop and record appropriate Non Destructive Testing (NDT) methodologies that could be employed when the LWTC entered a manufacturing phase [11].

Table 4: Mechanical Properties of Sample Casting

Identity	Direction	0.2% Proof MPa	UTS MPa	Elongation %	Reduction in Area %	Test Temp °C	Impact Value Joules			Average
A1	L	667	802	22	72	-40	141	149	140	143
						-120	75	90	69	78
A2	L	654	801	23	69	-40	153	149	160	154
						-120	64	60	112	79
A3	L	637	795	23	70	-40	140	136	142	139
						-120	65	71	72	69
A4	T	613	788	22	75	-40	138	135	127	133
						-120	79	63	56	66
A4	L	664	808	20	57	-40	171	158	165	165
						-120	44	53	51	49
A5	L	679	813	20	68	-40	137	135	144	139
						-120	46	56	49	50
GX3CrNi13-4 1.6982		500	700/	15		-40	100			
BS EN 10213			900			-120	27			

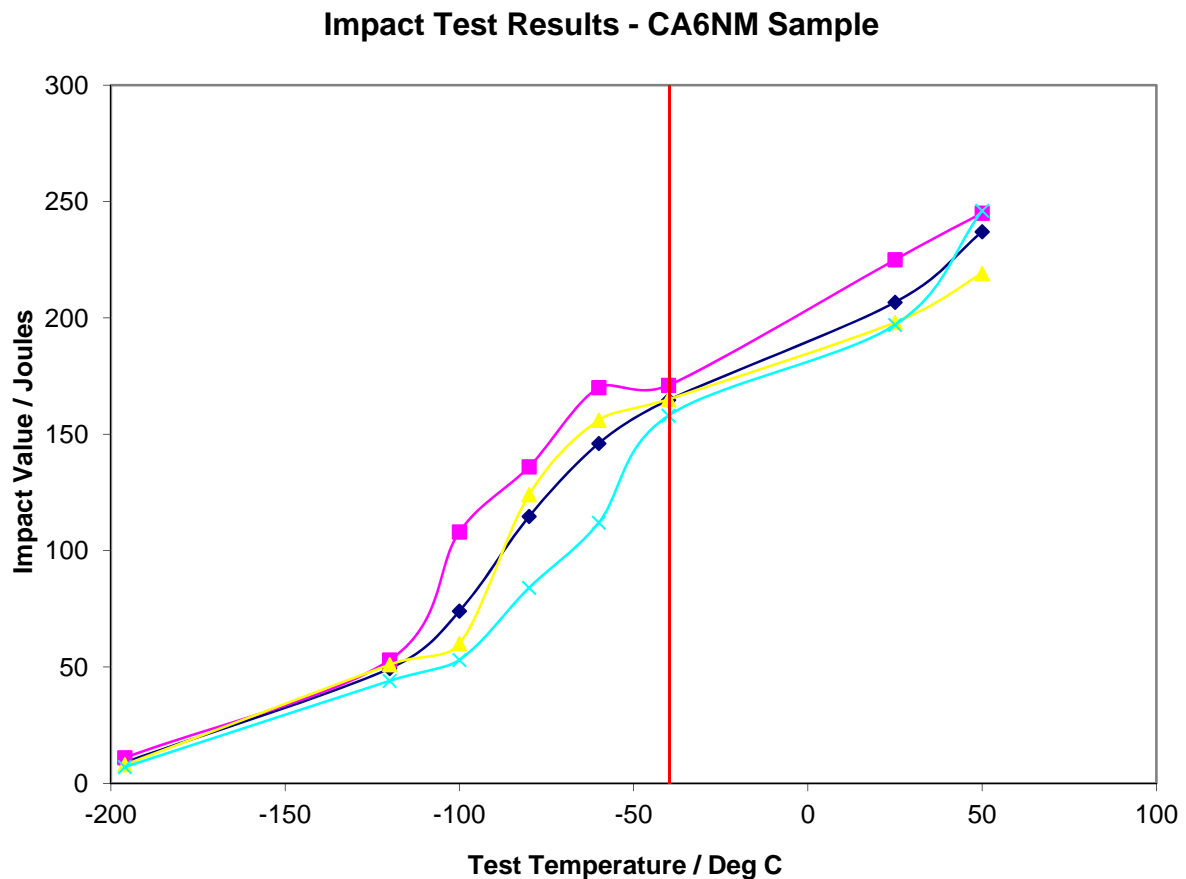


Fig. 10: Charpy impact test results – CA6NM

Fig. 10 shows Charpy impact test results at various temperatures for samples taken from the LWTC test section. The results demonstrate that the cast material remains ductile at temperatures significantly below the lower operating range, with some resistance still evident at -196°C . These results, in conjunction with previous studies [12] that investigated a postulated CA6NM flaw response to a 9m impact at -40°C , provide evidence of satisfying the requirements of [8].

ACT PERFORMANCE

The LWTC will be required to demonstrate suitable performance when subjected to a number of specific accident scenarios, as defined in [8]. The object of these assessments is to ascertain whether the containment boundary of the package would be compromised by these accidents. This involves analysis and testing of the package during hypothetical impact conditions and a 30 minute hydrocarbon fuel-air pool fire.

The main components that constitute the containment boundary are the LWTC body, the lid, the lid attachment bolts and the elastomer (EPDM-30H) seal arrangement housed in the lid. During development of the package, the performance of these seals is measured against the following pass/fail criteria:

- (1) The compression set of the seals due to NCT/ACT [13]
- (2) Post ACT – retained $\geq 10\%$ compression [14]

A seals assessment computer programme [13] was used to understand the compression set the seals would incur during their operational life due to thermal and dose rate effects on the seal material. This programme uses material test data to understand the potential loss of seal elasticity when subjected to

specific thermal and radiation environments for given time periods. For the LWTC, initial assessments have shown that the calculated amount of compression set is minimal.

The SWTC suite of transport packages use a 15mm cord containment seal. This seal was also considered for the LWTC design, but due to the size/mass of the LWTC components, the availability and performance of a larger, 20mm cord seal was also considered. The larger chord increases the allowable seal compression loss post ACT (**Fig 11**).

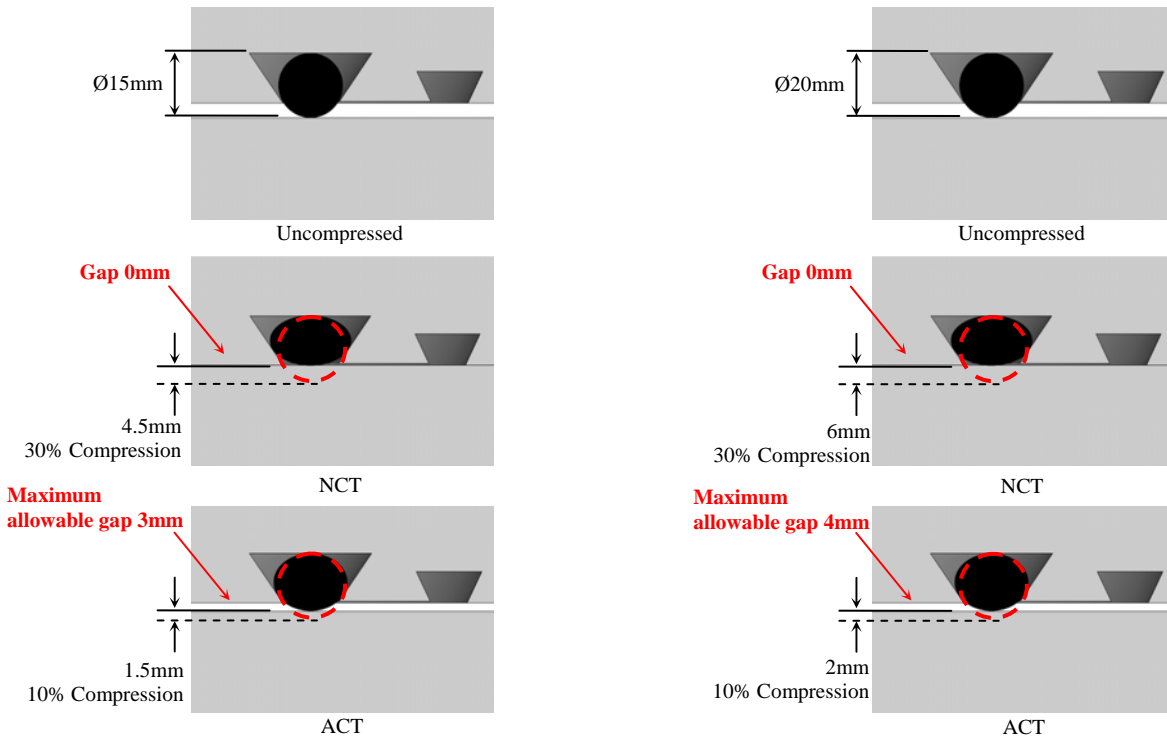


Fig. 11: Containment seals – Operating compression and minimum post ACT

Regulatory accident scenarios have been studied analytically and through an iteration process, the results have been used to understand and improve the performance of the design. Two of these assessments are discussed below. Although these have currently been analysed in isolation, the final design must be able to meet the required seal compression criteria following a cumulative accident i.e. a 9m worst orientation impact, followed by the fuel fire. However, due to the novelty of this design, it was important in this development phase to fully understand the response of the LWTC to design changes in isolation prior to performing such cumulative analytical assessments.

9m Impact Assessment

Satisfying the requirements for the 9m drop test is considered one of the central challenges to the LWTC due to its size, mass and the unusually large body/lid interface. Regulations require the package to be dropped from 9m (measured from the lowest point on the package) onto an unyielding surface. This theoretical target maximises the energy the package structure is forced to absorb during the impact event. The analysis must consider and identify the most onerous impact orientations that prove most challenging to the containment boundary.

Maximising the geometry of the LWTC for rail movement and operational requirements meant that removable energy absorbers, common on spent fuel type package designs, were excluded. This led to the development of permanent energy absorbing features that are integrated into the body and lid

components, **Fig. 12**. Their initial geometry was derived from a theory proposed in a technical paper [15].

Early in the analysis the need to evaluate and prioritise design variables that would affect the impact performance of the package were identified. The variables were grouped into two categories; those anticipated to have major design and performance implications and those that act as tuning parameters (**Table 5**).

Table 5: Design variables effecting impact performance

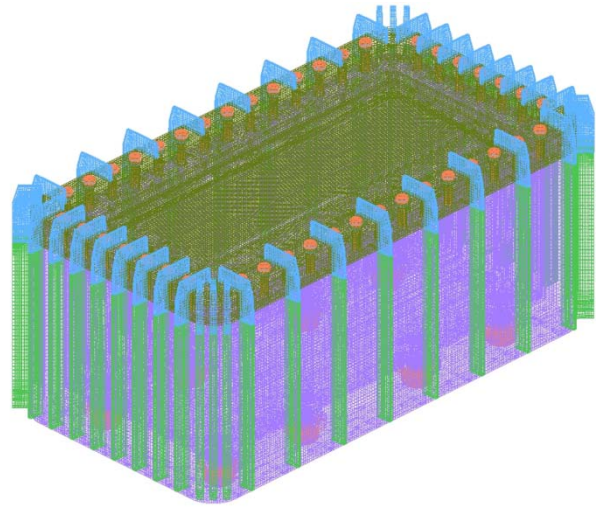
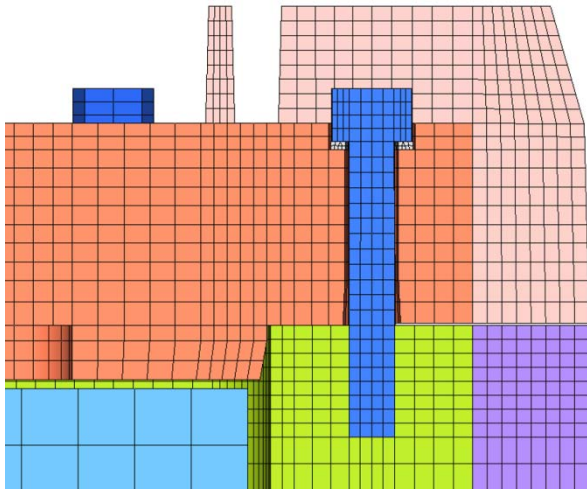
Major Design Variable	Minor Design Variable
Energy absorbers	Length Thickness Draft angles Material type No. of energy absorbers
Lid bolts	No. of bolts Bolt diameter Bolt torque/pre-load Material type
Waste retention	Underside of lid Base of package Inner wall of package
Package body	Wall thickness Length Width
Lid seal chord	Diameter Initial compression

The wall thickness was defined by shielding considerations which in turn, drove the overall package mass. A change to the wall thickness would necessitate a reduction in length of the package to accommodate the associated increase in mass. A solution was first sought through a sensitivity study of the minor variables of the energy absorbers. Analysis commenced with the 260mm wall needed to satisfy the shielding requirements. Subsequent sensitivity studies varied the minor design variables of these features, to reduce the peak lid-body seal gap to within the limits identified (**Fig. 11**).

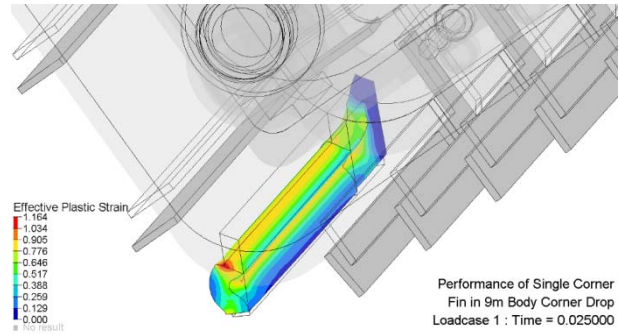
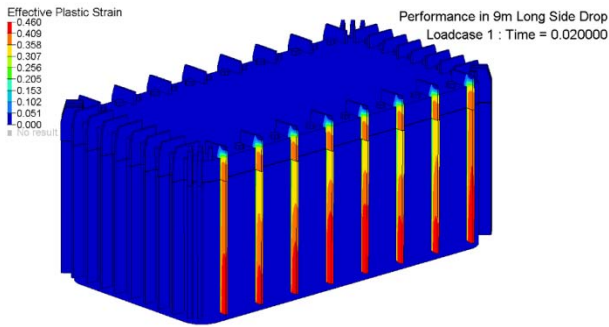
Initially, 11 different drop orientations were assessed to identify the worst case. The long side drop proved to be particularly onerous and was subject to the first of several focused sensitivity studies. After 9 iterations the performance of the design was improved sufficiently to reassess the package incorporating the new design changes in each drop orientation.

The subsequent results indicated a new worst case drop orientation, the body corner drop, which became the focus of a further sensitivity study. After 14 iterations on the corner energy absorbers, the design which performed the best was identified. A third sensitivity study is currently underway, focused on another of the major design variables; the lid retention system/bolts. In summary exploratory studies of the energy absorbers, lid bolts and waste retention have been carried out (or are ongoing) and have made significant advances in the development of the LWTC. An example is provided in **Fig. 12 [16]**.

FEA modelling



Behaviour assessed in multiple drop orientations



Sensitivity analysis used to improve performance in worst case drop orientations

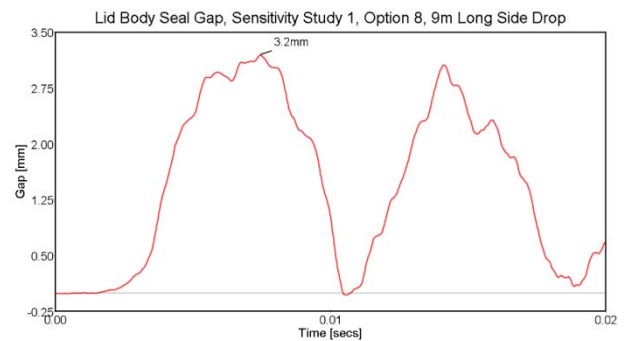
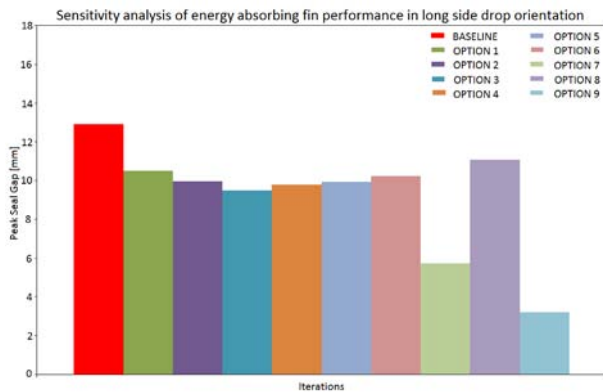
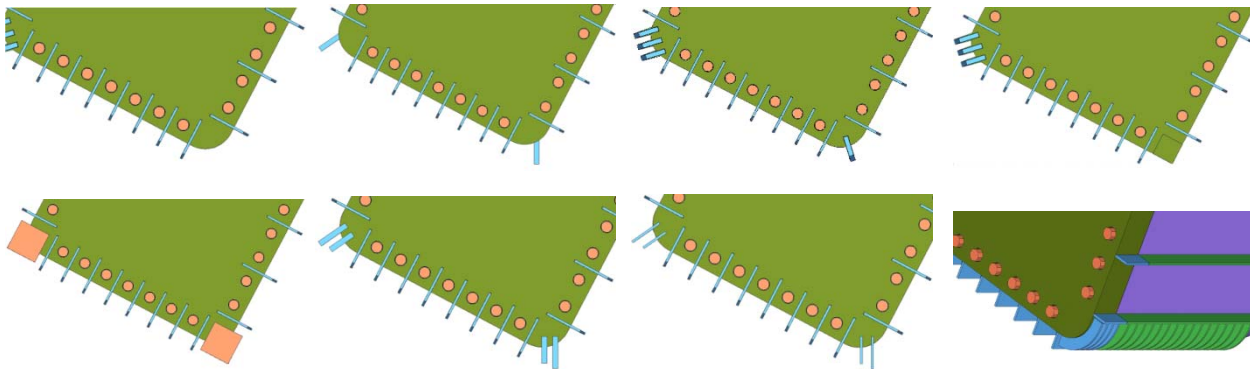


Fig .12: Development of the LWTC performance in a 9m drop using Finite Element Analysis

Thermal Assessment

The LWTC thermal analysis [17] was executed in three sequentially coupled analyses:

1. Steady state – NCT
2. Transient – 30 minute pool fire ACT
3. Transient – Cool down phase, post ACT

The steady state analysis assumed the LWTC was loaded with the oversize waste package which produces an internal heat load of 570W (linearly extrapolated from the 3m³ box maximum of 200W) and the package subjected to the environmental conditions specified in [8]. As expected, the maximum temperatures during NCT are relatively low. The maximum lid seal temperature predicted was 55°C and the maximum external surface temperature was 58°C, occurring at the centre of the lid. This is satisfactory for a package transported under exclusive use [8].

The subsequent 30 minute pool fire analysis used the results of the steady state analysis as the initial boundary condition. **Fig. 13** shows a summary of the results during and after the fire. The maximum temperature predicted was 727°C after 30 minutes, occurring at the extremities of the lid energy absorbing features. The time histories in the figure are from two nodes on the lid seal; one that cooled down the slowest and one that produced the highest temperature.

Temperature profile after 30 minutes in a 800°C pool fire

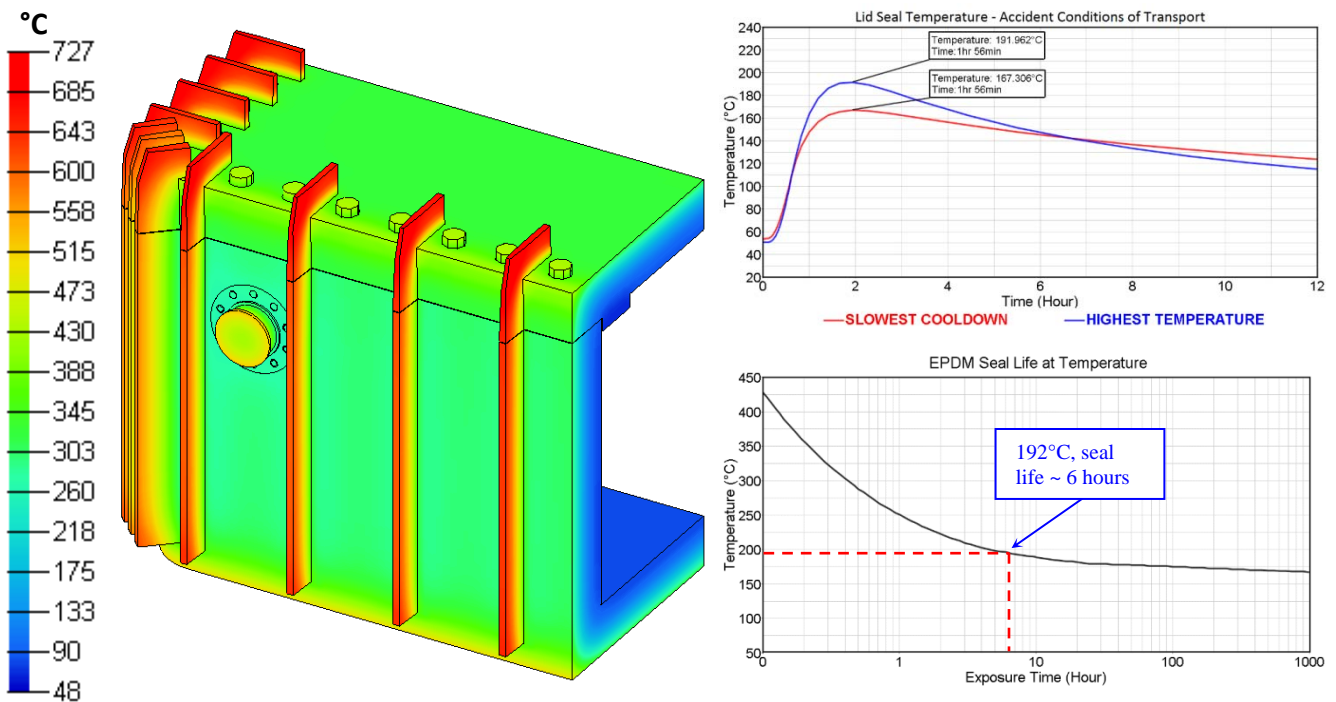


Fig .13: Heat transfer analysis during and after 30 minute pool fire

Due to thermal inertia the temperatures in the body and lid continued to rise at the end of the 30 minutes fire. This short term temperature excursion has a limited effect on the performance of the containment seal material [13]. Of more significance is the effect of thermal expansion, which causes the lid to distort. This makes it necessary to assess the lid-body gap against the previously identified seal performance criteria (**Fig. 11**).

The thermal stress performance of the LWTC was assessed by monitoring the lid-body seal gap throughout the transient and the stresses in the lid bolts, lid and body. The results indicated that the lid-body seal gap could be reduced through minor design changes and that major components were subject to some localised plasticity due to high contact forces.

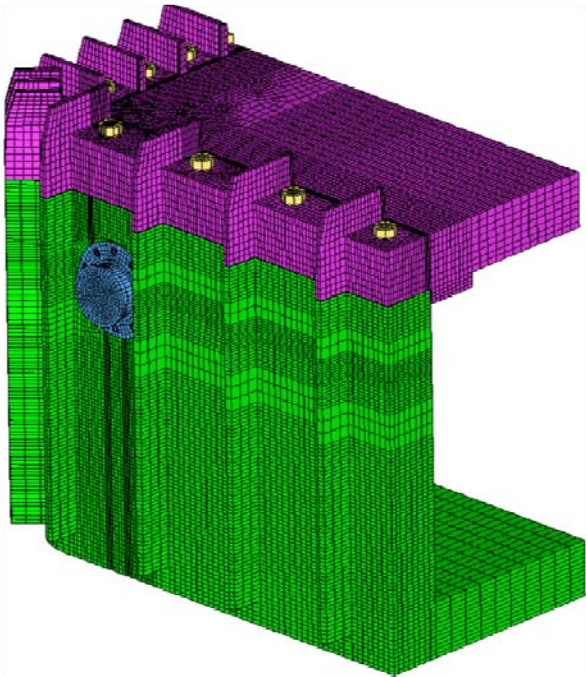
A matrix of design variables that influence the thermal stress performance was initially identified and the design of a lid relief was the focus of a sensitivity study (**Table 6**). This variable was chosen because it was not anticipated to influence the impact performance. The results demonstrated that increasing the relief size reduced the lid-body seal gap but increased the average stresses in the lid bolts. An example of the thermal analysis is provided in **Fig. 14**.

Table 6: Design variables effecting thermal stress performance

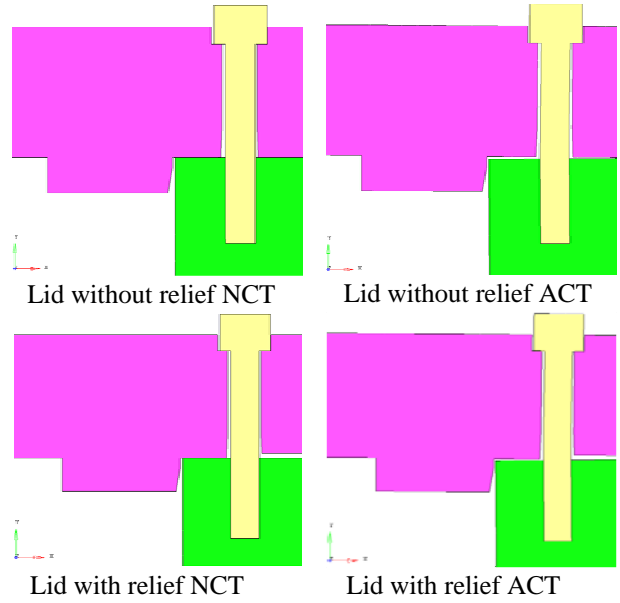
Major Design Variable	Minor Design Variable
Lid bolts	No. of bolts Bolt diameter Bolt torque/pre-load Material type
Lid relief	Angle Depth
Package body	Wall thickness Length Width
Thermal insulator	Material Location Thickness
Lid seal chord	Diameter Initial compression

In summary the thermal stress results indicate that small improvements to the design are necessary to meet the requirements of TS-R-1. Ongoing studies include further sensitivity on major design variables such as the number of lid bolts. Future work will assess the robustness of the design due to variability of material properties and boundary conditions including cumulative accident conditions.

FEA Modelling



Sensitivity analysis used to improve performance



Behaviour assessed throughout fire and cool down period

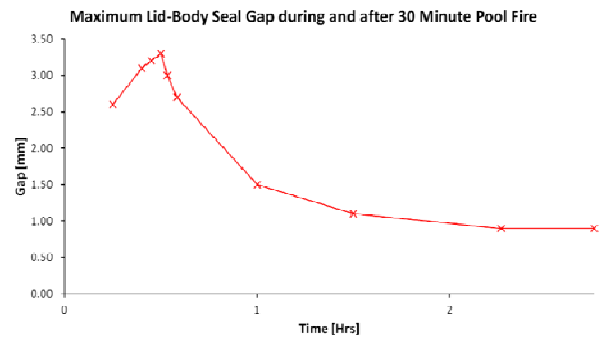
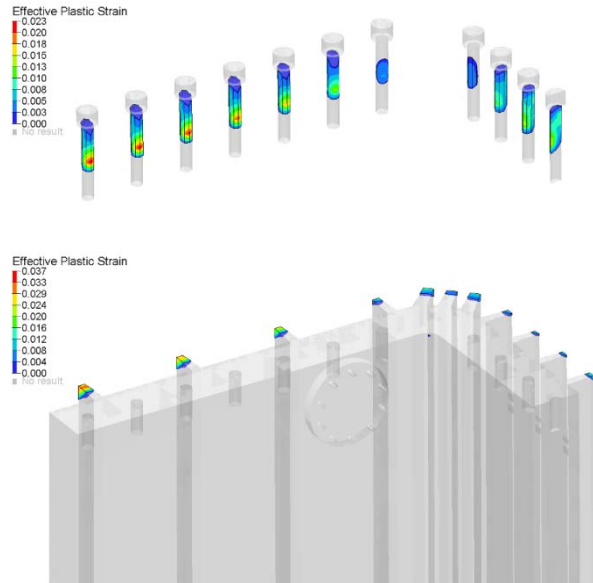
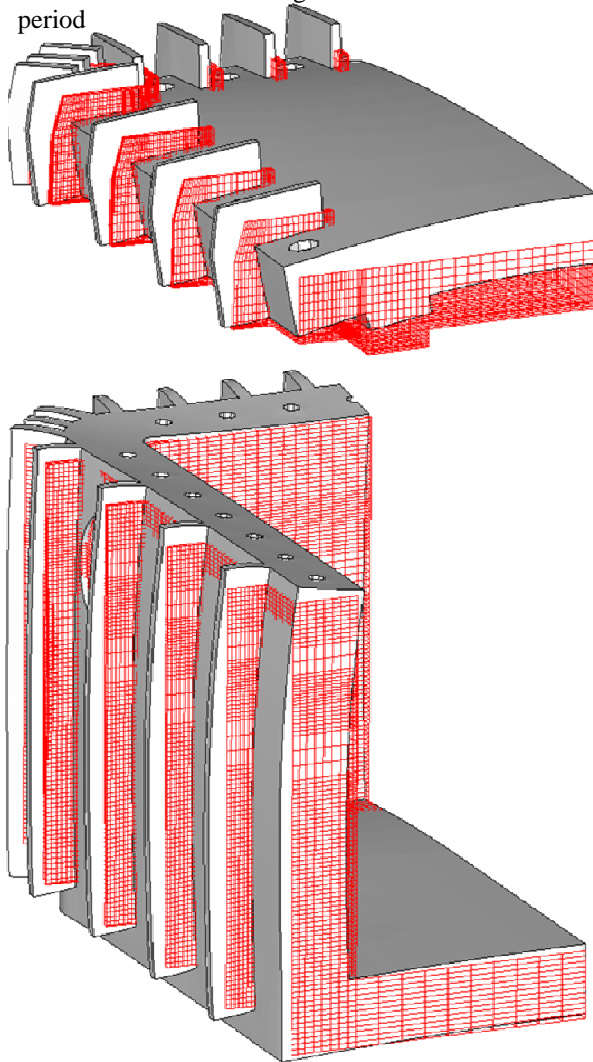


Fig. 14: Development of the LWTC thermal stress performance during and after 30 minute pool fire using Finite Element Analysis

CONCLUSIONS

The LWTC presents a number of technical challenges that have been addressed in this design development phase. Handling of the package at both a GDF and at UK waste producer sites has been reviewed with the stakeholders and the risks posed are understood and are comparable to operational issues with currently operated irradiated fuel/HLW transport packages. Transport of the LWTC on the UK rail network has also been considered. The design of a rail wagon capable of transporting such a package has been progressed and there are positive indications that this concept will achieve unrestricted usage. This work has ensured that the LWTC will not be limited by a specific GDF location and also clarifies the requirement for rail wagon numbers/costs in respect of the operational life of a GDF. The materials used for the main LWTC components have been studied in detail and a cost effective solution which satisfies regulatory requirements has been identified. In addition to these mitigated risks, a significant amount of analysis has been performed to understand the response of the LWTC to regulatory ACT. Through a structured iteration process, the design has been progressively improved and the risks associated with its performance progressively reduced via enhanced understanding of the packages response. In the current development phase analysis studies continue to refine the design and further work will ensure that the effects of cumulative accidents are fully considered. These wide ranging studies undertaken to understand the LWTC design also provides the opportunity to review the design of the SWTC fleet and reinforce their Design Safety Reports prior to licensing submission.

The current preliminary design phase as described in this paper will be completed by late August 2013. The LWTC project is an excellent example of how INS is supporting the NDA estate by deploying in-house engineering skills to support major strategic objectives.

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