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Demonstration of the impact accident performance of the TRU-Shield Waste Package

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Abstract

Dounreay Site Restoration Limited (DSRL) is proposing to use a new shielded waste container TRU-Shield for the packaging and disposal of wastes from the Dounreay site. The TRU-Shield is a shielded cylindrical container with a stainless steel-lead-stainless steel sandwich structure and the lid is connected to the body by stainless steel bolts. It is envisaged that the waste will either be loose waste contained within multiple containers in a "Russian doll" arrangement, or encapsulated in grout. As a waste package to be disposed in the eventual Geological Disposal Facility (GDF), it has to satisfy the waste packaging requirements defined by the Radioactive Waste Management Limited (RWM), among which, impact performance requirement in drop accident scenarios. And before the packaging process can be commence, it has to obtain a Letter of Compliance (LoC) from the RWM. Arup was engaged by DSRL to demonstrate the impact performance of the TRU-Shield package. This paper presents a summary of the work.

Introduction

Dounreay Site Restoration Limited (DSRL) was considering using a new shielded waste container TRU-Shield for the packaging and disposal of specific types of wastes from the Dounreay site. As a waste package to be disposed in the eventual Geological Disposal Facility (GDF), it has to satisfy the waste packaging requirements of the Radioactive Waste Management Limited (RWM). One of the requirements is its performance in the GDF impact accident scenario.

To demonstrate impact performance, three 15m drop tests were carried out on an "original" design of the TRU-Shield at Oak Ridge National Laboratories in 2011-2012. Subsequently, a number of changes were made to the design. And in 2014, DSRL commissioned Arup to evaluate and demonstrate the impact performance of the revised design with the aid of finite element (FE) simulation.

Arup’s work consisted of two tasks:

Task 1 - Develop an FE model of the TRU-Shield package as used in the drop tests and benchmark the model against the 15m drop tests.

Task 2 - Revise the FE model to the revised TRU-Shield design, then analyse and evaluate its impact performance

Description of the TRU-Shield package in the drop tests

The TRU-Shield consists of a circular lid and a cylindrical body, and both the lid and the body have a steel-lead-steel sandwich structure. The lid is secured to the body by twelve A2-70 stainless steel bolts, and “Rivnuts” are used as attachment points for the bolts in the body. A rectangular stainless steel pallet is welded to the base of the drum.

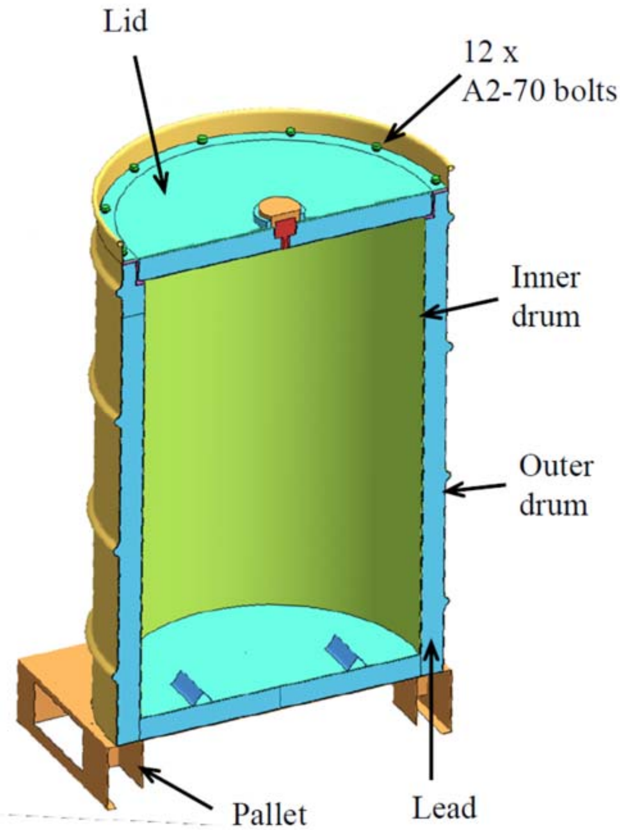

Figure 1 Section through the TRU-Shield

The drop test package consisted of a “Russian Doll” contents which comprised of metal bars which represented the waste contained within a carbon steel crate, which is in turn contained in a Z6033 container, which is then contained in a 330 litre drum, and which is in turn contained in the TRU-Shield. This is illustrated below:

Metal bars representing the waste, contained in a Crate | Z6033 | 330l drum | TRU-Shield

Figure 2 Components of the drop test package

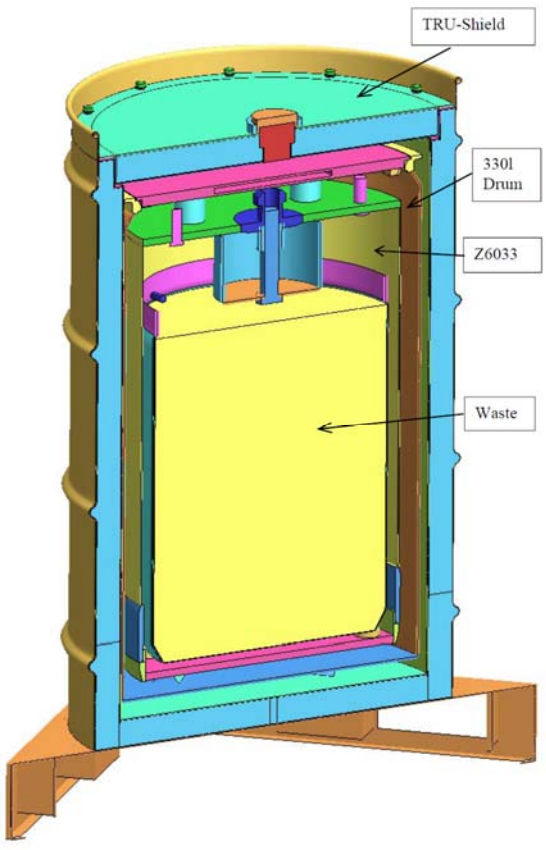

Figure 3 Illustration of the Russian Doll contents of the drop test package

Test conditions and measurements

Four drop tests, three from 15m and one from 1.2m were performed at the National Transport Research Centre of Oak Ridge National Laboratories in 2011-2012. Four nominally identical drop test packages were used in the four drop tests, and each drop test package was only drop tested once. The drop orientation of the three 15m drops were centre of gravity over lid edge, side drop and centre of gravity over bottom corner. The target for each test was the flat effectively unyielding target at the drop test facility.

Photographs were taken before and after the drop tests, and the drop test packages were cut up and taken apart after the drop tests to evaluate the damages. No static measurement in terms of extent of deformation and extent of knockback were taken. And no transient data in terms of acceleration-time history or strain-time history was measured.

Finite element model

Each of the containers were modelled with a combination of thin shell and solid elements. The mesh was designed taking into account the geometry of the components, as well as the expected extent of deformation of the components in the drop tests. The mesh was most refined in the TRU-Shield, reflecting (a) the intricacies of the design in the lid-body interface area, (b) the relative importance of the TRU-Shield in providing containment and shielding over the other containers in drop test package, and (c) the large deformations of the TRU-Shield in comparison with the other containers in the package. For all containers, the same mesh was used in each “repeating unit” of the geometry around the circumference, such that difference in behavior due to different location with respect to the impact, is not due to differences in the mesh. And the same model was used in the analysis of all three 15m drop tests. All the models were full models.

In the model of the TRU-Shield, the mesh was most refined in the lid-body interface area, due to the small details of the Rivnuts, the bolts and the bolt holes as well as the large deformations in the area. In contrast, the mesh of the lead was deliberately coarse in order to cope with the large deformations. The lid-body bolts of the TRU-Shield were modelled explicitly in solids with the modelling methodology developed in the RWM’s Bolt Study, which consisted of extensive physical testing of different type of stainless steel bolts (in terms of size, steel grade and geometry) in tensile and shear tests up to failure at a range of strain rates, and benchmarking of FE models against the tests. The Rivnuts were also modelled explicitly in solid elements. The threaded interface between each bolt and its Rivnut was modelled as a continuous mesh.

Contact surfaces were defined extensively to simulate the interface between the different components and between the containers.

All the analyses were carried out in LS-DYNA v971 R4.2.1 MPP in double precision.

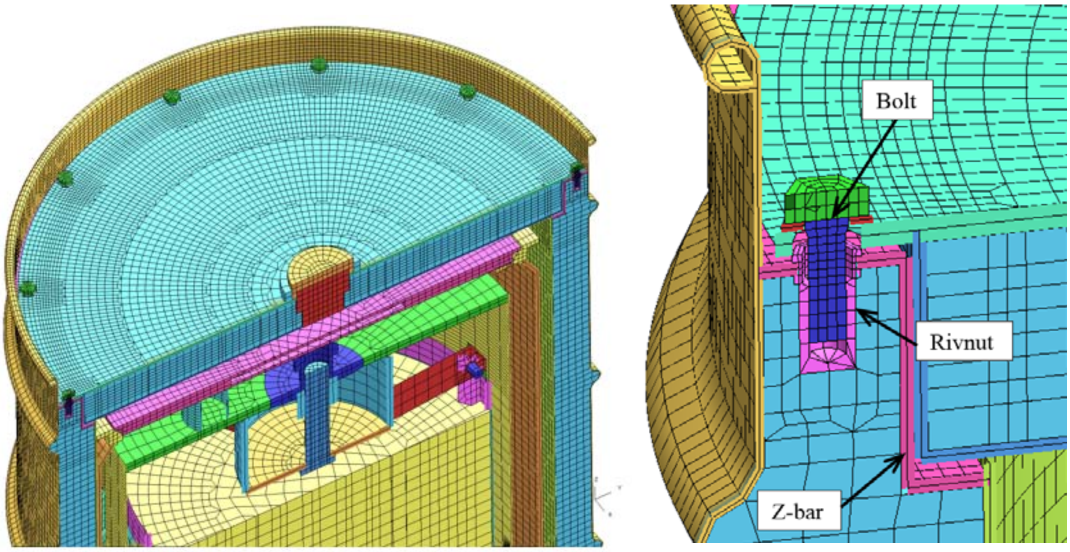

Figure 4 Section through the FE model of the TRU-Shield

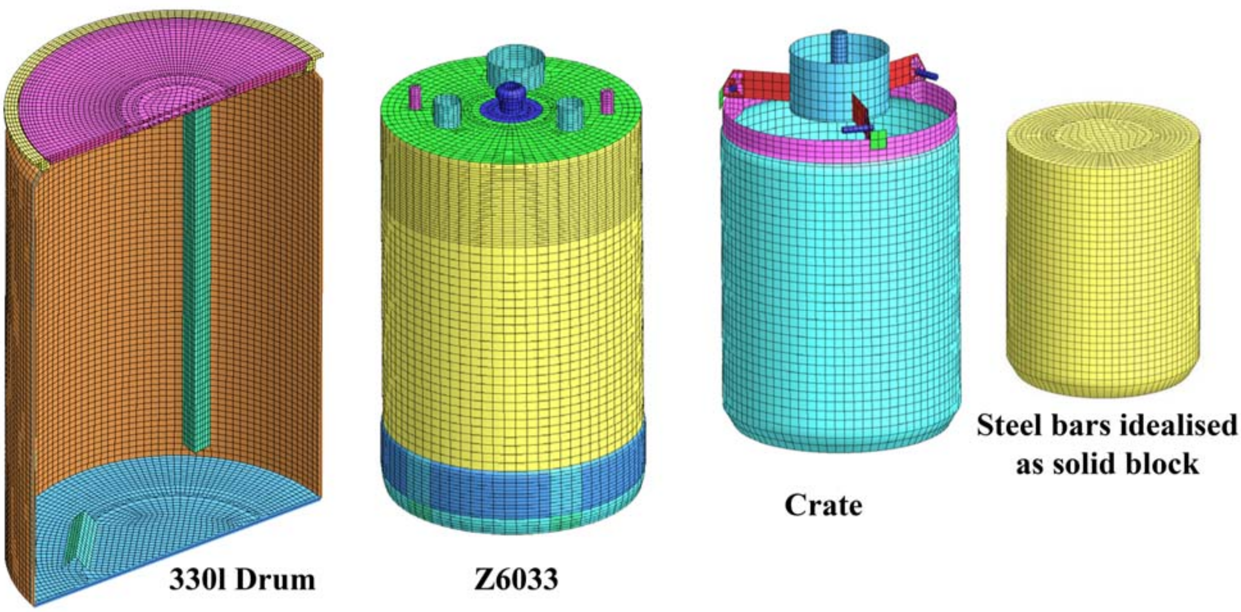

Figure 5 FE model of the contents of the TRU-Shield

Analysis set-up

At the start of the analysis of each impact scenario, the model was located close to the target, oriented in the correct orientation, and was given an initial velocity which corresponds to the impact velocity after falling 15m. Each analysis was run until the package had rebounded and the internal energies settled to a constant value.

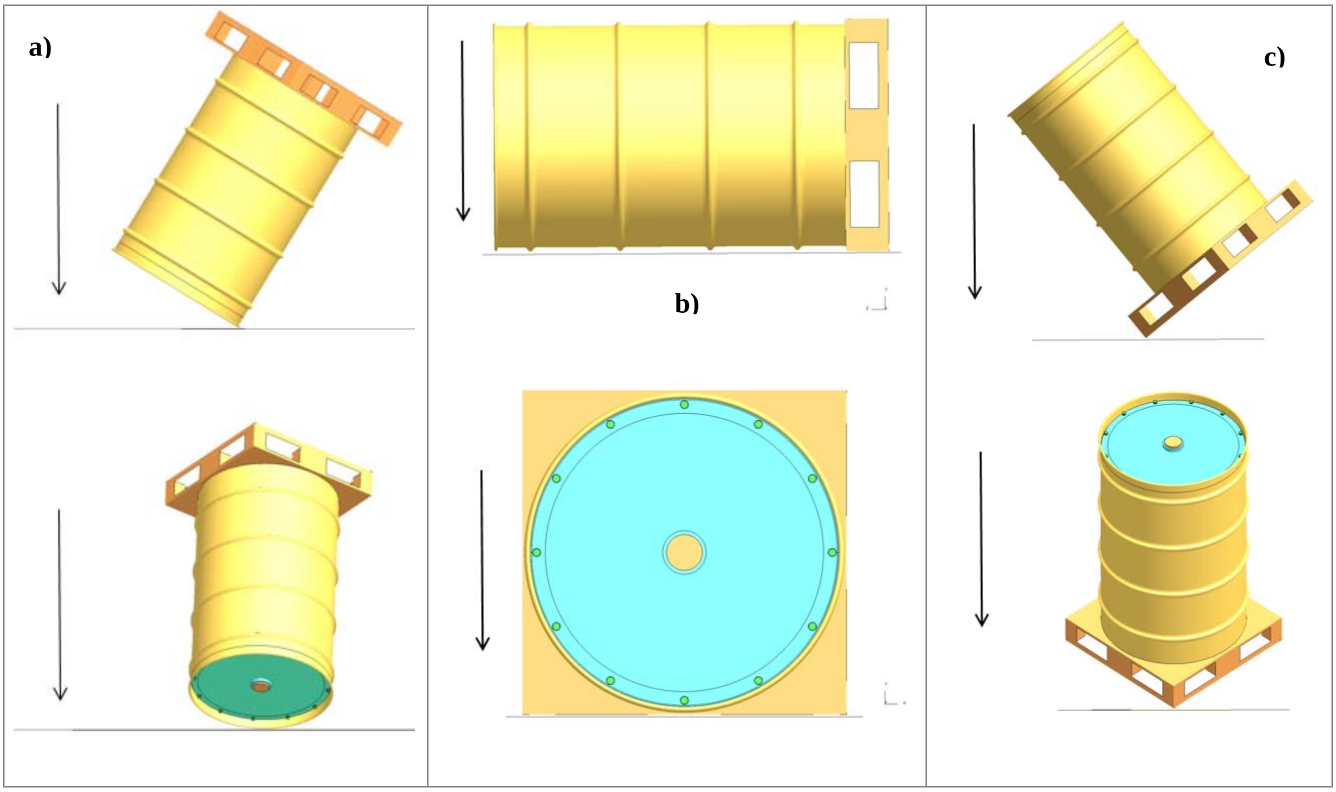

Figure 6 Drop orientations – a) Lid edge drop, b) Side drop, c) Base edge drop

Comparison of analysis results with drop test results

Deformed geometry from the analyses were compared to the deformed drop test package as shown in the post-test photographs. This is the only means of comparison available as no transient measurement or static measurement were taken from the drop tests. Comparisons are shown in the following figures:

Figure 7 Lid edge drop – Drop test result vs analysis result

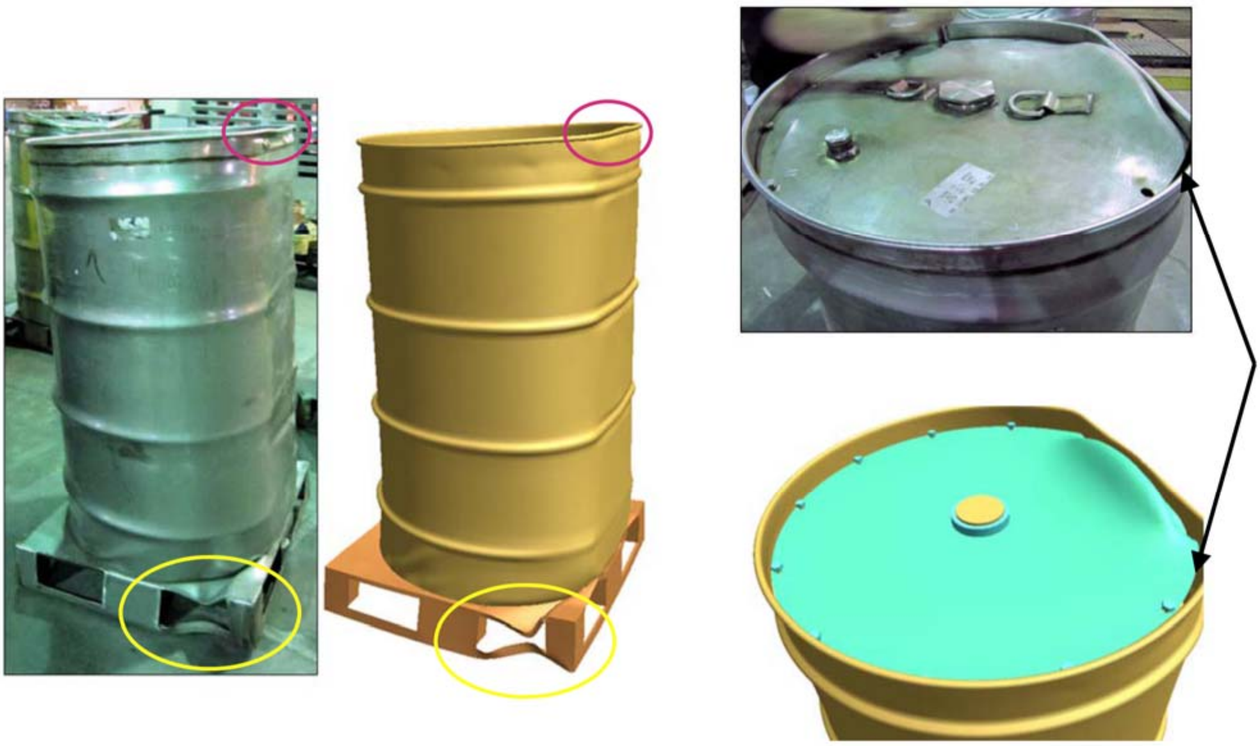

Figure 8 Side drop - Drop test result vs analysis result

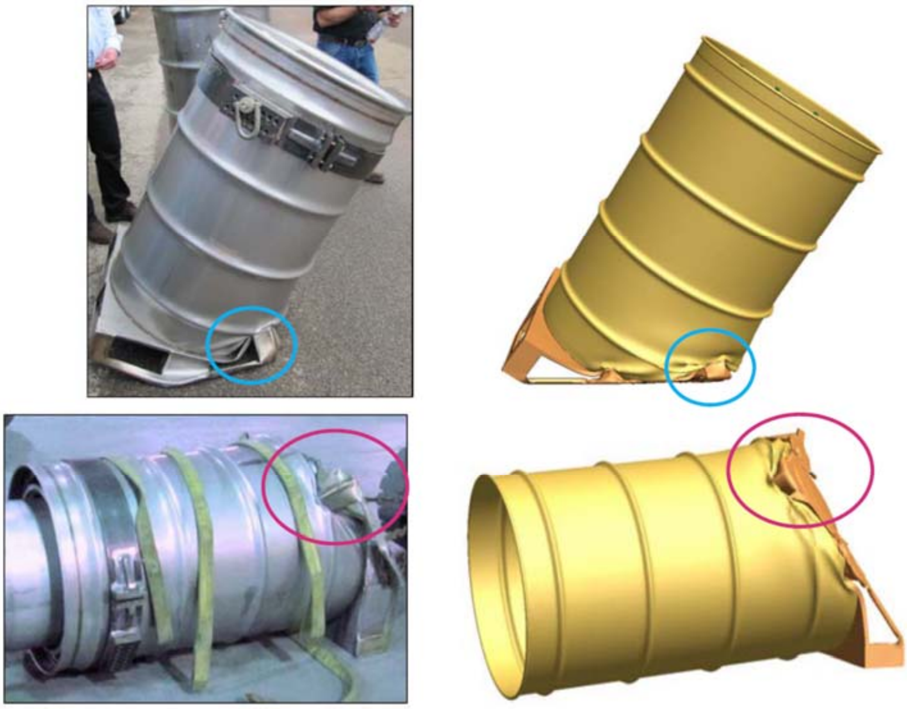

Figure 9 Base edge drop - Drop test result vs analysis result

Conclusions from Task 1

Excellent correlation between the deformations from the tests and from the FE analyses have been obtained in all three of the analysis. This is adequate to confirm that the model is reliable and robust, the material properties are reasonable, and the initial and boundary conditions are correct. This ensured that the analysis and evaluation of the revised TRU-Shield design could be undertaken with confidence in the modelling methods.

Description of the revised TRU-Shield

On the basis of the drop test results and discussions with RWM, DSRL made a number of changes to the TRU-Shield following the drop tests. Most significantly, the pallet was removed, the roll ring at the top of the drum was replaced with a 17mm wide x 20mm tall lifting beam and it was decided to weld the Rivnuts to the top surface of the body flange. The model from Task 1 was modified to incorporate these changes as shown below.

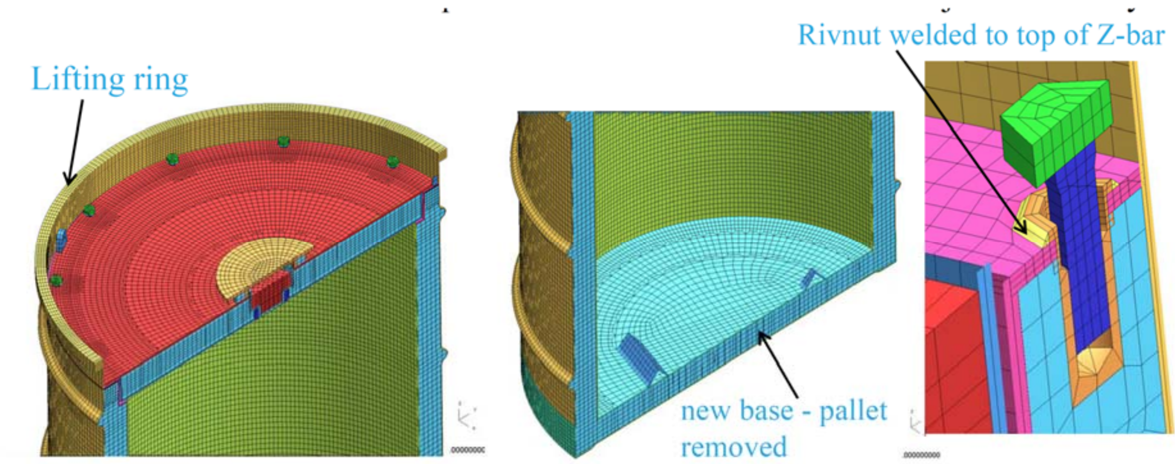

Figure 10 Section through the revised TRU-Shield FE model

Impact scenarios

RWM requires the performance of the package to be demonstrated in a drop onto a flat unyielding target and a drop onto an aggressive target. The drop height in the drop onto the flat target is 11m, and the drop height for the drop onto an aggressive target is 10m, measured from the initial point of impact on the package to the impact point on the aggressive target. The aggressive target is the top corner of a corner lifting 3 cubic metre box package.

In these scenarios, the release of radionuclides must be low and predictable, release behaviour must be progressive, and the release of radioactive contents is required not to result in the relevant regulatory dose limits to workers or members of the public being exceeded.

Selection of drop orientation for the analyses

There are an infinite number of orientations that a drum waste package can impact a flat target. Centre of gravity over point/edge/surface of impact orientations are generally the most onerous orientations in that these orientations maximize the drop energy that is absorbed by the deformation of the drum and minimize the drop energy that would be lost to rigid body motion. In the TRU-Shield package, the fact that the lid is connected to the body at discrete points (i.e. 12 bolts) rather than continuously (e.g. with a welded lid) make the bolts vulnerable to failure and the lid-body interface most prone to breach during large deformations. Impact orientations in which the lid-body connection is directly involved in the knockback deformations in which the interface was sheared or pried (i.e. lid edge drop and side drop) were therefore analyzed as they were deemed to be the most onerous drop scenarios. Two different hoop orientations were also considered. A base edge drop was also analyzed as it has the potential to be challenging for the integrity of the body.

For the drop onto an aggressive target, the lid was again the most vulnerable location, in terms of potential for local damage and damage to the lid-body interface. The drum was oriented to incur the worst damage in both respects.

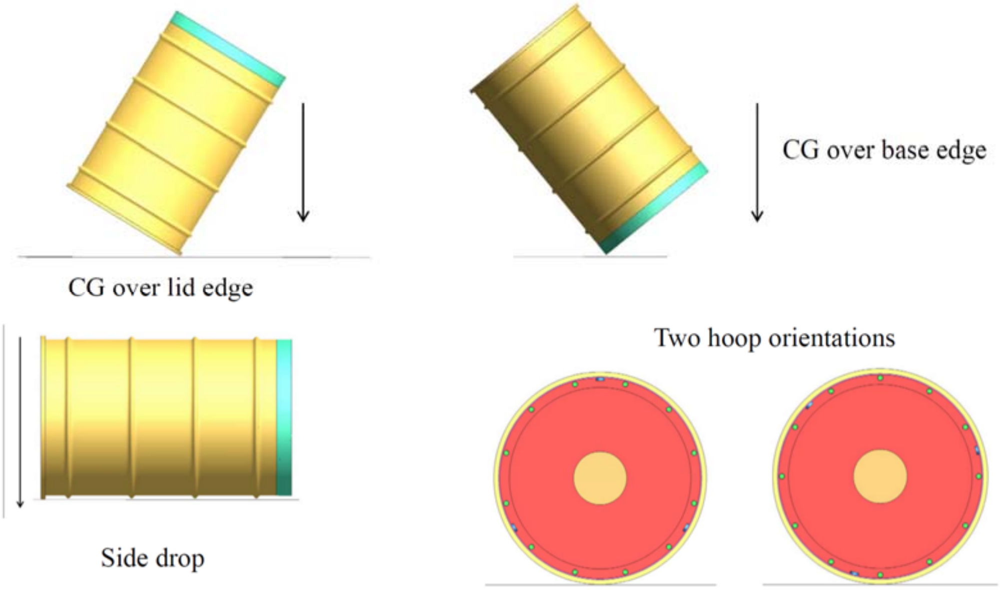

Figure 11 Orientations for the drop onto a flat target

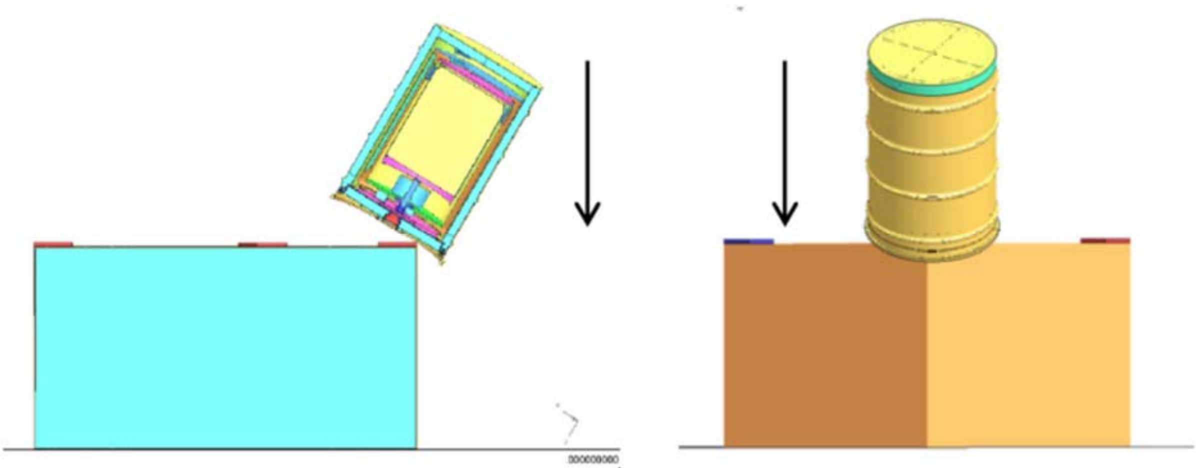

Figure 12 Orientation for drop onto an aggressive target

Behavior in the lid edge drop

The rim of the lifting beam contacted the target first. It proceeded to bend onto the target, bending the upstand below it. As the event continued to progress, the knockback increased and the area of the package in contact with the target enlarged and a progressively larger area of the lid bent to contact the target. As the knockback area enlarged, the lid pivoted about the knocked back area and tended to “kick up” at the opposite edge. Two bolts failed, one in the impact zone and one on the opposite side.

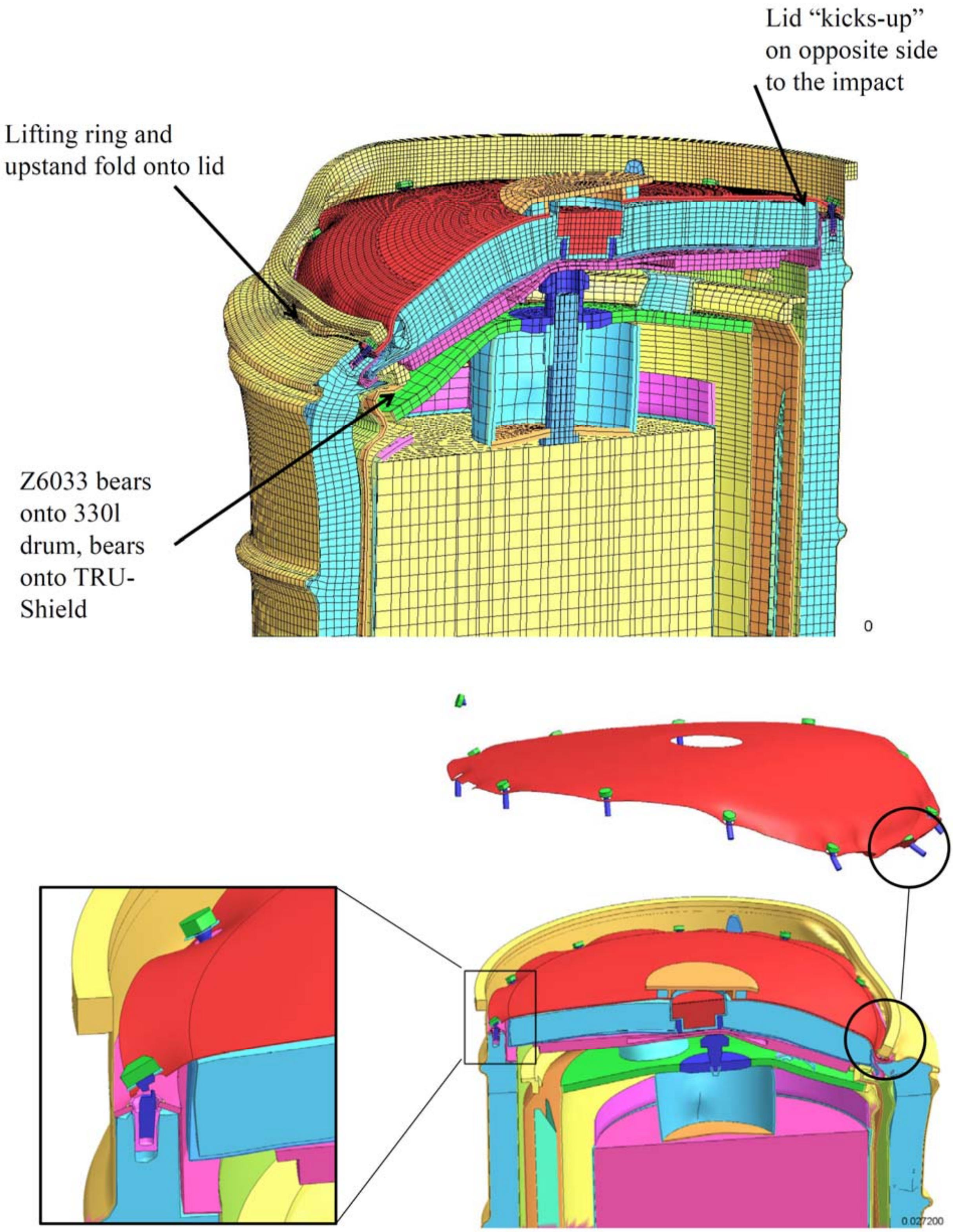

Figure 13 Lid edge drop - deformation at the end of the impact event

Behavior in the side drop

The side of the lifting beam contacted the target first. The rolling rings of the outer drum then hit the target and began to flatten. As the body continued to flatten against the target, the upper lid plate buckled outwards and the body bulges sideways, causing three bolts to fail.

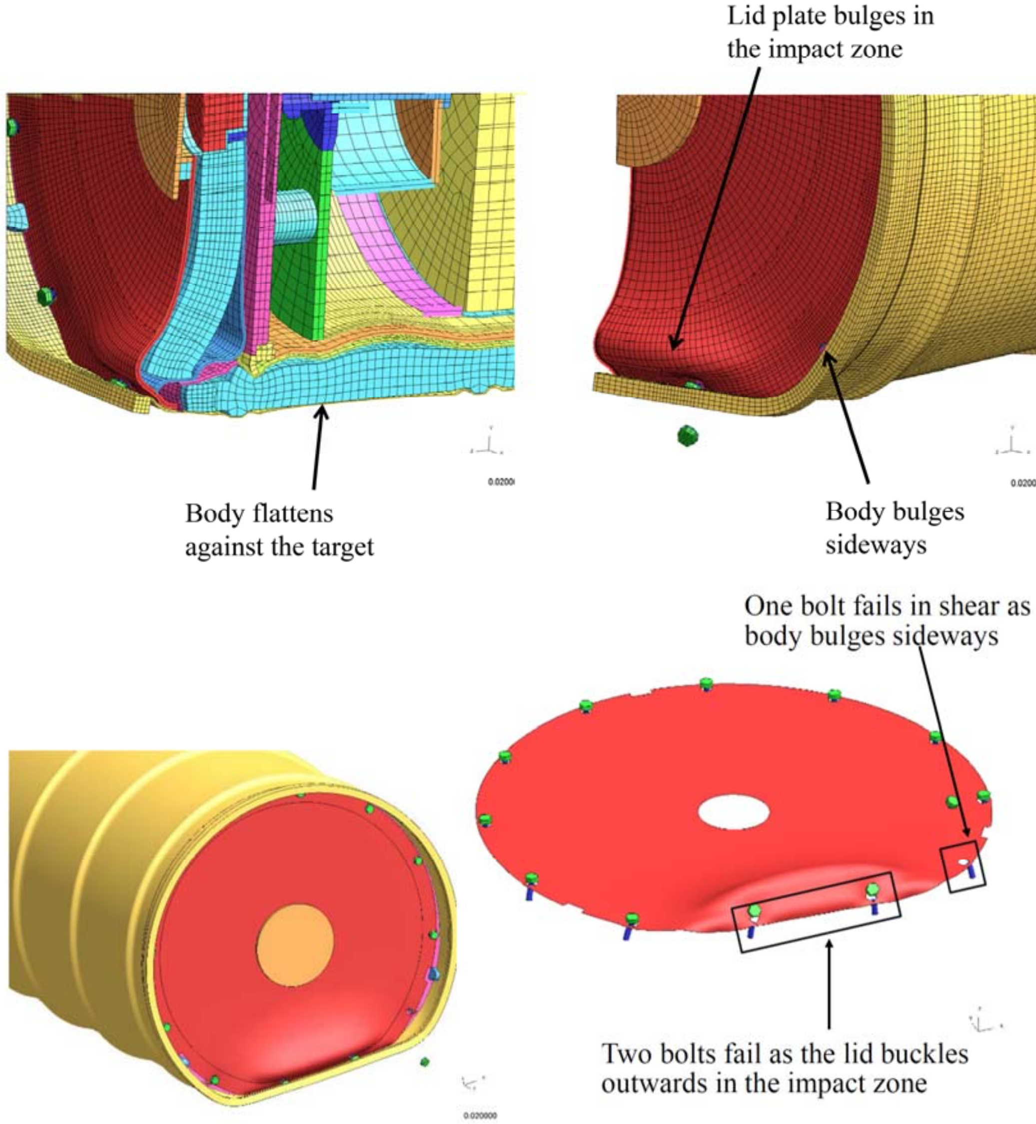

Figure 14 Side drop hoop orientation 2 – Deformation at the end of the impact event

Behavior in the base edge drop

The bottom edge of the TRU-Shield contacted the target first. Both the base and the outer drum began to flatten against the target. As the impact progressed the knockback area increased. As the lead between the drum skins continued to compress, the inner cylinder deformed in a similar manner as the outer drum and base. The payload containers buckled in a similar manner to the TRU-Shield but the deformation was not as pronounced. No bolts failed in this drop orientation.

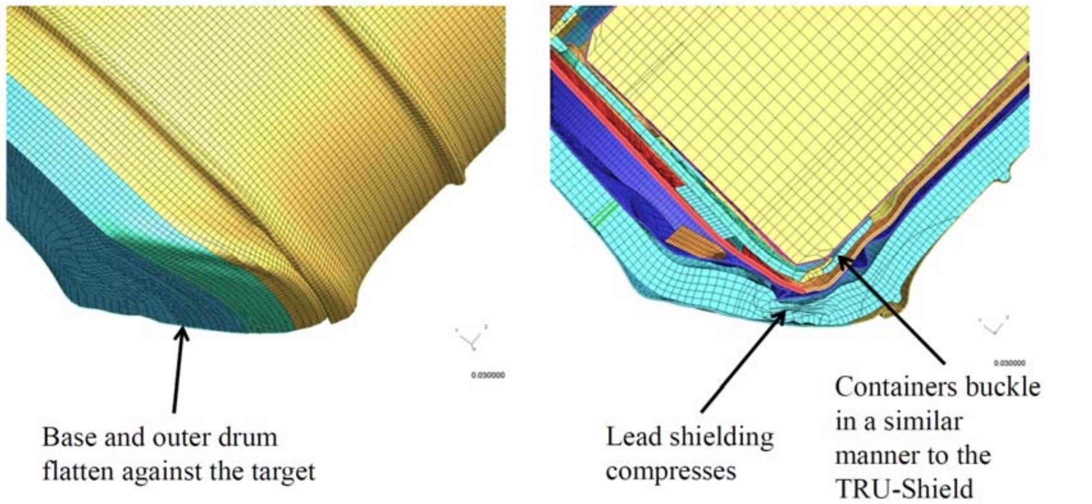

Figure 15 Base edge drop – Deformation at the end of the impact event

Behavior in the aggressive target drop

The drum lid indented as it bore onto the box's corner plate. As the event progressed, the indentation increased and the contact area increased. The lid upper plate tore as the corner of the box indented into the lid. The indentation and the bending of the lid pulled the lid radially towards the center of the drum, shearing a number of bolts in the process.

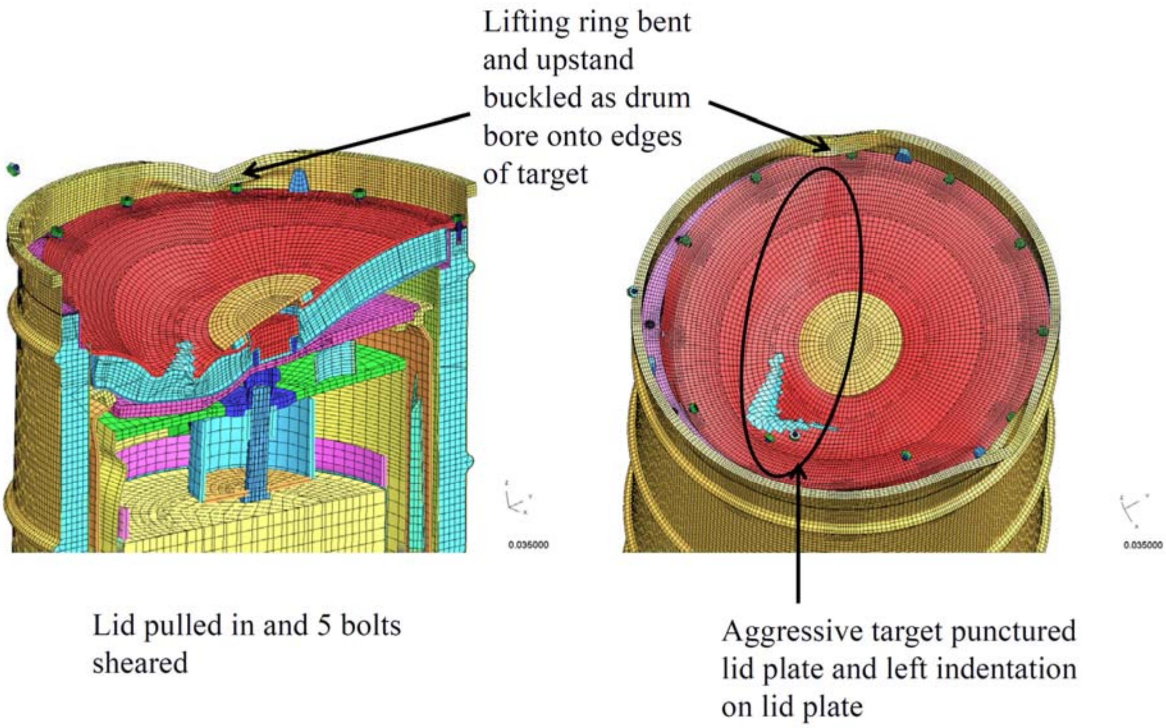

Figure 16 Aggressive target drop – Deformation at the end of the impact event

Conclusions from Task 2

Performance criteria is based on activity release, release must be low and predictable, and behaviour must be progressive. In the revised design of the TRU-Shield, a maximum of 4 bolts out of 12 failed in the drop onto a flat target scenario and 5 bolts out of 12 failed in the drop onto an aggressive target scenario. However, in both the lid edge drop and the drop onto an aggressive target, the upstand folds onto the lid and there is no gross loss of containment. Although there are high plastic strains which exceed failure strain a number of places, they are local or only involve one of the two liners. The Rivnuts are not expected to pull out in any scenario. In addition, since active content is located deep inside the "Russian doll" set up, there is no possibility that any could be released. It was envisaged that the TRU-Shield may be used for alternative waste contents. If so, the existing 12 x M10 A2-70 bolts will be replaced by 16 x M12 A2-70 bolts to improve its performance.

However, since the completion of the work, it was decided that the TRU-Shield would not be used, as the presence of lead in the proposed GDF is considered undesirable.