A Validated Impact Analysis Model for ILW Transport Containers

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INTRODUCTION

UK Nirex Limited (Nirex) is developing a deep repository for the disposal of intermediate level and low level radioactive wastes (ILW and LLW). Nirex is also responsible for producing standard designs of transport containers. One concept under consideration is the Concept L reusable shielded transport container (RSTC) which is being designed to IAEA Type B requirements (IAEA 1990). The contents of the RSTC will normally be cemented ILW in four 500 litre drums, or in a single $3m^3$ box or drum of similar outside dimensions to the four 500 litre drums in their transport frame.

The RSTC will be produced in a range of shielding thicknesses from 70mm to 285mm, to meet the requirements of different wastes. Figure 1 shows the 70mm version, and Figure 2 shows the 285mm version.

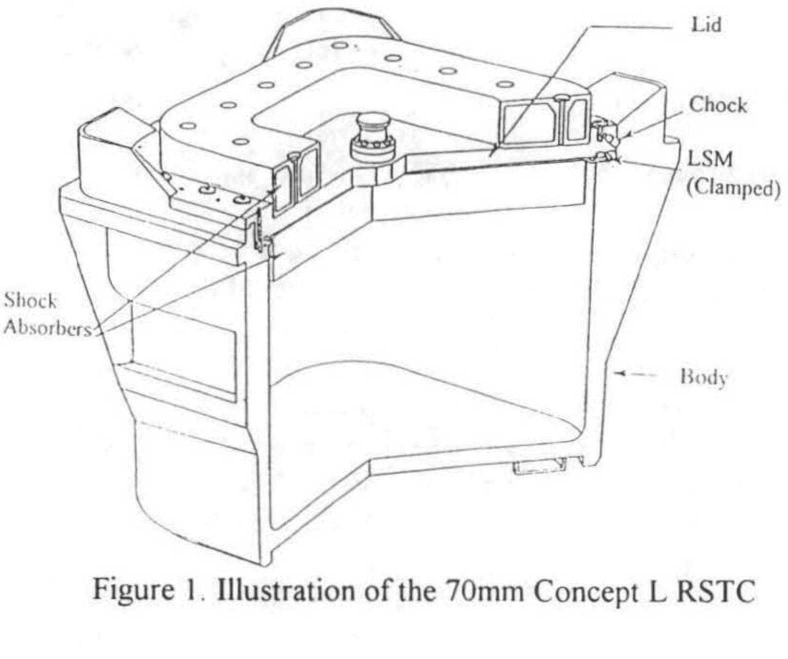

Figure 1. Illustration of the 70mm Concept L RSTC

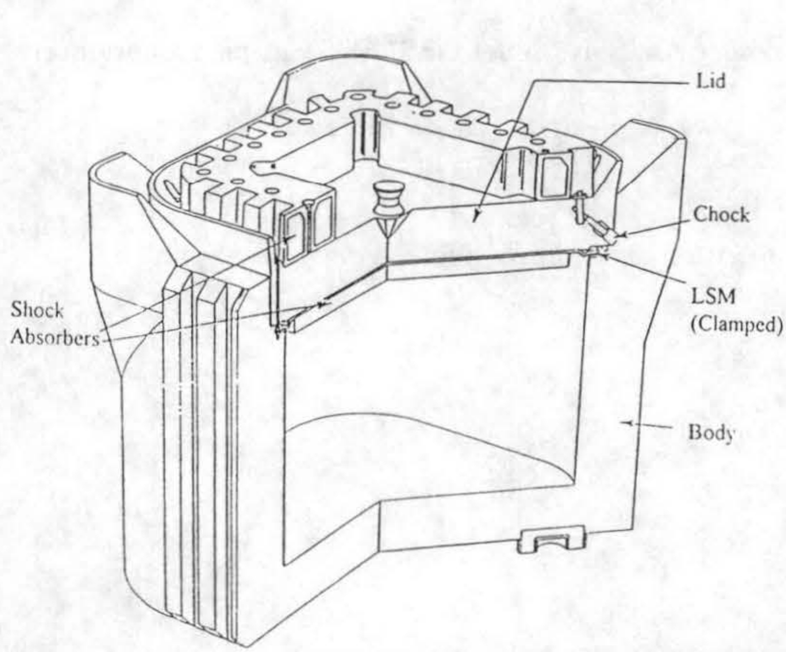

Figure 2. Illustration of the 285 mm Concept L RSTC

The main features of the Concept L design are as follows.

- The lid is slightly inset into the top of the body and is retained by 24 radial chocks around the periphery.

The sealing function is provided by a lid seal member (LSM) which is clamped to the body sealing face, independently of the lid and its retaining chocks. The LSM consists of an outer flange which carries a double elastomer O-ring seal, which is joined to a central flat plate by a thin convoluted transition section. In normal operation the LSM is lightly attached to the underside of the lid, but these attachments are designed to break away under impact so that the LSM can flex independently, following the movements of the seal face on the container body.

- Impact resistance is provided by integral solid metal flow shock absorbers projecting beyond the four top corners of the body and by ribs on the sides. To deal with lid-down impacts there is a stainless steel-clad wooden shock absorber on the top of the lid, and an internal honeycomb shock absorber to limit the impact of the contents on the underside of the lid.

Various aspects of the design have been described in detail elsewhere (Sievwright et al. 1991; Smith et al. 1992; McKirdy et al. 1994). This paper describes the development of a validated impact analysis model for the RSTC Concept L, based on measured results from a series of regulatory drop tests on one-third-scale models of the 70mm and 285mm versions.

DROP TESTING

The IAEA Transport Regulations (IAEA 1990) require a 9m drop test onto a flat, rigid target in the least favourable impact attitudes. Compliance may be demonstrated by a combination of analytical modeling and practical drop tests. A series of fully-instrumented drop tests were therefore carried out on one-third-scale models of the 70mm and 285mm containers, each carrying four one-third-scale 500 litre drums in a transport frame (or "stillage").

The impact attitudes used in the drop tests were selected from the results of earlier analytical modeling, which showed that the potentially most damaging attitudes would be with the centre of gravity over a lid corner or over a lid edge, and a flat impact on one side.

The drop test tower incorporated vertical guide rails, and runners were attached to the RSTC to ensure that it did not rotate out of the desired impact attitude while falling. The last two metres of the drop were in free-fall, but high-speed photography showed that the correct impact attitude was achieved within a fraction of a degree.

The instrumentation included accelerometers and strain gauges connected to high-speed data recorders by a free-falling umbilical cable; for example Figure 3 shows the locations of some of the accelerometers and strain gauges for the lid corner drop of the 70mm model.

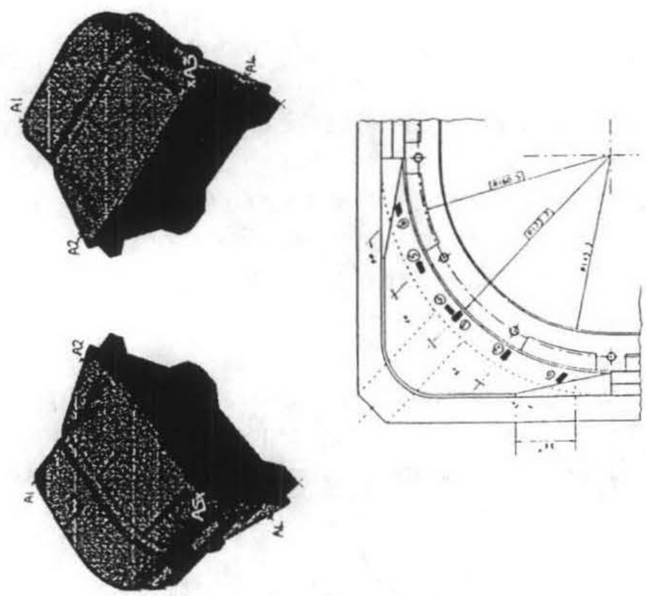

Figure 3. Typical accelerometer and strain gauge positions for lid corner drop tests

Two high-speed cameras filmed each drop from orthogonal viewpoints, and all image frames were accurately timed. Each drop was also recorded using a video camera. Several reference points were scribed on the container body and lid to enable any distortions resulting from the drop to be established by physical metrology.

This instrumentation provided data that could be compared directly against the predictions of the finite element (FE) models described below. The results of the drop testing are presented as part of the comparisons with the model predictions.

FINITE ELEMENT MODELING

Finite element models using the DYNA3D software (Whirley and Engelmann 1993) were developed for the two containers of different nominal wall thickness and for a range of impact attitudes. It had already been established that the most severe impact attitudes possessed bilateral symmetry, so that half-models could be used. These in turn were based on one-eighth vertical slices of each RSTC, from the corner to the mid-wall, which were then rotated and reflected to build the required half-models. It is assumed that all damage will be symmetrical, and that the RSTC will not move out of the plane of symmetry during the impact. (In practice the RSTC struck the target at the correct angle as described above, and did not rotate significantly until the rebound phase which was about 0.1 seconds after first contact.) The model also assumed that the contents of the RSTC act as a monolithic mass, so that the drums and their transport frame have no relative movements. Evidence from the drop tests showed that in most cases the drums did remain in position in the stillage.

The wooden shock absorber on the lid was omitted because it does not affect the structural response of the RSTCs in the impact attitudes modelled. The target used in the drop tests was modelled explicitly, since it cannot be assumed that any practical impact target is rigid. Another major simplification was that although the same scale models were used for more than one drop test, the FE models were assumed to be undistorted. Post-test metrology supports this assumption because permanent distortions outside of the impact area were minimal, and the containers were always dropped onto undamaged areas.

Appropriate material properties were used throughout the FE models. The upper parts of the external shock absorber "ears" (Figures 1 and 2) were modelled with strain-rate-enhanced yield stresses, and the internal shock absorber was modelled with a constant crush stress.

Measured coefficients of friction between the RSTC and the target are not available. Analysis of the results of the first drop test indicated that a value of 0.15 gave good agreement, and the same value was used for all other tests. Elsewhere in the model, the same value was used for other coefficients of friction, with two exceptions. Instead of modelling the lid-retaining chock mechanisms the coefficient of friction around the chock locations was increased to 0.75, ensuring that the chocks remained in position during the impact. Friction was excluded from the contacts between the transport frame and the interior container walls, ensuring that the full weight of the RSTC contents could act on the internal shock absorber.

For each container, the following impact attitudes were considered, in each case for a 9m free drop producing an impact velocity of 13.3 m s^{-1}.

- **Lid corner** – The plane of symmetry cuts diagonally through from the impact point to the uppermost base corner (Figure 4). The contents have already slid down to rest against the interior shock absorber.
- **Lid edge** – The plane of symmetry cuts through the centre of the RSTC from the impact edge to the uppermost base edge (Figure 5) and both corner shock absorbers contact simultaneously. The contents have already slid down to rest against the interior shock absorber.
- **Flat side** – The contents have already slid down to rest against the impact side and the interior shock absorber.

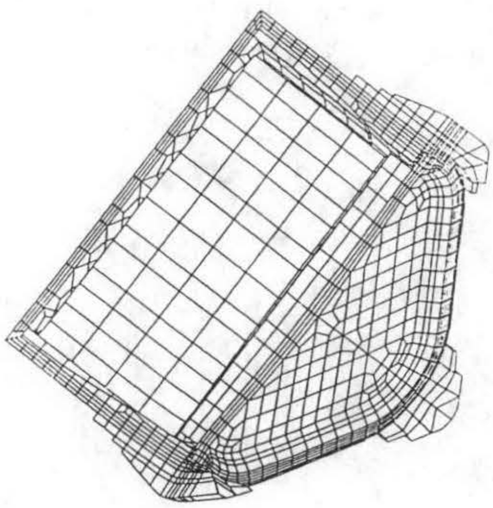

Figure 4. Finite Element model for 70mm Concept L lid corner impact

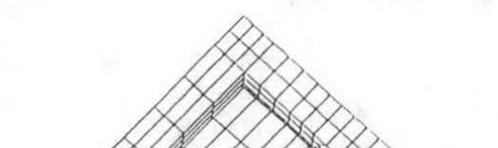

Figure 5. Finite Element model for 285mm Concept L lid edge impact

VALIDATION OF MODEL

The bases for comparison between the practical results and the predictions of the FE analyses are deformation contours, accelerometer traces (unfiltered and filtered) and strain gauge data. Owing to the volume of data generated for the two container models, each dropped in three impact attitudes, only examples and a summary can be given here.

The measured deformations in general agreed very well with the predictions, both in shape and in the extent of "knock-back" from the undeformed profile. For example the measured knock-back of the diagonal through the shock absorber in Figure 4 was 38mm and the predicted peak transient knock-back was 37mm. More generally, agreement in the deformation results was within ±5mm.

Unfiltered accelerometer traces were difficult to compare (for example Figure 6), but low-pass filtering with a cut-off frequency of 400Hz produced smoothed traces that can be compared much more readily. The lower graph in Figure 6 shows the same traces, smoothed electronically for the drop test and in software for the FE model.

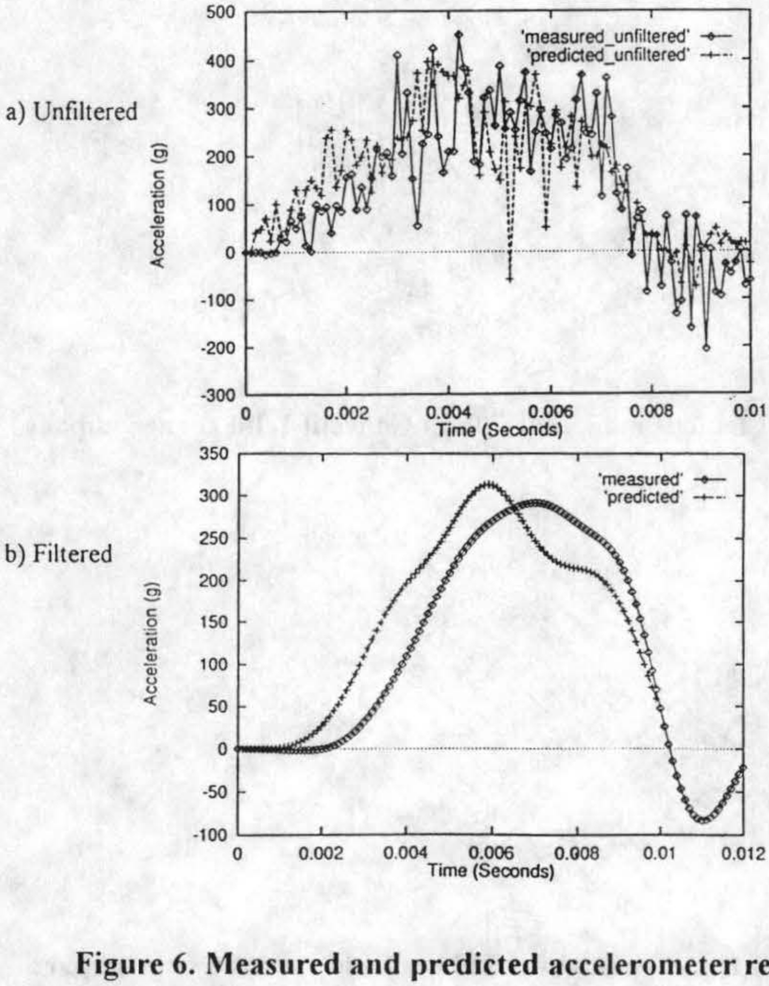

Figure 6. Measured and predicted accelerometer responses

Measured strains and deformation contours detected small asymmetries in the way the containers landed on most occasions. However, a number of strain gauges failed on impact. In the FE model the areas of the container that remain elastic are more subject to numerical "noise" in the strain data than those in areas of higher deformation, but the measured traces for the gauges in the elastic regions generally changed from compressive to tensile near the times predicted by the model. Measured strain rates up to $100s^{-1}$ were recorded; no gauges could be mounted at the points of impact but predicted strain rates in these areas were of the order of $4000s^{-1}$ for the 70mm container and $1600s^{-1}$ for the 285mm container.

There are a number of possible sources of discrepancy between the measured and predicted results. The accuracy of a finite-element model is dependent on the mesh size, mesh density, geometrical accuracy and assumptions regarding elastic and plastic material properties, friction, and strain rate dependency. Sources of experimental inaccuracy include: asymmetry of impact; the positions of strain gauges and accelerometers, and how rigidly they were attached; timing the moment of first contact; the settings and performance of trace filtering hardware; damage to the impact area during secondary impacts following the main rebound; and the cumulative deformation of containers that had been dropped more than once.

It is possible that valid components of the acceleration were suppressed by filtering, but it would require detailed spectral analysis of both the measured and predicted signals to investigate this. It is also possible for interfaces in the model to generate large local accelerations as elements inter-penetrate and are forced back, and these numerical transients can propagate into adjacent elements. However, the agreement between filtered acceleration measurements and predictions was generally very good.

There was reasonable agreement in strain gauge data. Known sources of inaccuracy from the model are the use of straight-sided elements to represent curved surfaces such as the corner shock absorbers, and the fact that the model calculates strains at the centroids of the 3-D "brick" elements whereas all measurements were made at the surface. This could be overcome by coating the surface with thin 'shell' elements. Because of the large variations in strains encountered at a single point (e.g. $-1000\mu\varepsilon$ to $-100{,}000\mu\varepsilon$ for one gauge) and the high strain rates (up to $4000s^{-1}$) a future model might also use finite elements closer in size to the strain gauges themselves.

CONCLUSIONS

The model has been validated in the following respects:

1. The extent and shape of knock-back displacements in the impact zone can be accurately predicted, generally to better than ±5mm.
2. Deceleration transients are well predicted, with good agreement when both measurements and predictions have been processed by low-pass filtering.

3. Strains are predicted with varying levels of agreement, partly because predictions are for centroids of elements, and not for the surfaces where strains were measured.

There were no systematic differences in these conclusions between the 70mm and 285mm container models.

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