ASSESSMENT OF THE SEALING SYSTEM OF AN ILW TRANSPORT CONTAINER IN A 9m REGULATORY IMPACT

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SUMMARY

UK Nirex Ltd is developing a range of reusable shielded transport containers (RSTCs) to ensure the safe transport of immobilised intermediate level waste to a future UK deep repository for disposal. The RSTCs use an inset lid for mechanical strength and radiation shielding, but the containment boundary is provided by a separate lid seal member (LSM). The LSM is a semi-flexible steel diaphragm surrounded by a rim which carries a double O-ring seal. The LSM rim is clamped to a flat mating surface on the container body.

A finite element model has been developed for an RSTC with a wall thickness of 285mm, in order to assess its containment performance in 9m regulatory drop tests (IAEA 1996). The challenge was to predict the size of small gaps that might appear between the LSM rim and the RSTC body seal face; this level of detail would be 1-2 orders of magnitude smaller than the displacements experienced in the impact zone.

The model was first validated against a series of one-third scale model drop tests of the RSTC. The validated model was then analysed for 9m regulatory impacts in the six worst impact attitudes. The behaviour of the LSM was assessed for each attitude and the seal face gaps between the LSM and the body were determined. Although small gaps of about 0.5mm are predicted, it is likely that containment would be preserved.

INTRODUCTION

UK Nirex Ltd is responsible for the development of a deep repository for the disposal of intermediate level and some low level radioactive wastes (ILW and LLW). Nirex is also responsible for producing standard designs of reusable shielded transport containers (RSTCs) for the transport of waste to the repository. The contents of an RSTC will normally be cemented ILW, either as four 500-litre drums in a transport frame, or as a single $3m^3$ box or drum of similar outside dimensions. The RSTCs will be produced in two shielding thicknesses, 70mm and 285mm (designated RSTC-70 and RSTC-285), to suit the requirements of the different waste streams. The complete transport package, consisting of the RSTC and the waste package contents, will have to conform to IAEA Type B standards (IAEA 1996) and consequently it will require Competent Authority Approval.

The main features of the RSTC-285 design are as follows:

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

- The containment boundary is provided by a separate lid seal member (LSM) beneath the container lid. The LSM is a flat semi-flexible steel diaphragm connected by a bellows-type convolution around its perimeter to a rim which is 42mm wide by 25mm high. The rim carries a double O-ring seal and is clamped to a flat seal face on the container body by 28 clamps and bolts, so that the O-rings are compressed against the seal face. This arrangement is independent of the lid and its retaining chocks. In normal use the LSM is lightly attached to the underside of the lid, but these attachments are designed to break away easily under impact so that the LSM and its rim can flex independently.

- Impact mitigation is provided by integral solid metal flow shock absorbers on the top four corners of the body and by integral ribs on the sides. Four feet on the base limit accelerations in base-down impacts. For inverted impacts, a crushable aluminium honeycomb shock absorber on the underside of the LSM limits the force of the contents on the lid.

- Fire insulation is provided by ceramic fibre wool contained in stainless steel cladding on the outside of the RSTC.

A series of drop tests in a number of different attitudes had been carried out on one-third scale models of the RSTC-70 and RSTC-285 (Gray et al. 1995). These tests were undertaken not only to demonstrate compliance with the IAEA Transport Regulations, but also to generate sufficient data to validate finite element (FE) models which could predict the impact performance of the RSTC in attitudes that had not been tested. This paper describes a series of FE analyses of the RSTC-285 in 9m regulatory impacts (IAEA 1996) to confirm its sealing performance.

The focus of previous FE analyses of RSTCs (Gray et al. 1995) has been the prediction of global behaviour, estimating with increasing reliability the deceleration transients and the extent and shape of knock-back displacement in the impact zone. The requirement for this next stage of work was to predict with accuracy the gaps that might appear between the LSM and the RSTC body seal face after an impact. The challenge was that these gaps could be 1-2 orders of magnitude smaller than the knock-back displacements in the impact. This required an FE model of the LSM which was sufficiently detailed to represent such local deformations.

SCOPE OF ANALYSES

The work consisted of four phases :

1. Creating an FE model of the RSTC-285.

2. Validating the model against one-third scale model drop tests, comparing both global and local behaviour of the RSTC and LSM.

3. Assessing the impact performance of the RSTC-285 in 9m regulatory impacts in the following attitudes: flat-side, lid-corner, lid-edge, side-edge, lid-down and base-down. This included assessing the behaviour of the LSM for each attitude and determining the development of any gaps between the LSM rim and the body seal face.

4. Determining the most onerous impact attitude in terms of gap openings.

THE MODEL

All FE analysis was undertaken using LS-DYNA3D (Livermore Software Technology Corporation 1995). A detailed FE model of the RSTC-285 was created (Figure 1).

Because all of the impact attitudes to be considered were symmetric about a plane perpendicular to the impact target, a half-model was sufficient for the analyses. For the lid-corner and side-edge attitudes, the plane of symmetry divided the container from one corner to the opposite corner. For all the other attitudes, the plane of symmetry lay from mid-side to mid-side.

The design of the FE mesh was crucial to the success of the analysis. A high element density was used in modelling the LSM, its clamping system and the regions around the body seal face. This was required to predict seal gaps with an accuracy in the order of 0.1mm, which is four orders of magnitude smaller than the RSTC overall dimensions. The LSM rim, lugs, clamps and aluminium shock absorber were all modelled using solid elements, while the rest of the LSM was modelled using shells (Figure 2). The bolts were also modelled in detail down to the level of the top of the bolt holes in the body, but were assumed to remain un-deformed below this plane. A fine mesh was also needed over components such as the corner shock absorbers, where deformations would control the loads transferred to the LSM.

However, in order to keep the overall size of the model down, a much coarser mesh was used in regions which were not expected to significantly affect the behaviour of the seal face, and where predicted deformations were small. Similarly, linear stress elements were used in areas of high deformation, but constant stress elements which are computationally less expensive were used elsewhere. The contents of the container were modelled as a single rigid body, thus reducing the overall computational expense, but also maximising the energy transferred to the RSTC. The chocks were modelled as integral parts of the lid; this is justified because the possible failure modes are either shear failure of the chock in a plane parallel to the side of the lid, or bearing failure of chock slots in the RSTC body, both of which can be assessed by the model. Stainless steel cladding and thermal insulation were not modelled as they would not have a significant effect on the impact performance of the RSTC.

In total, each half-model consisted of approximately 70,000 elements. The majority were solid six- or eight-noded brick elements, and the remainder (all in the LSM) were three- or four-noded shell elements.

Pre-stress in the bolts was created by raising the temperature of the clamps, so that their simulated expansion would exert the desired tensions in the bolts. Internal gas pressure was also applied, corresponding to either the maximum or the minimum operating pressure for normal transport (whichever produced the worst case for each impact attitude). These initial stresses throughout the container were allowed to reach equilibrium before the impact analysis itself began.

MODEL VALIDATION

A series of validation studies was carried out in which results from FE analyses were compared with the results of three corresponding one-third scale model drop tests. The tests chosen for the validation exercise were a 9m lid-edge drop, a 9m lid-corner drop and a flat-side drop.

Results from all three drop tests were used primarily to verify global container behaviour, including metal flow deformation behaviour of the shock absorbers and deceleration transients. Figures 3 shows good agreement between the acceleration histories of the 9m lid-edge drop test and that predicted by the FE analysis.

In addition to verifying the global behaviour of the RSTC, results of the flat-side drop test were used to verify the global and local deformation behaviour of the LSM. Again there was very good agreement between the acceleration transients in the test and in the analysis, with peak acceleration differing by less than 4%. The deformations of the RSTC and the LSM were also predicted very well: Figure 4 shows the roll-over of the bellows convolution as found in the test, and Figure 5 shows comparisons between LSM lug deformation from the drop test and from the analysis.

These three studies demonstrated the validity of the analysis techniques for some of the worst impact attitudes, and gave confidence that the FE model could accurately predict the behaviour of the RSTC-285 in untested drop attitudes as well.

SENSITIVITY STUDIES

It is important to recognise that practical drop test results are subject to experimental scatter. This would be particularly true of the LSM gap openings, which are typically less than 1mm. A series of sensitivity studies was therefore undertaken using the model of the flat-side drop test, to assess the sensitivity of the LSM behaviour to small changes in initial conditions that would be responsible for experimental scatter. Two parameters were varied: the coefficient of friction between the LSM and the body seal face; and the initial LSM bolt pre-loads.

Although the overall predicted behaviour of the LSM was found to be relatively insensitive to small variations in pre-load and friction, the same does not apply to the dimensions of the gap openings, which were rather sensitive to initial conditions. This is probably true of the real-life behaviour also. Therefore the predicted gaps cannot be taken as absolute values, but rather as an indication of what the gap size would be in a postulated impact scenario.

9m FLAT-SIDE IMPACT

Six analyses were carried out using the validated model of regulatory 9m impacts (IAEA 1996) in the six worst attitudes as shown in Figure 6. In each case, the centre of gravity was vertically above the initial point (or line or plane) of impact. The analysis was carried out for a duration sufficient for the container to begin its rebound. Stresses during secondary impacts before the container comes to rest would be much lower than in this initial impact.

The 9m flat-side attitude was the most onerous in terms of seal gap opening and peak deceleration (510g). Contact is made with the impact target simultaneously along the four top-to-bottom ribs, and the two shorter side-to-side ones. Crushing of these ribs was predicted to be greatest at the base of the container, where their depth was reduced by 39%.

The LSM rim remained supported by the container body along the leading (impact) edge, but the diaphragm and the other three sides of the rim continued to move forwards. As a result, the LSM convolutions were compressed on the leading edge and stretched on the trailing edge. The sides of the rim slid until they were brought to rest by deformation of the interlocking lugs and bolts, and the rim buckled at the two corners adjacent to the impact edge. The trailing edge of the LSM slid partially across the seal face on the body until brought to rest by deformation of the lugs and bolts along that edge. The inner O-ring stopped close to the edge of the RSTC body but remained in contact with the seal face.

The predicted buckling in the LSM rim at the two leading edge corners gave rise to seal gaps of approximately 0.5mm. At the trailing edge corners, where the rim was moved out slightly from under the clamps, the clamping force acted more towards the outside edge of the rim. Combined with a positive internal pressure acting on the diaphragm, this twisted the rim, giving rise to gaps of 0.5mm at the inside edge. The predicted gaps along the sides of the LSM rim were generally below 0.1mm and did not exceed 0.3mm at the termination of the analysis. Previous work has demonstrated that these gap openings would be sealable by the O-rings (McKirdy et al. 1994).

OTHER RESULTS

For the 9m side-edge impact, the maximum gap predicted was 0.3mm, except on the symmetry plane where a maximum transient gap of 0.7mm was measured on the inside edge, reducing to 0.6mm by the end of the analysis. The gap was caused more by a deformation of the container body than by a deformation of the LSM rim, so this prediction is unlikely to be affected by small changes in initial conditions. The predicted maximum transient gaps for the 9m lid-down, 9m lid-edge, 9m lid-corner and 9m base-down attitudes were all less than 0.3mm. The maximum predicted gap at the end of any of these analyses was less than 0.1mm. No bolt failures were predicted.

DISCUSSION

The LSM design performs well for upward or downward deformations, as demonstrated by the relatively small gaps predicted for the lid-down and base-down attitudes. This is because most of the inertia load of the flat LSM diaphragm is transmitted directly to either the lid or the contents in these attitudes, and the convolutions ensure that negligible load is transferred to the LSM rim. Deformation of the rim results from motion of the LSM in its own plane, most notably in the flat-side attitude, when the inertia load is transferred into the container wall via the bolts, lugs and the rim itself.

The greatest gap observed at the inside edge of the LSM rim at the end of any of these analyses was only 0.6mm (in the 9m side-edge impact). The 9m flat-side impact caused more distortion of the LSM rim, but produced a slightly smaller predicted gap (0.5mm). The O-ring seal can bridge such gaps (McKirdy et al. 1994).

CONCLUSIONS

Detailed 70,000-element FE models of the Nirex RSTC-285 were created, and validated against the results of three drop tests. Good agreement was obtained between test and analysis results, for both global and local parameters.

The sensitivity study showed that the FE model can reproduce experimental scatter in LSM gaps caused by variations in friction and bolt pre-load. It also predicted that the gap openings between the LSM and the container body would be sensitive to initial conditions; thus the predicted gaps cannot be taken as absolute values, but rather as an indication of what the gap size would be in a postulated impact scenario.

Regulatory drop tests from 9m (IAEA 1996) were analysed in six impact attitudes. In terms of overall gap openings between the body seal face and the LSM rim, the most onerous were the 9m flat-side and 9m side-edge attitudes, for both of which a maximum gap opening of approximately 0.6mm was predicted by the analysis. It is likely that this gap would reduce if the analysis was continued until the container came to rest.

The results obtained from this analytical work, and the measured performance of the O-ring seals, have confirmed the results obtained from the drop test work that the RSTC-285 will retain its containment after the regulatory 9m drop tests.

REFERENCES

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McKirdy et al, *Testing of the Sealing Arrangements for the Nirex Reusable Shielded Transport Containers*, Proceedings of The Third International Conference on Transport for the Nuclear Industry, Windermere, England, June 1994.

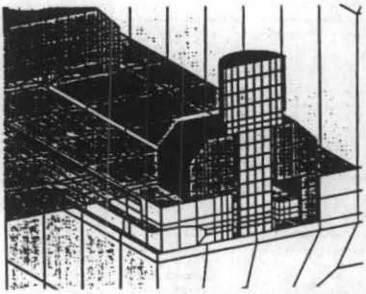

Figure 2. Finite element representation of LSM.

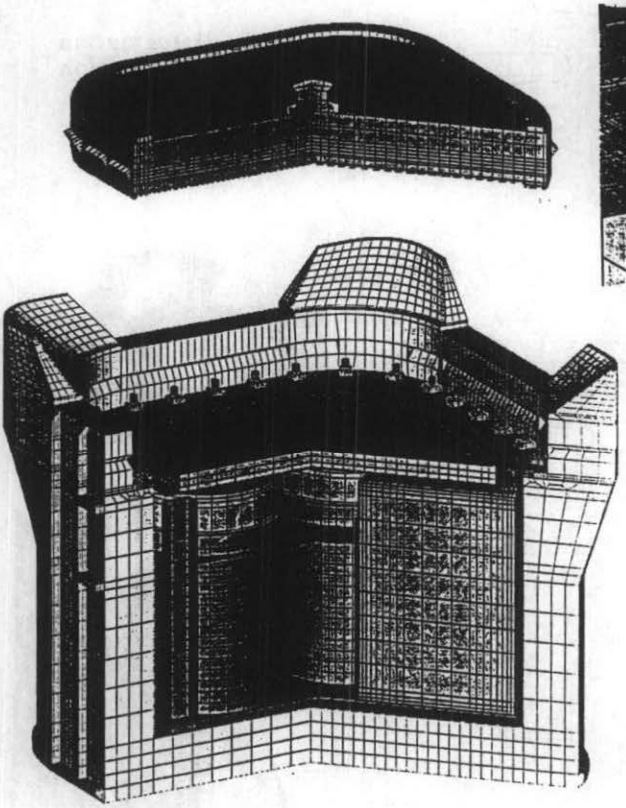

Figure 1. Finite element model of the RSTC-285

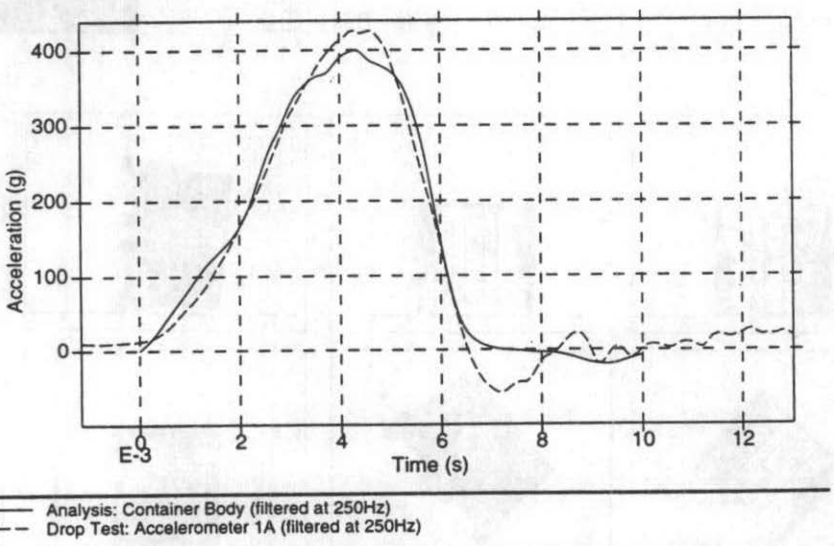

Figure 3. Comparison between FE analysis and 9m drop test: lid-edge impact

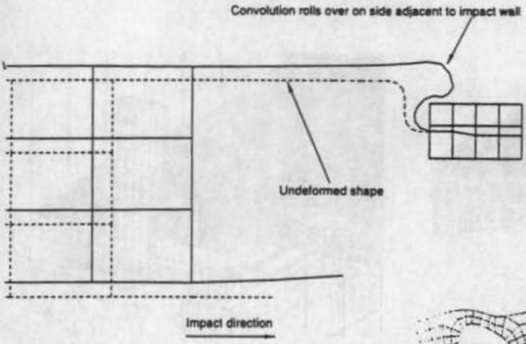

Figure 4. Deformation of bellows convolution in flat-side impact.

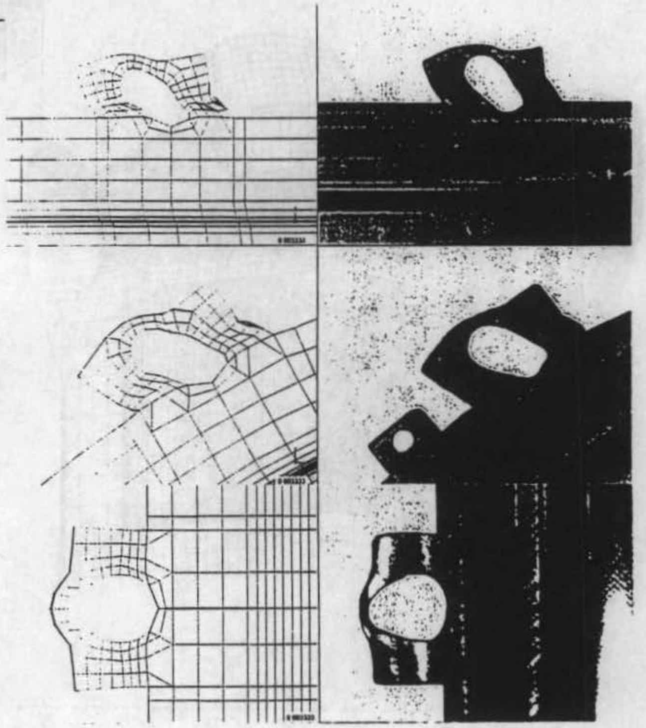

Figure 5. Comparison of LSM lug deformation between FE analysis and drop test.

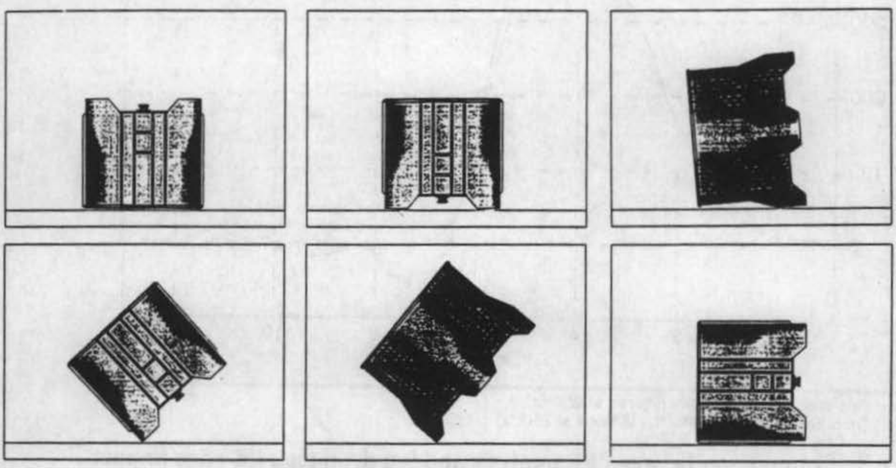

Figure 6. The six impact attitudes