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1648C FEA MODEL IMPACT VALIDATION AND VERIFICATION

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ABSTRACT

International Nuclear Services is the design authority for a nuclear transport package known as the 1648C. It has been licensed to transport radioactive materials but was to be re-licensed to transport fissile contents for the first time. This required verifying that the package response accurately reflects the physical response in ACT impact conditions; however the 1648C has never been physically drop tested.

All previous licences and justifications of the 1648C have been based upon computer simulations and sufficiently similar responses to an earlier package known as the 1648A. This validation work looked to accurately model the drop test of the 1648A carried out in 1980. This would prove the modelling methodology was sufficient to apply to the 1648C.

An updated FE model has been built using modern techniques to verify and recertify the 1648C. The model assessed provided a means of certifying the package for future shipments of radioactive material. The FE model of the 1648C was verified against the FE model of the 1648A, which had been validated against the physical drop tests.

All analyses completed successfully and agreement proved to be good between the FE models and the physical drop test report for the 1648A. The 1648C package performed as anticipated, given the similarity of the designs.

The safety report for the package was accepted, and the 1648C was licensed to transport the fissile contents. The new FE model has allowed subsequent desktop studies to be carried out on the 1648C.

INTRODUCTION

The 1648C transport package had been identified for the transport of radioactive material. This package had previously been licensed as a Type B(M) and used successfully for a number of transports. The new contents required a new licence to transport, where the package was certified as a Type AF due to the fissile material.

In order to substantiate the licence, the Package Design Safety Report (PDSR) for the 1648C had to be revised to become applicable for the transport. This meant that several of the analytical assessments, especially the impact accident conditions of transport (ACT), had to be updated. All previous licences and justifications of the 1648C have been based upon computer simulations and sufficiently similar responses to an earlier package known as the 1648A.

In the 1970's the package known as the 1648A was developed by British Nuclear Fuels Limited (BNFL). This package was drop tested in 1980 to prove compliance with the IAEA transport regulations [1] for impact ACT. During the drop tests, the package shock absorber became severely damaged, and in some cases it detached completely. This led to a redesign of the 1648A shock absorber and package body before entering production.

In the early 1990's a design variant package was developed using the experience gained from the 1648A package. This package was very similar to the 1648A with subtle differences in the design and materials used. This package was the 1648C. Based upon its similarity to the 1648A design, the 1648C was never physically drop tested; all performance justifications have been made by comparison with the 1648A package. Previous analytical work had been carried out for the 1648C package; however it was necessary to recertify the FEA models of the 1648C using modern techniques.

A model of the 1648A replicating the drop tested package was built using finite elements (FE). This was compared to the physical drop tests measurements to validate the model and prove its accuracy. A FE model of the 1648C was built using the same methodology, and analysed in the same drop orientations to verify it provided suitable agreement to progress with the PDSR and transport licence application, without having to perform any physical drop testing on the package.

TRANSPORT PACKAGES

The main differences in the 1648A and 1648C package designs are listed in *Table 1*, and a sectioned 1648C is illustrated in *Figure 1*. Some of the materials used for the components were revised in the later 1648C; the package lid changed from mild steel to stainless steel, the lid bolts and trunnions changed to a stronger stainless steel.

Table 1: Key differences between 1648A and 1648C packages

		1648A	**1648C**
(1)	Wall Thickness	328.5mm	232.5mm
(2)	Cavity Diameter	108mm	300mm
(3)	Cavity Length	690mm	676mm
	Licensed Weight	4240kg	4000kg

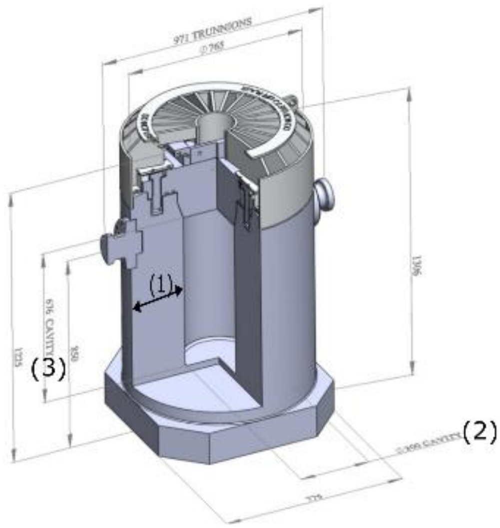


Figure 1: Section illustration of the 1648C package

The shock-absorber design also changed from the 1648A to the 1648C package. On the 1648A package that was drop tested, the shock absorber sat proud of the package body and provided a weak point during the punch testing especially. In some drops the shock absorber became so damaged it separated from the package. On the 1648C package the shock absorber was redesigned to sit inbound of the body diameter, meaning it could not be caught from underneath and pulled off.

DROP TESTS IDENTIFIED FOR COMPARISON

In order to validate the finite element model of the 1648A package, the model had to sufficiently replicate the performance of the package witnessed during the physical drop tests. These were reported by the Central Electricity Generating Board (CEGB) in [2]. In total, the 1648A was drop tested in 10 different orientations.

During the validation of the 1648A and verification of the 1648C, 4 drop orientations were selected for the analysis. These were selected from the testing programme as they had reported deformations, accelerations or bolt failures. These values could be verified through the analysis to determine the validity of the FE models. In some cases the material failures experienced during the physical testing were too severe to replicate in FEA. A number of other orientations were analysed in FEA, however the CEGB report [2] provided insufficient data which could be used to validate the FEA model.

Only two orientations are reported here;

1. Drop 2: 35.5° from vertical. Base down from 9m onto a flat unyielding target, impact taken on base edge.
2. Drop 9: 6.5° from vertical. Base down from 1m onto a steel punch, impact taken under edge of shock absorber.

FEA MODELS

Models of both the 1648A and 1648C transport packages were built in FEA using the same methodology. All analyses was carried out using LS-DYNA explicit R7.1.2 [3].

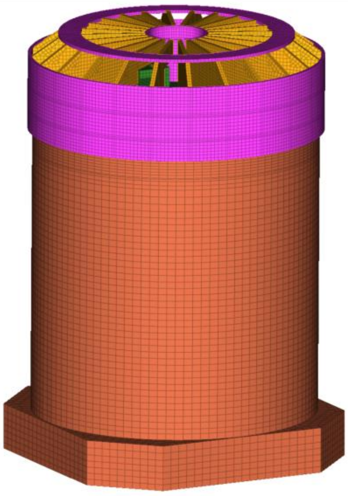
Each of the package geometries had been simplified where possible by removing features which are unnecessary for the impact analysis such as small rivets, threaded details and the O-ring grooves and O-ring seals. The trunnions were removed from the 1648A model as they were not influential in the drops identified for verification, however their weight was accounted for in the package body.

The existing PDSR's for each package list a licensed weight of 4240kg for the 1648A, and 4000kg for the 1648C. In order to have the FEA models perform as accurately as possible the overall weights need to be matched. The models will not be exactly as the manufactured packages due to the simplifications made in the pre-processing stage. The 1648A drop test model weighed 4220kg (-0.47% from existing licensed weight), and the 1648C model weighed 3831kg (-4.23% from existing licensed weight).

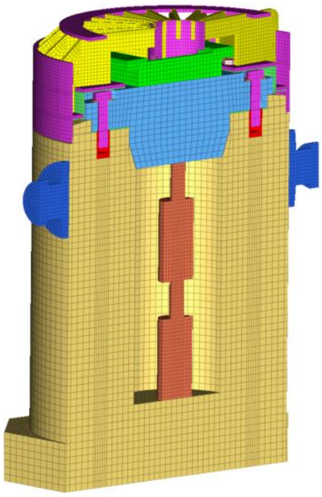
The licensed weight for the 1648C includes a maximum contents allowance of 95kg; for comparison with the 1648A the same 6.3kg scrap buckets were inserted into the package. Comparing only the empty package weights, the manufactured 1648C weighs 3868kg and the empty package in FEA weighs 3825kg, a difference of 43kg (-1.11%).

For the base edge drop test, the packages were modelled taking advantage of half symmetry to create a more efficient analysis. For the drop onto the punch, a full 360° FEA model had to be produced for the 1648A to replicate the drop test conditions and understand the loading through the shock absorber and its bolts. The 1648C model was analysed with a half symmetry model due to the differences in the shock absorber.

Figure 2 shows the FEA models built for the full 1648A package and the half model of the 1648C package.



(a) 1648A drop test full model



(b) *1648C half model*

Figure 2: FEA models of the 1648A (full) and 1648C (half)

RESULTS

Drop 2 - 35.5° 9m drop onto base edge

Physical Test

The point of impact was the large base edge as shown in *Figure 3*. The CEGB report [2] describes that the package impacted in the intended orientation and rebounded to a height of approximately 400mm before falling and coming to rest horizontally on the target plate.

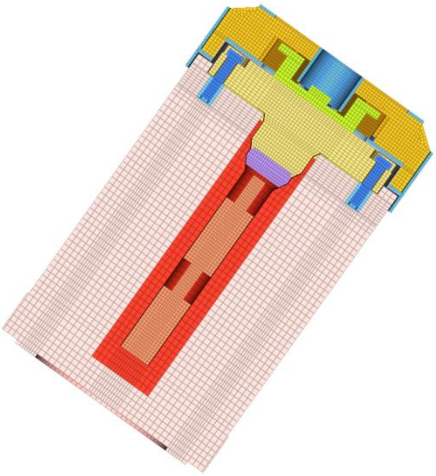
The base edge was deformed approximately 20mm from the primary impact, and an indent of 2.5mm was measured in the drop test target plate. The deformation on the package edge indicated an average deceleration of 400g during the impact.

Figure 3: Intended orientation of package for drop 2

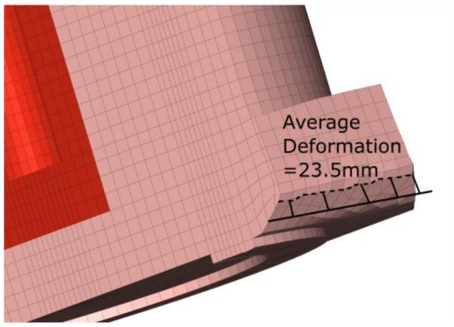
1648A drop test FEA

The 1648A FE model was orientated with its major axis tilted 35.5° from vertical. A velocity equivalent to that generated from a 9m free fall was applied to the model. The termination time of the analysis was 50ms which captured the primary impact and the package rebounding to 77mm but did not capture any package rotation or its eventual resting position. It was unnecessary to run for a longer duration as the primary impact had been the cause of the deformation to the base edge.

Figure 4a shows the FEA model in its initial orientation. *Figure 4b* highlights the deformation of the base edge. The deformation ranged from 19.9mm to 27.9mm across the nodes on this edge. An average was taken which predicts the knockback as 23.5mm (equivalent to an average deceleration of 383g). The analysis was modelled with a rigid wall meaning that the target plate could not deform like it did in the physical drop test. The FEA prediction is 17.5% greater than the drop test results, or 4.4% larger when compared to the total deformation of the package and target plate.



(a) Initial orientation for 1648A FEA



(b) Deformation on base edge

Figure 4: 1648A drop test - Before and after

1648C FEA Model

Figure 5 shows the deformation predicted on the base edge of the 1648C FEA model following a 9m drop at 35.5°. The deformation ranged from 17.24mm to 25.92mm, producing an average knockback of 22mm. This was equivalent to an average deceleration of 409g.

The deformation predicted by the 1648C is 6.4% lower than predicted in the 1648A FEA drop test model, and is a result of different material properties applied to the package bodies in both models.

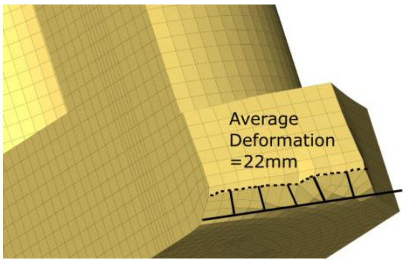


Figure 5: 1648C FEA - Deformation on base edge

For the purpose of verifying the 1648C FEA model and that the methodology could replicate real life conditions, the 1648C FEA was only compared to the 1648A FEA and not compared to the physical tests on the 1648A.

Drop 9 - 6.5° 1m drop onto punch

Physical test

The point of impact was the edge of the shock absorber that protruded from the package body, perpendicular to the trunnion axis. The bolts securing the stock absorber to the package were not equally distributed around the shock absorber. The punch connected where the shock absorber was mounted by two bolts in close proximity. The initial orientation of the package is shown in *Figure 6.*

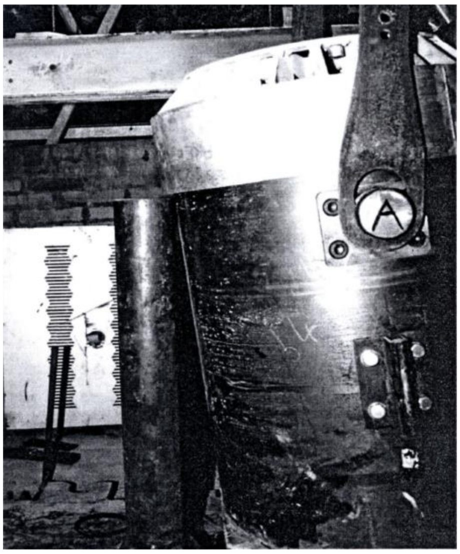


Figure 6: Intended orientation of package for drop 9

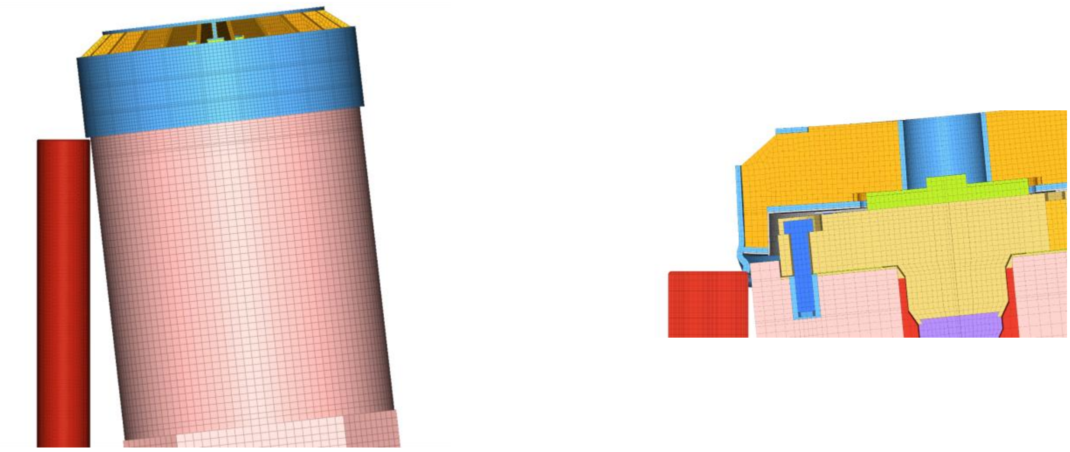
The drop test report [2] noted that the punch contacted the package body approximately 75mm below the lip of the shock absorber and it scratched into the body as the package continued to fall. The lip of the shock absorber caught on the top of the punch causing it to lift approximately 65mm upwards. At this point, the base of the package rotated towards the punch and contacted the supports. The package came to rest on its base.

Three of the shock absorber bolts were completely pulled through the shock absorber as a result of the impact. The remaining three were partially pulled through. It is unclear which three of the shock absorber bolts were pulled through the shock absorber as a result of the impact, however it was anticipated that the three bolts closest to the punch were the most likely to have been pulled through. The CEGB report does not report any of the bolts failing. This suggests it was the shock absorber plate that failed, and the bolts remained attached into the package lid.

1648A drop test FEA

The FEA model of the 1648A was ran without cumulative damage from the other drops; the shock absorber fitted was in ‘as-new’ condition. As this drop was intended to catch the lip of the shock absorber, the previous damage experienced from the other drop orientations did not prevent the lip from protruding wider than the package body. The punch was modelled true to size but as a rigid body rather than a steel bar in order to inflict maximum damage to the package. The package was orientated as shown in *Figure 7a.* An initial velocity equivalent to a free fall from 1m was applied to the model.

When the package dropped onto the punch the FEA predicted the shock absorber was lifted 38mm, which subsequently pulled on the shock absorber bolts. *Figure 7b* shows a cross section of the shock absorber catching on the top of the punch and how it lifted away from the lid. The analysis did not cause the shock absorber to lift as far as the physical test. This is likely to be attributed to slight differences in the material properties of the FE model and the physical package.



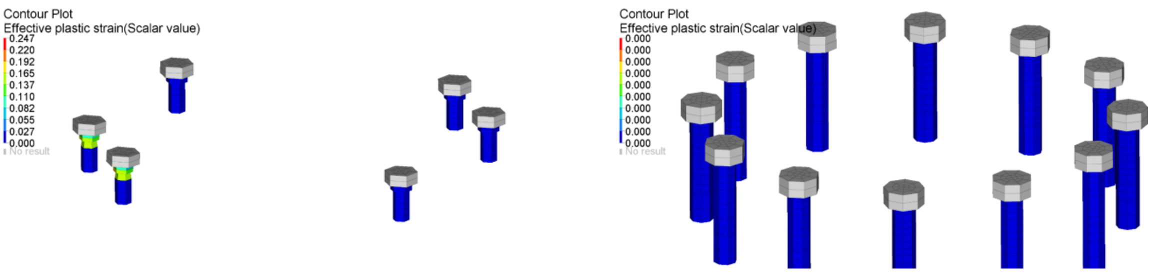
(a) Initial orientation for 1648A FEA drop 9

(b) Section view showing shock absorber deformation

Figure 7: 1648A drop test - pre and post drop test

The two bolts closest to the punch experienced large plastic strains in the shanks (24.7%) as the shock absorber caught on the top of the punch and stretched them 11.3mm. The next two closest shock absorber bolts were 90° from the punch. They had plastic strains of 0.6%, and elongated by 0.27mm. The final two bolts had no plastic strain which was to be expected as they were on the far side of the package, opposite the punch.

The plastic strain distribution in the shock absorber bolts is shown in Figure *8a*. The plastic strains were also checked in the shanks of the lid bolts to confirm that there would have been no challenge to the lid integrity from this drop orientation. As anticipated the lid bolts remained elastic, *Figure 8b.*



(a) Shock absorber bolts

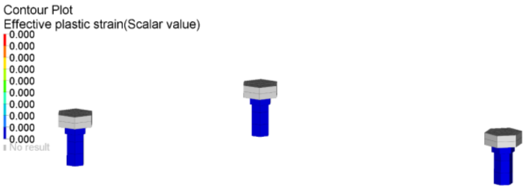
(b) Lid bolts

Figure 8: 1648A drop test - Effective plastic strains in bolts

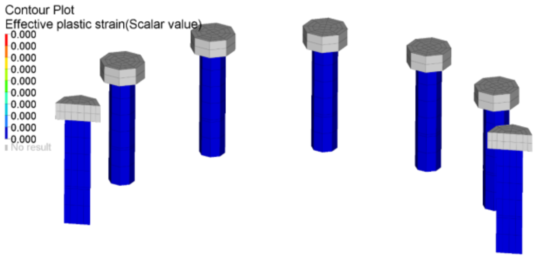
1648C FEA Model

As mentioned earlier, in some of the physical drop orientations the 1648A shock absorber became severely damaged, and in some cases it detached completely. This led to a redesign of the 1648A shock absorber and package body before the package entered production. This same design was carried over into the 1648C package, where the shock absorber sat inboard of the package body.

Due to the shock absorber design, there was no longer an edge to catch on the punch. The modification to the shock absorber proved to be a better design and significantly improved the results of the plastic strains in the shock absorber bolts. The shock absorber bolt shanks and the lid bolt shanks all remained elastic throughout this analysis. These are shown below in *Figure 9.*



(a) Shock absorber bolts



(b) Lid bolts

Figure 9 1648C production - Effective plastic strains in bolts

CONCLUSIONS

Given the data provided for the physical tests of the 1648A package reported by CEGB [2], the FEA model of the 1648A drop test package shows satisfactory agreement to the physical drop tests conducted in 1980. This proved model of the 1648A could be validated, and the methodology applied to the 1648C with confidence in the applicability of the techniques used.

The subsequent design improvements for the 1648A package and 1648C package proved to be beneficial in improving the results of the drop tests. The evidence gathered is sufficient to verify the modelling approach and the performance of the 1648C package.

The impact performance of the 1648C has been demonstrated to date by comparing it with the earlier 1648A variant. Models of both the 1648A and the 1648C have shown sufficient similarity and agreement with test data. The change in the package designs (the shock absorber in particular) and the materials used showed an improved performance for the 1648C, based upon the drop tests analysed. This assessment provides evidence that there is confidence the 1648C package would meet the drop test requirements of SSR-6 [1], without having to undergo additional physical testing. The full report for this work is documented in [4].

ADDITIONAL NOTES

The 1648A package has been officially retired from use, however may be used to transport some legacy material that is very similar to a previous safety case and licence submission following another licence application. The 1648C packages, on the other hand, are still used for the transportation of radioactive materials.

Following the completion of the verification analysis, a full drop orientation study and more detailed analysis with the change of contents was carried out to substantiate its ongoing use for the transport of radioactive materials. The work supported the safety case submission to relicense the 1648C as a Type AF, and was successfully award it's licence to transport. In 2017 three 1648C packages were used to transport material under the new licence.

The FEA model of the transport package has allowed for additional desktop studies to be undertaken, including analysis to increase the maximum weight of the contents without compromising the containment boundary provided between the package lid and the body.

The verification process has also allowed for existing FEA techniques to reviewed and revised, enhancing the understanding of the package and also the LS-DYNA software.

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[3] Livermore Software Technology Corporation (LSTC). (2014). LS-DYNA Keyword User's Manual

[4] Boag, RG. (2017). "*Validation of the FEA 1648A Model with Drop Test Data, and Comparison of the 1648C FEA Model."* INS/ENG/R/16/273. International Nuclear Services (INS).