NUMERICAL SIMULATION AND EXPERIMENTAL TESTING OF BRIT LEAD CASK (BLC)

D.K.Sahoo, J.V.Mane*, V.R.Bhave, P.Srivastava, & A.K.Kohli

Board of Radiation and Isotope Technology
* Bhabha Atomic Research Centre
Department of Atomic Energy, India

ABSTRACT

BRIT lead cask (BLC) has been designed as ‘Type B (U)’ package to transport 100kCi of Co-60 sealed sources. The main design feature is its inclined fins on the outer surface. The fins are designed to protect the cask from damaging effects of 9m drop on rigid surface in accident conditions and to enhance heat dissipation during normal conditions of transport. The performance of cask after impact is numerically simulated to assess the structural integrity using explicit Finite Element code PAM – CRASH specialized for nonlinear dynamic simulations. The most damaging orientation was found out from the various possible drop situations by numerical analysis. Experimental drop of the prototype cask on unyielding target was conducted followed by 800^0C fire test.

Radiometry test of the damaged cask was carried out to ascertain the shielding integrity of the cask. The paper presents comparison of numerical simulation and the experimental drop test results. The results are found to be in good agreement. The results of Radiometry before and after the accident conditions are also discussed.

Keywords: Inclined fins, Structural integrity, Fire testing.

INTRODUCTION

BLC is designed as a Type B (U) transportation cask to carry 100 kCi of Co-60 sealed sources. The cask is used to transport radioactive material Co-60 from Hot cell to the Irradiator site for the source replenishment. It is also used for storage of radioactive material at site. It has been designed to meet the safety series IAEA Code TS-R-1, 2009 [1], Safety guide TS-G-1.1(Rev 1)2008 [2] and AERB/ SC/TR-1 [3] for Safe Transportation of Radioactive Material. In order to meet the regulatory requirement the cask has to maintain its structural integrity under 9m drop test on an unyielding target. The cask performance was studied with and without fins under 9m drop by numerical simulation. The effect of fins under 1m drop test was studied by Jaksic [4]. The cask with fins was also analysed in different orientations such as corner, horizontal, end and inverted end to find out the worst orientation. A prototype of the cask was dropped in the most damaging orientation and results were analysed.

DESCRIPTION

The cask consists of main body, plug, source cage and base plate etc. Fig. 1 shows a photograph of BLC. The cask is made up of SS-304L with lead as shielding material. The main design feature is that it consists of 8 nos of 20mm thick fins and 16 nos of 6mm thick fins at the outer periphery which protect the cask from damaging effects of 9m drop on rigid surface in accident condition and enhance heat dissipation during normal conditions of transport. These fins are inclined at an angle to the outer shell of the cask so that any impact will bend the fins in the pre-orientation rather than piercing into the cask. An outer cover of 3mm thick is placed on the cask to keep the temperature of the accessible surface within limit.

Fig. 1: Photo of the BLC – 100 Cask

NUMERICAL ANALYSIS

Finite Element model for the cask with and without inclined fins was constructed using FEMAP v-8.0. Fig. 2 shows the finite element model of the cask with inclined fins. All the plates of the cask are modeled using 3D, 4 node bilinear shell elements and lead is modeled using 8 node 3D brick elements. Fins used as shock absorber are modeled as shell elements. Material for bolts is SA 540 Gr 24. The bolts are modeled using one dimensional beam element. Failure model for the bolts is considered with 1% plastic strain.

In the event of impact of cask on an unyielding target, the cask is subjected to loadings of high intensity resulting in geometrically nonlinear behavior. This is further complicated by a nonlinear material behavior resulting from plastic flow of materials. To simulate these large deformation and inelastic material response, the cask was analyzed by a non linear FE code PAM-CRASH [5].

Some of the assumptions made include: the structural welds are not considered in the model and uniform base material is modelled across any surface, the material properties for the analysis is considered at room temperature, the unyielding target is assumed to be a perfectly rigid wall without friction and the interfaces such as steel-steel & steel-lead are considered frictionless. Table 1 shows the properties of the material considered for analysis. The stress-strain relation of these materials were expressed by bilinear approximation and based on isotropic hardening rule.

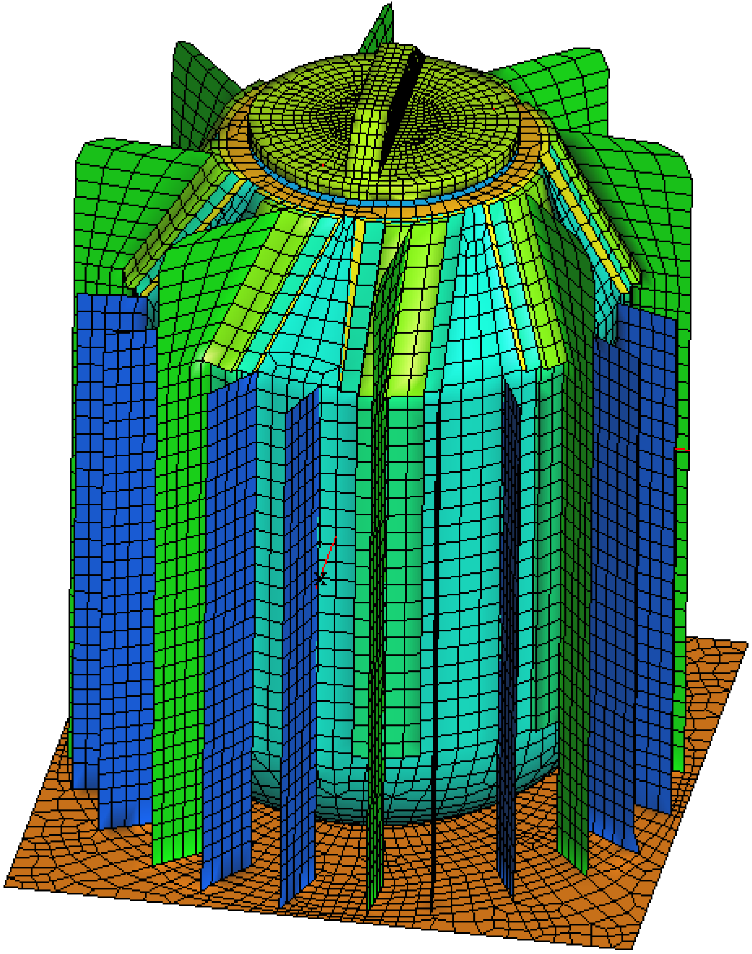

Fig.2: F.E. Model of cask with inclined fin

Table 1 Properties of Materials Employed

Sr. No.	**Properties**	**Steel (SS 304L)**	**Lead**	**Bolt SA 540 Gr B24**
1	Material law	Bilinear Elastic-Plastic	Bilinear Elastic-Plastic	Bilinear Elastic-Plastic with1%plastic strain
2	Density	7800 kg/m³	11350 kg/m³	7800 kg/m³
3	Young's modulus	200E9 N/m²	Not Used	200E9 N/m²
4	Poisson's ratio	0.3	Not Used	0.3
5	Yield stress	170 E6 N/m²	3.2 E6 N/m²	1035E6 N/m²
7	Ultimate stress	485 E6 N/m²	Not Used	1140E6N/m²
8	Strain – rate Cowper Symond's model parameters	C=100 P=10	None	None

RESULTS AND DISCUSSION

Analysis results show, that cask without inclined fins, was not meeting the structural integrity criteria. Stresses generated in the cask without fins are much higher than that of the cask with fins. Fig. 3 shows the stress intensity and time history plot for cask with and without fins where maximum stress took place. Stress intensity in the outer shell for cask without fins and with fins are 501 MPa and and 390 MPa respectively. Table 2 shows stresses in various components for cask with and without fins.

Fig. 4 shows the deceleration and time history plot of the cask without fins and with fins when dropped in the corner orientation. The g-loading for the cask without fin and with fin are 121g and 114g respectively. The above results states that stresses and loadings generated in the cask are reduced after incorporation of inclined fins.

The cask with inclined fins was later studied for different orientations such as corner, end, side and inverted end. Table 2 shows the maximum stress intensity in various parts of the cask under 9 m drop for different orientation. Stress qualification is carried out as per ASME Sec III Div 1, Appendix F [6]. For containment structure stress limit is lesser of 0.9 S_u and for non containment structure stress limit is lesser of 3.6 S_y, or S_u.

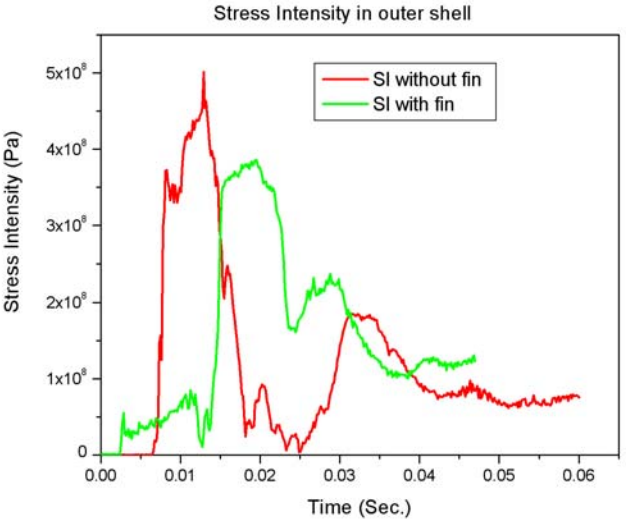

Fig.3 Stress intensity and time history in outer shell under 9m corner drop

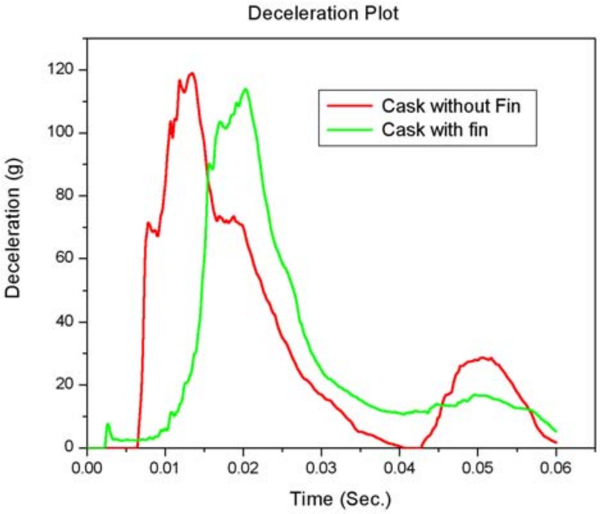

Fig.4 Deceleration and time history of cask with and without fin 9m horizontal

Table 2 Maximum stress intensities for various orientations by finite element analysis

Component / Material	Stress Limit (MPa)		Observed Maximum S.I. **(MPa)**			
		Corner Drop without fin	Corner Drop with fin	Side drop with fin	Inverted end Drop with fin	End Drop with fin
Outer shell of cask	485	501	390	336	279	398
Inner shell of cask	485	387	386	363	471	310
Steel casing of lid plug	485	426	383	431	451	403
Top plate *	485	693	476	320	471	357

* stresses in the projected part that is used to lift the plug of the top plate are not reported as it is a 50mm thick solid and high stresses in this region will not impair the safety of the cask.

Table 2 shows that stresses generated in the cask under different orientations are meeting the structural integrity criteria. Stresses generated in the cask for the corner and inverted end drop are relatively higher than the stresses generated in the side and horizontal drop. This is due to the fact that fins are absorbing more energy in side. This is supported by the fact that larger deformations of the fins are also observed in the side. And in the end drop, in addition to the deformation of fins, lead acts as a cushioning material reducing the stress generated in the cask. Fig 5, 6, & 7 shows the deformation of cask under 9 m drop in different orientations.

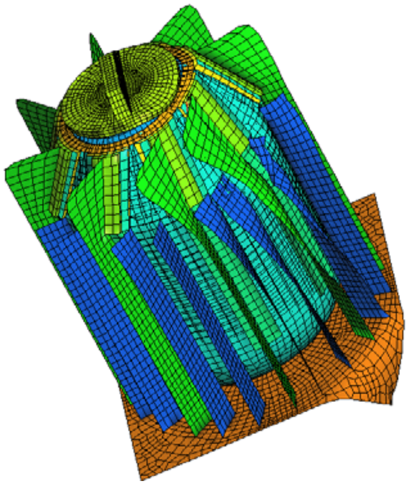

Fig.5 Final deformation under 9m corner drop

Fig.6 Final deformation under 9m horizontal drop

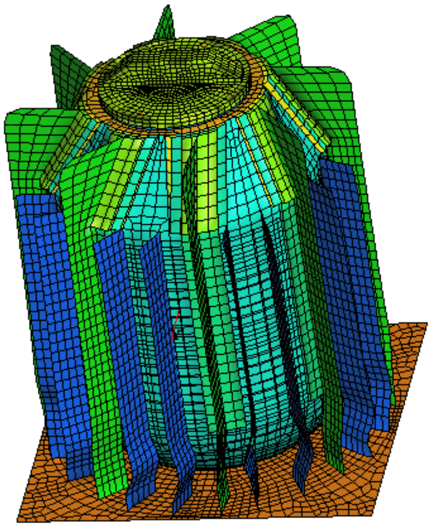

Fig.7 Final deformation under 9m end drop

Fig. 8 shows the axial force generated in the closure bolts for different orientations. The force generated in the corner drop is 206253 N and is greater than that of other drops. In the corner drop the closure bolts are also subjected to bending moment. Considering both axial force and bending moment, the closure bolts are more vulnerable in corner drop than the other drop under consideration.

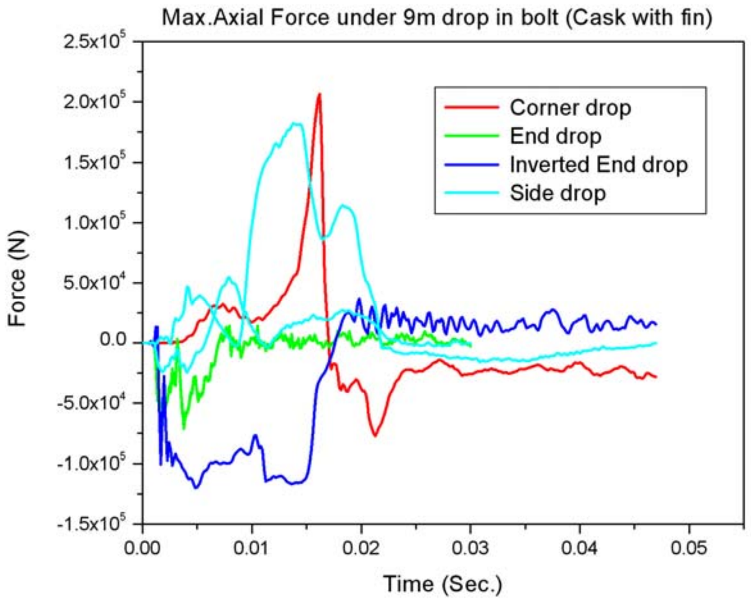

Fig.8 Axial force time history on bolt under 9m drop of cask with fin

Based on the stresses generated in the cask and force on the closure bolt of the cask, corner drop was considered as the worst orientation that can potentially damage the structural integrity of the cask.

EXPERIMENTAL TEST

Automotive Research Association of India (ARAI), Pune, has a test facility for transportation packages up to 10Te. Prototype of the cask was dropped from 9m on the unyielding target. Corner orientation was selected for the drop test. Fig. 9 shows the orientation of the cask under 9 m drop test.

Fig.9 Orientation of the cask under 9m drop

Fig 10 and 11 show the deformation of the cask analytical and experimental results. The deformation pattern of the cask after the drop test closely resemble for analytical and experimental methods.

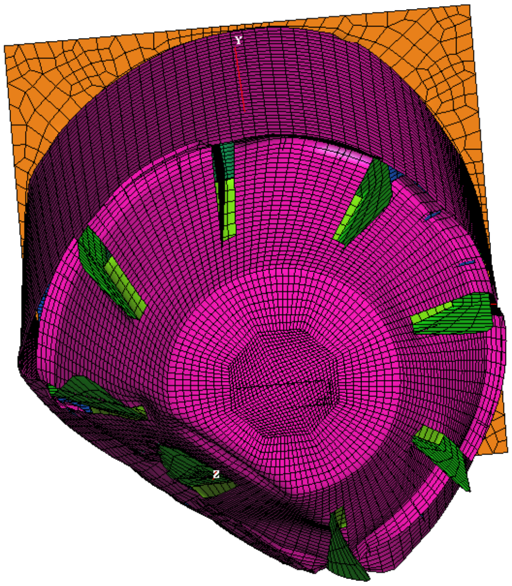

Fig.10 Deformation of the cask after the analysis   Fig.11 Deformation of the cask after the drop test

The inclined fins behaviour was as expected from the numerical analysis. Visual inspection shows that there was no major damage to the cask body. After the drop test the deformed cask also went for 1m punch test and 800^0 C fire test. No leakage of lead from the cask was observed. This confirms that the cask has met the structural integrity criteria.

Radiometry was carried out before and after the 9 m drop test. The cask outer surface was divided into number of grids so that radiation levels can be measured at every point of the cask (Fig. 12). Radiometry was carried out before and after the drop test using 98 kCi and 50 kCi of Co-60 respectively. The maximum radiation levels observed on the surface before and after the drop test was 70 mR/hr and 75mR/hr respectively. It is seen that maximum radiation levels are observed at the point of impact i.e. where there is maximum shielding loss. The radiation levels at all the parts are within limit and meet the regulatory requirements.

Fig 12 Radiometry carried out on the deformed cask.

Conclusion

Numerical analysis shows that the cask without fin was not meeting the structural integrity criteria under 9m corner drop on an unyielding target. Therefore, inclined fins are necessary. Numerical analysis was also carried out for different orientation of the cask. Based on the results, corner drop was considered to be the most damaging.

The design validation was done through numerical simulation and experimental test. Prototype of the BLC with fin was dropped from 9 m on an unyielding target. Visual check after the drop test showed no apparent damage to the cask body. The mode of deformation of the inclined fins corresponds to the pre-computed data obtained from numerical analysis. The integrity of the cask retained intact and the stresses developed in the bolts are within limits.

Radiometry results confirm that radiation levels are higher at the point of impact where there is maximum reduction in the lead thickness. The available lead thickness is sufficient to keep the radiation levels below 1R/hr at 1m distance.

Acknowledgement:

The authors thank Refuelling Technology Division of BARC and ARAI, Pune, for providing their facilities to carry out the work. The authors would like to thank Mr R.G.Agrawal, Mr S.Raju, and Mr V.M. Chavan, for providing necessary support in this work.

.

References:

1) IAEA (ed.), 'Regulation for the safe transport of radioactive material' Safety Guide TS-R-1, 2009, Vienna, IAEA
2) IAEA (ed.), 'Advisory Material for the IAEA regulations for the safe transport of radioactive material' Safety Guide TS-G-1.1(Rev.1)2008, Vienna, IAEA
3) AERB (ed.), 'Regulation for Safe Transportation of Radioactive Material', 1986, AERB/ SC/TR-1, India
4) N Jaksic, K.F.Nilsson, Numerical simulation of the one meter drop test on a bar for the Castor Cask. In: PATRAM 2007, Miami, Florida, USA, October 21-26.
5) "PAM Crash" Commerial code for Explicit Dynamic Analysis, 2002
6) ASME, Boiler and Pressure Vessel Code, Section III, Div. 1 Appendix F: Rules for Evaluation of Service Loadings with Level D Service Limits, 1994