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EVALUATION ON STRUCTURAL INTEGRITY OF "MSF" TRANSPORT AND STORAGE CASK BASED ON RESULTS OF DROP TEST

Tadashi Kimura[1], Akio Kitada[1]

Junichi Kishimoto[2], Yuichi Saito[2], Yoshiyuki Saito[2]

(1) Mitsubishi Heavy Industries, Ltd., Takasago R&D Center, Takasago, Japan
(2) Mitsubishi Heavy Industries Ltd., Kobe Shipyard & Machinery Works, Kobe, Japan

ABSTRACT

Drop tests were conducted with a full scale drop test model for MSF cask (Mitsubishi Spent Fuel cask). The drop attitudes were specified as slap down drop followed by 1m puncture test and vertical drop, which could affect sealing performance at lid parts. To evaluate a structural integrity of MSF cask fleet, an analysis model for drop test which can simulate acceleration and strain time histories at body and lid during drop impact was established.

INTRODUCTION

MSF (Mitsubishi Spent Fuel) cask for transport and storage of higher burn-up and shorter cooling time fuels have been developed. A series of drop tests in line with IAEA transport regulations [1] were conducted with a full scale model by the German Federal Institute for Materials Research and Testing (BAM) to prove structural integrity of MSF cask. In order to evaluate an structural integrity of MSF cask during drop impact, an analysis model was established. The outline is as follows.

(1) Full-scale drop test model and test results
    Full-scale drop test model which was used for the drop tests is shown and the drop test results with the full-scale model are described.

(2) Description of numerical analysis model
    Analysis model to analyze an impact response are described.

(3) Validity of analysis model
    Analyses results are compared with tests results to show the validity of the analysis model.

FULL-SCALE DROP TEST MODEL AND TEST RESULTS

Figure 1 shows the full scale model. The model had a body shell of low-alloy forged steel (with mass of 117 ton), and individual 69 square pipes simulating 69 separate basket cells and rectangular steel bars simulating envelopes and weight of BWR fuels were installed as internal structures. The internal structures had mass of 21 ton. Epoxy resin-based neutron shielding materials were arranged around the cask body shell. Double closure lids system equipped with metallic O-rings were applied to the sealing part. At the both ends shock absorbers, which consisted of three kinds of wood (oak/red cedar/balsa) and steel plates, were attached.

Table 1 shows measuring results of leakage rates before and after each drop test. Leakage rates before the drop tests were below 1x10^{-8}Pam^3/s under each drop condition. Meanwhile, the leakage rates after the drop tests, some of which increase two or three orders more than those before the tests, completely satisfy the criteria based on the IAEA transport regulations. The above results proved containment integrity during transport.

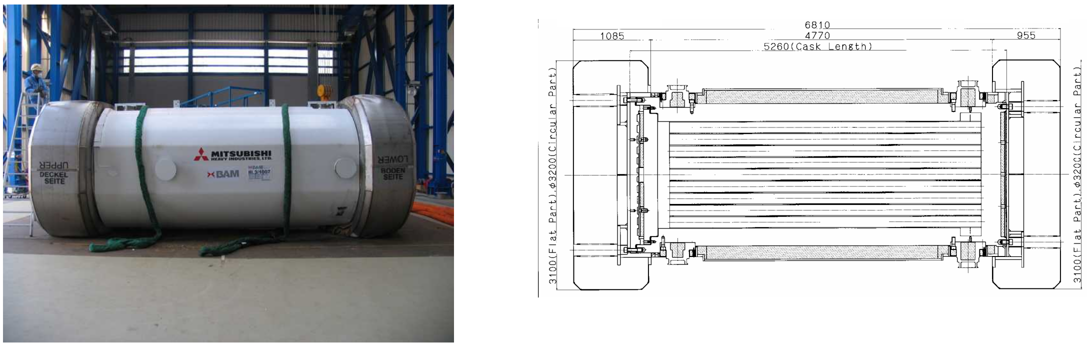


Figure 1. Full Scale Drop Test Model

Table 1. Leakage Rates after Each Drop Test Sequence (Full Scale Model)

(Unit: Pam^3/s)

Seq. No.	ORIENTATION	PRIMARY LID		SECONDARY LID	
		Before	After	Before	After
1	9.3m slap down	$< 1\times10^{-11}$	$< 1\times10^{-11}$	7.4×10^{-9}	1.6×10^{-6}
2	1m puncture (*)	$<1\times10^{-11}$	2.0×10^{-11}	1.6×10^{-6}	7.8×10^{-7}
3	9.3m vertical drop	1.0×10^{-8}	3.9×10^{-6}	2.0×10^{-11}	1.7×10^{-11}
4-1	0.3m slap down	2.5×10^{-11}	1.0×10^{-11}	1.5×10^{-11}	$< 1\times10^{-11}$
4-2	9m slap down (**)	1.0×10^{-11}	$< 1\times10^{-11}$	$< 1\times10^{-11}$	3.0×10^{-7}

(*) Sequence No.2 following Sequence No.1 were conducted without a change of gaskets aiming at the middle of the secondary lid side to which the maximum damage could be caused.

(**) Sequence No.4-2 following Sequence No.4-1 were conducted without a change of gaskets.

NUMERICAL ANALYSIS MODEL

In order to simulate accurately an impact response such as acceleration of cask main body and lids and structural response such as strain of body flange and lids, an analysis model for drop test model was established according to the procedure shown in Figure 2. Especially, shock absorber was modeled based on compression properties obtained from shock absorber compression tests. In the analyses, a general purpose transient dynamic finite element program "LS-DYNA" was used. A shock absorber model and cask body model are described below.

Shock absorber model

Shock absorbers for drop test model consisted of three kinds of woods, inner and outer steel plates. Wood blocks were held and constrained by the inner steel plates and covered by outer steel plates. First, wood element tests were conducted to obtain basic data of wooden materials for establishment of the model. Next, shock absorber compression tests were conducted with a scale model of shock absorber to obtain compression properties of shock absorber. Material properties for the analysis model were determined based on the compression properties of shock absorber. Figure 3 shows comparison of compression properties between analyses results and measuring results obtained from the shock absorber compression tests.

As shown in Figure 4, shock absorber compression properties obtained from the tests well agree with those from the analyses.

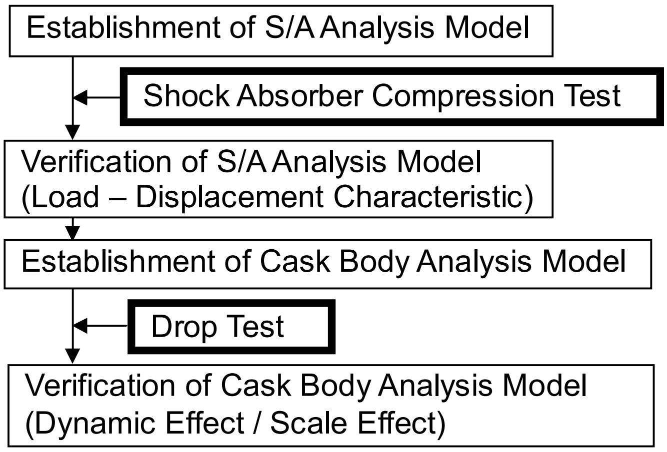
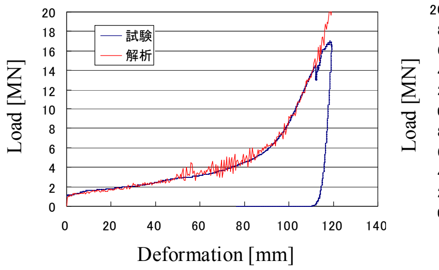
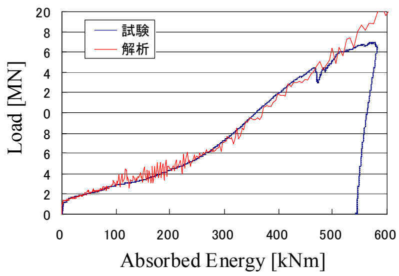


Figure 2. Verification Procedure





(a) Load-displacement characteristics (b) Load-energy properties

Figure 3. Comparison between Results of Shock Absorber Compression Tests and Analyses

Cask body model

A cask body model includes body shell with neutron shielding material, lids, bolts and internal structures. The analysis model of cask is shown in Figure 4. The internal structures were modeled as individual 69 rigid bodies. Only upper shock absorber was attached to the cask body model in analyses. An elasto-plastic model was applied to the analyses as material properties. Furthermore a strain rate dependency of strength for woods and steel plates was considered in impact analyses. [2][3] Drop attitudes in analyses were specified as slap-down, 1m puncture and vertical drop, which could affect sealing performance at lid parts. Initial conditions were determined based on the drop test results as follows:

(1) Vertical drop

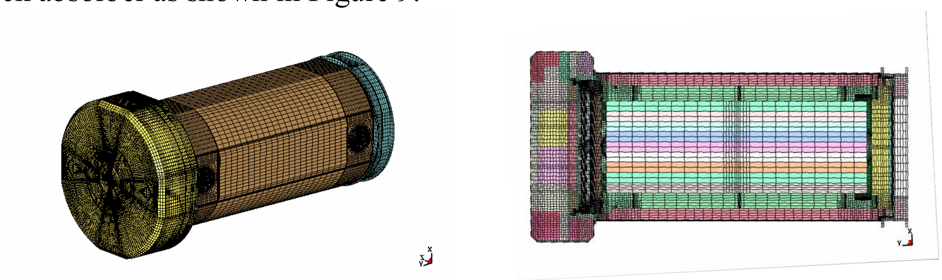
Figure 5 shows the accelerations at the top of body, which indicates a delayed internal impact of the internal structures from inside to the primary lid. Therefore a gap between internal structure and cask body (primary lid) was considered as an initial condition as shown in Figure 6.

(2) Slap down

Figure 7 shows the accelerations at the top, middle and bottom of cask body. An analysis was conducted focusing the secondary impact which caused load acting on the lid side, as shown in Figure 8. An initial velocity at the secondary impact was calculated based on the analytical equation [4] and applied to cask body. Table 2 shows comparison of secondary impact velocities between the analytical values and the values obtained from the slap down test results.

(3) 1m puncture drop

Figure 8 shows the accelerations at the top of cask body, which indicates that a primary impact was caused by a penetration of bar through the outer steel plates of shock absorber and that a secondary impact was caused by impact of bar to the inner steel plates of shock absorber. Assuming that energy absorption by the primary impact and a compression of shock absorber wood is low, only inner steel plates of shock absorber were modeled as a shock absorber as shown in Figure 9.



(a) Outline of model (b) shock absorber model

Figure 4. Analysis Models

Table 2. Comparison of Velocity at Center of Main Body

	Angle velocity [rad/s]	Liner slap down velocity [m/s]
Test results	2.82	9.84
Analytical results	2.98	10.2

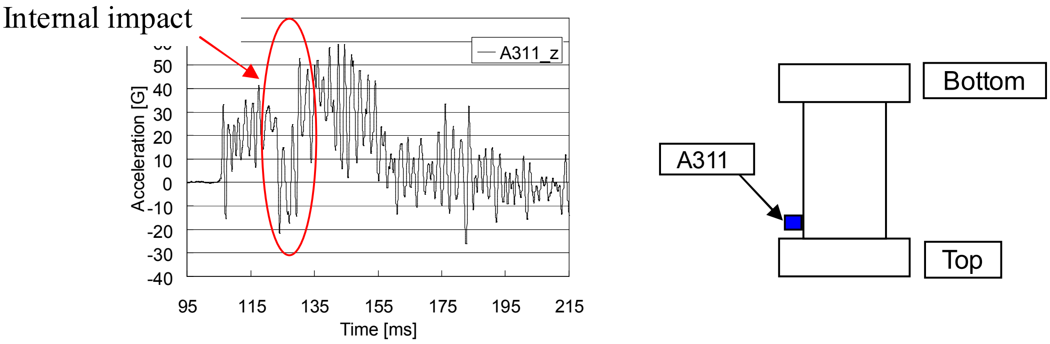


Figure 5. Acceleration Time Histories under Vertical Drop Test

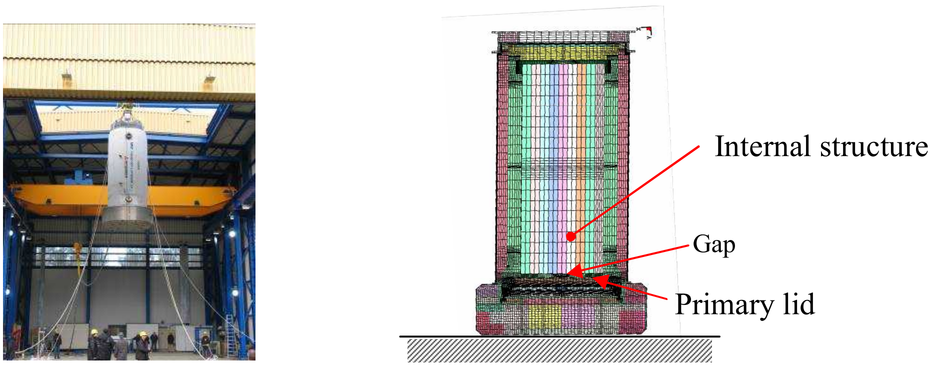


Figure 6. Analysis Model for Vertical Drop Test

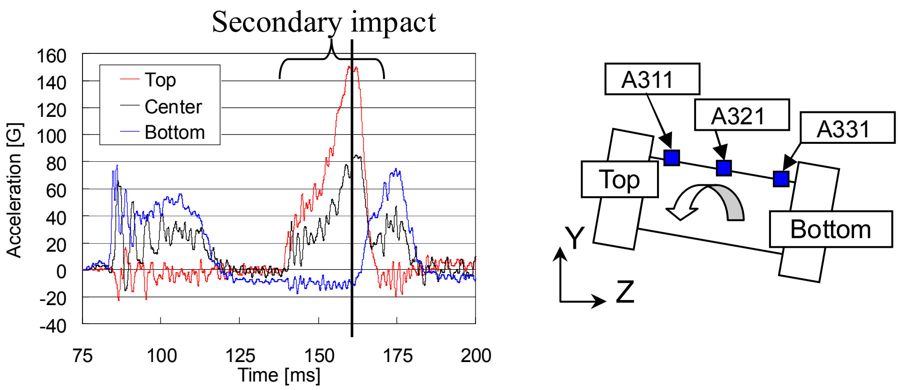


Figure 7. Acceleration Time Histories under Slap-down Test

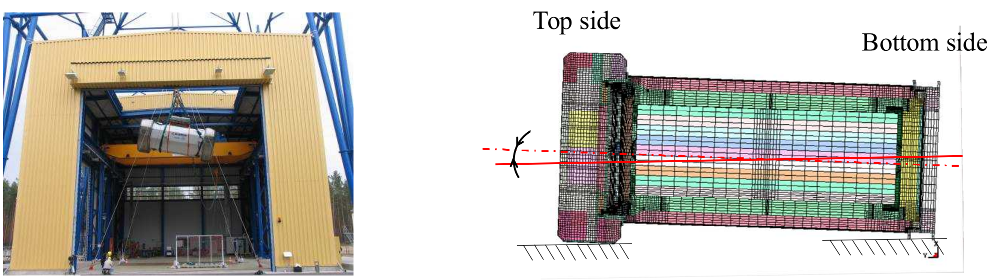


Figure 8. Analysis Model for Slap-down Test

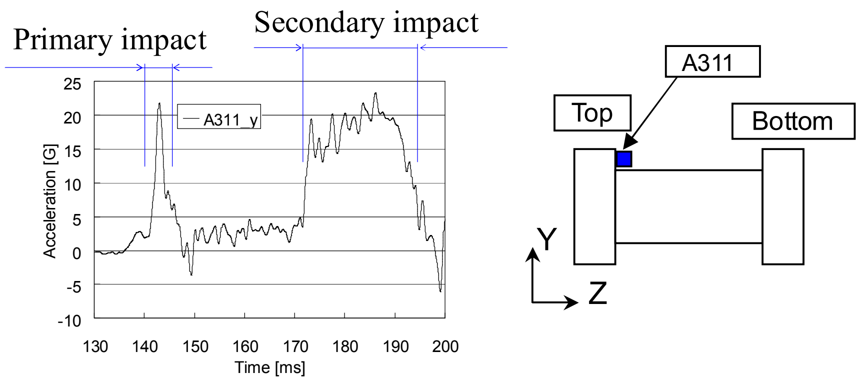


Figure 9. Acceleration Time Histories under 1m Puncture Test

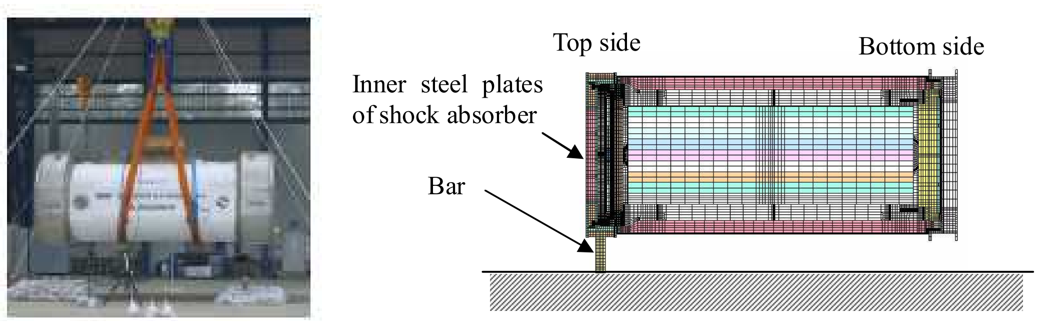


Figure 10. Analysis Model for 1m Puncture Test

VALIDITY OF NUMERICAL ANALYSIS MODEL

Vertical drop

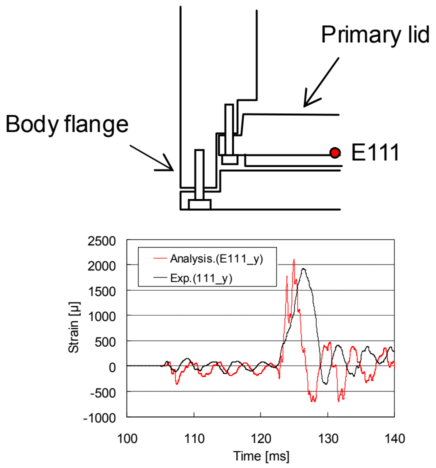
Figure 11 shows comparison of structural response such as bending strain of primary lid and axial strains on the primary lid bolts between tests results and analysis results. The analyses results indicates that response of the primary lid and the lid bolts due to delayed impact of internal structure under 9.3m vertical drop could be simulated taking the gap between the internal structure and primary lid into account.

Slap down

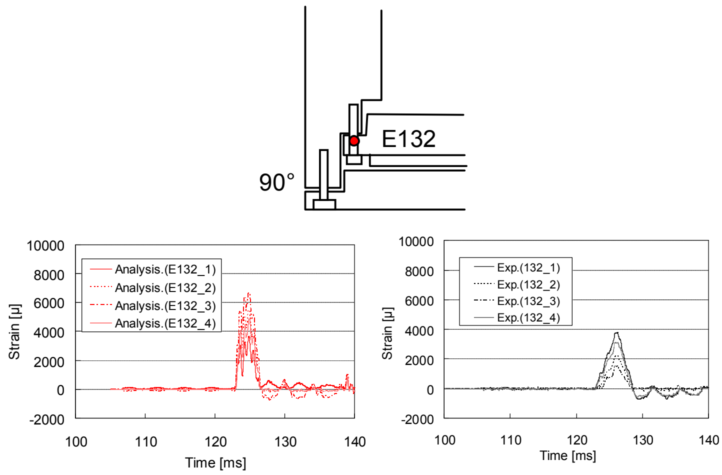
Figure 12 shows comparison of structural response such as bending strains at body flange parts as well as at primary lid between tests results and analyses results. The analysis results show that bending behavior of flange and the secondary lid at secondary impact of slap-down could be simulated.

1m puncture drop

Figure 13 shows comparison of response near the sealing part between tests results and analyses results. The analysis results for strain at an early stage was higher than test results because the impact velocity of cask was determined without consideration of impact energy absorption due to the penetration of outer steel plates and compression of wood was not considered. The analysis results show that bending behavior of flange and the secondary lid could be simulated.



(a) Bending strain on primary lid



(b) Axial strain on primary lid bolts

Figure 11. Strain-Time Histories during Vertical Drop

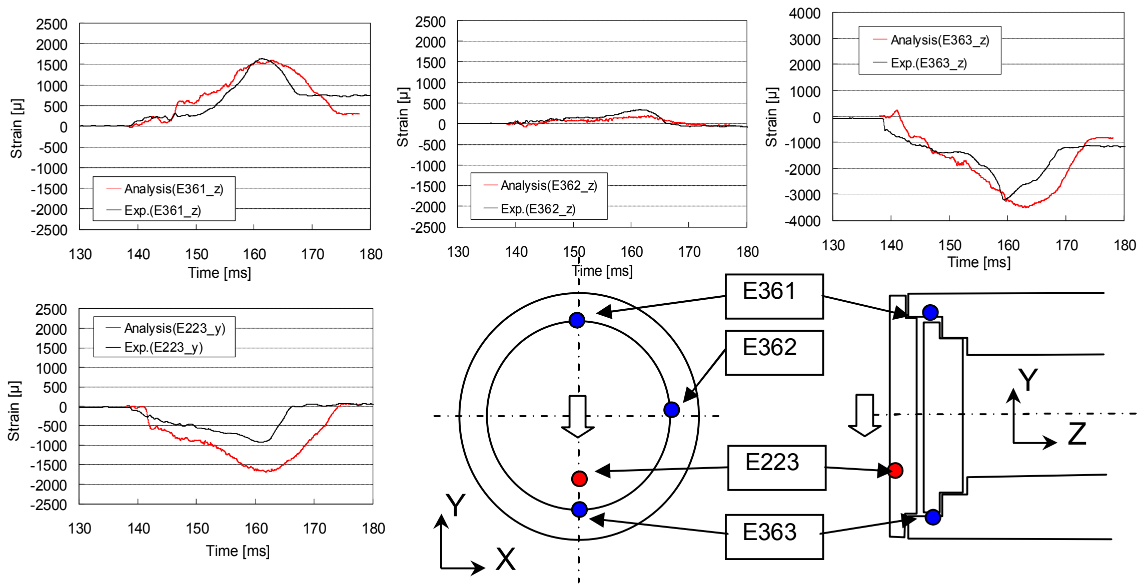
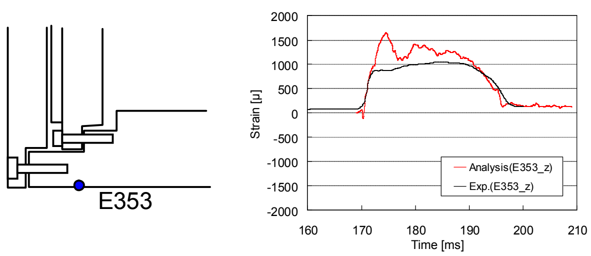
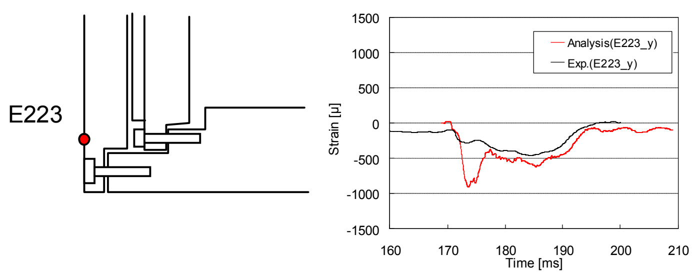


Figure 12. Strain-Time Histories during Slap Down Drop



(a) Bending strain on body flange



(b) Bending strain near secondary lid bolts

Figure 13. Strain-Time Histories during Slap Down Drop

CONCLUSIONS

In order to simulate impact response and strain of cask body and lids, the analysis model was established based on the results of the drop tests with full-scale drop test model and the shock absorber compression test.

This analysis model and analysis conditions are used for drop impact analysis for MSF cask.

ACKNOWLEDGMENTS

MHI thanks BAM for giving MHI the opportunity to present pictures taken on the BAM test facility, Germany. Statements in this presentation concerning test results reflect MHI's point of view only; MHI's statements do not represent the official BAM point of view, and are subject to further investigations within the German licensing procedure.

REFERENCES

[1] IAEA SAFETY STANDARDS SERIES, Regulations for the Safe Transport of Radioactive Material, 2005 Edition Safety Requirements, Safety Standards Series No. TS-R-1

[2] Chatani et al.,"Impact Strength of Low Density Woods" (in Japanese), Japan Society of Mechanical Engineers 2001 annual conference lecture memoirs,2001

[3] Chatani et al., "Study about impact strength of balsa", The 50th anniversary Japan Society of Materials Science foundation memory arts and sciences lecture, 2001

[4] T.Quercetti, et. al., "Analytical, Numerical and Experimental Investigations on the Impact Behaviour of Packagings for the Transport of Radioactive Material under Slap Down Conditions", PATRAM 2001, Chicago (USA), September 3-7, 2001