DEMONSTRATIVE DROP TESTS OF A NATURAL UF_6 TRANSPORT PACKAGE DURING HANDLING ACCIDENT

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SUMMARY

Natural Uranium Hexafluoride (UF_6) is transported in a steel container called 48Y-cylinder. Up to now, various safety experimental and numerical evaluations have been performed to demonstrate the integrity of the 48Y-cylinder itself. During transport, the 48Y-cylinder is supported on the flat rack marine container with exclusive frame, tightening devices and heat protective covers, (hereinafter called a natural UF_6 transport package). In this paper, the drop test and analysis results are presented to demonstrate the integrity of a natural UF_6 transport package subjected to drop impact under realistic drop accidents, for example, during handling in the port.

Drop test condition was determined by the pre-drop test analysis with DYNA-3D computer code. In 12m horizontal drop analysis onto unyielding surface, the impacted area of the cylinder by the support frame was severely damaged and the maximum deformation strain was reached to the ultimate strain of the material. Therefore, drop height was set to 12m. In the drop test, the dummy weights were installed in the test container and the deformation and acceleration were measured.

After the drop test, 48Y-cylinder and the exclusive frame were considerably deformed and the tightening devices were damaged. However the leak-tightness was not lost during the drop test. Moreover, the numerical model installed in the DYNA-3D code was also validated. Thus, the integrity of a natural UF_6 transport package against a drop impact during handling accident was demonstrated.

INTRODUCTION

UF_6 is transported by a steel container called 48Y-cylinder. Since the 48Y-cylinder containing natural UF_6 is classified as a non-fissile Type A package under Japanese Regulations, a free drop test from 0.6 meter onto the unyielding target so as to incur the maximum damage is imposed on it. Up to now, various safety experimental and numerical evaluations have been performed to demonstrate the integrity of the 48Y-cylinder itself (Shirai, 1992). During transport, the 48Y-cylinder is supported on the flat rack marine container as shown in Fig.1. However, the integrity of this package subjected to drop impact under realistic drop accidents, for example, during handling in the port, has not been demonstrated. In this paper, the drop test and analysis results are presented to demonstrate the integrity of a natural UF_6 transport package against the drop impact during handling accident. This drop program was carried out by CRIEPI under the sponsorship of Science and Technology Agency of Japan.

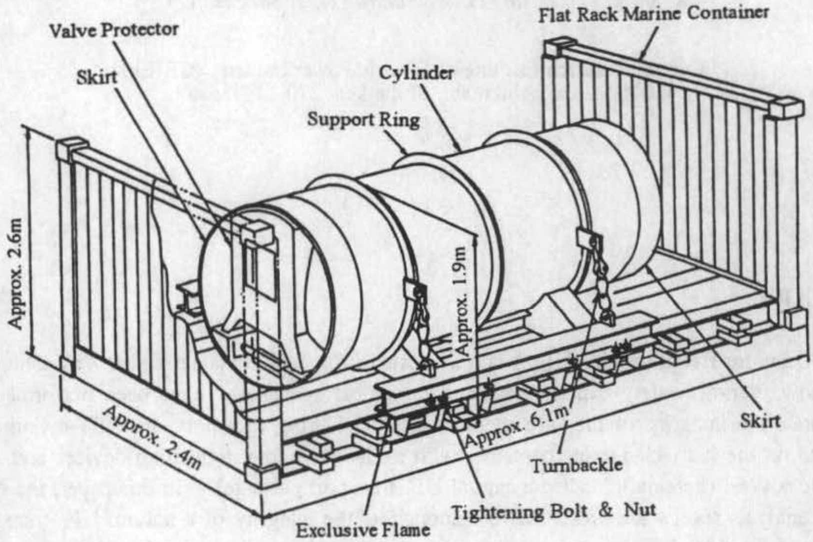
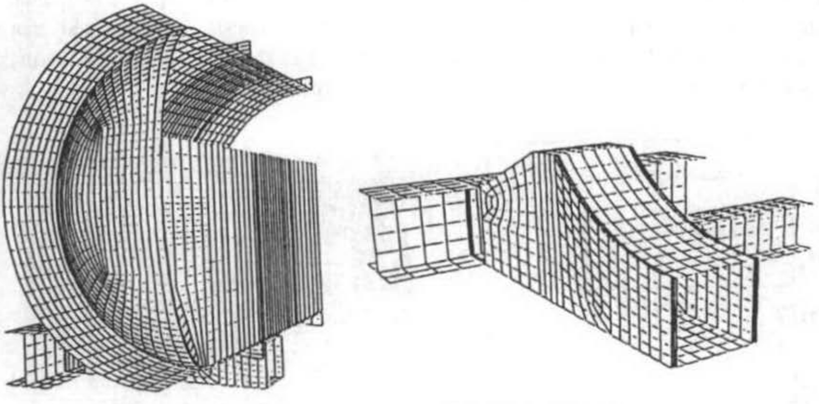


Fig.1 A natural UF_6 transport package on an exclusive frame

PRE-DROP TEST ANALYSIS

Pre-drop test analysis of a natural UF_6 transport package was performed to estimate a critical drop height at the most critical location and determine the test condition. The horizontal drop orientation on to the unyielding surface was selected considering a realistic handling condition and the severe local damage due to the interaction impact force between a 48Y-cylinder and a exclusive frame. A dynamic analysis was performed using DYNA-3D code, which has been used extensively in another CREIPI test program (Shirai, 1990).

Fig.2 shows the finite element model. One-quarter double symmetric model was taken for the drop test analysis since both the loading and geometry were rationally symmetric in the longitudinal section and the center cross section. In order to simplify the analysis, the equivalent solid elements were applied as a substitute which occupied two-thirds of the volume of the 48Y-cylinder and the valve protector attached in Japan was neglected. The joint conditions of the analytical model used slide and void elements applied to the contact zone of both the 48Y-cylinder and exclusive frame to simulate the interaction force during drop impact. The rotation of the elements is restricted at the cross-section facing symmetrical section, and the analytical mode restricts movement in the drop direction at the node position on the unyielding surface. For initial conditions, the free-fall velocity from the drop height was applied to each node of finite element models.



(Overall View) (Exclusive Frame)

Fig.2 Finite Element Model

Table1 shows material properties used in the analyses. 48Y-cylinder and an exclusive frame was made of SA516 Grade60 and SS41, respectively. The stress-strain relation of these materials was expressed by bilinear approximation and based on the isotropic hardening rule. For failure criterion, the Von-Mises yield criterion was applied. As to the containment, the only hydro-static effect was considered and its density was modified appropriately. It is well known that the characteristics of mechanical properties such as yield stress are affected by its strain rate.

The dynamic magnification factor for yield stress due to strain rate can be derived from the material test results as shown in Fig.3 (Lindholm, 1990). Symonds-Ting type equation was used and expressed as equation (1).

$$\frac{\sigma_{yd}}{\sigma_{ys}} = 1.0 + \left(\frac{\dot{\varepsilon}}{D}\right)^{1/P} \qquad (1)$$

where σ_{yd} is the dynamic strength of the material and σ_{ys} is the static strength of the material. Parameter Constants D and P are summarized as shown in Table2.

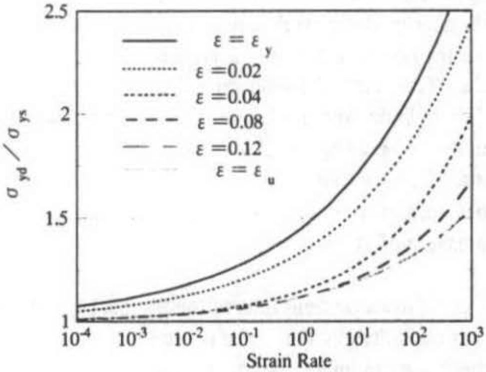


Fig.3 Strain Rate Effect

Table1 Material Properties

Material	SA516 Grade60	SS41	Containment
Density	7.8 kg/m^3	7.8 kg/m^3	5.0 kg/m^3
Elastic Modulus	214.3GPa	214.3GPa	117.7GPa
Hardening Modulus	0.4GPa	1.1GPa	0.0GPa
Yield Stress	347MPa	255MPa	2.3MPa
Poisson Ratio	0.3	0.3	0.3

Table2 Constants D and P

Strain	D	P
ε_y	5.4×10^1	5.04
0.02	1.7×10^2	4.74
0.04	1.0×10^3	3.62
0.08	4.7×10^3	3.96
0.12	1.6×10^4	4.51
ε_u	1.5×10^4	4.49

Fig.4 shows the relation between drop height and maximum equivalent plastic strain generated in the 48Y-cylinder. In 12m pre-drop test analysis, the impacted area of the cylinder by the exclusive frame was severely damaged as shown in Fig.5 and the maximum plastic deformation strain reached the ultimate strain of the material.

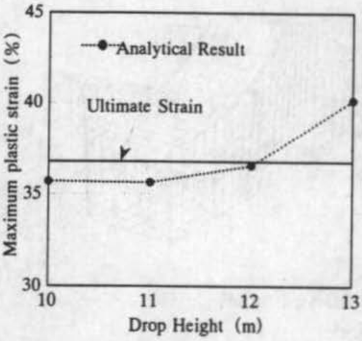


Fig.4 Drop Height and Maximum Equivalent Plastic Strain

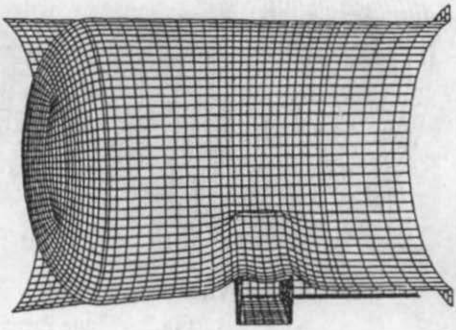


Fig.5 Calculated deformation (12m drop height)

DROP TEST

According to the pre-drop test analysis results, drop test height was set to 12m which would be almost critical height of the natural UF_6 transport package. Drop test was performed at the Yokosuka Research Laboratory of CRIEPI (Kanagawa-ken, Japan). Regarding UF_6 , dummy granular steels equal to the total weight of the contents (12,500kg) were used. As for the object target, the unyielding object surface described in the IAEA regulations for the Safe Transport of Radioactive Materials was applied. To estimate the impact force on the 48Y-cylinder and exclusive frame, acceleration and strain were measured at various points in the test package as shown in Fig.6. Moreover, soap test was performed to confirm the integrity of sealability of the filling valve against drop test. These tests were carried out before and after the drop tests using an actual 1-inch valve and nitrogen gas at internal pressure of 10MPa.

Fig.7 shows photographs of the test package after the drop test. The exclusive frame was considerably deformed due to the longitudinal bending as supported by the flat rack container on each end and the tightening devices were collapsed by the buckling due to the compressive impact force. 48Y-cylinder was locally damaged near the impacted area (cross section K,L,M) by the frame with crushing to 112mm as shown in Fig.8.

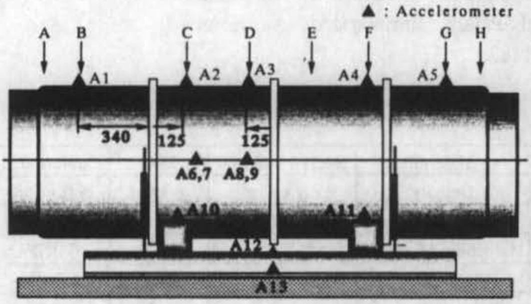
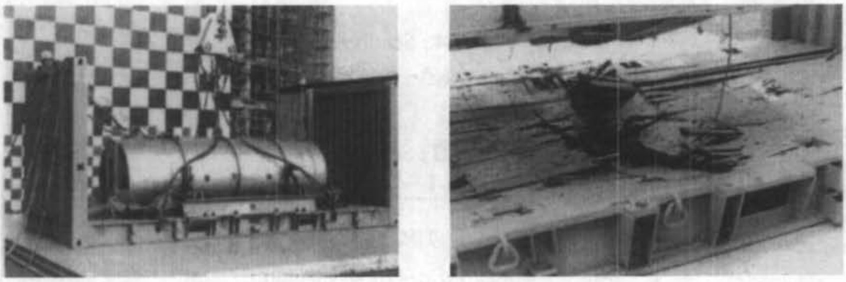
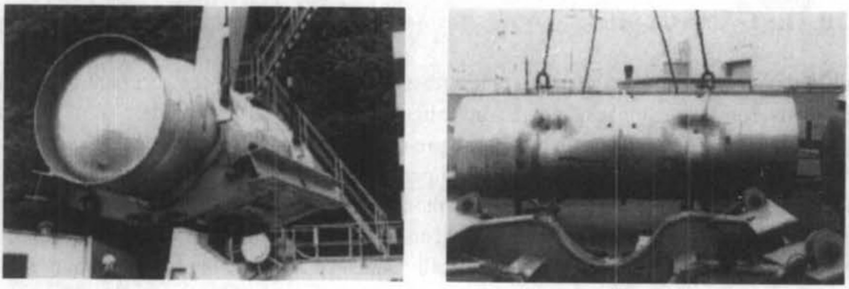


Fig.6 Measuring Points of Acceleration at Drop Test

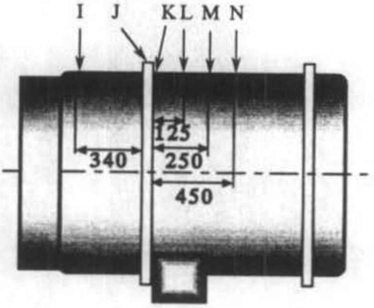


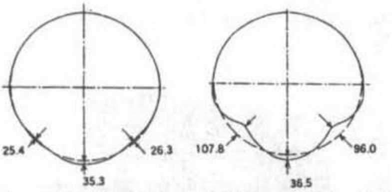
(Overall view after the test) (Deformed flat rack container)



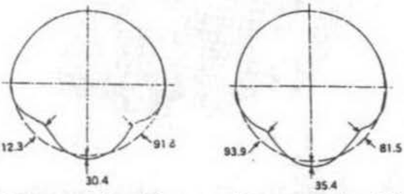
(Deformed exclusive frame) (Damaged 48Y-cylinder)

Fig.7 Deformed Test Package with the Exclusive Frame after the Drop Test





(Cross section N) (Cross section M)



(Cross section L) (Cross section K)

Fig.8 Deformation of the 48Y-cylinder

Fig.9 shows time histories of accelerometers at various points in the test container, measured in the drop test. The high frequency components were removed from these time histories by a low pass filter (320Hz). The average deceleration value was about 100G in the cross section D and no plastic strain was generated near the 1-inch valve and plug. As the maximum compressive force generated in the tightening device was about 500kN which was beyond the ultimate force (450kN), the tightening device was collapsed. According to the soap test, it was found that the leak-tightness was not lost during the drop test.

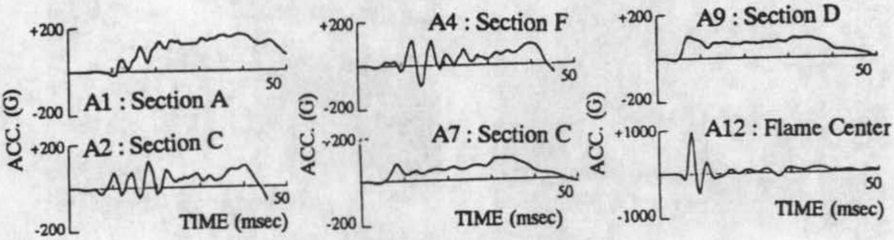


Fig.9 Time histories of acceleration

DROP TEST ANALYSIS

Firstly, by comparing the analytical results with experimental results, the accuracy of the drop test analysis for the test package was investigated with DYNA-3D code. For drop test analysis, the same finite element model as pre-drop test analysis was applied except only boundary conditions which were modified to permit the bending movement of the exclusive frame considering the realistic deformation mode as shown in Fig.7. Fig.10 shows the simulated deformation of finite element model for the 12m horizontal drop test. An important plastic strain occurred in the vicinity of the locally damaged area and the corresponding strains reached 34.1% on the outer surface and 21.9% on the inner surface. In Fig.11, the test results and the analytical results were compared as to the deformed shape at the most damaged cross section. In the analysis, the maximum crushed depth was generated at about 91mm after the drop impact, in good agreement with the test results.

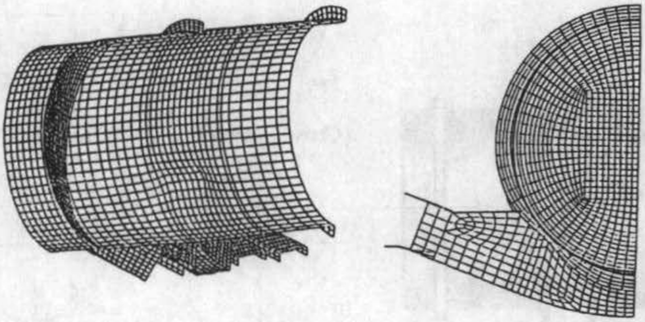
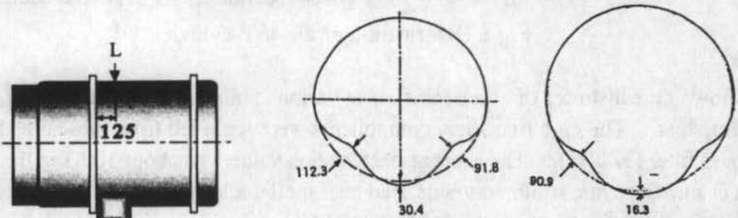


Fig.10 Simulated Deformation for 12m Horizontal Drop Test



(Test Results) (Analytical Results)

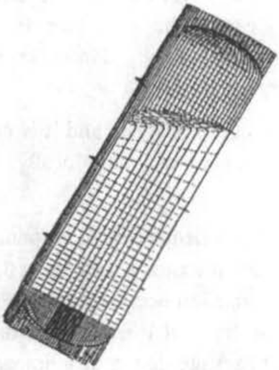
Fig.11 Comparison between the Test Results and the Analytical Results

DEMONSTRATIVE DROP TEST ANALYSES

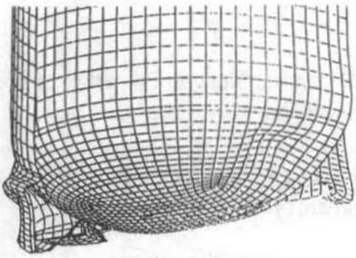
To clarify the critical drop height on to the unyielding surface and demonstrate the integrity of the natural UF_6 transport package during a realistic handling, drop test analyses for various drop orientations were performed. Table3 shows the summary of the demonstrative drop test analyses. For the 48Y-cylinder without the exclusive frame, the horizontal, vertical and gravity corner orientation were considered. For the natural UF_6 transport package with the exclusive frame, only horizontal orientation was considered. Fig.12, Fig.13 and Fig.14 shows the simulated deformation by finite element model with DYNA-3D code for the vertical, gravity corner and horizontal drop impact from 12m height onto unyielding surface, respectively. In case of vertical and gravity corner orientation, local deformation occurred due to the impact force interacted between 48Y-cylinder and the valve protector, but there was no damage to the valve. According to these analytical results, it was made clear that the generated equivalent plastic strain was less than the ultimate strain in each drop orientation.

Table3 Summary of the Demonstrative Drop Test Analyses

Drop Orientation		Drop Height	Target Object	Max. Plastic Strain		Ultimate Strain
				Inner Surface	Outer Surface	
48Y-Cylinder with valve protector	Horizontal	12.0m	Unyielding	25.0%	12.5%	36.8%
	Vertical			36.4%	15.3%	
	Gravity Corner			36.4%	24.6%	
UF_6 Package with the Exclusive Frame	Horizontal			36.6%	36.2%	

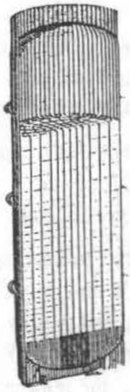


(Analysis model)

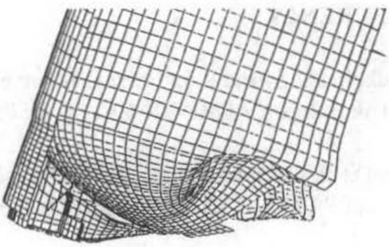


(Deformation)

Fig.12 Vertical Drop Analysis



(Analysis model)



(Deformation)

Fig.13 Gravity Corner Drop Analysis

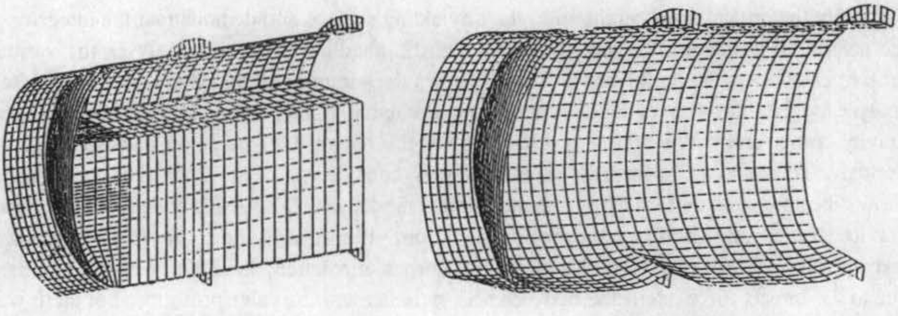

(Analysis model) (Deformation)

Fig.14 Horizontal Drop Analysis

CONCLUSION

In this study, a drop test and numerical drop analysis were performed to demonstrate the integrity of a natural UF_6 transport package subjected to an impact representative of a realistic drop accidents. Following the results of the drop test and analyses, the outline of contents and results is summarized below.

1) Drop test onto unyielding surface from critical height was performed using a natural UF_6 transport package. After the drop test, 48Y-cylinder and the exclusive frame were considerably deformed and the tightening devices were damaged. However the leak-tightness of the 48Y-cylinder was not lost during the drop test.

2) FEM with DYNA-3D computer code was applied to the drop analysis and it is confirmed that the accuracy of the drop analysis is good enough to estimate locally damaged deformation that generated in the transport package.

3) Based on the drop test and analysis results for various drop orientations, it is found that the critical drop height onto unyielding surface for each orientation was at least greater than 12m. In case of vertical and gravity corner orientation, local deformation occurred due to the impact force interacted between 48Y-cylinder and the valve protector, but there was no damage to the valve. Thus, the integrity of a natural UF_6 transport package due to drop impact during handling accident was demonstrated.

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SESSION 15.1

Fuel Cycle Transports