# The Integrity Verification Tests and Analyses of a 48Y Cylinder for Transportation of Natural Uranium Hexafluoride

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## INTRODUCTION

Natural Uranium Hexafluoride ($UF_6$) has been transported to the demonstration enrichment plant (DP), operated by Power Reacter and Nuclear Fuel Development Corporation (PNC), at Ningyo-Pass in Okayama Prefecture since April 1988.
Natural $UF_6$ will be also transported to the commercial enrichment plant (CP) after its completion, which is under construction at Rokkasho-mura in Aomori Prefecture.
In this study we conducted following tests and analyses to verify the safety of natural $UF_6$ transportation.

i ) A free drop test and analysis
ii ) A fire resistance test and analysis
iii ) A water immersion test

Since a 48Y Cylinder containing natural $UF_6$ is classified as a non-fissile Type A package under Japanese Regulations, we conducted a free drop test, and its analysis in order to verify that it conforms to the requirements of a non-fissile Type A package. The test item ii ) and iii ) are not required for a non-fissile Type A package according to Japanese Regulations. The test item ii ) are conducted in relation with the IAEA TECDOC-423. This study was sponsored by the 10 major Japanese electric utilities.

## TESTS AND ANALYSES FOR NORMAL CONDITIONS OF TRANSPORT

Since a 48Y Cylinder containing natural $UF_6$ is classified as a non-fissile Type A package under Japanese Regulations, it is subjected to the tests for normal conditions of transport.
In the free drop test a cylinder has to be dropped onto the target so as to incur the maximum damage. Since the containment integrity of a cylinder was supposed to be lost after a free drop in which the direction of the valve was downward, we developed a valve protector effective under such impacts as shown in figure 1. The behavior of the cylinder installed value protector was analysed for a vertical, an horizontal and a inclined drop test using the ABAQUS code and the DYNA-3D code. The height of drop tests was 0.6 meters. The demonstration test was also made for an

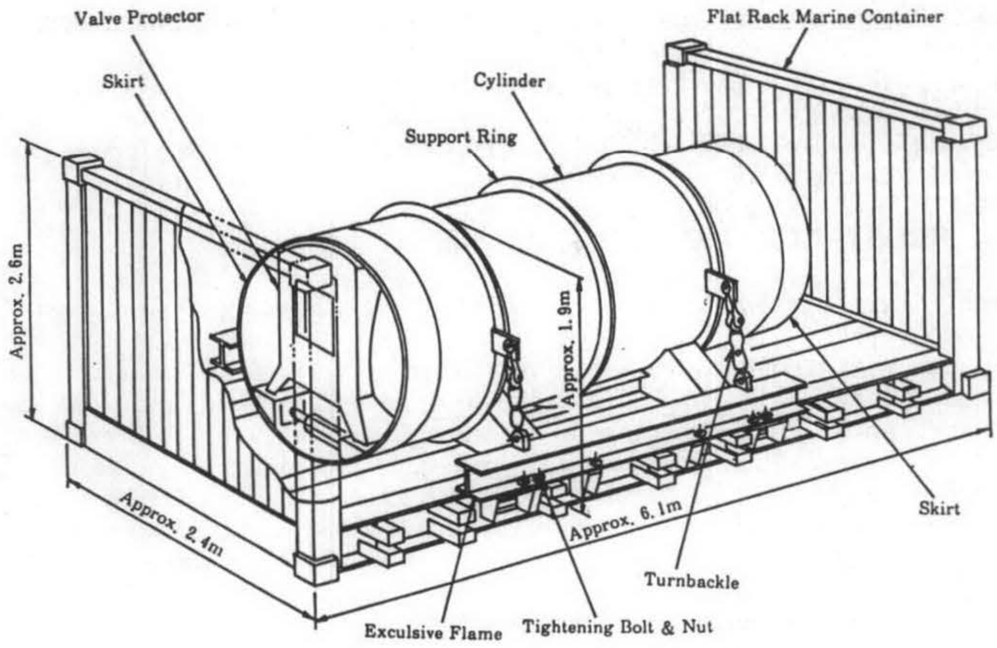


Fig. 1 48Y Cylinder during Transport

Table 1 Results of the Free Drop Tests and Analyses

| Direction | Deformation | Accellation | Evaluation |
|---|---|---|---|
| Vertical | Analysis 13.5mm (skirt) | 51G | Although the gap between the valve and the valve protecter decreased from 36mm to 23 mm caused by the deformation of the skirt, the integrity of the value was maintained. |
| Horizortal | Analysis 6.8mm (skirt) | 83G | Although maximum stress and plastic strain are occurred at the bottom of support rigs, the integrity of the package was maintained. |
| Inclined | Analysis 14.3mm (skirt) | 45G | Test results are well supported by analyses. According to analyses, the gap between the valve and the valve protecter changed to 34mm after drop and the intergrity of the valve was maintained. The package and the valve were completely sound also according to a visual inspection and a leaktightness test after the drop test. |
| | Test 13.0mm (skirt) | 49G | |

inclined drop using a full scale model of a 48Y cylinder containing steel shot as a substitute for $UF_6$. The results of each test and analysis (as shown in table 1) shows that the valve is completely sound and the integrity of containment is maintained although the body, skirts, support rings and the valve protector of the cylinder were locally deformed. The inclined drop test proved the effectiveness of the valve protector, and is well supported by analyses.

## A FIRE RESISTANCE TEST AND ANALYSIS

### General

Since a fire test is one of the tests for accident conditions of transport, which is subjected on a Type B and fissile package, it is not required for a 48Y cylinder containing natural $UF_6$ according to Japanese Requlations. However we have carried out investigation into the fire resistance capability of a 48Y cylinder, considering the IAEA TECDOC-423. In order to verify the adequacy of analysis method the fire resistance test and its analysis were carried out on a full sacle model filled with steel shot as a substitute of $UF_6$ Using that analysis model, analysis on a 48Y cylinder assumed to contain natural $UF_6$ are carried out. The following are evaluated items which are critical phenomenon on the safety of the package.

i) Hydraulic rupture due to thermal expansion of $UF_6$
ii) Rupture due to vapor pressure of $UF_6$ and fall in steel stength
iii) Loss of containment of a valve due to melt of solder.

Acoording to the preliminary analysis, we have developed a heat protective cover in order to maintain the integrity of containment even if it is in fire conditons.
In order to make it as light as possible, it has 14mm thick and only covers both ends of cylinder. It has laminated structure as shown in figure 3. During the fire test, the emmisivity is measured on the surface of a cylinder. The ABAQUS code is used for analysis.

### Fire Resistance Tests and Analysis on A Full Scale Model

The fire resistance tests were carried out on a full scale model of a 48Y cylinder both with and without the heat protecrive covers and the valve protector. The ambient temperature during the test was 800 ℃ and the test duration was 30 minutes.
The test results show that the maximum temperature of the valve was always below its melting point under fire conditions and the effectiveness of the heat protective covers is thus proven.
The results of the tests and analyses are shown in figure 2. This figure shows that test results are well simulated by analysis. This analysis method is applied for analyses on a 48Y cylinder assumed to contain natural $UF_6$. The emmisivity of the outer surface of a 48Y cylinder is measured during the fire tests. It is approximately 0.6 as shown in figure 3.

### Analysis of actual cylinder containing $UF_6$

The fire resistance analysis was carried out for a 48Y cylinder in the case where it contained natural $UF_6$ under fire conditions of 800℃-30min. applied in the same way as described in paragraph. 3.2. The analyses were made for both cylinders with and without the heat protective covers.

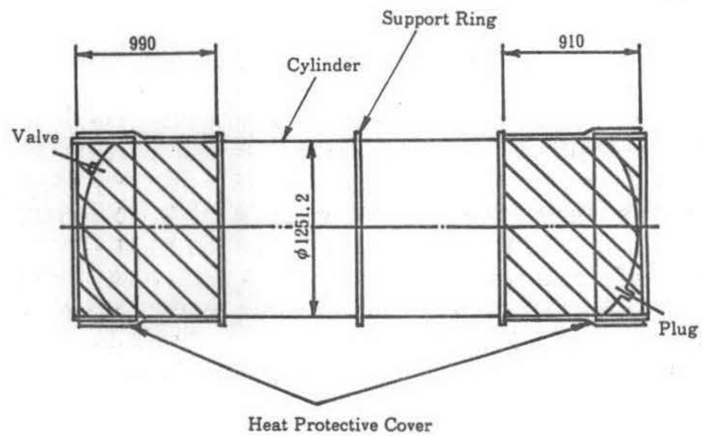


Fig. 2 Heat Protective Cover

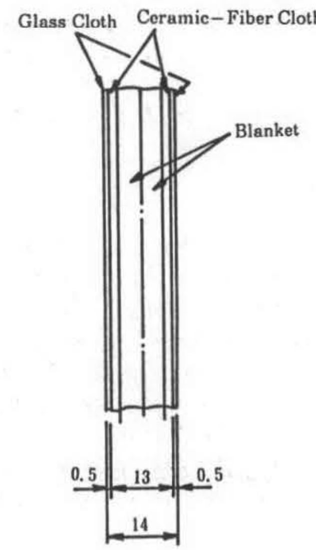


Fig. 3 Laminated Structure of Heat Protective Cover

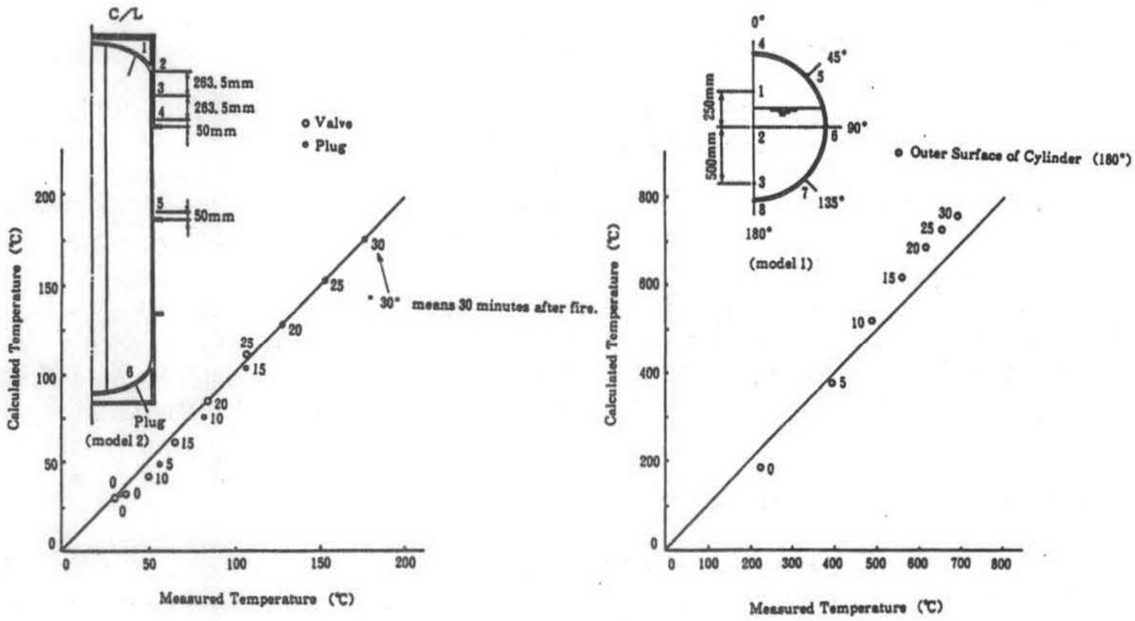


Fig. 4 Comparison between Analysis and Test

i ) Acceptance criteria

Critical phenomenon on the safety of a 48Y cylinder under fire conditions are hydraulic rupture, rupture due to vapor pressure and melting of valve lead.
The acceptance criteria for hydraulic rupture is given by thefollowing equation, which means that the volume of $UF_6$ ($V_{UF}$) comes to be equal to that of a cylinder ($V_{CY}$) caused by thermal expansion of $UF_6$;

$$V_{UF}=V_{CY}$$

For rupture due to vapor pressure, the acceptance criteria is given by the following equation ;

$$P_{IN}=P_{CY}$$

where,

$P_{IN}$: Vapor pressure of $UF_6$
$P_{CY}$: Ultimate pressure of a cylinder, determined by Tresca's epuation ;

$$P_{CY}=\sigma_Y \cdot \ell og\ (D_2/D_1)$$

where,

$\sigma_Y$ : Yield strength of steel,
$D_2$ : Outer diameter of cylinder
$D_1$ : Inner diameter of cylinder

$P_{CY}$ is approximately 58.0 kgfG/mm$^2$ at room temperature and lowers proportionally with temperature.
For melting of lead the acceptance criteria of valve temperatııre is 203℃, (i.e. the melting point of lead).

ii ) Analysis model and procedure

It is necessary to obtain the following temperature in order to evaluate the fire resistance capability of a 48Y cylinder containing natural $UF_6$ ;

- o The maximum temperature the $UF_6$
- o The maximum temperature the cylinder
- o The maximum temperature the valve

Theose temperatures are calculated using two simple models, that is the two dimensional and the axial-rotative model with safety factor. Temperature of $UF_6$ is calculated using a two dimentional model as shown in figure 4 and that of the cylinder and the valve is calculated using the axial-rotative model as shown in figure 5. Detail of these models have been described in *Safety Evaluation of the Transport Container for Natural Uranium-Hexafluoride under Fire Accident*, H. Yamakawa et al., from Conference Proceedings of ' Urnium-Hexafluoride-Safe Handling, Processing, adn Transporting' (1988)

iii ) Boundary conditions

Heat transfer between the cylinder and the environment is assumed to be made by radiation and force convection. The emmmisivity of a cylinder is 0.6 from the measurement and of the heat protective covers and the environment, 0.8 and 0.9 respectively according to the IAEA Transport Regulations. The effect of the

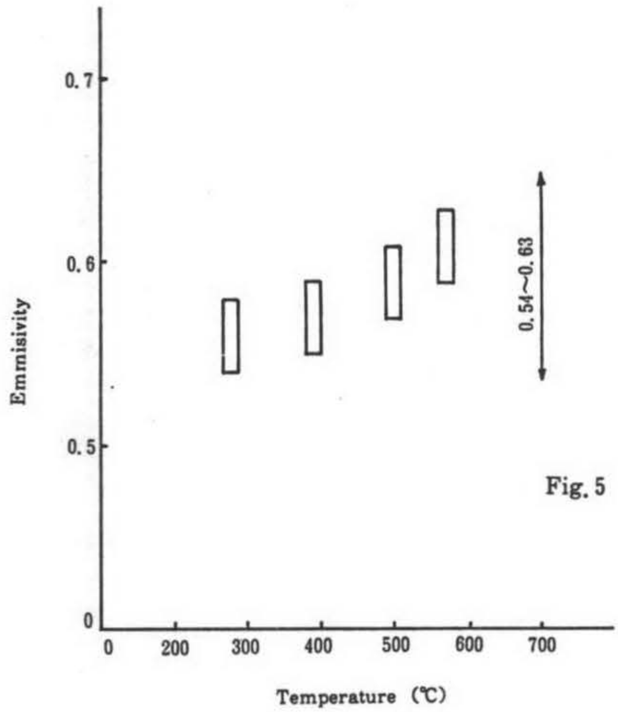


Fig. 5 Measured Emmisivity of 48Y Cylinder

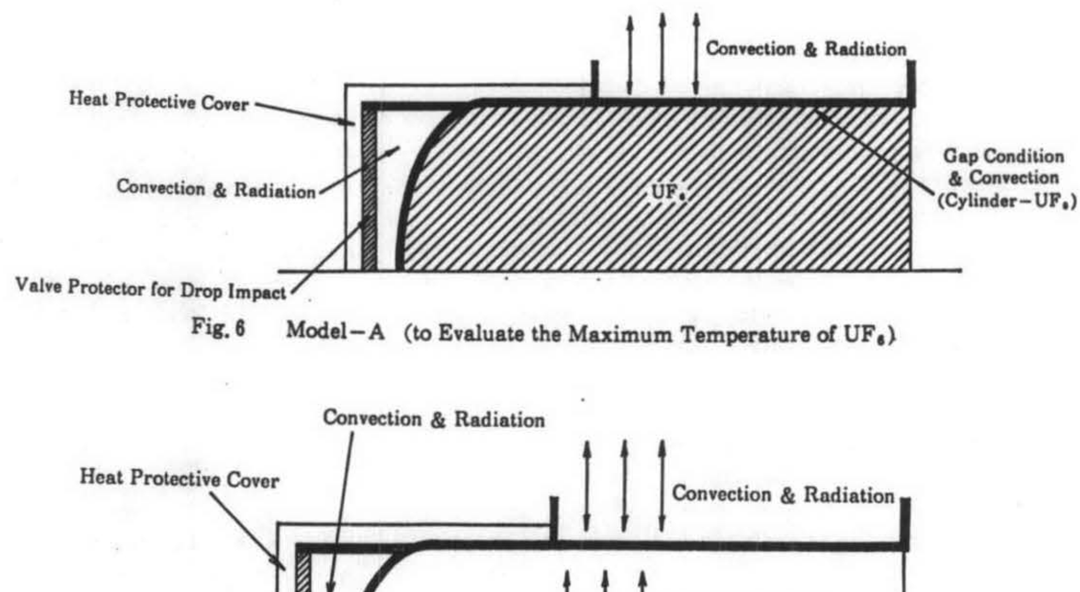


Fig. 6 Model−A (to Evaluate the Maximum Temperature of $UF_6$)

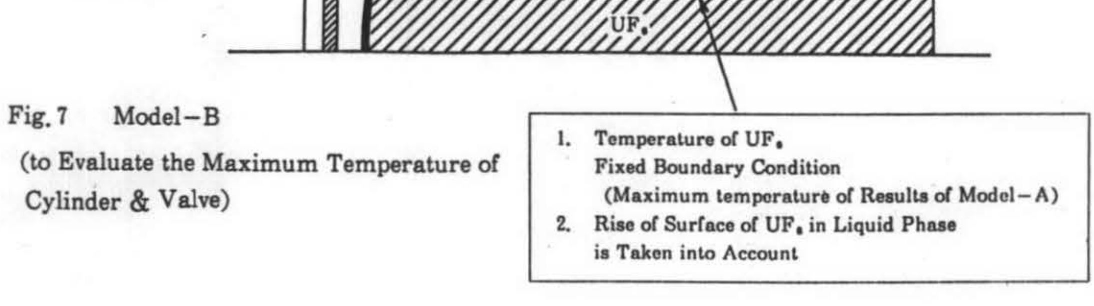


Fig. 7 Model−B
(to Evaluate the Maximum Temperature of Cylinder & Valve)

thermal gap between the inner surface of a cylinder and solid $UF_6$ is considered at the beginning of the fire test.
The initial temperature of a cylinder and $UF_6$ is set at 38℃ and the ambient temperature is set at 800℃ during the fire conditions and again 38℃ after that.

iv) Results
The results of this analyses are shown in table 2, figure 6 and figure 7.
The maximum volume of $UF_6$ is 96 percent of a cylinder in case of the fire conditions without the heat protective covers and 86 percent with it. Accordingly a 48Y cylinder containing natural $UF_6$ will never be broken by hydraulic rupture due to the thermal expansion of $UF_6$ even if not equipes with the heat protective covers. Since the inner pressure of a cylinder is below the ultimate pressure during fire conditions, rupture due to vapor pressure of $UF_6$ will also never occur. When the valve is covered by the heat protective covers, its maximum temperature reaches only 144℃. So the lead solder never melt and the integrity of containment is maintained during and after fire conditions.

## A WATER IMMERSION TEST

The water immersion test was conducted using a full scale model of a 48Y cylinder in order to obtain the data of its deformation and leakage against the outer pressure. It was confirmed that no leakage or deformation were obseaved at up to 600 meters depth in water.

## CONCLUSIONS

i) In the free drop test, a cylinder was dropped onto the target so as to incur the maximum damage for containment. The direction of the valve was downward and the axis of the cylinder was inclined. The results show that the valve was completely sound and the integrity of containment was kept. The test proved the effectiveness of the valve protector that we had developed.

ii) As for the fire resistance capability of a 48Y cylinder, we conducted thermal tests and analyses according to the specifications of the IAEA Regulations and obtained the following results.

(1) Hydraulic rupture due to thermal expansion of $UF_6$ and rupture due to vap or pressure do not occur.
(2) Heat protective covers installed in both ends of a cylinder effectively eliminate leakage from the valve and maintain integrity of containment.

iii) In the water immersion test, no leakage or deformation were observed at a lower pressure than that equivalent to 600m depth in water.

## REFERENCES

H. Yamakawa et al.,*Safety Evaluation of the Transport Container for Natural Uranium-Hexafluoride under Fire Accident,* from Conference Proceedings of ' Uranium-Hexafluoride-Safe Handling, Processing, and Transporting' (1988)

Table 2 Results of Analyses for a 48Y Cylinder Containing $UF_6$

| Items | Case 1 (without cover) | Case 2 (with cover) |
|---|---|---|
| Maximum Volume of $UF_6$ | 96% (15min) | 86% (approx. 20hr) |
| Maximum Vapor Pressure | 24kgf/㎠ (0min) | 11 kgf/㎠ (0min) |
| Maximum Temperature | | |
| $UF_6$ | 182℃ (0min) | 146℃ (0min) |
| Valve | Not applied | 144℃ (7min) |
| Cylinder | 581℃ (0min) | 595℃ (0min) |
| Ultimate Pressure of Cylinder | 30kgf/㎠ (0min) | 28kgf/㎠ (0min) |

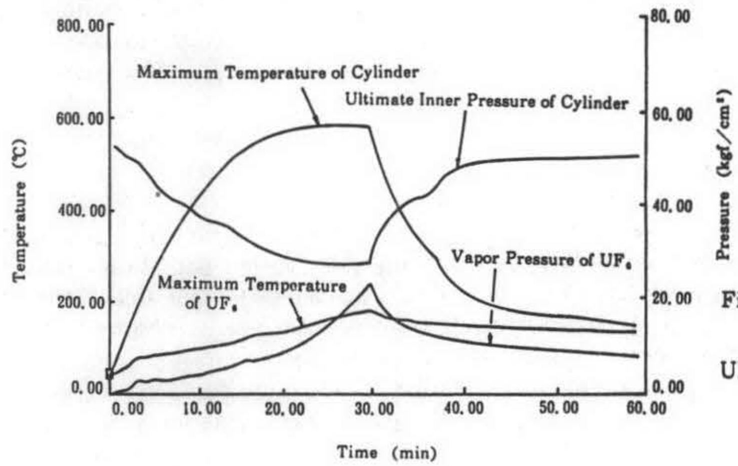


Fig. 8 Ultimate Inner Pressure of Cylinder and Vapor Pressure of $UF_6$ under Fire Condition (Case 1)

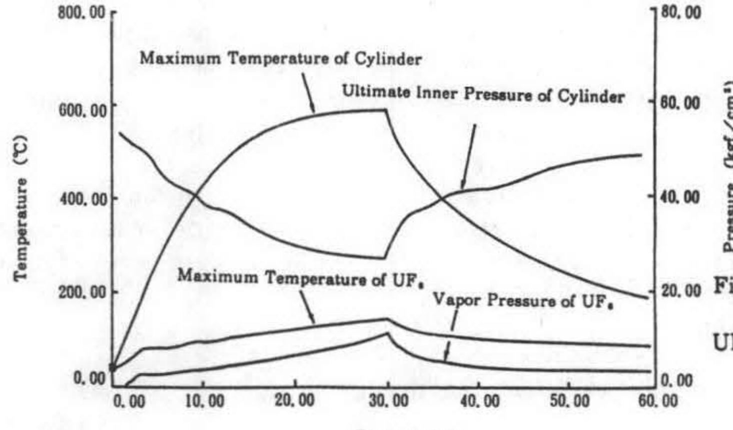


Fig. 9 Ultimate Inner Pressure of Cylinder and Vapor Pressure of $UF_6$ under Fire Condition (Case 2)