TESTING PROGRAM FOR THE MODEL 21PF-1 PROTECTIVE OVERPACKS

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Summary

A testing program, supported by an international group of owners of the model 21PF-1 protective overpacks, was held in 1996 as part of a recertification effort for these packagings. The DOT-21PF-1 and the NCI-21PF-1 overpacks are used throughout the world to ship uranium hexaflouride (UF_6). In recent years, the shipping packages, consisting of a model 30B cylinder within a protective overpack, came under intense scrutiny from the U.S. Department of Transportation (DOT) and the U.S. Nuclear Regulatory Commission (NRC). This was a result of changes that had been made in the foam formulation used for fire protection of these overpacks. Subsequent testing indicated that, at certain orientations, the overpacks may not adequately protect the cylinder valve from the 30 foot (9 meter) drop and puncture testing required by the regulations, 10 CFR Part 71.

In 1995, the United States Enrichment Corporation (USEC) agreed to design a valve protection device (VPD) to provide additional protection during the drop test sequence. The VPD fits over and around the valve within the skirt of the 30B cylinder. USEC initiated the formation of an international consortium of overpack owners who collaborated in funding the development, testing, and recertification effort. This group represented the entire UF_6 industry, with participating companies from France, Gemany, Japan, South Korea, Spain, Sweden, the United Kingdom, and the United States. Together, they worked toward a common solution to keep these overpacks -- over 75% of the worldwide inventory -- in service.

With the assistance of Transnuclear, Inc., which served as the technical lead for the program, an extensive test plan was developed and implemented. After several months of preliminary testing and related design changes, full scale compliance testing was performed on the overpacks. The testing program, designed in accordance with the hypothetical accident conditions of 10 CFR 71 and IAEA Safety Series 6, consisted of drop and puncture testing, a fully engulfing fuel fire and subsequent leak testing. The packages performed well during the tests and the test results showed that, with the VPD installed, both the DOT-21PF-1 and the NCI-21PF-1 overpacks successfully protected the cylinder valve.

Complete Safety Analysis Reports for the DOT-21PF-1 and the NCI-21PF-1 packagings were submitted to the DOT and NRC, respectively. The Certificate of Competent Authority for the DOT-21PF-1 overpack was received in June 1997 and the Certificate of Compliance (CoC) for the NCI-21PF-1 packaging was received in September 1997. The successful completion of the recertification effort allows the UF_6 industry to continue using the model 21PF-1 overpack.

Background

The DOT-21PF-1 overpacks were designed to use SP-9 phenolic foam as a fire retardant. Because the major ingredient in the SP-9 foam, the phenolic resin, became unavailable in 1985, a substitute resin was used by the manufacturer, Nuclear Containers, Inc. (NCI). The overpacks (both DOT-21PF-1B and the NCI-21PF-1) fabricated by NCI from 1985 to 1991 used this substitute resin. Because pitting later discovered on the overpack shells was attributed to chloride attack from foam components, the formula for the phenolic foam was modified to maintain the chloride content under 200 ppm.

To verify that both the DOT and NCI-21PF-1 packagings with this new "low chloride" foam formulation met the hypothetical accident conditions of 10 CFR 71, NCI performed testing in 1995. This testing was performed on the NCI-21PF-1 overpack but because of the similarity in these designs and the subsequent concerns surrounding them, the test data were applicable to the DOT-21PF-1 overpacks, as well. This testing resulted in elevated leak rates from the 30B cylinder (in the NCI-21PF-1 overpack) when it was subjected to the drop and puncture tests in the 13.5° from vertical center of gravity (cg) over valve orientation. The elevated leak rates were attributed to the collapse of the cylinder skirt, which in turn allowed the end wall of the overpack to impact the cylinder valve. An explanation given for the cylinder skirt having collapsed was because it had been previously damaged (from earlier drop tests) and repaired. This raised questions because there was no apparent record that the UF_6 industry had a practice of damaging and repairing cylinder skirts.

USEC agreed to develop a VPD design that would protect the cylinder valve from damage during testing. Complete full scale 10 CFR 71 compliance testing was planned to demonstrate that the overpack with the VPD met the regulatory requirements. Because this was an international problem that jeopardized future shipments of UF_6, overpack owners around the world joined USEC to support this program. Transnuclear, Inc. (TN) was selected to serve as technical lead for the program.

Several varieties of the VPD were designed and subjected to preliminary drop and puncture tests. The final valve protection device design consists of five pieces. There are three aluminum inserts which are designed to fit against the cylinder head and occupy the void within the cylinder skirt and around the valve. Each aluminum insert is roughly a 120° section within the cylinder skirt. A primary insert fits over the cylinder valve and two secondary inserts fill the remaining sections of the cylinder skirt. These inserts are held in place with the use of a spacer that fits against the cylinder head and a spider which locks the inserts against the cylinder skirt. Photos 1, 2, and 3 show the valve protection device as it is being loaded in the 30B cylinder.

Photo 1
Secondary Inserts & Spacer in 30B Cylinder

Photo 2
Primary Insert in Place Over 30B Cylinder Valve

Photo 3
Spider in Place VPD Installation Complete

In planning the test program, TN reviewed the history of testing conducted on the DOT- and NCI-21PF-1 overpacks. Based on that review, it was concluded that the following two drop orientations had the most potential for damaging the 30B cylinder.

- 13.5° from vertical c.g. over valve with the package oriented so that the valve would be in the impact area. In this orientation, the overpack end wall could deform into the cylinder skirt and impact the valve.

- 30° from vertical with the package oriented so that the valve would be in the impact area. In this orientation, 30B cylinder skirt could collapse and impact the cylinder valve.

Throughout the test program, meetings were held with the NRC, the DOT, as well as the overpack owners' consortium, to hear and address their concerns.

Testing Program

The testing was composed of two stages. The first stage involved the drop and puncture testing in compliance with 10 CFR 71. The second stage consisted of drop and puncture testing followed by a fire test. The testing was performed at Southwest Research Institute in San Antonio, Texas with continuous monitoring by TN and oversight by USEC.

Since two angles had the potential for being the worst orientation, both overpack designs were drop and puncture tested at those angles. A standard DOT-21PF-1 overpack and a "high chloride" foam formulation NCI packaging were used for these preliminary tests. The "high chloride" NCI-21PF-1 overpacks were used because there were no "low chloride" overpacks available for testing and because the overpack wood and metal dimension were identical for both overpacks. The regulators agreed that the "high chloride" overpacks were considered representative for determining worst orientation.

Prior to testing, basic measurements were taken on all test articles. The first stage drop and puncture testing followed these basic steps:

- *Simulation of Damage and Repair to the Cylinder Skirt.* Although a recent survey of overpack owners indicated that bending and straightening the cylinder skirt was not industry practice, the cylinder skirts, nonetheless, were bent and straightened for the testing, to assure conservatism in its results. The valve was removed from the cylinder and the cylinder skirt was bent inward in the region of the valve. The valve area of the skirt was heated and a load was applied, using a hydraulic cylinder, to bend the region a minimum of 1 inch (2.54 cm). Once the bending was completed, the cylinder skirt was reheated and then straightened to approximate its original configuration.

- *Loading Cargo into the Cylinders.* Once the cylinder skirt was repaired, steel shot was loaded into the cylinder to simulate the UF_6 load. The specific heat of steel is similar to the solid UF_6. Parrafin was not used since it could mask a leak after the fire test. Following cylinder loading, the 1-inch 30B cylinder valve was installed using standard procedures to a torque of 400 ft-lbs (55 kg-m).

- *Leak Testing.* To verify that the packages were leak tight prior to testing, a bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig (gauge pressure 0.69 MPa). The internal pressure was held for a period of 15 minutes, and no bubbles were permitted. Following the bubble test, a helium mass spectrometer test was performed by evacuating the cylinder and introducing helium around the valve cap, valve stem, valve packing nut and the valve seat. The acceptance criterion was an air leakage rate of less than 1×10^{-7} std cc/sec.

- *Installation of Valve Protection Device and Loading Cylinder into Overpack.* Once the cylinder was verified as leak tight, the VPD was installed. Then the 30B cylinder with valve protection device was loaded into the overpack with the valve in the 12 o'clock position.

- *Package Cooling.* To ensure the most unfavorable test conditions in accordance with 10 CFR 71.73(b), the packages were cooled to -20°F (-29°C) prior to drop testing. This was done to address regulator concerns that the cold temperatures would cause any moisture in the wood to freeze and therefore result in a harder impact. Cooling the packages to this temperature required approximately 4 days.

- *30 Foot Free Drop.* The test article was positioned at an orientation of either 13.5° or 30° from vertical (with valve positioned to receive the impact). The package was lifted to a height of 30 feet (9 meters). A pneumatically-actuated quick release mechanism was used to release the test item: no guidance of the test item was provided during the drop. Following the 30 foot (9 meter) drop. deformation data of the unopened overpack were measured and recorded. The overpack was then placed into the cooling chamber until the 40 inch (1 meter) puncture test could be performed. (Photo 4)

- *40 inch Puncture.* The test article was positioned at an orientation of either 13.5° or 30° from vertical with the location of the valve positioned directly above the puncture bar. A crane lifted the package to a height of 40 inches (1 meter) and it was released by the pneumatically-actuated quick release mechanism. Again. no guidance of the test item was provided during the drop. Deformation data of the overpack were measured and recorded. (Photo 5)

Photo 4 -
30 foot (9 meter) Free Drop
13.5° from Vertical
DOT-21PF-1B Overpack

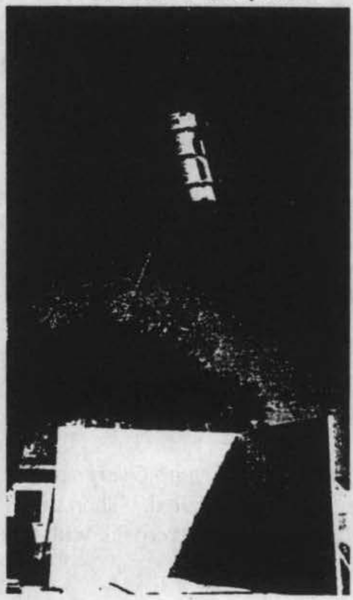
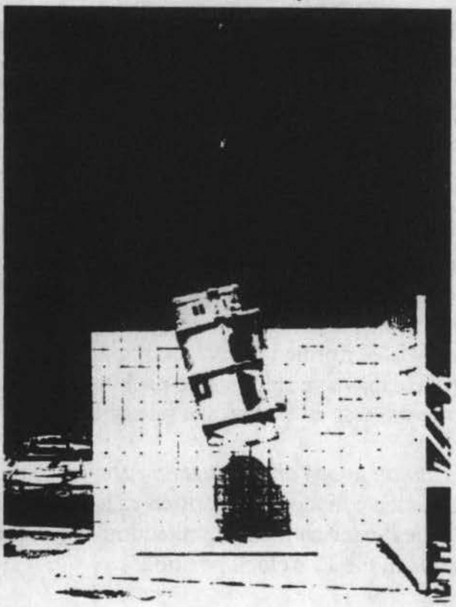


Photo 5 -
40 inch (1 meter) Puncture
13.5° from Vertical
DOT-21PF-1B Overpack



- *Opening the Packages.* Following the puncture tests, the packages were opened. Deformation data of the valve protection device. the cylinder skirt and the overpack was measured and recorded.

- *Post-Test Leak Testing.* Similar to the pre-test leak testing, a 100 psig (gauge pressure 0.69MPa) soap bubble and a helium mass spectrometer leak test were performed and the results were recorded.

- *Post-Test Hydrostatic Pressure Testing*. Since there are no elastomeric seals on the cylinder or in the valve, the leakage path into the cylinder is identical to the leakage path out of the cylinder. Therefore, instead of performing the water immersion test of 10 CFR 71.73(c)(5), an equivalent hydrostatic pressure test was performed. The test pressure was set at 19 psig (gauge pressure 0.13MPa). The steel shot was emptied from the cylinder through the bottom plug and with the cylinder valve in the 6 o'clock position, the cylinder was filled with tap water and a blue dying agent. The pressure in the cylinder was increased to 19 psig (gauge pressure 0.13MPa) and held for a minimum of eight hours. Periodically the valve cap, valve stem, valve packing nut and the valve seat were checked for any indication of water leakage from the cylinder.

This first stage testing identified that the 13.5° from vertical center of gravity over valve was the worst test orientation. The second stage of testing subjected a representative NCI-21PF-1 overpack, taken out of active service, to the full scale 10 CFR 71.73 compliance test program. Because the NCI and DOT-21PF-1 overpack were similar thermally and the DOT regulations allow data extrapolation to be used in drawing conclusions, the fire test results from the NCI package were applied to the DOT package. The second stage testing was identical to the first stage testing except that the following steps were performed after the puncture test:

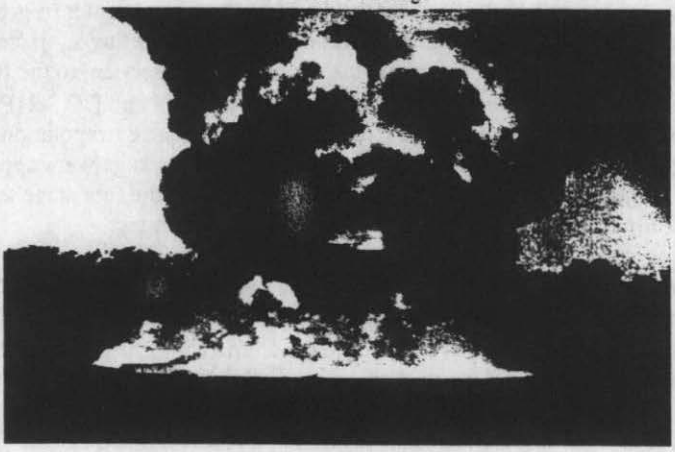
- *Package Preparation.* Prior to testing, the cylinder was instrumented with thermocouples, maximum irreversible temperature sensors (150-500°F or 66-260°C) and heat sensitive paint (range from 125-1100°F or 52-593°C). Six thermocouples around the package were used to monitor the temperature of the fire. Thermocouples consisted of 20 gage, type K, Chromel-Alumel grounded junctions with magnesium oxide insulation and Inconel 600 sheath. The thermocouple wires were connected to instrumentation leads. These were protected in an insulated pipe and connected to an instrumentation trailer. At the instrumentation trailer, the temperature of the cylinder and the fire (and the subsequent cooldown period) were recorded.

- *Package Warming.* In accordance with 10 CFR 71.73(b) for the most unfavorable test conditions, the packages were warmed to 100°F (38°C) prior to the fire test. The warmed package was considered most unfavorable for the thermal test because it would result in the maximum package temperature during the fire. Package warming took approximately 3 days.

- *Fire Test Facility.* A 25' × 25' (7.6 m × 7.6 m) fire pan was filled with water and No. 2 diesel fuel. The required amount of fuel was estimated and filled in the pan prior to the test. The package was set on a stand 40 inches (1 meter) above the fuel surface. The stand was water cooled to prevent collapse during the fire. The fire pan was surrounded by a 30' × 30' (9.1 m × 9.1 m) primary containment pan filled with water only. This resulted in a fire area slightly greater than that specified in the regulations.

Fire Test. The fire was performed at dusk, when wind speed was lowest. Prior to initiation of the fire, the wind speed was continuously monitored. Wind speeds of 4 mph (6.4 km/h) with some gusts up to 6 mph (9.6 km/h) were considered acceptable for conducting the test. In addition the wind direction was monitored to ensure that the flame did not roll over onto instrumentation leads. The standing diesel fuel was lit with a torch. The NCI-21PF-1 package (with valve protection device installed) was subjected to a 31-minute fully engulfing fuel/air fire. No external sources were used to stop any continued burning of the package. (Photo 6)

Photo 6
Fully Engulfing Fire
NCI-21PF-1 Package



- *Package Cooldown.* The package was left on the test stand and its temperature was continuously monitored for the duration of the night.

- *Opening the Packages.* Following the cooldown, the package was opened. Deformation data of the VPD, the cylinder skirt and the overpack was measured and recorded.

- *Post-Test Leak Testing.* Similar to the pre-test leak testing, a 100 psig (gauge pressure 0.69 MPa) soap bubble leak test and a helium mass spectrometer leak test were performed and recorded.

- *Helium Mass Spectrometer Leak Test - System Calibration.* In addition to verifying the calibration of the equipment, a system calibration of the helium leak detection equipment was performed. A fixture, with a known leak rate, was placed at the valve location of the 30B cylinder. (The valve had previously been tested and found to be "leak tight"). Helium was introduced continuously around the fixture. A leak was immediately detected and once it stabilized it was comparable to the known leak rate. This system calibration verified that the helium leak detector would detect a leak almost immediately and that the final indicated leak rate would be comparable to the actual leak rate.

Post-Test Hydrostatic Pressure Testing. A 19 psig (gauge pressure 0.13 MPa) hydrostatic pressure test was performed and the results recorded.

Test Results

The packages were opened for post-test inspection, with the cylinder and its VPD carefully removed and measurements taken. The "bridge" of the valve protection device did deflect during testing but in no case did it appear to impact the valve. The following deformations in the area of the "bridge" were measured on the VPDs:

Test Conditions	VPD Deformation
DOT-21PF-1B - 13.5° Orientation	0.110 in (2.8 mm)
DOT-21PF-1B - 30° Orientation	0.041 in (1.0 mm)
NCI-21PF-1B - 13.5° Orientation	0.146 in (3.7 mm)

The leak test results also indicated that the VPD protected the valve. No unacceptable leakage was detected from the cylinders after testing. A summary of the leak test results and the hydrostatic pressure test are provided below:

Test Conditions	100 psig Soap Bubble Test Results	Helium Mass Spectrometer Measured Leak Rate (std cc/sec)	19 psig Hydrostatic Test Results
DOT-21PF-1B - 13.5° Orientation	No Leak	$< 1 \times 10^{-7}$	NP
DOT-21PF-1B - 30° Orientation	No Leak	$< 1 \times 10^{-7}$	NP
NCI-21PF-1B - 13.5° Orientation	No Leak	$< 1 \times 10^{-7}$	No Leak

* NP - Not Performed since helium leak detector indicted that the cylinder was leak tight.

The test program successfully demonstrated that the DOT- and NCI-21PF-1 overpacks with the valve protection device will protect the 30B cylinder through the hypothetical accident conditions of 10 CFR 71.73.

Conclusion

A successful testing program was designed and implemented for the 21PF-1 packages. Throughout the program, the DOT and NRC were continuously informed of its progress. The regulators, along with the consortium members, were invited to witness all testing (except for the fire testing which was limited due to safety reasons) and the NRC was present for portions of the testing. This approach helped build confidence in the package and VPD design.

The results of the testing were presented to the NRC and DOT in Safety Analysis Reports in February 1997. The DOT approved the DOT-21PF-1 overpack in June 1997 and the NRC approved the NCI-21PF-1 packaging in September 1997.

SESSION 3.3

Back-End and Spent Fuel Transportation