UPDATE AND INSULATION TESTING FOR URANIUM HEXAFLUORIDE TRANSPORT OVERPACKS – UNITED STATES DEPARTMENT OF TRANSPORTATION SPECIFICATION 21PF-1

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Abstract

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The slightly enriched product UF_6 shipped from the enriching plants for the world's nuclear power plants must be protected in order to conform to domestic and international transport regulations. The principal overpack currently in use is the US Department of Transportation (DOT) Specification 21PF-1 which protects Model 30 UF_6 cylinders (Title 49, Code of Federal Regulations, Part 178.121, Specification 21PF-1; Fire and Shock Resistant, Phenolic-Foam Insulated, Metal Overpack. Specification 21PF-1 (Horizontal Loading Overpack)). Operational problems have developed from both design and lack of maintenance, resulting in the entry of water into the insulation zone. In order to minimize this water entry, design modifications are necessary to the 21PF-1 overpacks. Proposed modifications for existing overpacks are to be made only after any water absorbed within the phenolic foam insulation is reduced to an acceptable level. New 21PF-1 overpacks will be fabricated under an enhanced design. In both cases, proposed quality assurance/control requirements in the fabrication, modification, use and maintenance of the overpacks are applicable to fabricators, modifiers, owners and users. Design changes are reviewed in Part I. The phenolic foam is the thermal barrier of the protective overpacks, which maintains the UF_6 below its triple point in the event of exposure to elevated temperatures. Evaluation of the thermal qualities of the overpack required extensive analytical modeling correlated with experimental measurement. An experimental programme was devised to measure the thermal conductivity and heat capacity of the phenolic foam from room temperature to approximately 1475°F (1073K). The test programme, which consisted of the guarded hot plate method for thermal conductivity and drop calorimetry for heat capacity determination, is reviewed in Part II.

* Operated by Martin Marietta Energy Systems, Inc. for the US Department of Energy.

INTRODUCTION

In order to meet the packaging requirements of domestic and IAEA transport regulations, the cylinders of slightly enriched UF_6 shipped from the world's enriching plants are contained within overpacks. The 21PF-1 overpacks have been utilized to provide the required mechanical and thermal protection. A prototype which was subjected to the hypothetical accident test series in the mid-1960's, successfully provided the necessary protection. After being specified as a DOT specification package, it has been accepted for world-wide use. The current design of the 21PF-1 overpack has features which require frequent inspection and maintenance. These features include metal components fabricated of carbon steel and a non-metal covered closure interface of wood which steps down from outside to inside. When routine maintenance is not provided, the combination of warping of the wood in the step-joint and corrosion of the carbon steel permits water to enter the insulation cavity. The process is accelerated due to exposure to the moist, corrosive atmosphere during transport on sea going vessels. In 1984, the U.S. Department of Energy (DOE) filed a petition for change to the DOT regulations to modify the design of the 21PF-1 overpacks. The Notice of Proposed Rulemaking was published as a Notice in the U.S. Federal Register. The modifications were to apply to existing overpacks as well as overpacks fabricated in the future. Since 1984, there has been additional testing to assure that the insulation in the existing overpacks after moisture removal provides the required protection. Subsequent design improvements have been submitted by the DOE to the DOT for the final rulemaking. The DOE is also proposing mandatory quality assurance/control requirements for the fabrication, modification, use, and maintenance of the 21PF-1 overpacks. Part I is a review of the proposed modifications in the 21PF-1 overpacks for the modifications. Phenolic foam provides both mechanical and thermal protection. Significant testing of the insulation involved determination of its thermal properties. An experimental program was devised to measure the thermal conductivity and heat capacity of the phenolic foam insulation from room temperature to 1475°F (1073K). This program consisted of the guarded hot plate method for determining thermal conductivity and drop calorimetry for determining heat capacity. These thermal properties are now available for incorporation into appropriate heat transfer codes. Part II is a review of this test program.

PART I - MODIFICATIONS TO U.S. DEPARTMENT OF TRANSPORTATION SPECIFICATION 21PF-1 OVERPACKS

The modifications of the 21PF-1 overpack design are basically to upgrade and enhance previously fabricated and new overpacks to provide regulatory protection to the contained cylinders of UF_6 and to minimize routine maintenance. In order to assure that the fabrication and modifications are made as specified and that the

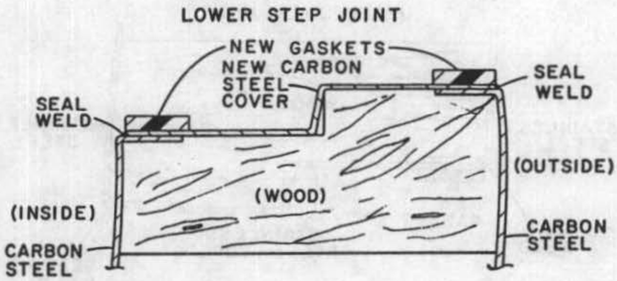

FIG. 1. Proposed modifications to existing DOT specification 21PF-1 overpacks.

overpacks are maintained, the DOE is proposing that mandatory quality assurance/control requirements which cover the fabrication, modification, use and maintenance of the 21PF-1 overpacks. These requirements would apply to fabricators, modifiers, owners and users. Thus, domestic fabricators and modifiers would be required to have a U.S. Nuclear Regulatory Commission (NRC) approved quality assurance program. Owners and users would also be required to have an NRC approved or equivalent program. This is intended to assure that the 21PF-1 overpacks meet all prescribed regulatory standards. The design modifications are divided into two groups - for existing overpacks and for new overpacks.

The existing 21PF-1 overpacks must be thoroughly inspected prior to initiating modification and to assure that the moisture content of the phenolic foam insulation is sufficiently low. A drying procedure to remove absorbed water has been developed. Tests such as those described in Part II of this paper verify that the dried phenolic foam provides an appropriate level of protection.

Proposed modifications to the existing 21PF-1 overpacks include:

1. Covering the lower step joint with carbon steel which is continuously welded to the inner and outer skins of the overpack. Painting step joint with intumescent paint. See FIG. 1.

2. Installing two one-piece molded gaskets made of Silastic E RTV rubber.

3. Drilling holes in the longitudinal stiffener angles.

4. Providing specifications for welding and corrosion repair.

5. Drilling holes in stiffener rings.

6. Sealing joints between stiffeners and outer shell.

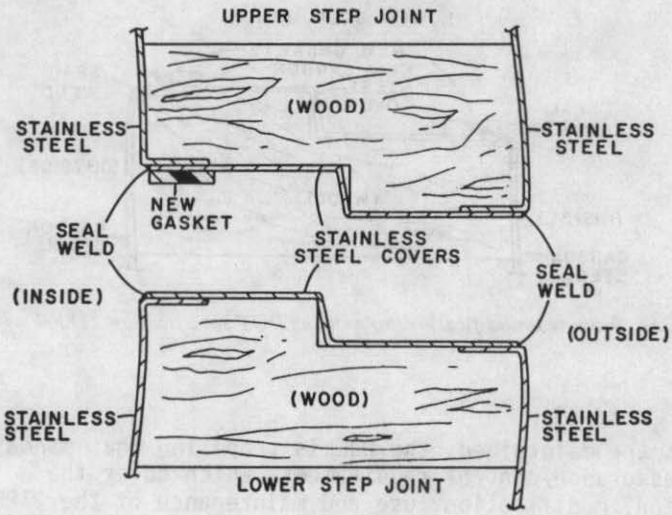

FIG. 2. Proposed modification to new DOT specification 21PF-1 overpacks.

7. Covering vent holes in outer shell with plastic plugs.
8. Detailed instructions for weighing.

Proposed modifications to 21PF-1 overpacks fabricated in the future include:

1. Changing wood materials from hard or sugar maple to white oak.
2. Changing metal parts from carbon steel to stainless steel, Type 304-L for sheet, plate and angle and flat bar and to 300 series for other parts.
3. Specifying welds as continuous, full penetration.
4. Reversing step joint with the step being upward from outside to inside and covering both upper and lower joints with steel. Painting step joint with intumescent paint. Step joint closure with metal-to-metal contact at outer step. See FIG. 2.
5. Replacing gaskets by single one-piece molded gasket made of Silastic E RTV rubber.
6. Adding detailed instructions for weighing.

CONCLUSIONS - PART I

The proposed design modifications of the DOT Specification 21PF-1 overpacks are planned to enhance the overall protection of the contained UF_6 cylinders during transport. While maintenance of the overpacks will be simplified and reduced to a minimum, routine inspections and maintenance will be required in order to assure that the total package is in proper condition for transport. Fabrication, modification, repair and use of these overpacks predicated on mandatory and fully implemented quality assurance/control programs applicable to all concerned parties will provide this confirmation.

PART II - PHENOLIC FOAM INSULATION TESTS

Thermal conductivity and heat capacity of the phenolic foam overpack insulation were experimentally determined by the guarded hot plate and drop calorimetry methods respectively. The guarded hot plate technique is an applicable American Society for Thermal Conductivity of Materials by Means of the Guarded Hot Plate, ASTM C177-63. The instrument utilized in the experimental program was a Dynatech Model TCFG-N18 incorporating cryogenic and elevated temperature testing capabilities and was constructed according to the provisions of ASTM C177-63. The configuration of the tester is a vertical assembly of heating elements and homogeneous test samples. The samples and heater elements employed were 8 in (.20m) diameter disks with flat, parallel surfaces with thermocouples positioned in grooves in mating surfaces. The test stack consisted of a main-guard heater at the center of the assembly. The main heater is a 4 in (.10m) diameter direct current resistive element supplying the heat flux through the metered element by a gap which incorporates a thermopile controlling the guard heater to maintain the same temperature as the main heater. The two test samples and heaters are arranged in the assembly in accordance with the provisions of ASTM C177-63. Heat sinks at each end of the axial arrangement of heaters and samples establish thermal equilibrium. The main-guard heater assembly is surrounded by an outer guard heater maintained isothermally with respect to the guard heater. The test stack is enclosed within an annulus of insulating material surrounded by a liquid nitrogen/water cooled jacket. The complete assembly is enclosed within a bell jar for vacuum or inert gas testing.

The thermal conductivity of a material is defined as the time rate of heat flow through unit area per unit temperature gradient in the direction perpendicular to an isothermal surface. The guarded hot plate test method requires the establishment of steady state heat flow conditions. The use of identical samples with nominally identical thickness results in a symmetrical distribution of the heat generated in the test stack. The calculated thermal conductivity is the average value of the two test samples. The test temperature for a thermal conductivity value is the mean temperature of the two samples. The reported temperature represents the sample mid-thickness surface temperature. Variances due to processing, environmental history, porosity, material inhomogeneity or anisotropy, and temperature are variables influencing thermal conductivity. In general, the thermal conductivity of a material increases with increasing temperature. A porous insulator in air will contain entrapped air, and the presence of the gas phase influences the effective thermal conductivity of the material. These tests were conducted in an atmosphere of dry nitrogen whose thermal conductivity is essentially equivalent to that of air. Entrapped air in the sample porosity provided sufficient oxidation to char the phenolic foam during testing. The overpack design encases the phenolic foam in a stainless steel housing with limited access to free oxygen. The conditions of the guarded hot plate tests simulate the foam in the overpack, although the time exposures in the guarded hot plate tests exceed considerably the thirty minute functional requirement of the insulation with the overpack subjected to an outside surface temperature of 1075K.

A prior test series using a thermal comparator was conducted in order to determine the effects of water saturation followed by drying on the thermal properties of the foam. This test series showed no deleterious effects from this environmental condition at the 366K limiting temperature of the comparator. Extrapolation of the comparator data to elevated temperatures was not possible, necessitating the guarded hot plate test series. The guarded hot plate test series was conducted with freshly formulated and exposed samples. The environmental effects samples in this series were water saturated followed by three consecutive freeze, thaw cycles. Comparison of data between conditioned and freshly formulated material revealed substantially identical thermal conductivities from room temperature to 644K. The data indicate increasing thermal conductivity as a function of temperature, with the relationship being approximately linear over the range of 366K to 810K. A transient test was conducted at a mean sample temperature of 954K for Sample Set 3 in which steady state heat flow was not established. The computed thermal conductivity in this test indicates a rapidly increasing thermal conductivity with temperature above 810K, although the calculated value is not considered accurate due to the lack of steady state conditions. Following the transient excursion to a mean sample temperature, steady state conditions were re-established at a test temperature of approximately 477K which was a test point achieved previously in going to the 954K. The re-test at this temperature was performed in order to determine possible material effects from charring at elevated temperature. The re-test at 477K resulted in a higher value for the thermal conductivity compared with the ascending temperature measurement. This result indicates that material decomposition through elevated temperature exposure contributes to increased thermal conductivity. The measured thermal conductivities ranged from 0.035W/m*K to 0.121W/m*K from a mean sample temperature of 366K to 816K. The temperature thermal conductivity relationship for sample set 4 is depicted in FIG. 3. The transient conductivity derived for sample set 3 at 954K was 0.266W/m*K, substantially higher than the measured values up to

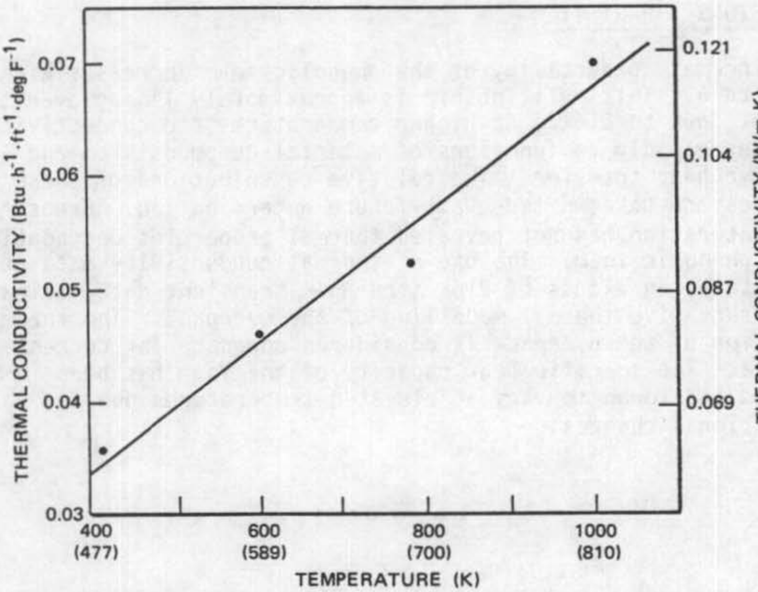

FIG. 3. Thermal conductivity as a function of temperature.

a temperature of 816K. The trend toward significantly higher thermal conductivity above 816K is attributable to material decomposition and an increasing contribution from radiative heat transfer at high temperature.

A second experimental program to characterize the thermal properties of the phenolic foam was conducted to measure the specific heat capacity of the material at elevated temperatures. The specific heat capacity is expressed in terms of calories per gram per degree Kelvin. The experimental approach employed the method of drop calorimetry whereby a sample is dropped from a furnace at elevated temperature into a water bath insulated from its surroundings and maintained at some known, lower temperature. The heat absorbed by the calorimeter is equal to the difference in heat content between the initial final sample temperatures. The phenolic foam samples tested were encased in stainless steel containers in order to prevent excessive decomposition and water absorption. The test samples were equilibrated at 1075K prior to being dropped into the water calorimeter (maintained isothermally at 298K prior to insertion of the test sample). The experimental data presented a range of 703J/kg*K to 795J/kg*K at a temperature of 1075K. The range of measured heat capacities is attributed to variances from material decomposition of the foam samples at elevated temperatures.

CONCLUSIONS - PART II

The thermal conductivity of the phenolic foam increases with temperature. This relationship is approximately linear over the range of 366K to 816K. At higher temperatures the conductivity increases rapidly as functions of material decomposition and radiative heat transfer. The relative contributions of these processes are unknown and await future determination. Exposure to water saturation has not revealed thermal properties degradation of the phenolic foam. The use of thermal conductivity data at temperatures in excess of 816K (the 954K transient data) allows for conservative thermal modelling of the overpack. The thermal protection of the overpack is considered adequate for current criteria. The specific heat capacity of the foam has been measured and found to vary at elevated temperatures due to compositional changes.