# Type B Plutonium Transport Package Development That Uses Metallic Filaments and Composite Materials*

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## INTRODUCTION

A new design concept for a Type B transport packaging for transporting plutonium and uranium has been developed by the Transportation Systems Department at Sandia National Laboratories (SNL). The new design came about following a review of current packagings, projected future transportation needs, and current and future regulatory requirements.

United States packaging regulations specified in Title 49, Code of Federal Regulations Parts 173.416 and 173.417 (for fissile materials) offer parallel paths under the heading of authorized Type B packages for the transport of greater than $A_1$ or $A_2$ quantities of radioactive material. These pathways are for certified Type B packagings and specification packagings. Consequently, a review was made of both type B and specification packages.

A request for comment has been issued by the U.S. Nuclear Regulatory Commission (NRC) for proposed changes to Title 10, Code of Federal Regulations Part 71. These regulations may therefore change in the near future. The principle proposed regulation change that would affect this type of package is the addition of a dynamic crush requirement for certain packagings. The U.S. Department of Transportation (DOT) may also re-evaluate the specifications in 49 CFR that authorize the fabrication and use of specification packagings. Therefore, packaging options were considered that will meet expected new regulations and provide shipment capability for the U.S. Department of Energy well into the future.

The possible lack of available packagings caused SNL to undertake a preliminary development program for a new Type B packaging that could meet present and future regulatory requirements. As a result of this program SNL developed a new design for a package that could transport similar quantities of plutonium and uranium that are currently carried in the DOT-6M packagings. The new package design uses nested cylindrical containment vessels (double containment) with threaded closures and elastomeric seals. A composite overpack of metallic wire mesh and ceramic or quartz cloth insulation materials is provided for structural and thermal protection of the containment vessels in an accident environment.

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Two prototype packages were fabricated and subjected to dynamic crush (500 kg steel plate dropped 9 meters onto the package) environments. Subsequent evaluation indicated no deformation in the seal areas of the containment vessels that would jeopardize containment of the material. Wall sections were fabricated to obtain empirical thermal physical data for the composite wall for pre- and post-accident conditions. Finally, a thermal computer model was developed and benchmarked by test results to predict package behavior during a fire environment. Numerous tests were performed on material samples to obtain structural data for the wire mesh and composite materials and a structural model developed to capture the performance of an air transport package subjected to a high speed impact (Neilsen and Pierce 1992). Data from that work demonstrated that the material performed isotropically in a global fashion.

## PACKAGE DESIGN

The design that is presented in Figure 1 uses materials and assembly techniques different from those used in previous packaging designs. This new approach utilizes aluminum wire mesh and composite materials such as quartz cloth insulation, to provide impact, puncture, and thermal protection to a containment vessel during hypothetical accident environments prescribed in Title 10, Code of Federal Regulations Part 71. The overpack also enables the container to survive the severe dynamic crush environment proposed for inclusion to 10 CFR 71.

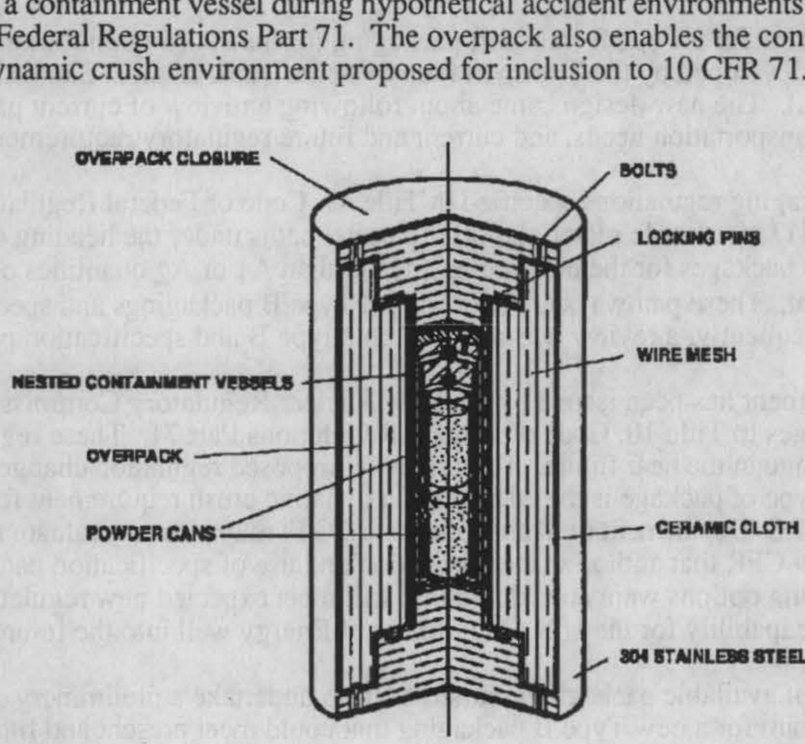

Figure 1. Type B Plutonium Transportation Package Concept

## OVERPACK

The overpack was conservatively designed from empirical data to meet a dynamic crush environment and to provide thermal protection in a fire environment. The overpack was also sized to allow adequate dissipation of 20 watts of internally generated decay heat. Wire mesh made of aluminum alloy is used for crush protection and cloth insulation is sandwiched at intervals in the wire mesh to provide additional thermal protection. A thin shell of 304 stainless steel encases the wire mesh and insulating materials for handling purposes and weather protection. The overpack consists of a main cylindrical body with identical stepped-end plugs with redundant fasteners. The overpack is 45.7 cm in diameter and 98.9 cm in length with an overpack wall thickness of 15.2 cm. The overpack consists of a stackup of layers of 5154 aluminum wire mesh with wires that are .3 mm diameter on a mesh spacing of one wire every 1.5 mm. The ceramic insulation cloth is .4 mm thick. The composite wall in the cylinder was fabricated by radically wrapping 5 zones with 60 layers of wire mesh and two layers of insulation cloth in each zone. The overpack end caps were fabricated with the wire mesh and insulation configured the same as the sidewall.

Since the wire mesh composite material does not burn, it provides an alternative to organic materials typically used in transportation containers. A *typical* light-weight container designed to transport radioactive material consists of containment vessel(s) and overpack. A bolted o-ring closure typically is used to seal the containment vessel(s). Material placed in the overpack is designed to shield the radioactive contents, as well as to provide thermal and structural protection to the containment vessel during a postulated accident. Rigid polyurethane foam, or Celotex$^{\text{tm}}$, is commonly incorporated into the design to ensure the thermal and structural integrity of the container is not compromised during an accident condition. Thermal testing of a package must be performed sequentially as specified in 10 CFR 71. Structural damage to the outer skin of the container, resulting in sufficient oxygen access and heat exposure, can lead to extensive burning of organic materials. In addition, under certain conditions, the organic material could continue to burn slowly (self-sustained smoldering combustion) after the end of the fire test. If the organic material continues to burn long after the fire, it could provide a threat to the integrity of the containment vessel.

The composite overpack is designed so that during normal conditions of transport, the wire mesh does not adversely affect the container's ability to dissipate the decay heat generated by the radioactive material. The package relies on passive means (heat conduction through the wall) to dissipate the decay heat from the containment vessel to the environment by natural convection and thermal radiation. An inert gas may be used within the containment vessel as a cooling medium, however, this is not expected to be needed. The wire mesh, therefore, must be configured in such a way that it does not unduly impede the normal outward flow of heat from the radioactive material to the environment. For normal conditions of transport, if the wire mesh were to provide too much of a thermal barrier for the decay heat, undesirably high inner-container temperatures (i.e., high seal temperatures) could be reached.

The overpack costs for production were estimated to be approximately $3500, based on components purchased and fabrication costs for the prototype packages.

## CONTAINMENT VESSELS

The containment vessels for the current design are nested one inside the other (Figure 2) and are fabricated from 304 stainless steel. These vessels provide a double containment boundary around the contents. The containment system is conservatively designed with the inner vessel having a 6.4 mm wall thickness and the outer vessel a 9.5 mm wall thickness. The inner vessel may be omitted if only single containment is required. The free space in the containment vessels is kept to a minimum.

Multiple concepts were established for an inner containment vessel that could carry two cans of material that are 10.8 cm outer diameter and 17.8 cm long. The vessels were similar, however, different closure techniques were evaluated. Three of the concepts were fabricated for evaluation. The vessels fabricated utilized threaded, breech-lock, and retaining ring closures. An overview of each design, including an evaluation of operational features such as operating

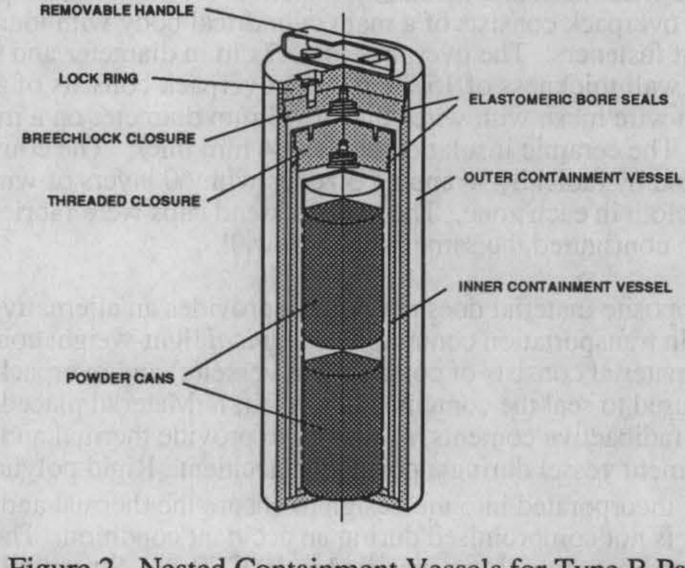

Figure 2. Nested Containment Vessels for Type B Package

the closure, performing leak tests, manufacturability was performed. A cost estimate for each was provided by means of a cost estimating computer program maintained and generated by the Mechanical Processing Department at SNL. The cost estimates were based on 1989 costs for a single vessel, and unit costs based on the production of 700 units. Two of the containment designs were felt to be the most promising.

Each design incorporates a bore seal for ease of assembly, seal testing, and seal protection. An elastomeric seal (o-ring) is used as the primary seal to establish the containment boundary, and a second o-ring used to establish a means of performing a helium leak test on the primary seal. Each design also incorporates a method of using the seal test port to introduce helium into the main cavity. This is done by seating the primary seal at the top of the sealing surface so that this seal is above the test port. Helium can then be introduced by (1) partially evacuating the cavity and backfilling with helium one or more times, (2) applying a slight over-pressure of helium and releasing one or more times, or (3) providing a second port on the same plane, establish a flow of helium gas for a fixed period of time and allowing the helium to mix with the inner atmosphere. Once helium gas has been introduced into the cavity, the closure is fully seated so that the seal test port is located between the primary seal and the secondary o-ring. A helium leak detector may then be used to determine the leak tightness of the vessel.

The first containment vessel evaluated was a threaded closure which was fabricated for evaluation and found to be easy to use. The leak testing method worked well, however, testing also demonstrated that dissimilar materials are required for the body and closure, in addition to the use of dry lubricant to prevent thread galling and seizing. The single prototype cost for the vessel was $1291 with unit cost for production being $306.

A breech-lock closure with a lock plate was also fabricated for evaluation. This design was found to work well but needed mechanical assistance for ease of operation. The leak test method worked well but testing demonstrated the friction of o-rings on the closure made the process somewhat difficult to perform by hand. A mechanically assisted external closure mechanism would be necessary for actual use. The single prototype cost was determined to be $2306 with a unit cost for production of $631.

An evaluation of the above options, as well as others, indicate that a simple containment vessel utilizing a threaded closure with two o-rings in a bore seal arrangement would be more cost effective, and yet a very user-friendly design. A face seal with a threaded closure could also be easily incorporated into the design as an alternative to the bore seal.

For double containment, it is assumed a containment vessel identical to the inner containment vessel or one that utilized a separate type of closure would be used to enclose the inner vessel. Since the outer container is larger, it would require more materials and machining than the smaller design, however, for estimating purposes, the costs are assumed to be essentially the same for each vessel.

## DYNAMIC CRUSH TESTS

Two prototype packages were fabricated to the above specifications for evaluation in dynamic crush environments. An axial dynamic crush test was performed on a prototype package at the Aerial Cable Test Facility at SNL. A 500 kg steel plate was dropped 9 m onto a prototype package that was positioned on end on the essentially unyielding target. The overpack was sectioned following the test for a post-test evaluation. The overpack skin buckled as desired without incurring any rips or tears. The overpack closure system also performed well with no loss of integrity. The wire mesh/composite impact mitigator also crushed as desired without any unexpected results. The containment vessel had no detectable deformation resulting from the test. Figure 3 shows a cutaway section of the overpack.

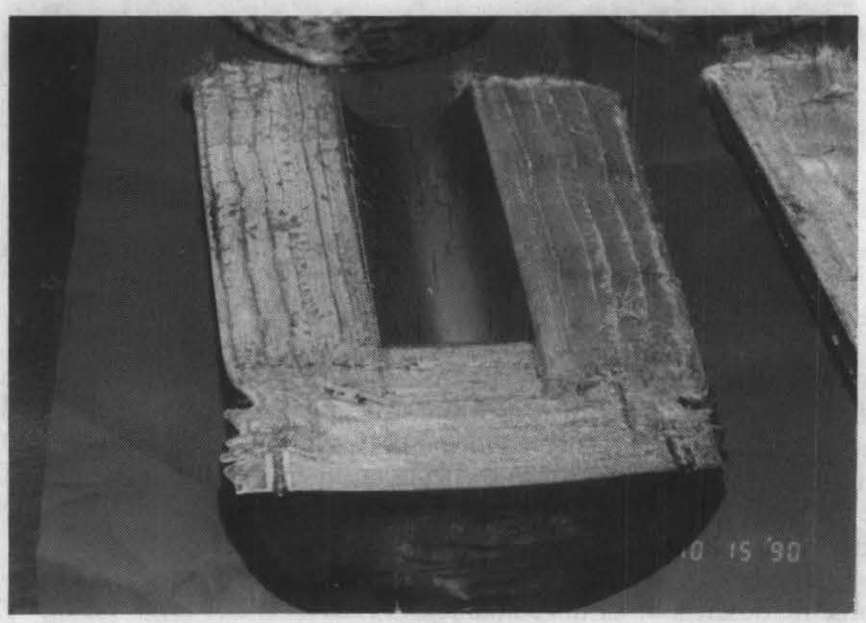

Figure 3. Cutaway Section of Package Following End-On Dynamic Crush Test

A second prototype transport packaging utilizing composite materials and wire mesh was subjected to a side-on dynamic crush test. A 500 kg steel plate was dropped 9 meters onto the prototype package that was positioned on its side on the unyielding target at the Aerial Cable Test Facility at SNL. The overpack materials absorbed the energy of the plate as desired without subjecting the containment vessel to high (yield level) stresses. The overpack shells deformed without tearing or failing any bolts. The containment vessel suffered no permanent deformation and remained leak tight. Figure 4 shows a cutaway of the overpack that also has the undamaged containment vessel still in the unit.

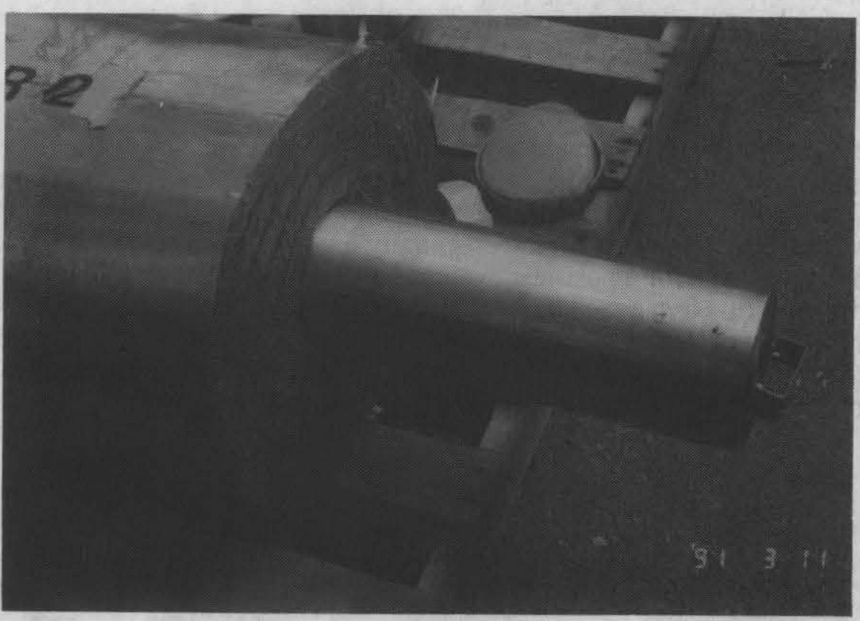

Figure 4. Cutaway of Prototype Package Following Side-On Dynamic Crush Test

## THERMAL EVALUATION

A series of thermal tests were performed at the Radiant Heat Facility at SNL. A one-dimensional test article with the same composite structure as the prototype was fabricated for each test. The test articles were subjected to an 800°C thermal environment for 30 minutes. The results of these tests were used to develop a two-dimensional, axisymmetric thermal model to investigate the thermal characteristics of the package when subjected to both normal and accident environments.

From the geometric description of the container, PATRAN (PDA Engineering 1990) was used to generate a two-dimensional computational mesh. The thermal analyzer, P/Thermal (Rockenbach 1990), was utilized to solve for the two-dimensional temperature distribution within the container. To simulate the decay heat load of a radioactive source, an energy generation rate of 20 watts was distributed evenly over the inner surface of the overpack. The boundary conditions for the hypothetical fire condition, exposed the whole package to a radiant heat source of 800°C, with an emissivity of 0.9 for 30 minutes and the package surface absorptivity was 0.8. The pre-fire steady-state temperature distribution assumed the container dissipates its 20 watts of decay energy to still ambient air at 38°C, but neglected any solar insulation to the container. To examine the possibility of further temperature increases within the container, the analysis continued beyond the 30-minute fire for a 3-1/2 hour cool-down period. During both the fire and cool-down periods, the inner surface of the overpack was conservatively assumed to be adiabatic (perfectly insulated).

For normal conditions of transport, assuming the containment vessel is transporting radioactive material that dissipates 20 watts, the model predicts a temperature of 65.5°C at the wire mesh overpack/containment vessel interface. Figure 5 illustrates the temperature response, starting from the steady state profile of the wire mesh overpack during exposure to the radiant heat source and for 3-1/2 hours following the fire. Since the containment vessel is not explicitly modeled, the temperature of the inner wall of the overpack is assumed to be indicative of the containment vessel seal temperature. For an undamaged package, the predicted maximum seal temperature therefore is about 10°C below the continuous use temperature limit (232°C) for most elastomeric seals. Additional insulation material may be easily added to the package if testing indicates that the seal temperatures will exceed allowable limits when subjected to a regulatory accident environment.

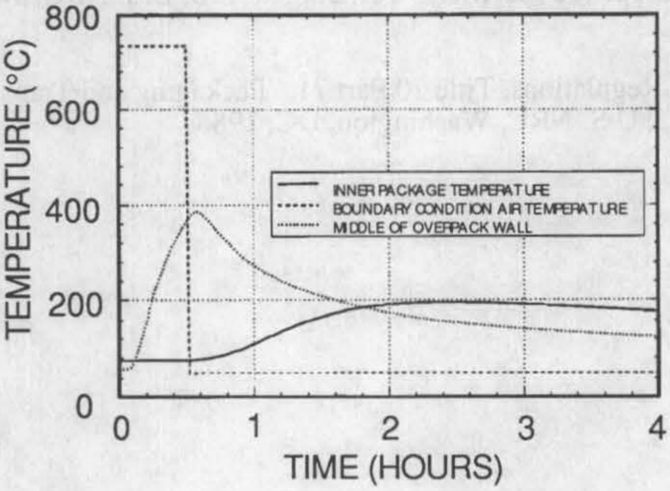

Figure 5. Predicted Temperature Profile of Package Subjected to 30 Minute Fire

## CONCLUSIONS

The results of the experiments to date have verified and demonstrated several key points:

1. Although materials have not been optimized, aluminum wire mesh may be used as an overpack material with desirable and predictable results.

2. This concept allows a composite wall to be easily fabricated which can incorporate wire mesh for energy absorption, composites for puncture and intermediate thermal protection (i.e., Kevlar, fiberglass, or graphite) and insulation material such as ceramic cloth for primary thermal protection. This allows the design to be easily tailored to the application.

3. The wire mesh exhibits global isotropic behavior when configured as a multilayer overpack for energy absorption. This allows a simpler and less expensive computer model to be used to predict the crush performance of the package.

4. Fabrication of a complex composite overpack is relatively simple and inexpensive.

5. A Type B plutonium transport package could be developed and certified that could meet the requirements for DOE plutonium shipments for less than $5000 if manufactured in quantity.

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