DEVELOPMENT OF A CONTAINER FOR THE TRANSPORTATION AND STORAGE OF PLUTONIUM BEARING MATERIALS

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INTRODUCTION

There is a large backlog of plutonium contaminated materials at the Rocky Flats Environmental Technology Site near Denver, Colorado, USA. The clean-up of this site requires this material to be packaged in such a way as to allow for efficient transportation to other sites or to a permanent geologic repository. Prior to off-site shipment of the material, it may be stored on-site for a period of time. For this reason, it is desirable to have a container capable of meeting the requirements for storage as well as the requirements for transportation. Most of the off-site transportation is envisioned to take place using the TRUPACT-II Type B package, with the Waste Isolation Pilot Plant (WIPP) as the destination. Prior to the development of this new container, the TRUPACT-II had a limit of 325 FGE (fissile gram equivalents) of plutonium due to criticality control concerns. Because of the relatively high plutonium content in the material to be transported, transporting 325 FGE per TRUPACT-II is uneconomical. Thus, the purpose of the new containers is to provide criticality control to increase the allowed TRUPACT-II payload and to provide a safe method for on-site storage prior to transport.

The Pipe Overpack Container was developed to meet these needs. It consists of an outer 55 gallon steel drum with polyethylene drum liner, a layer of cane fiberboard to provide insulation and energy absorption, and an inner stainless steel pipe container. The pipe container contains a welded-on pipe flange with an integral elastomeric O-ring and a bolted on lid. The pipe containers are currently built in two sizes: 6-inch (15.2 cm) diameter and 12-inch (30.5 cm) diameter. The lid of the pipe container contains a filter to allow venting of gases created by thermal or radiolytic decomposition of the materials to be stored and transported. The outer drum contains a similar filter.

This paper will describe the analysis and testing used to demonstrate that the Pipe Overpack Container provides safe on-site storage of plutonium bearing materials in unhardened buildings and provides criticality control during transportation within the TRUPACT-II. Analyses included worst-case criticality analyses, analyses of fork-lift tine impacts, and analyses of roof structure collapse onto the container. Testing included dynamic crush tests, bare pipe impact tests, a 30-minute totally engulfing pool-fire test, and multiple package impact tests in end-on and side-on orientations.

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DESCRIPTION OF PACKAGE

The Pipe Overpack Container consists of an inner stainless steel pipe with nominal 1/4 inch (0.63 cm) thick walls, a flat welded bottom, a welded pipe flange at the top, and a bolted lid sealed with a single O-ring. This pipe is currently available in two sizes, with nominal 6 inch (15.2 cm) diameter and 12 inch (30.5 cm) diameter. The plutonium bearing materials are packaged in cans that are placed within this pipe. The number and size of the cans may differ depending on the material and the size of the inner pipe. The pipe is surrounded by a cane fiberboard insulating and impact limiting material and placed within a standard US DOT Type 7A waste drum (Thorp et al. 1998). The 6-inch containers have a loaded mass of about 150 kg and the 12-inch containers have a loaded mass of about 250 kg.

CRITICALITY ANALYSIS

Criticality analyses were performed to assure the TRUPACT-II/Pipe Overpack Container system used during transportation would maintain a k-effective of less than 0.95 for all postulated accident scenarios (Ammerman and Smith 1998). Conservative assumptions for these analyses included: neglecting the spacing between containers provided by the drum overpack and the flange at the lid end of the pipe, having the TRUPACT-II completely flooded by water (increased neutron moderation), having the TRUPACT-II acts as a perfect neutron reflector, allowing the plutonium contained in the residues within the inner pipe to migrate, having the plutonium uniformly mixed with moderator, and treating all of the plutonium as elemental Pu-239. For the analyses, the height of the Pu/moderator layer was varied and the material above this layer was varied in order to determine the worst case. Figure 2 shows the geometry used for the criticality analysis of the 6-inch containers filled 3/8 full with the Pu/moderator mixture. The highest value for k-effective was 0.86, and occurred for the case with the Pu uniformly mixed in 3/8 the height of the pipe and with the rest of the pipe filled with water.

STRUCTURAL ANALYSES

The ability of the Pipe Overpack Container to prevent dispersal of residues during several accident scenarios was investigated via modeling (Ludwigsen et al. 1998) with the Sandia

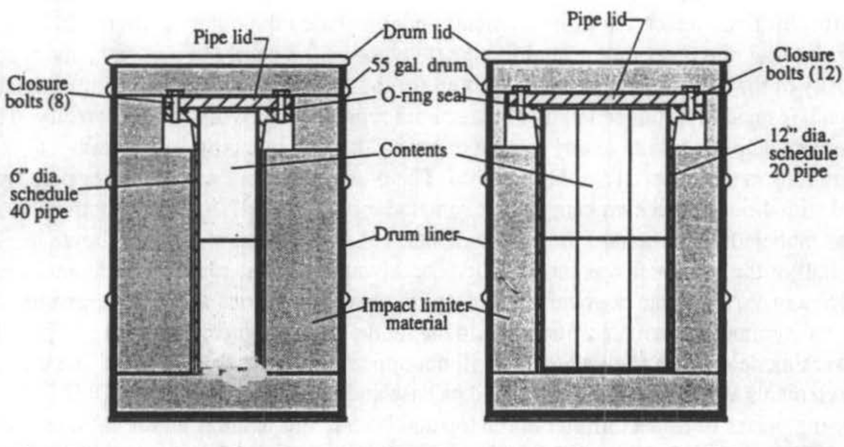

Figure 1: Diagram of the Pipe Overpack Container. The left figure is the 6" container and the right figure is the 12" container.

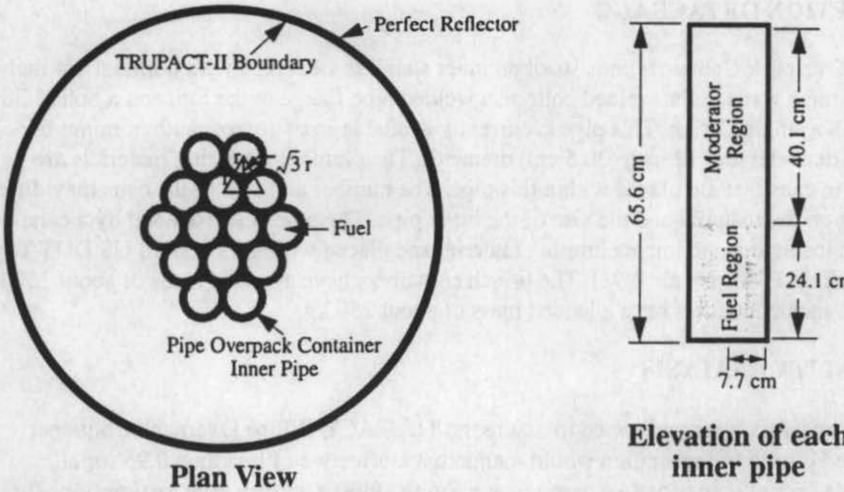

Figure 2: Tight-packed geometry (14-pipe, single layer, six-inch pipes, 3/8 Pu height)

developed transient dynamic finite element code PRONTO-3D. One potential risk to pipe integrity during handling or storage is the puncture of the container by the tine of a forklift. For the analysis, a forklift with a weight of 12,550 pounds (mass of 5700 kg) was assumed to be traveling at 10 mph (4.5 m/s) when its tine impacted the container. The container was assumed to be against a rigid wall. The impacting position of the tine was chosen to maximize damage of the inner pipe container. Other possible accident scenarios involve the collapse of the roof structure of the storage building. Three possible impact orientations of the roof onto the package were analyzed: a flat section of roof impacting the top of the container, a flat section of roof impacting the side of the container, and the edge of a section of roof impacting the side of the container. In all analyses the roof section was assumed to be rigid and traveling at constant velocity. The amount of energy absorbed by the package prior to failure was calculated. This allows the risk assessment for these types of accidents to determine the weight of a roof section necessary to cause the package to fail and the probability of that weight of roof section impacting a package.

For the forklift tine impact, the finite element model included the outer drum, the impact limiting material, the inner pipe container, the plywood in the base, the contents, and the tine. The density of the tine was increased to account for the mass of the forklift. The tine also had a square end, instead of a rounded end, which should represent the worst case geometry. The sharp corners help contribute to any tearing or penetration by inducing large strain concentrations in the materials at this location. The outer drum wall and the inner pipe were modeled with 4-node shell elements and the remainder of the model, including both ends of the pipe, was modeled with 8-node solid hex elements. The finite element mesh is shown in Figure 3. Only half of the container was modeled to take advantage of the plane of symmetry present in the problem. Appropriate boundary conditions to prevent rotations and displacements across the plane of symmetry were incorporated into the model. In the figure, the drum and pipe walls which were modeled with shell elements will not appear to have any thickness. The thickness of these elements are included in the model data base and are used within the PRONTO3D code. The missing pieces of impact limiter in the top and bottom are in areas where little response is expected. They were left out to simplify the construction of the model.

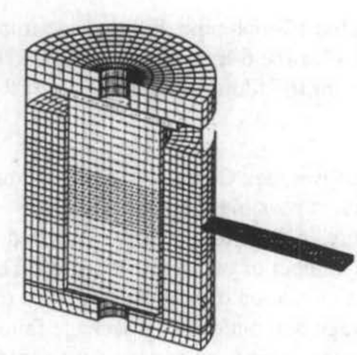

Figure 3: Finite element model of the Pipe Overpack Container with 12 inch inner pipe.

The impact is treated in three steps. In the first step, the reduction of velocity occurring during penetration of the outer carbon-steel drum is determined. The deformations resulting from this step are shown in the left plot of Figure 4. In the second step, the finite element mesh is modified by removing the drum and impact limiting material between the tine and the inner pipe. This mesh is shown in the middle plot of Figure 4. In the final step, the tine is impacted against the inner pipe at the reduced velocity determined in step one. The deformations resulting from this impact are shown in the right plot of Figure 4. Near the corner of the tine the strains exceeded the value assumed for failure of the pipe wall, and slight tearing of the wall is expected at this location.

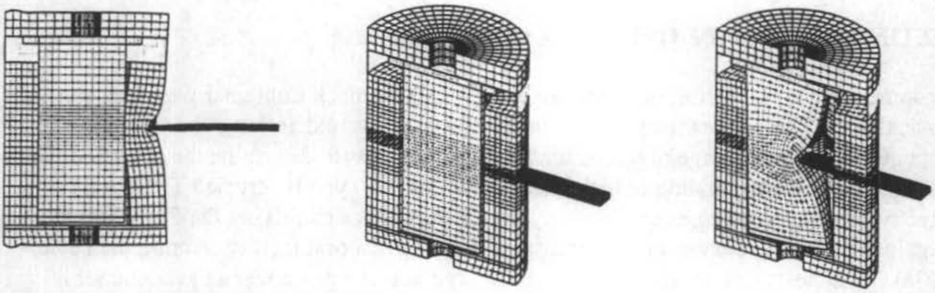

Figure 4: Deformations to the 12-inch Pipe Overpack Container resulting from penetration of a fork-lift tine. The left plot shows the deformations as the tine penetrates the drum, the center plot shows a modified model used for impacting the inner pipe, and the right plot shows the deformations to the inner pipe.

For the container with the six-inch pipe, a similar analysis was performed. The increased stiffness of the smaller diameter pipe results in a shorter distance required to tear the pipe wall, consequently less energy is being absorbed prior to shell tearing. In this case, significant tearing is expected around the tine, and it is quite likely that the tine will completely penetrate into the pipe cavity.

For impacts by a falling roof section, the finite element model used for the inner pipe was essentially the same as that shown in Figure 3. In these analyses the roof section was given a constant velocity, and the simulations were continued until a point where the container was assumed to fail. This failure could be either due to large strains in the pipe wall, or to opening of the seal between the pipe lid and its flange. The energy absorbed by crushing of the outer drum and impact limiting material was estimated based on test results (Ammerman et al. 1997a) and added to the finite element results using superposition.

The energy absorbed by the 6-inch and 12-inch pipes for the top and side impacts are shown in Figure 5. For the top impacts the maximum loads experienced in the pipes are 1780 kN for the 6-inch pipe and 1870 kN for the 12-inch pipe. The total amount of energy absorbed prior to failure is about 158 kJ for the 6-inch pipe and 175 kJ for the 12-inch pipe. For the side impacts the maximum loads experienced in the pipes are 2800 kN for the 6-inch pipe and 3320 kN for the 12-inch pipe. The total amount of energy absorbed prior to failure is about 90 kJ for the 6-inch pipe and 169 kJ for the 12-inch pipe.

The analyses provide the amount of energy a single Pipe Overpack Container is able to absorb prior to failure in several orientations. In a real accident it is possible that more than one container will be impacted by the collapsing roof structure, and the total energy absorbed is equal to the energy absorbed by each package times the number of packages impacted. The amount of energy absorbed by a single package gives an indication of how massive of a roof section can fall from a given height and impact the package without causing package failure. For example, the 158 kJ of energy absorbed by the 6-inch container in an end impact orientation plus the 45 kJ absorbed by the drum and impact limiting material in this orientation, implies that this package would not fail if impacted by a 3400 kg roof section falling from 6 meters. For a 10 cm thick reinforced concrete slab this equates to a section more than 3.5 meters square. Similarly, the analyses showed that even if the edge of the slab were to impact the container, a roof section larger than 1 meter square falling from 6 meters would be required to cause failure.

TESTING OF THE PIPE OVERPACK CONTAINER

For some accident scenarios, the response of the Pipe Overpack Container was determined by physical tests. These scenarios fell into two categories: tests to determine the suitability of the container for on-site storage of plutonium residues, and tests to determine the ability of the container to prevent migration of the plutonium within the Type B certified TRUPACT-II. Three types of tests were performed solely for the purpose of qualifying the Pipe Overpack Container for on-site storage prior to transportation to a disposal facility (Ammerman et al. 1997a). These tests simulated environments that can not take place when the container is configured for transportation and enclosed within the TRUPACT-II. The first of these tests was a dynamic crush test, in which the Pipe Overpack Container is impacted by a 500 kg steel plate falling from a distance of 9 meters while resting on an unyielding target. This test was intended to simulate the conditions the container might be subjected to if the storage building were to

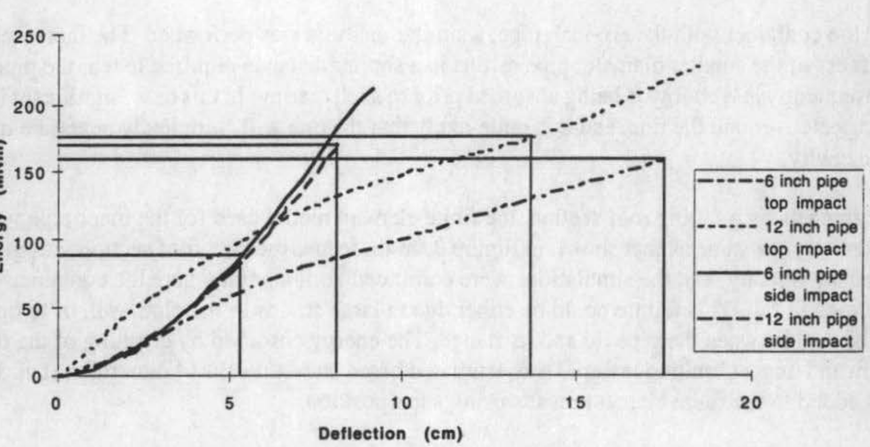

Figure 5: Energy absorbed by the 6 inch and 12 inch pipes due to top and side impacts of a flat roof section.

collapse onto it. Figure 6 shows a picture of the test set-up and typical results from the test. Four tests of this type were performed, two with 6-inch containers and two with 12-inch containers. In all of the tests the inner pipes remained undamaged.

The second type of tests performed were 3-meter drops of the bare inner pipe onto an unyielding target. At the time of the tests, a possible storage scenario was to place bare pipes in a rack within the storage building. This test was done to simulate the response of the pipes if the rack were to tip over. This test also demonstrates the safety of the pipe if it were to be dropped during handling prior to placement within the overpack drum.

The third test to qualify the Pipe Overpack Container for on-site storage was a totally engulfing pool fire test. This test was used to determine the response of the container to a fire within the storage building. In the test four drums using two types of drum filters (one with a stainless steel housed carbon media filter and three with polyethylene housed carbon media filters) were subjected to a 30-minute totally engulfing open-air jet fuel fire. This type of fire test generally results in flame temperatures between 800° C and 1100° C. Figure 7 shows the containers in the pool just as the fire is burning out and the tops of the pipes following the test. The polyethylene housed filters softened during the fire test. The overpressurization of drum due to the thermal decomposition of the liner and impact limiting material then blew the filter out of the drum lid and allowed for venting of the drum. For the drum with the stainless steel housed filter, the flow rate through the filter was not sufficient to relieve the overpressurization, and the entire lid and upper portions of the impact limiting material were blown off. The pipe in this container experienced very high temperatures, and the elastomeric seal was very decomposed. All of the other containers had peak pipe-lid temperatures below 100° C, as indicated by the temperature labels seen in Figure 7. The results of this test led to the specification of polyethylene housed filters for all drum lids.

The tests performed to support transportation of the Pipe Overpack Container within the Type-B TRUPACT II were aimed at demonstrating that within the TRUPACT-II these containers would prevent migration of their plutonium contents (Ammerman et al. 1997b). Within the

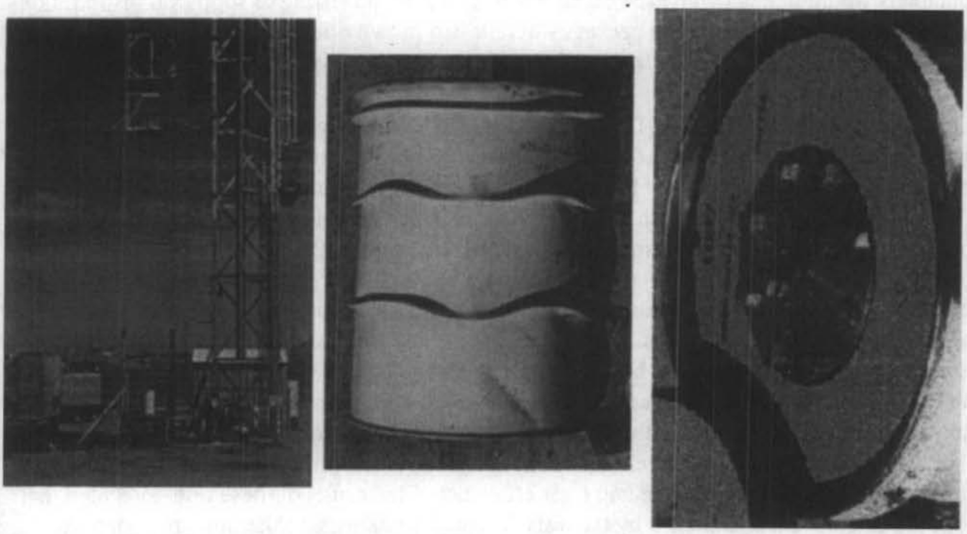

Figure 6: Test set-up and typical results from the dynamic crush test. The inner pipe remains undamaged from this test.

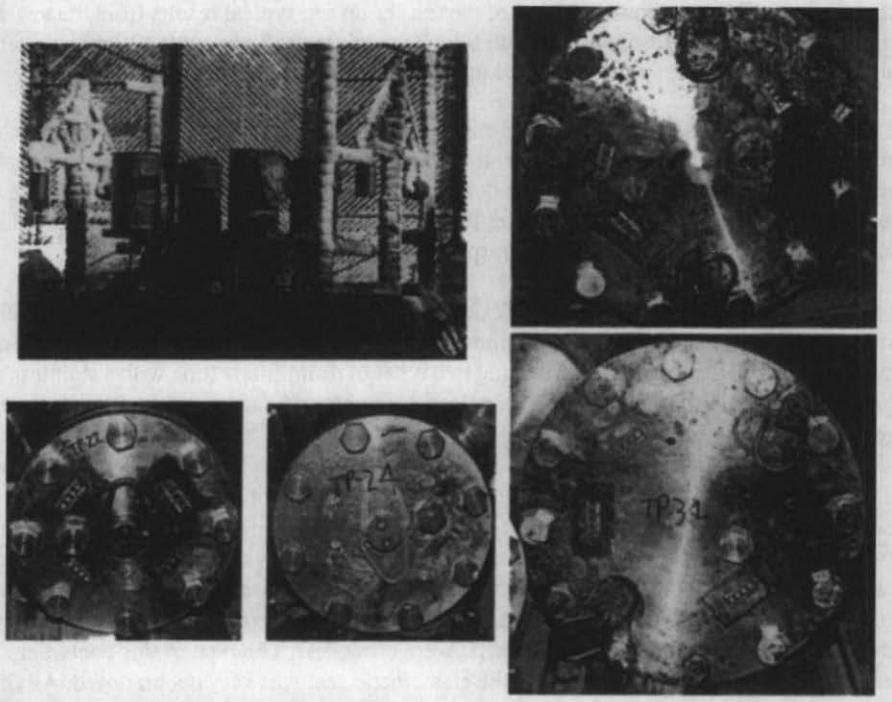

Figure 7: Pipe Overpack Containers at the end of the fire and pipe tops following removal from the overpacks. Note the front-right container in the fire has its lid off. The lid of the pipe from this package (TP-24) became hot enough to burn off the temperature labels and tar from the decomposition of the impact limiting material.

TRUPACT-II the Pipe Overpack Containers would be configured in two layers of seven containers each. During an impact test of a loaded TRUPACT-II, it is likely that these containers would interact with each other. For this reason, the testing to support transportation involved multiple packages. The packages were tested in two orientations: end-on, impacting on the closure end, and side-on. In the side-on impact one seven-pack was 12-inch containers and the other seven-pack was six-inch containers. For these tests the containers were tested within an uncertified TRUPACT-II Inner Containment Vessel. Figure 8 shows the deformations to the Pipe Overpack Containers following these tests. For the end-on impacts three configurations of containers were tested: a six-inch container on top of a 6-inch container, a 12-inch container on top of a 12-inch container, and a 12-inch container on top of a 6-inch container. Figure 8 shows the deformations to the drum for the 12-inch on 6-inch impact.

Following all of these tests the inner pipe containers were leak checked using a helium mass spectrometer. For these leak checks the holes in the filters were plugged. Therefore, the leak check measured the containment boundary of the pipe, its lid, the O-ring seal between the pipe and the lid, and the gasket between the filter and the pipe lid. The only container that was not leak-tight was TP-24 (the one in the drum that the lid blew off during the fire test). In addition, all of the filters on the pipe lids were sent back to the manufacturer to assure that they were still within specifications for flow rate and filter efficiency. The results of these tests indicated that all of the filters were undamaged by the tests. The lack of damage to the inner pipe container implies that it will prevent migration of plutonium out of the pipe, and therefore provide criticality control during transportation within the TRUPACT-II.

Figure 8: Deformations to the Pipe Overpack Containers following a seven-pack side-on impact within a TRUPACT-II Inner Containment Vessel and a two-drum stack end-on impact.

CONCLUSIONS

The analyses and tests reported here indicate the Pipe Overpack Container can provide substantial protection of the plutonium residues contents, both in on-site storage and in shipment within the TRUPACT-II to a final repository. Utilization of the Pipe Overpack Container during transportation greatly increases the efficiency of the TRUPACT-II for the transportation of residues. Allowing over an eight-fold increase in the amount of material that can be transported in a single shipment.

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CONCLUSIONS

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REFERENCES

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SESSION 6.3

Sealing and Leaktightness