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*Title:* Air Transport of Plutonium Metal: Content Expansion Initiative for the Plutonium Air Transportable (PAT-1) Packaging

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# AIR TRANSPORT OF PLUTONIUM METAL:

# CONTENT EXPANSION INITIATIVE FOR THE PLUTONIUM AIR TRANSPORTABLE (PAT-1) PACKAGING


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## ABSTRACT

The National Nuclear Security Administration (NNSA) has submitted an application to the Nuclear Regulatory Commission (NRC) for the air shipment of plutonium metal within the Plutonium Air Transportable (PAT-1) packaging. The PAT-1 packaging is currently authorized for the air transport of plutonium oxide in solid form only. The INMM presentation will provide a limited overview of the scope of the plutonium metal initiative and provide a status of the NNSA application to the NRC.


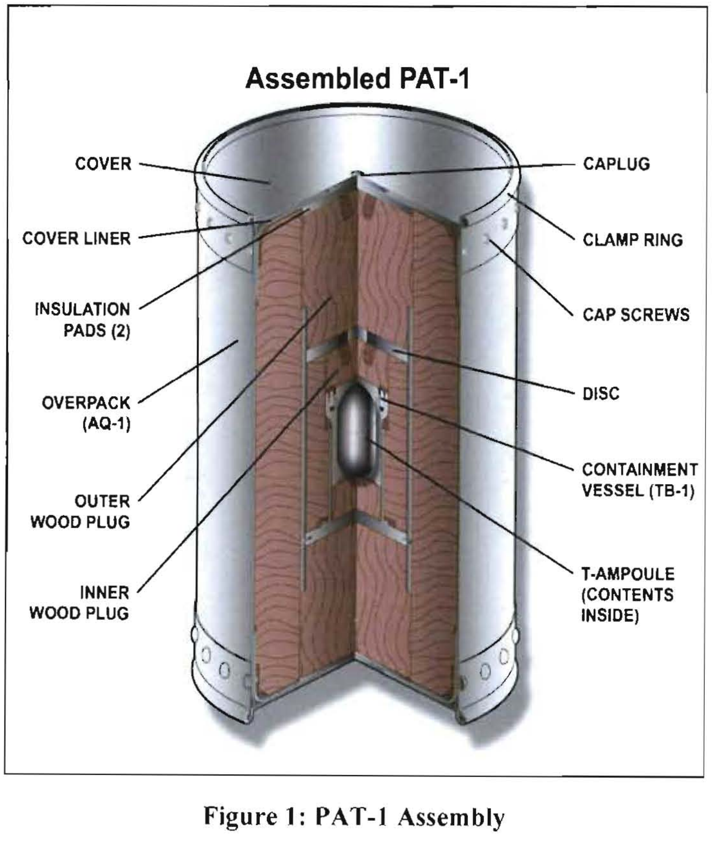


**Figure 1: PAT-1 Assembly**

## INTRODUCTION

Shown in Figure 1, the PAT-1 is certified under *Title 10, Code of Federal Regulations Part 71* by the U.S. Nuclear Regulatory Commission (NRC) per Certificate of Compliance (CoC) number 0361 and is currently at Revision 9. The docket number is 71-0361 and the package identification number is USA/0361/B(U)F-96.

The PAT-1 was originally developed by Sandia National Laboratories (SNL) under contract to the NRC in the late 1970s to requirements specified in *NUREG-0360, Qualification Criteria to Certify a Package for Air Transport of Plutonium*. SNL released the first Safety Analysis Report for the PAT-1 in June of 1978.

## PAT-1 ASSEMBLY OVERVIEW

The PAT-1 (see Figure 1) is comprised of a stainless steel and redwood protective overpack designated as the AQ-1, a stainless steel containment vessel designated the TB-1, and a plutonium metal content container designated as the T-Ampoule.

The AQ-1 protective overpack is a 65-gallon stainless steel drum approximately 42 ½" long by 24 ½" in diameter. The walls of the AQ-1 consist of approximately 8" of grain oriented redwood encased within double stainless steel drums. A copper heat conducting element and an aluminum load distributer are encased with the redwood. The redwood is a three-part redwood assembly consisting of the outer assembly and two plug assemblies. The lid is secured to the body with twenty-three 3/8" diameter bolts. The weight of the package is approximately 500 pounds (227 kilograms).

The TB-1 containment vessel, shown in Figure 2, is approximately 8 ½" long by 6 ¾" outside diameter. The minimum wall thickness of the TB-1 is approximately ½". The interior cavity is approximately 7 ½" long by 4 ¼" in diameter with hemispherical ends. The body and lid are constructed of PH13-8Mo precipitation hardened forged stainless steel. The TB-1 is closed by twelve ½" diameter closure bolts and sealed with a copper gasket and knife edges. The weight of the TB-1 when loaded with 4.4 pounds (2 kilograms) of contents is approximately 41.7 pounds (19 kilograms).

The T-Ampoule, also shown in Figure 2, is a plutonium metal content container machined from Ti-6Al-4V titanium alloy billet. The T-Ampoule is sized to closely fit within TB-1 for a diametrical and axial clearance of approximately 0.030". The T-Ampoule is sealed by a threaded lid and body containing an elastomeric O-ring in a bore-seal configuration.

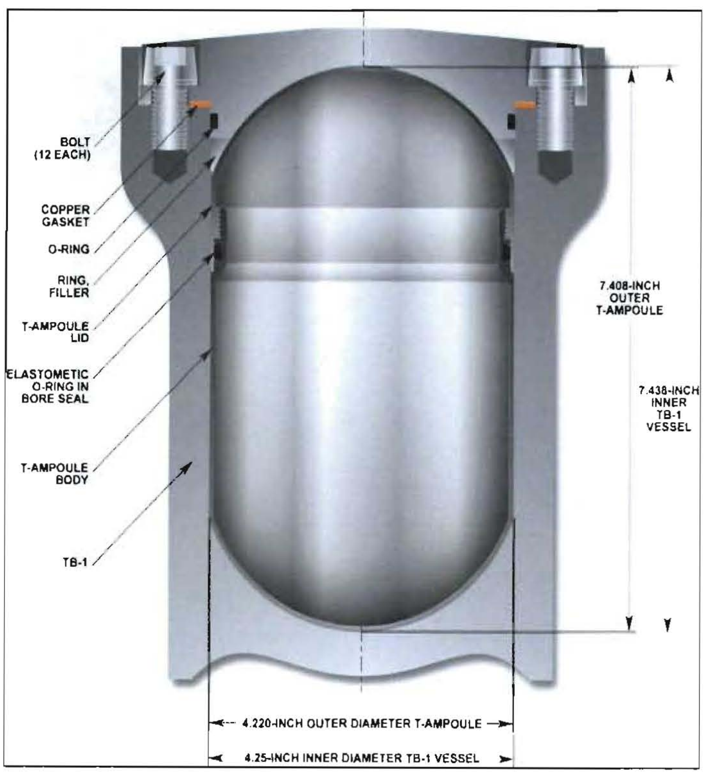


**Figure 2: TB-1 and T-Ampoule Assembly**

Several protective functions are provided by the T-Ampoule to the TB-1 during the accident conditions stated in *10 CFR 71.74, Accident Conditions for Air Transport of Plutonium*. First, it provides a physical barrier between the plutonium metal and the TB-1 interior surface resulting from the 129 meters per second (288 miles per hour) impact accident condition. Secondly, it also provides a eutectic reaction barrier between the plutonium metal and the iron TB-1 alloy at the elevated temperatures resulting from the 1-hour fire test. Lastly, it provides an enclosure for maintaining an inert cover gas over the plutonium metal to minimize oxidation during normal conditions of transport.

## CURRENT AUTHORIZED CONTENTS

The PAT-1 is authorized to transport by air plutonium oxide and its daughter products in any solid form. The plutonium oxide may be mixed with uranium oxide and it daughter products provided it is also in solid form.

The permissible quantity of material per package is 2.0 kilograms (4.4 pounds) of radioactive material, plus 16 grams of water and 10 grams of polyethylene or polyvinylchloride bagging material. The maximum decay heat load of the contents is limited to a maximum of 25 watts.

## PROPOSED CONTENT: PLUTONIUM METAL

An addendum to the PAT-1 Safety Analysis Report (SAR) has been submitted to the NRC requesting plutonium metal packed in titanium containers be added as authorized contents.

The proposed plutonium metal configurations are:

Proposal 1: Figure 3 details plutonium metal cast or machined into a hollow cylinder form. The cylinder form was chosen to provide a favorable configuration that would be deformable during the high velocity impact test. The deformable characteristic supports the prevention of any penetration or fracture of the T-Ampoule wall, and ultimately and damage to the TB-1.

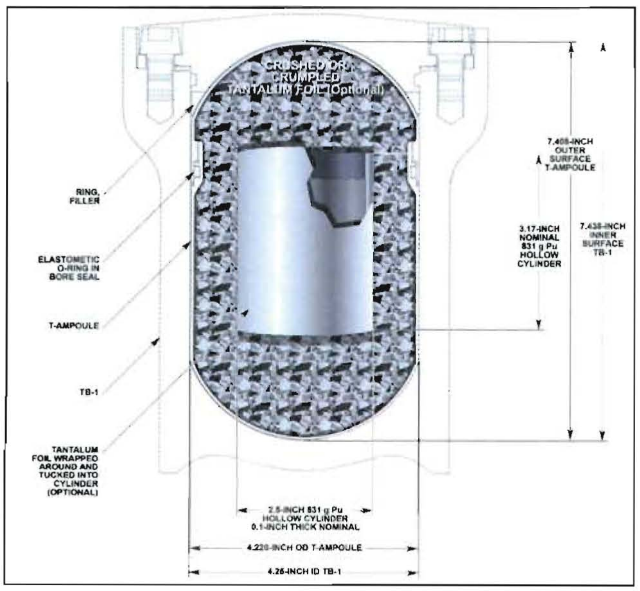

**Figure 3: 831 gram plutonium cylinder**

The maximum mass of the plutonium metal cylinder is limited to 831 grams. The basis for the maximum 831 grams mass is its relationship to a maximum activity limit 3,000 $A^2$, subject to actual isotopic composition. For many future users of the PAT-1 packaging, the 3,000 $A^2$ limit will set the maximum mass of plutonium allowed to be transported per package.

Prior to loading the plutonium metal cylinder into the T-Ampoule, the metal is wrapped in tantalum foil. Additional tantalum foil is crumpled to fill the void space around the cylinder which is roughly centered in the T-Ampoule. In addition to cushioning the plutonium cylinder, the tantalum foil also precludes any transfer of surface contamination between the plutonium cylinder and the T-Ampoule titanium metal.

Proposal 2: Figure 4 introduces the use of sample containers. The largest sample container is the SC-2. Two SC-2 sample containers can be loaded with plutonium metal contents and then securely located into the T-Ampoule using a titanium cradle assembly (see Figure 6). Each SC-2 sample container has a maximum allowable plutonium metal mass of 338 grams. The T-Ampoule is therefore limited to a maximum mass of 676 grams (2 x 338 grams).

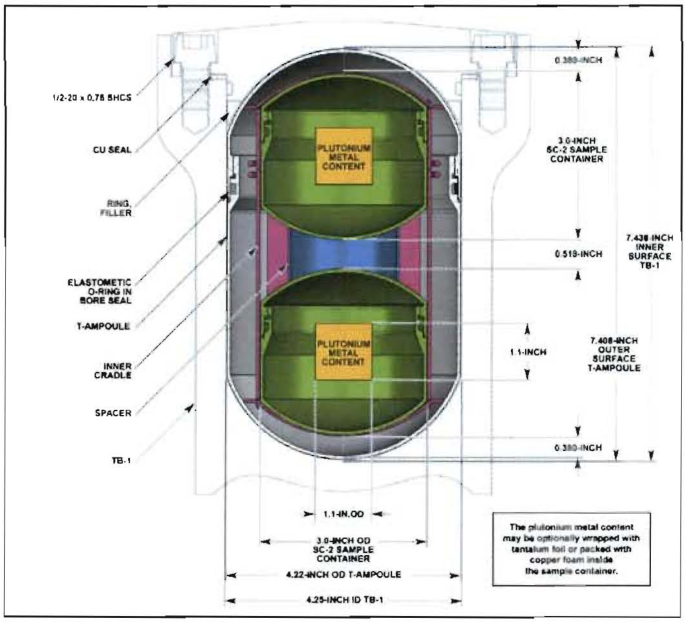


**Figure 4: SC-2 Assembly Configuration**

Because the plutonium metal mass is substantially less than the mass discussed in Proposal 1, the plutonium metal is not limited to a specific geometric shape. The metal can be solid cylinders, discs, rectangular, etc.

Proposal 3: Figure 5 illustrates the use of the smaller of the two sampler containers, the SC-1. Three SC-1 sample containers can be loaded into the T-Ampoule utilizing the same titanium cradle assembly (Figure 6) previously discussed. The only difference is the use of different length spacers used between the SC-2 or SC-1 sample containers.

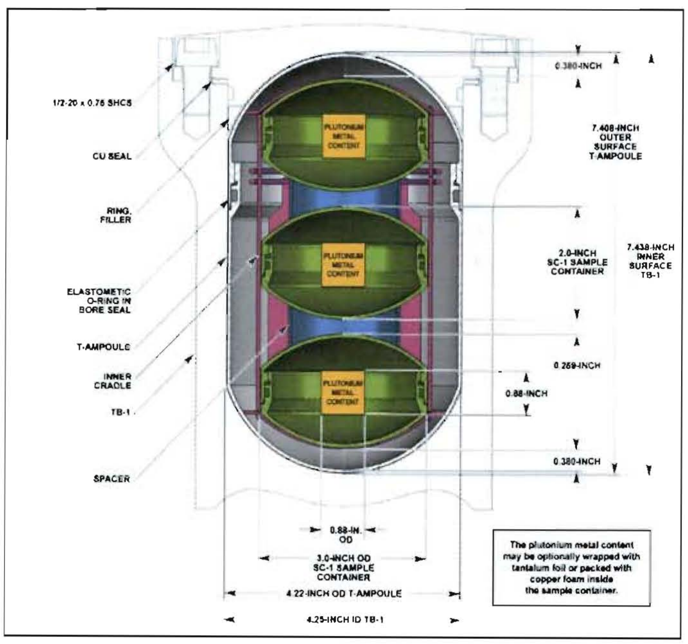


**Figure 5: SC-1 Assembly Configuration**

Each SC-1 sample container has a maximum allowable plutonium metal mass of 174 grams. The T-Ampoule is therefore limited to a maximum mass of 522 grams (3 x 174 grams). When beryllium is a part of the metal matrix, the maximum mass is reduced to 60 grams in the SC-1 and 180 grams in the T-Ampoule.

Both the SC-1 and SC-2 sample containers employ a threaded closure with an elastomeric O-ring in a bore-seal configuration. The sample containers are machined from Ti-6Al-4V titanium alloy billet. Plutonium metal is wrapped in tantalum foil and closed with an inert gas atmosphere for minimization of oxide formation.

In Proposal 1 and Proposal 2, the sample containers are securely located within the T-Ampoule by use of a titanium cradle assembly. Figure 6 depicts the various components making up the cradle assembly. The only component difference between the SC-1 and SC-2 configuration is the number and length of the spacer(s) used.

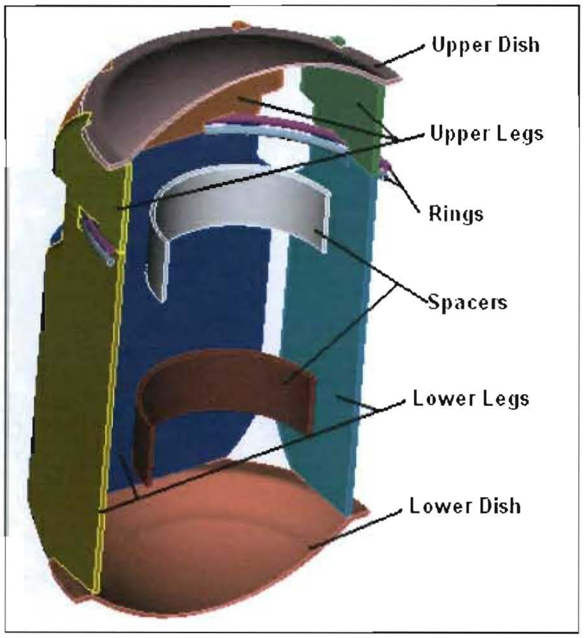


**Figure 6, Cradle Assembly**

The use of the cradle assembly is important in establishing and maintaining a specific position for the SC-1 and SC-2 sample containers. This positional certainty provides a known distance for potential velocities in the structural finite element analysis.

## STUCTURAL ANALYSIS

Extensive structural analysis was performed on the TB-1, T-Ampoule, and sample containers to ensure the TB-1 maintained containment throughout the 10 CFR air accident conditions. One of the primary goals of the various structural analyses was to ensure the integrity of the T-Ampoule wall was maintained...no ruptures, tears, or cracks. The analyses were performed using the Sandia National Laboratory developed nonlinear finite element code, PRONTO-3D. PRONTO-3D is a structural mechanics code developed specifically for impact analysis and modeling large nonlinear deformations. Many orientations were analyzed including end, side and corner impacts.

Figure 7 shows the PAT-1 in a top down impact containing the hollow plutonium metal cylinder inside of the T-Ampoule. As clearly illustrated, the hollow cylinder buckles and does not rupture the T-Ampoule wall.

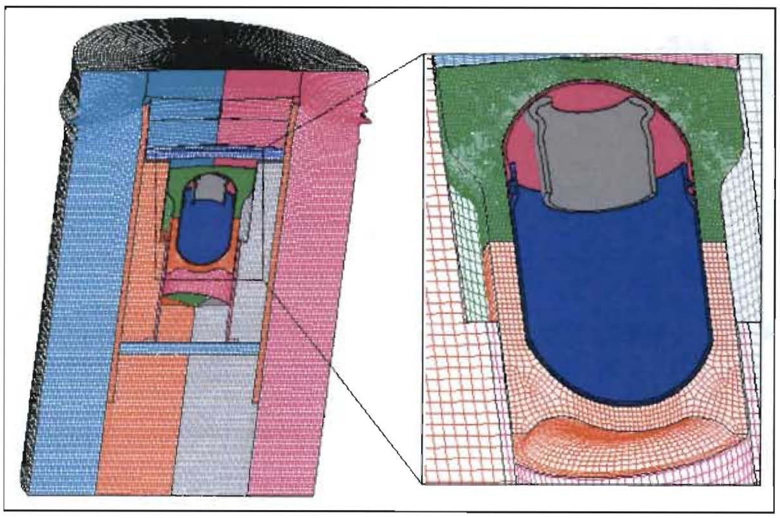

**Figure 7**

Figure 8 shows the same hollow cylinder configuration, but the orientation is for a side impact. The hollow plutonium metal cylinder simply collapses against the T-Ampoule wall.

Although not show here, an analysis was performed on a hollow plutonium metal cylinder with a mass of 731 grams. The 731 gram cylinder was identical to the 831 gram cylinder in diameter and wall thickness. However, the overall length was reduced to achieve the 731 gram mass. This allowed an analysis to compare a lower mass accelerating a greater distance against a larger mass traveling a shorter distance. Both configurations were found to be below the critical tearing parameters established for the T-Ampoule wall and therefore set the bounding mass limits for plutonium metal in hollow cylindrical form.

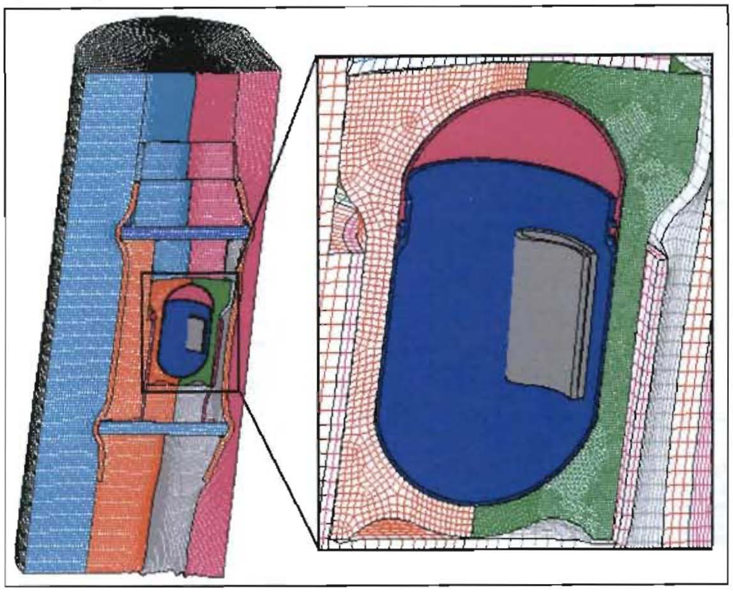

**Figure 8**

Figure 9 shows the SC-2 sample containers in a side impact configuration. As illustrated, the solid plutonium metal is securely retained in the T-Ampoule.

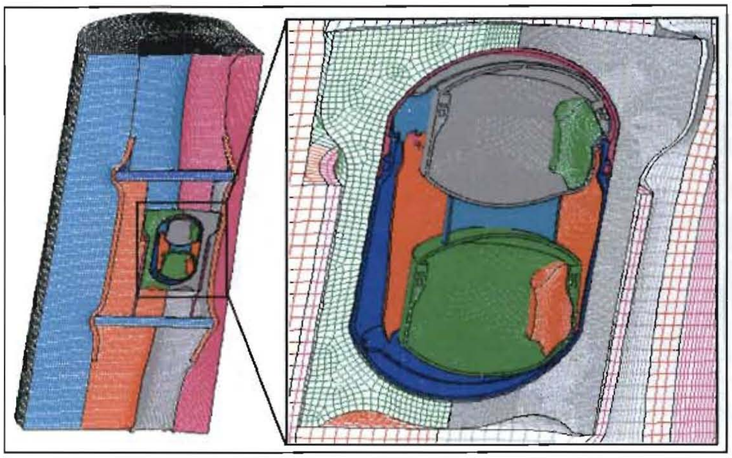

**Figure 9**

Figure 10 shows SC-1 sample containers in a corner impact configuration. The results were consistent with the analysis for the SC-2 sample containers.

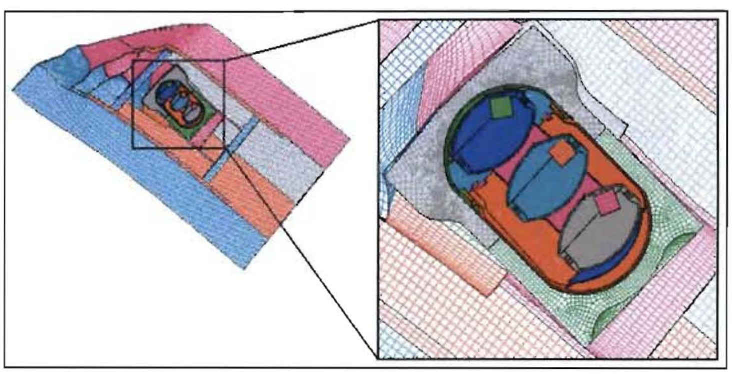

**Figure 10**

In summary, a series of analyses were performed on the PAT-1 package and its contents to determine the integrity of the TB-1 and T-Ampoule when subjected to the requirements of 10 CFR 71.71 (Normal conditions of transport), 10 CFR 71.73 (Hypothetical accident conditions) and 10 CFR 71.74 (Accident conditions for air transport of plutonium). Six sets of analyses were conducted, leading up to detailed impact analyses of the PAT-1 package, including its TB-1 containment vessel and the T-Ampoule eutectic barrier. Using a strain-based failure criterion, it was shown that the T-Ampoule would not rupture and would continue to function as a eutectic barrier between the stainless steel TB-1 vessel and the solid metal plutonium contents. In addition, an analysis of the bolts securing the TB-1 lid showed that the lid will remain intact and the seal remain leak tight.

## EUTECTIC MITIGATION

Temperatures reached in the PAT-1 package due to the 1-hour fire test required by 10 CFR 71.74(a)(5), raised the potential for a eutectic to form between the plutonium metal and the iron in the TB-1 stainless steel vessel. At the conclusion of the 1-hour fire test, the TB-1 reached a peak temperature of 582°C (/1080°F). This peak temperature is well above the lower plutonium-iron eutectic temperature of approximately 410°C (770°F). Therefore, to preclude any potential eutectic formation, Ti-6Al-4V titanium alloy (1,604°C melt point) was chosen for the construction of the T-Ampoule. The T-Ampoule is designed primarily to provide the protective barrier between the plutonium metal and the iron present in the TB-1 PH13-8Mo stainless steel material. As previously discussed in the structural section, the T-Ampoule was design and evaluated to maintain absolute integrity throughout the accident condition testing.

Los Alamos National Laboratory report *LA-UR-08-07663, Plutonium Metal Compatibility with Materials of the Ti-6Al-4V Packaging System*, evaluated all combinations of metals possible with the plutonium metal system in the PAT-1 package. Binary and ternary eutectic composition phase diagrams were evaluated for potential combinations that could form a eutectic composition below peak temperature of the TB-1 reached during the fire test. Approximately 43 combinations of system metals were evaluated.

The lowest temperature eutectic composition was the plutonium-beryllium at 595°C (1103°F), which is 13°C (23°F) higher than the highest temperature excursion of 582°C (1080°F) reached in the TB-1 containment vessel. Therefore, formation of a eutectic composition challenging the containment performance of the PAT-1 package is unlikely and fully mitigated by the T-Ampoule robust design.

## CONTAINMENT

The potential to raise the pressure within the TB-1 due to the thermal decomposition of the elastomeric O-rings in the T-Ampoule and the sample containers (SC-1 and SC-2) was evaluated. Los Alamos National Laboratory report, *LA-UR-08-07810, Thermal Decomposition of Viton® O-rings for PAT-1 Accident Scenario,*Error! Reference source not found. documents the calculations performed to examine the rise in pressure from decomposition of the elastomeric O-rings.

The T-Ampoule with three SC-1 sample containers was used for the calculation since it represented the largest volume of elastomeric material. The pressure rise from the O-rings undergoing complete decomposition (no remaining char), was conservatively calculated at 887.28 psi. Summing this pressure with the pressure of 42.7 psia at 582°C (1080°F), and with the decay heat load pressure of 34.2 psia, the total pressure in the TB-1 would be 964.2 psia.

The PAT-1 SAR, Section 4.4.2 stipulates that the maximum allowable TB-1 pressure during the post-fire plutonium air transport accident condition was 1,110 psia. Therefore, the total maximum calculated pressure, including the thermal decomposition of the O-rings, is conservatively below the maximum TB-1 allowable pressure by 146 psia.

## PROGRAM STATUS

The PAT-1 Safety Analysis Report Addendum, Revision 0, was submitted in September of 2009 to the NRC. The NRC completed its initial review and issued a Request for Additional Information (RAI) in March of 2010. The RAI responses are currently being prepared for a submittal date in August of 2010.

Initially, there will be three PAT-1 packagings available for use. Depending on demand, additional units will be fabricated as needed.