December 23, 2010

Mr. Maximo A. Barela
Packaging Certification Division
National Nuclear Security Administration
P.O. Box 5400
Albuquerque, NM 87185

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 0361 FOR THE MODEL PAT-1 PACKAGE

Dear Mr. Barela:

As requested by your application dated September 21, 2009, enclosed is Certificate of Compliance No. 0361, Revision No.10, for the Model No. PAT-1 package. The staff's Safety Evaluation Report is also enclosed.

The National Nuclear Security Administration (NNSA) is registered as user of the package under the general license provisions of 10 CFR 71.17. This approval constitutes authority to use the package for shipment of radioactive material and for the package to be shipped in accordance with the provisions of 49 CFR 173.471.

If you have any questions regarding this certificate, please contact me or Chris Staab of my staff at (301) 492-3321.

Sincerely,

/RA/
Robert Johnson, Acting Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Docket No. 71-0361
TAC No. L24377

Enclosures: 1. Certificate of Compliance No. 0361, Rev. No. 10
2. Safety Evaluation Report

cc w/encls.: R. Boyle, Department of Transportation
J. Shuler, Department of Energy

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SAFETY EVALUATION REPORT

Model No. PAT-1 Package
Docket No. 71-0361
Certificate of Compliance No. 0361
Revision 10

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SAFETY EVALUATION REPORT

Docket No. 71-0361
Model No. PAT-1 Package
Certificate of Compliance No. 0361
Revision 10

SUMMARY

By application dated September 21, 2009, the National Nuclear Security Administration (NNSA) applied to the U.S. Nuclear Regulatory Commission for a revision to the Certificate of Compliance (CoC) for the PAT-1 package.

The revision to the PAT-1 package is to add plutonium metal to the list of authorized contents of the PAT-1 package. The package is authorized by the certificate for use under the general license provisions of 10 CFR 71.17. The certificate will expire on December 31, 2015.

The staff has concluded the package meets the requirements of 10 CFR Part 71 by using the guidance in NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material."

References

National Nuclear Security Administration, application dated September 21, 2009 and PAT-1 Safety Analysis Report (SAR) Addendum, SAND2010-6109 Revised submitted on December 15, 2010.

1.0 GENERAL INFORMATION

1.1. Packaging

The Plutonium Air Transportable Package, Model PAT-1, is a shipping container for transporting plutonium oxide (PuO_2) and its daughter products, or a mixture of PuO_2 and uranium oxide (UO_2) and its daughter products by air. The purpose of this revision is to incorporate plutonium (Pu) metal as a new payload for the PAT-1 package. The Pu metal is packed in an inner container (designated the T-Ampoule) that replaces the PC-1 inner container.

The difference between the PAT-1 with T-Ampoule configuration and the currently certified PAT-1 with PC-1 configuration is the PAT-1 with T-Ampoule configuration consists of (1) a T-Ampoule containing plutonium metals, and (2) the Ring Filler. The Ring Filler is used to fill the void space between the top of the T-Ampoule and the containment vessel (TB-1) closure lid. The Ring Filler is 10.72 cm (4.22 in.) in diameter, 1.27 cm (0.5 in.) thick, and is manufactured of titanium (Ti) alloy 6Al-4V (hereafter referred to as Ti-6Al-4V, Grade 5). The PAT-1 with PC-1 configuration consists of the PC-1, aluminum honeycomb spacer, 2000 g (4.41 lb) authorized content, and associated packing material. The approximate weights for the AQ-1 overpack, TB-1 containment vessel, PC-1 Product Can (including aluminum spacer), and contents is 225 kg (496 lb). The PAT-1 with T-Ampoule configuration is limited to the current certified TB-1 gross payload weight of 2100 g (4.7 lbs).

The T-Ampoule's primary components consist of a body (bottom), lid (top), and elastomeric Viton® O-ring. The T-Ampoule is fabricated with an approximate wall thickness of ½ inch from solid billets of Ti-6Al-4V, Grade 5. Ti-6Al-4V, Grade 5 was selected for its high strength, light weight, and high resistance to eutectic reaction with plutonium metal. The T-Ampoule has a smooth finish on the interior and exterior surfaces to facilitate decontamination, and its body and lid sections are joined together and sealed using a screw-thread joint with an elastomeric Viton® O-ring bore seal to maintain content quality.

1.2 Drawings

This packaging is constructed in accordance with Drawing Nos. R99794, Revision A, sheet 1 of 1 in the SAR Addendum and Drawing No. 1001, Revision A, sheet 1 of 1 in the SAR.

1.3 Contents

The T-Ampoule's internal packing consists of:

1) A nested two-sample-container configuration (SC-2), including one spacer packed and supported by a titanium Inner Cradle, or
2) A nested three-sample-container configuration (SC-1), including two spacers packed and supported by a titanium Inner Cradle, or

3) A Pu metal hollow cylinder with or without tantalum foil wrapped around the outside of the cylinder (and having the free ends of the foils tucked into the cylinder).

The plutonium metal contents may be wrapped with tantalum foil or not wrapped based on operational need before they are loaded in SC-1 or SC-2 sample containers. The tantalum foil ranges in thickness from 0.00254 cm (0.001 in.) to 0.0229 cm (0.009 in.), and the minimum purity ranges from 99.75% (3N5), to 99.98% (3N8), or to 99.99% (4N). For packing the Pu metal hollow cylinder content, tantalum foil may be used, but is not required.

1.3.1 Type and Form of Material

Plutonium metal contents carried within the T-Ampoule and sample containers include the following configurations:

1) Various geometric shapes of alloyed Pu metal, including (1) circular discs of varying diameters and thicknesses, (2) rectangular strips of varying lengths, widths, and thicknesses, (3) cylinders in sizes and masses up to those used in the structural analysis, (4) random shapes used for chemistry analysis, and (5) composites as specified in Table 1.

2) Hollow right-circular cylinders of alloyed plutonium metal specified in Table 1.

3) Composite plutonium/beryllium (Pu/Be) materials of different geometries.

1.3.2 Maximum Quantity of Material per Package

See below in Table 1.

Table 1

Payload Configuration	Total Plutonium Content Weight in T-Ampoule (g)	Dimensions of Plutonium Contents
Pu metal hollow cylinder (Electro-Refined or alloyed) in T-Ampoule Assembly	731 to 831	6.350 cm (2.500 in.) OD, 5.801 cm (2.284 in.) ID × 7.087 cm (2.790 in.) length for 731 g payload to 6.350 cm (2.500 in.) OD, 5.801 cm (2.284 in.) ID × 8.054 cm (3.171 in.) length for 831 g payload Unilateral tolerances for the cylinder: -0.000 in./+0.010 in. applied to the outside diameter -0.010 in./+0.000 in. applied to the inside diameter
SC-1 Assembly; up to 174 g alloyed delta phase Pu metal in each container in T-Ampoule Assembly	0 to 523	Any configuration of plutonium metal, not to exceed maximum gross Pu weight specified per sample container. (Bounding analysis performed with a 2.23 cm (0.88 in.) OD × 2.23 cm (0.88 in.) long solid cylinder).
SC-2 Assembly up to 338 g alloyed delta phase Pu metal in each container in T-Ampoule Assembly	0 to 676	Any configuration of plutonium metal, not to exceed maximum gross Pu weight specified per sample container. (Bounding analysis performed with a 2.79 cm (1.10 in.) OD × 2.79 cm (1.10 in.) long solid cylinder).
SC-1 Assembly, up to 60 g bonded Pu/Be metal content with alpha barrier in each container in T-Ampoule Assembly	0 to 180	Composite content not to exceed 60 g per sample container *SC-1*
SC-2 Assembly, up to 60 g bonded Pu/Be metal content with alpha barrier in each container in T-Ampoule Assembly	0 to 120	Composite content not to exceed 60 g per sample container *SC-2*

1.4 Criticality Safety Index 0.1

Based on the statements and representations in the application, as supplemented, the staff concludes that NNSA has described the overall design of the PAT-1 configuration with the T-Ampoule Assembly in sufficient detail to provide an adequate basis for its evaluation against 10 CFR Part 71.

2.0 STRUCTURAL AND MATERIALS EVALUATION

The objective of this review is to verify that the structural and materials performance of the package presented in the SAR Addendum is adequately evaluated to meet the requirements of 10 CFR Part 71, including the tests and conditions specified under normal conditions of transport (NCT), hypothetical accident conditions (HAC), and accident conditions for air transport of plutonium (ACATP).

2.1 Structural Design

2.1.1 Description of Structural Design

The PAT-1 transportation package evaluated in the SAR Addendum is made of three principal structural components: the AQ-1 Overpack, TB-1 Containment Vessel, and the T-Ampoule inner container.

The SAR Addendum is concerned only with the addition of the T-Ampoule as a replacement for the PC-1 stainless steel inner container and associated changes affecting the TB-1 containment vessel.

T-Ampoule: The titanium T-Ampoule is similar in design to the stainless steel PC-1 that was evaluated in a previous version of the PAT-1 package. The purpose of the titanium inner container is to provide a eutectic barrier between the new content of plutonium metals and the stainless steel TB-1 Containment Vessel.

2.1.2 Design Criteria

The applicant demonstrates structural capabilities of the package by tests and analyses. The packaging drop tests are used to evaluate the AQ-1 and TB-1 performance of the previously approved configuration of the PAT-1. The SAR Addendum only considers changes to the TB-1 Containment Vessel or those areas not evaluated in the previously approved configuration. SAR Addendum Subsection 2.1.2.1 summarizes the structural design criteria as well as load combinations for package design. SAR Addendum Subsection 2.1.2.2 summarizes the design criteria for the accident conditions for the air transport of plutonium. SAR Addendum Subsection 2.1.4 identifies codes and standards. These design criteria are reviewed as follows:

Normal Conditions of Transport and Hypothetical Accident Conditions:

Tables 2-3 and 2-4 of the SAR Addendum list the allowable stress intensities for demonstrating structural acceptability of the package components under the NCT and HAC.

Load Combinations:

SAR Addendum Subsection 2.1.2.1 notes that load cases for Normal Conditions of Transport and Hypothetical Accident Conditions are applied as indicated in Regulatory Guides 7.6 and 7.8. The ten load combination cases, as listed in SAR Addendum Table 2-2, involve pressure, thermal, and free-drop impact loads. This meets the intent of the NCT and HAC load combination provisions.

Accident Conditions of Air Transport of Plutonium:

Previous testing demonstrated that the TB-1 Containment Vessel will remain elastic and limit the release to less than 1 A_2 in one week. The applicant therefore established a criterion of limiting stresses to below yield, which will provide reasonable assurance that the release limit will be satisfied. The design criteria of the T-Ampoule consisted of prevention of through wall tearing which would potentially allow plutonium contents to come into contact with stainless steel components of the TB-1. The strain criteria set by the applicant was established to provide reasonable assurance that initiation of ductile tearing would be precluded.

Codes and Standards:

The Codes and Standards used for the AQ-1 and the TB-1 Containment Vessel are the same as those identified in the previously approved configuration. The T-Ampoule was evaluated using the ASME Code, Section VIII, Division I.

2.1.3 Fabrication and Examination

The applicant provided a specification (PAT-1040) in SAR Addendum Subsection 1.3.3, which provides the requirements for materials specification and fabrication/examination requirements.

2.2 Weights and Centers of Gravity

The maximum gross weight of the package is 496 lbs. Table No. 2-5 of the SAR Addendum summarizes information on weights of package components and corresponding centers of gravity for the PAT-1 package components. The location of the package center of gravity is calculated as 20.2 inches from the bottom end along a longitudinal centerline.

2.3 Materials Evaluation

The SAR Addendum specifies the addition of Pu metal as a content of the shipping package. For use with a Pu metal payload, a new inner container, the T-Ampoule, replaces the normally used PC-1 stainless steel inner container. Both the PC-1 and the T-Ampoule are used inside the TB-1 containment vessel.

The T-Ampoule is a hollow cylinder with hemispherical ends and nominal wall thickness of approximately 1/2 inch, machined from solid Ti-6Al-4V, Grade 5 alloy bars. The T-Ampoule closure is a bolted-lid. For Pu metal shipments, the lid is sealed with a copper gasket. For Pu oxide shipments, a copper gasket and Viton O-ring combination is employed.

The applicant analyzed and documented three T-Ampoule packaging configurations in the SAR Addendum. One configuration consists of two titanium SC-2 sample containers supported and held in position by a titanium Inner Cradle. A second configuration consists of three SC-1 sample containers supported and held in position by a titanium Inner Cradle. The third configuration consists of a single Pu metal hollow cylinder supported by crushed tantalum foil surrounding the cylinder.

The amount of Pu metal or alloy may not exceed 831 grams. It may be alloyed with up to 1% gallium, with additional 0.16% impurities (excluding decay products).

2.3.1 Adverse Chemical or Galvanic Reactions

Since the amended contents material (Pu metal) is shipped in dry form, no adverse chemical or galvanic reactions can occur due to liquid-based chemical activity.

The maximum temperature of the T-Ampoule during a hypothetical fire accident is 153^{o}C. The maximum temperature of the TB-1 containment vessel is 147^{o}C. Given these low temperatures, there is no concern regarding possible high-temperature eutectic reactions between the T-Ampoule, the sample containers, the contents, or other packaging materials such as the tantalum foil. Additionally, the high-temperature properties of the optional Viton O-ring seal materials are adequate for the 153 degree C maximum fire accident temperature. The maximum temperature of the T-Ampoule resulting from a hypothetical jet-fuel fire is lower than the lowest melting point eutectic that could theoretically be formed in the system.

The staff finds that the temperatures experienced by the T-Ampoule and contents are such that no adverse chemical or galvanic reactions would occur during the hypothetical fire accident conditions.

2.3.2 Effects of Radiation on Materials

The radiation dose to the package materials resulting from the proposed contents was calculated and provided in the SAR. The analysis showed that the total cumulative dose over a hypothetical 1-year continuous exposure time is orders of magnitude lower than what is required to affect metallic components. Thus, no adverse radiation effect will occur for any metallic components over the license period and beyond.

The TB-1 containment vessel in the PAT-1 with plutonium metal content package uses an elastomeric O-ring. The calculated gamma dose to the elastomeric seals of the TB-1 containment vessel and the T-Ampoule is approximately 2.8×10^4 rads / yr. The neutron dose is calculated to be 3.4×10^4 rem / year based on SAR Addendum Table 5-12 *Estimation of Degree of Overprediction in Bounding Pu Source Used in This Study*. The applicant provided data on Viton "A" O-rings from DuPont, *Radiation Resistance of Viton*, in SAR Addendum Subsection 2.2.3.4 where the manufacturer indicated that the material can withstand doses of $10^5 – 10^6$ rad with little or no effect on physical properties. The applicant also provided additional data from the Bouquet report (*Radiation Thresholds for Synthetic Elastomers*, IEEE Transactions on Nuclear Science, Vol. NS-32, No. 6, December 1985) that reviewed Viton material which showed results similar to the DuPont data. Thus the calculated doses based on SAR Addendum Table 5-12 would have little or no effect on physical properties of a Viton O-ring in a one year time period. The staff finds that radiation will not adversely affect seal performance.

2.3.3 Examination

The T-Ampoule will be fabricated and inspected in accordance with Section VIII, Division 1, of the ASME B&PVC. ASTM standards are used for the procurement of the materials used in fabrication. The staff finds these codes and standards acceptable.

2.3.4 Cold

Low temperatures will not adversely affect the performance of the stainless or Ti components of the package system. There is no low temperature ductile-to-brittle transformation as is the case for ordinary carbon steel materials. Thus, brittle fracture is not a possibility and thus the low temperature performance of the entire package is assured. The staff finds the materials selected for the design are adequate for performance at the design minimum temperature.

The issue of O-ring loss of elasticity was assessed. Since the O-rings do not form part of the containment boundary, degradation in O-ring performance is immaterial to the overall package performance or safety.

2.3.5 Material Properties

The staff finds that the thermal properties of the Ti-6Al-4V alloy (used in the T-Ampoule) referenced by the applicant acceptable.

2.3.6 Description of the Containment System

The constituents of the plutonium metal content package's containment system are the TB-1 containment vessel body and lid, and the copper gasket.

The plutonium oxide content package's containment system remains unchanged. The constituents of the plutonium oxide content package's containment system under NCT and HAC are the TB-1 containment vessel body and lid and the elastomeric O-ring, and the vessel body and lid, and copper gasket under ACATP.

2.4 General Standard for All Packages (10 CFR 71.43)

2.4.1 Minimum Package Size

The minimum dimension of the PAT-1 package is approximately 24.5 inches. It is greater than the minimum overall dimension of 4 inches, which meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper-Indicating Features

A tamper indicating seal is made by attaching a wire to the bolted lid clamping ring on the AQ-1 drum. This satisfies the tamper-proof requirements of 10 CFR 71.43(b).

2.4.3 Positive Closure

The PAT-1 positive closure was previously evaluated and approved.

2.5 Lifting and Tie-Down Standards for All Packages (10 CFR 71.45)

2.5.1 Lifting Devices

The PAT-1 lifting analysis was previously evaluated and approved.

2.5.2 Tie-Down Devices

The PAT-1 tie-down analysis was previously evaluated and approved

2.6 Normal Conditions of Transport (10 CFR 71.71)

2.6.1 Heat

The applicant evaluated the PAT-1 for the effects of heat during testing of the previously approved configuration. The differences between the PAT-1 previously approved configuration and that of the PAT-1 with Pu metal content addressed in the SAR Addendum are: 1) TB-1 of the Pu metal package does not use the elastomeric O-ring, and 2) the PC-1 is replaced with the titanium T-Ampoule. Therefore, the titanium T-Ampoule is the only new component that has the potential to change stress values on the TB-1 containment vessel due to differential thermal expansion. The applicant performed calculations and demonstrated that a) thermal expansion due to heat would not substantially close internal gaps thereby creating thermal stresses on the TB-1 or T-Ampoule and b) stresses due to internal pressure from decay heat and helium generation were substantially lower than allowable stresses for the TB-1 or T-Ampoule. Thus, the requirements of 10 CFR 71.71(c)(1) are satisfied.

2.6.2 Cold

The applicant evaluated the PAT-1 for the effects of cold temperature during testing of the previously approved configuration. The differences between the PAT-1 previously approved configuration and that of the PAT-1 with Pu metal content addressed in the SAR Addendum are: 1) TB-1 of the Pu metal package does not use the elastomeric O-ring, and 2) the PC-1 is replaced with the titanium T-Ampoule. Therefore, the titanium T-Ampoule is the only new component that has the potential to change stress values on the TB-1 containment vessel due to differential thermal contraction. The applicant performed calculations and demonstrated that thermal contraction due to cold would not substantially close internal gaps thereby creating thermal stresses on the TB-1 or T-Ampoule. On the basis of the above, the staff has reasonable assurance to conclude that the package structural performance is adequate for meeting the cold condition requirements of 10 CFR 71.71(c)(2).

2.6.3 Reduced External Pressure

The PAT-1 was subjected to reduced external pressure during testing. Changes presented in the SAR Addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

The PAT-1 was subjected to increased external pressure during testing. Changes presented in the SAR Addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration

The PAT-1 was evaluated for vibration during testing. Changes presented in the Addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(5) are satisfied.

2.6.6 Water Spray

The PAT-1 was evaluated for water spray during testing. Changes presented in the SAR Addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(6) are satisfied.

2.6.7 4-ft Free Drop

The PAT-1 was evaluated for a 4-ft free drop in the previously approved configuration and it was concluded that the NCT free drop was inconsequential to the structural integrity of the package. The applicant also noted that despite a change in package contents, the 4-ft NCT drop does not pose a significant challenge to the structural integrity of the package when compared with the air transport accident. Given that the TB-1 remains essentially elastic during the air transport accident, it can reasonably be concluded that the TB-1 will also remain elastic during 4-ft NCT drops.

On the basis of the above, the staff concludes that the package is capable of maintaining its structural integrity to meet the requirements of 10 CFR 71.71(c)(7).

2.6.8 Corner Drop

The PAT-1 package is a fissile material package that weighs more than 220 lbs. Therefore, the corner drop test does not apply to this package because of its weight in accordance with 10 CFR 71.71(c)(8).

2.6.9 Compression

The PAT-1 was evaluated for compression during testing. Changes presented in the SAR addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(9) are satisfied.

2.6.10 Penetration

The PAT-1 was evaluated for penetration during testing. Changes presented in the SAR addendum have no effect on the conclusions drawn for the previously approved package. Thus the requirements of 10 CFR 71.71(c)(10) are satisfied.

2.7 Hypothetical Accident Conditions (10 CFR 71.73)

2.7.1 30-ft Free Drop

The applicant performed simple verification analyses to determine that the structural and confinement integrity of the package would not be affected by a 30 ft end drop, a side drop, and a CG over corner drop. This is because the TB-1 containment vessel is designed for aircraft accident conditions which are much more severe than the aforementioned drop test conditions. Drop testing has revealed no adverse effects, and the verification models demonstrated successful structural performance.

The staff concludes that the package is structurally capable of meeting the requirements of 10 CFR 71.73(c)(1).

2.7.2 Crush

The applicant evaluated the PAT-1 for effects due to dynamic crush because the overall package density for the current configuration is below 62.4 lb/ft^3 and the overall mass is below 1100 lbs. The applicant evaluated 20 scenarios, which varied both package orientation and content configuration and the evaluations were performed in the same manner as the air transport accident analysis.

<u>T-Ampoule</u>

The applicant used two evaluation parameters to determine the relative structural integrity for the T-Ampoule. The applicant first evaluated stress triaxiality in equivalent strain space and compared computed values with an experimentally derived strain locus (bounding limit for Average Stress Triaxiality and Equivalent Plastic Strain). The second evaluation investigated those elements, which exceeded the strain locus bounding limit by means of a Tearing Parameter, which is an indicator of the relative margin prior to the initiation of ductile tearing. The applicant reported that in no case was the Tearing Parameter limit reached thereby demonstrating that there was no initiation of ductile tearing of the T-Ampoule.

<u>TB-1</u>

The applicant also compared through thickness stresses with allowable stresses from Reg. Guide 7.6 and the ASME Code for the TB-1 containment vessel. In all cases, the through thickness stresses in the TB-1 did not exceed stress allowable stress intensities. The applicant did report localized surface stresses that exceeded allowable stress intensities. However, these localized surface stresses were isolated anomalies associated with spurious contact stresses, and not through thickness average or peak stresses.

Staff reviewed the calculation results and concludes that dynamic crush will have a minor effect on the structural integrity of the PAT-1. Therefore, the requirements of 10 CFR 71.73(c)(2) are satisfied.

2.7.3 Puncture

Puncture was previously evaluated during testing and shown to be inconsequential to the TB-1. Since minor damage was only observed on the AQ-1 drum, no further analysis was required.

2.7.4 Thermal

The applicant evaluated the PAT-1 for the thermal effects of HAC during testing of the previously approved configuration. The only change in the current configuration is the addition of the T-Ampoule, which due to different materials of construction could change stress values as a result of differential thermal expansion. The applicant performed calculations and demonstrated that: a) thermal expansion due to heat would not substantially close internal gaps and therefore would not result in thermal stresses on the TB-1 or T-Ampoule and b) stresses due to internal pressure from decay heat and helium generation were substantially lower than allowable stresses for the TB-1 or T-Ampoule. Thus, the requirements of 10 CFR 71.71(c)(1) are satisfied.

2.7.5 Immersion - Fissile Material

The TB-1 containment was shown to remain sealed when tested, as reported in the previously approved Safety Analysis Report.

2.7.6 Immersion - All Packages

The TB-1 containment was shown to remain sealed when tested in the previously approved Safety Analysis Report.

2.7.7 Deep Water Immersion Test

Not applicable for type B packages containing less than 10^5 A_2. Therefore, the Deep Water Immersion Test is not applicable to this package.

2.7.8 Summary of Damage

Testing showed that the TB-1 was essentially undamaged due upon conclusion of the NCT and HAC required tests. Only a small subset of evaluations were done to evaluate the effects of dynamic crush and to verify stress states for the most structurally demanding HAC drop orientations. In all cases, the stress states and overall damage demonstrated acceptable margins of safety.

2.8 Accident Conditions for Air Transport of Plutonium (10 CFR 71.74)

2.8.1 Discussion

To demonstrate the capability of the PAT-1 to withstand the regulatory air transport accident, the applicant has relied on physical testing which was performed in support of the original licensing action. Because under known temperatures plutonium metal has a potential for a eutectic reaction when it comes in contact with iron (stainless steel in TB-1), it was determined that a more rigorous analytic approach was necessary to rule out a breach of the PAT-1's eutectic prevention barrier (titanium T-Ampoule).

The analytical approach consisted of the following:

1) Validation model

   This model was a baseline overpack model used for comparison against data from the physical testing performed on the PAT-1. Since the original test was not instrumented, the validation was based on overall deformation patterns. The contents as represented in this model were a simplified version of PuO_2 powder. To compliment the validation program, a fully instrumented materials test program was implemented to develop additional information about high velocity impacts into titanium packaging components.

2) Fully detailed model for NCT

   The fully detailed model for NCT (and HAC crush) included representations of the various metal contents, the internal cradle structure, as well as detailed geometric features such as the rolled stainless steel lids.

3) Fully detailed model for HAC crush

4) Less detailed model for high velocity impact of the PAT-1 with plutonium metal contents.

   The less detailed model had all the same features as the fully detailed model, except that the rolled stainless steel lids were simplified as they provided limited energy absorption.

2.8.2 Full Package Validation Model

Appendix 2.12.2 provides the full evaluation of the overpack validation model. It was demonstrated in this appendix and via videoconference that the overpack validation model reasonably predicted the response of the overpack assembly during a high velocity impact. Staff noted as part of a Request for Additional Information, that the redwood model used by

Sandia has an established and acceptable pedigree for use in this application

2.8.3 Impact Test and Material Failure

The applicant used two evaluation parameters to determine the relative structural integrity of the T-Ampoule. The first evaluated stress triaxiality in equivalent strain space and compared computed values with an experimentally derived strain locus (bounding limit for Average Stress Triaxiality and Equivalent Plastic Strain). The second evaluation investigated those elements, which exceeded the strain locus bounding limit. Elements exceeding the bounding limit were evaluated by means of a Tearing Parameter. The Tearing Parameter used is an indicator of the relative margin of safety from initiation of ductile tearing.

<u>Average Stress Triaxiality and Equivalent Plastic Strain</u>

The applicant used a reverse ballistic titanium impacter and drop table dynamic crushing of a T-Ampoule dome to develop data which was then organized into an interaction diagram for stress informed equivalent plastic strain. The interaction diagram was referred to as a Locus in Equivalent Plastic Strain-Stress Triaxiality Space. It should be noted that this diagram represents actual test data and should not be considered a failure locus since no part of the component specimens showed initiation of cracking, despite being highly strained.

This strain locus was then used when evaluating the PAT-1 with metal contents to determine whether or not portions of the T-Ampoule exceeded the bounding stress informed equivalent plastic strains produced during component testing. If the equivalent plastic strains with stress triaxiality effects produced in the high velocity analytical models fall within the Strain Locus, then a positive margin of safety exists. If the equivalent plastic strains fall outside the locus, a positive margin of safety against initiation of tearing may still exist, but an alternate failure criterion is necessary because the plastic strains are outside the range of applicability for the strain locus. This demonstrates inherent conservatism with this approach.

<u>Tearing Parameter</u>

For equivalent plastic strains which fall outside the Strain Locus, an alternate measure of relative safety margin was utilized. This criterion was referred to as the Tearing Parameter and is based on a cumulative damage function related to plastic strains which are scaled by the stress ratio of maximum stress to maximum stress minus the mean stress. This damage is accumulated until a critical value is reached and is referred to as the Critical Tearing Parameter. This is truly a stress informed strain based failure criterion, since it more rapidly accumulates damage as the denominator (maximum stress minus mean stress; similar to stress triaxiality) gets smaller, meaning the stress state is closer to triaxial tension. The Critical Tearing Parameter is derived from a uniaxial tension test followed by an analytical model which is solved iteratively until initiation of ductile tearing is shown to occur under the same conditions as in the test.

Strain Rate Effects

The staff inquired about the validity of the component tests performed to develop the stress triaxiality-equivalent plastic strain locus since the impact velocities used in these tests were much lower than what was seen in a regulatory high speed impact. The applicant noted that the relative velocities of the contents and the T-Ampoule were lower than the raw impact velocity, but those relative velocities still exceeded the rated velocity of the reverse ballistics impact used for the component tests. As such, the staff requested further evaluation to demonstrate that an unanalyzed condition did not exist. The applicant provided a response which showed that the strain rates achieved in the lower velocity component tests actually exceeded those of the detailed evaluation of the PAT-1 overpack and plutonium metal contents.

2.8.4 NCT, HAC, and High Velocity Impact Analyses

SAR Addendum Subsection 2.12.5 provides details of each of the individual orientations that were evaluated, including end, side, and CG over corner impacts for plutonium metal hollow cylinders, solid delta-phase plutonium in sample containers, and Pu/Be composite cylinders in sample containers. All internals including plutonium contents and associated sample containers were pre-positioned in the worst possible orientations internally to impart maximum damage.

SAR Addendum Subsection 2.8.4 provides a graphical summary of elements that exceeded the strain locus and subsequently a comparison of the calculated Tearing Parameter for each of those elements. It should be noted that only in a small number of cases/locations was the strain locus exceeded and then in those cases the reported Tearing Parameter was significantly lower than the Critical Tearing Parameter (lowest factor of safety was 1.62). In summary, no initiation of tearing was indicated in any location in the T-Ampoule for any of the orientations presented in the SAR Addendum.

2.8.5 Bolt Analysis

The bolts in the PAT-1 package were shown to remain elastic during original qualification by test. However, the applicant performed a simplified analysis to verify that forces applied to the lid region were lower than the applied bolt preload. In addition, the applicant showed qualitatively that the bolted closure region was not subjected to direct loading on the bolts nor was there inherent prying action due to the design of the package.

2.8.6 Summary

The applicant submitted a comprehensive battery of analyses results coupled with test data to demonstrate that the T-Ampoule is not subjected to loadings sufficient enough to initiate ductile tearing of the eutectic barrier. As part of these evaluations, the applicant presented a defense in depth approach to acceptance criteria (Stress Informed Equivalent Plastic Strain, Tearing Parameter) that is both realistic and conservative. Staff finds that the results presented by the applicant are sufficient to provide reasonable assurance that the eutectic barrier will remain intact. Therefore, the requirements of 10 CFR 71.74 have been satisfied.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

The evaluation in the SAR Addendum for Part 71.74 also satisfies 10 CFR 71.55(f).

2.10 Special Form

The SAR Addendum does not consider special form.

2.11 Fuel Rods

The SAR Addendum does not consider fuel rods.

2.12 Appendices

The appendices contained detailed analyses results which the staff reviewed in detail as part of the SAR Addendum submittal. The staff also engaged the applicant in a videoconference in which the applicant presented their analysis approach and selected results animations for the staff to review in real time. These analyses are supporting calculations for evaluations and conclusions presented in SAR Addendum Subsections 2.6, 2.7 and 2.8.

Evaluation Findings:

The staff reviewed the PAT-1 Safety Analysis Report Addendum which presented a revised design for air shipment of plutonium to accommodate plutonium metals. Based on the statements and representations contained in the application, response to the staff request for additional information dated 9/20/2010, extended technical video conference on 4/23/2010, and the conditions given in the Certificate of Compliance, the staff concludes that the package has adequately been described and evaluated to demonstrate its structural and materials capabilities to meet the requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

3.1 Review Objectives

The objective of the review of PAT-1 package is to verify that the thermal performance of the package has been adequately evaluated for the tests specified under NCT and HAC and that the package design satisfies the thermal requirements of 10 CFR Part 71. This case was also reviewed to determine whether the package fulfills the acceptance criteria listed in Section 3 of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material," as well as associated Interim Staff Guidance (ISG) documents.

3.2 Description of the Thermal Design

3.2.1 Package Design Features

A Ring Filler and a T-Ampoule inner container replace the PC–1 inner container and aluminum spacer documented in the SAR. There are three basic configurations for plutonium metal contents within the T-Ampoule. One configuration consists of two titanium SC-2 sample containers supported and held in position inside the T-Ampoule by a titanium Inner Cradle. The plutonium metal content within the SC-2 is a solid Pu metal cylinder of a diameter and length of 1.1 inches. A second configuration consists of three SC-1 sample containers supported and held in position inside the T-Ampoule by a titanium Inner Cradle. The configuration consists of three SC-1s and the plutonium metal sample packed in an SC-1 is a solid cylinder 0.88 inches (0.0224 m) in diameter and length. A third configuration consists of a single Pu metal hollow cylinder weighing from 731 to 831 grams (1.61 to 1.83 lbm) supported by crushed tantalum foil surrounding the cylinder. The T-Ampoule, Ring Filler, SC-1, SC-2, Inner Cradle, and plutonium metal content all have melting temperatures above the 582°C (1080°F) temperature observed in the TB-1 during the plutonium air transport fire test described in SAR Addendum Subsection 3.6.1.2.

3.2.2 Content Heat Load Specification

The PAT-1 package was assessed for a total decay heat load of its radioactive contents of 25 watts. Sections 3.3 and 3.4 of the application demonstrate that with the 25 watt decay heat, the overall thermal performance of the PAT-1 package with the T-Ampoule and its plutonium metal payload is essentially the same as demonstrated in the SAR. Thermal evaluation of the PAT–1 with the T-Ampoule and its plutonium metal content configurations assumed a total decay heat of 25 watts.

3.2.3 Summary Tables of Temperatures

The results from the thermal evaluation of the AQ-1, TB-1, and the T-Ampoule assuming the bounding concentrated internal heat described in SAR Addendum Subsection 3.1.2 of the application are summarized in

Table 3-1 of the SAR Addendum. These results show that the PAT-1 also protects the new components inside the TB-1.

3.2.4 Summary Tables of Maximum Pressures in the Containment System

Table 3-2 of the SAR Addendum summarizes the maximum pressures inside the T-Ampoule for the NCT, HAC, and ACATP conditions specified in 10 CFR 71.71, 71.73, and 71.74, respectively. As demonstrated in Sections 2, 3.3.2, 3.4.3, 3.4.5, and 4 of the SAR Addendum, the pressures that arise in the container during NCT, HAC, and ACATP conditions do not result in a loss of containment.

3.3 Material Properties and Component Specifications

3.3.1 Material Thermal Properties

Material properties (density, specific heat, and thermal conductivity) for aluminum, ETP copper, stainless steel, and redwood were used in the analysis provided in the SAR Addendum. The thermal properties for Ti-6Al-4V used in the computer analysis are presented in Table 3-4 of the SAR Addendum.

3.3.2 Component Specifications

The service temperature range for TB-1 package components is provided in Table 3-5 of SAR Addendum. Service temperature range is specified for the following components: T-Ampoule O-ring, TB-1 copper gasket, T-Ampoule, titanium Inner Cradle, Ring Filler, Pu/Be content, and tantalum foil.

3.4 General Considerations for Thermal Evaluations

3.4.1 Evaluation by Analyses

The applicant performed the PAT-1 package thermal evaluation by analysis using a finite element thermal code. The finite element code used in the evaluation is well referenced and all modeling assumptions have been correctly justified and the appropriate thermal properties used.

3.4.2 Evaluation by Tests

As described in SAR Addendum Subsection 3.4.1, the supplemental evaluation documented in the SAR Addendum was performed by analysis using a finite element method of evaluation. Physical tests were the primary means used to demonstrate that the PAT-1 package met 10 CFR 71.74 requirements. As stated in the SAR, the TB-1 reached a maximum temperature of approximately 582°C (1080°F) during the thermal test. This maximum temperature is not affected by any of the packaging or content modifications presented in the SAR Addendum. Therefore, the maximum TB-1 temperature used in the SAR Addendum for the calculation loads due to internal pressure and thermal expansion during the plutonium aircraft fire environment is 582°C (1080°F).

3.4.3 Margins of Safety

Sufficient margins of safety were demonstrated by the applicant in terms of predicted temperatures, pressures, and thermal stresses. The application does not discuss the effects of uncertainties in thermal properties, test conditions and diagnostics, and analytical methods. However, due to the well established method of evaluation the applicant used, shown margin, and very low decay heat of the proposed contents, the staff has reasonable assurance the package will perform as predicted by the thermal evaluation provided in the SAR Addendum.

3.5 Thermal Evaluation under Normal Conditions of Transport

The applicant used the Patran Thermal (P/Thermal) finite element analysis computer code to perform the PAT-1 package thermal evaluation. P/Thermal can be used to analyze a variety of thermal issues, including those related to nuclear transport packages. P/Thermal can solve one-, two-, and three-dimensional (3-D) conduction, convection, and radiation heat transfer problems. The finite element model includes a 3-D model of the PAT-1 package. Package features such as the different wood grain orientations and the respective anisotropic thermal properties of the redwood, the aluminum Load Spreader, the copper heat transfer tube, the stainless steel TB-1, and the titanium T-Ampoule where included in the model. The 25-watt power from the Pu was conservatively applied to a small region on the inner surface of the T-Ampoule to maximize the thermal affect to the T-Ampoule seal. A natural convection heat transfer coefficient obtained for a correlation developed for horizontal cylinders was applied to the surface exposed to the environment. A summary of the boundary conditions applied to the package is provided in Table 3-6 of the SAR Addendum. These boundary conditions are consistent to the specified conditions in 10 CFR 71.71.

3.5.1 Heat and Cold

The applicant predicted a maximum T-Ampoule “seal” temperature of approximately 122°C (251°F) even in the very conservative internal heat load scenario. Therefore, the performance of the elastomeric O-ring in the T-Ampoule is not degraded and maintains product quality, as this temperature is within the operating range specified by the manufacturer. The maximum seal region temperature of the TB-1 was 114°C (238°F). This temperature is within the operating temperature range of the metallic seal. Therefore, the TB-1 is able to maintain containment. By not assuming any internal heat generation, the applicant stated that the minimum temperature any PAT-1 package component could reach is -40°C (-40°F). The copper seal used in the TB-1 is unaffected at this low temperature Therefore, the PAT-1 can maintain containment at this low temperature extreme even without taking credit for any decay heat of the contents, which will definitely heat the seal region of the TB-1 to above -40°C (-40°F).

3.5.2 Maximum Normal Operating Pressure

The applicant predicted a maximum normal operating pressure (MNOP) within the TB-1 of 29 kPa (4.2 psig). This MNOP was calculated using the average internal surface temperature of the T-Ampoule as the average temperature of the gas inside the TB-1, which is 103.3°C (218°F) and the contribution to the internal pressure over time due to alpha decay.

The staff reviewed selected calculations and results for NCT and found them acceptable.

3.6 Thermal Evaluation under Hypothetical Accident Conditions

The applicant used the same P/Thermal model that was used for the NCT analysis to perform the HAC analysis. The applicant stated that since the deformations shown in the SAR after the package was dropped from 30 feet are minimal, the computer model used for the HAC thermal evaluation represents an undamaged package. Boundary conditions were modified to meet those specified in 10 CFR 71.73(c)(4) In addition, the same model was used in a model verification exercise to simulate the 52 minute fire.

3.6.1 Initial Conditions

The applicant applied the temperature distributions predicted during NCT as initial condition for the transient analysis of the HAC described in 10 CFR 71.73.

3.6.2 Fire Test Conditions

The applicant perform the HAC analysis by subjecting The PAT-1 package model to the thermal transient conditions specified in 10 CFR 71.73 to evaluate whether the TB-1 can maintain containment and the T-Ampoule maintain seal (for product quality, not regulatory purpose). The boundary conditions that were used in the analysis of 30-minute fire test are summarized in Table 3-10 of the SAR Addendum: ambient temperature of 1010°C (1850°F), convection heat transfer coefficient of 11.5 W/m^2-K, package surface emissivity of 0.8, and fire emissivity of 1.0.

3.6.3 Maximum Temperatures and Pressures

Applicant's HAC predicted results of the AQ–1, TB-1, and the T-Ampoule, assuming the bounding concentrated internal heat described in Subsection 3.1.2 of the SAR Addendum are summarized in Table 3-11 of the SAR Addendum. The components listed in this table did not reach temperatures of concern. Only the redwood regions closer to the outer skin of the package are expected to degrade as wood chars at temperatures above 288°C (550°F). Nevertheless, PAT-1 protects the package contents during and after the exposure to HAC, per 10 CFR 71.73. Based on average temperature of the gas inside and the pressure generation due to alpha decay, the applicant predicted a maximum pressure of 40 kPa (5.8 psig) during HAC. Based on the analysis results, the applicant concluded that the PAT-1 package provides containment for the proposed new payload inside the TB-1 and adequately contains the material inside the T-Ampoule, as maximum seal temperatures are within manufacturer's specifications and the TB-1 can withstand the pressure that would arise during and after the HAC fire event.

3.6.4 Maximum Thermal Stresses

The applicant estimated the T-Ampoule maximum expansion by assuming the T-Ampoule is a 0.2 m (7.418 in.) long cylinder. Assuming a temperature increase of (153°C – 21.1°C) = 132°C ([308°F – 70°F] = 238°F), the expansion produced equal 0.23 mm (0.009 in.) in the longitudinal direction and 0.41 mm (0.0161 in.) in circumference (or 0.13 mm [0.0051 in.] in diameter). Since the gap between the T-Ampoule and the TB-1 is 0.381 mm (0.015 in.) around the entire perimeter, the T-Ampoule will not expand enough to induce any stress on the TB-1, even if the expansion of the TB-1 is ignored.

The staff reviewed selected calculations and the SAR Addendum results for HAC and found them acceptable. The HAC model of the PAT-1 payload and assumed damage configurations adequately represents the various contents and heat loads that are requested.

3.7 Thermal Evaluation under ACATP

A thermal test of the PAT-1 package is not required because per the thermal evaluation, of the relatively large thermal margins for all components. Physical tests were the primary means used to demonstrate that the PAT-1 package met 10 CFR 71.74 requirements. As stated in the SAR, the TB-1 reached a maximum temperature of approximately 582°C (1080°F) during the thermal test. This maximum temperature is not affected by any of the packaging or content modifications presented in the SAR Addendum. Therefore, the maximum TB-1 temperature used in the SAR Addendum for the calculation loads due to internal pressure and thermal expansion during the plutonium aircraft fire environment is 582°C (1080°F).

3.8 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR 71.

4.0 CONTAINMENT EVALUATION

4.1 Review Objective

The application proposes to:

1) Incorporate the Pu metal as a new payload for the PAT-1 package, and
2) Demonstrate that the PAT-1 with the new T-Ampoule Assembly and the packing within the TB-1 Containment Vessel meet the containment requirement of 10 CFR 71.

The analysis performed for this SAR Addendum application demonstrates that the replacement of the PC-1 and associated packaging material with the T-Ampoule and associated packaging and the addition of the plutonium metal content are not significant with respect to the design, operating characteristics, and safe performance of the containment system. The PAT-1 package's other component designs, currently authorized PuO_2 content mass and form, and maximum decay heat of 25 watts remain unchanged.

The objective of this review is to verify that the package design satisfies the containment requirements of 10 CFR Part 71 under NCT, HAC, and ACATP.

4.2 Description of Containment System

The PAT-1 packaging consists of AQ-1 overpack, TB-1 containment vessel, T-Ampoule containing plutonium metals, and Ring Filler. The TB-1 containment vessel is a stainless steel vessel surrounded by a stainless steel and redwood overpack (AQ-1). The T-Ampoule provides a eutectic prevention barrier between the stainless steel TB-1 and the plutonium metal payload for NCT, HAC, and ACATP. As described in the SAR Addendum, the TB-1 O-ring is not used for plutonium metal shipments.

The PAT-1 with T-Ampoule configuration is limited to the current certified TB-1 gross payload of 2100 g (4.7 lbs). The Ring Filler is used to fill the void space between the top of T-Ampoule and the TB-1 closure lid. The Ring Filler is 10.72 cm (4.22 in) in diameter, 1.27 (0.5 in) cm thick, and is manufactured of titanium (Ti) alloy 6Al-4V, Grade 5.

The PAT-1's containment system for the plutonium metal shipments consist of the TB-1's body, lid and copper gasket as described in the SAR Addendum.

4.2.1 Containment Boundary

The applicant defined the TB-1 containment vessel and the copper gasket within TB-1 container as the containment boundary under NCT, HAC, and ACATP. As described in this SAR Addendum, the TB-1 O-ring is not used for plutonium metal shipments. The copper gasket seals the TB-1 body to lid interface and remains sealed and maintains containment during all 10 CFR 71 specified conditions including the post-fire plutonium air transport accident.

The staff reviewed the containment design features in SAR Addendum Chapters 1 and 4, and verified that the application has the same containment boundary as the PAT-1 package with PC-1, previously certified by U.S. NRC per CoC USA/0361B(U)F-96. The staff ensured that all components of the containment system are well defined in SAR Addendum and displayed in its drawings of 2A0259 - 2A0269, in accordance with NUREG/CR-5502 Engineering Drawings for 10 CFR 71 Package Approvals."

The configuration within the TB-1 containment vessel for plutonium metal shipments can be: 1) T-Ampoule for bulk metal hollow cylinder; or 2) T-Ampoule for Sample Container-1 (SC-1) or Sample Container-2 (SC-2) for smaller metal samples. The staff reviewed the PAT-1 containment design features presented in SAR Addendum Chapters 1 and 4 and confirmed that the application adequately describes the containment system, including special requirements of plutonium and its metal contents, in compliance with 10 CFR 71.33 and 71.43. The staff ensured that the containment system components are shown in SAR Addendum drawings of 2A0259 ~ 2A0269.

4.2.2 Special Requirements for Plutonium

The applicant specified in SAR Addendum 4.1.1 that the PAT-1 package with T-Ampoule and its associated packing is designed to contain the plutonium metal payload contents which are solid, pure or alloyed plutonium metal or Pu/Be composite samples. The staff ensured that the PAT-1 with T-Ampoule and its associated packing should meet the requirements of 10 CFR 71.63 "shipments containing plutonium must be made with contents in solid form, if the contents contain greater than 0.74 TBq (20 Ci) of plutonium."

The applicant in Chapter 2 of the SAR Addendum demonstrated through structural analysis that the titanium T-Ampoule eutectic prevention barrier between the Pu metal contents and the TB-1 containment vessel remains intact and functional during all conditions (NCT, HAC, and ACATP) analyzed.

Contents

The applicant defined the ranges of total plutonium content weight in the T-Ampoule: 731-831 grams of electro-refined or alloyed Pu for Pu metal hollow cylinder, 0-522 grams of alloyed delta phase Pu metal for Sample Container-1 (SC-1), 0-676 grams of alloyed delta phase Pu metal for Sample Container-2 (SC-2), 0~180 grams of bonded Pu/Be metal content for SC-1, and 0-120 grams of bonded Pu/Be metal content for SC-2. Individual maximum weights for the sample containers are summarized in SAR Addendum Table 1-1. The minimum content weight of 731 grams for the Pu metal hollow cylinder is specified because a complete weight range for the hollow cylinder is not evaluated.

The geometric shapes of alloyed Pu metal allowed in PAT-1 include (1) circular discs of varying diameters and thicknesses, (2) rectangular strips of varying lengths, widths, and thicknesses, (3) cylinders in sizes and masses up to those used in structural analysis, (4) random shapes used for chemistry analysis, and (5) composites as specified in SAR Addendum Table 1-1.

Ancillary plastics (i.e., PET, HDPE, PTFE, and PVC) may be used in T-Ampoule and secondary container labels. The amount of ancillary plastics authorized in the PAT-1 with T-Ampoule configuration is controlled by a Certificate of Compliance condition.

4.3 General Considerations

4.3.1 Type A Fissile Packages

The PAT-1 package is designated as a Category I, Type B, fissile material package, a shipping package for air-transport of plutonium and in compliance with 10 CFR Part 71.

4.3.2 Type B Packages

The PAT-1 transportation package is designated as a Category I, Type B fissile material package, consisting of radioactive materials consisting of a maximum decay heat of 25.0 watts and a maximum plutonium metal content weight of 831 grams as defined in SAR Addendum Table 1-1.

The proposed plutonium metal contents in PAT-1 with T-Ampoule include one of the following:

1) Electro-refined; or

2) Pu of various ages containing stabilization alloys such as gallium; or

3) Composite samples consisting of Pu and beryllium (Be) separated by an alpha barrier (Ti) to preclude neutron generation.

4.3.3 Combustible-Gas Generation

Based on a literature review, the reaction products produced by pyrolysis of O-rings and ancillary plastics were determined to be CO, CO_2, HF, CF_4, C_2F_4, C_3F_6, H_2O Cl_2 F_2, and C_4F_8, as documented in the SAR Addendum. The applicant assumed that the maximum amount of gas is formed on a molar basis, since the species in the PAT-1 would form the greatest amount of the product, and therefore represents the maximum pressure contribution from the combination of sources.

1) The applicant performed the calculation of the pressure rise, due to O-ring degradation, inside the TB-1 containment vessel and selected the packing configuration of SC-1 as the bounding case because SC-1 configuration include four O-rings when compared to three O-rings in SC-2 configuration and one O-ring in hollow-cylinder configuration.

2) The applicant assumed that all available hydrogen, carbon and fluorine are liberated and then calculated the maximum moles of gaseous products that would produce a pressure of 1110 psia within an unoccupied internal TB-1 volume of 1103.01 cm^3 and under T = 1080^oF (or 582.2^oC) for the PAT-1 hypothetical accident condition.

3) Instead of claiming that the theoretical excess of carbon will remain as solid, unreactive char, based on that (a) any oxygen present at the time of initial packaging is scavenged completely, and (b) the TB-1 containment vessel remains intact during the regulatory specified accident conditions and the solid char is experimentally observed, even in the oxidative thermal decomposition of fluoroelastomers, the applicant conservatively estimated a pressure increase of 43.7 atm (or 642 psi) by assuming that the additional oxygen was to be made available in the TB-1 and sample containers to produce CO(g) or CO_2(g). Thereby, the overall pressure in the TB-1 rises to 75.5 atm (or 1110 psia).

4) Instead of assuming that the products of pyrolysis of the ancillary plastic generates hydrocarbon gases based on experimental evidence (Moldoveanu, referenced in SAR Addendum Subsection 2.12.8), the applicant conservatively estimated the increase of 468 psia by assuming that additional oxygen will be made available in the TB-1 and sample containers to produce CO or CO_2 gas and possibly Cl_2 and F_2, and H_20. This follows the same logic used in the no-char assumption in SAR Addendum Subsection 4.5.4. Therefore the overall pressure rises to 1110 psia.

5) The applicant demonstrated that the TB-1 design pressure of 1110 psia at 1080°F has a factor of safety of 1.98 based on an analysis in SAR Addendum Subsection 2.12.8 using the ASME Boiler and Pressure Vessel Code's design criteria.

The staff agreed that the calculations of estimated overall pressure, performed by Sandia National Laboratories and Los Alamos National Laboratory, are very conservative by including the formation of HF, CF_4, and CO/CO_2. Therefore, the staff reviewed SAR Addendum 2.12.8 for design pressure calculation of PAT-1 and accepted the claiming for phenomena mentioned above (items 3 and 4) that the total pressure within the TB-1 with three SC-1 configuration with O-rings and ancillary plastics is equal to the design limit of 1110 psia.

4.4 Containment Under NCT

4.4.1 Containment Design Criterion

The PAT-1 package is designed, fabricated, and leak tested to preclude the release of the radioactive materials in excess of the limits prescribed in 10 CFR 71.51(a)(1) "A Type B package must be designed, constructed and prepared for shipment so that no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A_2 per hour will occur under tests specified in 10 CFR 71.17 for NCT."

4.4.2 Demonstration of Compliance with Containment Design Criterion

The applicant performed the thermal analysis documented in the SAR Addendum using a localized 25.0 watt thermal source against the O-ring seal of the T-Ampoule and calculated an average temperature of 103.3°C (218.0°F). The applicant assumed that the gas within the TB-1 containment vessel behaves as an ideal gas with an initial room temperature of 20°C and determined a maximum internal pressure of 18.9 psia in the TB-1 containment vessel.

The applicant assumed that the TB-1 containment vessel is filled at ambient temperature and reaches the NCT temperature of 103.3°C quickly and calculated a pressure of 0.067 psia from helium generation due to alpha decay of 1300 g plutonium under V = 1.252 liters. Finally, the applicant defined the MNOP of 18.9 psia (or 4.2 psig) as a sum of the pressures from internal heat generation and alpha decay.

4.5 Containment Under HAC

The PAT-1 package is designed, fabricated, and leak tested to preclude the release of the radioactive materials in excess of the limits prescribed in 10 CFR 71.51(a)(2) "No escape of krypton-85 exceeding 10 A_2 in one week and no escape of other radioactive material exceeding a total amount of A_2 in one week." The leakage rate tests for the TB-1, which is the primary containment vessel, remain below the maximum allowable limit under HAC, in accordance with ANSI N14.5.

4.5.1 Containment Design Criterion

<u>Maximum Internal Pressure in TB-1</u>

The applicant performed the pressure calculations for TB-1 containment with:

1) Normal extreme temperature of -40°C, NCT temperature of 104°C (slightly over 103.3°C), and HAC temperature of 136°C,

2) Maximum plutonium masses of 676 g in SC-2, 523 g in SC-1, and 831 g in Pu metal hollow cylinder, and

3) Void volumes of 1.103 liters in SC-2, 1.112 liters in SC-1, and 1.275 liters in Pu metal hollow cylinder.

The applicant calculated and presented the following information in SAR Addendum Subsection 4.5.3: the pressure for TB-1 containment (Table 1), the helium pressure increase in TB-1 for 1300 grams of Pu

(Table 3), and the helium pressure increase in TB-1 for 831 grams of Pu (Table 4) under -40°C, NCT, HAC, and ACATP.

4.5.2 Demonstration of Compliance with Containment Design Criterion

The applicant assumed an initial room temperature of 21°C (70°F) and calculated a pressure of 20.4 psia within the TB-1 containment container as the result of internal heat generation of 25.0 watt from the plutonium metal contents. The applicant then derived a pressure of 0.073 psia from helium generation for 1300 g of Pu metal via alpha decay heat, and determined a total pressure of 20.5 psia as a result of internal heat generation and alpha decay heat.

4.6 Containment Under Post-Fire Plutonium Air Transport Test

The test conducted under the plutonium air transport fire test in the SAR demonstrated that the TB-1 performed successfully at a temperature of 1080°F and 1110 psia thus setting the criteria for the TB-1 containment vessel. The applicant analyzed the thermal decomposition of O-rings to examine the pressure rise from decomposition of the elastomeric O-rings and ancillary plastic within T-Ampoule, and two SC-2 or three SC-1 sample containers in post-fire plutonium air-transport accident. The configuration with three SC-1s and the selected quantity of ancillary plastic yielded the highest pressure rises as demonstrated in SAR Addendum Subsection 2.12.8 and discussed and summarized in Subsection 4.3.3 of this SER. That subsection demonstrates that the containment vessel meets the criteria of the test.

4.7 Leakage Rate Tests for Type B Package

The PAT-1 leak-testing requirements of the containment boundary are based on the smallest maximum allowable leakage generated from the maximum plutonium content defined in SAR Addendum. The applicant performed the maximum allowable leakage rate analyses, based on ANSI N14.5, for NCT, HAC, and ACATP. The applicant used a worst-case maximum allowable leakage rate to calculate the reference air and the helium leakage rates, using a bounding mass of 1300 grams of plutonium contents in oxide form to certify the leakage criteria, shown in SAR Addendum Table 4.5.6.1.

SAR Addendum Table 4.5.6.1

Isotopic Distribution	Ancillary plastic composition	NCT [a]		HAC [a]		ACATP	
		$L_{R,N-air}$ (ref-cm^3/s)	$L_{R,N-He}$ (cm^3/s)	$L_{R,A-air}$ (ref-cm^3/s)	$L_{R,A-He}$ (cm^3/s)	$L_{R,PA-air}$ (ref-cm^3/s)	$L_{R,PA-He}$ (cm^3/s)
No ^{241}Pu decay	polyethylene terephthalate	5.1244 E-06	8.8373 E-06	9.4686 E-02	9.8072 E-02	1.7546E-03	2.0876E-03
	polyethylene	5.1244 E-06	8.8373 E-06	9.4686 E-02	9.8072 E-02	1.7339E-03	2.0642E-03
	polyvinyl chloride	5.1244 E-06	8.8373 E-06	9.4686 E-02	9.8072 E-02	1.7487E-03	2.0810E-03
	polytetrafluoroethylene	5.1244 E-06	8.8373 E-06	9.4686 E-02	9.8072 E-02	2.1844E-03	2.5725E-03
Complete ^{241}Pu decay to ^{241}Am	polyethylene terephthalate	4.2787 E-06	7.4737 E-06	7.9817 E-02	8.3008 E-02	1.4703E-03	1.7873E-03
	polyethylene	4.2787 E-06	7.4737 E-06	7.9817 E-02	8.3008 E-02	1.4729E-03	1.7673E-03
	polyvinyl chloride	4.2787 E-06	7.4737 E-06	7.9817 E-02	8.3008 E-02	1.4854E-03	1.7816E-03
	polytetrafluoroethylene	4.2787 E-06	7.4737 E-06	7.9817 E-02	8.3008 E-02	1.8549E-03	2.2012E-03

[a] Since temperatures associated with pyrolysis of the ancillary plastics are not reached during NCT and HAC, the various plastics have no affect on the regulatory leakage criteria at those conditions.

The staff reviewed the measured volumetric leakage rates shown in SAR Tables 4-1 and the calculated volumetric leakage rates listed in SAR Addendum Table 4.5.6.1, and agreed that the evaluations on the leak-rate analyses are conservative and are in compliance with 10 CFR 71.51(a)(1), 71.51(a)(2), and 71.64(a)(1)(i):

1) The measured helium leak-rates, shown in SAR Table 4.1, are much below the maximum allowable helium leak rates for (1) no ^{241}Pu decay and complete and for (2) complete ^{241}Pu decay to ^{241}Am under NCT and HAC,

2) The highest measured leakage rate of 4.5 x10^{-5} atm-cm^3/s is less than the maximum allowable regulatory leakage rates of 1.4703 x 10^{-3} ref-cm^3/s at 1110 psia under ACATP, and

3) A maximum mass release of 1.7 x 10^{-4} grams/week (or 0.17 mg/week) is much below the allowable mass release limits of 0.2763 grams/week with no ^{241}Pu decay and 0.2334 grams/week with total ^{241}Pu decay to ^{241}Am, under ACATP conditions.

4.8 Evaluation Findings

Based on the containment evaluation, the staff concluded that the containment design of PAT-1 package has been adequately described, and evaluated and that the package design satisfies the containment requirements of 10 CFR Part 71 under NCT, HAC, and ACATP.

4.8.1 The staff has reviewed the description of the containment system and has reasonable assurance that the information provided in the SAR Addendum satisfies the containment requirements of 10 CFR 71,

4.8.2 The staff has reviewed the calculations used to derive the leakage rates and has reasonable assurance that there shall be no release or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A_2 per hour in 10 CFR 71.51(a)(1) for NCT, A_2 in a week in 71.51(a)(2) for HAC, and A_2 in a week in 71.64(a)(1)(i) for ACATP,

4.8.3 The staff has reviewed the package design, construction, and preparations for shipment and has reasonable assurance that the containment of the package will not extend beyond the specified allowable limits during NCT consistent with the tests specified in 10 CFR 71.71,

4.8.4 The staff has reviewed the package design, construction, and preparations for shipment and has reasonable assurance that the containment of the package will not exceed the specified allowable short-term limits during HAC consistent with the tests specified in 10 CFR 71.73, and

4.8.5 The staff has reviewed the package design, construction, and preparations for shipment and has reasonable assurance that the containment of the package will not exceed the specified allowable short-term limits during ACATP consistent with the tests specified in 10 CFR 71.74.

4.8.6 The electro-refined plutonium metal as defined by the isotopic composition in SAR Addendum Subsection 1.2.2 must be shipped within one year of manufacture.

4.8.7 Each TB-1 with T-Ampoule configuration shall be leak tested to leaktight prior to shipment. The leak rate tests shall be conducted in accordance with ANSI N14.5 using calibrated equipment as described in the SAR Addendum. A radiological survey must be performed on each PAT-1 package prior to shipment. Validation that the survey was performed must be communicated to the package destination and retained by the shipper as part of shipment records. Surface contamination on any accessible part of the package must not exceed the limits specified in 49 CFR 173.443, Table 9. Emanations must not exceed the limits specified in 49 CFR 173.441. Measurement equipment used for surveys must be calibrated and of sufficient accuracy.

4.8.8 The total pressure within TB-1 container must not exceed the design pressure of 1095 psig (1110 psia) under NCT, HAC and ACATP. Prior to loading, the contents should be brushed clean to remove any oxide present on the surface.

5.0 SHIELDING EVALUATION

The objective of this review is to verify that the new proposed contents of the Plutonium Air Transportable Package, Model PAT-1, meet the external radiation requirements of 10 CFR Part 71 under NCT and HAC. The existing license authorizes PuO_2 and its daughter products, or a mixture of PuO_2 and UO_2 and its daughter products. This application amends the license to include Pu metal as authorized payload.

The staff evaluated the source term of the new contents as compared to those of the existing approved contents. The review also looked at the methods and calculations employed by the applicant to determine expected gamma and neutron radiation at locations near the package surface and at specific distances away from the package.

5.1 Shielding Description

5.1.1 Design Features

The PAT-1 consists of a PC-1 stainless steel inner container, a TB-1 stainless steel containment vessel (CV), and an AQ-1 protective overpack assembly. The packaging also consists of the T-Ampoule and its associated hardware for the Pu metal shipments, and the PC-1 and associated hardware for the PuO_2 shipments.

The PAT-1 with Pu metal content containment vessel’s internal configurations will consist of either two SC-2 sample containers nested in the titanium Inner Cradle or three SC-1 sample containers nested in the titanium Inner Cradle, or a Pu metal hollow cylinder with or without tantalum foil wrapped around the outside of the cylinder with the loose ends tucked into the hollow faces of the cylinder. Additionally, crushed/crumpled tantalum foil may or may not surround the cylinder. The T-Ampoule consists of a body (bottom), lid (top) and an O-ring. The body and lid are fabricated from Ti-6Al-4V, Grade 5.

The additional requirements for shipments of Pu by air have been performed.

5.1.2 Summary Table of Maximum Radiation Levels

Maximum NCT and HAC dose rates are reported in Table 5-1. The maximum expected total dose rate expected on the side of the package surface is 59.6 mrem/hr. The dose rate 1m away from the surface is 2.9 mrem/hr. Both of these values are below the limit set in 71.47. Under hypothetical accident conditions, the dose rate at 1m is expected to rise to 5.3 mrem/hr.

5.2 Source Specification

A mass limit is placed on the source materials, depending on the specific composition of the Pu containing materials. In all cases, the source material must be solid. The contents are limited to a maximum mass of 1300 g of Pu metal, or 200 g of Pu contents in the case of plutonium/beryllium (Pu/Be) sources. An additional limitation placed on the Pu/Be sources is a contact surface area of 91 cm^2 or less.

Three source geometries are analyzed: full density, solid sphere of 2.63 cm; reduced density smear that fills the central region; full-density, thin, hollow cylinder with inner and outer radii of 5.249 and 5.4 cm respectively, and a height of 15.11 cm. The shape of the source determines the degree to which the source particles are self-shielded for gamma and the magnitude of the neutron multiplication due to fission.

5.2.1 Gamma Source

The bounding gamma source is based on a limiting Pu isotopic vector. Mass and heat limits are 1300 g and 25 watts, respectively. The mass limits for specific isotopes are listed Table 5-2. Each of the Pu isotopes, with the addition of Am-241 modeled with Pu-241, are assumed to be at their individual isotopic maximum to generate the gamma source. This results in a source equivalent of 2197 g of Pu and 40 W of decay heat, which is beyond the mass and heat limits of the package. This is a conservative adjustment as it overestimates the expected package source term.

A series of 7 depletion calculations are preformed with ORIGEN-ARP, which utilizes the same ORIGEN-S code used to generate the neutron, photon and decay heat values. This code makes an additional step of using tabulated cross-sections for each reactor system expected to produce the plutonium. The three reactors selected are: pressurized water reactor using Westinghouse 17x17 fuel; CANDU reactor; and the Hanford N Reactor. Only the Hanford reactor is calculated at low burnup (2 GWd/t), while all fuel types are analyzed at medium (5 GWd/t for CANDU and Hanford, and 35 GWd/t for PWR fuel) and high burnup (10 GWd/t for CANDU and Hanford, and 60 GWd/t for PWR fuel).

The results of the isotopic depletion calculation are presented in SAR Addendum Table 5-10, with the maximum amount found for each isotope among the fuel type/burnup combinations is used to determine the isotopic fraction presented in SAR Addendum Table 5-11. This should give a realistic estimate of the source material.

5.2.2 Neutron Source

The neutron emission from the Pu/Be source is limited to 363 n/s/cm^2 and accounts for isotopic composition as a result of decay. However, it is the spontaneous fission and alpha-n reactions from the larger Pu metal load that are bounding. As a result, the isotopic basis for the neutron source spectrum is the same as that of the gamma source. The energy spectrum is presented in SAR Addendum Table 5-4, with a neutron emission rates per isotope as a function of decay time presented in SAR Addendum Figure 5-4.

The Pu/Be neutron source magnitude and energy spectrum was analyzed with the SOURCE4C code. The type of source analyzed is known as an interface source, where alpha particles emitted from the Pu (and Am) materials produce n-alpha reactions at the Be interface. The source analysis ignores the alpha barrier typically present during shipping. Since the neutron source rate is dependent on un-shielded surface contact, the bounding surface area was set to that equal of the TB-1 container cross-section. The bounding source term is assumed to be in full maximum surface area contact on both sides of a Pu/Be disk with complete decay of ^{241}Pu to ^{241}Am. The resulting neutron source spectrum is presented in SAR Addendum Table 5-14.

5.3 Shielding Model

Credit is not taken for the T-Ampoule or any packing materials contained therein, the inner redwood assembly or the thicker portions of the TB-1 vessel. All structural components are defined using standard isotopic compositions while also selecting minimal density from other sources, if available. Material compositions are summarized in SAR Addendum Table 5-6.

Since the expected neutron dose rate from a Pu/Be source will be much less than the plutonium metal source under both NCT and HAC, the bounding neutron source in the shielding analysis is assumed to be 100 percent ^{239}Pu to maximize subcritical multiplication.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant investigated various geometry and source placement configurations within the central region of the vessel. The bounding neutron source geometry is the full-density solid sphere situated outward such that the source material is touching the wall of the TB-1 vessel. The bounding source geometry for the gamma dose is the smeared source material filling the central region, which minimizes self-shielding.

The surface and 1m dose rates were estimated using the SAS4 sequence of the SCALE 5.1 package. The cross-section library used was the SCALE 27N-18COUPLE library for both neutrons and photons.

BONAMI/NITAWL was used for cross section processing. The one-dimensional discrete ordinates code XSDRNPM automatically generated the biasing parameters for the final Monte Carlo analysis, which was done with MORSE-SGC. The codes and library used are appropriate for this shielding analysis.

Point detectors were placed at various locations 1 m from the surface. Limitations in the detector model required that surface dose rates be estimated with point detectors 1 cm from the package surface. This will have negligible effect on the predicted surface dose rate.

5.4.2 Input and Output Data

ORIGEN-S input decks are provided, and the output is used to generate the radiation source for the SAS4 shielding program. Sample SAS4 input is provided for 2 cylindrical source configurations under HAC and NCT. Both a SAS1 and SOURCE4C input sample is provided for the Pu/Be spherical source and interface problem, respectively.

5.4.3 Flux-to-Dose-Rate conversion

The flux-to-dose-rate conversion factors are taken from ANSI/ANS-6.1.1-1977 with the neutron and photon group factors listed in SAR Addendum Tables 5-7 and 5-8.

5.4.4 External Radiation Levels

Given the number of bounding and conservative assumptions, the predicted dose rates given in SAR Addendum Table 5-1 are expected to be much higher than the actual dose rates.

5.4.5 Confirmatory Analyses

The staff reviewed the applicants shielding model and analyses. The staff found the software, methods and simplifications to facilitate the analyses to be appropriate and conservative.

The staff performed shielding calculations using MCNP and MicroShield. The MicroShield simulations were used to determine the approximate gamma attenuation expected from the Pu/Be source given the package material and minimum source-to-surface distances listed in SAR Addendum Subsection 5.5.3 and to estimate exposure rates for the package surface. MCNP was used to analyze a nested cylinder model like the one used in the SAS4 analysis with the source spectrum and intensity taken from the SAR Addendum.

5.5 Evaluation Findings

The staff concludes that the design of the shielding system for the PAT-1 is in compliance with 10 CFR Part 71 and the applicable design and acceptance criteria have been satisfied. The evaluation of the shielding system provides reasonable assurance that the PAT-1 will provide a safe package for the transport of solid plutonium metal via air. The staff reviewed the assumptions for both normal conditions of transport and hypothetical accident conditions, and verified the external radiation levels are reasonable assurance that this package satisfies 10 CFR 71.63 and 10 CFR 71.73.

6.0 CRITICALITY EVALUATION

The staff reviewed changes to the criticality analysis for the PAT-1 package as well as the capability of the package to provide adequate protection against any inadvertent criticality from the canister contents when used during air transportation.

6.1 Criticality Design Criteria and Features

The primary feature important for criticality control of the PAT-1 package is the ability of the TB-1 containment vessel to retain the fissile material under NCT and HAC. Due to the limited inner volume of the TB-1, the quantity of water that is available for neutron moderation is limited. Containment integrity is maintained as described in SAR Addendum Chapter 4. During air transport containment integrity is assumed to fail.

6.1.1 Criticality Design Features

The inner volume of the TB-1 has a volume of approximately 0.4 gallons and effectively limits the amount of water that would be available for moderation. Credit is taken for the spacing provided by the package for NCT and HAC. No criticality controls are placed on the packaging materials that may be inside the TB-1, including sample holders and containers, structural supports, tantalum foil, plastic bagging, etc. Optimal water moderation is considered for both NCT and HAC in order to eliminate the need to limit the quantity of hydrogenous packaging materials that may be used within the TB-1 containment vessel.

The staff evaluated the PAT-1 criticality design features and found them acceptable. The applicant’s analysis provides reasonable assurance that the criticality safety design of the package meets the regulatory requirements of 10 CFR Part 71.

6.2 Fissile Material Contents

6.2.1 Plutonium Metal – General Form

The PAT-1 may be loaded with up to 1300 grams of plutonium metal in any geometric form or number of pieces. The isotopic composition of the Pu is not controlled and is assumed to be 100 percent ^{239}Pu. ^{241}Pu is not considered a credible payload since this would require expensive isotopic enrichment and accounts for a very small amount of material available for transport. The Pu may be alloyed with other metals or may contain impurities. These other materials are conservatively left out of the criticality model since they would decrease the density of the modeled Pu and would either have no effect or reduce the reactivity of the system.

Since there are no controls on the geometric form of the Pu metal, the maximum theoretical density of 19.84 g/cm^3 is assumed. Extraneous moisture may be present on the Pu, but is accounted for by modeling the full range of water moderation. Neutron multiplying materials like beryllium or uranium are not permitted in the TB-1 unless identified as a source as indicated in SAR Addendum Subsection 6.2.2.

6.2.2 Plutonium Metal – Pu/Be Sources

Additional restrictions are placed on Pu/Be sources that may be loaded into the TB-1. The maximum amount of Pu metal or alloy is limited to 200 grams and the beryllium allowed is limited to 30 grams. No other neutron multiplying materials are allowed within the TB-1. Full water reflection is evaluated.

6.3 General Considerations

6.3.1 Model Configuration

The applicant focused on modeling one of the allowed package loadings permitted, which was the general form Pu limit of 1300 grams. Since the limits placed on Pu/Be sources are much smaller masses, and the fact that if the Be is replaced with Pu metal on either a mass or volume basis the PAT-1 would still be far below the 1300 gram limit, this makes the 1300 gram evaluation bounding. Full water moderation was used in all cases and varied to ensure that this was the most conservative assumption. Due to the limited volume inside the TB-1 the Pu metal is under moderated in all cases.

A detailed model was constructed using nominal dimensions of the PAT-1 and this model was simplified during the subsequent modeling. This detailed model was used to confirm that the simplified models that were used for most of the parametric studies are adequately conservative. The base simplified model assumed all of the Pu metal was in a spherical configuration and is modeled as various mixtures of ^{239}Pu metal and water. At the maximum theoretical density, the 1300 grams of Pu fills about 4 in^3 of the TB-1, leaving about 86 in^3 of space that is filled with water. The Pu is contained within the TB-1 inner cylindrical volume that was filled with water, and this was centered within either a redwood or water cylinder and contained in a stainless steel shell.

Conditions of reflection outside the package model were varied depending on which model was being used. Full density water reflection is used for the single package analysis. For NCT, nothing is assumed between packages and the entire array is reflected with full density water.

Damaged container models were created for the end-impact and side-impact test cases. This resulted in a shorter model in the first case and a hemispherical model in the second. The final damaged container model was created specifically for 10 CFR 71.55(f) to meet the requirement to ship fissile material packages by air. The model assumed varying radii of ^{239}Pu metal spheres with a mass of 1300 grams and reflected by 20 cm of water to demonstrate that provided there is no leakage of water into the TB-1 containment vessel, a single package is subcritical without taking credit for the geometry of the package or the continued presence of any package structural materials.

The staff evaluated the criticality models and found them acceptable. The material compositions and densities used were appropriate and provide reasonable assurance that the PAT-1 was adequately modeled.

6.3.2 Material Properties

The materials used in the PAT-1 package include ^{239}Pu metal, water, PH13-8Mo stainless steel, redwood, SS-304, aluminum and copper as identified in Table 6-2 of the SAR Addendum. The fissile material was evaluated over a wide range of densities and homogeneously mixed with water. Water densities were varied from zero to full density. The PH13-8Mo stainless steel contains trace elements that are either absorbers or weak moderators and are modeled as described in Table 6-3 of the SAR Addendum.

Although the load spreader contains cadmium-plated copper, the cadmium was omitted from the model since Cd is a strong thermal neutron absorber and would decrease the reactivity of the package.

6.3.3 Computer Codes and Cross-Section Libraries

The SCALE 5.1 computer software package was used for all analysis and validation calculations using the CSAS25 sequence and the 238 energy group ENDF/B-VI nuclear data.

6.3.4 Demonstration of Maximum Reactivity

6.3.4.1 For the single package under NCT a parametric study evaluated the impact on k_{eff} from various modeling approximations and determined that the maximum reactivity is achieved by replacing the redwood and steel of the package with full density water and when the 1300 grams of Pu metal is spread throughout the inside of the intact TB-1 containment vessel and mixed with the maximum quantity of water that could also be present. Additional calculations were performed to demonstrate that the detailed model was bounded by the simplified model used in the evaluation.

6.3.4.2 For arrays of packages under NCT calculations were performed by placing undamaged packages in both square and hexagonal arrays and varying the contents from pure ^{239}Pu metal to Pu-water mixtures. The maximum k_{eff}+2σ under NCT was found to be 0.651 for a package containing a pure metal sphere in a hexagonal array of 2646 packages.

6.3.4.3 For arrays of packages under HAC, both the end-impact and side-impact cases were analyzed, and the maximum k_{eff}+2σ was found to be during side-impact with 1300 grams Pu mixed with 1412 grams water in 1152 packages in a hexagonal array as depicted in Figure 6-12 of the SAR Addendum.

6.3.4.4 For air shipment of fissile material, additional HAC requirements under 10 CFR 71.55(f) were addressed assuming no water in-leakage for a single package. Although no water in-leakage is assumed, the analysis does assume that up to 1412 grams of water may be inside the TB-1 as a bounding model to account for the presence of hydrogenous and other materials that do not multiply neutrons. Due to the limited quantity of Pu and hydrogenous packaging material that could be present in the TB-1 containment vessel, a criticality is not possible in a single package. The Pu sphere was varied in dimension and water moderation and reflected by 20 cm of full density water and found that the maximum k_{eff}+2σ was 0.7148. All structural materials, package materials, and package dimensions are not taken credit for in this evaluation.

6.3.4.5 Staff performed confirmatory analyses on the most reactive configurations described by the applicant. The SCALE6 computer software package was used using continuous energy cross section data. Significant parameters were varied to ensure maximum reactivity peaks were adequately captured and in all instances staff calculations agreed with those performed by the applicant.

6.4 Single Package Evaluation

6.4.1 Configuration

The bounding model is the simplified model described in SAR Addendum Subsection 6.3.1 where the redwood and outer steel container is replaced with water. 1300 grams of ^{239}Pu was distributed within the internal volume of the TB-1 containment vessel and mixed homogenously with 1412 grams of H2O, with the entire package reflected by 30 cm of full density water. This model is bounding for both the single package NCT and HAC since the TB-1 is modeled as holding as much water as physically possible. The redwood, load spreader, gaps, and outer steel drum are all modeled as full density water, therefore, no further in-leakage of water is possible.

6.4.2 Results

The maximum $k_{eff}+2\sigma$ was found to be 0.7077. This is considerably under the upper subcritical limit of 0.9456 applicable to this case and demonstrates that a single package is subcritical under NCT and HAC.

6.5 Evaluation of Package Arrays under NCT

6.5.1 Configuration

Using the bounding simplified model described above, the packages were arranged in a 19x15.5x9 hexagonal array containing 2646 packages and reflected on all sides by 30 cm of full density water.

6.5.2 Results

The maximum $k_{eff}+2\sigma$ was found to be 0.6510. This is considerably under the upper subcritical limit of 0.8893 applicable to this case and demonstrates that array of up to 2646 packages is subcritical under NCT, and therefore the proposed array limit of 2500 packages is also subcritical under NCT, corresponding to a CSI of 0.1.

6.6 Evaluation of Package Arrays under HAC

6.6.1 Configuration

Using the bounding simplified model, the maximum reactivity was found using the side impact scenario. Packages were modeled with 1152 packages in a near cubic array and pairs of packages were arranged in a tight fitting hexagonal array as shown in Figure 6-12 and mirrored on both the bottom and left hand side. Optimum interstitial moderation was modeled and the entire array was reflected by 30 cm of full density water.

6.6.2 Results

The maximum $k_{eff}+2\sigma$ was found to be 0.7155. This is considerably under the upper subcritical limit of 0.9396 applicable to this case and demonstrates that array of up to 1152 packages is subcritical under HAC, and therefore the proposed array limit of 1000 packages is also subcritical under HAC, corresponding to a CSI of 0.1.

6.7 Fissile Material Packages for Air Transport

6.7.1 Configuration

Based on the evaluation performed in SAR Addendum Subsection 6.3.4.4, the limiting configuration is a Pu metal sphere with a radius of 7.067 cm containing 1300 grams of ^{239}Pu mixed homogenously with 1412 grams of water and reflected by 20 cm of full density water.

6.7.2 Results

The maximum k_{eff}+2σ was found to be 0.7148. This is considerably under the upper subcritical limit of 0.9462 applicable to this case and demonstrates that a single package with no water in-leakage is subcritical without taking credit for packaging materials and dimensions.

6.8 Benchmark Evaluations

Staff reviewed the benchmark evaluations and bias determination performed by the applicant and found them to be applicable for each identified case. In all instances an administrative margin of 0.05 was used. The upper safety limit (USL) and bias were determined using nonparametric methods for all but two of the applications since they did not fit a normal distribution. These were determined using the number of benchmark configurations to validate the application and a desired population fraction of 0.95 above the minimum k_{eff}. The USL was then determined by subtracting the administrative margin, the nonparametric margin, and two standard deviations from the minimum k_{eff} value. For the two cases that fit a normal distribution, the USL was calculated using USLSTATS.

6.9 Burnup Credit

Burnup credit is not used in the PAT-1.

6.10 Evaluation Findings

6.10.1 SAR Addendum Chapter 6, sufficiently describes the packaging design in sufficient detail to allow evaluation of their effectiveness for criticality safety and is in compliance with 10 CFR Part 71.

6.10.2 The fissile material contents are described in sufficient detail to provide a basis for the criticality evaluation of the PAT-1.

6.10.3 The staff has reviewed the criticality description and evaluation of the package and concludes that it addresses the criticality safety requirements of 10 CFR Part 71.

6.10.4 The staff has reviewed the criticality evaluation of a single package and concludes that it is subcritical under the most reactive credible conditions.

6.10.5 The staff has reviewed the criticality evaluation of the most reactive array of 5N packages and concludes that it is subcritical under normal conditions of transport.

6.10.6 The staff has reviewed the criticality evaluation of the most reactive array of 2N packages and concludes that it is subcritical under hypothetical accident conditions, including those conditions applicable under air transport.

6.10.7 The staff has reviewed the benchmark evaluation of the calculations and concludes that they are sufficient to determine an appropriate bias and uncertainties for the criticality evaluation of the package.

6.11 References

1. U.S. Code of Federal Regulations, PACKAGING AND TRANSPORTATION OF RADIOACTIVE MATERIAL, Title 10, Part 71.

2. U.S. Nuclear Regulatory Commission, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, NUREG-1617, January 2000.

7.0 PACKAGE OPERATIONS EVALUATION

The objective of this review is to verify that the operations used to load and unload the proposed plutonium metal contents for the PAT-1 package with T-Ampoule meet the requirements of 10 CFR Part 71 and that the operating procedures are adequate to assure this air-transportable package will be operated in a manner consistent with its evaluation for approval.

7.1 Package Loading

7.1.1 Preparation for Loading

The applicant listed the procedures for package loading preparation. The applicant will inspect the overpack (AQ-1), containment vessel (TB-1), O-ring, Ring Filler, T-Ampoule, titanium Inner Cradle, and sample containers (SC-1s and SC-2s) to ensure the package is not damaged and both radiation and surface contamination levels are within the allowable limits.

Each TB-1 with plutonium metal content must be leak tested to leaktight (1.0×10^{-7} ref-cm^3/s) prior to shipment. The leak rate test must be conducted in accordance with ANSI N14.5 using calibrated equipment as described in SAR Addendum. The PAT-1 with plutonium metal content package's TB-1 containment vessel should maintain the leak rates below the allowable limits under NCT, HAC, and ACATP (SAR Addendum Table 4.5.6.1).

7.1.2 Loading of Contents

The applicant listed the procedures for loading a payload to the PAT-1 package with T-Ampoule in SAR Addendum Subsection 7.1.2, including loading Pu metal hollow cylinder or sample containers into T-Ampoule, loading T-Ampoule into TB-1 container, closing TB-1 container, and loading TB-1 into overpack (AQ-1).

7.2 Package Unloading

The applicant provides adequate procedures for unloading the contents from the PAT-1 packaging in SAR Addendum Subsection 7.2. Procedures are provided for removing the TB-1 containment vessel from the assembled PAT-1, removing the T-Ampoule from the TB-1 containment vessel, and unloading the T-Ampoule Assembly.

7.3 Preparation of Empty Package for Transport

The applicant provides adequate procedures for preparing the PAT-1 with or without an empty T-Ampoule.

7.4 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the operating procedures meet the requirements of 10 CFR Part 71 and these procedures are adequate to assure the package will be operated in a manner consistent with its evaluation for approval.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

The staff reviewed the PAT-1 with T-Ampoule configuration transport package to ensure that the package will be tested and maintained in accordance with 10 CFR Part 71, and to ensure that the welding examinations, the fabrication leakage rate tests and the maintenance/periodic leakage rate tests are done in accordance with regulatory requirements.

8.1 Acceptance Tests

SAR Addendum Subsection 8.1 specifies review, inspection, and testing of the package. The acceptance tests and inspections considered critical to the safe operation of the PAT-1 package are requirements in CoC.

8.1.1 Visual Inspections and Measurements

The visual inspections are mainly performed for T-Ampoule components during fabrication. The inspections include, but not limited to, markings, surface conditions, and measurements (i.e., tolerance dimensions, positioning, edge breaks, and surface finish).

8.1.2 Weld Inspections

There are no welds in the T-Ampoule components. The weld examinations are not applicable.

8.1.3 Structural and Pressure Tests

The containment vessel TB-1 shall be pressure-tested, as described in CoC USA/0361B(U)F-96, in accordance with 71.85(b). The T-Ampoule assembly, SC-1 assembly, and SC-2 assembly are not containment vessels, and therefore the pressure tests are not required for acceptance and maintenance.

8.1.4 Leakage Tests

The acceptance tests of the T-Ampoule components are described in SAR Addendum Table 8-2. The leakage tests of the acceptance tests for T-Ampoule assembly, SC-1 assembly, and SC-2 assembly are tested to 10^{-3} ref-cm^3/s for retention of the glove box atmosphere for product quality. The containment TB-1 with a metal seal is tested to 10^{-7} ref-cm^3/s for acceptance leak tests.

8.1.5 Component Tests

The O-rings for T-Ampoule, SC-1 and SC-2 shall be inspected for cracks, gouges or other damage.

8.1.6 Thermal Tests

Thermal testing is not required, since the maximum heat generation of the payload is the same as that in the SAR.

8.2 Maintenance Tests

The applicant provides adequate maintenance tests for the PAT-1 with T-Ampoule transport package. The periodic test and maintenance requirements for the TB-1 containment vessel are described in SAR Subsection 8.3.1 and amended in SAR Addendum Subsection 8.2.2. The TB-1 copper gasket is replaced prior to every use therefore there are no maintenance requirements for the TB-1 copper gasket.

8.2.1 Structural and Pressure Tests

There are no structural or pressure test required for maintenance of the T-Ampoule components.

8.2.2 Leakage Tests

The T-Ampoule assembly is not a containment boundary for NCT, HAC, and ACATP. The SAR Addendum defines the leakage rate test requirements for T-Ampoule, SC-1, and SC-2.

8.2.3 Component and Material Tests

The O-rings for T-Ampoule, SC-1 and SC-2 shall be inspected for cracks, gouges or other damages.

8.2.4 Thermal Tests

Thermal testing is not required, since the maximum heat generation of the payload is the same as that in the SAR.

8.2.5 Miscellaneous Tests

Subsection 8.1.8 of the SAR Addendum describes an annual test to ensure the SC-1 and SC-2 sample containers fit and function properly with the titanium Inner Cradle of the T-Ampoule Assembly. It also provides inspection and repair instructions if tightness is observed.

8.3 Evaluation Findings

Based on review of the statements PAT-1 with plutonium metal content transport package application, the staff concludes that the acceptance tests for the packaging meet the containment requirements of 10 CFR Part 71 and that the maintenance program is adequate to assure packaging containment performance during its service life.

CONDITIONS

The following are conditions in CoC No. 0361, Revision No. 10:

- The PAT-1 is designated as a Category I Type B fissile material package with the maximum content of 831 g (1.83 lb) of plutonium metal.
- The TB-1 O-ring is removed from PAT-1 design for the plutonium metal shipment per this SAR Addendum.
- The TB-1 with plutonium metal contents is limited to 2.1 kg (4.7 lb).
- The total plutonium content weights in the T-Ampoule are limited to 731-831 grams of electro-refined or alloyed Pu for Pu metal hollow cylinder, or 0-522 grams of alloyed delta phase Pu metal for SC-1 configuration (maximum of 174 grams/SC-1), or 0-676 grams of alloyed delta phase Pu metal for SC-2 configuration (maximum of 338 grams/SC-2), or 0-180 grams of bonded Pu/Be metal content for SC-1 configuration (maximum of 60 grams/SC-1), or 0-120 grams of bonded Pu/Be metal content for SC-2 (maximum of 60 grams/SC-2).
- The maximum decay heat of the PAT-1 package is 25.0 watts.
- The electro-refined plutonium metal as defined by the isotopic composition in SAR Addendum Subsection 1.2.2 must be shipped within one year of manufacture.

- Each TB-1 with T-Ampoule configuration shall be leak tested to leaktight prior to shipment. The leak rate tests shall be conducted in accordance with ANSI N14.5 using calibrated equipment as described in the SAR Addendum. A radiological survey must be performed on each PAT-1 package prior to shipment. Validation that the survey was performed must be communicated to the package destination and retained by the shipper as part of shipment records. Surface contamination on any accessible part of the package must not exceed the limits specified in 49 CFR 173.443, Table 9. Emanations must not exceed the limits specified in 49 CFR 173.441. Measurement equipment used for surveys must be calibrated and of sufficient accuracy.

- The package shall be prepared for shipment, operated, tested, and maintained in accordance with Chapter 7 and Chapter 8 of the SAR and/or SAR Addendum, as applicable.

- The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

- The certificate expires on December 31, 2015.

CONCLUSION

NRC staff evaluated the Model No. PAT-1 package and documented the security assessment separately, as it contains sensitive information that cannot be made publicly available. The security assessment should be reviewed prior to approval of any amendment to this application.

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, the staff concludes that the PAT-1 with T-Ampoule Assembly transport package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 0361, Revision No. 10,
on December 23, 2010 .