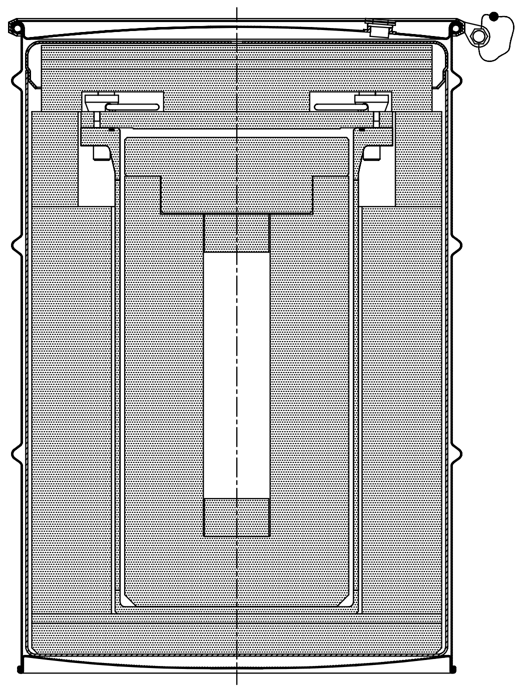
Los Alamos NATIONAL LABORATORY EST. 1943

DOCKET 71-9329

S300

Fissile Material Transport Package



Safety Analysis Report

Revision 1
November 2006

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1. GENERAL INFORMATION

This chapter of the Safety Analysis Report (SAR) presents a general introduction and description of the model **S300** packaging. The S300 packaging is identical to the S300 pipe overpack currently used as a payload container within the TRUPACT-II[1], and is qualified as a DOT 7A Type A transportation packaging. This application seeks validation of the S300 packaging as a Type AF-96 fissile materials shipping container per the definitions in 10 CFR §71.4[2].

The major components comprising the S300 packaging are discussed in Section 1.2.1, *Packaging*, and a detailed drawing of the package design is presented in Section 1.3.1, *Packaging General Arrangement Drawings*.

1.1 Introduction

The S300 packaging has been developed as a safe means for transporting a single Los Alamos Special Form Capsule (SFC). Radioactive contents consist of ^{239}Pu contained in plutonium-beryllium (PuBe) sealed neutron sources. As determined in Section 1.2.2, *Contents*, the S300 package carries a Type A quantity of fissile material with a Criticality Safety Index (CSI) of zero. The S300 package is designed for transport via highway, rail, or vessel. The S300 is designed, fabricated, and used according to the Quality Assurance program requirements discussed in Chapter 9, *Quality Assurance*.

1.2 Package Description

1.2.1 Packaging

1.2.1.1 Packaging Description

As illustrated in Figure 1-1, the S300 packaging is functionally divided into three parts: 1) the impact-absorbing protection provided by the 55-gallon drum and dunnage, 2) the confinement vessel consisting of the pipe component, and 3) the neutron shielding provided by the high-density polyethylene (HDPE) shielding insert. Containment and criticality control are afforded by the SFC. The S300 packaging is identical to the S300 Pipe Overpack, described in Section 4.4 of the CH-TRU Payload Appendices.

Overpack Components. The S300 package design utilizes a standard 55-gallon drum as an outer container. A standard bolted clamping ring secures the drum lid to the drum body. The drum, clamping ring, and bolt may be plated or painted carbon steel, or bare stainless steel. A rigid polyethylene liner (body and lid) is located within the inside periphery of the drum. The liner lid is pierced and the drum lid is fitted with a filter vent to allow continuous venting of the volume

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[1] U.S. Department of Energy (DOE), *Safety Analysis Report for the TRUPACT-II Shipping Package*, USNRC Certificate of Compliance 71-9218, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

[2] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Packaging and Transportation of Radioactive Material, 01-01-06 Edition.

within the drum. Cane fiberboard dunnage is used within the poly liner to hold the pipe component in an approximately central position and to absorb shock. The lower shock absorbing buffer includes a sheet of exterior plywood. Using shims of fiberboard or plywood, the clearance between the dunnage and the interior surface of the liner lid is maintained to less than 1/2 inch.

Pipe Component. As illustrated in Figure 1-2, the pipe component consists of a cylindrical pipe welded to a flat cap at the bottom end and a pipe bolting flange at the other end. The pipe component is closed with a flat lid which is attached by 12, 7/8-9 UNC stainless steel bolts having a minimum tensile strength of 75,000 psi. The weldment and lid are made from ASTM Type 304 or 304L stainless steel material. The lid features two lift rings located on the bolt circle, or optionally, a single, centrally located lift ring. A filter vent is installed in the lid. The lid/flange joint features a butyl or ethylene/propylene rubber O-ring dust seal of nominally 3/16 inch cross sectional diameter.

The maximum outer diameter of the pipe is 12.8 inches, the outer diameter of the flange is 16.3 inches, and the overall maximum length (including lifting rings and bolt heads) is 27.5 inches. The minimum thickness of the pipe wall is 0.219 inches, and the minimum thickness of the bottom cap is 0.25 inches. The nominal thickness of the lid is 0.9 inches.

Shielding Insert. The neutron shielding insert is a two-part assembly consisting of a cylindrical body and stepped lid which nominally fills the cavity within the pipe component. The shielding lid is held in place by the bolted lid of the pipe component. The insert is made from solid, high-density polyethylene (HDPE) plastic. The thickness of the sides and ends is nominally four inches. Supplemental shield plugs having a thickness of two inches are used at both ends of the payload cavity. The remaining payload cavity is nominally 13 inches long and 3.5 inches in diameter.

Two specific SFC types are used within the S300 package, as discussed in greater detail in Section 1.2.2, *Contents*.

1.2.1.2 Gross Weight

The gross shipping weight of the S300 package is a maximum of 480 pounds. A summary of component weights is provided in Table 2-1 of Section 2.1.3, *Weights and Centers of Gravity*.

1.2.1.3 Neutron Moderation and Absorption

The S300 package does not require specific design features to provide neutron moderation and absorption for criticality control. Fissile material in the payload is limited to an amount that ensures safely subcritical packages for both NCT and HAC. The fissile material limit is based on an optimally moderated and reflected configuration of fissile material. An infinite array of bare SFCs is safely subcritical as discussed in Chapter 6, *Criticality Evaluation*.

1.2.1.4 Receptacles, Valves, Testing, and Sampling Ports

A filter vent through the S300 packaging drum lid and a second filter vent in the pipe component lid comprise the only penetrations to the payload cavity. The SFC is not vented. No other receptacles, valves, testing, or sampling ports are utilized on the S300 packaging.

1.2.1.5 Heat Dissipation

The S300 package is designed with a passive thermal system. The amount of decay heat generated by the maximum payload is insignificant, as discussed in Section 3.1.2, *Content's Decay Heat*.

1.2.1.6 Coolants

Due to the passive heat transfer design of the S300 package, no coolants are utilized.

1.2.1.7 Protrusions

The external configuration of the S300 packaging is that of a standard 55-gallon drum, and consequently has no significant protrusions.

1.2.1.8 Lifting and Tie-down Devices

The S300 packaging is lifted, handled, and tied down using separate hardware designed for these purposes. Consequently, there are no lifting or tiedown devices which are an integral or structural part of the packaging.

1.2.1.9 Pressure Relief System

Containment of radioactive materials is afforded by the payload SFC, which has no pressure relief devices. As discussed earlier, one filter vent is located in the drum lid and one in the pipe component lid.

1.2.1.10 Shielding

As discussed in Chapter 5, *Shielding Evaluation*, the payload sources emit alpha particles and neutrons. The HDPE neutron shielding insert is used to demonstrate compliance with NCT dose limits. As will be demonstrated, no shielding is required for compliance with HAC dose limits.

1.2.2 Contents

The S300 package transports a single Special Form Capsule (SFC) with total contents not exceeding 350 grams ^{239}Pu in solid form in a plutonium-beryllium (PuBe) sealed neutron source. Table A-1 of 10 CFR 71 states the specific activity of ^{239}Pu as 0.0023 TBq/gram. For 350 grams, the maximum activity of the contents is therefore 0.805 TBq. Per Table A-1 of 10 CFR 71, the A_1 limit for special form material is 10 TBq; thus, the S300 package carries a Type A quantity of radioactive material.

There are two different SFC models of similar design, carrying the designations Model II and Model III. Each is fabricated of Type 304 stainless steel, with a nominal wall thickness of 1/2 inch, and bottom and threaded top cap thicknesses of 3/4 inch. The top cap holds a tapered sealing plug in place, and is designed with a shearable stem to preclude removing the cap once installed. The Model II has an additional impact plug held loosely in place with a snap ring. The capsule dimensions are given in the following table.

Capsule	Outer Diameter, in	Outer length, in*
Model II	3.0	11.75
Model III	2.5	7.0

*After stem shear-off.

The Model II SFC is shown in Figure 1-3, and the Model III SFC is shown in Figure 1-4. Additional discussion of the special form capsules is provided in Section 2.10, *Special Form*. Table 1-1 gives the maximum contents for the S300 package for the Model II and Model III capsules under non-exclusive and exclusive use.

Table 1-1 - S300 Package Contents Limits, grams of ^{239}Pu

Payload Type	Non-Exclusive Use		Exclusive Use	
	Model II SFC	Model III SFC	Model II SFC	Model III SFC
Plutonium-Beryllium Sealed Sources	206	160	350	160

1.2.3 Special Requirements for Plutonium

The S300 package contains a maximum of 350 grams of ^{239}Pu in solid form. Therefore, no special requirements apply.

1.2.4 Operational Features

The S300 package is not considered to be operationally complex. All operational features are readily apparent from an inspection of the drawing provided in Section 1.3.1, *Packaging General Arrangement Drawings*, and the previous discussions presented in Section 1.2.1, *Packaging*. Operational procedures and instructions for loading, unloading, and preparing an empty S300 package for transport are provided in Chapter 7, *Operating Procedures*.

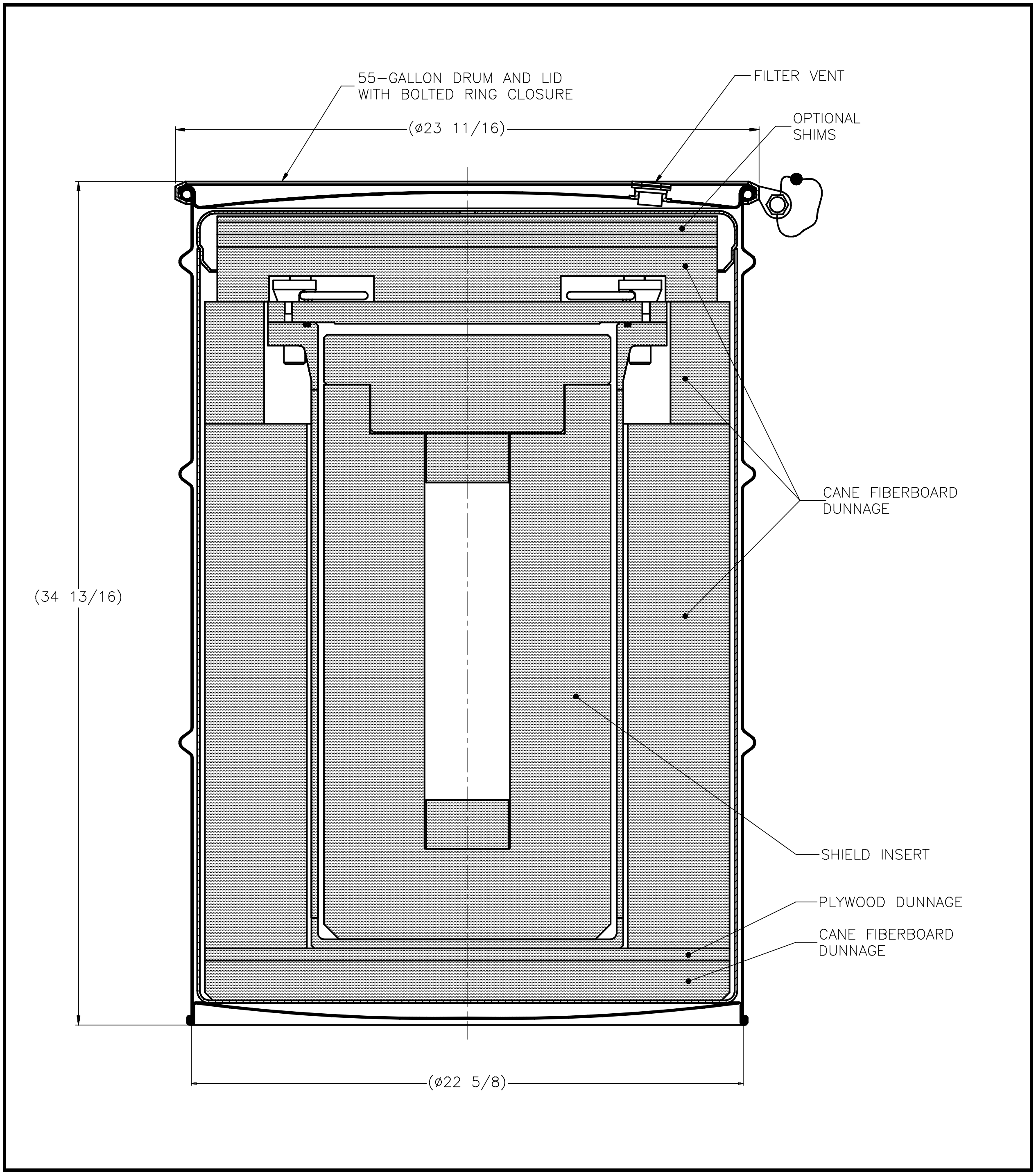

Figure 1-1 – S300 Package Configuration

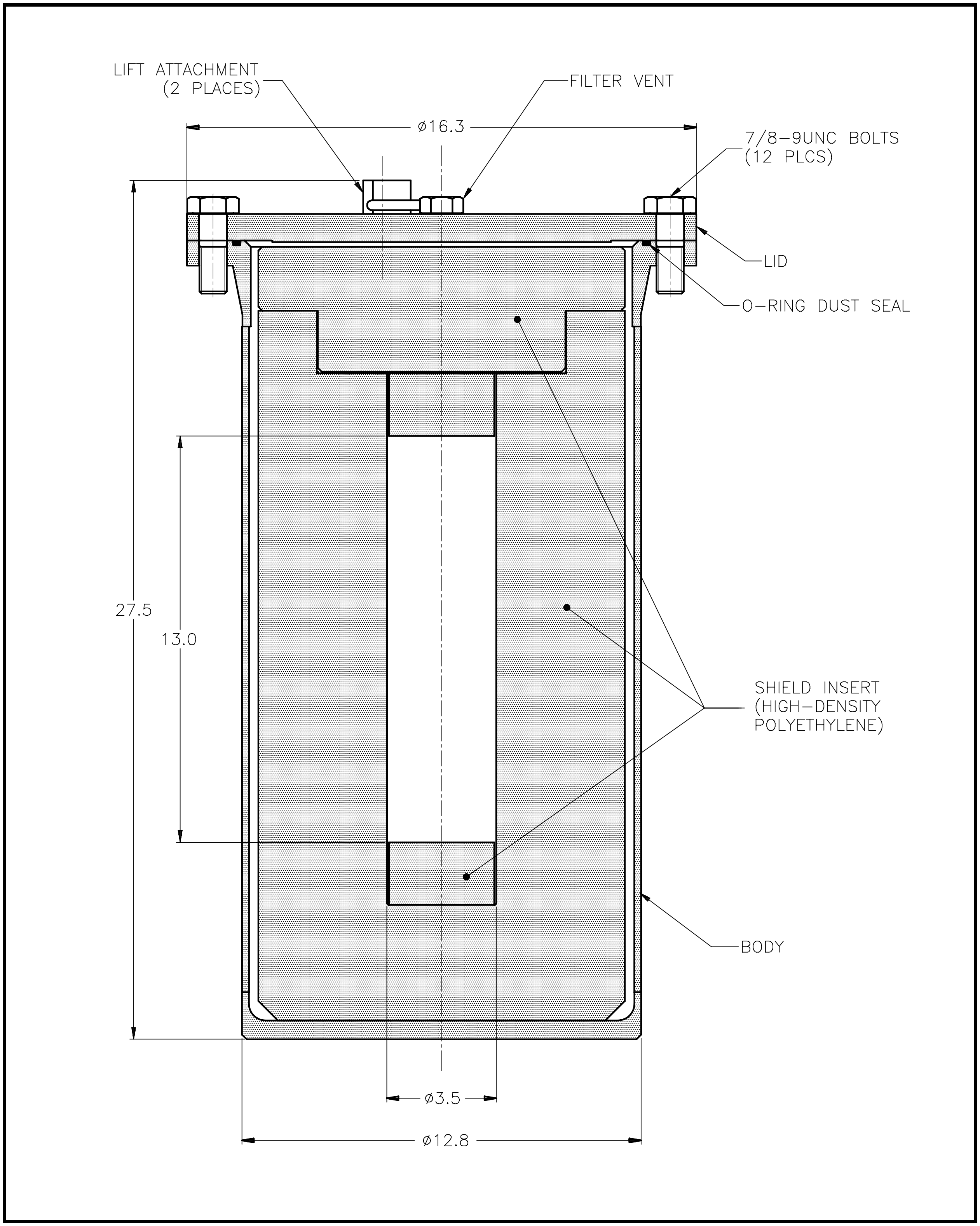

Figure 1-2 – Pipe Component (Confinement Vessel) Configuration

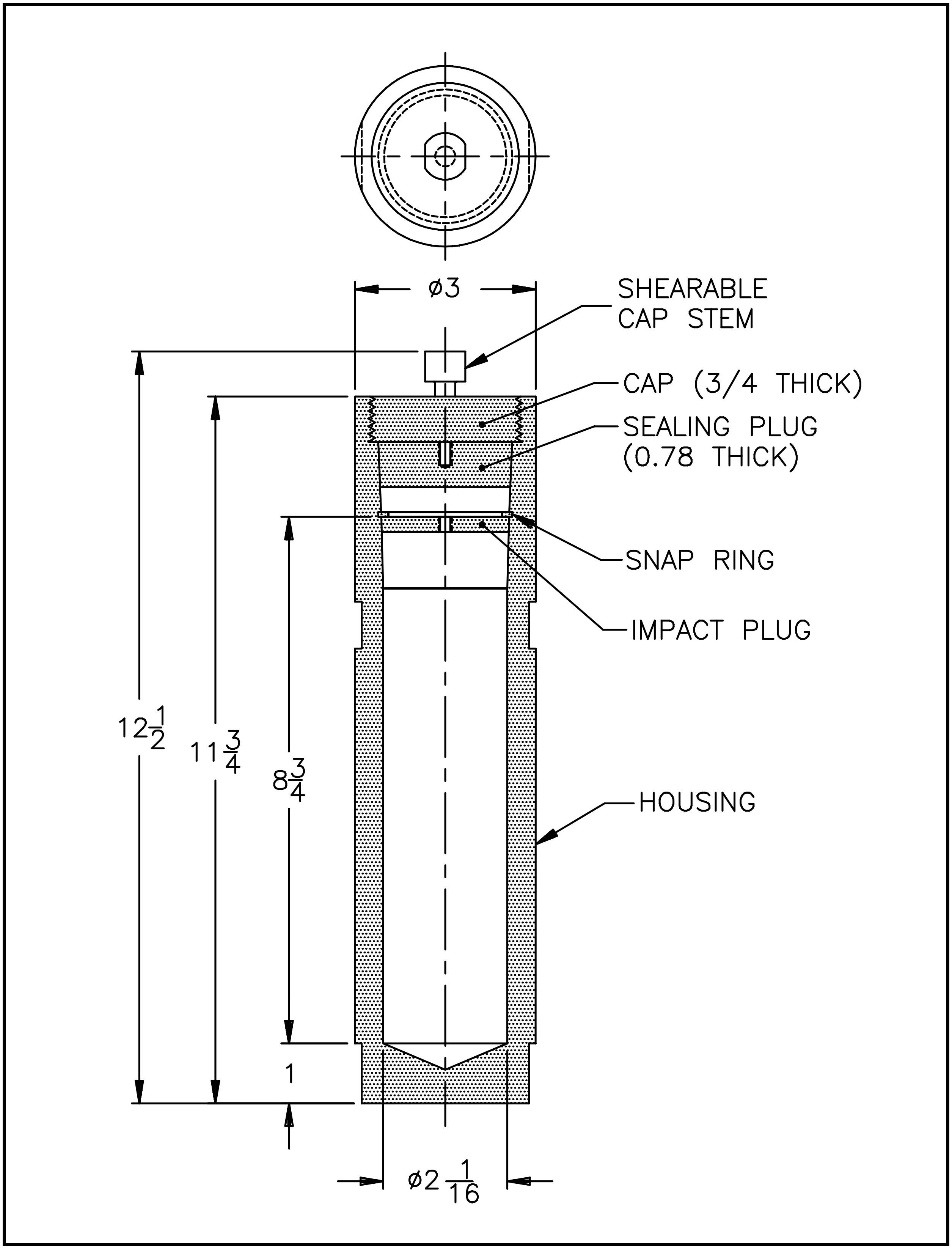

Figure 1-3 – Model II Special Form Capsule

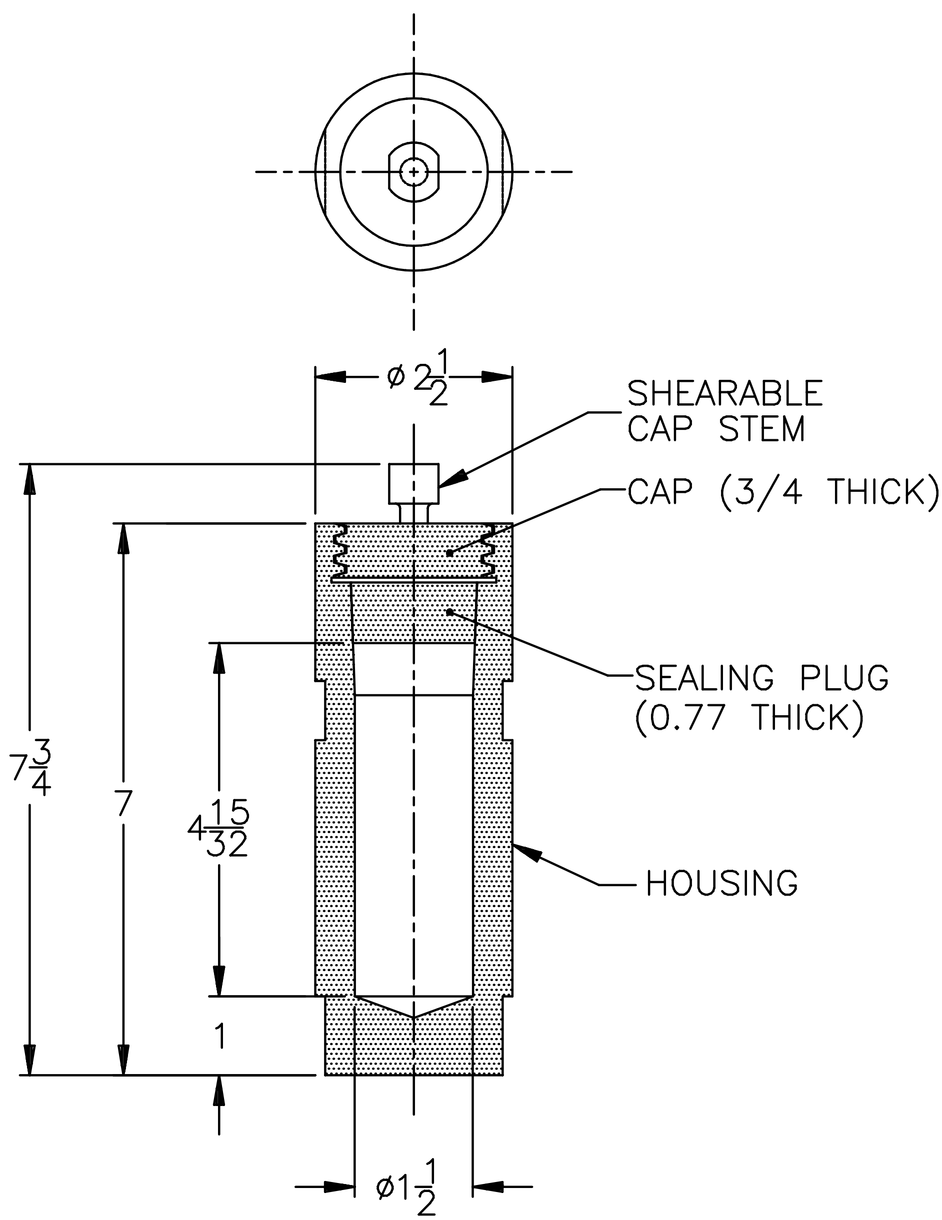

Figure 1-4 – Model III Special Form Capsule

1.3 Appendix

1.3.1 Packaging General Arrangement Drawings

(60999-SAR, 3 sheets)

2. STRUCTURAL EVALUATION

This chapter identifies and describes the principal structural design aspects of the S300 package, and demonstrates the structural safety of the packaging system and compliance with the structural requirements of 10 CFR 71. Demonstration of compliance is accomplished using a combination of performance tests, reference to previous demonstrations, and reasoned argument.

For normal conditions of transport (NCT), demonstration of compliance is by testing of a S300 package prototype (vibration, free drop, corner drop) and by reference to tests of similar packages (water spray, stacking, penetration). For hypothetical accident conditions (HAC), demonstration is by reference to tests of similar packages, showing that the environment provided for the SFC by the S300 package in the free drop, puncture, and fire tests is bounded by the tests used to qualify the capsules as special form.

2.1 Description of Structural Design

2.1.1 Discussion

The S300 package is designed to transport a single Los Alamos Special Form Capsule (SFC). Radioactive contents consist of ^{239}Pu contained in a PuBe sealed neutron source. Transport is by highway, rail, or vessel.

The packaging is functionally divided into three parts: 1) the impact-absorbing protection provided by the 55-gallon drum and dunnage, 2) the confinement vessel consisting of the pipe component, and 3) the neutron shielding provided by the high-density polyethylene (HDPE) shielding insert. Containment of radioactive material is afforded by the SFC, per 10 CFR §71.4.

The S300 package employs cane fiberboard dunnage within the overpack to provide attenuation of shock loading during normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The pipe component, made of austenitic stainless steel, provides a compact, robust confinement for the SFC during NCT and during most HAC events. While the pipe component may not remain fully intact following the entire series of HAC mechanical test events, it nonetheless provides an environment that is less severe than the mechanical testing performed on the special form capsule during its qualification. The shielding insert provides, besides biological shielding of neutrons, further attenuation of shock and vibration. Of note, the shielding analysis documented in Chapter 5, *Shielding Evaluation* and the criticality evaluation documented in Chapter 6, *Criticality Evaluation*, demonstrate that an adequate level of biological shielding and subcriticality under worst-case moderation, respectively, are maintained by a bare capsule under HAC.

2.1.2 Design Criteria

The S300 package, in conjunction with the SFC, has been designed to meet all the applicable structural requirements of 10 CFR 71. The design objectives for the S300 package are twofold:

1. Demonstrate that, under NCT, the S300 package maintains confinement of the SFC within the shield insert, and experiences an insignificant reduction in its effectiveness to withstand HAC; and
2. Demonstrate that the environment afforded to the SFC by the S300 under HAC is bounded by the environment to which the SFC was exposed during special form qualification testing.

Consequently, the design criteria for NCT are that the S300 package exhibit only minor damage subsequent to the NCT conditions and tests, including no damage that would materially affect the outcome of a subsequent HAC test.

For HAC, the design criteria are that the S300 package protect the SFC from conditions more severe than those experienced in the special form qualification 9-meter free drop, percussion, and heat tests specified in 10 CFR §71.75.

Material properties are controlled by the acquisition of critical components to ASTM standards, as described in Section 2.2, *Materials*.

The materials utilized in the S300 package are not subject to brittle fracture. The steel drum, due to its thin section (approximately 0.055 inches) is not susceptible to brittle fracture at cold temperatures. The pipe component and lid bolts are made from austenitic stainless steel, and are thus not subject to brittle fracture.

The S300 package is normally used for one-time shipment and permanent storage, and is consequently not subject to cyclic usage fatigue. If used more than once, the only components of the S300 package which could be subject to cyclic usage stress are the fasteners. These items (the pipe component lid bolts and the drum closure ring bolt) are few and simple, and can be adequately inspected to ensure integrity prior to use. Fatigue associated with normal vibration over the road is discussed in Section 2.6.5, *Vibration*.

2.1.3 Weights and Centers of Gravity

Weights of the S300 packaging components are presented in Table 2-1. Due to the symmetric design, the center of gravity is located approximately at the geometric center of the package.

Table 2-1 – S300 Component Weights

Component	Weight (lb)
Overpack (drum, liner, dunnage)	180
Pipe Component (empty)	180
Shield Insert	90
Special Form Capsule (Loaded)	30
Total:	**480**

2.1.4 Identification of Codes and Standards for Package Design

The S300 package functions primarily as an overpack for the SFC. In lieu of reliance on the use of codes or standards in design, compliance with requirements is demonstrated via full scale testing of the S300 package for NCT, and via U.S. DOT special form certification of the SFC for both NCT and HAC.

2.2 Materials

2.2.1 Material Properties and Specifications

The S300 packaging is constructed of several common structural materials, such as carbon steel, stainless steel, cane fiberboard, and high density polyethylene (HDPE). The pipe component is made from ASTM Type 304/304L stainless steel, having a minimum yield strength of 25,000 psi and a minimum ultimate strength of 70,000 psi. The pipe component lid bolts are made from stainless steel having a minimum ultimate strength of 75,000 psi. The cane fiberboard dunnage is made from ASTM C208 material, having a minimum density of 14 lb/ft^3.

2.2.2 Chemical, Galvanic, or Other Reactions

The materials of construction are inherently resistant to chemical or galvanic corrosion. Deleterious corrosion or other reactions are not anticipated during normal use. In addition, all of these materials have been used in Type A packagings for many years without incident. However, if unusual corrosion of the carbon steel outer drum occurs, this can be readily detected during preparation of the packaging for use. Both the pipe component and the SFC are made from austenitic stainless steel. The other packaging components, such as HDPE and fiberboard, are not subject to chemical degradation or corrosion during normal use.

2.2.3 Effects of Radiation on Materials

The radioactive contents of the SFC generate primarily neutrons via a α-n reaction. Most of the neutrons are captured by the shield insert before reaching any other components of the packaging. In any case, the payload represents a relatively weak source of neutrons, and no significant degradation of the materials of the packaging will occur. Thus, the requirements of 10 CFR §71.43(d) are satisfied.

2.3 Fabrication and Examination

2.3.1 Fabrication

The S300 packaging uses conventional processes for the fabrication of the packaging components. No special processes or techniques are used. All parts are fabricated or purchased in accordance with approved fabrication drawings. Pipe component flange and bottom end welds are made in accordance with the ASME B&PV Code, Section III, Division 1, Subsection NG, Article NG-4400, and are complete joint penetration welds.

2.3.2 Examination

Each component of the S300 packaging is examined per the approved fabrication drawings to ensure acceptable materials and workmanship. Pipe component flange and bottom end welds are examined in accordance with the ASME B&PV Code, Section III, Division 1, Subsection NG, Articles NG-5230 and NG-5260, and accepted in accordance with Articles NG-5350 and NG-5360.

2.4 General Requirements for All Packages

2.4.1 Minimum Package Size

The minimum dimension of the S300 packaging is the drum diameter of approximately 24 inches. Thus, the minimum four-inch requirement of 10 CFR §71.43(a) is satisfied.

2.4.2 Tamper-Indicating Feature

A tamper-indicating lock wire and seal is installed through a cross-drilled hole in the drum lid bolting-ring bolt. The drum lid cannot be removed without destroying the seal. Thus, the requirement of 10 CFR §71.43(b) is satisfied.

2.4.3 Positive Closure

The containment system of the S300 packaging is supplied by the SFC. Once closed, the SFC cannot be opened without destroying the capsule, thus meeting the requirement of 10 CFR §71.4. The SFC is carried within the shield insert, which is confined within the pipe component. The lid of the pipe component is attached by 12 bolts which are not accessible during transport. Thus, the SFC cannot be released from the shield unintentionally, meeting the requirement of 10 CFR §71.43(c).

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices

No lifting devices are provided that are used to lift the entire packaging.

2.5.2 Tie-Down Devices

There are no tie-down devices which are a structural part of the S300 packaging. Either single or multiple packages in the same shipment may be palletized, with strapping, banding, shrink-wrapping, and/or netting used to secure and immobilize the packages. Failure of these restraint devices will not compromise the ability of the S300 package to protect the payload, satisfying the requirement of 10 CFR §71.45(b). For shipment as exclusive use, the S300 package shall be secured to a pallet or shipping skid at least four inches in height.

2.6 Normal Conditions of Transport

2.6.1 Heat

2.6.1.1 Summary of Pressures and Temperatures

As presented in Section 3.3.1, *Heat and Cold*, the maximum S300 package temperature is 165 ºF. Since all cavities of the package are vented, the maximum normal operating pressure (MNOP) is equal to ambient.

2.6.1.2 Differential Thermal Expansion

The shield insert, made of HDPE, takes up most of the volume inside the pipe component. It has an outer diameter of 11.8 inches and an assembled length of 24.8 inches. The pipe component has a minimum internal diameter of 12.0 inches and an internal length equal to:

$$25.6 - 0.1 - 0.35 - 0.05 = 25.1 \text{ inches,}$$

where:

25.6 inches is the nominal length of the body
0.1 inches is the negative tolerance on body length
0.35 inches is the maximum bottom plate thickness
0.05 inches is the thickness of the lid step which protrudes into the cavity on the lid end.

The thermal expansion coefficient for HDPE is 0.0001 in/in/ºF.[1] The differential temperature is between the NCT hot temperature of 165 ºF and room temperature of 70 ºF, or 95 ºF. The diametral (D-CLR) and axial (A-CLR) clearances are:

$$\text{D} - \text{CLR} = 12.0 - 11.8(1 + 0.0001 \times 95) = 0.088 \text{ inches}$$
$$\text{A} - \text{CLR} = 25.1 - 24.8(1 + 0.0001 \times 95) = 0.064 \text{ inches}$$

Note that the thermal expansion of the steel pipe component is conservatively neglected. Therefore positive clearances under NCT hot temperatures are maintained.

2.6.1.3 Stress Calculations

Since there are no interferences of components and no internal pressures, this section does not apply.

2.6.1.4 Comparison with Allowable Stresses

Since there are no stresses in the S300 packaging due to heat conditions, this section does not apply.

[1] CRC Press, *Handbook of Tables for Applied Engineering Science*, 2nd Edition, 1973, p. 152.

2.6.2 Cold

As presented in Section 3.3.1, *Heat and Cold*, with an internal decay heat load of zero, no insolation, and an ambient temperature of -40 ºF, the average package temperature will be -40 ºF. None of the materials of construction (i.e., thin carbon steel comprising the 55-gallon drum, austenitic stainless steel comprising the pipe component and special form capsules, high-density polyethylene shielding, and cane fiberboard and wood dunnage) undergo a ductile-to-brittle transition at temperatures of -40 ºF or higher. Therefore, the NCT cold event is of negligible consequence.

2.6.3 Reduced External Pressure

Since containment of radioactive material is afforded by the SFC, and since both the pipe component and the overpack drum are vented, the effect of a reduced external pressure on the S300 package of 3.5 psia, per 10 CFR §71.71(c)(3), is negligible.

2.6.4 Increased External Pressure

Since containment of radioactive material is afforded by the SFC, and since both the pipe component and the overpack drum are vented, the effect of an increased external pressure on the S300 package of 20 psia, per 10 CFR §71.71(c)(4), is negligible.

2.6.5 Vibration

The effects of vibration normally incident to transport have been evaluated by test, both on generic 17C, 55-gallon drums and on three S300 package prototypes.

As documented in the U.S. Department of Energy *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, Appendix D, Table D-24 (reproduced as Figure 2-1), the effects of the vibration test specified in 49 CFR 178.608[2] on three generic 17C drums loaded with sand and lead bricks and weighing between 900 and 1000 lb, were negligible.

Specific testing of three S300 prototype packages was also performed as documented in Appendix 2.12.1, *Type A Testing*. The prototypes were identical in design and manufacture to standard production units. Using a steel bar as a simulated payload, the pipe component and outer drum were closed and fasteners torqued as for shipment. Each package was subjected to testing on a vibrating platform, where the sinusoidal motion had a peak-to-peak displacement of one inch. The packages were not restrained except by passive horizontal barriers at the edges of the platform. For a test duration of one hour, each package was vibrated such that a strip of steel having a thickness of 1/16 inch could be passed between the bottom of the package and the test platform. After the tests, the packages were opened and inspected. The test had no observable effect on the drum, the poly liner, shield insert, or pipe component. Only a small amount of dust was generated from sliding wear of the cane fiberboard components. Thus, the effect of vibration normally incident to transport, per 10 CFR §71.71(c)(5), is not of concern for the S300 package.

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[2] Title 49, Code of Federal Regulations, Part 178, Subpart K, *Specifications for Packagings for Class 7 (Radioactive) Materials*, and Subpart M, *Testing of Non-bulk Packagings and Packages*.

2.6.6 Water Spray

As documented in the U.S. Department of Energy *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, Appendix D, Table D-24 (reproduced as Figure 2-2), the 17C and 17H 55-gallon steel drums passed the water spray test as specified in 10 CFR §71.71(c)(6) without damage or inleakage of water. The filter used in the drum lid is not capable of passing significant amounts of water. Furthermore, since the drum outer package is made of metal with a sealed and bolted lid, the water spray will have no effect on the materials of the package which could affect any of the subsequent tests. Thus, the effect of water spray is not of concern for the S300 package.

2.6.7 Free Drop

For a package mass less than 11,000 lb, 10 CFR §71.71(c)(7) requires a free drop of the specimen through a distance of four feet onto a flat, essentially unyielding surface. The package should fall in an orientation for which the maximum damage is expected. In determining the worst-case orientation, it is noted that the primary consideration must be the retention of the drum closure lid. The worst-case orientation for closure lid retention will be one for which the deformation at the drum lid closure ring is greatest. Other considerations, such as impact severity, are not governing for a package such as the S300 which has a relatively compliant response and for drops from the comparatively low height of only four feet. Since no significant damage occurs to the internal pipe component as a result of the much more challenging 30 ft HAC free drop, as discussed in Section 2.7.1, *Free Drop*, the pipe component cannot be damaged in the 4 ft NCT free drop.

The worst-case orientation for drum lid closure ring deformation is the center of gravity (CG) over corner, lid down case. This is because the deformation of the package is concentrated in one location at the impact point. Other orientations may be considered as follows. In the top-down orientation (axis vertical), the entire drum lid closure ring would strike the ground at one time, and the deformation would be well distributed. It would thus not be possible to dislodge the drum closure lid in the top-down orientation. In a side-slapdown orientation, some of the kinetic energy would be applied to the primary impact end, and the remainder to the secondary impact end. This division of energy means that the deformation at the drum lid closure ring would be less than in the CG over corner case, where all of the energy is applied in one location. Therefore, the CG over corner orientation is worst-case. The drum lid closure ring joint should be placed at the point of impact, since the ring is not continuous at that point and somewhat more deformation can therefore be expected.

As documented in Appendix 2.12.1, *Type A Testing*, one S300 package was dropped from four feet in two orientations: one center of gravity over corner, and one horizontal. In each case, the drum lid clamping ring bolt was at the point of impact. The test target had a weight well in excess of 10 times the test package. Since the water spray test had no effect as documented above, the free drop test unit was not subject to water spray prior to the free drop test.

From both tests, the damage was bounded by a crush distance of one inch (measured along a line from the theoretical corner of the drum towards the geometric center of the drum.) After testing, the lid remained securely fastened to the drum. There was no effect on the internal shielding or dunnage components, nor any effect on the pipe component. Thus, the effect of the free drop test is not of concern for the S300 package.

2.6.8 Corner Drop

This test does not apply, since the S300 package is a fissile material cylindrical package weighing more than 220 lb, as specified in 10 CFR 71.71(c)(8).

2.6.9 Compression

As documented in the U.S. Department of Energy *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, Appendix D, Table D-24 (reproduced as Figure 2-3), a 17C, 55-gallon drum weighing 1,000 lb was loaded with a weight of 5,525 lb (a weight conservatively much greater than the required 5 times the weight of the actual S300 package which is 5 × 480 = 2,400 lb) for 24 hours. There were no effects on the package, which passed the test. Thus, the effect of the compression test, per 10 CFR §71.71(c)(9), is not of concern for the S300 package.

2.6.10 Penetration

As documented in the U.S. Department of Energy *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, Appendix D, Table D-31 (reproduced as Figure 2-4), 17C and 17H 55-gallon drums, including bung filters, are capable of passing the penetration test specified in 10 CFR §71.71(c)(10) with negligible damage (small dents). Thus, the effect of the penetration test is not of concern for the S300 package.

2.7 Hypothetical Accident Conditions

10 CFR §71.55 requires that packages containing fissile material be evaluated for criticality with the inclusion of any damage resulting from the NCT tests specified in §71.71 plus the damage from the HAC tests specified in §71.73. As demonstrated in Section 2.6, *Normal Conditions of Transport*, the damage from the NCT tests was negligible, and consequently its effects are not included in the HAC considerations below. The following sections describe the response of the S300 package and of the SFC payload to the hypothetical accident conditions. As discussed in Section 2.1.2, *Design Criteria*, the design criteria for HAC are that the S300 package protect the SFC from conditions more severe than those experienced in the special form qualification 30-ft free drop, percussion, and heat tests of the SFC, specified in 10 CFR §71.75.

2.7.1 Free Drop

10 CFR §71.73(c)(1) requires a free drop of the specimen through a distance of 30 ft onto a flat, essentially unyielding surface. A comprehensive series of tests in the worst-case orientations was not performed on the S300 package; however, a conservative prediction of its response may be made as follows.

The effect of the free drop impact on the internal pipe component will be discussed first. The response of the pipe component to various impact orientations is documented in Ammerman, *et* *al*,[3] which describes drop testing performed during qualification of the pipe overpack container for use in the TRUPACT-II package. The S300 is structurally identical to the pipe overpack container which is the subject of the report. The container was dropped 30 ft in both horizontal and vertical orientations. In the horizontal orientation, the pipe component lid was vertical, and the closure bolts were consequently loaded in shear by the weight of the pipe lid. In the vertical orientation, the pipe component lid was horizontal, and the closure bolts were consequently loaded in tension by the weight of the contents of the pipe and by the pipe lid. These two orientations bound the loading on the pipe component lid. In both cases, the pipe component was leaktight after testing. In the case of the S300, there is no requirement for the pipe component to be leaktight, since special form capsules are transported. Therefore, the pipe component will easily emerge intact from the HAC free drop test.

Next, the response of the S300 drum overpack will be considered. Smith and Gelder[4] report on 30-ft free drop tests of the 6M Specification Package at various impact orientations. The 6M package is a drum package of similar size, weight, and construction to the S300. The weight of the package was 640 lb. The results showed that for the standard clamping ring, total loss of the drum lid could not be ruled out, particularly in the center of gravity over corner and shallow angle orientations. Blanton[5] reports similar results from testing similar drum closures. Consequently, it would be conservative to assume that the S300 drum lid could be lost in the free drop test. In that case, the ejection of the drum contents, including the steel pipe component, might be possible. However, since the drum lid could not be lost until impact, which occurs at essentially zero elevation, the pipe component itself, which is located within a surrounding layer of shock-absorbing cane fiberboard, would not experience any significant damage from the free drop test.

From these considerations, it is concluded that, subsequent to the free drop test, the pipe component may be separated from the S300 outer components, but will remain intact without significant damage. This is a conservative assumption which bounds all other post-drop assumptions in which the package exhibits a greater degree of integrity.

2.7.2 Crush

10 CFR §71.73(c)(2) requires that the crush test be performed on fissile material packages which have a mass not greater than 1,100 lb and a density not greater than 62.4 lb/ft^3. Because the S300 package has a maximum weight of 480 lb and a volume of 8.13 ft^3 (based on a diameter of 22.6 inches and a height of 35 inches), leading to a maximum density of 480/8.13 = 59 lb/ft^3, the crush test is applicable. The crush test is specified as an impact of a 1,100 lb mass falling from 30 ft, oriented so as to suffer the maximum damage. Since a conservative evaluation of the free drop test concludes that the pipe component may become separated from the S300 package during the free drop test, the crush test must be considered to occur on the pipe component, resting on an unyielding surface. A crush test was not performed on the pipe component of the

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[3] Ammerman, D. J., Bobbe, J.G., Arviso, M, and Bronowski, D.R., *Testing in Support of Transportation of Residues in the Pipe Overpack Container*, SAND97-0716, Sandia National Laboratories, April 1997.

[4] Smith, Allen C., and Gelder, Lawrence F., *Drop Tests for the 6M Specification Package Closure Investigation*, WSRC-MS-2004-00221, April 30, 2004.

[5] Blanton, P. S., *Responses of Conventional Ring Closures of Drum Type Packages to Regulatory Drop Tests with Application to the 9974/9975 Package*, WSRC-MS-2002-00452, August, 2002.

S300 package. However, it will be shown that the forces and stresses sustained by the SFC during capsule qualification testing according to 10 CFR §71.75 bound the forces and stresses which could be imposed on the SFC in the crush test.

For the crush test, it is clear that the side orientation (pipe component lying on its side on the unyielding surface) is governing over the upright or inverted orientations. To evaluate the effect of the crush plate impact, it will be conservatively assumed that only the polyethylene shield component is lying on the unyielding surface, with the SFC inside; all of the steel parts of the pipe component will be neglected. This is an extremely conservative assumption, but one that simplifies the calculations required. The crush plate then strikes the top edge of the shield component with an energy equal to 1,100 lb × 360 inches = 396,000 in-lb. The SFC, having an outer diameter of 3 inches and a length of 11.75 inches, lies within the shield cavity having a diameter of 3.5 inches and a length of 13 inches. The worst case loading on the SFC would be in the event that the polyethylene collapsed and completely folded around the SFC, embedding the SFC in the plastic shield. The compressive loading applied to the SFC in this case would be in line with the motion of the crush plate and equal to the "flow" stress of the polyethylene, as shown in Figure 2-5. The "flow" stress is a measure of the deformation stress of a solid material, and is equal to the numerical average of yield and ultimate stress, or:

$$\sigma_{\text{FlowPoly}} = \frac{\sigma_{\text{Y}} + \sigma_{\text{U}}}{2} = 5{,}250 \text{ psi}$$

where, for high-density polyethylene at the high end of the property range, $\sigma_Y = 5{,}000$ psi and $\sigma_U = 5{,}500$ psi.[6] The sealing plug of the SFC fits tightly within the opening in the body of the SFC, as shown in Figure 1-3 (Model II SFC) and Figure 1-4 (Model III SFC). By making a further extremely conservative assumption, i.e., that the entire pressure load on the outside of the SFC is transmitted to the sealing plug (i.e., the ½-inch thick SFC body wall has no stiffness), it is clear that the maximum interface pressure between the SFC body and sealing plug is equal to the polyethylene flow stress, or 5,250 psi.

This stress value is fairly modest compared to the yield strength of the Type 304 stainless steel from which the SFC components are constructed (yield stress of 30,000 psi). However, it is also less than the maximum interface pressure developed in the sealing plug during the qualification testing of the SFCs, as will now be shown.

During qualification testing of the SFCs, a prototypic specimen was dropped 9 m (29.5 ft) in a horizontal orientation onto a flat, horizontal, unyielding surface. An estimate of that impact severity can be made as follows. The energy of the drop is assumed to be absorbed by plastic flow of the outer surface of the SFC specimen. The energy absorbed by the steel is equal to the volume of material displaced, multiplied by the "flow" stress of the steel, or:

$$\text{E}_{\text{A}} = \text{V}\sigma_{\text{FlowSS}}$$

In this case, the flow stress is:

[6] CRC Press, *Handbook of Tables for Applied Engineering Science*, 2nd Edition, p. 140.

$$\sigma_{FlowSS} = \frac{\sigma_Y + \sigma_U}{2} = 52{,}500 \text{ psi}$$

where, for Type 304 stainless steel, $\sigma_Y = 30{,}000$ psi and $\sigma_U = 75{,}000$ psi.[7] The volume of displaced metal is equal to the area of a segment of a circle multiplied by the length of the capsule, or:

$$V = \frac{1}{2} r^2 (\text{rad}\,\theta - \sin\theta) L$$

where the radius of the capsule, r = 1.5 inches, the length of the capsule, L = 11.75 inches, and θ is the included angle of the crush plane of the cylinder as deformation proceeds. These dimensions apply to the larger Model II SFC, which is governing by having the lower impact of the two capsule types. Combining these three equations, the energy absorbed by the capsule is:

$$E_A = 693{,}984(\text{rad}\,\theta - \sin\theta)$$

The deformation distance, d, of the surface is related to the included angle by the equation:

$$\theta = (2)\cos^{-1}\left[\frac{(r - d)}{r}\right]$$

The energy of the capsule is equal to its bounding weight, or W = 30 lb from Table 2-1, multiplied by the drop height of 29.5 × 12 = 354 inches, or E_C = 10,620 in-lb. Equating E_A and E_C, the deformation distance d is found to be equal to 0.0383 inches and θ = 0.4529 radians. The width of the crush plane is:

$$w = 2(r)\sin\frac{\theta}{2} = 0.674 \text{ inches}$$

The area of the crush plane is wL = 7.92 in^2. Under a flow stress of 52,500 psi, the impact load is:

$$F = wL\sigma_{FlowSS} = 415{,}800 \text{ lb}$$

The impact in gs is found from:

$$g = \frac{F}{W} = 13{,}860\text{g}$$

The sealing plug, having a diameter of 2.06 inches and a width of 0.78 inches as shown in Figure 1-3, has a volume of 2.6 in^3. Using a density of stainless steel of 0.29 lb/in^3, the weight of the sealing plug, w_{Plug} = 2.6 × 0.29 = 0.754 lb. Under impact loading, the inertia force of the sealing plug against the inside opening of the SFC is:

[7] ASME B&PV Code, Section II, Part D, Table 2A, represented by specification A479.

$$F_{Plug} = w_{Plug} g = 10{,}450 \text{ lb}$$

where g = 13,860 as found above. The interface bearing stress between the sealing plug and the SFC body is:

$$\sigma_{Drop} = \frac{F_{Plug}}{A_{Plug}} = 6{,}491 \text{ psi}$$

where $A_{Plug} = 2.06 \times 0.78 = 1.61$ in^2 is the bearing area of the sealing plug. This stress arises from the lateral loading of the sealing plug on the inner sealing surface of the SFC. If the sealing plug were to permanently deform the inner surface during the free drop impact, the leaktight condition of the SFC could be lost. However, as shown, not only is the lateral stress well below the yield strength of Type 304 stainless steel, but this test was performed during special form qualification, without loss of leaktight condition of the test specimen. The corresponding stress resulting from the crush test is found above to be equal to 5,250 psi. Since this stress is also well below material yield, and is also below the stress developed during qualification testing (5,250 < 6,491), the special form qualification testing conditions bound the conditions corresponding to the crush test. Note also that very conservative assumptions regarding the crush test were made as discussed above, thus greatly overestimating the stresses in the SFC from the crush test.

Due to the impact of the crush plate with the pipe component, a shear load could be developed in the pipe component lid bolts. While unlikely, it is conservatively assumed that all of the lid bolts shear off, removing the lid, and allowing the SFC to be separated from the pipe component. Of note, this separation occurs only as a consequence of the potential shear of the pipe component lid bolts. Since the potential separation of the SFC from the pipe component could only occur after impact, when the crush plate had essentially come to rest, no significant interactions between the SFC and the crush plate could occur.

2.7.3 Puncture

10 CFR §71.73(c)(3) requires the drop of the package onto a six-inch diameter steel bar from a height of 40 inches. As discussed in Section 2.7.2, *Crush*, the most conservative assumption regarding the outcome of the crush test is that the SFC becomes separated from all other parts of the S300 packaging and interacts directly with the puncture bar.

Because the SFC is smaller than the puncture bar, the flat top of the puncture bar presents essentially the same target as the free drop target (i.e., flat and essentially unyielding). However, as required by 10 CFR §71.75, the SFC was dropped onto an essentially unyielding flat surface from a height of 30 ft during special form qualification testing, or nine times as far as in the 40-inch puncture drop test. Therefore the most conservative puncture bar test scenario is bounded, to a very significant degree, by the special form qualification testing performed on the SFC.

Other, less severe outcomes could result from the free drop, crush, and puncture drop tests. While it is unlikely that the drum could survive all of these tests with its lid fully intact, it is possible that the SFC could still be retained within the pipe component. The criticality consequences of this scenario, as well as the most conservative case of the release of the SFC from the pipe component, are considered in Chapter 6, *Criticality Evaluation*.

2.7.4 Thermal

10 CFR §71.73(c)(4) requires the exposure of the S300 packaging to a hypothetical fire. The most conservative assumption regarding the initial conditions of the S300 packaging before the fire, as discussed above, is that due to the mechanical tests (free drop, crush, and puncture), the SFC has been separated entirely from the package and is exposed to the fire without any package components to shield it. The thermal evaluation is presented in Section 3.4, *Thermal Evaluation under Hypothetical Accident Conditions*.

2.7.4.1 Summary of Pressures and Temperatures

As shown in Section 3.4.3, *Maximum Temperatures and Pressures*, the effects of an exposure of a bare SFC to the thermal conditions of 10 CFR §71.73(c)(4) is essentially equivalent to the heat test of 10 CFR §71.75(b)(4), in which the capsule is heated to 1,475 ºF for 10 minutes. Although the duration of the test is slightly different between the two cases (the test specimen is exposed to the 1,475 ºF environment for 30 minutes in §71.73(c)(4), whereas the SFC is heated explicitly to 1,475 ºF for 10 minutes in §71.75(b)(4)), the maximum temperature in each case is essentially equal to the fire temperature of 1,475 ºF. Since the special form heat test of 10 CFR §71.75(b)(4) was sustained by the tested capsules without loss of leaktight condition, then the SFC will remain leaktight following the HAC thermal test.

The possible retention of the SFC within an intact pipe component during the HAC thermal test is not of concern. In that case, the polyethylene shielding material would begin to decompose due to the elevated temperature. Gases which could form as a result of decomposition would partially escape through the pipe component lid vent, and after decomposition of the lid O-ring dust seal, which would occur shortly after the beginning of the fire, gases could also escape past the lid closure joint. Any pressurization of the pipe component which might occur would be external to the SFC. Since that would drive the tapered sealing plug further into its seat, it would have the tendency to enhance, rather than degrade, the sealing of the capsule.

2.7.5 Immersion – Fissile Material

10 CFR §71.73(c)(5) requires performance of the immersion test for packages containing fissile material. The criticality evaluation presented in Chapter 6.0, *Criticality Evaluation*, assumes optimum hydrogenous moderation of single SFCs and arrays of SFCs, thereby conservatively addressing the effects and consequences of water in-leakage.

2.7.6 Immersion – All Packages

10 CFR §71.73(c)(6) requires performance of an immersion test under a head of water of at least 50 ft. Since the test package may be undamaged, the condition applied to the SFC is merely one of external water pressure. Any effects on the S300 packaging components would be immaterial. The test water pressure of 21.7 psi would have a negligible effect on the relatively small, thick-walled SFC. The direction of pressure would also have the effect of driving the sealing plug deeper into its seat. Therefore, the immersion test is not of concern.

2.7.7 Deep Water Immersion Test

The S300 package is a Type AF package; hence, this requirement does not apply.

2.7.8 Summary of Damage

The discussions of sections 2.7.1, *Free Drop*, through 2.7.7, *Deep Water Immersion Test*, demonstrate that the S300 package in conjunction with the SFC payload prevents release or dispersal of the radioactive contents of the SFC when subjected to all applicable hypothetical accident tests. In particular, the criteria established in Section 2.1.2, *Design Criteria*, namely that the S300 package protect the SFC from conditions more severe than those experienced in the special form qualification 30-ft free drop, percussion, and heat tests of the SFC, were met.

The results of the special form qualification tests are discussed in Section 2.10, *Special Form*. The shielding and criticality control consequences of the separation of the SFC and contents from the rest of the S300 packaging under HAC is discussed in Chapter 5, *Shielding Evaluation*, and Chapter 6, *Criticality Evaluation*.

2.8 Accident Conditions for Air Transport of Plutonium

The S300 package is not transported by air; hence, this section does not apply.

2.9 Accident Conditions for Air Transport of Fissile Material Packages

The S300 package is not transported by air; hence, this section does not apply.

2.10 Special Form

The radioactive contents of the SFC consist of ^{239}Pu in solid form as Plutonium-Beryllium sealed neutron sources. The contents are contained within special form capsules of two specific types: Model II and Model III. Each capsule is of similar design, and differ primarily only in dimensions. The sealing technique is the same for both models.

The Model II SFC, illustrated in Figure 1-3, is fabricated of Type 304 stainless steel, with a nominal wall thickness of almost 1/2 inch, and bottom and top threaded cap thicknesses of 3/4 inch. The contents are located below a snap ring that holds an impact plug in place axially, followed by a tapered sealing plug nominally 3/4 inch thick. The threaded cap is designed with a shearable stem to preclude removal of the cap once installed. The outer length of the closed Model II is 11-3/4 inches (excluding the shearable cap stem), and the outer diameter is three inches. The interior cavity length is 8-3/4 inches, and the interior cavity diameter is 2-1/16 inches. The Model II SFC meets the requirements of 10 CFR §71.75, and carries the IAEA Certificate of Competent Authority Special Form Radioactive Materials Certificate Number USA/0696/S-96, Revision 1, issued by the Department of Transportation.

The Model III SFC, illustrated in Figure 1-4, is fabricated of Type 304 stainless steel, with a nominal wall thickness of 1/2 inch, and bottom and top threaded cap thicknesses of 3/4 inch. The contents are located below a tapered sealing plug nominally 3/4 inch thick. The threaded cap is designed with a shearable stem to preclude removal of the cap once installed. The outer length of the closed Model III is seven inches (excluding the shearable cap stem), and the outer diameter is 2-1/2 inches. The interior cavity length is 4-1/2 inches, and the interior cavity diameter is 1-1/2 inches. The Model III SFC meets the requirements of 10 CFR §71.75, and carries the IAEA Certificate of Competent Authority Special Form Radioactive Materials Certificate Number USA/0695/S-96, Revision 1, issued by the Department of Transportation.

Both capsules are assembled and tested according to written procedures. To ensure proper assembly, each capsule is checked with a gauge that measures how far the tapered plug has been inserted into the capsule body. Measurements of the tapered plug insertion are made both before and after the final tightening and shear-off of the cap stem. These measurements are recorded on the data sheet belonging to each capsule. If the measurements meet the standards established for the capsule design, proper assembly is assured.

2.11 Fuel Rods

The S300 package does not carry fuel rods; hence, this section does not apply.

Table E-1. Steel Drums--Compliance With Vibration Standard (49 CFR 178.608).

Specific packaging	No. tested	Weight (lb)	Contents	Results	Comments
Packagings for dockets in this category that are pre-HM-181 are considered to be acceptable based on evaluation and/or by comparison with similar packagings.					
DOT-17C (UN1A2) (55-gal)	2	1,000	Sand and lead bricks	2 pass	Drums were observed for leakage at filter location, ring and bolt location, and bottom of drum; nothing was detected.
	1	900	Flour/fluorescein sand, lead bricks	1 pass	Drums were observed for leakage at filter location, ring and bolt location, and bottom of drum; nothing was detected.

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Figure 2-1 - Vibration Test Results for a DOT-17C Steel Drum
(Table E-1 from U.S. Department of Energy, *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, DOE/RL-96-57, Revision 0)

Table D-1.a. Water Spray Test Results for Steel Drums.

STEEL DRUMS	
Specific packaging	**Test/Analysis Results**
DOT-6C, 5-gal	By comparison, this drum would meet this requirement.
DOT-6C, 10-gal	By comparison, this drum would meet this requirement.
DOT-17C, 5-gal	By comparison, this drum would meet this requirement.
DOT-17C, 30-gal	By comparison, this drum would meet this requirement.
DOT-17C, 35-gal	Three loaded and three empty drums were tested and passed.
DOT-17C 55-gal	Three drums were subjected to this test and passed (Configuration RF-1).
DOT-17C, 55-gal w/pressure relief device	Three lids with the Nucfil[a] filters were subjected to the water spray test and no water passed through the filter (Configurations HF-1 and RF-2).
DOT-17C, 55-gal w/HDPE liner	The same data shown for the 17C 55-gal drum would apply here (Configurations HF-2, LL-1, MD-1 and RF-3).
DOT-17C, 55-gal w/HDPE vented liner	One test unit package was subjected to the test conditions and passed (Configurations RF-4 through RF-8). [Dockets 89-13-7A and 90-18-7A]
DOT-17H, 30-gal	Three drums were subjected to this test and passed (Configuration OR-1).
DOT-17H, 30-gal w/filter	One test unit package was subjected to the test conditions and passed (Configurations AW-1 and FM-1). [Dockets 90-17-7A and 90-20-7A]
DOT-17H, 55-gal	Three drums were subjected to this test and passed.
MS-24347-1[b]	By comparison, this drum would meet this requirement.
MS-24347-7[b]	Two drums were subjected to this test and passed.
MS-27684-1[b]	By comparison, this drum would meet this requirement.
MS-27684-2[b]	By comparison, this drum would meet this requirement.
MS-27684-3[b]	Three drums were subjected to this test and passed.
MS-27684-6[b]	By comparison, this drum would meet this requirement.
MS-27684-8[b]	Three drums were subjected to this test and passed.
MS-27683-7[b]	Three drums were subjected to this test and passed.
MS-27683-13[b]	By comparison, this drum would meet this requirement.
MS-24683-21[b]	Three drums were subjected to this test and passed.

See Table D-1.b. Water Spray Test Results for Steel Drums (Packaging Specialties). (2 pages)

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Figure 2-2 - Water Spray Test Results for a DOT-17C Steel Drum
(Table D-1.a from U.S. Department of Energy, *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, DOE/RL-96-57, Revision 0)

Table D-24. Compression Test Results for Steel Drums. (2 pages)

Specific packaging	Authorized gross weight (lb)	Compression test weight (lb)	Test duration (hr)	Test/analysis data and results		Comments
				No. tested	Results	
DOT-6C 5-gal	80	500	>24	1	1 pass	No detectable effect.
DOT-6C 10-gal	160	928	>24	1	1 pass	No detectable effect.
DOT-17C 5-gal	100	520	>24	1	1 pass	No detectable effect.
DOT-17C 30-gal	500	Not tested[a]	--	--	--	Pass, based on testing of DOT-17H 30-gal drum.
DOT-17C 35-gal	400	2,060	>24	1	1 pass	No detectable effect.
DOT-17C 55-gal	1,000	Not tested[b]	--	--	--	Pass, based on testing of DOT-17H 55-gal drum.[c]
DOT-17C 55-gal with pressure relief devices	1,000	Not tested[c]	--	--	--	Pass, based on testing of DOT-17H 55-gal drum.[c]
DOT-17C 55-gal with HDPE liner	1,000	5,525	>24	1	1 pass	Passed. [Dockets 89-13-7A and 90-18-7A]
DOT-17H 30-gal	500 400	2,700 2,069	>24 >24	1 1	1 pass 1 pass	No detectable effect. No detectable effect. [Dockets 90-17-7A and 90-20-7A]
DOT-17H 55-gal	1,000	5,100	>24	1	1 pass	No detectable effect.
MS-24347-1[d]	10	100	48	1	1 pass	No detectable effect.
MS-24347-7[d]	35	200	48	1	1 pass	No detectable effect.
MS-24684-1[d]	60	300	>24	1	1 pass	No detectable effect.
MS-27684-2[d]	110	Not tested	--	--	--	Pass, based on comparison to test data on comparable drum.
MS-27684-3[d]	80	401	>24	1	1 pass	No detectable effect.
MS-27684-5[d]	80	500	>24	1	1 pass	No detectable effect.

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Figure 2-3 - Compression Test Results for a DOT 17-C Steel Drum
(Table D-24 from U.S. Department of Energy, *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, DOE/RL-96-57, Revision 0)

Table D-31. Penetration Test Results for Steel Drums. (4 pages)

Specific packaging	Test/analysis results			Comments
	No. tested	Location	Results	
DOT-6C (5-gal)	1	Lid at center	1 pass	0.50-in. dent
	1	Side at seam	1 pass	1.00-in. dent
	1	Lid near closure ring	1 pass	0.25-in. dent
DOT-6C (10-gal)	1	Lid at center	1 pass	0.50-in. dent
	1	Side at seam	1 pass	0.75-in. dent
	1	Lid near closure ring	1 pass	0.50-in. dent
DOT-17C (5-gal)	Not tested	--	--	Pass, based on test data shown for comparable or lesser gauge steels.
DOT-17C (30-gal)	Not tested	--	--	Pass, based on test data shown for comparable or lesser gauge steels.
DOT-17C (35-gal)	1	Lid near center	1 pass	0.625-in. dent
	2	Lid near edge	2 pass	0.500-in. dent max.
	1	Side near seam	1 pass	0.250-in. dent
DOT-17C (55-gal)	Not tested	--	--	Pass, based on test data shown for comparable or lesser gauge steels.
DOT-17C (55-gal) Pressure Relief Device Nucfil[a] Filter	3	Center of filter	3 pass	Air flow was established after each test with flour/fluorescein as contents. There was no visible evidence of loss of contents, and no loss of contents was detected under a black light.
DOT-17C (55-gal) with HDPE Liners	1	Lid center	1 pass	Minor damage
	1	Side	1 pass	Same result
	1	Bottom	1 pass	Same result
	1	Filter	1 pass	Minor damage [Dockets 89-13-7A and 90-18-7A]

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Figure 2-4 - Penetration Test Results for a DOT-17C Steel Drum

(Table D-31 from U.S. Department of Energy, *Test and Evaluation Document for DOT Specification 7A Type A Packaging*, DOE/RL-96-57, Revision 0)

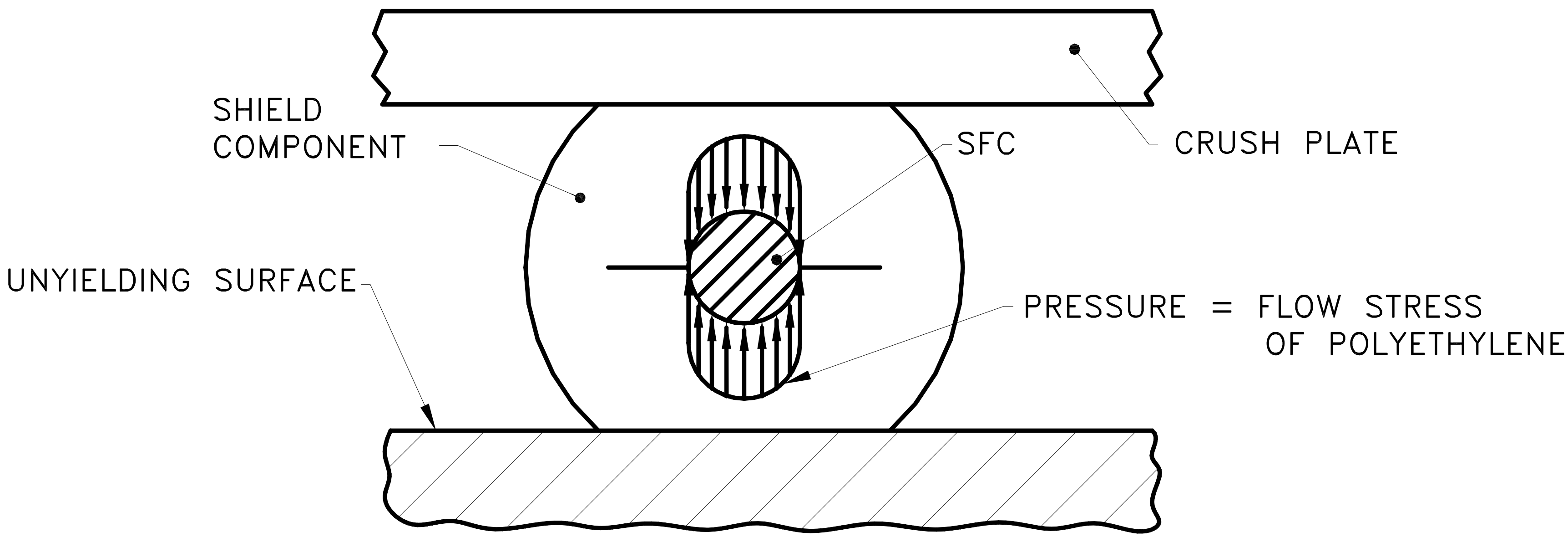

Figure 2-5 - Configuration of Shield Component and SFC in Crush Test

2.12 Appendix

2.12.1 Type A Testing

This appendix will detail testing that was performed on the S300 to qualify it as a DOT Type A package. Both vibration and free drop testing were performed on a S300 prototype in 2002.

Three test units were tested, having the serial numbers and overall weights listed in Table 2.12.1-1 below. Each test unit conformed to the drawings given in Appendix 1.3.1, *Packaging General Arrangement Drawings,* with the exception of the two, two-inch thick shield insert end plugs. Absence of those components would have no material effect on the test results. The payload consisted of a solid steel bar having a diameter of three inches, a length of 11.13 inches, and a weight of 22.5 lb. The steel bar provided an adequate simulation of the SFC, which, when loaded, is essentially solid metal. For testing, the test units were assembled and closed according to the packaging general arrangement drawings.

Table 2.12.1-1 - S300 Test Unit Serial Numbers and Weights

Test Unit Serial No.	Weight, lb
1T	444
2T	448
3T	448

2.12.1.1 Vibration Testing

A vibration test is required to qualify packages as DOT Type A packages, as stated in 49 CFR 173.24a(5): *"Vibration. Each non-bulk package must be capable of withstanding, without rupture or leakage, the vibration test procedure specified in Sec. 178.608 of this subchapter."* The vibration test requirements are found in 49 CFR 178.608. In fulfillment of this requirement, the three units were tested on a vibrating platform.

The vibration test machine was based on a wide flange I-beam, simply supported at each end, with a platform holding the test unit located at its center. A simple pivoting link provided lateral stability. Also mounted on the platform was a variable speed electric motor with a significant imbalance attached. By varying the speed of the motor and the amount of the imbalance, the beam was driven at resonance in a first mode of vibration. The test unit motion was not limited vertically, and was only limited horizontally by passive barriers which kept the unit from falling off of the platform. The amplitude of the motion was measured by tracing the platform motion using a pen attached to the platform against stationary paper. The peak-to-peak amplitude was one inch. The degree of vibration was such that a 1/16-inch thick steel strap could be passed between the test unit and the platform during oscillation, as required by 49 CFR 178.608. The frequency of the machine at resonance was approximately 4 – 5 Hz. The test setup is shown in Figure 2.12.1-1.

Each test was conducted for one full hour after the amplitude and the 1/16-inch bounce requirements were achieved. Upon completion of each test, the drum was moved to the floor and inspected. All tests had identical results. There was no evidence of cracking or other distress of the drum sidewall. The drum lid clamping ring bolt and all of the bolts of the pipe components were still snug. There was no damage to the shield insert components. The only change which occurred was a minor enlargement of the recesses in the upper dunnage. The recesses are provided to clear the bolt heads on the pipe component. No other damage to the upper or lower dunnage was found. This very slight damage could have no effect on the ability of the package to survive any other required tests. Therefore, the S300 passed the vibration testing.

2.12.1.2 Free Drop Testing

A free drop test is required to qualify packages as DOT Type A, as stated in 49 CFR 178.350(a): *"Each packaging must…be designed and constructed so that it meets the requirements of §§173.403, 173.410, 173.412, 173.415, and 173.465 of this subchapter for Type A packaging."* The acceptance criteria is found in 49 CFR 173.412(j): *"When evaluated against the performance requirements of this section and the tests specified in Sec. 173.465 or using any of the methods authorized by Sec. 173.461(a), the packaging will prevent--*

(1) Loss or dispersal of the radioactive contents; and

(2) A significant increase in the radiation levels recorded or calculated at the external surfaces for the condition before the test."

The free drop requirements are found in 49 CFR 173.465. In fulfillment of this requirement, one S300 test unit (serial no. 3TD, see Table 2.12.1-2) was tested using a drop pad having a weight of approximately 50,000 lbs and a steel impact surface. Since the test units weighed just over 500 lbs each, the weight of the drop pad is well in excess of 10 times the test unit weight, and qualifies as an unyielding surface.

The test series consisted of a one-foot drop sequence and a four-foot drop sequence. The one-foot drops were performed an accordance with 49 CFR 173.465(c)(2), since the payload is fissile, and consisted of a drop onto each quarter of each rim in the center-of-gravity (CG) over corner orientation. One of the drops was directly on the clamping ring bolt. The one-foot drops were followed by two, four-foot drops according to 49 CFR 173.465(c)(1). One drop was in the CG over corner orientation, and the second was in the drum axis horizontal orientation. In both cases, the clamping ring bolt was at the point of impact. Each drum was dropped a total of ten times (eight, one-foot, and two, four-foot drops).

Damage to the packages due to the drop testing was very modest, particularly in the case of the one-foot drops, for which damage was negligible. Damage due to the one-foot drops consisted in a small amount of bending of the upper or lower rims, but no deformation occurred in the wall of the drum proper.

The four-foot, CG over corner drops deformed the area of the clamping ring joint by an amount which was less than one inch in each case. Subsequent impact on the side at the same location drove the clamping ring legs in toward the center of the drum, but they still protruded from the side of the drum by at least 3/4 inches. There was also minor damage to the rolling hoops from side impact. However, the clamping rings were still snug to the drum in each case, and the clamping ring bolts were tight after all drops. Damage was modest enough that adequate wrench clearance remained to allow removal of the clamping ring bolt. Inside the drum, all components were in near-new condition. The only evidence of impact was some chips and dust from the cane fiberboard dunnage. The drum wall at the clamping ring bolt location was bent radially inward by approximately 7/8 inch, such that the drum poly liner was trapped in place. The bolts on the pipe component were tight, and there was no damage to the shield insert.

In summary, the drop damage was limited to minor deformations of the drum and lid in the near vicinity of the impact point. Deformations are summarized in Table 2.12.1-2. Photographs of the free drop test results are given in Figure 2.12.1-2 through Figure 2.12.1-7. There could be no loss or dispersal of the payload contents, and any increase in external radiation levels would be negligible. Therefore, the S300 passed the free drop testing.

Table 2.12.1-2 - Free Drop Impact Deformations, inches

Serial No.	Leg	Height
3TD	15/16	3/4

Notes:

1. The serial number for the drop tests is carried over from the vibration testing; thus drop test serial number 3TD is the same package as vibration test unit 3T.

2. The Leg dimension is measured from the original flat extreme top end of the drum to the top edge of the deformed clamping ring at the maximum deformation point, measured parallel to the drum axis, *before* the horizontal drop.

3. The Height dimension is measured from the drum cylindrical wall surface to the outermost protrusion of the bolting components at the clamping ring joint, measured along a radius *after* the horizontal drop.

Figure 2.12.1-1 - Vibration Test Setup

Figure 2.12.1-2 - S300 CG over Corner Four-Foot Free Drop

Figure 2.12.1-3 - Damage from CG over Corner Four-Foot Free Drop

Figure 2.12.1-4 - S300 Side Four-Foot Free Drop

Figure 2.12.1-5 - Damage from Side Four-Foot Free Drop

Figure 2.12.1-6 - Lid Removed After All Drops

Figure 2.12.1-7 - Pipe Component Internals After All Drops

3. THERMAL EVALUATION

This chapter identifies and describes the principal thermal design aspects of the S300 package, and further demonstrates the thermal safety of the packaging system and compliance with the thermal requirements of 10 CFR 71.

3.1 Description of Thermal Design

3.1.1 Design Features

The major components comprising the S300 package are discussed in Section 1.2.1, *Packaging*, and a detailed drawing of the package design is presented in Section 1.3.1, *Packaging General Arrangement Drawings*. Since the radioactive contents are in special form, the S300 package does not include any features specifically designed to enhance or control thermal performance.

3.1.2 Content's Decay Heat

^{239}Pu is an alpha emitter with a Q-alpha of 5.244 MeV[1]. The heat produced is:

$$Q_{Source-Unit} = 5.244\left(10^{6}\right)\frac{eV}{decay}\times 1\frac{decay}{Bq-s}\times 1.6021\left(10^{-19}\right)\frac{J}{eV} = 8.496\left(10^{-13}\right)\frac{W}{Bq}$$

where a watt is equal to one J/s. Since, per Section 1.2.2, *Contents*, the payload consists of a maximum of 0.805 TBq of ^{239}Pu, the total heat generation is:

$$Q_{Source} = Q_{Source-Unit}\times 0.805\left(10^{12}\right) = 0.68\ W$$

This value is negligible compared to the conservatism of the analytical approach, and may be neglected in calculations.

3.1.3 Summary of Temperatures

The maximum temperature of the S300 package under NCT is bounded by 165 ºF. Under HAC, the maximum temperature of the SFC is bounded by the HAC thermal test flame temperature of 1,475 ºF.

3.1.4 Summary of Maximum Pressures

Since all cavities of the S300 packaging are vented, there is no internal pressure under NCT or HAC.

[1] Brookhaven National Laboratory National Nuclear Data Center, http://www.nndc.bnl.gov, accessed 5-1-06.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

Due to the conservative simplifying assumptions used in the thermal analysis, relatively few material properties are required. Any necessary thermal material properties are identified and referenced when used.

3.2.2 Component Specifications

The S300 packaging is fabricated primarily of carbon steel, Type 304 or 304L austenitic stainless steel, and high-density polyethylene (HDPE) for neutron shielding and shock protection. Cane fiberboard and optional plywood are also used within the overpack interior cavity for primary shock protection.

Type 304 and 304L stainless steel is in common use in transport packages, exhibiting structural and thermal integrity for cold temperatures to -40 ºF, and hot temperatures exceeding 1,475 ºF.

The cane fiberboard is rated for continuous use in temperatures up to 212 ºF, as shown in Figure 3-1.

The HDPE used in the shield insert can be used continuously at temperatures of approximately 200 ºF or above; however, a conservative temperature of 180 ºF will be adopted based on recommendations of a manufacturer of HDPE shielding material, as shown in Figure 3-2.

A rubber gasket may be used between the 55-gallon drum lid and body. Since the 55-gallon drum only serves to provide a protective overpack for the pipe component, loss of the rubber gasket is of no safety consequence. Because the payload is in special form, the elastomeric O-ring dust seal used in the pipe component performs no safety function.

3.3 Thermal Evaluation under Normal Conditions of Transport

3.3.1 Heat and Cold

3.3.1.1 Heat

Since the decay heat within the package is negligible, the maximum temperature of the package will be defined by the regulatory solar loads and the 100 ºF regulatory ambient temperature.

Under NCT, the package is mounted in an upright position on its transporter. This establishes the orientation of the exterior surfaces of the package for determining the free convection heat transfer coefficients and insolation loading. The bottom of the package has no insolation, and is conservatively assumed to be in an adiabatic condition with regard to heat loss.

The thermal conditions that are considered for NCT are those specified in 10 CFR §71.71(c)(1). Accordingly, a 38 ºC (100 ºF) ambient temperature with the following insolation values are used for heat input to the exterior package surfaces.

Form and Location of Surface	Total Insolation for a 12-Hour Period	
	($gcal/cm^2$)	(Btu/in^2)
Flat surfaces transported horizontally: • Base • Other surfaces	 None 800	 None 20.49
Flat surfaces not transported horizontally	200	5.12
Curved surfaces	400	10.24

The S300 package may be treated as a simple, right circular cylinder with an external diameter of 22.6 inches and an external height of 35 inches. According to the table above, the insolation for flat surfaces transported horizontally (i.e., the drum top) is 20.49 Btu/in^2 over 12 hours, or 1.71 $Btu/hr\text{-}in^2$, and for curved surfaces (i.e., the drum side) the value is half as much, or 0.86 $Btu/hr\text{-}in^2$. The total external area of the package top, $A_T = (\pi/4)(22.6)^2 = 401$ in^2, and the total external area of the package side, $A_S = (\pi)(22.6)(35) = 2{,}485$ in^2. The total heat load into the package top is then $Q_T = (401 \times 1.71)\alpha = 685.7\alpha$ Btu/hr, and the total heat load into the package side, $Q_S = (2{,}485 \times 0.86)\alpha = 2{,}137.1\alpha$ Btu/hr, where α is the solar absorbtivity, discussed below.

The S300 package outer surface may be either unpainted stainless steel or painted carbon steel. For unpainted stainless steel, the emissivity may be conservatively taken as 0.25[2], and the solar absorbtivity as 0.5[3]. For paint, conservatively assuming dark paint, the emissivity may be taken as 0.9[4], and the solar absorbtivity as 0.9[4]. Therefore, the equation for radiative heat transfer to the package top and side surfaces, Q_R, given a surface temperature, T, and an ambient temperature, $T_\infty = 100$ ºF, is:

$$Q_R = \sigma\varepsilon(A_T + A_S)(T^4 - T_\infty^4) = \left(3.437(10)^{-8}\right)(\varepsilon)\left[T^4 - T_\infty^4\right] \text{ Btu/hr}$$

where the Stefan-Boltzman constant, $\sigma = 1.714(10)^{-9}$ $Btu/hr\text{-}ft^2\text{-}R^4$, the top surface area, $A_T = 401$ $in^2 = 2.78$ ft^2, the side surface area, $A_S = 2{,}485$ $in^2 = 17.27$ ft^2, and the temperatures are in degrees-Rankine. Both sets of emissivity/absorbtivity data will be used to solve the heat transfer equations, as shown below.

Heat is rejected from the package by convection. The equation for convective heat transfer from the package top and side surfaces, Q_C, given a surface temperature, T, and an ambient temperature, $T_\infty = 100$ ºF, is:

$$Q_C = Ah(T - T_\infty)$$

The convective heat transfer coefficient, h, is:

---

[2] W. D. Wood, et al., *Thermal Radiation Properties of Selected Materials, Volume I*, p56. The emissivity of 0.25 is a conservative lower-bound value for clean and smooth stainless steel, leading to conservatively higher temperatures for NCT.

[3] CRC Press, *Handbook of Tables for Applied Engineering Science*, 2nd Edition, 1973, Table 2-9, p212.

[4] Frank Kreith, *Principles of Heat Transfer*, 3rd Edition, Intext Press, Inc., 1973, Table 5-2, p237.

$$h = Nu\frac{k}{L} \text{ Btu/hr-ft}^2\text{-°F}$$

where k is the conductivity of air at the film (i.e., package surface) temperature, and L is the effective length of the vertical surface or cylinder diameter for the horizontal surface.

Horizontal Surface. Using equations 7-21 and 7-22 from Kreith, the temperature-dependent natural convection film coefficient, h_{CT}, for flow of air over a horizontal planar surface (i.e., package top), may be found using:

$$Nu = 0.54(Gr\,Pr)^{1/4} \quad \text{for } 10^5 < Gr < 2\times10^7 \qquad (7\text{-}22)$$

$$Nu = 0.14(Gr\,Pr)^{1/3} \quad \text{for } 2\times10^7 < Gr < 3\times10^{10} \qquad (7\text{-}21)$$

For all subsequent calculations, a package surface temperature of 150 ºF is assumed for developing natural convection film coefficients, which is sufficiently close to the actual temperature of the surfaces.

For flow over circular plates, Kreith recommends using a length equal to 90% of the plate's diameter, or L = 0.9D; thus, for the drum diameter of 22.6 inches, the length, L = 0.9 × 22.6 = 20.3 inches = 1.7 feet. The Grashof number, Gr, is:

$$Gr_T = \left(\frac{\rho^2 g\beta L^3}{\mu^2}\right)(\Delta T) = 3.206\times10^8$$

where, interpolating from Table A-3 of Kreith for air at 150 ºF, the quantity $\rho^2 g\beta/\mu^2 = 1.305\times10^6$ 1/ºF ft^3, L = 1.7 feet, and $\Delta T = (150 - T_\infty) = 50$ ºF. Therefore, equation 7-21 is appropriate. Using this equation, the convective film coefficient is:

$$h_T = (0.14)\left(\frac{k}{L}\right)\left(\frac{\rho^2 g\beta L^3}{\mu^2}Pr\right)^{1/3}(\Delta T)^{1/3} = 0.2249(\Delta T)^{1/3} \text{ Btu/hr-ft}^2\text{-°F}^{4/3}$$

where, from Table A-3 of Kreith for air at 150 ºF, the conductivity of air, k = 0.0164 Btu/hr-ft-ºF, and Pr = 0.72. Since the top surface area, $A_T = 2.78$ ft^2, the equation for convective heat transfer from the package top surface, Q_{CT}, is:

$$Q_{CT} = A_T h_T (T - T_\infty) = 0.625(T - T_\infty)^{4/3} \text{ Btu/hr}$$

Vertical Sides. Using equations 7-19b and 7-20 from Kreith, the temperature-dependent natural convection film coefficient, h_{CS}, for flow of air over a vertical planar or cylindrical surface (i.e., the package side), is:

$$Nu = 0.555(Gr\,Pr)^{1/4} \quad \text{for } 10 < Gr < 1\times10^9 \qquad (7\text{-}19a)$$

$$Nu = 0.13(Gr\,Pr)^{1/3} \quad \text{for } Gr > 1\times10^9 \qquad (7\text{-}20)$$

In this case, the film temperature is assumed to be 150 ºF as before, and consequently the Grashof number only differs from the previous one by the cube of the ratio of the characteristic length, L. For the drum side, L_S = 35/12 = 2.92 ft. The Grashof number is:

$$Gr_S = \left(\frac{L_S}{L}\right)^3 Gr_T = 1.625 \times 10^9$$

Therefore, equation 7-20 is appropriate. Using this equation, the convective film coefficient is:

$$h_S = (0.13)\left(\frac{k}{L}\right)\left(\frac{\rho^2 g \beta L^3}{\mu^2} Pr\right)^{1/3} (\Delta T)^{1/3} = 0.2088(\Delta T)^{1/3} \text{ Btu/hr-ft}^2\text{-ºF}^{4/3}$$

where the values for k and Pr are the same as before. Since the side surface area, A_S = 17.27 ft^2, the equation for convective heat transfer from the package side surface, Q_{CS}, is:

$$Q_{CS} = A_S h_S (T - T_\infty) = 3.606(T - T_\infty)^{4/3} \text{ Btu/hr}$$

Collecting terms and balancing heat loads:

$$Q_R + Q_{CT} + Q_{CS} = Q_T + Q_S$$

Substituting,

$$\left(3.437(10)^{-8}\right)(\varepsilon)\left[T^4 - T_\infty^4\right] + (0.625 + 3.606)(T - T_\infty)^{4/3} = (685.7 + 2{,}137.1)\alpha$$

For bare stainless steel where ε = 0.25 and α = 0.5, this equation may be solved for T = 159.8 ºF. For dark painted carbon steel, where ε = 0.9 and α = 0.9, the result is essentially identical at T = 160.4 ºF. Conservatively, the NCT maximum temperature of the S300 package is taken as 165 ºF. This temperature is below the continuous use temperatures for any component of the packaging given in Section 3.2.2, *Component Specifications*.

3.3.1.2 Cold

With an internal decay heat load of zero, no insolation, and an ambient temperature of -40 ºF, the average package temperature will be -40 ºF. None of the materials of construction (i.e., thin carbon steel comprising the 55-gallon drum, austenitic stainless steel comprising the pipe component and special form capsules, HDPE shielding, and cane fiberboard and wood dunnage) undergo a ductile-to-brittle transition at temperatures of -40 ºF or higher. Therefore, the NCT cold event is of negligible consequence.

3.3.2 Maximum Normal Operating Pressure

Since all cavities of the S300 packaging are vented, the internal pressure is equal to ambient pressure at all times.

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WALLS • CEILINGS • FLOORS

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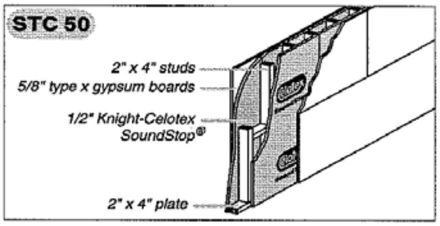
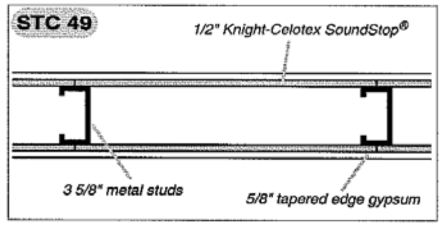


- **Framing:** 2"x 4" studs, 16" o.c. 2"x 4" top and bottom plates. 2" x 4" fire blocks installed horizontally at framing mid-height.
- **Inner Board:** 1/2" SoundStop® applied vertically to both sides of studs. Fastened by 5d coated nails 12" o.c. along edges and intermediately, nail heads dimpled. Joints staggered on opposite sides.

Additional sound deadening applications for residential and commercial construction are available on our web site **www.knightcelotex.com**.



- **Framing:** 3 5/8" metal studs, 24"o.c. Metal track floor and ceiling
- **Inner Board:** SoundStop® Board applied vertically to both sides of studs; fastened with 1" drywall screws 16"o.c. along the edges and intermediately.

Specifications

Manufactured to meet ASTM C 208 Type One (sound deadening board) and ANSI-A 194.1.

Fiberboard is listed in the Gypsum Association Fire Resistance and Sound Design Manual (WPGA 3330) in a one-hour fire rated wall system.

Note: SoundStop® board must be applied vertically. Check with code officials in your area. SoundStop® must be installed behind drywall.

Technical Information / Warnings / Warranty Information

MAX TEMP RATING →

WARNING: KNIGHT-CELOTEX, LLC SOUNDSTOP® FIBERBOARD MUST NOT BE USED IN CLOSE PROXIMITY TO CHIMNEYS, HEATER UNITS, FIREPLACES, STEAM PIPES OR OTHER SURFACES WHICH COULD PROVIDE LONG TERM EXPOSURE TO EXCESSIVE HEAT (MAXIMUM 212°F) WITHOUT ADEQUATE THERMAL PROTECTION. CONSULT THE APPROPRIATE HEATING APPLIANCE MANUFACTURER'S INSTRUCTIONS BEFORE INSTALLATION.

STORAGE

PRIOR TO INSTALLATION, STORE AT A LOCATION WHERE HUMIDITY AND TEMPERATURE DUPLICATES THOSE DURING INSTALLATION AND OCCUPANCY IN ORDER TO STABILIZE THE SHEATHING. STORE IN COVERED UNHEATED AREA PROTECTED FROM THE WEATHER AT ALL TIMES. AFTER APPLICATION OF THE SHEATHING, IT IS RECOMMENDED THAT THE EXTERIOR FINISH BE APPLIED WITHIN 30 DAYS. IF APPLIED SHEATHING SHOULD GET WET, WAIT UNTIL IT IS COMPLETELY DRY BEFORE APPLICATION OF EXTERIOR SIDING.

Characteristics, properties or performance of materials manufactured by Knight-Celotex, LLC herein described are derived from data obtained under controlled test conditions. Knight-Celotex, LLC makes no warranties, express or implied, as to the characteristics, properties, or performance under any variations from such conditions in actual construction. Knight-Celotex, LLC assumes no responsibility for the effects of structural movement.

Limited Warranty

Knight-Celotex, LLC warrants its products and materials against manufacturing defects and defective materials or workmanship for a period of six months from the date products are shipped from our plant.

Claims

If a claim is made under this warranty it must be in writing, describing the defect in full, and promptly submitted to our address below.

Exclusions from Warranty

1. Knight-Celotex, LLC strives to produce its products to obtain high quality and excellence however, these products are susceptible to imperfections due to the nature of the materials. All final decisions concerning quality and excellence remain exclusively in the discretion of the Knight-Celotex, LLC.
2. This warranty does not include problems arising from improper installation or exposure to moisture and does not cover normal wear and tear or changes in color.
3. If a manufacturing defect does occur, Knight-Celotex, LLC will replace any defective products with new products but will cover only those particular items deemed to be defective. (Knight-Celotex, LLC reserves the right to refund to you the purchase price of any defective item.)
4. Failure to install in accordance with Knight-Celotex, LLC's approved procedures voids all warranties.

Remedies and Limitations

Knight-Celotex, LLC shall not be obligated or liable for labor or other costs related to dismantlement, installation, repair or replacement of defective products or materials.

Claims under this warranty are limited to replacement of defective products or material.

Implied Warranties

No implied warranties shall extend beyond warranty as stated here.

Incidental or Consequential Damages

Knight-Celotex, LLC disclaims and will not be responsible for any incidental or consequential damages arising from any manufacturing defect in its products.

This Warranty is the only express Warranty provided by Knight-Celotex, LLC. No employee, representative or agent nor any other person has authority to assume or incur on behalf of Knight-Celotex, LLC any obligation or liability in place of or in addition to this Warranty. This Warranty provides specific legal rights, and other rights, which vary from state to state, may be available.

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SSSS03.06

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for more than 50 years

Figure 3-1 - Cane Fiberboard Thermal Properties
(taken from Knight-Celotex Fiberboard SoundStop® product bulletin SSSS03.06)

System Specifications

Products Available

Catalog No. 201 is available in a wide variety shapes including slabs, bricks, rods, and pellets. It is easily shaped and cut using ordinary woodworking and metalworking tools. As an alternative to shaping material in your own shop, Thermo Electron Corporation can also machine Catalog No. 201 to close tolerances according to your specifications.

Neutron Shielding Material Specifications

Composition Data

Active Components:

Hydrogen atom density / cm3:	6.6 x 10^{22}
Natural isotope distribution:	99.98% 1H
Boron atom density / cm3:	2.6 x 10^{21}
Natural isotope distribution:	19.6% 10B and 80.4% 11B
Weight percent of all isotopes of boron:	5.00%
Total Density:	0.95 g / cm^3

Radiation Properties

Macroscopic thermal neutron cross section:	2.00 S (cm^{-1})
Gamma resistance:	5 x 10^8 R
Neutron resistance:	2.5 x 10^{17} N/ cm^2

Physical Properties

Appearance and Odor

State:	bricks, blocks, slabs
Color	white
Odor	no odor

Mechanical Properties

Machining of 201:	Excellent
Hardness:	N/A
Tensile Strength (ASTM D368):	N/A
Compressive Strength:	800 PSI

Thermal Properties

Recommended Temperature Limit:	180 °F (82.2 °C)
Melting Point:	210°F (98.8 °C)
Boiling Point:	300°F (148.8 °C)
Thermal Conductivity:	1
Heat Capacity:	N/A
Cubical Coefficient of Expansion:	6.1 x 10^{-4}
Linear Coefficient of Expansion:	2 x 10^{-4}
Vapor Pressure (mm Hg):	N/A
Vapor Density (Air = 1):	N/A
Evaporation Rate (ether=1):	N/A
Percent Volatile by Volume:	N/A
Specific Gravity (H2O = 1):	0.9 - 1.0 g/cm^3

Chemical Properties

Chemical Name & Synonyms:	Borated Polyethylene
Trade Name & Synonyms:	Catalog No. 201
Chemical Family:	Polyolefin's
Formula:	Mixture (CH2) n, B
Solubility in Water:	Negligible

Reactivity Data

Reactive Materials	
Reactive Acids	N/A
Reactive Bases	N/A
Reactive Metals and Metal Compounds	N/A
Reactive Oxidizing Agents	N/A
Reactive Reducing Agents	N/A

Material Incompatibility

Materials to Avoid:	N/A
Hazardous Decomposition Products	
Solid	None
Liquid	None
Gas	None
Hazardous Polymerization:	Will Not Occur

This specification sheet is for informational purposes only and is subject to change without notice. Thermo makes no warranties, expressed or implied, in this product summary.

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Figure 3-2 - Polyethylene Shielding Thermal Properties
(taken from Thermo-Electron Corporation, Neutron Shielding Material Catalog No. 201 Product Specifications, ©2003)

3.4 Thermal Evaluation under Hypothetical Accident Conditions

The most conservative assumption regarding the initial conditions of the S300 packaging before the fire is that due to the mechanical tests (free drop, crush, and puncture), the SFC has been separated entirely from the package and is exposed to the fire without any package components to shield it. 10 CFR §71.73(c)(4) requires that the package be exposed to a fire having an average temperature of 800 ºC (1,475 ºF) and a flame emissivity of 0.9 for 30 minutes. In the case of the S300, that would mean exposure of the SFC. The special form qualification testing, per 10 CFR §71.75, requires that the capsule be heated to 1,475 ºF for 10 minutes. With regard to capsule temperature, these two requirements are essentially equivalent, as shown by a simple heat transfer calculation.

3.4.1 Initial Conditions

The initial conditions for the SFC going into the HAC fire are: separation of the SFC from the S300 packaging, and an initial temperature of 165 ºF, consistent with NCT hot, full solar conditions.

As noted in Section 2.7.3, *Puncture*, the HAC free drop, crush, and puncture drop tests may not lead to full separation of the SFC from the other components of the S300 packaging. If the pipe component survived the HAC impact events intact, the SFC would be located within the polyethylene shielding, located within the steel pipe component. This scenario would be much more favorable than full exposure of the bare SFC to the hypothetical accident fire, due to the considerable protection from fire temperature which would be afforded by the pipe component and shielding materials. Any combustion of the polyethylene shield material which might occur would be quite limited compared to the full fire environment. Therefore, the most conservative condition for the HAC thermal event is exposure of the bare SFC to the fire.

3.4.2 Fire Test Conditions

The standard conditions required by 10 CFR §71.73(c)(4) were used in the analysis.

3.4.3 Maximum Temperatures and Pressures

Since the capsule is compact and made of thick steel (diameter between 2.5 and 3 inches, and wall thickness approximately 1/2 inches), its internal temperature during the hypothetical fire may be assumed to be uniform compared to the environment temperature. According to Kreith, Section 4-2,

Change in internal energy of the capsule during dθ	=	net heat flow from the environment during dθ

For a combination of convection and radiation, the transient heat transfer equation is (based on equation 4-1 of Kreith):

$$c\rho V dT = \left[\sigma A \varepsilon \left(T_\infty^4 - T^4\right) + hA\left(T_\infty - T\right)\right] d\theta$$

This can be rearranged for numerical solution as follows:

$$T_{NEW} = T_{OLD} + \frac{\sigma A \varepsilon \left(T_\infty^4 - T_{OLD}^4\right) + hA\left(T_\infty - T_{OLD}\right)}{c\rho V}\Delta\theta$$

To account for the flame emissivity of 0.9, an equivalent environment temperature could be used. The equivalent temperature will have the same emissive power with an emissivity of 1.0 as the flame has with a temperature of 1,475 ºF and an emissivity of 0.9. The equivalent temperature is:

$$T_\infty = \left[0.9\left(T_{Flame}^4\right)\right]^{1/4} = 1{,}885\ ^\circ R = 1{,}425\ ^\circ F$$

where T_{Flame} = 1,935 ºR (1,475 ºF). Conservatively, however, an environment temperature of T_∞ = 1,475 ºF and a flame emissivity of 1.0 will be used in this analysis.

Conservatively, the area (A) and weight (ρV) of the smallest capsule are used, since it will reach the fire temperature fastest. The Model III capsule has an outer diameter of 2.06 inches and a length of seven inches, thus an area of 0.45 ft^2 and a weight (assuming solid steel with a density of 0.29 lb/in^3) of 10.0 lb. The initial temperature of the capsule is 165 ºF for NCT as found above. A conservatively high convection coefficient of h = 10 Btu/hr-ft^2-ºF is used, and the emissivity of the capsule is 0.8, per 10 CFR §71.73(c)(4). The specific heat of the steel in the capsule has an average value of 0.13 Btu/hr-ºF through the heat-up temperature range of 200 ºF to 1,500 ºF[5]. Using these parameters with a straightforward numerical solution of the equation for T_{NEW}, the capsule temperature would reach 99% of the environment temperature (i.e., 1,460 ºF) after an exposure of just under 19 minutes. The dwell time at the peak fire temperature would therefore be approximately (30 – 19) = 11 minutes before the end of the fire. Since 10 CFR §71.75 requires that the capsule be heated to 1,475 ºF and held there for 10 minutes, the effects on containment of the requirements of 10 CFR §71.75 and §71.73(c)(4) are essentially equivalent. Therefore, the requirements for exposure of the package (in this case, the SFC) to the HAC fire have been met by the qualification testing of the SFC.

Since the test capsules were leaktight following the thermal qualification test (as documented in Section 2.10, *Special Form*), they will also be leaktight following the HAC, 30-minute fire test. In addition, it is noted that none of the materials of construction of the capsules would be affected by either the required temperature of 1,475 ºF nor hold time at that temperature. Exposure to the combustion of any of the flammable materials of construction of the S300 package (cane fiberboard, polyethylene) could not create conditions that would exceed the ability of the stainless steel components of the SFC to remain leaktight.

3.4.4 Maximum Thermal Stresses

Direct exposure of the SFC to the fully engulfing fire has been shown to be equivalent to the qualification testing performed on the capsule. Since the SFC was leaktight after qualification testing, thermal stresses are not of concern.

[5] $C_p = k/\rho\alpha$, where k (thermal conductivity) and α (thermal diffusivity) are taken from the ASME B&PV Code, Section II, Part D, Table TCD, averaged using data at 200 ºF and 1,500 ºF. Density (ρ) is taken as 501 lb/ft^3.

3.4.5 Accident Conditions for Air Transport of Fissile Material

The S300 package will not be air transported; hence, this section does not apply.

4. CONTAINMENT

Containment of radioactive materials is provided by the SFC. See Section 2.10, *Special Form*, for more details on the SFC. Since the S300 package does not provide containment, this section does not apply.

5. SHIELDING EVALUATION

This chapter documents the shielding analysis for the S300 transportation package with a ^{239}PuBe sealed neutron source. Both non-exclusive use and exclusive use conditions are considered. For non-exclusive use conditions, dose rates on the surface and 1 m are calculated for normal conditions of transport (NCT) and are shown to be less than the 10 CFR 71 limits of 200 mrem/hr and 10 mrem/hr, respectively. For exclusive use conditions applicable to a closed transport vehicle, dose rates on the package surface, vehicle surface, and 2 m from the vehicle surface are shown to be less than the 10 CFR 71 limits of 1000 mrem/hr, 200 mrem/hr, and 10 mrem/hr, respectively. For hypothetical accident conditions (HAC), the dose rates are less than 1000 mrem/hr at 1 m.

5.1 Description of Shielding Design

5.1.1 Design Features

The S300 packaging is a 55-gallon drum with polyethylene shielding inside of a 12-inch stainless steel pipe component (see Figure 1-1). The interior of the pipe contains radial and axial solid polyethylene shielding to provide an inner cavity with a diameter of 3.5 inches and a length of 17 inches. Solid disks of polyethylene, two inches thick, are also placed at the top and bottom of the cavity, reducing the usable cavity length to 13 inches. External to the steel pipe component is fiberboard dunnage. The outer dimension of the S300 drum is that of a standard 55-gallon drum, i.e., nominally 24 inches in diameter and 35 inches in height. Plywood and fiberboard dunnage are also present in the drum above, below, and around the pipe component. Dunnage is added to the top of the package as required so that the gap between the dunnage and top lid is less than 1/2 inch. The dimensions of the package are provided in Table 5-1.

The packaging includes polyethylene (shielding, $\rho = 0.92$ g/cm^3), stainless steel (pipe component, $\rho = 7.94$ g/cm^3), dunnage ($\rho = 0.224$ g/cm^3), and carbon steel (drum, $\rho = 7.8212$ g/cm^3). The material specifications are discussed further in Section 5.3.2, *Material Properties*.

Table 5-1 – S300 Packaging Dimensions

Component	Actual Dimension (inches)
Steel Pipe OD	12.8 (max)
Steel Pipe length	25.6
Steel pipe wall thickness	0.219 (min)
Steel pipe floor thickness	0.25 (min)
Steel Pipe lid thickness	0.9
Diameter of Polyethylene Plugs	3.5
Height of Polyethylene Plugs	2.0
ID of Polyethylene Sleeve	3.5
OD of Polyethylene Sleeve	11.8
Inner cavity height poly sleeve	17.0
Thickness poly sleeve lid	4.0
Thickness poly sleeve bottom	22.7-17.0-2.0 = 3.7
Outside drum height	34-13/16
Thickness of bottom dunnage	2.1
Height of pipe dunnage	21.4
Height of flange dunnage	4.8 + 0.5 = 5.3
Thickness of top dunnage (thickest location)	2.6
OD of dunnage	21.5 (slightly smaller for top dunnage)
ID of pipe dunnage	13.1
ID of flange dunnage	16.6

5.1.2 Summary Table of Maximum Radiation Levels

The source may be contained within one of two special form capsules, the Model II and Model III. The Model II is larger than the Model III and therefore may hold a larger mass of source material. Maximum dose rates are provided for the following three scenarios:

- Table 5-2: Model II Capsule containing 206 g Pu (12.77 Ci), Non-Exclusive Use
- Table 5-3: Model II Capsule containing 350 g Pu (21.70 Ci), Exclusive Use (closed vehicle)
- Table 5-4: Model III Capsule containing 160 g Pu (9.92 Ci), Non-Exclusive Use

The transport index (TI) is the maximum dose rate at 1 m from the surface of the package. For non-exclusive use, the TI = 7.4. The TI for the Model II Capsule bounds the TI for the Model III Capsule.

The HAC dose rates are computed only for the maximum Pu loading of 350 g and are provided in Table 5-5.

Table 5-2 – Model II Capsule NCT Dose Rates (Non-exclusive use)

206 g Pu	**Package Surface (mrem/hr)**			**1 m from Package Surface (mrem/hr)**		
TI = 7.4	**Top**	**Side**	**Bottom**	**Top**	**Side**	**Bottom**
Gamma	<10.7	11.4	10.7	<0.3	0.5	0.3
Neutron	<104.4	188.3	104.4	<3.5	6.9	3.5
Total	<115.1	**199.7**	115.1	<3.8	7.4	3.8
Limit		200			10	

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-3 – Model II Capsule NCT Dose Rates (Exclusive use)

350 g Pu	**Package Surface (mrem/hr)**			**Vehicle Surface (mrem/hr)**		
TI = NA	**Top**	**Side**	**Bottom**	**Top**	**Side**	**Bottom**
Gamma	<18.1	19.3	18.1	<8.0	0.8	8.0
Neutron	<177.4	320.0	177.4	<79.8	11.8	79.8
Total	<195.5	**339.3**	195.5	<87.8	12.6	87.8
Limit		1000			200	
	2m from Vehicle Surface (mrem/hr)					
	Top	**Side**	**Bottom**			
Gamma	NA	0.1	NA			
Neutron	NA	1.6	NA			
Total	NA	1.7	NA			
Limit		10				

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-4 – Model III Capsule NCT Dose Rates (Non-exclusive use)

160 g Pu	Package Surface (mrem/hr)			1 m from Package Surface (mrem/hr)		
TI = 5.7	Top	Side	Bottom	Top	Side	Bottom
Gamma	<8.3	8.8	8.3	<0.3	0.4	0.3
Neutron	<81.1	146.3	81.1	<2.7	5.4	2.7
Total	<89.4	155.1	89.4	<3.0	5.7	3.0
Limit		200			10	

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-5 – Bounding HAC Dose Rates

350 g Pu	1 m from Package Surface (mrem/hr)		
	Top	Side	Bottom
Gamma	0	0	0
Neutron	57.1	57.1	57.1
Total	57.1	57.1	57.1
Limit		1000	

5.2 Source Specification

The source is a solid ^{239}PuBe neutron source. As the mass of the source may vary between packages, the source is computed on a per Ci basis.

5.2.1 Gamma Source

As the source is a neutron emitter, the primary gamma source is many orders of magnitude smaller than the neutron source and may be neglected. The gamma dose rates reported are the result of capture gammas emitted when the neutrons are absorbed in the polyethylene.

5.2.2 Neutron Source

The neutron spectrum from this source is calculated using the SOURCES-4A computer program[1] as documented in report LA-UR-02-5120[2]. This reference is included in Section 5.5.1, *Neutron Source Document LA-UR-02-5120*. The plutonium is modeled as infinitely dilute within the beryllium target material, which results in a bounding source magnitude. The neutron source for 1 Ci of ^{239}Pu as a function of energy is provided in Table 5-6. All MCNP dose rate calculations are performed for a source strength corresponding to 1 Ci of ^{239}Pu.

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[1] SOURCES-4A: A Code for Calculating (alpha, n), Spontaneous Fission, and Delayed Neutron Sources and Spectra, Oak Ridge National Laboratory RSICC Code Package CCC-661 (June 1999).

[2] A Comparison of Dose Rates from (alpha, n) and Spontaneous Fission Neutron Sources, LA-UR-02-5120, Rev. 0, 2002.

Table 5-6 – PuBe Neutron Source (per Ci ^{239}Pu)

Upper Energy (MeV)	Neutrons/s
0	0.000E+00
0.01	1.391E+00
0.02	4.617E+00
0.05	2.892E+01
0.1	9.017E+01
0.2	2.744E+02
0.4	5.029E+03
0.6	2.107E+04
0.8	3.209E+04
1.0	3.480E+04
1.3	5.139E+04
1.7	5.191E+04
2.1	6.207E+04
2.4	6.154E+04
2.7	7.517E+04
3.0	1.224E+05
3.3	1.562E+05
3.6	1.467E+05
4.0	1.806E+05
4.4	1.643E+05
5.0	2.208E+05
6.0	2.200E+05
7.0	2.037E+05
8.0	2.311E+05
9.0	1.737E+05
10.0	1.049E+05
12.0	1.427E+04
15.0	4.309E-05
20.0	3.342E-06
Total	2.334E+06

5.3 Shielding Model

5.3.1 Configuration of Source and Shielding

NCT shielding models consider damage from 4-ft drop tests, which is negligible as discussed in Section 2.6.7, *Free Drop*. Damage is primarily confined to the rim of the package. The minor bending in the package rim is below the level of detail in the MCNP models because the protruding rims and locking mechanism are not modeled for simplicity. The MCNP model geometry is shown in Figure 5-1. Note that the model is simplified in the region of the pipe flange, although this simplification has negligible impact on the results.

Subsequent to a drop, it is assumed that the source will be shifted to a position that would generate the highest dose rates, i.e., at the bottom center of the package for the bottom dose rate calculation, or to the side of the package for the side dose rate calculation, as shown in Figure 5-2. It is conservatively assumed that the inner packaging would cease to be concentric if the S300 were lying on its side, closing the air gaps between the source and the dose rate locations. For simplicity, these air gaps are eliminated in the MCNP models in the side and bottom directions, although the thickness of each region is maintained. The net effect is to reduce the overall dimensions of the package, which conservatively brings the source closer to the dose rate locations.

It is not necessary to calculate dose rates on the top of the S300 because dose rates on the bottom will bound dose rates on the top for the following reasons: 1) there is a steel plug within the capsule above the source, but none below the source, 2) the top lid of the pipe component is thicker than the bottom (0.9 inches vs. 0.25 inches), 3) the top dunnage is thicker than the bottom dunnage (2.6 inches vs. 2.1 inches), placing the package surface farther from the source, and 4) the polyethylene shielding is thicker on the top than at the bottom (4.0 inches vs. 3.7 inches). Because the bottom dose rates bound the top dose rates, models with the S300 in an upside-down orientation with all air gaps closed between the source and the S300 lid are not developed.

The source is modeled as $Pu\text{-}Be_{13}$, and the tantalum and stainless steel cladding that surrounds the source is conservatively neglected. The geometry of the source is consistent with 160 g Pu in a PuBe source. The diameter of the source is 1.3”, and the height is 2.95”, consistent with the inner dimensions of the tantalum inner container. A density of 3.7 g/cm^3 is computed based on the Pu mass and dimensional information.

Each source is enclosed in a stainless steel capsule. Two special form capsule designs are available, designated as the Model II and Model III capsules. Dimensions of these capsules are provided on Figure 1-3 and Figure 1-4 for the Model II and III capsule, respectively. As the source is a neutron source only, the capsule provides little shielding (capture gammas are generated outside the capsule). As the capsule has little effect on the dose rates, rather than develop separate models for each capsule type, a “hybrid” capsule is developed to bound both capsule designs. The hybrid capsule combines the minimum thicknesses from the two capsule types, see Table 5-8. Note that the overall length, ID, and OD of the capsules has been adjusted so that no air gap is present between the capsule and the inner polyethylene sleeve. This simplification has been made for modeling convenience and has no impact on the calculation.

In the HAC configuration, the source is modeled as a point source. As the S300 lid may not remain on the package in an accident, it is assumed for the HAC models that all shielding is absent. Although the source capsule would remain intact, for simplicity no credit is taken for the stainless steel capsule and dose rates are computed over a sphere 1 m from the source.

Table 5-7 – S300 Overpack As-Modeled Dimensions

Component	Actual Dimension (inches)	As-Modeled Dimension (inches)
Steel Pipe OD	12.8 (max)	12.188
Steel Pipe length	25.6	25.7
Steel pipe wall thickness	0.219 (min)	0.219
Steel pipe floor thickness	0.25 (min)	0.25
Steel Pipe lid thickness	0.9	0.9
Diameter of Polyethylene Plugs	3.5	3.5
Height of Polyethylene Plugs	2.0	2.0
ID of Polyethylene Sleeve	3.5	3.5
OD of Polyethylene Sleeve	11.8	11.75
Inner cavity height poly sleeve	17.0	17.0
Thickness poly sleeve lid	4.0	4.0
Thickness poly sleeve bottom	22.7-17.0-2.0 = 3.7	3.7
Outside drum height	34-13/16	35
Thickness of bottom dunnage	2.1	2.1
Height of pipe dunnage	21.4	26.6 (combined pipe and flange dunnage)
Height of flange dunnage	4.8 + 0.5 = 5.3	26.6 (combined pipe and flange dunnage)
Thickness of top dunnage (thickest location)	2.6	3.1 (additional 0.5" assumed[3])
OD of dunnage	21.5 (slightly smaller for top dunnage)	20.588
ID of pipe dunnage	13.1	12.188
ID of flange dunnage	16.6	12.188

[3] In actual practice, dunnage will be added to the top of the package so that the gap between the top dunnage and the lid is less than 1/2 inch thick.

Table 5-8 – Hybrid Capsule Dimensions

Component	Model II Capsule Actual Dimension (inches)	Model III Capsule Actual Dimension (inches)	Hybrid Dimension used in MCNP (inches)
Overall length (not including shearable cap)	11.75	7.00	13.0
Thickness of cap	0.75	0.75	0.75
Thickness of sealing plug	0.78	0.77	0.77
Diameter and length of hole in sealing plug	0.25/0.38	NA	0.25/0.38
ID	2.062	1.50	2.562
OD	3.00	2.50	3.5
Side Thickness	0.469	0.5	0.469
Bottom Thickness	<1.0 when drill point included	<1.0 when drill point included	0.5

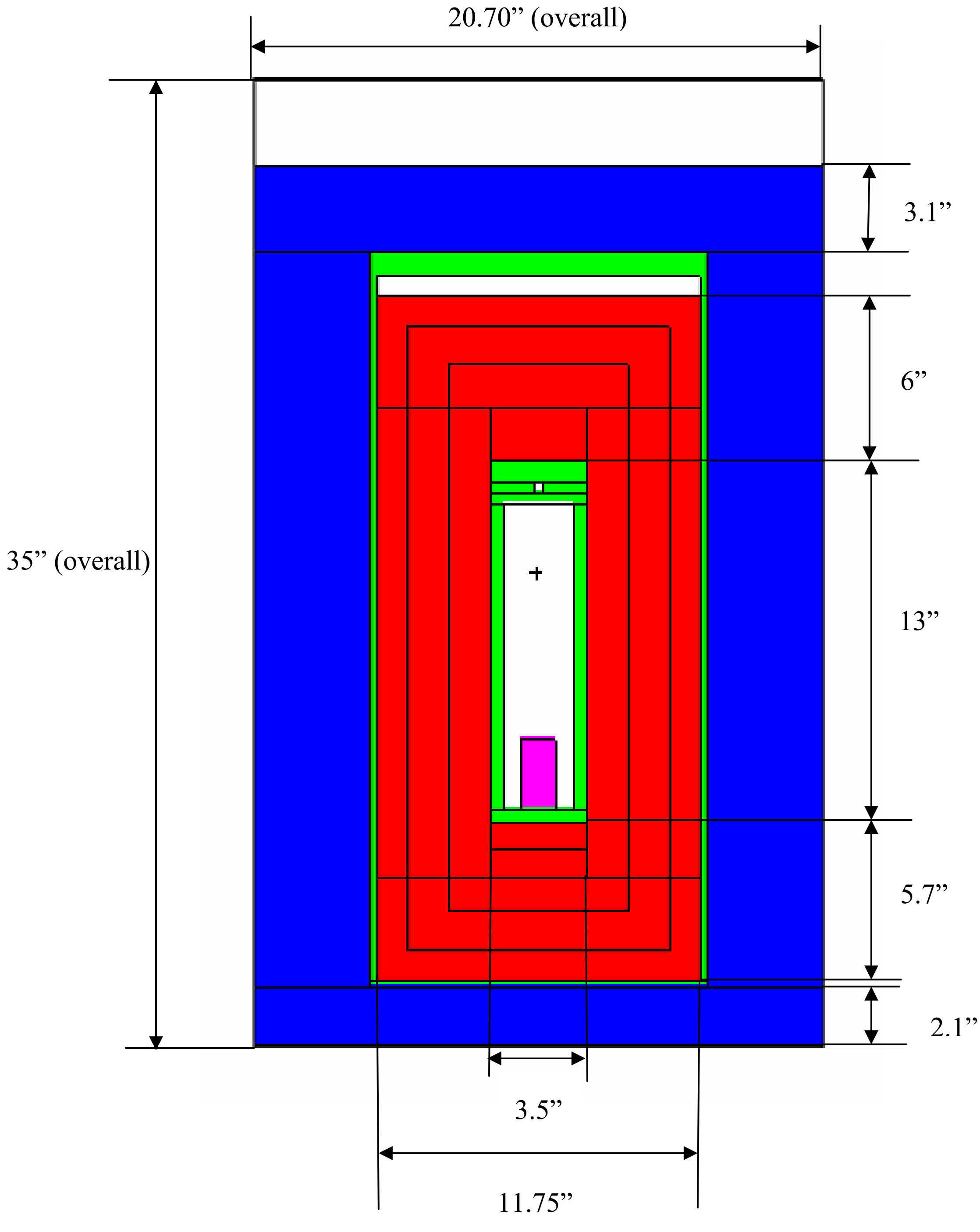
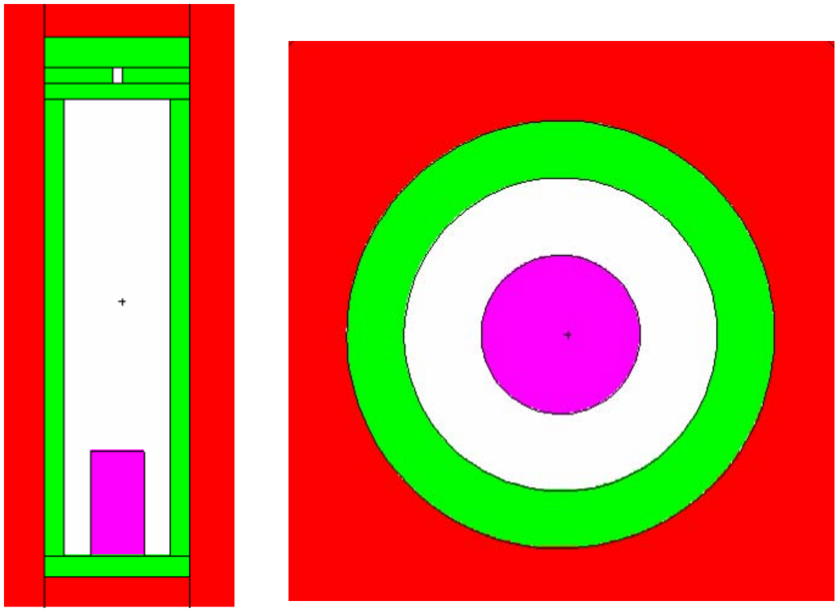
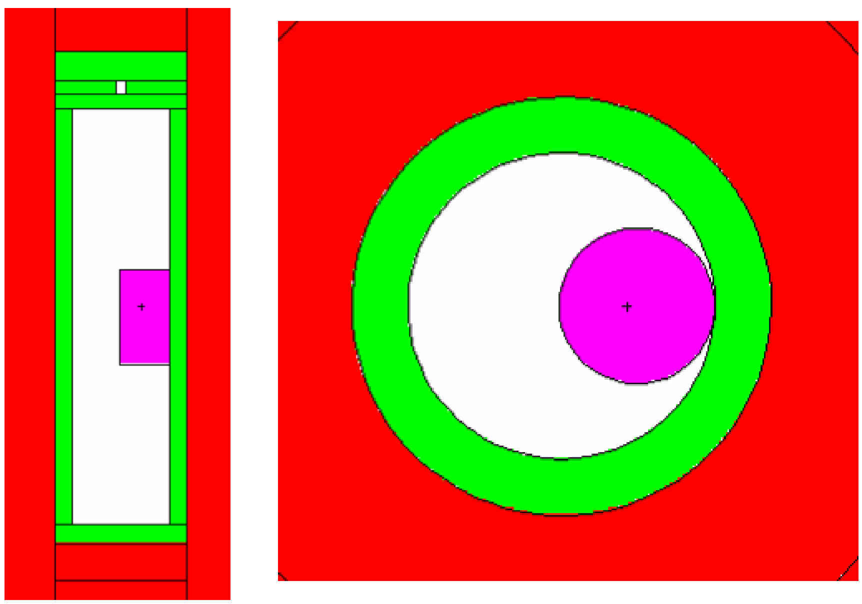


Figure 5-1 – S300 Packaging MCNP Model



Source in bottom position



Source in side position

Figure 5-2 – Source Positions for Bottom and Side Models

5.3.2 Material Properties

The material properties are provided in Table 5-9. The composition and density of common materials are taken from the SCALE Standard Composition Library[4]. Compositions are input as either atoms per molecule or weight percent (wt. %), depending on how the composition is listed in the reference. The dunnage is assumed to have the same composition as redwood but with a density of 14 lb/ft^3 (0.224 g/cm^3), as shown on the SAR drawing. The PuBe density is computed, as discussed in Section 5.3.1, *Configuration of Source and Shielding*.

Table 5-9 – Material Properties

Polyethylene, CH_2 (density = 0.92 g/cm^3) (from SCALE)					
Element	Library ID	Atoms	Element	Library ID	Atoms
Hydrogen	1001	2	Carbon	6000	1
304SS (density = 7.94 g/cm^3) (from SCALE)					
Element	Library ID	Wt. %	Element	Library ID	Wt. %
Carbon	6000	0.08	Manganese	25055	2.0
Silicon	14000	1.0	Iron	26000	68.375
Phosphorus	15031	0.045	Nickel	28000	9.5
Chromium	24000	19.0	-	-	-
Dunnage – Composition: Redwood, $C_6H_{10}O_5$ (density 0.224 g/cm^3) (composition from SCALE, density from SAR drawing)					
Element	Library ID	Atoms	Element	Library ID	Atoms
Carbon	6000	6	Oxygen	8016	5
Hydrogen	1001	10	-	-	-
Carbon steel (density = 7.8212 g/cm^3) (from SCALE)					
Element	Library ID	Wt. %	Element	Library ID	Wt. %
Carbon	6000	1.0	Iron	26000	99.0
$PuBe_{13}$ Source (density = 3.7 g/cm^3)					
Element	Library ID	Atoms	Element	Library ID	Atoms
Plutonium	94239	1	Beryllium	4009	13

5.4 Shielding Evaluation

5.4.1 Methods

MCNP5 v1.30 is used for the shielding analysis[5]. MCNP5 is a standard, well-accepted shielding program utilized to compute dose rates for shielding licenses. A three-dimensional model is developed that captures all of the relevant design parameters of the S300 package. Dose rates

[4] Standard Composition Library, NUREG/CR-0200, Rev. 6, Volume 3, Section M8, September 1998.

[5] MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, LA-CP-03-0245, April 2003.

are calculated by tallying the neutron and gamma fluxes over surfaces (or volumes) of interest and converting these fluxes to dose rates.

The models are run in coupled neutron/photon mode to accurately tally gammas generated by the interaction of neutrons with the shielding material.

5.4.2 Input and Output Data

Three input/output cases are used to generate the results. Case S300BOTTOM generates the dose rates at the bottom of the package, while case S300OFFCENTER generates the dose rates at the side of the package. Case S300HAC generates the dose rates for the HAC condition. A sample input file (S300OFFCENTER) is provided in Section 5.5.2, *Sample Input File*. All cases are run with a 1 Ci PuBe source and the results are scaled to the desired source activity.

Russian roulette is utilized to accelerate program convergence. Convergence for this geometry is relatively quick, as the model geometry is not complex. The 10 MCNP statistical checks are met for the bottom tallies. The 10 MCNP statistical checks are not provided for the mesh tallies, although the statistical uncertainty is low and the results are well behaved.

5.4.3 Flux-to-Dose Conversion

ANSI/ANS-6.1.1-1977 flux-to-dose-rate conversion factors are utilized for both neutron and gamma radiation. These factors are obtained from the MCNP user's manual and are provided in Table 5-10.

Table 5-10 – ANSI/ANS 1977 Flux-to-Dose-Rate Conversion Factors

Neutron		Gamma	
E (MeV)	(mrem/hr)/(n/cm^2/s)	E (MeV)	(mrem/hr)/(γ/cm^2/s)
2.50E-08	3.67E-03	0.01	3.96E-03
1.00E-07	3.67E-03	0.03	5.82E-04
1.00E-06	4.46E-03	0.05	2.90E-04
1.00E-05	4.54E-03	0.07	2.58E-04
1.00E-04	4.18E-03	0.1	2.83E-04
0.001	3.76E-03	0.15	3.79E-04
0.01	3.56E-03	0.2	5.01E-04
0.1	2.17E-02	0.25	6.31E-04
0.5	9.26E-02	0.3	7.59E-04
1	1.32E-01	0.35	8.78E-04
2.5	1.25E-01	0.4	9.85E-04
5	1.56E-01	0.45	1.08E-03
7	1.47E-01	0.5	1.17E-03
10	1.47E-01	0.55	1.27E-03
14	2.08E-01	0.6	1.36E-03
20	2.27E-01	0.65	1.44E-03
		0.7	1.52E-03
		0.8	1.68E-03
		1	1.98E-03
		1.4	2.51E-03
		1.8	2.99E-03
		2.2	3.42E-03
		2.6	3.82E-03
		2.8	4.01E-03
		3.25	4.41E-03
		3.75	4.83E-03
		4.25	5.23E-03
		4.75	5.60E-03
		5	5.80E-03
		5.25	6.01E-03
		5.75	6.37E-03
		6.25	6.74E-03
		6.75	7.11E-03
		7.5	7.66E-03
		9	8.77E-03
		11	1.03E-02
		13	1.18E-02
		15	1.33E-02

5.4.4 External Radiation Levels

For non-exclusive use, dose rates are computed at the package surface (r = 26.2868 cm) and 1 m (r = 126.2868 cm) from the package surface. For exclusive use, dose rates are computed at the package surface, the vehicle surface, and 2 m from the vehicle surface. For the exclusive use calculations, it is assumed that the vehicle is a trailer with a width of 102 inches and that the package is on a pallet four inches high in the center of the vehicle. Because the trailer width results in a dose rate location of r = 129.54 cm at the vehicle side surface, this tally is essentially equivalent to the 1 m surface tally (r = 126.2868 cm) and the 1m surface tally is conservatively used for both tallies. The bottom of the vehicle is assumed to be at the bottom of the four-inch pallet, and no credit is taken for shielding by the pallet or bed of the trailer. The tally 2 m from the side of the vehicle is located at r = 326.2868 cm.

The bottom tallies are computed with the source at the bottom center of the package (case name S300BOTTOM). Therefore, dose rates on the bottom surfaces are circumferentially symmetric about the centerline of the package, allowing concentric tallies that converge quickly. Segmenting surfaces are utilized to calculate the bottom dose rates in annular regions.

The side tallies are computed with the source off-center within the capsule (case name S300OFFCENTER). Calculation of the side dose rates is more complex because the side dose rates are not circumferentially symmetric. Because the source is assumed to shift to the inner wall of the package, the side surface dose rate near the source will be higher than the dose rate on the opposite side of the source. To capture this non-symmetric effect, a cylindrical mesh tally is utilized. For the side tallies of interest that utilize mesh tallies (surface and 1 m), the mesh tally has a height of 2.95 inches (to coincide with the source height) and a thickness of 1 cm. Circumferentially, the mesh is divided into 36 segments of equal width, or a segment width of 10°. Zero degrees corresponds to the positive x-axis (the location of the source) and the tally is indexed in the counterclockwise direction. A standard circumferentially symmetric tally is utilized for the 2 m side dose rate tally because the effect of radially shifting the source would not be detectable at this distance.

Dose rates computed for a 1 Ci PuBe source are provided in Table 5-11 through Table 5-14. As expected, the maximum bottom dose rates at all locations occur at the center of the package, as shown in Table 5-11. The bottom dose rates bound the top dose rates; therefore, the top dose rates are not computed.

The dose rates 2 m from the side of the vehicle are provided in Table 5-12. Dose rates are calculated in three axial bands (beside, above, and below the source). The height of the center band is equal to the height of the source. Although the tally below the source is showing a slightly higher dose rate than the dose rate at the center, the dose rates are essentially the same (within statistical fluctuation) for the three axial tally locations.

The dose rates at the package side surface and 1m from the package side surface are provided in Table 5-13 and Table 5-14, respectively. Note that the same tally is used for dose rates 1 m from the package side surface and at the vehicle side surface. Dose rates are computed in 10° circumferential increments. The variation in dose rate with circumferential location is apparent on the package surface, although the effect is much reduced at 1m. In both cases, the dose rates are a maximum near $\theta = 0°$ and a minimum near $\theta = 180°$, as expected. Comparison with the bottom dose rates indicates that the side dose rates bound the bottom dose rates. The side dose rates are bounding because the side has less shielding than the bottom.

As the dose rates provided in Table 5-11 through Table 5-14 are for a 1 Ci source, these dose rates must be scaled to the actual source strength for the various scenarios. The dose rates for any arbitrary source may be computed by multiplying these dose rates by the actual source strength in Ci. Per 10 CFR 71 Table A-1, the specific activity of ^{239}Pu is 0.062 Ci/g. The specific activity may be used to convert a ^{239}Pu mass into Ci. For example, the activity corresponding to a 160 g Pu source is (160 g)(0.062 Ci/g) = 9.92 Ci. In this manner, the dose rates for the various source strengths of interest may be computed.

NCT dose rates are computed for the following three scenarios:

- The largest source allowable within the Model II Capsule that does not exceed the non-exclusive use dose rate limits (206 g),
- 350 g source in the Model II Capsule (350 g is the largest source allowed for the Model II Capsule) for exclusive use shipments, and
- 160 g source in the Model III Capsule (160 g is the largest source that can geometrically fit in the Model III Capsule) for non-exclusive use shipments.

The Model II Capsule NCT dose rates for non-exclusive use are provided in Table 5-15. For 206 g of ^{239}Pu, the limiting dose rate of 199.7 mrem/hr (limit = 200 mrem/hr) occurs at the side surface of the package, and the TI = 7.4. The limiting dose rate is intentionally chosen to be close to the limit to maximize the allowable source. The actual dose rate will be confirmed by measurement prior to shipment. The conservatism in the modeled source is also significant, as the modeled source strength of $2.33(10^6)$ n/s/Ci is computed assuming an infinitely dilute mixture of ^{239}Pu in Be and will bound the true value by about 25%, since 1.7 to $1.8(10^6)$ n/c/Ci is typical.

The Model II Capsule NCT dose rates for exclusive use are provided in Table 5-16. For 350 g of ^{239}Pu, the maximum dose rate of 339.3 mrem/hr (limit = 1000 mrem/hr) occurs on the side of the package.

The Model III Capsule NCT dose rates for non-exclusive use are provided in Table 5-17. It is assumed that 160 g is the maximum size of the source that may geometrically fit within the Model III Capsule, and the maximum surface dose rate of 155.1 mrem/hr does not approach the limit of 200 mrem/hr. The S300 containing a Model III Capsule has a maximum TI = 5.7, which is bounded by the TI of the Model II Capsule.

The HAC model (case name S300HAC) is simply a point source with a spherical surface tally at 1m from the point source. The geometry of the source and packaging is not modeled, which conservatively ignores all shielding and places the tally location closer to the source. The 1 Ci dose rate is due to neutrons only and has a value of 2.63 ± 0% mrem/hr. (The statistical uncertainty is 0% because the model converges rapidly.) For the limiting case of 350 g ^{239}Pu, the dose rate is (350)(0.062)(2.63) = 57.1 mrem/hr, which is far below the limit of 1000 mrem/hr. The result is also summarized in Table 5-18. As no shielding is present, the gamma dose rate is zero because there is no shielding material to generate capture gammas. The increase in neutron dose rate that results from ignoring the shielding far offsets the decrease in gamma dose rate due to a lack of capture gammas.

Table 5-11 – NCT Bottom Dose Rates (mrem/hr), 1 Ci ^{239}Pu

Bottom Surface of Package						
Radial Location (cm)	**Neutron**	**σ**	**Gamma**	**σ**	**Total**	**σ**
0 to 2.5	**8.17**	**2%**	**0.83**	**2%**	**9.01**	**2%**
2.5 to 7.5	7.80	1%	0.78	1%	8.58	1%
7.5 to 12.5	6.28	1%	0.67	1%	6.95	1%
12.5 to 17.5	4.47	1%	0.51	1%	4.98	1%
17.5 to 26.5	4.47	1%	0.36	1%	4.83	1%
Bottom Surface of Vehicle						
Radial Location (cm)	**Neutron**	**σ**	**Gamma**	**σ**	**Total**	**σ**
0 to 2.5	**3.79**	**3%**	**0.35**	**3%**	**4.14**	**3%**
2.5 to 7.5	3.68	1%	0.37	1%	4.05	1%
7.5 to 12.5	3.31	1%	0.34	1%	3.65	1%
12.5 to 17.5	2.79	1%	0.29	1%	3.09	1%
17.5 to 26.5	0.84	0.3%	0.071	0.3%	0.91	0.3%
1 m from Bottom Surface of Package						
Radial Location (cm)	**Neutron**	**σ**	**Gamma**	**σ**	**Total**	**σ**
0 to 7.5	**0.27**	**3%**	**0.025**	**4%**	**0.30**	**3%**
7.5 to 12.5	0.27	3%	0.025	3%	0.29	3%
12.5 to 17.5	0.26	2%	0.025	2%	0.29	2%
17.5 to 126.5	0.17	0.5%	0.018	0.4%	0.18	0.4%

Table 5-12 – NCT Side 2m Dose Rates (mrem/hr), 1 Ci ^{239}Pu

Axial Location (cm)	Neutron	σ	Gamma	σ	Total	σ
Above Source	0.071	1%	0.005	1%	0.076	0.5%
Beside Source	0.071	1%	0.005	1%	0.076	0.5%
Below Source	**0.072**	**1%**	**0.005**	**1%**	**0.077**	**0.5%**

Table 5-13 – NCT Side Surface Dose Rates (mrem/hr), 1 Ci ^{239}Pu

Circumferential Location (degrees)	Neutron	σ	Gamma	σ	Total	σ
0 to 10	14.53	1%	0.90	1%	15.42	1%
10 to 20	14.37	1%	0.86	1%	15.24	1%
20 to 30	14.10	1%	0.87	1%	14.97	1%
30 to 40	13.63	1%	0.87	1%	14.50	1%
40 to 50	13.47	1%	0.86	1%	14.33	1%
50 to 60	13.12	1%	0.84	1%	13.96	1%
60 to 70	12.72	1%	0.84	1%	13.56	1%
70 to 80	12.56	1%	0.83	1%	13.38	1%
80 to 90	12.23	1%	0.81	1%	13.03	1%
90 to 100	11.82	1%	0.79	1%	12.62	1%
100 to 110	11.61	1%	0.79	1%	12.40	1%
110 to 120	11.75	1%	0.78	1%	12.53	1%
120 to 130	11.38	1%	0.77	1%	12.16	1%
130 to 140	11.26	1%	0.76	1%	12.02	1%
140 to 150	11.24	1%	0.75	1%	11.99	1%
150 to 160	11.06	1%	0.75	1%	11.81	1%
160 to 170	11.11	1%	0.76	1%	11.87	1%
170 to 180	11.13	1%	0.75	1%	11.88	1%
180 to 190	11.33	1%	0.73	1%	12.06	1%
190 to 200	11.01	1%	0.75	1%	11.76	1%
200 to 210	11.02	1%	0.75	1%	11.77	1%
210 to 220	11.21	1%	0.77	1%	11.97	1%
220 to 230	11.17	1%	0.75	1%	11.93	1%
230 to 240	11.35	1%	0.78	1%	12.13	1%
240 to 250	11.71	1%	0.78	1%	12.49	1%
250 to 260	11.71	1%	0.79	1%	12.49	1%
260 to 270	11.89	1%	0.79	1%	12.68	1%
270 to 280	12.37	1%	0.81	1%	13.18	1%
280 to 290	12.71	1%	0.82	1%	13.53	1%
290 to 300	12.85	1%	0.84	1%	13.69	1%
300 to 310	13.13	1%	0.84	1%	13.97	1%
310 to 320	13.59	1%	0.85	1%	14.44	1%
320 to 330	13.78	1%	0.87	1%	14.65	1%
330 to 340	14.16	1%	0.87	1%	15.03	1%
340 to 350	14.20	1%	0.89	1%	15.09	1%
350 to 360	**14.75**	**1%**	**0.89**	**1%**	**15.63**	**1%**

Table 5-14 – NCT Side 1m/Vehicle Surface Dose Rates (mrem/hr), 1 Ci ^{239}Pu

Circumferential Location (degrees)	Neutron	σ	Gamma	σ	Total	σ
0 to 10	0.54	2%	0.035	2%	0.57	2%
10 to 20	0.53	2%	0.036	2%	0.56	2%
20 to 30	0.52	2%	0.036	2%	0.55	2%
30 to 40	0.52	2%	0.036	2%	0.56	2%
40 to 50	0.53	2%	0.035	2%	0.56	2%
50 to 60	0.51	2%	0.035	2%	0.54	2%
60 to 70	0.50	2%	0.036	2%	0.54	2%
70 to 80	0.50	2%	0.035	2%	0.53	2%
80 to 90	0.49	2%	0.034	2%	0.52	2%
90 to 100	0.48	2%	0.034	2%	0.52	2%
100 to 110	0.47	2%	0.034	2%	0.51	2%
110 to 120	0.47	2%	0.032	2%	0.51	2%
120 to 130	0.47	2%	0.034	2%	0.51	2%
130 to 140	0.46	2%	0.033	2%	0.49	2%
140 to 150	0.47	2%	0.034	2%	0.51	2%
150 to 160	0.46	2%	0.033	2%	0.49	2%
160 to 170	0.46	2%	0.032	2%	0.49	2%
170 to 180	0.45	2%	0.033	2%	0.48	2%
180 to 190	0.46	2%	0.032	2%	0.50	2%
190 to 200	0.48	2%	0.033	2%	0.51	2%
200 to 210	0.46	2%	0.034	2%	0.49	2%
210 to 220	0.48	2%	0.033	2%	0.51	2%
220 to 230	0.46	2%	0.033	2%	0.49	2%
230 to 240	0.47	2%	0.033	2%	0.50	2%
240 to 250	0.47	2%	0.035	2%	0.50	2%
250 to 260	0.47	2%	0.034	2%	0.51	2%
260 to 270	0.48	2%	0.035	2%	0.52	2%
270 to 280	0.49	2%	0.034	2%	0.52	2%
280 to 290	0.49	2%	0.034	2%	0.53	2%
290 to 300	0.50	2%	0.036	2%	0.53	2%
300 to 310	0.51	2%	0.034	2%	0.55	2%
310 to 320	0.51	2%	0.034	2%	0.54	2%
320 to 330	0.53	2%	0.036	2%	0.57	2%
330 to 340	0.51	2%	0.035	2%	0.54	2%
340 to 350	0.53	2%	0.035	2%	0.57	2%
350 to 360	**0.54**	**2%**	**0.037**	**2%**	**0.58**	**2%**

Table 5-15 – Model II Capsule NCT Dose Rates (Non-exclusive use)

206 g Pu	**Package Surface (mrem/hr)**			**1 m from Package Surface (mrem/hr)**		
TI = 7.4	**Top**	**Side**	**Bottom**	**Top**	**Side**	**Bottom**
Gamma	<10.7	11.4	10.7	<0.3	0.5	0.3
Neutron	<104.4	188.3	104.4	<3.5	6.9	3.5
Total	<115.1	**199.7**	115.1	<3.8	7.4	3.8
Limit		200			10	

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-16 – Model II Capsule NCT Dose Rates (Exclusive use)

350 g Pu	**Package Surface (mrem/hr)**			**Vehicle Surface (mrem/hr)**		
TI = NA	**Top**	**Side**	**Bottom**	**Top**	**Side**	**Bottom**
Gamma	<18.1	19.3	18.1	<8.0	0.8	8.0
Neutron	<177.4	320.0	177.4	<79.8	11.8	79.8
Total	<195.5	**339.3**	195.5	<87.8	12.6	87.8
Limit		1000			200	
	2m from Vehicle Surface (mrem/hr)					
	Top	**Side**	**Bottom**			
Gamma	NA	0.1	NA			
Neutron	NA	1.6	NA			
Total	NA	1.7	NA			
Limit		10				

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-17 – Model III Capsule NCT Dose Rates (Non-exclusive use)

160 g Pu	**Package Surface (mrem/hr)**			**1 m from Package Surface (mrem/hr)**		
TI = 5.7	**Top**	**Side**	**Bottom**	**Top**	**Side**	**Bottom**
Gamma	<8.3	8.8	8.3	<0.3	0.4	0.3
Neutron	<81.1	146.3	81.1	<2.7	5.4	2.7
Total	<89.4	155.1	89.4	<3.0	5.7	3.0
Limit	200			10		

Note: All reported dose rates are rounded to the nearest one-tenth, although the total dose rate values are based on the sum of unrounded values. Therefore, the sum of the rounded gamma and neutron dose rates will not necessarily equal the total rounded dose rate value.

Table 5-18 – Bounding HAC Dose Rates

350 g Pu	**1 m from Package Surface (mrem/hr)**		
	Top	**Side**	**Bottom**
Gamma	0	0	0
Neutron	57.1	57.1	57.1
Total	57.1	57.1	57.1
Limit	1000		

5.5 Appendices

5.5.1 Neutron Source Document LA-UR-02-5120

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Title: A COMPARISON OF DOSE RATES FROM (alpha,n) AND SPONTANEOUS FISSION NEUTRON SOURCES

Author(s): S. L. GOGOL AND J. R.BLAND

Submitted to: SAFETY ANALYSIS REPORT FOR THE TRUPACT-II RRES-SAOSR

Los Alamos
National Laboratory

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A Comparison of Dose Rates from (alpha, n) and Spontaneous Fission Neutron Sources

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Executive Summary

The purpose of this report is to estimate comparative dose rates from a range of common isotopic neutron sources. This data was used to identify the isotopic neutron source that will produce the greatest dose rate per curie.

Eighteen different neutron source generating material configurations were modeled to analyze the dose rates at various distances. The list of the neutron sources evaluated is provided in Appendix A.

The neutron production rates and spectra generated from these neutron sources are from (α,n) reactions, spontaneous fission, and delayed neutron emissions. The creation of a neutron source from the (α,n) reactions is due to the decay of the radionuclide in the homogeneous media. The absolute neutron source strength and neutron spectra, were incorporated into the MCNP model and the resulting neutron interactions generate the neutron and gamma dose rate contributions. Secondary neutron multiplication is not an issue with these sources and drum packing materials.

Four neutron source generating material configurations created dose rates (mrem/h-Ci) approximately 10 times or more greater than the rest of the sources evaluated. These four highest neutron sources are ^{238}PuBe, ^{241}AmBe, ^{239}PuBe and $^{244}CmO_2$, and the results are provided in Table 1. Error associated with neutron dose rates is $\leq$0.1%. The error associated with the gamma dose rate component was between 1 to 5%, and the gamma dose rate was 10^{-5} to 10^{-8} times smaller than the neutron dose rate component. Thus, the gamma dose rate was insignificant compared to the neutron dose rate component and the error associated with the gamma dose rate was irrelevant. Reference Table D-1 for the variation between the neutron and gamma components with respect to the contributions to the total dose rate.

Table 1. Summary of Four Highest Dose Rate Neutron Sources

Source Material	Total Dose Rate (mrem/h-Ci with error ≤ 0.1%)			
	Source Surface	1 foot	1 meter	2 meter
^{238}PuBe	1.46E+04	4.61E+01	4.64E+00	1.23E+00
^{241}AmBe	1.45E+04	2.63E+01	4.62E+00	1.22E+00
^{239}PuBe	1.15E+04	3.64E+01	3.66E+00	9.67E-01
$^{244}CmO_2$	1.24E+04	1.17E+00	1.79E-01	4.73E-02

Introduction
It is estimated that some 18,000[1] sealed radioactive sources are currently unwanted or will become excess over the next five to ten years. The Off-Site Source Recovery Project at Los Alamos National Laboratory has the responsibility of collecting these unwanted and excess radioactive sources for ultimate disposal. While the vast majority of these neutron producing sources contain americium or plutonium, other isotopic neutron sources will be collected through this program.

In this report, estimates of dose rates at various distances from bare sources are calculated. The calculations were made using the transport code MCNP[2], and the computer code SOURCES-4A. The result of the calculations, dose and relative error, may be used for planning purposes to initially assess transportation and storage requirements.

Source Term Analysis
The absolute neutron source strength was determined for an infinite dilute mixture of actinide within a target material using the SOURCES-4A computer code.

User input files, referred to as Tape 1 files, were generated using LASTCALL[4] user interface for Sources-4A. User input required for LASTCALL includes: 1) element constituent fractions, i.e., the atom fractions of the elements of the target material, 2) source nuclide atom densities, i.e., the atom densities of the actinide, and 3) the target radionuclides atom fractions, i.e., the atom fraction in the medium of the radionuclide undergoing the alpha-n reaction. Absolute neutron spectra and magnitudes generated in the output file (tape 7) were input into a neutron transport code to estimate the Effective Dose Equivalent (EDE). The SOURCES neutron energy spectra used for the dose rate calculations are provided in Appendix A.

Methodology for Dose Rate Calculations
The EDE rate was determined for the neutron and photon component as a function of geometry and distance from an unshielded neutron-generating source. Dose rate calculations were performed using the Monte Carlo N-Particle (MCNP) transport code, version MCNP 4B. This radiation transport code incorporates the model geometry, source term, radiation interactions, and the conversion of neutron or photon fluence rate in dose rate.

Description of Geometry
The source cylindrical container was modeled with a 4.5212 cm radius and a height of 43.18 cm. The neutron source material was modeled inside the source container with the dimensions of 1 cm radius and a height of 7.6 cm.

There were two MCNP models to determine the dose rate. One model determined the dose rate at 1 foot, 1 meter, and 2 meters from the side of the source container and the second model determined the dose rate at the surface of the source container. The two dose rate MCNP models and the model of the source container/neutron source are illustrated in Appendix B. The only material incorporated in this model was dry air, which was located outside the source container.

The source was modeled as a volume source located in the cylindrical source container. The neutron production and energy spectra for each type of neutron source generating materials and non-neutron source materials were determined using SOURCES-4A[4], as outlined in Appendix A of this report. The illustrations of the MCNP models for the tally dose rate analysis are provided in Appendix B.

Dose Rate Calculations
To calculate the dose rate at each of the tally distances from the source container, circular tally surfaces were modeled at 1 foot, 1 meter and 2 meters from the side of the cylindrical source container, and a tally on the side of the cylindrical source container. The dose rate was determined by taking the energy fluence rate passing through the tally surface and using ANSI/ANS-6.1.1 1977,

Neutron and Gamma-Ray Flux-to-Dose-Rate Factors. The dose rate for the tally surface was the average of the calculated dose rate over the surface area. The dose rates for the 1 foot, 1 meter and 2 meter tally surfaces were determined using a MCNP f2 tally. An F4 cell fluence tally was used to determine dose rate over a small cylindrical tally cell (0.01 cm.) around the side of the modeled source container, Appendix B.

MCNP Input Files
Two separate MCNP input files were used to evaluate the dose rates from the various sources. One MCNP input file evaluated the dose rates at 1 foot, 1 meter, and 2 meters from the side of the cylindrical source container and the other input file evaluated the cylindrical side surface dose rate. An example for each input file is provided in Appendix C.

Results
The neutron source models with the highest dose rate are ^{238}PuBe, ^{241}AmBe, ^{239}PuBe, and ^{244}Cm Oxide, Table 1. The neutron, photon and total dose rate breakdown for the eighteen neutron source material configurations are provided in Appendix D. The neutron dose rate contribution to the total dose from the neutron sources was 10^5 to 10^8 greater than the gamma dose rate component.

Conclusion
Dose rates from common isotopic neutron sources were established to determine a bounding radionuclide/target combination that will establish a maximum expected dose rate from any source that will be transported by the Off Site Source Recovery Program. Neutron spectra and energies were established using SOURCES-4A. The analysis results indicate that the 1 Ci. radionuclide/target combinations with the highest dose rate was ^{238}PuBe.

References

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Appendix A
SOURCES-4A Neutron Energy Spectrum for Neutron Source Material

Table A-1. Neutron Source – Neutron Energy Distribution

Am-241 Be

MeV	Distribution
0.00	0
0.01	1.392E+00
0.02	4.621E+00
0.05	2.894E+01
0.10	9.024E+01
0.20	2.746E+02
0.40	5.032E+03
0.60	2.109E+04
0.80	3.229E+04
1.00	3.931E+04
1.30	5.935E+04
1.70	6.251E+04
2.10	7.268E+04
2.40	6.950E+04
2.70	8.067E+04
3.00	1.226E+05
3.30	1.707E+05
3.60	1.803E+05
4.00	2.253E+05
4.40	2.090E+05
5.00	2.878E+05
6.00	3.353E+05
7.00	2.669E+05
8.00	2.816E+05
9.00	2.242E+05
10.00	1.499E+05
12.00	2.625E+04
15.00	9.964E-05
20.0	8.937E-06
Total	2.923E+06

Cm-244 Oxide

MeV	Distribution
0.00	0
0.7143	5.407E+04
1.429	1.293E+05
2.143	1.176E+05
2.857	1.636E+05
3.571	3.007E+05
4.286	3.213E+05
5.00	2.867E+05
5.714	2.199E+05
6.429	1.959E+05
7.143	1.689E+05
7.857	1.671E+05
8.571	1.457E+05
9.286	1.281E+05
10.00	9.265E+04
10.71	2.570E+04
11.43	4.264E+03
12.14	2.289E+01
12.86	1.265E+01
13.57	6.950E+00
14.29	3.796E+00
15.00	2.066E+00
15.71	1.117E+00
16.43	6.038E-01
17.14	3.230E-01
17.86	1.733E-01
18.57	9.362E-02
19.29	4.736E-02
20.00	2.896E-02
Total	2.521E+06

Pu-238 Boron

MeV	Distribution
0.00	0
1.00	4.180e+04
2.00	4.296e+04
3.00	1.515e+04
4.00	2.306e-02
5.00	1.859e+04
6.00	8.532e+03
7.00	1.980e+02
8.00	8.749e-01
9.00	3.866e-01
10.00	1.673e-01
11.00	7.113e-02
12.00	2.979e-02
13.00	1.231e-02
14.00	5.028e-03
15.00	2.032e-03
16.00	8.144e-04
17.00	3.261e-04
18.00	1.234e-04
19.00	5.328e-05
20.00	1.557e-05
Total	1.503e+05

Pu-239 Li (20:1)

MeV	Distribution
0.00	0
1.00	4.938E+04
2.00	1.653E+03
3.00	8.399E-02
4.00	4.814E-02
5.00	2.547E-02
6.00	1.278E-02
7.00	6.166E-03
8.00	2.887E-03
9.00	1.319E-03
10.00	5.909E-04
11.00	2.602E-04
12.00	1.129E-04
13.00	4.841E-05
14.00	2.052E-05
15.00	8.609E-06
16.00	3.579E-06
17.00	1.485E-06
18.00	6.087E-07
19.00	2.482E-07
20.00	9.294E-08
Total	5.103E+04

Pu-238 Be

MeV	Distribution
0.00	0
0.01	1.451E+00
0.02	4.728E+00
0.05	2.943E+01
0.10	9.139E+01
0.20	2.777E+02
0.40	5.039E+03
0.60	2.109E+04
0.80	3.229E+04
1.00	3.936E+04
1.30	5.951E+04
1.70	6.273E+04
2.10	7.290E+04
2.40	6.966E+04
2.70	8.082E+04
3.00	1.227E+05
3.30	1.708E+05
3.60	1.810E+05
4.00	2.262E+05
4.40	2.100E+05
5.00	2.892E+05
6.00	3.378E+05
7.00	2.689E+05
8.00	2.829E+05
9.00	2.255E+05
10.00	1.513E+05
12.00	2.652E+04
15.00	1.938E-02
20.00	1.334E-03
Total	2.937E+06

Pu-239 Be

MeV	Distribution
0.00	0
0.01	1.391E+00
0.02	4.617E+00
0.05	2.892E+01
0.10	9.017E+01
0.20	2.744E+02
0.40	5.029E+03
0.60	2.107E+04
0.80	3.209E+04
1.00	3.480E+04
1.30	5.139E+04
1.70	5.191E+04
2.10	6.207E+04
2.40	6.154E+04
2.70	7.517E+04
3.00	1.224E+05
3.30	1.562E+05
3.60	1.467E+05
4.00	1.806E+05
4.40	1.643E+05
5.00	2.208E+05
6.00	2.200E+05
7.00	2.037E+05
8.00	2.311E+05
9.00	1.737E+05
10.00	1.049E+05
12.00	1.427E+04
15.00	4.309E-05
20.00	3.342E-06
Total	2.334E+06

Pu-239 Li (13:1)

MeV	Distribution
0.00	0
1.00	4.301E+04
2.00	1.438E+03
3.00	8.399E-02
4.00	4.814E-02
5.00	2.547E-02
6.00	1.278E-02
7.00	6.166E-03
8.00	2.887E-03
9.00	1.319E-03
10.00	5.909E-04
11.00	2.602E-04
12.00	1.129E-04
13.00	4.841E-05
14.00	2.052E-05
15.00	8.609E-06
16.00	3.579E-06
17.00	1.485E-06
18.00	6.087E-07
19.00	2.482E-07
20.00	9.294E-08
Total	4.445E+04

Pu-239 Li (50:1)

MeV	Distribution
0.00	0
1.00	3.642E+04
2.00	1.218E+03
3.00	8.399E-02
4.00	4.814E-02
5.00	2.547E-02
6.00	1.278E-02
7.00	6.166E-03
8.00	2.887E-03
9.00	1.319E-03
10.00	5.909E-04
11.00	2.602E-04
12.00	1.129E-04
13.00	4.841E-05
14.00	2.052E-05
15.00	8.609E-06
16.00	3.579E-06
17.00	1.485E-06
18.00	6.087E-07
19.00	2.482E-07
20.00	9.294E-08
Total	3.764E+04

Table A-1. (continued) Neutron Source – Neutron Energy Distribution

Pu-239 F

MeV	Distribution
0.00	0
1.00	9.122E+04
2.00	1.410E+05
3.00	2.591E+04
4.00	3.919E-02
5.00	2.074E-02
6.00	1.040E-02
7.00	5.020E-03
8.00	2.350E-03
9.00	1.074E-03
10.00	4.811E-04
11.00	2.119E-04
12.00	9.196E-05
13.00	3.941E-05
14.00	1.671E-05
15.00	7.009E-06
16.00	2.914E-06
17.00	1.209E-06
18.00	4.956E-07
19.00	2.021E-07
20.00	7.567E-08
Total	2.581E+05

Am-241 Li

MeV	Distribution
0.00	0
1.00	2.722E+04
2.00	4.431E+03
3.00	6.731E-02
4.00	3.983E-02
5.00	2.183E-02
6.00	1.137E-02
7.00	5.708E-03
8.00	2.784E-03
9.00	1.326E-03
10.00	6.201E-04
11.00	2.853E-04
12.00	1.294E-04
13.00	5.802E-05
14.00	2.573E-05
15.00	1.131E-05
16.00	4.925E-06
17.00	2.125E-06
18.00	9.190E-07
19.00	3.932E-07
20.00	1.636E-07
Total	3.165E+04

Pu-238 Oxide

MeV	Distribution
0.00	0
0.01	1.822E-01
0.02	3.552E-01
0.05	1.624E+00
0.10	3.590E+00
0.20	9.653E+00
0.40	2.213E+01
0.60	2.594E+01
0.80	2.699E+01
1.00	2.825E+01
1.30	4.805E+01
1.70	8.526E+01
2.10	1.211E+02
2.40	1.147E+02
2.70	1.213E+02
3.00	1.125E+02
3.30	8.964E+01
3.60	6.468E+01
4.00	5.132E+01
4.40	1.876E+01
5.00	6.822E+00
6.00	5.293E+00
7.00	1.943E+00
8.00	8.807E-01
9.00	3.892E-01
10.00	1.684E-01
12.00	1.016E-01
15.00	1.950E-02
20.00	1.342E-03
Total	9.616E+02

Pu-238 C-13

MeV	Distribution
0.00	0
1.00	1.312E-16
2.00	3.061E-19
3.00	6.435E-18
4.00	3.178E-16
5.00	5.448E-16
6.00	4.668E-16
7.00	3.243E-16
8.00	5.692E-17
9.00	2.619E-21
10.00	1.133E-21
Total	1.849E-15

Pu-239 Oxide

MeV	Distribution
0.00	0
0.01	8.356E-02
0.02	1.787E-01
0.05	8.857E-01
0.10	2.000E+00
0.20	5.752E+00
0.40	1.290E+01
0.60	1.222E+01
0.80	1.053E+01
1.00	1.195E+01
1.30	2.640E+01
1.70	5.792E+01
2.10	9.619E+01
2.40	9.788E+01
2.70	9.986E+01
3.00	8.319E+01
3.30	5.960E+01
3.60	3.569E+01
4.00	1.725E+01
4.40	2.895E+00
5.00	1.415E+00
6.00	3.876E-01
7.00	3.427E-03
8.00	1.604E-03
9.00	7.331E-04
10.00	3.284E-04
12.00	2.074E-04
15.00	4.309E-05
20.00	3.342E-06
Total	6.352E+02

Am-241 Oxide

MeV	Distribution
0.00	0
0.01	1.212E-01
0.02	2.447E-01
0.05	1.116E+00
0.10	2.378E+00
0.20	6.371E+00
0.40	1.363E+01
0.60	1.610E+01
0.80	1.651E+01
1.00	1.771E+01
1.30	3.278E+01
1.70	6.674E+01
2.10	1.051E+02
2.40	1.046E+02
2.70	1.124E+02
3.00	1.048E+02
3.30	8.303E+01
3.60	5.911E+01
4.00	4.524E+01
4.40	1.424E+01
5.00	2.370E+00
6.00	1.132E+00
7.00	5.984E-03
8.00	2.918E-03
9.00	1.390E-03
10.00	6.500E-04
12.00	4.347E-04
15.00	9.964E-05
20.00	8.937E-06
Total	8.058E+02

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Table A-2. Spontaneous Fission Neutron Energy Distribution

Pu-238

MeV	Distribution
0.0	0.0
1.5	4.654E-19
3.0	3.412E-19
4.5	1.457E-19
6.0	5.196E-20
7.5	1.672E-20
9.0	5.020E-21
10.5	1.433E-21
12.0	3.936E-22
13.5	1.048E-22
15.0	2.715E-23
Total	1.028E-18

Pu-239

MeV	Distribution
0.00	0
1.00	5.286E-02
2.00	5.484E-02
3.00	3.623E-02
4.00	2.077E-02
5.00	1.099E-02
6.00	5.514E-03
7.00	2.660E-03
8.00	1.245E-03
9.00	5.691E-04
10.00	2.549E-04
11.00	1.123E-04
12.00	4.873E-05
13.00	2.089E-05
14.00	8.853E-06
15.00	3.714E-06
16.00	1.544E-06
17.00	6.405E-07
18.00	2.626E-07
19.00	1.074E-07
20.00	4.010E-08
Total	4.314E-01

Am-241

MeV	Distribution
0.00	0
1.00	9.400E-02
2.00	9.921E-02
3.00	6.731E-02
4.00	3.983E-02
5.00	2.183E-02
6.00	1.137E-02
7.00	5.708E-03
8.00	2.784E-03
9.00	1.326E-03
10.00	6.201E-04
11.00	2.853E-04
12.00	1.294E-04
13.00	5.802E-05
14.00	2.573E-05
15.00	1.131E-05
16.00	4.925E-06
17.00	2.125E-06
18.00	9.190E-07
19.00	3.932E-07
20.00	1.636E-07
Total	3.445E-01

Cm-244

MeV	Distribution
0.00	0
2.00	3.722E+04
4.00	3.906E+04
6.00	2.617E+04
8.00	1.523E+04
10.00	8.192E+03
12.00	4.179E+03
14.00	2.051E+03
16.00	9.774E+02
18.00	4.547E+02
20.00	2.074E+02
Total	1.337E+05

Area not used

Area not used

End of Appendix A

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Appendix B
MCNP Model Illustration

Figure B-1: One foot, one meter, and 2 meter model used a circular band around the side of the cylinder at respective distance, f2 surface tally.
Figure B-2: Surface Dose Rate Model used a thin (0.01 cm) f4 volume tally around the side of the source cylinder
Figure B-3: Illustration of source container and neutron source model

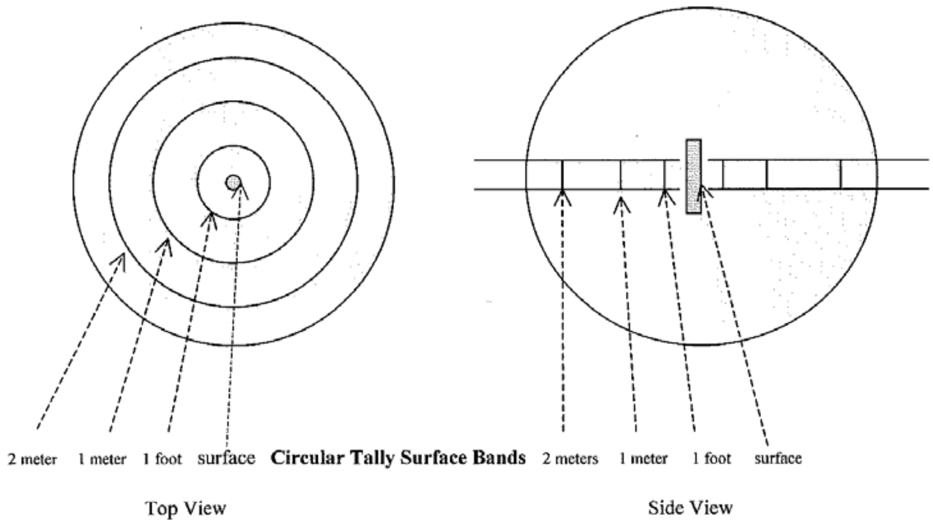

Figure B-1. Tally Model Illustration for 1 foot, 1 meter and 2 meter distance from source

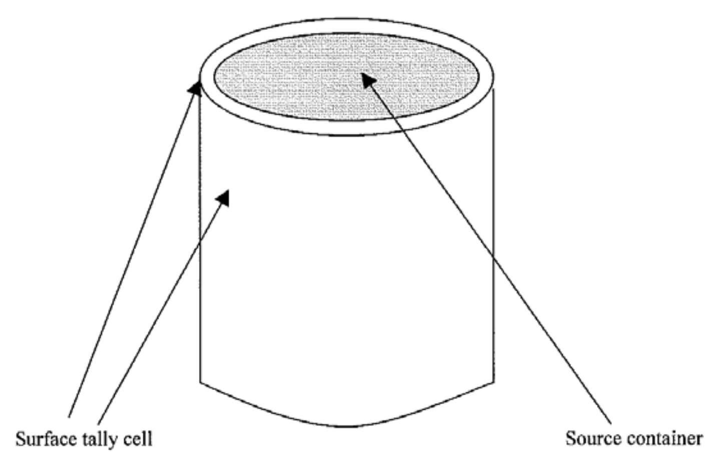

Figure B-2. Illustration of Source Surface Volume tally (volume tally cell 0.01 cm thick)

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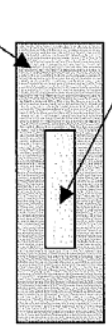

Figure B-3. Illustration of Source Container and Neutron Source

End of Appendix B

Appendix C
MCNP Input Files

C-1. MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

C-2. MCNP Input File for Source Surface Dose Rate Analysis

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C-1. MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

```
Neut&(n,gam) dose rates from Pu-238Be Cylindrical Source Container
c  Source Dose Rate Determination
c  Only material is air outside cylindrical source container
c
c  Tally at 1 foot, 1 meter and 2 meters from source side surface
c  (Surface performed on another input)
c  Source: Pu-238Be
c  File Name: DPu38Be
c  Source modelled only
c
c  HSR-12 Rad Eng Team
c  Los Alamos National Laboratory
c  July 01, 2002 @ 1700 hrs
c
c  ***** Cells Descriptions **********
 1  0          -1   6  -8             imp:n=1 imp:p=1 $ source reg
c *** Keep geometry from drum and filled drum components with air ***
 3  1 -0.001  -64 -10   5  (1:-6:8)   imp:n=1 imp:p=1 $ air cell around source
 5  1 -0.001  -65   5 -16 (64:-5:10)  imp:n=1 imp:p=1 $ air cell around source
 8  1 -0.001  -66   4 -11 (65:-5:16)  imp:n=1 imp:p=1 $ air cell around source
 9  1 -0.001  -67   4 -11  66         imp:n=1 imp:p=1 $ air cell around source
10  1 -0.001  -68   4 -11  67         imp:n=1 imp:p=1 $ air cell around source
11  1 -0.001  -68  14  -4             imp:n=1 imp:p=1 $ air cell around source
12  1 -0.001  -68   3 -14             imp:n=1 imp:p=1 $ air cell around source
13  1 -0.001  -68 -12  11             imp:n=1 imp:p=1 $ air cell around source
14  1 -0.001  -69 -12   3  68         imp:n=1 imp:p=1 $ air cell around source
15  1 -0.001  -70 -12   3  69         imp:n=1 imp:p=1 $ air cell around source
30  1 -0.001  -70 -17  12             imp:n=1 imp:p=1 $ air cell around source
16  1 -0.001  -71 -13   2 (70:17:-3)  imp:n=1 imp:p=1 $ air cell around source
c
17  0      28 -29 30  -31 32 -33(71:13: -2)  imp:n=1 imp:p=1  $ box at surface
24  0 -48  38 -39    (-28:29:-30:31:-32:33)  imp:n=1 imp:p=1  $ cylinder at 1
18  0  34 -35 36 -37 38 -39 48               imp:n=1 imp:p=1  $ box 1m
25  0 -49  44 -45    (-34:35:-36:37:-38:39)  imp:n=1 imp:p=1  $ cylinder at 2
19  0  40 -41 42 -43 44 -45 49               imp:n=1 imp:p=1  $ box 2m
20  0       (-40:41:-42:43:-44:45)          imp:n=0 imp:p=0  $ outside world
c
c 22  0 46  imp:n=1 imp:p=1  $fake for tally check
c 23  0 47  imp:n=1 imp:p=1  $fake for tally check
c 31  0 50  imp:n=1 imp:p=1  $fake for tally check
c 32  0 51  imp:n=1 imp:p=1  $fake for tally check
c
c ******* End of Cells ***************

c ******* Surfaces Descriptions ******************
c  Source Size  3" (7.62 cm ) Height by 3/4" (1.905 cm) Diameter
  1  cz     4.5212    $ outer radius of source region
  6  pz    18.6055    $ bottom of source cavity
  8  pz    61.7855    $ top source cavity
c
c Tally Surface for Cylinder
 50 pz     47.8155    $ top plane at center +7.62      ) H=15.24
 51 pz     32.5755    $ bottom plane at center -7.62   )
c
 28 px   -35.001      $ plane at 1 foot
 29 px    35.001      $ plane at 1 foot
 30 py   -35.001      $ plane at 1 foot
 31 py    35.001      $ plane at 1 foot
 32 pz    -0.1        $ plane at bottom surface
 33 pz    88.8        $ plane at top surface
 34 px -104.5001      $ plane at 1 meter
 35 px  104.5001      $ plane at 1 meter
 36 py -104.5001      $ plane at 1 meter
 37 py  104.5001      $ plane at 1 meter
 38 pz -100.1         $ plane at 1 meter
 39 pz  188.8         $ plane at 1 meter
 48 cz  104.500       $ cylinder at 1
 40 px -204.501       $ plane at 2 meter
 41 px  204.501       $ plane at 2 meter
 42 py -204.501       $ plane at 2 meter
 43 py  204.501       $ plane at 2 meter
```

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C-1. (continued) MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

```
 44 pz -299.8        $ plane at 2 meter
 45 pz  288.8        $ plane at 2 meter
 49 cz  204.500      $ cylinder at 2
c tally
 46 32 cx   4.       $ tally cylinder
 47 33 cz   4.       $ tally cylinder
c ******* End of Surfaces  ********************
c

c ** translations of tally cylinders **
*tr32   0.0   0.0   40.1955
*tr33   0.0   0.0    0.0
c
c ++++++++++++  Materials +++++++++++++++++
c  Dry Air (density @ 7,000 ft - 0.001 g/cc
m1     7014.60c -0.7522 $ Nitorgen 14
       7015.60c -0.0028 $ Nitorgen 15
       8016.60c -0.2320 $ Oxygen 16
       18000.59c -0.0130 $ Argon-natural
        plib=02p elib=01e
c  +++++++++  End of Materials ++++++++++++++++++
c  **********Source Information ******************
mode  n p
totnu
phys:n  20          $30-MeV upper neutron energy
cut:n               $Implicit capture for neutrons
phys:p              $Detailed photon physics over whole energy range
cut:p  j .01  0     $Analog capture for photons
c
sdef  cel=1  pos=0.0 0.0  40.1955  erg=d2  par=1
      axs=0.0 0.0 1.0  rad=d5  ext=d6
si5       0.0 0.9525
si6       7.62
c Neutron energy spectrum from SOURCES for 1 Ci Pu-238Be
#       si2       sp2
      0.00        0
      0.01    1.451E+00
      0.02    4.728E+00
      0.05    2.943E+01
      0.10    9.139E+01
      0.20    2.777E+02
      0.40    5.039E+03
      0.60    2.109E+04
      0.80    3.229E+04
      1.00    3.936E+04
      1.30    5.951E+04
      1.70    6.273E+04
      2.10    7.290E+04
      2.40    6.966E+04
      2.70    8.082E+04
      3.00    1.227E+05
      3.30    1.708E+05
      3.60    1.810E+05
      4.00    2.262E+05
      4.40    2.100E+05
      5.00    2.892E+05
      6.00    3.378E+05
      7.00    2.689E+05
      8.00    2.829E+05
      9.00    2.255E+05
     10.00    1.513E+05
     12.00    2.652E+04
     15.00    1.938E-02
     20.00    1.334E-03
c    Total    2.937E+06
c  ***********End of Source Information **************
c
c
c **** TALLIES *****************************************************
c    **** Multipliers determination *******
c (src par)/s = [(2.937E+06 neuts/s) per Ci 238 Pu
```

C-1-2

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C-1. (continued) MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

```
c Multiplier for dose-rate conversion = [X tally_par/(src_par*cm^2)
c (2.937E+06 src_par/s)[(Y*E-12 Sv cm^2)/(tally par)](100 rem/Sv)(3600 s/h)
c (1000 mrem/rem) x 1 = 1.05732E+03 mrem/h-Ci
c
c
fc2 Neutron dose rates side 1 foot, 1 meter, 2 meter (mrem/h-Ci)
fm2   1.05732E+03
f2:n  71 48 49
fs2   -51 50
sd2  6.46420E+03 7.55367E+03 2.1991E+03 1 1 6.5659 1 1 1.2749E+04
tf2  3j 3
fq2   e s
c
fc12 gamma dose rates side 1 foot, 1 meter, 2 meter (mrem/h-Ci)
fm12  1.05732E+03
f12:p  71 48 49
fs12   -51 50
sd12  6.46420E+03 7.55367E+03 2.1991E+03 1 1 6.5659 1 1 1.2749E+04
tf12  3j 3
fq12   e s
c
fc22 Neutron dose rates top (mrem/h-Ci)
fm22   1.05732E+03
f22:n  33 39 45
fs22   -47
sd22  50.2655 1 50.2655 1 50.2655 1
tf22  3j 1
fq22   e s
c
fc32 gamma dose rates top (mrem/h-Ci)
fm32   1.05732E+03
f32:p  33 39 45
fs32   -47
sd32  50.2655 1 50.2655 1 50.2655 1
tf32  3j 1
fq32   e s
c
fc42 Neutron dose rates bottom (mrem/h-Ci)
fm42   1.05732E+03
f42:n  32 38 44
fs42   -47
sd42  50.2655 1 50.2655 1 50.2655 1
tf42  3j 1
fq42   e s
c
fc52 gamma dose rates bottom (mrem/h-Ci)
fm52   1.05732E+03
f52:p  32 38 44
fs52   -47
sd52  50.2655 1 50.2655 1 50.2655 1
tf52  3j 1
fq52   e s
c  ********** End of Tally **********************
c
c
c  +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
c  +++++++ANSI 1977 Fluence to Dose Conversion Factors +++++++++++++++++++
c   Neutron
c    Neutron-Fluence to Dose Conversion Factors vs Energy
c    from ANSI/ANS-6.1.1-1977.
c    Energy units are MeV and conversion-factor units are 1E-12*Sv*cm**2
de2   2.50E-08 1.00E-07 1.00E-06 1.00E-05 1.00E-04 1.00E-03 1.00E-02 1.00E-01
      5.00E-01 1.00E+00 2.50E+00 5.00E+00 7.00E+00 1.00E+01 1.40E+01 2.00E+01
df2   10.19     10.19     12.39     12.61     11.61     10.44     9.89     60.28
      257.22    366.67    347.22    433.33    408.33    408.33    577.78    630.56
c
c  Photon
c    Photon Fluence-to-Dose- Conversion Factors vs Energy
c    from ANSI/ANS-6.1.1-1977.
c    Energy units are MeV and conversion-factor units are 1.E-12*Sv*cm^2
```

C-1-3

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C-1. (continued) MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

```
de12        0.01   0.03  0.05    0.07    0.1     0.15    0.2     0.25
            0.3    0.35  0.4     0.45    0.5     0.55    0.6     0.65
            0.7    0.8   1.0     1.4     1.8     2.2     2.6     2.8
            3.25   3.75  4.25    4.75    5.0     5.25    5.75    6.25
            6.75   7.5   9.0    11.0    13.0    15.0
df12       11.0    1.62  0.81    0.72    0.79    1.05    1.39    1.75
            2.11   2.46  2.74    3.00    3.25    3.53    3.78    4.00
            4.22   4.67  5.50    6.97    8.31    9.50   10.61   11.14
           12.25  13.42 14.53   15.56   16.11   16.69   17.69   18.72
           19.75  21.28 24.36   28.61   32.78   36.94
c
c    Neutron-Fluence to Dose Conversion Factors vs Energy
c    from ANSI/ANS-6.1.1-1977.
c    Energy units are MeV and conversion-factor units are 1E-12*Sv*cm**2
de22    2.50E-08 1.00E-07 1.00E-06 1.00E-05 1.00E-04 1.00E-03 1.00E-02 1.00E-01
        5.00E-01 1.00E+00 2.50E+00 5.00E+00 7.00E+00 1.00E+01 1.40E+01 2.00E+01
df22     10.19    10.19    12.39    12.61    11.61    10.44     9.89    60.28
         257.22   366.67   347.22   433.33   408.33   408.33   577.78   630.56
c
c Photon Fluence-to-Dose- Conversion Factors vs Energy
c from ANSI/ANS-6.1.1-1977.
c Energy units are MeV and conversion-factor units are 1.E-12*Sv*cm^2
de32     0.01   0.03  0.05    0.07    0.1     0.15    0.2     0.25
         0.3    0.35  0.4     0.45    0.5     0.55    0.6     0.65
         0.7    0.8   1.0     1.4     1.8     2.2     2.6     2.8
         3.25   3.75  4.25    4.75    5.0     5.25    5.75    6.25
         6.75   7.5   9.0    11.0    13.0    15.0
df32       11.0    1.62  0.81    0.72    0.79    1.05    1.39    1.75
            2.11   2.46  2.74    3.00    3.25    3.53    3.78    4.00
            4.22   4.67  5.50    6.97    8.31    9.50   10.61   11.14
           12.25  13.42 14.53   15.56   16.11   16.69   17.69   18.72
           19.75  21.28 24.36   28.61   32.78   36.94
c
c    Neutron-Fluence to Dose Conversion Factors vs Energy
c    from ANSI/ANS-6.1.1-1977.
c    Energy units are MeV and conversion-factor units are 1E-12*Sv*cm**2
de42    2.50E-08 1.00E-07 1.00E-06 1.00E-05 1.00E-04 1.00E-03 1.00E-02 1.00E-01
        5.00E-01 1.00E+00 2.50E+00 5.00E+00 7.00E+00 1.00E+01 1.40E+01 2.00E+01
df42     10.19    10.19    12.39    12.61    11.61    10.44     9.89    60.28
        257.22   366.67   347.22   433.33   408.33   408.33   577.78   630.56
c
c Photon Fluence-to-Dose- Conversion Factors vs Energy
c from ANSI/ANS-6.1.1-1977.
c Energy units are MeV and conversion-factor units are 1.E-12*Sv*cm^2
de52       0.01   0.03  0.05    0.07    0.1     0.15    0.2     0.25
           0.3    0.35  0.4     0.45    0.5     0.55    0.6     0.65
           0.7    0.8   1.0     1.4     1.8     2.2     2.6     2.8
           3.25   3.75  4.25    4.75    5.0     5.25    5.75    6.25
           6.75   7.5   9.0    11.0    13.0    15.0
df52       11.0    1.62  0.81    0.72    0.79    1.05    1.39    1.75
            2.11   2.46  2.74    3.00    3.25    3.53    3.78    4.00
            4.22   4.67  5.50    6.97    8.31    9.50   10.61   11.14
           12.25  13.42 14.53   15.56   16.11   16.69   17.69   18.72
           19.75  21.28 24.36   28.61   32.78   36.94
c
c  ++++++++++End of Fluence-to-dose Conversion +++++++++++++++++++++++
c
dbcn    12j 235423
prdmp   j 1e9 j 1
ctme    9999
nps     5e8
print 30 35 40 50 110 128 130 140 160 161 162
```

C-1-4

End of C-1. (continued) MCNP Input File for 1 foot, 1 meter and 2 meter Dose Rate Analysis

----

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C-2. MCNP Input File for Source Surface Dose Rate Analysis

```
Neut&(n,gam) dose rates Pu-238 Be Source
c  Dose Rate Surface of Source
c  Source only Surface Dose Rate Analysis
c  File name:  Pu38BeS
c
c  HSR-12 Rad Eng Team
c  Los ALamos National Laboratory
c  July 11, 2002 @ 1830 hrs
c
c +++++ Cells +++++++++++
 1  0         -1 5 -6        imp:n=1 imp:p=1  $ source volume
 2  0          1 -7 5 -6      imp:n=1 imp:p=1  $ source cylinder
 3  1 -0.001 -2 3 -4 #1 #2 imp:n=1 imp:p=1  $ source cavity
 4  0         -100 #3        imp:n=1 imp:p=1  $ volume outside source cavity
 5  0          100            imp:n=0 imp:p=0  $ outside world
c ++++++ End of Cells +++++++++
c

c +++++++++  Surfaces ++++++++++++++++++++
  1  cz    0.9525  $ inner radius of source container
  2  cz    4.5212  $ outer radius source cavity
  3  pz    0.00    $ bottom of source cavity
  4  pz   44.00    $ top of source cavity
  5  pz   18.19    $ bottom of source
  6  pz   25.81    $ top of source
  7  CZ    0.9625  $ outer radius of source container
100  s     0 0 0 100.0
c  +++++++ End of Surfaces ++++++++++++++++++++++

c
c  +++++++++Material Description ++++++++++++++
c  Dry Air (density @ 7,000 ft - 0.001 g/cc)
m1    7014.60c -0.7522 $ Nitorgen 14
      7015.60c -0.0028 $ Nitorgen 15
      8016.60c -0.2320 $ Oxygen 16
     18000.59c -0.0130 $ Argon-natural
      plib=02p elib=01e
c  ++++++++ End of Material Description ++++++++
c
c  ++++++++  Source Information ++++++++++++++++
mode  n p
totnu
phys:n  20          $30-MeV upper neutron energy
cut:n               $Implicit capture for neutrons
phys:p              $Detailed photon physics over whole energy range
cut:p  j .01  0     $Analog capture for photons
c
sdef  cel=1  pos=0.0 0.0  18.20  erg=d2  par=1
      axs=0.0 0.0 1.0  rad=d5  ext=d6
si5       0.0 0.9524
si6       7.60
c Neutron energy spectrum from SOURCES for 1 Ci Pu-238 Be Source
#       si2       sp2
      0.00        0
      0.01   1.451E+00
      0.02   4.728E+00
      0.05   2.943E+01
      0.10   9.139E+01
      0.20   2.777E+02
      0.40   5.039E+03
      0.60   2.109E+04
      0.80   3.229E+04
      1.00   3.936E+04
      1.30   5.951E+04
      1.70   6.273E+04
      2.10   7.290E+04
      2.40   6.966E+04
      2.70   8.082E+04
      3.00   1.227E+05
      3.30   1.708E+05
      3.60   1.810E+05
      4.00   2.262E+05
```

C-2-1

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C-2. (continued) MCNP Input File for Source Surface Dose Rate Analysis

```
     4.40   2.100E+05
     5.00   2.892E+05
     6.00   3.378E+05
     7.00   2.689E+05
     8.00   2.829E+05
     9.00   2.255E+05
    10.00   1.513E+05
    12.00   2.652E+04
    15.00   1.938E-02
    20.00   1.334E-03
c    Total   2.937E+06
c  +++++++End of Source Information +++++++++++++++++
c
c ++++++++++++++++++++++++++++++++++++++++++++++++++++
c ++++++++ Tallies ++++++++++++++++++++++++++++++++++
c
c    **** Multiplier Determination ******
c (src par)/s = [(2.937E+06 neuts/s) per Ci Pu-238 Be
c Multiplier for dose-rate conversion = [X tally_par/(src_par*cm^2)
c (2.937E+06 src_par/s)[(Y*E-12 Sv cm^2)/(tally par)](100 rem/Sv)(3600 s/h)
c (1000 mrem/rem) x 1 = 1.05732E+03 mrem/h
c   *****  End of Multiplier Determination *******
c
c    *****  Tally  *************
fc4 Neutron dose rates side Surface(mrem/h-Ci)
fm4   1.05732E+03
f4:n  2
e4    0.5 1.0 1.5 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 15.0 20.0 25.0 30.0
c
fc14 gamma dose rates side Surface (mrem/h-Ci)
fm14   1.05732E+03
f14:p   2
e14    0.5 1.0 1.5 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 15.0 20.0 25.0 30.0
c
c  ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
c  ++++++ ANSI 1977 Fluence-to-Dose Conversion Values ++++++++++++++++++++
c    Neutron-Fluence to Dose Conversion Factors vs Energy
c    from ANSI/ANS-6.1.1-1977.
c    Energy units are MeV and conversion-factor units are 1E-12*Sv*cm**2
de4   2.50E-08 1.00E-07 1.00E-06 1.00E-05 1.00E-04 1.00E-03 1.00E-02 1.00E-01
      5.00E-01 1.00E+00 2.50E+00 5.00E+00 7.00E+00 1.00E+01 1.40E+01 2.00E+01
df4    10.19    10.19    12.39    12.61    11.61    10.44     9.89    60.28
      257.22   366.67   347.22   433.33   408.33   408.33   577.78   630.56
c
c Photon Fluence-to-Dose- Conversion Factors vs Energy
c from ANSI/ANS-6.1.1-1977.
c Energy units are MeV and conversion-factor units are 1.E-12*Sv*cm^2
de14       0.01   0.03  0.05    0.07    0.1     0.15    0.2     0.25
           0.3    0.35  0.4     0.45    0.5     0.55    0.6     0.65
           0.7    0.8   1.      1.4     1.8     2.2     2.6     2.8
           3.25   3.75  4.25    4.75    5.      5.25    5.75    6.25
           6.75   7.5   9.     11.     13.     15.
df14       11.0   1.62  0.81   0.72     0.79    1.05    1.39    1.75
           2.11   2.46  2.74   3.00     3.25    3.53    3.78    4.00
           4.22   4.67  5.50   6.97     8.31    9.50   10.61   11.14
          12.25  13.42 14.53  15.56    16.11   16.69   17.69   18.72
          19.75  21.28 24.36  28.61    32.78   36.94
c  ++++++++  End of Fluence-to-Dose Conversion Values +++++++++++++++++++
c
c
dbcn   12j 235423
prdmp  j 1e9 j 1
ctme   9999
nps    5e8
print 30 35 40 50 110 128 130 140 160 161 162
```

C-2-2

End of C-2. MCNP Input File for Source Surface Dose Rate Analysis

End of Appendix C

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Appendix D
Dose Rate Results

Table D-1 . Dose Rate from Select Neutron Sources					
Source Material	mrem/hr-Ci (neutron dose rate error < ± 0.1%)				
	Radiation Type	Source Surface	1 foot	1 meter	2 meters
Pu-238Be	Neutron	1.46E+04	4.61E+01	4.64E+00	1.23E+00
	Gamma	3.88E-03	2.44E-04	2.28E-05	5.89E-06
	Total	1.46E+04	4.61E+01	4.64E+00	1.23E+00
Am-241Be	Neutron	1.45E+04	2.63E+01	4.62E+00	1.22E+00
	Gamma	3.61E-03	1.36E-04	2.27E-05	5.93E-06
	Total	1.45E+04	2.63E+01	4.62E+00	1.22E+00
Pu-239Be	Neutron	1.15E+04	3.64E+01	3.66E+00	9.67E-01
	Gamma	3.21E-03	1.85E-04	1.75E-05	4.45E-06
	Total	1.15E+04	3.64E+01	3.66E+00	9.67E-01
Cm-244 Oxide	Neutron	1.24E+04	1.17E+00	1.79E-01	4.73E-02
	Gamma	3.36E-03	8.78E-07	1.24E-07	2.97E-08
	Total	1.24E+04	1.17E+00	1.79E-01	4.73E-02
Pu-239F	Neutron	1.00E+03	2.08E+00	3.20E-01	8.44E-02
	Gamma	1.88E-07	3.30E-08	7.97E-09	5.94E-10
	Total	1.00E+03	2.08E+00	3.20E-01	8.44E-02
Pu-238 Boron	Neutron	6.15E+02	1.28E+00	1.96E-01	5.18E-02
	Gamma	1.55E-05	7.77E-07	1.04E-07	2.63E-08
	Total	6.15E+02	1.28E+00	1.96E-01	5.18E-02
Pu-239Li (13:1)	Neutron	1.28E+02	2.32E-01	4.07E-02	1.07E-02
	Gamma	<1.00E-05	1.05E-09	<1.05E-09	<1.05E-09
	Total	1.28E+02	2.32E-01	4.07E-02	1.07E-02
Pu-239Li (20:1)	Neutron	1.47E+02	1.96E-01	3.45E-02	9.09E-03
	Gamma	<1.00E-05	9.49E-10	<9.49E-10	<9.45E-10
	Total	1.47E+02	1.96E-01	3.45E-02	9.09E-03
Pu-239Li (50:1)	Neutron	1.08E+02	1.96E-01	3.45E-02	9.089E-03
	Gamma	<1.00e-5	9.49E-10	<9.49E-10	<9.45E-10
	Total	1.08E+02	1.96E-01	3.45E-02	9.09E-03
Am-241 Li	Neutron	9.65E+01	2.01E-01	3.08E-02	8.12E-03
	Gamma	<1.00E-07	7.92E-10	<7.92E-10	<7.92E-10
	Total	9.65E+01	2.01E-01	3.08E-02	8.12E-03
Pu-239 Oxide	Neutron	2.77E+00	1.33E-02	1.34E-3	3.54E-04
	Gamma	1.78E-08	2.78E-09	2.81E-07	6.51E-11
	Total	2.77E+00	1.33E-02	1.34E-03	3.54E-04
Pu-238 Oxide	Neutron	4.21E+00	8.77E-03	1.34E-03	3.54E-04
	Gamma	3.85E-08	9.66E-10	9.18E-11	1.71E-11
	Total	4.21E+00	8.77E-03	1.34E-03	3.54E-04
Am-241 Oxide	Neutron	3.55E+00	7.37E-03	1.13E-03	2.99E-04
	Gamma	2.08E-08	9.97E-10	1.46E-10	3.37E-11
	Total	3.55E+00	7.37E-03	1.13E-03	2.99E-04

Illustration of Tally Locations

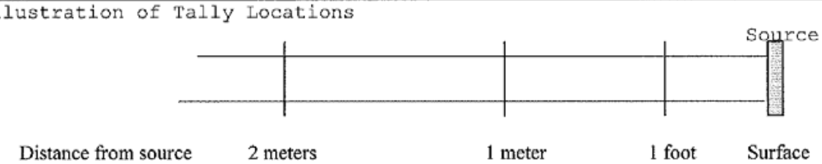

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Table D-1. (continued) Dose Rates from Select Neutron Sources						
		mrem/hr-Ci (neutron dose rate error < ± 0.1%)				
Source Material	Radiation Type	Source Surface	1 foot	1 meter	2 meters
Pu-238 C-13	Neutron	9.24E-18	1.92E-20	2.95E-21	7.77E-22
	Gamma	1.67E-24	6.16E-26	8.58E-27	2.22E-27
	Total	9.24E-18	1.92E-20	2.95E-21	7.77E-22
Pu-238	Neutron	4.20E-21	1.33E-23	1.34E-21	3.54E-25
	Gamma	1.72E-28	9.17E-30	9.68E-28	1.83E-31
	Total	4.20E-21	1.33E-23	1.34E-21	3.54E-25
Pu-239	Neutron	1.78E-03	3.69E-06	5.67E-07	1.50E-07
	Gamma	7.50E-11	2.65E-12	3.77E-13	8.48E-14
	Total	1.78E-03	3.69E-06	5.67E-07	1.50E-07
Am-241	Neutron	1.43E-03	2.97E-06	4.56E-07	1.20E-07
	Gamma	5.66E-11	2.39E-12	3.32E-13	8.07E-14
	Total	1.43E-03	2.97E-06	4.56E-07	1.20E-07
Cm-244	Neutron	5.58E+02	1.16E+00	1.78E-01	4.69E-02
	Gamma	2.21E-05	8.56E-07	1.18E-07	2.81E-08
	Total	5.58E+02	1.16E+00	1.78E-01	4.69E-02

End of Appendix D

D-2

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5.5.2 Sample Input File

Sample case S300OFFCENTER:

```
Neut&(n,gam) dose rates, S300
10   0           -505 500 -501  #11       imp:n=1   imp:p=1  $source reg
11   4  -3.7      302 -303 -510           imp:n=1   imp:p=1  $source
20   1  -0.92  -63    2   -3  62  -158   imp:n=1   imp:p=1  $poly sleve
30   1  -0.92  -63    2   -3  -159 158   imp:n=4   imp:p=4  $poly sleve
40   1  -0.92  -63    2   -3  159        imp:n=16 imp:p=16  $poly sleve
50   0         -63    5   -87            imp:n=16 imp:p=16  $void around
sleeve
60   1  -0.92  -63    4   -2 -158        imp:n=4   imp:p=4  $bottom poly
70   1  -0.92  -63    4   -2 -159 158    imp:n=16 imp:p=16  $bottom poly
80   1  -0.92  -63    4   -2  159        imp:n=64 imp:p=64  $bottom poly
90   1  -0.92  -63    3   -5 -158        imp:n=1   imp:p=1  $top poly
100  1  -0.92  -63    3   -5 -159 158    imp:n=4   imp:p=4  $top poly
110  1  -0.92  -63    3   -5  159        imp:n=16 imp:p=16  $top poly
120  2  -7.94   6 -4 -8                  imp:n=64 imp:p=64  $steel cont
bottom
130  2  -7.94   -8    4   -7 (63: -4: 87) imp:n=16 imp:p=16  $steel cont
140  3  -0.224  -59  -60    7             imp:n=16 imp:p=16  $dunnage
150  3  -0.224  -59   8   -7   6          imp:n=16 imp:p=16  $side fiber
board
160  3  -0.224  -59   12   -6             imp:n=64 imp:p=64  $bottom dun
170  0         -59  -10   60             imp:n=16 imp:p=16  $sp top barl
180  5  -7.8212  -13  -14   12 (59:-12:10) imp:n=16 imp:p=16  $barrel
190  5  -7.8212   15 -12 -13               imp:n=64 imp:p=64  $barrel bottom
200     0    (13: 14: -15) -100 -102 103 imp:n=64 imp:p=64  $ 1m/vehicle
surface
201     0    101 -103 -100               imp:n=64 imp:p=64  $ bottom vehicle
210     0    (100: 102: -101) 600 -601 -602 imp:n=16 imp:p=16  $ 2m vehicle
surface
500     2  -7.94   507 -500     -62    imp:n=1  imp:p=1  $ hybrid capsule
501     2  -7.94   500 -501 505 -62    imp:n=1  imp:p=1  $ hybrid capsule
502     2  -7.94   501 -502     -62    imp:n=1  imp:p=1  $ hybrid capsule
503     2  -7.94   502 -503 504 -62    imp:n=1  imp:p=1  $ hybrid capsule
504     2  -7.94   503 -506     -62    imp:n=1  imp:p=1  $ hybrid capsule
505     0          502 -503 -504       imp:n=1  imp:p=1  $ hybrid capsule
506     1  -0.92   506 -3 -62          imp:n=1  imp:p=1  $ 2" plug top
507     1  -0.92   508 -507 -62        imp:n=1  imp:p=1  $ 2" plug bottom
508     1  -0.92   2 -508 -62          imp:n=2  imp:p=2  $ 2" plug bottom
999     0          -600:601:602        imp:n=0  imp:p=0  $ outside interest

62       cz     4.445  $inner radius of poly sleve 3.5"id
63       cz    14.9225 $outer radius of poly sleve
2        pz    15.5067 $bottom of source (empty part) cylinder
3        pz    58.6867 $top of source (empty part) cylinder +17"
4        pz     6.1087 $bottom of bottom poly
5        pz    68.8467 $top of top poly
6        pz     5.4737 $bottom of steel container
7        pz    73.0377 $top of steel container
87       pz    70.7517 $top of steel container interior
8        cz    15.4788 $outer radius of steel container
60       pz    80.9117 $top of top dunnage
10       pz    88.7603 $top inside barrel
59       cz    26.1468 $outside radius fiberboard
12       pz     0.1397 $bottom inside barrel
```

```
13       cz    26.2868 $outside radius barrel $ 0.14 cm thick
14       pz       88.9 $top outside barrel
15       pz          0 $bottom outside barrel
100      cz   126.2868 $ 1 meter surface
101      pz   -100.0   $ 1 meter surface
102      pz    188.9   $ 1 meter surface
103      pz   -10.16   $ bottom of vehicle (4")
158      rcc          0          0     12.4587        0   $splitting surface
                      0      50.165      8.255
159      rcc          0          0      8.9662        0   $splitting surface
                      0      57.15      12.065
301      pz      26.2255  $ Tally Plane
302      pz      32.1183  $ Tally Plane/bottom of source
303      pz      39.6113  $ Tally Plane/top of source
304      pz      45.5041  $ Tally Plane
401      cz      2.5     $
402      cz      7.5
403      cz      12.5
404      cz      17.5
c   RJM
500     pz 21.8567
501     pz 49.8729
502     pz 50.8635
503     pz 51.8287
504     cz 0.3175
505     cz 3.2537
506     pz 53.7337
507     pz 20.5867
508     pz 18.0467
510     c/z 1.6 0 1.651
c 511     pz 32.6517
c 512     pz 39.0779
600     pz -200
601     pz  300
602     cz 329.54

mode  n p
c
c
c pure polyethylene (density = 0.92 g/cc)
m1    1001      2 $MAT
      6000      1
mt1   poly.60t
c
c 304SS (density = 7.94 g/cc)
m2    6000   -0.08
      14000  -1.0
      15031  -0.045
      24000  -19.0
      25055  -2.0
      26000  -68.375
      28000  -9.5
c
c dunnage - redwood comp (from scale), 0.224g/cm3 from SAR drawings
m3    6000  6
      1001  10
      8016  5
```

```
c
c   source material Pu-Be13
m4    94239  1
      4009   13
mt4   be.60t
c
c  carbon steel (density = 7.8212 g/cc)
m5    26000  -99.0
       6012  -1.0
cut:n             $Implicit capture for neutrons
phys:p     4j 1   $Detailed photon physics over whole energy range
cut:p  j .01  0   $Analog capture for photons
c
sdef        pos=1.6 0.0 35.8648 erg=d1   par=1 wgt=2.334E+06
            ext=d2 rad=d3 axs=0 0 1
si2         3.7465
si3         1.651
c Neutron energy spectrum from SOURCES for 1 Ci of 239Pu infinitely dilute in
Be
#      si1   sp1
        h    d
        0    0.000E+00
        0.01 1.391E+00
        0.02 4.617E+00
        0.05 2.892E+01
        0.1  9.017E+01
        0.2  2.744E+02
        0.4  5.029E+03
        0.6  2.107E+04
        0.8  3.209E+04
        1.0  3.480E+04
        1.3  5.139E+04
        1.7  5.191E+04
        2.1  6.207E+04
        2.4  6.154E+04
        2.7  7.517E+04
        3.0  1.224E+05
        3.3  1.562E+05
        3.6  1.467E+05
        4.0  1.806E+05
        4.4  1.643E+05
        5.0  2.208E+05
        6.0  2.200E+05
        7.0  2.037E+05
        8.0  2.311E+05
        9.0  1.737E+05
        10.0 1.049E+05
        12.0 1.427E+04
        15.0 4.309E-05
        20.0 3.342E-06
c            2.334E+06 total for 1 Ci Pu239
c
c Tallies
c
c     ANSI/ANS-6.1.1-1977 Neutron Flux to Dose Factors (mrem/hr)
de0     2.5e-08    1.0e-07    1.0e-06    1.0e-05    1.0e-04
        1.0e-03    1.0e-02    1.0e-01    5.0e-01    1.0
```

```
        2.5        5.0        7.0        10.0       14.0
        20.0
df0     3.67e-03   3.67e-03   4.46e-03   4.54e-03   4.18e-03
        3.76e-03   3.56e-03   2.17e-02   9.26e-02   1.32e-01
        1.25e-01   1.56e-01   1.47e-01   1.47e-01   2.08e-01
        2.27e-01
fc2 Neutron dose rates on surface side (mrem/h)
f2:n  13
fs2  -301 -302 -303 -304
c
fc12 Neutron dose rates at 1 m side/vehicle surface (mrem/h)
f12:n  100
fs12 -301 -302 -303 -304
c
fc22 Neutron dose rates on surface top (mrem/h)
f22:n  14
fs22  -401 -402 -403 -404
c
fc32 Neutron dose rates at 1 meter top (mrem/h)
f32:n  102
fs32  -402 -403 -404
c
fc42 Neutron dose rates on surface bottom (mrem/h)
f42:n  15
fs42  -401 -402 -403 -404
c
fc52 Neutron dose rates at 1 meter bottom (mrem/h)
f52:n  101
fs52   -402 -403 -404
c
fc62 Neutron dose rates on vehicle bottom (mrem/hr)
f62:n  103
fs62   -402 -403 -404
c
fc72 Neutron dose rates at 2 m from vehicle surface (mrem/h)
f72:n  602
fs72 -301 -302 -303 -304
c
fc102 Gamma dose rates on surface side (mrem/h)
f102:p  13
fs102  -301 -302 -303 -304
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de102       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df102       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc112 Gamma dose rates at 1 m side/vehicle surface (mrem/h)
f112:p  100
fs112 -301 -302 -303 -304
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
```

```
de112       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df112       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc122 Gamma dose rates on surface top (mrem/h)
f122:p  14
fs122  -401 -402 -403 -404
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de122       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df122       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc132 Gamma dose rates at 1 meter top (mrem/h)
f132:p  102
fs132  -402 -403 -404
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de132       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df132       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc142 Gamma dose rates on surface bottom (mrem/h)
f142:p  15
fs142  -401 -402 -403 -404
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de142       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df142       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc152 Gamma dose rates at 1 meter bottom (mrem/h)
```

```
f152:p  101
fs152   -402 -403 -404
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de152       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df152       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc162 Gamma dose rates at vehicle bottom (mrem/h)
f162:p  103
fs162   -402 -403 -404
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de162       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df162       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc172 Gamma dose rates at 2 m from vehicle side surface (mrem/h)
f172:p  602
fs172 -301 -302 -303 -304
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de172       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df172       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
c
c           Mesh tallies
c           A cylindrical mesh tally is placed around the package.
c           The radial regions of interest are from 26.54 to 27.54 (surface)
c           and 126.54 to 127.54 (1m).  Circumferentially there are 36
segments,
c           each 10 degrees wide.  Theta=0 corresponds to the positive x-axis.
c           radius=i
c           axial=j
c           circumferential=k
c
fmesh14:n    geom=cyl origin=0 0 0 axs=0 0 1 vec=1 0 0
             imesh=26.29 27.29 126.29 127.29
```

```
            iints=1 1 1 1
            jmesh=32.12 39.61
            jints=1 1
            kmesh=1
            kints=36
            out=ik
fmesh24:p   geom=cyl origin=0 0 0 axs=0 0 1 vec=1 0 0
            imesh=26.29 27.29 126.29 127.29
            iints=1 1 1 1
            jmesh=32.12 39.61
            jints=1 1
            kmesh=1
            kints=36
            out=ik
c      ansi/ans-6.1.1-1977 fluence-to-dose, photons(mrem/hr)/(p/cm**2/s)
de24       0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
           0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
           1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
           4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
           13.0   15.0
df24       3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
           8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
           1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
           5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
           1.18-2 1.33-2
prdmp  j j 1 2
ctme   300
```

6. CRITICALITY EVALUATION

This section describes the criticality evaluation, documenting the models and technical bases that support the conclusion that, for the plutonium limits provided in Chapter 1, *General Information*, the S300 package has a Criticality Safety Index (CSI) of zero. Therefore, an infinite array of packages would be subcritical if subjected to the Normal Conditions of Transport (NCT). Further, an infinite array of bare Special Form Capsules (SFC) would be subcritical if subjected to the Hypothetical Accident Conditions (HAC) of transport. Due to the relatively small plutonium mass limits and small internal volumes of the innermost vessels, all single packages are highly subcritical.

6.1 Description of Criticality Design

The S300 package has as its innermost containment vessel a single Special Form Capsule (SFC), as discussed in Section 2.10, *Special Form*. This SFC has been analyzed neutronically in isolation (as a single unit) and as infinite arrays and is shown to be subcritical for all NCT and HAC situations, for the content limits provided in Table 1-1. For conservatism and simplicity of analysis, most criticality evaluations have been based on the assumption that the package exterior to the SFC is not present. A few calculations have been performed to demonstrate that this claim of conservatism is indeed accurate. Thus the criticality design rests on the specified plutonium content limits and the very robust nature of the SFC.

6.1.1 Design Features

The only parts of the S300 package that are credited for criticality control are the plutonium content limits and the SFC. (As stated previously, it is demonstrated later in this chapter that neglecting all other parts of the package in the analyses is neutronically conservative.) While the SFCs are very robust and would likely not allow water ingress subsequent to the HAC, the internal volumes of both the Model II and the Model III are far below the minimum critical volumes for homogenous metal-water mixtures, thus assuring subcriticality were flooding to occur.

In essence, modeling only the SFC, either as a single unit or as an array, is analogous to making the assumption that as a result of either the NCT or the HAC that all parts of the package are removed or destroyed. This assumption obviously exceeds what could credibly occur. However, it can readily be shown to be conservative; it does result in simplified calculational analyses; and it leads to loading limits that are economical and acceptable.

6.1.2 Summary Table of Criticality Evaluation

A single SFC Model II or Model III is shown to be highly subcritical for the content limits given in Table 1-1 and under the conditions specified in 10 CFR 71.55(b), (d), and (e). Further, a single SFC is shown to be more reactive than a single S300 package under any of these conditions. Thus, the single S300 package is shown to be subcritical under all specified regulatory conditions.

An infinite array of SFCs is shown to be subcritical for the Table 1-1 content limits. This array is also shown to be more reactive than an infinite array of S300 packages either before or after being subjected to the NCT or HAC of transport. Thus the S300 package with either the Model II or Model III SFC is shown to have a CSI of zero when loaded in compliance with the limits in Table 1-1. The results that support the Table 1-1 limits are summarized in Table 6-1. As discussed more fully in Section 6.6, *Package Arrays Under Hypothetical Accident Conditions*, there is a situation whereby loading the SFC Model II with only two, 160g sources results in a slightly more reactive system than loading the SFC with two, 16g and two, 160g sources, the maximum loading that can physically fit in the SFC Model II. Thus, calculational results with both loadings are presented in Table 6-1.

Table 6-1 – k_{eff} Results for SFC Model II and Model III

	Model II	**Model III**
Loading (Pu in PuBe)	320g / 352g*	160g
Single Unit $k_{eff} + 2\sigma$	0.14573 / 0.14604	0.11909
Infinite Array $k_{eff} + 2\sigma$	0.82664 / 0.81443	0.82881
Upper Subcritical Limit (USL)	0.945	

*Note that 352g of Pu is conservatively used in the criticality analysis, as it results from the maximum loading of PuBe sources which can be physically accommodated. However, as seen in Table 1-1, the maximum allowable content is 350g of Pu.

6.1.3 Criticality Safety Index

The criticality safety index for this package is zero, based on an infinite array of SFCs under NCT and HAC conditions.

6.2 Fissile Material Contents

For a CSI of zero, Table 6-1 lists the most reactive ^{239}PuBe loadings that can be physically accommodated by the Model II SFC. The reference reproduced in Appendix 6.9.1, *PuBe Neutron Source Paper* documents that the PuBe sources have an atomic ratio of 13 Be atoms per Pu atom to within one percent and a density of approximately 3.7 grams per cubic centimeter. The actual PuBe density used in the criticality calculations was about 1.0% greater than 3.7 g/cc, namely ~3.73 g/cc. A higher density is slightly conservative from a multiplication factor standpoint. This slightly higher density was also different for the 16g and the 160g sources in order to enable the PuBe mass associated with either the 16g or the 160g sample to fit into the tantalum capsules as described in Appendix 6.9.2, *PuBe Source Dimensions*. The computer code given in Appendix 6.9.3, *Computer Input Listing*, shows these slightly elevated densities.

6.3 General Considerations

Many simplifications to the actual S300 package configuration have been made to simplify the neutronics analyses and to readily demonstrate neutronic conservatism for the stipulated regulatory conditions. In summary, it is demonstrated below that modeling only the SFC (either the Model II or Model III) is conservative relative to modeling the S300 package either as a single package or as an infinite array of packages subjected to the NCT or the HAC of transport.

6.3.1 Model Configuration

A simplified, but conservative, model of the S300 package was generated in order to permit comparisons between neutronic results for the entire package and the SFCs alone. This basic S300 model was used for single unit analyses and is shown in Figure 6-1. In generating this basic model, the rationale was that the nominal dimensions of the package would be preserved, but that slight reductions or increases in the masses would be made to assure neutronic conservatism.

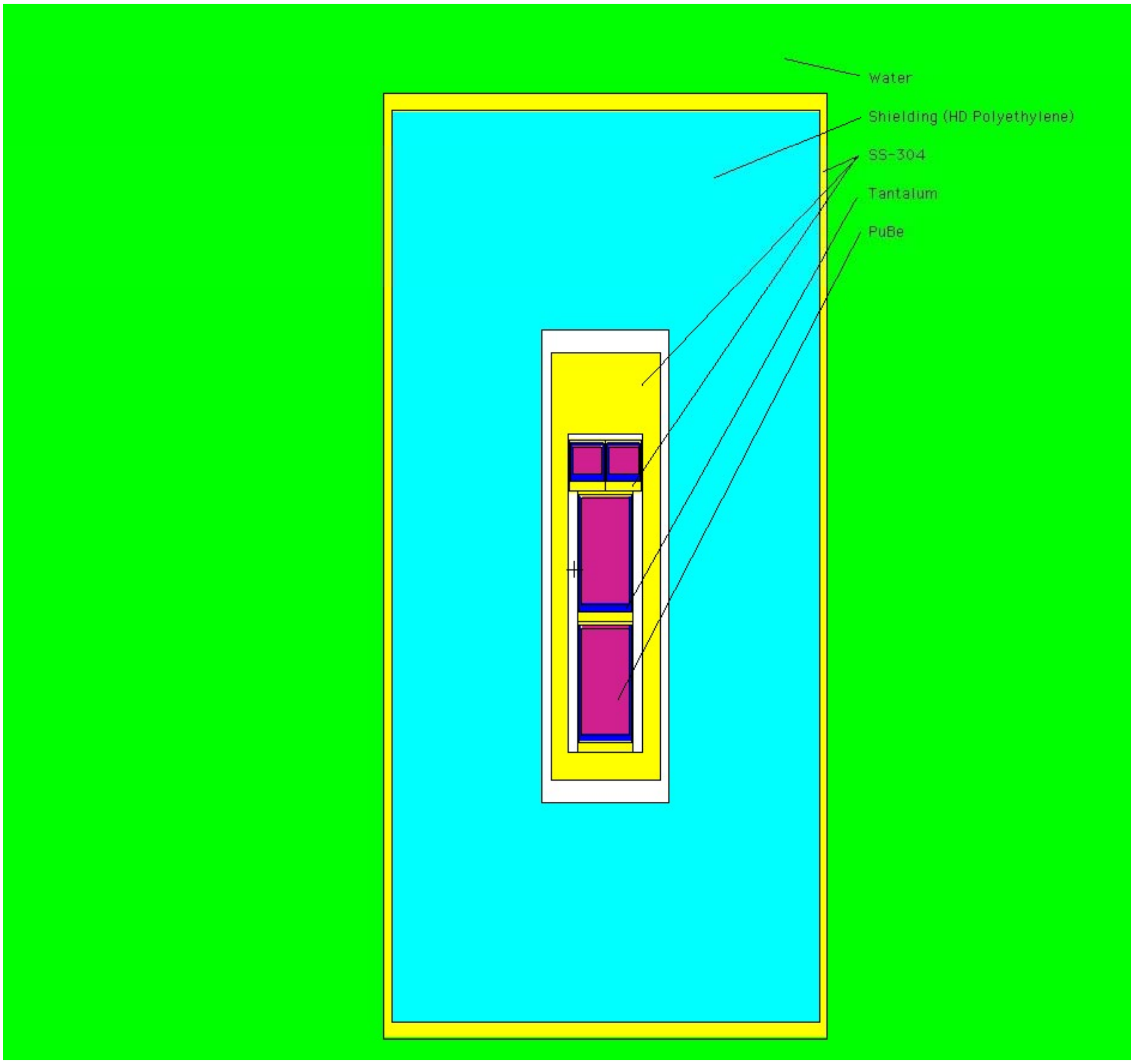

Figure 6-1 – Model of S300 Package Loaded with 352g of Pu in PuBe Sources

That is, steel masses associated with the pipe component were less than actual to conservatively model neutron absorption effects, and the high-density polyethylene mass was slightly in excess of actual to conservatively model reflection effects. The cane fiberboard was modeled as full density water extending to three feet radially and axially as measured from the exterior surface of the SFC to maximize reflection effects. The outer drum was neglected. Thus, as shown, Figure 6-1 is cropped and does not show the full extent of the water region.

The SFC Models II and III that are incorporated into both the basic S300 model in Figure 6-1 and in the stand-alone SFC models are shown in Figures 6-2 and 6-3, respectively.

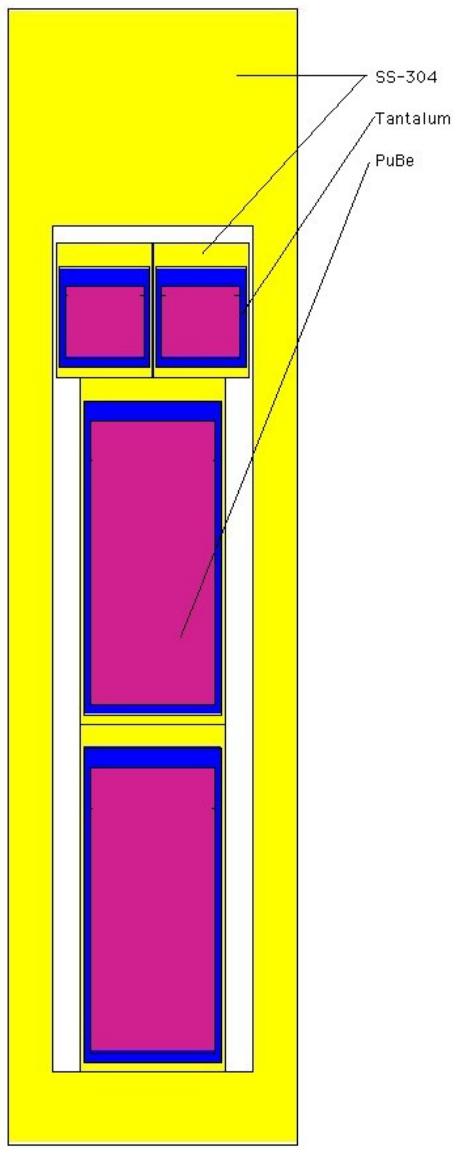

Figure 6-2 – Model II SFC Loaded with 352g of Pu in PuBe Sources

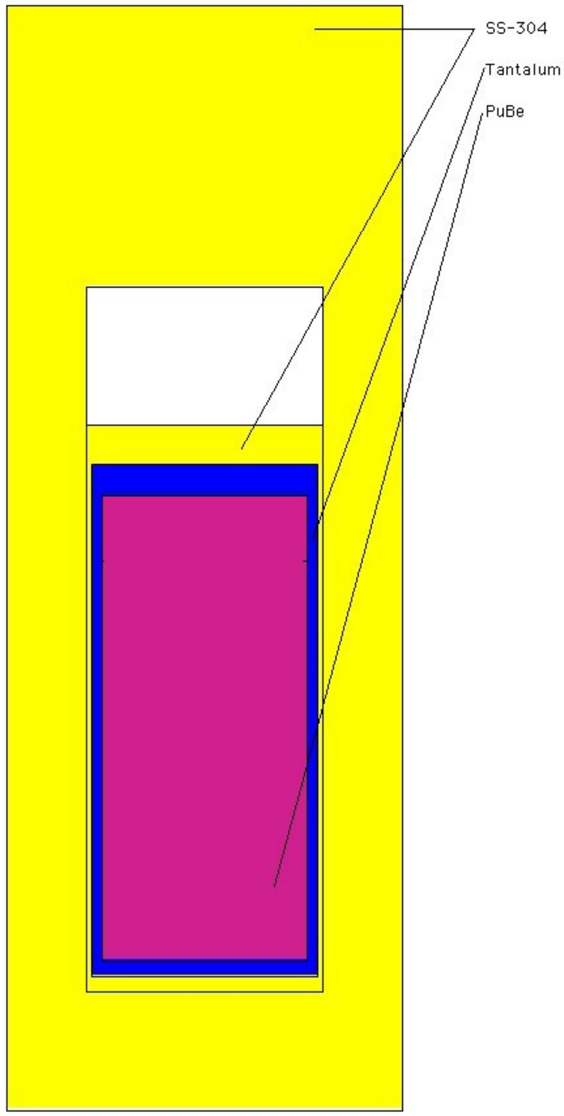

Figure 6-3 – Model III SFC Loaded with a 160g PuBe Source

The sizes and dimensions of the two PuBe sources modeled in these analyses are provided in Figure 6-4 and Table 6-2. Using a tantalum density of 16.6 g/cc, the tantalum masses for the 160g and 16g sources are 362.7g and 89.2g, respectively. Using a steel density of 7.92 g/cc, the steel masses for the 160g and 16g sources are 142.2g and 48.6g, respectively. Note that the ratio of the tantalum and steel masses to the plutonium mass is not a constant, but decreases significantly with increasing plutonium mass. The dimensions of the two SFCs are provided in Figure 1-3 and Figure 1-4.

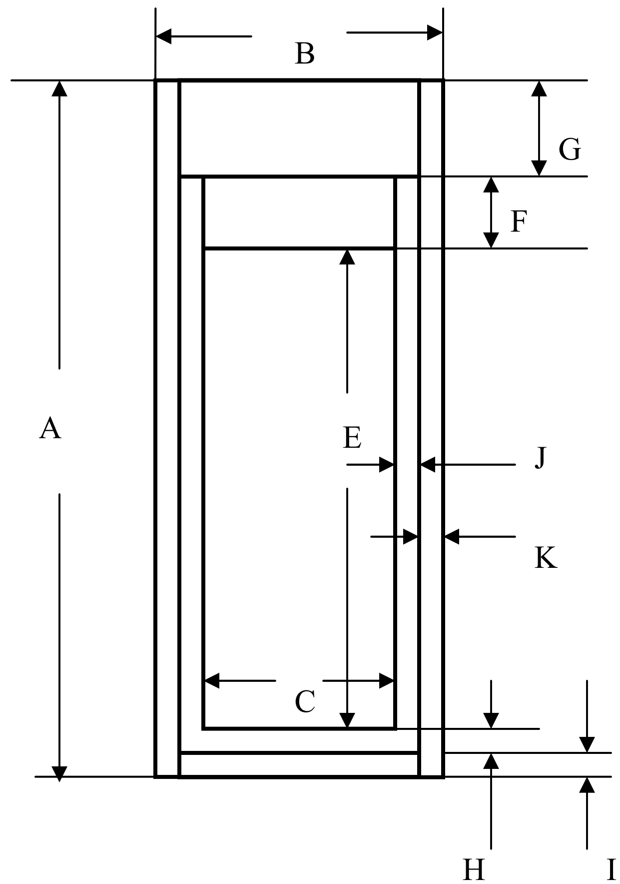

Figure 6-4 – PuBe Construction Overview

Table 6-2 – PuBe Construction Details (Dimensions in cm)

Pu Mass(g)	A	B	C	E	F	G	H	I	J	K
16	3.556	2.5294	2.062	1.905	0.254	0.254	0.508	0.635	0.1524	0.08128
160	9.144	3.805	3.302	7.493	0.254	0.254	0.508	0.635	0.1702	0.08128

6.3.2 Material Properties

The S300 masses and materials are taken from Figure 1-1 and Figure 1-2 and Table 2-1, with the cane fiberboard modeled as water. Note that the 304 stainless steel model density used here (7.92 g/cc) differs slightly from the density used in the shielding analysis given in Chapter 5, *Shielding Evaluation* (7.94 g/cc). It has no practical significance. The volumes of the various regions were conserved to a high degree. Note that the S300 single package model was only developed and used to compare to the water-reflected single SFC and thus show that the single SFC was more reactive and therefore a conservative model. Atomic number densities are provided in the computer code input listings in the Appendix to this chapter.

6.3.3 Computer Codes and Cross-Section Libraries

The neutronics calculations were performed with MCNP5 on the Los Alamos National Laboratory SB-CS group's Ganglion Cyst Cluster. The cross-section set was the ENDF/B-V cross-section library.

6.3.4 Demonstration of Maximum Reactivity

As single units the Model II and Model III SFCs are far subcritical, with or without water ingress into the SFC, as would be expected from the very small loading limits and very small internal volumes. The results in Section 6.4, *Single Package Evaluation*, show that either SFC surrounded by thick water is somewhat more reactive than a model representative of the S300 package, for the maximum allowable ^{239}Pu content. Because high-density polyethylene is a slightly better reflector than normal density water, the explanation for the maximum reactivity being associated with the thick-water reflected model is the significantly increased mass of steel in the S300 model and thus increased neutron absorption in non-fissile material.

The infinite array analyses in Section 6.5, *Evaluation of Package Arrays under Normal Conditions of Transport*, show that the multiplication factors of both SFC models are maximized when the moderation between the packages is minimized, i.e., zero. This is due to the large steel mass in the SFC that absorbs more neutrons as the neutron spectrum, particularly in the region between the units, is softened by moderation. Thus, any infinite array model that includes any polyethylene or cane fiberboard, or more steel than the SFC itself, such as is present in the S300 packaging (either before or after the NCT or the HAC of transport), would be less reactive than the SFC with zero interspersed moderation.

6.4 Single Package Evaluation

The most reactive reflection condition for each SFC model for the maximum plutonium loading was determined by calculating the multiplication factor with: 1) the SFC surrounded by the packaging model shown in Figure 6-1 and with the cane fiberboard modeled as normal density water; and 2) the SFC surrounded only by normal density water. In both models the water extended to 3 feet radially and axially from the outer boundaries of the SFC. These results are presented in Table 6-3 and clearly show that the latter of the two models is more reactive.

6.5 Evaluation of Package Arrays under Normal Conditions of Transport

As demonstrated in Section 6.6, *Package Arrays under Hypothetical Accident Conditions*, the models used to conservatively envelope HAC also envelope NCT.

Table 6-3 – Results of Calculations Demonstrating Most Reactive Reflection Conditions for Single Packages

Configuration	k_{eff}	σ	k+2σ
SFC II w/320g of Pu in PuBe In S300 Package	0.13050	0.00091	0.13232
SFC II w/320g of Pu in PuBe With Thick Water Reflection (3ft)	0.13069	0.00092	0.13253
SFC II w/320g of Pu in PuBe With Thick Water Reflection (3ft) & Flooded	0.14381	0.00096	0.14573
SFC II w/352g of Pu in PuBe With Thick Water Reflection (3ft) & Flooded	**0.14396**	**0.00104**	**0.14604**
SFC III w/160g of Pu in PuBe In S300 Package	0.11046	0.00070	0.11186
SFC III w/160g of Pu in PuBe With Thick Water Reflection (3ft)	0.11638	0.00081	0.11800
SFC III w/160g of Pu in PuBe With Thick Water Reflection (3ft) & Flooded	0.11765	0.00072	0.11909

6.6 Package Arrays under Hypothetical Accident Conditions

It was decided to evaluate only infinite arrays so that for the loading limits shown to be subcritical the CSI would be zero for all packages. Also, it was decided to model only the SFC and no other parts of the S300 packaging. Since the results below show that the most reactive infinite array is when there is no interstitial water (moderation) between the SFCs, this is a demonstration that this is the most reactive infinite array. To be assured that the moderation effect was monatonic for even thick water between the SFCs, the reflection boundary was set 5 cm beyond the SFC radial surface.

For the PuBe sources in the Model II SFC there is a situation whereby an infinite array of SFCs loaded with two, 160g sources is very slightly more reactive than were each SFC loaded with the maximum plutonium mass that can physically fit into the SFC, namely 352g. This is a result of the proportionately larger tantalum and steel loading for the 352g ^{239}Pu loading than for the 320g loading. Figure 6-2 and Figure 6-5 show these two models, respectively, and Figure 6-6 shows the multiplication factors as a function of the density of the interstitial water.

Also shown in Figure 6-6 are the results for a single 160g PuBe source in the SFC Model III as shown in Figure 6-3. Clearly the zero interstitial water, i.e., no moderation, case is the most reactive. For the SFC II with two, 160g and two, 16g sources, as well as for the SFC III with a single 160g source, these loadings fill the SFCs volumetrically and no more sources can be accommodated.

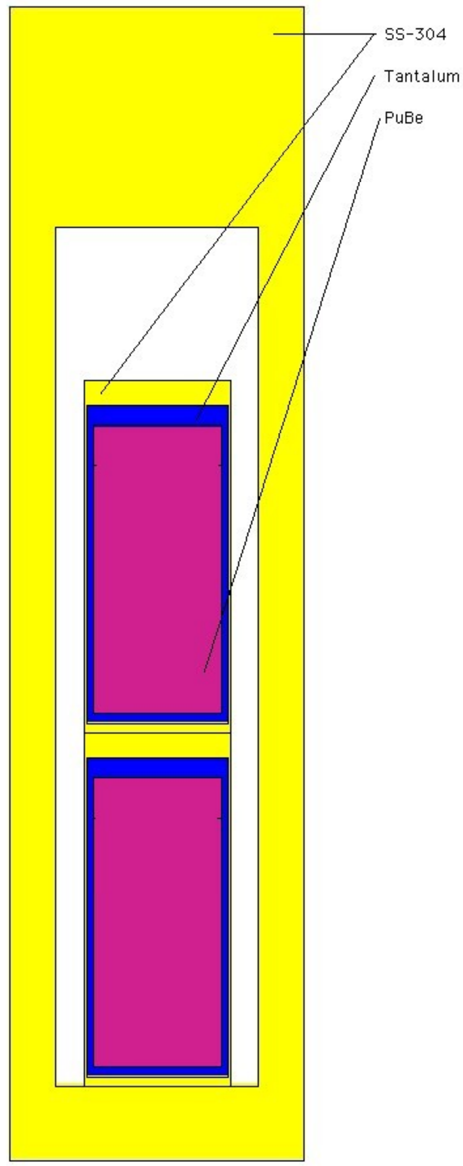

Figure 6-5 – Model II SFC Loaded with 320g of Pu in PuBe Sources

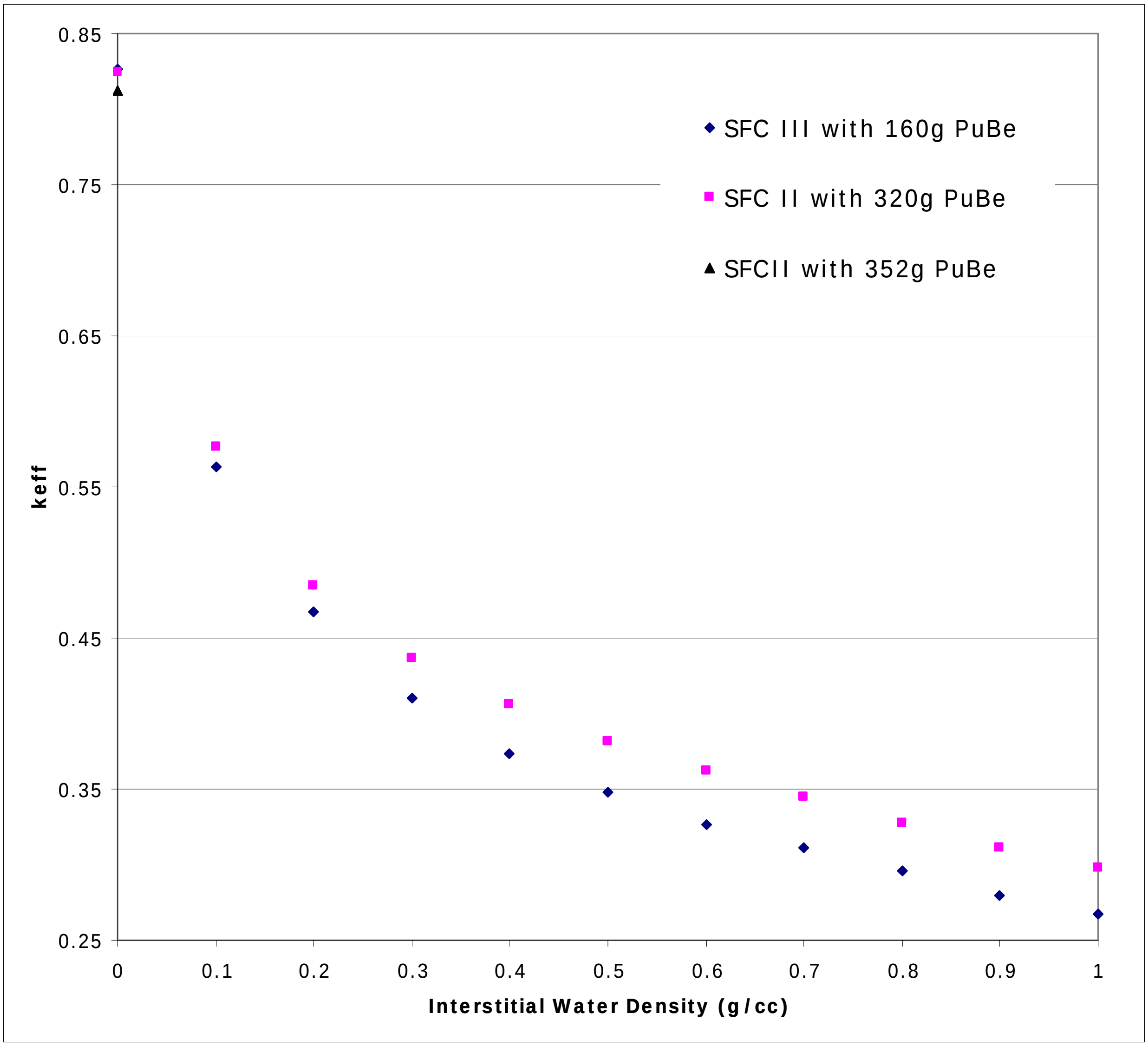

Figure 6-6 – Variation of k_{eff} with Interstitial Water Density

6.7 Fissile Material Packages for Air Transport

The S300 package will not be air transported; hence, this section does not apply.

6.8 Benchmark Evaluations

Model calculations for PuBe source contents show that the most reactive situations are representative of very fast neutron spectra, similar to metal systems without any moderation. Thus, essentially all plutonium benchmark experiments designated as FAST in the compilation of the International Critical Experiments Benchmark Evaluation Program[1] (ICSBEP) were deemed appropriate for determining the USL and thus the loading limits.

The same MCNP code and cross section library and the same computer platform were employed in the calculation of the multiplication factors for the benchmark experiments as for the model runs.

6.8.1 Applicability of Benchmark Experiments

The ICSBEP lists 41 benchmark experiments under the category PU-FAST. All of these were judged to be applicable to some degree. Due to fact that the maximum model reactivity was always associated with zero moderation, no other ICSBEP experiments were judged to be applicable. While all the maximum reactivity model calculations had neutron spectra in the plutonium bearing volume representative of very fast systems, the PuBe models also contained large masses of tantalum, a particularly strong neutron absorber. Experimental series PU-MET-FAST-045 includes large amounts of plutonium and tantalum in a fast neutron environment.

A comparison of the neutron spectra in the plutonium zone of two of the SFC models to the neutron spectra in the plutonium zone for one of the benchmark experiments is provided in Figure 6-7. This figure clearly shows the very fast nature of the most reactive models and also demonstrates that these benchmark experiments closely mirror this most important characteristic of the most reactive model. There were no reported experimental uncertainties associated with the experimental critical systems.

6.8.2 Bias Determination

The results from Table 6-4 demonstrate that simple systems dominated by plutonium fissioning in a fast neutron environment are calculated with the chosen code and cross-section set to a very high degree of certainty. The individual benchmark experiments are independent, diverse, and very high quality and the measured critical condition was calculated to within one percent in all cases except one. The average multiplication factor from these calculations is 1.00098 +/- 0.00165. The statistical convergence uncertainty in all cases was less than 0.0025.

The four highlighted cases in Table 6-4, viz. 18, 19, 21-001 and 21-002, all include beryllium reflection and are calculated very accurately. This lends confidence to accuracy of the high-energy beryllium cross sections.

The results of the tantalum-loaded experiments are provided in Table 6-5. The average multiplication factor from these calculations is 1.01454 +/- 0.00119, showing a definite positive bias and indicating that the tantalum cross-sections may be somewhat inaccurate. However, given the 350g content limit imposed by Table 1-1, even a relatively large administrative margin assignment (0.05 delta-k is judged to be adequate to assure subcriticality) is readily accommodated by the high degree of subcriticality of the maximum reactivity case in either SFC model (Table 6-1 and Figure 6-6 show that this value is approximately 0.82 for both SFC models). Thus a USL, while not closely approached, would be a multiplication factor of 0.95 less two sigma, or USL = 0.945.

[1] International Handbook of Evaluated Benchmark Experiments, 2005 Edition.

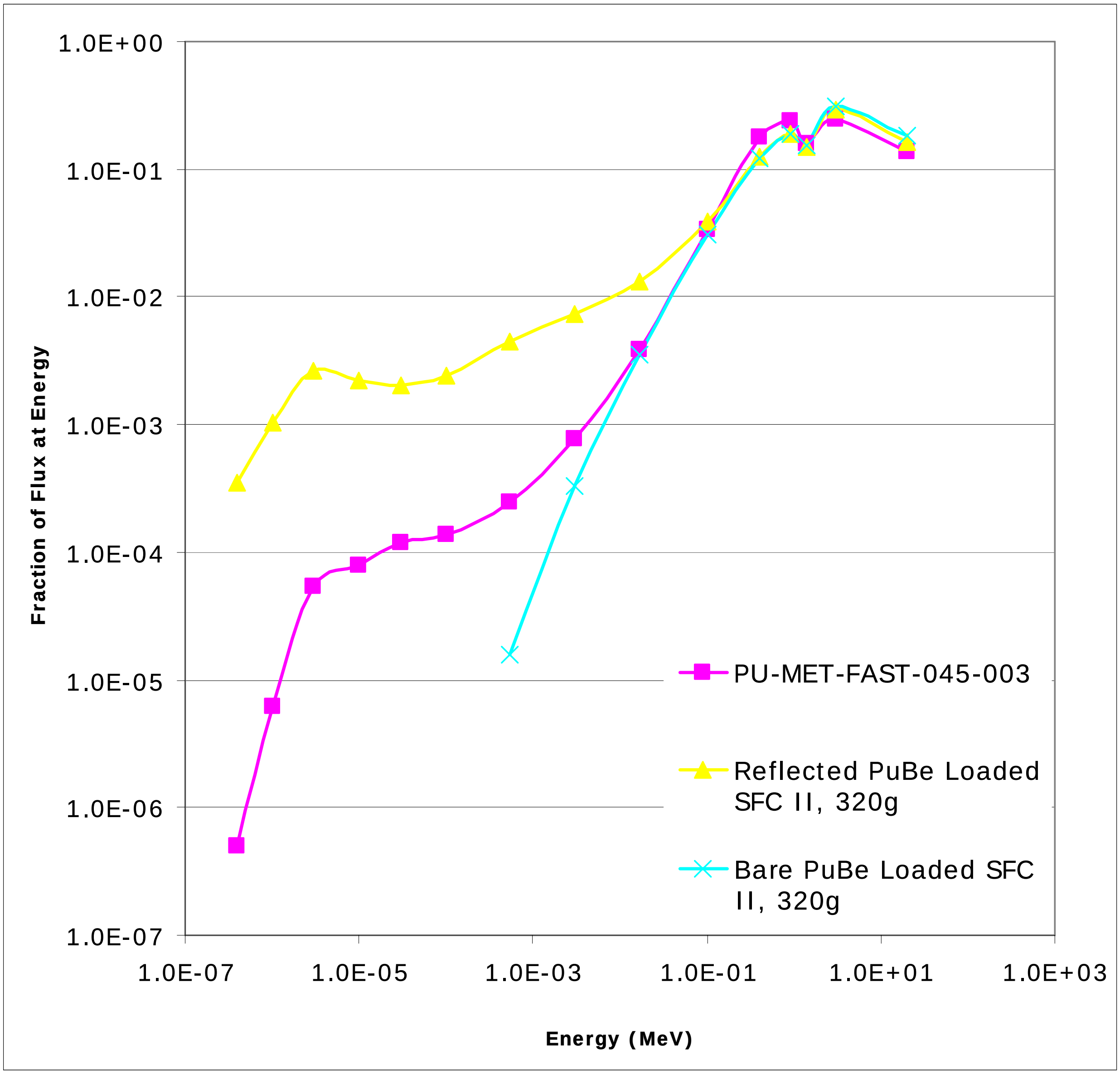

Figure 6-7 – Comparison of Spectra Between SFC Models and ICSBEP Benchmark Model

Table 6-4 – Results From Fast Spectrum Plutonium Benchmark Models

Model	k_{eff}	σ
PU-MET-FAST-001	0.99600	0.00128
PU-MET-FAST-002	1.00003	0.00122
PU-MET-FAST-004-001	0.99307	0.00091
PU-MET-FAST-004-002	0.99346	0.00095
PU-MET-FAST-005	1.01074	0.00122
PU-MET-FAST-006	1.00562	0.00206
PU-MET-FAST-008	1.00798	0.00131
PU-MET-FAST-009	1.00103	0.00130
PU-MET-FAST-010	1.00067	0.00125
PU-MET-FAST-011	1.00192	0.00152
PU-MET-FAST-012	0.99990	0.00227
PU-MET-FAST-013	0.99865	0.00223
PU-MET-FAST-014	1.00847	0.00196
PU-MET-FAST-015	1.00514	0.00207
PU-MET-FAST-017-001	0.99500	0.00100
PU-MET-FAST-017-002	1.00148	0.00101
PU-MET-FAST-018	0.99846	0.00131
PU-MET-FAST-019	1.00073	0.00065
PU-MET-FAST-020	0.99831	0.00226
PU-MET-FAST-021-001	1.00350	0.00166
PU-MET-FAST-021-002	0.99795	0.00149
PU-MET-FAST-024	0.99868	0.00216
PU-MET-FAST-025	0.99808	0.00188
PU-MET-FAST-026	1.00733	0.00177
PU-MET-FAST-027	1.00007	0.00205
PU-MET-FAST-031	1.00169	0.00224
PU-MET-FAST-032	1.00251	0.00167
Average	1.00098	0.00165
Average	1.00016	0.00133

Table 6-5 – Results From Tantalum Loaded Benchmark Experiment Model

Model	k_{eff}	σ
PU-MET-FAST-045-001d	1.00728	0.00115
PU-MET-FAST-045-002d	1.01769	0.00120
PU-MET-FAST-045-003d	1.01575	0.00121
PU-MET-FAST-045-004d	1.01267	0.00127
PU-MET-FAST-045-005d	1.01641	0.00127
PU-MET-FAST-045-006d	1.01495	0.00114
PU-MET-FAST-045-007d	1.01700	0.00108
Average	1.01454	0.00119

6.9 Appendices

6.9.1 PuBe Neutron Source Paper

The reference paper "Plutonium-Beryllium Neutron Sources, Their Fabrication and Neutron Yield" by R.E. Tate and A.S. Coffinberry (1958) is reproduced on the following pages.

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Plutonium–Beryllium Neutron Sources, Their Fabrication and Neutron Yield

By R. E. Tate and A. S. Coffinberry*

The (α, n) nuclear reaction has been utilized for twenty-five years as a source of neutrons. Mechanical mixtures were prepared from an alpha emitter, usually Ra^{226} or Po^{210}, and an element of low atomic number, usually beryllium. Now, however, nuclear reactors produce other alpha-emitting isotopes which can also be used as neutron sources when combined with beryllium.[1] Of the transuranic elements available as products of reactor operation, plutonium is the most abundant. An investigation of the neutron-emitting characteristics of plutonium–beryllium alloys was deemed desirable and such work was started at Los Alamos in 1949.

It was found that plutonium–beryllium alloys make very satisfactory neutron sources for low-flux applications. In particular, the compound $PuBe_{13}$ possesses several advantages over mechanical mixtures of polonium and beryllium or radium and beryllium, although the yield of neutrons per second per cubic centimeter is not as large. The neutron yield and energy spectrum of polonium–beryllium sources vary with the grain sizes of the constituents, as has been pointed out by Stewart.[2] These sources also require frequent time-dependent yield corrections. Disadvantages of radium–beryllium neutron sources include their high cost and their high gamma-ray background. The principal advantage of plutonium–beryllium sources is the stability of the neutron yield with respect to time, which derives from the 24,360-year half-life[3] of Pu^{239}. The growth in neutron flux is computed to be only 0.14% in 20 years if suitable plutonium is used. Another important characteristic of $PuBe_{13}$ is that it is the only commonly employed neutron source for which a specific weight of source material has a known and predictable neutron yield.

The metallurgical phase diagram of the plutonium–beryllium binary system has been reported by Konobeevsky[4] and by Schonfeld,[5] and it is characterized by a single compound $PuBe_{13}$ melting at a temperature estimated to be about 1950°C. The compound is face-centered cubic and has a measurable range of homogeneity.[6] Its density, as calculated from X-ray data, is 4.35 g/cm³. $PuBe_{13}$ is very brittle; its microhardness exceeds 575 kg/mm². It is resistant to oxidation and, unlike many intermetallic compounds of plutonium, does not disintegrate into hazardous powdery material in the laboratory atmosphere.

THE NEUTRON YIELDS

Stewart[2] has determined the neutron spectrum from a $PuBe_{13}$ source and by integration has obtained a total yield of 1.28×10^6 neutrons per second for the source, or 6.1×10^4 neutrons per second per gram of $PuBe_{13}$. Considering the possibilities for error in the method, this value appears to be in reasonably good agreement with an average value of 6.8×10^4 neutrons per second per gram obtained by comparing several specimens of $PuBe_{13}$ with Los Alamos secondary standards. A value of 6.7×10^4 neutrons per second per gram for $PuBe_{13}$ has been reported by Konobeevsky.[4] If, not knowing the isotopic composition, the specific activity of the plutonium used by Runnalls and Boucher[1] is assumed to be 1.4×10^8 disintegrations per minute per milligram, the neutron yield of $PuBe_{13}$ reported by them is calculated to be approximately 6.1×10^4 neutrons per second per gram.

When work on the plutonium–beryllium system was begun at Los Alamos in 1949, calculations were made to predict the neutron yield as a function of alloy composition. The method used was one that had been employed by Bethe[7] in calculating the proton yield of the (α, p) reaction for fluorine as compared to the proton yield of calcium fluoride. Because the form of the plutonium–beryllium phase diagram was completely unknown, and values of the highest possible neutron yields throughout the system were sought, it was assumed in making the calculations that all compositions consisted of a homogeneous single-phase alloy (i.e., the plutonium atoms were considered to be uniformly distributed throughout the beryllium atoms). It is apparent that, with respect to the (α, n) reaction, plutonium acts strongly as a diluent in alloys having a high plutonium content and beryllium similarly dilutes the beryllium-rich compositions, so that the maximum theoretical neutron yield for the hypothetical solid solutions, continuous from pure plutonium to pure beryllium, will occur at some intermediate composition determined as the resultant of two effects: (1) The energy of the alpha particles is dissipated by both plutonium and beryllium atoms in

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proportion to their numbers and to the stopping powers of the plutonium and beryllium atoms. (2) Alpha particles are supplied for the (α, n) reaction in proportion to the number of plutonium atoms present.

The yield of neutrons per alpha particle from the alloy is inversely proportional to the stopping power of the alloy per beryllium atom, i.e.,

$$\text{neutrons/alpha particle (alloy)} \sim \frac{1}{(N_{\mathrm{Pu}}S_{\mathrm{Pu}}+N_{\mathrm{Be}}S_{\mathrm{Be}})/N_{\mathrm{Be}}}. \quad (1)$$

where S_{Pu} and S_{Be} are the respective stopping powers per atom of plutonium and beryllium and N_{Pu} and N_{Be} are the numbers of plutonium and beryllium atoms. Then, in comparison with pure beryllium,

$$\frac{\text{neutrons/alpha particle (alloy)}}{\text{neutrons/alpha particle (pure Be)}} = \frac{S_{\mathrm{Be}}}{(N_{\mathrm{Pu}}S_{\mathrm{Pu}}+N_{\mathrm{Be}}S_{\mathrm{Be}})/N_{\mathrm{Be}}}. \quad (2)$$

Since the number of neutrons/alpha particle (pure Be) is the thick target yield Y for (α, n) reaction in Be,

$$\text{neutrons/alpha particle (alloy)} = Y\frac{N_{\mathrm{Be}}}{N_{\mathrm{Pu}}(S_{\mathrm{Pu}}/S_{\mathrm{Be}})+N_{\mathrm{Be}}}. \quad (3)$$

In the computation, $S_{\mathrm{Pu}}/S_{\mathrm{Be}}$ is assumed to be independent of energy, an assumption which seems to be approximately correct.[8]

The number of alpha particles per second per gram-atom of alloy may be written as

$$\text{alpha particles/sec/gram-atom} = 6.02\times10^{23}\lambda N_{\mathrm{Pu}}/(N_{\mathrm{Pu}}+N_{\mathrm{Be}}), \quad (4)$$

where λ is the decay constant for plutonium, i.e., the number of alpha particles per second per plutonium atom.

The product of expressions (3) and (4) is the number of neutrons per second per gram-atom of alloy. This calculation has been made for a series of compositions using the best currently available data for S_{Pu}, S_{Be}, Y and λ. The results are tabulated in Table 1 and plotted in Fig. 1. The yield of $PuBe_{13}$ is listed in Table 1 as 18.1×10^5 neutrons per second per 6.02×10^{23} atoms. Conversion of this value to yield per gram of $PuBe_{13}$ gives 7.1×10^4 neutrons per second, to be compared with the best Los Alamos experimental value mentioned above, 6.8×10^4 neutrons per second per gram of $PuBe_{13}$.

If the actual phase diagram of the plutonium–beryllium system represented a continuous series of

Table 1. Calculation of the Theoretical Neutron Yields of Plutonium-Beryllium Alloys

Atom fraction beryllium	$N_{\mathrm{Pu}}\frac{S_{\mathrm{Pu}}}{S_{\mathrm{Be}}}$	$\frac{N_{\mathrm{Be}}S_{\mathrm{Be}}}{N_{\mathrm{Pu}}S_{\mathrm{Pu}}+N_{\mathrm{Be}}S_{\mathrm{Be}}}$	*Neutrons per alpha particle*	*Alpha particles per sec per 6.02×10^{23} atoms*	*Neutrons per sec per 6.02×10^{23} atoms*
0.00	5.88	0.0000	0.00	54.2×10^{10}	0.0
0.10	5.30	0.0185	1.26×10^{-6}	48.8	6.2×10^5
0.20	4.71	0.0407	2.77	43.4	12.0
0.30	4.12	0.0677	4.60	37.9	17.4
0.40	3.53	0.1018	6.92	32.5	22.5
0.50	2.94	0.1454	9.88	27.1	26.8
0.60	2.35	0.2063	14.0	21.7	30.4
0.70	1.77	0.2835	19.3	16.3	31.5
0.80	1.18	0.404	27.5	10.84	29.8
0.90	0.59	0.604	41.1	5.42	22.3
0.9286[a]	0.42	0.689	46.8	3.87	18.1
1.00	0.00	1.000	68.0	0.00	0.0

[a] $PuBe_{13}$

Notes on the experimental data used in the calculations:

1. The mean energy for alpha particles from Pu^{239} is 5.14 Mev.[10]
2. The experimental stopping power of plutonium is not available. The stopping power of lead for alpha particles is used as an approximation. The mass stopping power of lead for 5.14 Mev alpha particles[11] is 0.225 Mev/mg/cm².
3. The experimental stopping power of beryllium for alpha particles is not available. The stopping power for protons is converted to the stopping power for alpha particles by the relation $S_\alpha = 4S_p$ at the same velocity; i.e., at one-fourth the energy.

   The mass stopping power of beryllium for 1.25 Mev protons[11] is 0.220 Mev/mg/cm². Thus, the mass stopping power of beryllium for 5 Mev alpha particles is computed to be 0.88 Mev/mg/cm².
4. The mass stopping powers are given in footnotes (2) and (3). However, atomic stopping powers are required for the ratio $S_{\mathrm{Pu}}/S_{\mathrm{Be}}$. The atomic stopping power is related to the mass stopping power by the relation[12]

$$S_a = S_m A/N,$$

where A is the atomic weight and N is Avagadro's number. The ratio of the atomic stopping powers is, therefore,

$$\frac{S_{\mathrm{Pu}}}{S_{\mathrm{Be}}} = \frac{0.225\times207}{0.88\times9} = 5.88.$$

5. The thick target yield of beryllium for 5.14 Mev alpha particles is 68 neutrons per 10^6 alpha particles.[13]
6. The decay constant of plutonium is computed from the 24,360-year half-life[9] by the relation

$$\lambda = 0.6931/T.$$

solid solutions, then the theoretical neutron yields would be as expected. However, the existence of the compound $PuBe_{13}$, and the negligible solid solubility both of plutonium in beryllium and of beryllium in plutonium, give rise to alloys which, except in the case of pure $PuBe_{13}$, consist of crystals of $PuBe_{13}$ distributed throughout a matrix of either plutonium or beryllium. Thus the neutron yield of pure $PuBe_{13}$ should lie on the curve of Fig. 1 and have the value indicated for 92.86 atomic per cent beryllium. But, for all other compositions, the actual neutron yield will be less than that computed for solid solution alloys, and if there were no (α, n) interaction between the crystals of $PuBe_{13}$ and the matrix phase in which they are contained, the neutron yield per cubic centimeter of alloy would be simply proportional to the volume of $PuBe_{13}$ per unit volume of alloy. On a gram-atomic (instead of unit volume) basis, these yields would lie along the two dashed straight lines in Fig. 1 identified as "rule of mixtures" values.

In Fig. 1 are plotted some experimental points representing the neutron yields of real alloy specimens. It is seen that, in the two-phase alloys consisting of crystals of $PuBe_{13}$ in a matrix of plutonium, the experimental yields, although smaller than the solid-solution values, are always greater than those required by the rule of mixtures. This is because there are beryllium atoms near the surface of the $PuBe_{13}$ crystals that lie within the range of alpha particles originating in plutonium atoms of the matrix. The alpha radiation which passes through the interface from the matrix into $PuBe_{13}$ augments the alpha-particle flux within a zone bordering the interface and thus increases the rate of (α, n) reaction within this portion of the $PuBe_{13}$. Because the surface area to volume ratio depends on crystal size, it follows that, for a given composition of plutonium–beryllium alloy, the smaller the $PuBe_{13}$ crystals contained in the matrix phase, the larger the neutron yield will be. This effect is illustrated in Fig. 1 by the experimental points representing specimens containing different sizes of crystals. An extremely fine grain size of the $PuBe_{13}$ would, of course, approach the condition of uniformly distributed atoms realized ideally in a solid solution or in the crystal structure of pure $PuBe_{13}$. Thus, although higher neutron yields per gram-atom of alloy are obtainable from alloys richer in plutonium than $PuBe_{13}$, only for the exact composition $PuBe_{13}$ is the neutron yield predictable.

In alloys containing more than 92.86 atomic per cent beryllium the $PuBe_{13}$ crystals occur in a matrix of beryllium. Under these circumstances a much smaller contribution to neutron yield additional to the rule-of-mixtures value results from a flow of alpha particles across the interface between the $PuBe_{13}$ and the beryllium matrix. In this case, alpha particles from plutonium atoms within the $PuBe_{13}$, but near the surface of the crystals, react with beryllium atoms in the matrix, as well as with those within the compound. Although not shown in Fig. 1, experimental values for the neutron yields of these alloys were found to lie

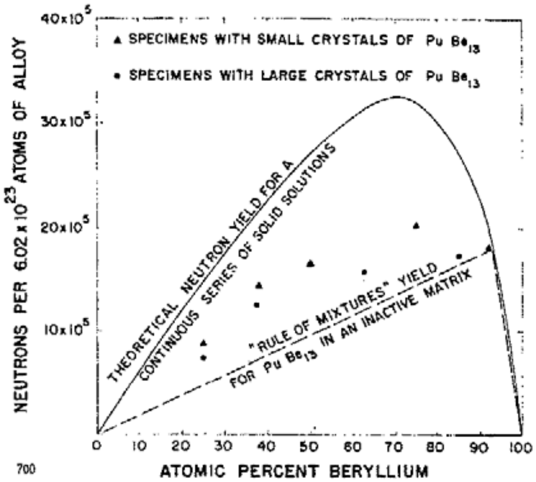


Figure 1. Neutron yield of plutonium–beryllium alloys

in the narrow region between the straight line and the curve at the extreme right of Fig. 1.

Runnalls and Boucher[1] have demonstrated nicely the dependence of neutron yield on the form and aggregational state of the component elements. In an investigation of beryllium-rich alloys of plutonium they observed, among other similar effects, a marked increase in neutron yield when the alloys melted.

Because plutonium is a product of the nuclear reactor, its isotopic composition is a function of reactor characteristics and operation. The stability of the neutron yield of a plutonium–beryllium source depends on the 24,360-year half-life of Pu^{239}. Other isotopes present are Pu^{238}, Pu^{240}, and Pu^{241}. The amount of Pu^{238} with its 89.6-year half-life in currently available plutonium is relatively small and the larger amounts of Pu^{240} have a 6580-year half-life. The effect of these isotopes on the rate of emission of neutrons is not significant for periods of ten to twenty years. If, however, an appreciable amount of Pu^{241} is present, the alpha-active daughter Am^{241} with its 12.9-year half-life alters the number of alpha particles per second per gram-atom and the virtue of a neutron source of constant yield is lost. 470

Coon† has calculated that the growth in rate of emission from a plutonium–beryllium source is related to the Pu^{241} content in the following manner:

$$\frac{Q_t}{Q_0} = 1 + k\,[1 - \exp(-t/18.6)],$$

where

Q_t = the neutron emission rate at the time t years,

18.6 = the mean life of Pu^{241} in years,

t = the time in years from the start of Am^{241} accumulation due to beta decay of Pu^{241},

and

Q_0 = the neutron emission rate in the absence of any Am^{241}.

† J. H. Coon, private communication.

The quantity k is obtained from the following expression:

$$k = \frac{1.27a(Pu^{241})/T(Am^{241})}{a(Pu^{239})/T(Pu^{239}) + a(Pu^{240})/T(Pu^{240}) + 1.27(a(Pu^{238})/T(Pu^{238}))},$$

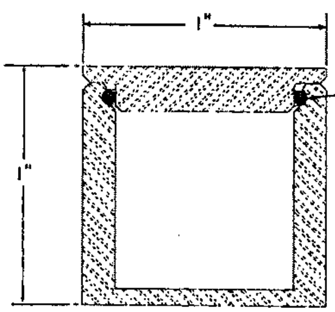
where

a = the relative abundance of the isotope,

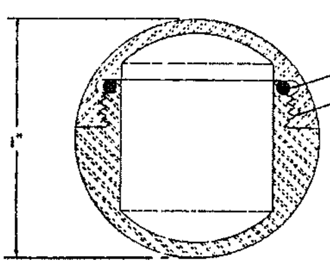
and T = the half-life of the isotope.

The numerical factor 1.27 appearing in this expression for k is the ratio of the number of neutrons produced by 5.48 Mev alpha particles (Am^{241} and Pu^{238}) and by 5.14 Mev alpha particles (Pu^{239} and Pu^{240}). This numerical value is taken from the experimental work of Runnalls and Boucher.[1]

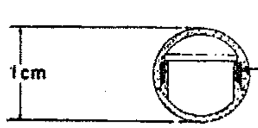
As a numerical example, the growth in the rate of neutron emission is 2.6% in 20 years from a plutonium–beryllium source prepared from plutonium containing 0.06% Pu^{241}. The growth is only 0.04% in 20 years from a similar source prepared from plutonium containing 0.003% Pu^{241}. Thus it is clear that the most useful neutron sources to be obtained from plutonium and beryllium have exactly the composition $PuBe_{13}$ and are fabricated from plutonium containing a minimum amount of Pu^{241}.



2a CYLINDRICAL SOURCE CAPSULE



2b SPHERICAL SOURCE CAPSULE



2c SPHERICAL SOURCE CAPSULE 700

Figure 2. Nickel source containers for $PuBe_{13}$

FABRICATION OF THE SOURCES

Like all alloys of plutonium, those of plutonium and beryllium are prepared in suitably equipped glove-boxes in order to minimize the hazards of handling the plutonium. The first plutonium–beryllium alloys were prepared at Los Alamos in 1950 by F. W. Schonfeld, C. R. Tipton, and R. D. Moeller. A satisfactory method for preparing them is to weigh appropriate amounts of the two metals into a beryllium oxide crucible. It is important to load the heavy plutonium metal on top of the lighter beryllium metal. Because the size of the melts is kept small for health physics reasons, it is helpful to load a single piece of each metal in order to obtain good alloying. If several small pieces are loaded, some may hang onto the crucible wall and not enter the melt. The crucible is heated by means of a tantalum susceptor in an induction furnace containing an argon atmosphere. At compositions corresponding to $PuBe_{13}$, the two elements react vigorously as the temperature approaches 1150°C, and the heat of this reaction suddenly carries the temperature of the small mass to approximately 1400°C. This exothermic reaction yields a friable mass having the character of coke. If the mass is further heated to about 2000°C it coalesces. Upon cooling, a hard, brittle ingot of $PuBe_{13}$ is obtained which possesses evidence of considerable solidification shrinkage. Runnalls and Boucher[1] have reported another method of preparation, namely, the reduction of plutonium trifluoride by powdered beryllium. After the reduction, beryllium trifluoride is distilled off leaving a fluoride-free alloy of plutonium and beryllium.

The alloys are encapsulated in order to permit their being handled in the laboratory without danger of spreading radioactive contamination. Capsules suitable for containing $PuBe_{13}$ should meet the following requirements:

1. They must be rugged in order to minimize the possibility of breaking a container.
2. They must be easily loaded and permit rapid sealing in order to minimize neutron exposure to personnel preparing the sources.
3. The seal must be tight in order to preclude the possibility of spreading radioactive material.
4. Magnetic containers are desirable, as they lend themselves to remote handling by magnetic methods.

Three styles of containers which have been evolved at Los Alamos are illustrated in Fig. 2. The one-inch cylindrical container was designed for a source strength of 10^6 neutrons per second, the larger spherical container for 4.5×10^5 neutrons per second, and the smaller spherical container for 6×10^4 neutrons per second. Nickel has proved to be a satisfactory material from which to machine these capsules.

Loading and sealing the capsules is done in glove-boxes. The cylindrical container (Fig. 2*a*) is loaded with crushed $PuBe_{13}$. Lumps of the compound, either the coke-like material or dense material produced by melting, are placed in the container. The lumps are simultaneously crushed and packed to a bulk density of approximately 3.7 g/cm^3 by ramming them with a suitable tool. The spherical containers (Figs. 2*b* and 2*c*) are loaded with a lump of material that has been melted and solidified in a beryllium oxide crucible. Frequently, in breaking the crucible away from the compound, the lump of compound is broken. This may make it difficult to fit the material into the container. Even if the lump is a single piece, the most compact source suggested by the X-ray density is not obtained because of a pipe formed in the ingot on solidification.

Capsules are sealed by induction brazing, using a preplaced hard solder ring. A solder containing 56% silver, 22% copper, 17% zinc, and 5% tin (American Platinum Works Silvaloy No. 355) and a paste-type flux containing fluorides and borates (Handy and Harmon Handyflux) have been found to give satisfactory results. The joint and solder are coated with a minimum amount of flux, the solder ring is positioned, and the flux is permitted to dry before the capsule is placed in the contaminated glove-box. After the capsule is loaded, it is placed in a soldering jig. For the smallest source the soldering jig is also used to hold the capsule during loading. Heat for soldering is applied by means of a single-turn coil connected to a rf transformer. After soldering, traces of oxidation and flux are removed from the capsule by pickling it in a hot solution of hydrochloric acid and cupric chloride. It is then rinsed in hot water.

Before each capsule is considered to be satisfactory, it must pass a leak test. This test is conducted by placing the capsule in a small pressure vessel in which a helium atmosphere is raised to a pressure of 200 psi. After 30 minutes the pressure is released, and the capsule is dropped into ethanol or a similar liquid having low surface tension. Leaks are indicated by helium bubbles streaming from the capsule. Containers which leak may be resoldered, or they may be opened and the material recanned.

Because all of the canning operations have taken place in a group of contaminated glove-boxes, the exterior of the capsule is contaminated and must be cleaned. This is done best by scrubbing the capsule to remove loose material from the surface and then vapor plating it in an atmosphere of nickel carbonyl to form a coating 5 mils thick.

The final step in the preparation of these sources is to have them calibrated in a graphite column using the technique described by Graves and Froman.[9]

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of G. I. Bell, J. H. Coon and J. T. Waber for helpful discussions. V. O. Struebing prepared many of the alloys and D. E. Hull helped solve most of the problems in the design of containers and brazed joints. Neutron counting was done by Groups P-4, CMB-3, and W-7 of the Los Alamos Scientific Laboratory.

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6.9.2 PuBe Source Dimensions

The following page shows a scanned copy of the original data sheet from Monsanto dated September 5, 1961 showing PuBe neutron source and container dimensions.

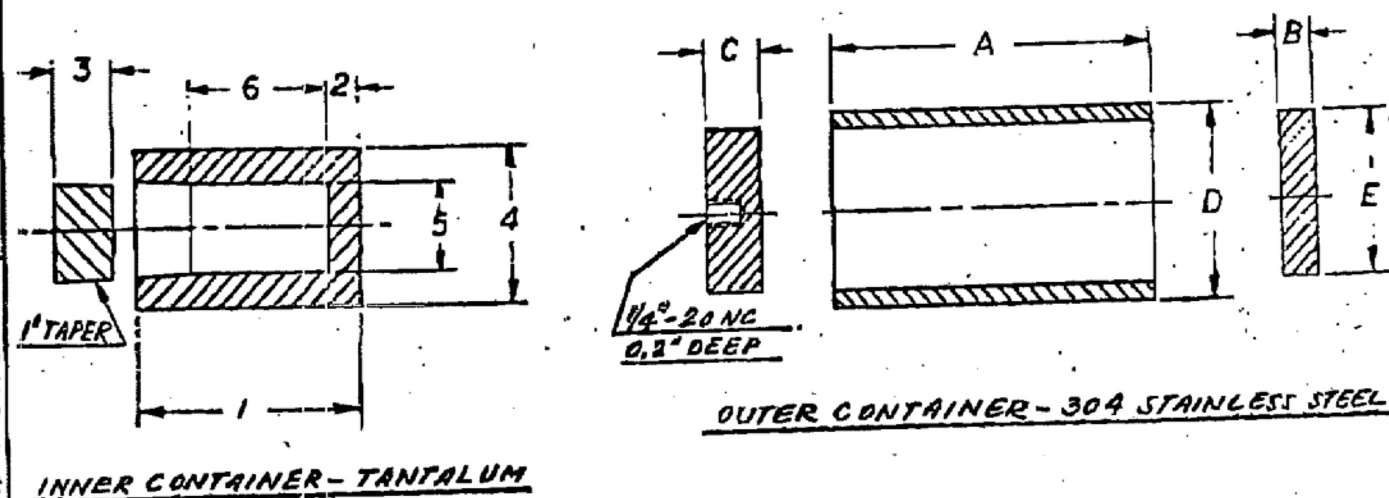
INNER CONTAINER DIMENSIONS (INCHES)

Curie Range	Part No. 1	2	3	4	5	6
1	1.05	0.100	0.200	0.934	0.814	0.750
2	1.80	0.100	0.200	0.934	0.814	1.50
3	2.55	0.100	0.200	0.934	0.814	2.25
4	3.30	0.100	0.200	0.934	0.814	3.00
5	4.05	0.100	0.200	0.934	0.814	3.75
5	2.50	0.100	0.200	1.184	1.064	2.20
7	3.40	0.100	0.200	1.184	1.064	3.10
10	3.25	0.100	0.200	1.434	1.300	2.95

OUTER CONTAINER DIMENSIONS (INCHES)

Part No. A	B	C	D	E
1.40	0.100	0.25	0.998	0.938
2.15	0.100	0.25	0.998	0.938
2.90	0.100	0.25	0.998	0.938
3.65	0.100	0.25	0.998	0.938
4.40	0.100	0.25	0.998	0.938
2.85	0.100	0.25	1.248	1.188
3.75	0.100	0.25	1.248	1.188
3.60	0.100	0.25	1.498	1.438

All dimensions ± 0.002



DRAWN 9.5.61 L.W.	MONSANTO RESEARCH CORP. DAYTON, OHIO
CHECKED	
APPD.	Pu Be SOURCE CONTAINER
SCALE NONE	
LOCATION DAYTON, OHIO	
AREA	
AUTH. NO.	
DWG. NO. NS-8	

6.9.3 Computer Input Listing

Listed here is the input deck for a single Model II SFC holding two, 160g PuBe sources surrounded by a thick water reflector. Note that the input deck contains the specifications for both the 16g and 160g PuBe sources and the pipe component. These input specifications are common to all input decks, including those with the Model III SFC. Thus the only parts of the input decks that are different between those with the Model II and those with the Model IIIs, and that are not present in the listing below, are the Model III specifications. These are provided at the end of this section. This is the reasoning for not including several input deck listings – they are largely duplicates.

```
C    Single SFC II Reflected with 320g Loading
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C               Model II SFC Specs
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    Inner Radius (cm)            2.6194
C    Outer Radius (cm)            3.81
C    Top & Bottom Thickness (cm)  1.905
C    Cavity Height (cm)           22.225
C    Total Height (cm)            29.845
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C               160 Gram Source Specs
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    PuBe Density (g/cc)          3.7143
C    Tantalum Density (g/cc)      16.6
C    PuBe Radius (cm)             1.651
C    PuBe Height (cm)             7.493
C    Void Height (cm)             7.493
C    Ta Side Thickness (cm)       0.17018
C    Ta Bottom Thickness (cm)     0.508
C    Ta Top Thickness (cm)        0.254
C    SS Side Thickness (cm)       0.08128
C    SS Bottom Thickness (cm)     0.635
C    SS Top Thickness (cm)        0.254
C    160g Source Radius (cm)      1.9025
C    160g Source Height (cm)      9.144
C    160g PuBe Volume (cc)        64.165
C    160g PuBe Mass (g)           238.33
C    Pu Mass (g)                  160
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C               16 Gram Source Specs
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    PuBe Density (g/cc)          3.7464
C    PuBe Radius (cm)             1.031
C    PuBe Height (cm)             1.905
C    Void Height (cm)             1.905
C    Ta Side Thickness (cm)       0.1524
C    Ta Bottom Thickness (cm)     0.508
C    Ta Top Thickness (cm)        0.254
C    SS Side Thickness (cm)       0.08128
C    SS Bottom Thickness (cm)     0.635
C    SS Top Thickness (cm)        0.254
C    16g Source Radius (cm)       1.2647
C    16g Source Height (cm)       3.556
C    16g PuBe Volume (cc)         6.3615
C    16g PuBe Mass (g)            23.833
C    Pu Mass (g)                  16
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C               Pipe Component (Confinement Vessel) Specs
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    H-to-D                       2.13
C    Shield Insert Density (g/cc) 0.92
C    Shield Insert Mass (g)       40823
C    Shield Radius (cm)           15.138
C    Shield Height (cm)           64.486
C    Steel Insert Density (g/cc)  7.92
```

```
C    Steel Insert Mass (g)        40823
C    Steel Radius (cm)            15.678
C    Steel Height (cm)            66.79
C    Water Density (g/cc)         1
C
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              160 Gram Source Construction
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1    1 -3.7143       -1 6 -7                     u=1  imp:n=1
3    2 -16.6         (1:-6:7) -2 5 -9                u=1  imp:n=1
4    3 -7.92        (2:-5:9)                        u=1  imp:n=1
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              16 Gram Source Construction
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5    1 -3.7464       -11 16 -17                   u=2  imp:n=1
7    2 -16.6         (11:-16:17) -12 15 -19          u=2  imp:n=1
8    3 -7.92        (12:-15:19)                     u=2  imp:n=1
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              SFC Construction
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
9    0    -3 4 -10                                   u=3  imp:n=1   fill=1
10   like 9 but trcl (0 0 9.144       )              u=3  imp:n=1
13   0    -21 4 -24 #9 #10                           u=3  imp:n=1
14   3    -7.92       (21:-4:24)                     u=3  imp:n=1
15   0                -22 23 -25                          imp:n=1   fill=3
16   4 -1            (22:-23:25) -31 36 -37             imp:n=1
17   0                (31:-36:37)                         imp:n=0

C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              160 Gram Source Surfaces
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1    cz   1.651
2    cz   1.8212
3    cz   1.9025
4    pz   1.905
5    pz   2.54
6    pz   3.048
7    pz   10.541
8    pz   10.541
9    pz   10.795
10   pz   11.049
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              16 Gram Source Surfaces
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
11   c/z   0 1.2747       1.031
12   c/z   0 1.2747       1.1834
13   c/z   0 1.2747       1.2647
14   pz   20.193
15   pz   20.828
16   pz   21.336
17   pz   23.241
18   pz   23.241
19   pz   23.495
110  pz   23.749
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              Model II SFC Surfaces
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
21   cz   2.6194
22   cz   3.81
23   pz   0
24   pz   24.13
25   pz   29.845
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              Pipe Component (Confinement Vessel) Surfaces
C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
31   cz   95.25
32   cz   15.138
33   cz   15.678
34   pz   -18.472
35   pz   -17.321
36   pz   -91.44
```

```
37   pz   91.44
38   pz   47.166
39   pz   48.317
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              Water Reflector Surfaces
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
41   cz   107.12
42   pz   -109.91
43   pz   139.76
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              Hex Lattice For Infinite Array
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*51  p     1.73205   1.0   0.0   7.62
*52  py    3.81
*53  p    -1.73205   1.0   0.0  -7.62
*54  p     1.73205   1.0   0.0  -7.62
*55  py   -3.81
*56  p    -1.73205   1.0   0.0   7.62

m1   94239.55c    1
     4009.50c     13
m2   73181.50c    1
m3   26000.50c   -0.695
     24000.50c   -0.190
     28000.50c   -0.095
     25055.50c   -0.020
m4   1001.50c     2
     8016.50c     1
mt4  lwtr.01t
m5   1001.50c     2
     6012.50c     1
mt5  poly.01t
kcode   1000 1.0 15 115
ksrc    0 0 6.7945
        0 0 14.287
        0 1.2747       21.971
        0 -1.2647      21.971
```

Following are the input specifications for the Model III SFC, as copied from an input listing.

```
C    Single SFC III Fully Reflected
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C              Model III SFC Specs
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C    Inner Radius (cm)            1.905
C    Outer Radius (cm)            3.175
C    Top & Bottom Thickness (cm)  1.905
C    Cavity Height (cm)           11.351
C    Total Height (cm)            17.78
C    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

6.9.4 Computer Output Listing

Listed here are excerpts from the MCNP output for the input listing provided in Section 6.9.3.

```
Thread Name & Version = MCNP5_LANL, 1.25
                                _
                               |_
          ._ _    _  ._   ._   |_
          | | |  (_  | |  |_)   _)
                          |
 +-------------------------------------------------------------------+
 |   This program was prepared by the Regents of the University of    |
 |California at Los Alamos National Laboratory (the University) under |
 |  contract number W-7405-ENG-36 with the U.S. Department of Energy  |
 |(DoE).  The University has certain rights in the program pursuant to|
 |  the contract and the program should not be copied or distributed  |
 | outside your organization.  All rights in the program are reserved |
```

```
 |by the DoE and the University.  Neither the U.S. Government nor the |
 | University makes any warranty, express or implied, or assumes any  |
 |     liability or responsibility for the use of this software.      |
 +--------------------------------------------------------------------+

1mcnp     version 5.mpi ld=12072004                    08/16/06 07:44:38
 ************************************************************************                 probid
=  08/16/06 07:44:38
 inp=input outp=output


 warning. universe map (print table 128) disabled.
    1-       C    Single SFC II Reflected with 320g Loading
    2-       C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    3-       C               Model II SFC Specs
    4-       C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    5-       C    Inner Radius (cm)            2.6194
    6-       C    Outer Radius (cm)            3.81
    7-       C    Top & Bottom Thickness (cm)  1.905
    8-       C    Cavity Height (cm)           22.225
    9-       C    Total Height (cm)            29.845

137-       C             Hex Lattice For Infinite Array
  138-       C    ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  139-       *51  p     1.73205   1.0   0.0   7.62
  140-       *52  py    3.81
  141-       *53  p    -1.73205   1.0   0.0  -7.62
  142-       *54  p     1.73205   1.0   0.0  -7.62
  143-       *55  py   -3.81
  144-       *56  p    -1.73205   1.0   0.0   7.62
  145-
  146-       m1   94239.55c    1
  147-            4009.50c     13
  148-       m2   73181.50c    1
  149-       m3   26000.50c   -0.695
  150-            24000.50c   -0.190
  151-            28000.50c   -0.095
  152-            25055.50c   -0.020
  153-       m4   1001.50c     2
  154-            8016.50c     1
  155-       mt4  lwtr.01t
  156-       m5   1001.50c     2
 warning. material   5 is not used in the problem.
  157-            6012.50c     1
  158-       mt5  poly.01t
 warning. material   5 is not used in the problem.
  159-       kcode   1000 1.0 15 115
  160-       ksrc    0 0 6.7945
  161-               0 0 14.287
  162-               0 1.2747       21.971
  163-               0 -1.2647      21.971
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
                      atom        gram                                           neutron
        cell  mat    density     density     volume       mass     pieces importance

     1     1    1  8.79108E-02 3.71430E+00 6.41652E+01 2.38329E+02     1  1.0000E+00
     2     3    2  5.52457E-02 1.66000E+01 2.18514E+01 3.62733E+02     1  1.0000E+00
     3     4    3  8.62390E-02 7.92000E+00 0.00000E+00 0.00000E+00     0  1.0000E+00
     4     5    1  8.86705E-02 3.74640E+00 6.36154E+00 2.38329E+01     1  1.0000E+00
     5     7    2  5.52457E-02 1.66000E+01 5.37219E+00 8.91783E+01     1  1.0000E+00
     6     8    3  8.62390E-02 7.92000E+00 0.00000E+00 0.00000E+00     0  1.0000E+00
     7     9    0  0.00000E+00 0.00000E+00 1.03977E+02 0.00000E+00     1  1.0000E+00
     8    10    0  0.00000E+00 0.00000E+00 1.03977E+02 0.00000E+00     1  1.0000E+00
     9    13    0  0.00000E+00 0.00000E+00 2.71113E+02 0.00000E+00     1  1.0000E+00
    10    14    3  8.62390E-02 7.92000E+00 0.00000E+00 0.00000E+00     0  1.0000E+00
    11    15    0  0.00000E+00 0.00000E+00 1.36104E+03 0.00000E+00     1  1.0000E+00
    12    16   4s 1.00309E-01 1.00000E+00 5.21114E+06 5.21114E+06     1  1.0000E+00
    13    17    0  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00     0  0.0000E+00

 total                                   5.21308E+06 5.21185E+06
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

```
                        tables from file rmccs

   1001.50c    1153  njoy                                                                       (
1301)      79/07/31.
   4009.50c    6717  njoy                                                                       (
1304)      79/06/07.
   8016.50c   23669  njoy
( 1276)     05/14/81
  24000.50c   89104  njoy                                                                       (
1324)      79/06/21.
  28000.50c   82267  njoy                                                                       (
1328)      79/06/21.
  94239.55c   67551  njoy                                                    total nu
( 1399)     02/21/85

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

  25055.50c   60097  njoy                                                                       (
1325)      79/06/21.
  73181.50c   29371  njoy                                                                       (
1285)      79/08/01.

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

  26000.50c   70549  njoy                                                                       (
1326)      79/09/04.

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   lwtr.01t   10193  hydrogen in light water at 300 degrees kelvin                           1001
0     010/22/85

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

      run terminated when   115   kcode cycles were done.
+
08/16/06 07:46:22
      C    Single SFC II Reflected with 320g Loading                                     probid
=  08/16/06 07:44:38
0
 neutron creation    tracks      weight        energy            neutron loss        tracks
weight        energy
                                 (per source particle)
(per source particle)

 source              100323    1.0000E+00    2.1400E+00          escape                   0    0.
0.
                                                                 energy cutoff            0    0.
0.
                                                                 time cutoff              0    0.
0.
 weight window            0    0.            0.                  weight window            0    0.
0.
 cell importance          0    0.            0.                  cell importance          0    0.
0.
 weight cutoff            0    2.3192E-01    4.4637E-07          weight cutoff       102109
2.3300E-01    5.5050E-07
 e or t importance        0    0.            0.                  e or t importance        0    0.
0.
 dxtran                   0    0.            0.                  dxtran                   0    0.
0.
 forced collisions        0    0.            0.                  forced collisions        0    0.
0.
 exp. transform           0    0.            0.                  exp. transform           0    0.
0.
 upscattering             0    0.            9.8460E-07          downscattering           0    0.
2.0143E+00
 photonuclear             0    0.            0.                  capture                  0
9.7247E-01    4.1340E-02
 (n,xn)                3572    3.3836E-02    3.4470E-02          loss to (n,xn)        1786
1.6918E-02    7.6372E-02
```

```
 prompt fission           0    0.            0.                  loss to fission         0
4.3364E-02    4.2483E-02
 delayed fission          0    0.            0.
     total          103895    1.2658E+00    2.1744E+00              total          103895
1.2658E+00    2.1744E+00

   number of neutrons banked                    2025        average time of (shakes)
cutoffs
   neutron tracks per source particle     1.0390E+00          escape            0.0000E+00
tco   1.0000E+33
   neutron collisions per source particle 3.1518E+02          capture           1.7587E+04
eco   0.0000E+00
   total neutron collisions                 31517597          capture or escape 1.7587E+04
wc1  -5.0000E-01
   net multiplication              1.0169E+00 0.0004          any termination   2.0471E+04
wc2  -2.5000E-01

 computer time so far in this run     4.99 minutes            maximum number ever in bank
2
 computer time in mcrun               4.63 minutes            bank overflows to backup file
0
 source particles per minute            2.4770E+04
 random numbers generated                268516278            most random numbers used was
16480 in history       47173

 range of sampled source weights = 7.7280E-01 to 5.9880E+00

 estimated system efficiency:  net = 37%  loss = 23% (locks) + 39% (comm.) +  0% (misc.)

 number of histories processed by each task
           0       12684       12743       12749       12728       12740       12751       12726
12743       12790
1neutron  activity in each cell
print table 126

                tracks     population   collisions   collisions     number        flux
average      average
        cell    entering                              * weight     weighted     weighted   track
weight   track mfp
                                                   (per history)    energy       energy
(relative)      (cm)

     1     1      126097       102099        78409    7.1597E-01   8.3072E-02   1.6808E+00
9.5219E-01   3.5952E+00
     2     3      152875       102107        24323    2.1275E-01   1.0869E-02   1.5478E+00
9.2807E-01   2.6267E+00
     3     4      158939       102108        14924    1.2439E-01   5.9714E-03   1.4268E+00
9.1057E-01   3.4889E+00
     4     5           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
     5     7           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
     6     8           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
     7     9           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
     8    10           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
     9    13      157098       100539            0    0.0000E+00   3.1811E-03   1.3303E+00
8.8848E-01   0.0000E+00
    10    14      202382       102108       243891    1.7822E+00   1.3264E-03   1.0505E+00
8.4091E-01   3.0870E+00
    11    15           0            0            0    0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
    12    16      149560       102099     31156050    1.5877E+02   4.8687E-05   2.5103E-01
5.7115E-01   8.1078E-01

     total        946951       611060     31517597    1.6160E+02
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 this calculation has completed the requested number of keff cycles using a total of      114654
fission neutron source histories.
```

```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 the results of the w test for normality applied to the individual collision, absorption, and
track-length keff cycle values are:

           the k( collision) cycle values appear normally distributed at the 95 percent
confidence level
           the k(absorption) cycle values appear normally distributed at the 95 percent
confidence level
           the k(trk length) cycle values appear normally distributed at the 95 percent
confidence level

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  the largest active cycle keffs by estimator are:                               the smallest
active cycle keffs by estimator are:

                   collision 0.16203 on cycle  81
collision 0.11143 on cycle 100
                  absorption 0.15482 on cycle  81
absorption 0.10827 on cycle  87
                track length 0.16560 on cycle  73
track length 0.10934 on cycle 108
1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle
number (| = final keff =  0.13069)

    cycle   active 0.12                                           0.13
0.14
   number   cycles  |-----------------------------------------------|--------------------------
----------------------|104       89  |                                              (---|k----)
|
      105       90  |                                              (---|k----)
|
      106       91  |                                               (--|k----)
|
      107       92  |                                               (--|k----)
|
      108       93  |                                              (---k----)
|
      109       94  |                                              (---k----)
|
      110       95  +                                              (---k----)
+
      111       96  |                                               (--|k----)
|
      112       97  |                                              (---|k----)
|
      113       98  |                                              (---k----)
|
      114       99  |                                             (----k----)
|
      115      100  |                                             (----k----)
|
                    |-----------------------------------------------|--------------------------
----------------------|
                  0.12                                            0.13
0.14
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 run terminated when   115   kcode cycles were done.

 computer time =    4.99 minutes

 mcnp     version 5.mpi 12072004                     08/16/06 07:46:23                     probid
=  08/16/06 07:44:38
```

7. PACKAGE OPERATIONS

This section describes the procedures used for opening, loading, closing, and unloading the S300 package.

7.1 Package Loading

7.1.1 Preparation for Loading

The S300 package should be loaded in a clean area that is protected from inclement weather. Provisions should be made for personnel protection and ALARA.

After placing the S300 package in position and securing the work area, loosen the drum clamping ring locknut and bolt and remove the drum lid, inner liner lid, and the top spacer and shims, exposing the lid of the pipe component.

Using the lifting ring(s) on the top of the pipe component, lift the pipe component from the S300 package. Alternately, the pipe component may be left inside the S300 package during loading. Remove all twelve of the 7/8-9 UNC lid attachment bolts and remove the pipe component lid. Using the wire bail, remove the shield insert lid. Remove the upper two-inch thick polyethylene shielding plug. Ensure the lower two-inch thick polyethylene shielding plug is in place at the bottom of the shield insert cavity. Inspect all parts for damage and replace or repair as necessary. Ensure that the pipe component O-ring is in good condition.

7.1.2 Loading of Contents

The radioactive contents of the S300 package must be contained inside a SFC before placement into the package. The maximum loading of the SFC shall comply with the limits given in Table 7-1. Inspect, load, close, and evaluate the closure of the SFC according to an approved procedure. When complete, lower the SFC into the shield insert cavity. Ensure that no more than one SFC (of any authorized type) is placed within the cavity. Place the upper two-inch thick polyethylene shielding plug on top of the SFC, and replace the shield insert lid. Ensure that the shield insert lid contacts the shield insert body, and that the lid is not supported by the contents.

Table 7-1 – SFC Package Contents Limits, grams of ^{239}Pu

Payload Type	Non-Exclusive Use		Exclusive Use	
	Model II SFC	Model III SFC	Model II SFC	Model III SFC
Plutonium-Beryllium Sealed Sources	206	160	350	160

7.1.3 Preparation for Transport

Optionally coat the pipe component O-ring with a light coat of vacuum grease, and replace the pipe component lid. Using a light coating of an approved thread lubricant, install the twelve 7/8-9 UNC lid attachment bolts hand tight. Optionally, a thread locking compound may be used on the bolt threads. Using a star pattern, tighten the bolts to a torque of 65 ± 5 ft-lb. After completion of the star pattern, check the tightness of each bolt sequentially.

If the pipe component was removed from the S300 package, use the lifting ring(s) to lift the pipe component and replace it into the S300 package. Ensure it is seated properly in the cavity provided. Replace the top spacer and shims, ensuring that the side of the top spacer having the recesses is facing down, and that the top spacer is properly seated over the bolt heads and lift ring(s). Using the inner liner lid, measure the distance between the top spacer (or shim, if present) and the underside of the inner liner lid. If the distance is greater than 1/2 inch, add shims as necessary to achieve a clearance of less than 1/2 inch. Then replace the inner liner lid.

Replace the drum lid and ensure it is seated properly on the drum. Ensure that a locknut is present on the bolt between the two clamping ring lugs. Tighten the drum clamping ring bolt to a final torque of 40 ± 5 ft-lb, tapping around the clamping ring using a soft-headed hammer while tightening the bolt. When fully tight, spin the locknut towards the unthreaded clamping ring lug and tighten. Optionally, if inadequate bolt threads exist to tighten the locknut against the unthreaded lug, the locknut may be tightened against the threaded lug.

Install the tamper indicating wire and seal through the cross-drilled hole in the drum clamping ring bolt. If the S300 is to be shipped by exclusive use, ensure that the package is secured to a pallet or skid at least four inches thick. Determine the surface contamination level of each package per 49 CFR §173.443.[1] Monitor the external radiation level of each package per 49 CFR §173.441.

The S300 package is now ready for transport.

7.2 Package Unloading

Upon receipt of the S300 package from the carrier, it may be immediately unloaded or optionally stored indefinitely in a safe and secure manner. Note that, due to the purpose for which the S300 package is intended, unloading of a package is not typically performed. Most S300 packages are stored with the payload intact and not reused, except as payload containers within a certified Type B package.

7.2.1 Opening the Package

The S300 package should be unloaded in a clean area that is protected from inclement weather. Provisions should be made for personnel protection and ALARA. After recording the condition of the tamper indicating device, remove the device.

[1] Title 49, Code of Federal Regulations Part 173 (10 CFR 173), *Shippers – General Requirements for Shipments and Packagings*, 01-01-06 Edition.

After placing the S300 package in position and securing the work area, loosen the drum clamping ring bolt and remove the drum lid, inner liner lid, and the top spacer and shims, exposing the lid of the pipe component.

Using the lifting ring(s) on the top of the pipe component, lift the pipe component from the S300 package. Alternately, the pipe component may be left inside the S300 package during unloading. Remove all twelve of the 7/8-9 UNC lid attachment bolts and remove the pipe component lid. Using the wire bail, remove the shield insert lid. Remove the upper two-inch thick polyethylene shielding plug.

7.2.2 Removal of Contents

After removal of the two-inch thick upper polyethylene shielding plug, the SFC is exposed. Remove the SFC and place in safe storage.

7.3 Preparation of Empty Package for Transport

If the S300 package is to be transported empty after an initial use, the following procedure shall be employed. Ensure that the SFC has been removed from the shield insert cavity. Place the upper two-inch thick polyethylene shield plug into the cavity, and replace the shield cavity lid. Replace the pipe component lid and thread in the twelve 7/8-9 UNC lid attachment bolts hand tight. Using a star pattern, tighten the bolts to a torque of 65 ± 5 ft-lb. After completion of the star pattern, check the tightness of each bolt sequentially.

If the pipe component was removed from the S300 package, use the lifting ring(s) to lift the pipe component and replace it into the S300 package. Ensure it is seated properly in the cavity provided. Replace the top spacer and shims, ensuring that the side of the top spacer having the recesses is facing down, and that the top spacer is properly seated over the bolt heads and lift ring(s). Replace all of the shims that were removed (if any). Then replace the inner liner lid.

Replace the drum lid and ensure it is seated properly on the drum. Ensure that a locknut is present on the bolt between the two clamping ring lugs. Tighten the drum clamping ring bolt to a final torque of 40 ± 5 ft-lb, tapping around the clamping ring using a soft-headed hammer while tightening the bolt. When fully tight, spin the locknut towards the unthreaded clamping ring lug and tighten. Optionally, if inadequate bolt threads exist to tighten the locknut against the unthreaded lug, the locknut may be tightened against the threaded lug. Finally, remove or render non-visible any shipping labels required to be displayed on loaded packages.

The S300 package is now ready for empty transport or indefinite storage.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

8.1.1 Visual Inspections and Measurements

The S300 packaging is subject to the conventional visual inspections and measurements normally incident to fabrication and purchase of components.

8.1.2 Weld Examinations

Pipe component flange and bottom end welds are examined in accordance with the ASME B&PV Code, Section III, Division 1, Subsection NG, Articles NG-5230 and NG-5260, and accepted in accordance with Articles NG-5350 and NG-5360.

8.1.3 Structural and Pressure Tests

No structural or pressure tests are applicable to the S300 package.

8.1.4 Leakage Tests

Because the pipe component is designed only to retain the shielding insert and SFC under NCT, a leakage test is not required.

8.1.5 Component and Material Tests

No acceptance tests are performed on S300 packaging materials or components.

8.1.6 Shielding Tests

Due to the simple design and construction of the shield insert as a right circular cylinder machined from a single billet of HDPE material, no shielding tests are needed for the S300 package.

8.1.7 Thermal Tests

Since the heat generation of the payload is negligible, thermal tests are not applicable to the S300 package.

8.2 Maintenance Program

For purposes of ALARA, the S300 Package is loaded and closed once, then sealed with a tamper-indicating device. The multifunction S300 is used as a transport package, a storage container (if required), and a final disposal container. The S300 may be transported more than once and stored if necessary before final disposal at the Waste Isolation Pilot Plant (WIPP). If it is required to inspect the contents of the S300 or open it for any reason, that activity shall be performed according to the procedures in Section 7.0, *Package Operations*.

To ensure that the S300 is in unimpaired condition, it shall be visually inspected before loading and prior to each transport. The visual inspection shall provide assurance that:

- The drum closure lid is properly installed and the clamping ring is intact and tight.
- The tamper-indicating device is intact.
- The drum has not experienced corrosion to the extent that its structural integrity would be impaired. Note: Loss of paint or surface corrosion that does not impair the structural integrity of the drum is acceptable.
- There are no penetrations through the drum or closure lid (except for the vent filter), there are no gross deformations of the drum or closure lid that could significantly affect structural integrity, and no evidence of water entry into the drum.
- There are no other indications which could prevent the S300 package from meeting the requirements of 10 CFR 71.

If a S300 package fails visual inspection prior to any transport, it shall be removed from service, and repaired and recertified, or replaced as necessary. Any replacement components shall comply with the drawings provided in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

9. QUALITY ASSURANCE

This chapter defines the Quality Assurance (QA) requirements and methods of compliance applicable to the S300 package. The S300 package described in this SAR is identical to the S300 pipe overpack currently used as a payload container within the TRUPACT-II package; and has been used as a qualified DOT 7A Type A transportation package by OSRP for a number of years.

The QA requirements for packaging established by the NRC are described in Subpart H of 10 CFR Part 71 (10 CFR 71). Subpart H is an 18-criteria QA program based on ANSI/ASME NQA-1. Guidance for QA programs for packaging is provided by NRC Regulatory Guide 7.10[1]. The QA requirements of DOE for the use of NRC certified packaging are described in DOE Order 460.1B[2].

The S300 packaging is designed and built for, and used by DOE; and must be approved by the NRC for the shipment of radioactive material in accordance with the applicable provisions of the DOT, described in 49 CFR 173, Subpart I. Procurement, design, fabrication, assembly, testing, maintenance, repair, modification, and use of the S300 package are all done under QA programs that meet all applicable NRC and DOE QA requirements.

The DOE Field Offices for shipping and receiving sites inspect and approve the respective shipper's and receiver's QA programs for equivalency to the NRC's QA program requirements in Subpart H of 10 CFR 71. Non-DOE users of the S300 package may only use it when approved to do so by the NRC.

QA requirements for the S300 package are discussed in the *Contact-Handled Transuranic Waste Authorized Methods for Payload Control* (CH-TRAMPAC). QA programs applicable to procurement, design, fabrication, assembly, testing, use, maintenance, and repair of the TRUPACT-II are also noted in Chapter 9.0 of the TRUPACT-II SAR. The certification and packaging QA requirements are based on the Carlsbad Field Office (CBFO) Quality Assurance Program Document (QAPD) and 10 CFR 71, Subpart H, *Packaging and Transportation of Radioactive Material, Quality Assurance.*

The Central Characterization Project (CCP) was established by the Department of Energy/Carlsbad Field Office (DOE-CBFO) to provide more efficient and cost effective characterization and certification of transuranic (TRU) waste using the resources of multiple corporate and national laboratory entities.

The CCP is the first centralized TRU waste characterization and certification project in the DOE complex. The Waste Isolation Pilot Plant (WIPP) Management and Operations contractor, Westinghouse TRU Solutions, LLC (WTS), manages the project, with technical support from Los Alamos National Laboratory (LANL) and Sandia National Laboratory (SNL). These two primary subcontractors provide operational support for CCP characterization operations in the

[1] U.S. Nuclear Regulatory Commission, Regulatory Guide 7.10, *Establishing Quality Assurance Programs for Packaging Used in transport of Radioactive Material, Revision 2*, March 2005.

[2] U.S. Department of Energy Order 460.1B, *Packaging and Transportation Safety,* 4-4-03.

field. Collectively, the subcontractors, WTS, LANL, and SNL personnel are all members of the CCP team.

The CCP is tasked with characterizing and certifying all aspects of TRU waste (e.g., Pu/Be sources) for disposal at WIPP. Accordingly, the CCP team must comply with DOE/WIPP 02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (CH-WAC).

The CH-WAC establishes the specific physical, chemical, radiological, and packaging criteria for acceptance of defense TRU waste shipments to WIPP in S300 packages. The CH-WAC also requires that the CCP produce documents, including a certification plan that addresses the applicable requirements and criteria specific to packaging, characterization, certification, and shipping of TRU waste, such as Pu/Be special form sources, to WIPP for disposal.

To accommodate the aforementioned requirement to develop a certification plan, the CCP has produced document CCP-PO-002, *Transuranic Waste Certification Plan* as well as CCP-PO-003, *CCP Transuranic Authorized Methods for Payload Control*. Within these documents reside requirements for effective application of a QA program founded on the CBFO QAPD and 10 CFR 71, Subpart H.

The CCP team implements the Quality Assurance Plan (QAP) established in Section 4.0 of CCP-PO-002. This QAP establishes the overall QA program requirements as well as establishes measures for design, procurement, fabrication, testing, use, inspection, examination, maintenance, repair, modification, handling, storage, shipping, and cleaning. The DOE-CBFO approves the QAP before transuranic material is packaged and transported to the WIPP or other sites.

Compliance methods are documented in DOE-CBFO approved programmatic Transuranic Waste Authorized Methods for Payload Control (TRAMPACs) and/or waste-specific data TRAMPACs. The DOE-CBFO managing and operating contractor performs surveillance of users' payload compliance procedures or data package to ensure the requirements of this CH-TRAMPAC are met. The DOE-CBFO periodically audits users' payload compliance QA programs.

In addition to CCP QA requirements, OSRP must also comply with the extensive Quality Assurance Program (QuAP) at Los Alamos National Laboratory (LANL). The QuAP is the approved institutional description of the overall management system at LANL that provides a level of confidence that both its business management and technical processes are effective and efficient.

The LANL QuAP is issued under the authority of the Laboratory Director and reflects the values of LANL senior management. It is consistent with requirements of the prime contract and LANL Governing Policies on performance, safety, and safeguards and security, and it promotes compliance with federal, state, and local regulations and codes.

This QuAP establishes the LANL quality assurance program requirements for site-wide implementation and is to serve as the basis for LANL quality assurance program acceptability. It is designed such that implementation of the full scope of requirements as stated in DOE Order 414.1, Quality Assurance (current contractual version), constitutes compliance to nuclear safety quality assurance criteria required by 10 CFR 830, Subpart A, *Nuclear Safety Management Quality Assurance Requirements*.

In the interests of ALARA, OSRP recovery team members handle recovered radioactive sources as little as possible. Therefore, when sources are packaged by OSRP at the recovery site for transport, they are actually ready for final disposition at WIPP (or interim storage at LANL if necessary). Since the multi-function S300 must be able to serve as transport packaging, storage container, and disposal container, OSRP is required to comply with all aspects of CCP QA and LANL QA program descriptions whenever packaging Pu/Be sources into an S300 container.

A detailed discussion of the LANL/CCP QA program which governs OSRP packaging operations is presented on the following pages to demonstrate compliance with 10 CFR 71, Subpart H.

9.1 Organization

9.1.1 LANL/Central Characterization Project Organization

The responsibilities for transuranic (TRU) source management of the LANL/CCP are distributed within various organizations. This section identifies the organizations involved and describes the responsibilities of and interactions between these organizations.

9.1.1.1 Central Characterization Project Management

CCP management has overall responsibility for successfully accomplishing activities. Management provides the necessary planning, organization, direction, control, resources, and support to achieve their defined objectives. Management is responsible for planning, performing, assessing, and improving the work.

CCP management is responsible for establishing and implementing policies, plans, and procedures that control the quality of work, consistent with requirements.

CCP QA management responsibilities include:

- Ensuring that adequate technical and QA training is provided for personnel performing activities.
- Ensuring compliance with all applicable regulations, DOE orders and requirements, and applicable federal, state, and local laws.
- Ensuring that personnel adhere to procedures for the generation, identification, control, and protection of QA records.
- Exercising the authority and responsibility to STOP unsatisfactory work such that cost and schedule do not override environmental, safety, or health considerations.
- Developing, implementing, and maintaining plans, policies, and procedures that implement the QAPD.
- Identifying, investigating, reporting, and correcting quality problems.
- Members of the CCP management are responsible for achieving and maintaining quality in their area. Quality achievement is the responsibility of those performing the work.

Quality achievement is verified by persons or organizations not directly responsible for performing the work.

- CCP management empowers employees by delegating authority and decision making to the lowest appropriate level in the organization.
- Figure 9.1-1, *LANL/CCP Organization*, is a functional organization chart pertaining to TRU characterization and certification activities of LANL/CCP. The following subsections identify the organizations that oversee LANL/CCP and describe the roles and responsibilities of key positions charged with implementing the requirements defined in the QA plan.

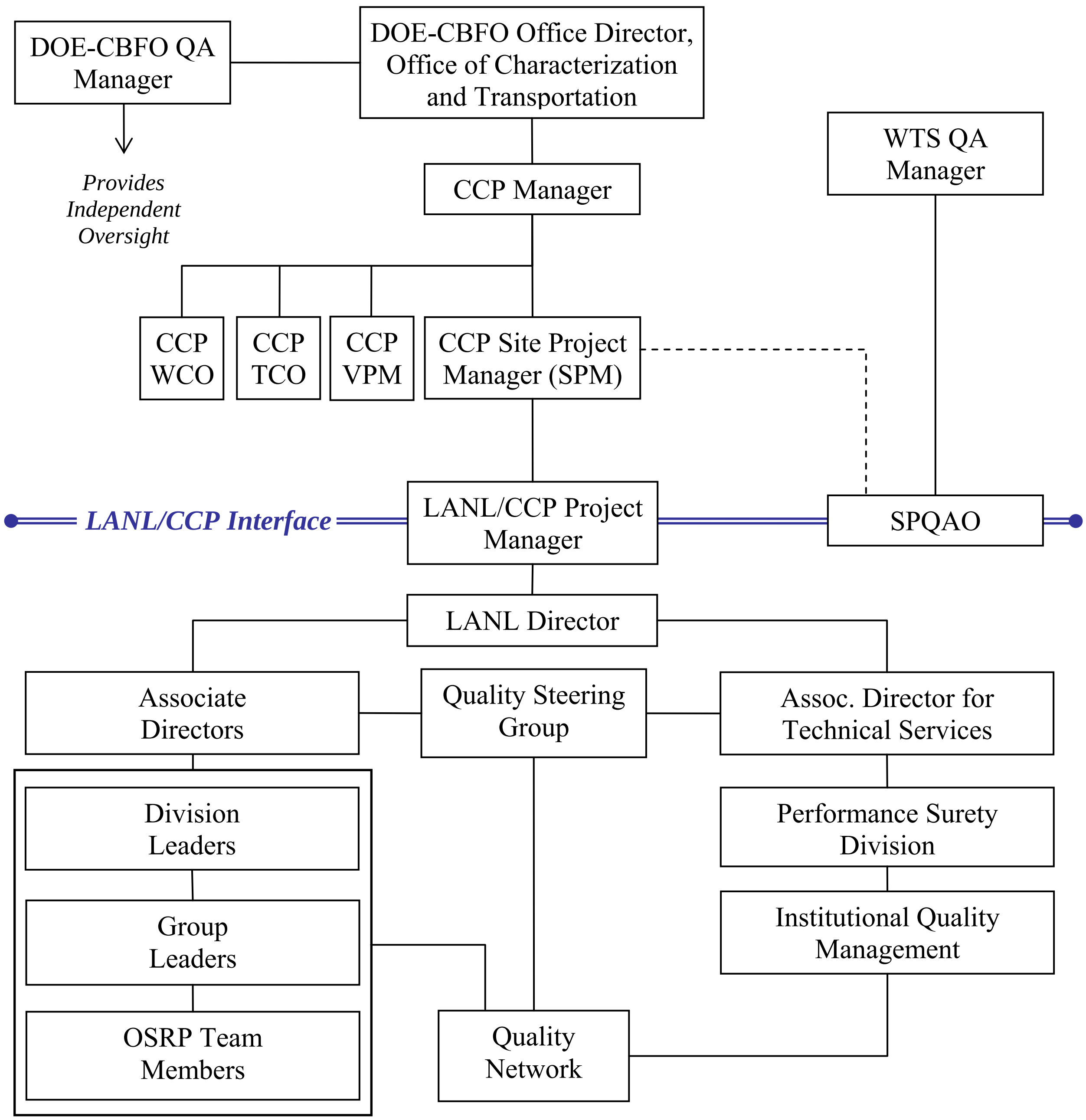


Figure 9.1-1 - LANL/CCP Organization

9.1.1.2 DOE-CBFO Quality Assurance Manager

The DOE-CBFO QA Manager provides independent oversight of QA activities of the CCP.

9.1.1.3 DOE-CBFO Office Director, Office of Characterization and Transportation

The DOE-CBFO Office Director, Office of Characterization and Transportation, provides overall policy direction and oversees CCP characterization and certification activities and approves the QA plan.

9.1.1.4 CCP Manager

The CCP Manager is responsible for the day-to-day management and direction of CCP activities. The CCP Manager is responsible for:

- Ensuring successful CCP/site interface.
- Ensuring CCP plans and operations are coordinated, integrated, and consistent with DOE-CBFO programs, policies, and guidance.
- Coordinating CCP activities and functioning as principal point-of-contact (POC) with DOE-CBFO and other regulating agencies.
- Reviewing and approving the QA plan.

9.1.1.5 CCP Site Project Manager (SPM)

The Site Project Manager (SPM) is the principal POC with DOE [including CBFO and National TRU Program (NTP)] for technical activities associated with TRU. The SPM coordinates with the CCP Waste Certification Official (WCO) and Transportation Certification Official (TCO) and oversees CCP activities to ensure that TRU is characterized and certified compliant with WIPP requirements. Specific responsibilities assigned to the SPM include the following:

- Developing, maintaining, reviewing, approving, and implementing CCP procedures and plans. Development, approval, and implementation of procedures and plans will occur at the earliest time consistent with the schedule for accomplishing the activities.
- Scheduling revisions and distributing CCP procedures and plans and forwarding these documents (if significantly revised) to DOE-CBFO for review and approval before implementation. The term “significantly revised” means non-editorial changes in accordance with the QAPD, Section 1.4.3.
- Ensuring CCP personnel receive appropriate training and are properly qualified, so that suitable proficiency is achieved and maintained.
- Obtaining Acceptable Knowledge (AK) information from waste generators regarding U.S. Environmental Protection Agency (EPA) hazardous waste codes.
- Assigning additional EPA hazardous waste codes to TRU waste based on analytical results, as applicable.
- Reviewing and approving interface documents.
- Waste selection and tracking.

- Halting characterization or certification activities if problems affecting the quality of certification processes or work products exist.
- Validating and verifying characterization data.
- Reconciling verified data with data quality objectives.
- Evaluating and reconciling AK information with characterization data.
- Preparing and submitting SPM Data Validation Summaries, Waste Stream Profile forms, Characterization Information Summaries, Waste Stream Characterization Packages, and QA/Quality Control (QC) reports to DOE-CBFO.

The SPM may delegate any of these activities to another individual; however, the SPM retains ultimate responsibility for ensuring that CCP certification requirements are met.

9.1.1.6 CCP Site Project Quality Assurance Officer (SPQAO)

The SPQAO provides QA oversight and planning for TRU characterization and certification, verifies the implementation of QA requirements, and provides day-to-day guidance on quality-related matters. The SPQAO has the authority to stop CCP work activities if quality is not assured or controlled. The SPQAO has no responsibilities unrelated to the QA Program that would prevent appropriate attention to QA matters. The SPQAO is responsible for verifying the achievement of quality by those performing the work. As shown in Figure 9.1-1, *LANL/CCP Organization*, the CCP SPQAO reports directly to the WTS QA Manager, so that required authority and organizational freedom are provided, including sufficient independence from cost and schedule considerations. The SPQAO's specific responsibilities include:

- Reviewing and approving CCP procedures and plans; including the QA plan.
- Interfacing with WTS QA for activities in CCP-PO-008, *CCP Quality Assurance Interface with WTS QA Program*.
- Coordinating and participating in internal and external audits and assessments to verify compliance.
- Tracking compliance and evaluating trends in compliance with QA objectives.
- Performing assessments of testing, sampling, and analytical facilities.
- Tracking and trending CCP nonconformances and corrective action reports.
- Verifying CCP corrective actions.
- Validating and verifying data at the project level.
- Submitting semi-annual and other QA/QC reports to the SPM and DOE-CBFO.
- Coordinating responses to CCP nonconformance reports (NCRs) generated by DOE-CBFO or other external assessment organizations.
- Reviewing and approving supplier and subcontractor QA Plans.
- Reviewing interface documents.

- Providing guidance to all CCP organizations concerning identification, control, and protection of QA records.
- Comparing Visual Examination (VE) and radiography data, and calculating miscertification rates.
- Stopping work if quality is not assured or controlled.
- Providing day-to-day guidance on quality-related matters.
- Maintaining liaison with participant QA organizations and other affected organizations.
- Developing, establishing, and interpreting QA policy and ensuring effective implementation.
- Interfacing, as appropriate, with the DOE-CBFO staff, participants, and other stakeholders on QA matters.
- Assisting subordinate organizations with quality planning, documentation, quality measurement, and problem identification and resolution.
- Initiating, recommending, or providing solutions to quality problems through designated channels.
- Ensuring that further processing, delivery, installation, or use is controlled until proper disposition of a nonconformance, deficiency, or unsatisfactory condition has occurred.
- Coordinating with responsible management on resolution of differences of opinion involving the definition and implementation of QA Program requirements. If not resolved, progressively elevating the issues to successively higher levels of management as necessary.
- Ensuring that a graded approach is used to exercise control over activities affecting quality to an extent consistent with their importance.
- Interfacing with the CCP WCO and TCO on matters related to waste characterization, certification, and transportation.

The SPQAO may delegate one or more individuals to perform the above functional responsibilities; however, the SPQAO retains ultimate responsibility for ensuring compliance with CCP QA requirements.

9.1.1.7 CCP Waste Certification Official (WCO)

The CCP WCO is responsible for reviewing data and information necessary to document TRU payload containers prepared for shipment to WIPP meet specified criteria. The WCO coordinates activities related to waste certification. Specific duties and responsibilities of the WCO include the following:

- Certifying that packages and shipments meet CH-WAC requirements.
- Interfacing with the CCP SPM, TCO, and SPQAO on matters related to characterization and certification.

- Stopping certification activities if problems affecting the quality of certification processes or work products exist.
- Ensuring that certification data entered into the WIPP Waste Information System (WWIS) are accurate and demonstrate the acceptability of the material for transport to and disposal at the WIPP.
- Reviewing the applicable CCP plans and procedures and any other waste certification-related documents.
- Reviewing the QA plan.
- Preparing responses to deficiency reports.

The WCO may delegate one or more individuals to perform the above responsibilities; however, the WCO retains ultimate responsibility for ensuring compliance with CH-WAC requirements.

9.1.1.8 CCP Transportation Certification Official (TCO)

The CCP TCO documents and certifies that payload containers and assemblies to be transported meet the requirements of CCP-PO-003. Specific responsibilities of the TCO include:

- Reviewing the applicable CCP transportation plans and transportation procedures.
- Interfacing with the CCP SPM, WCO, and SPQAO on matters associated with transportation.
- Reviewing and maintaining CCP-PO-003.
- Ensuring that data used in completion of the transportation documents are accurate and demonstrate that the waste is acceptable for transportation.
- Preparing and signing Payload Container Transportation Certification Documents and Overpack Payload Container Transportation Certification Documents.
- Preparing and signing Payload Assembly Transportation Certification documents.
- Assisting the SPQAO with preparation of responses to deficiency reports in transportation matters.
- Ensuring that the transportation data entered into the WWIS are accurate and demonstrate that waste is acceptable for disposal at WIPP.
- Reviewing interface documents.
- Halting transportation certification activities if problems affecting the certification or work process exist.

9.1.1.9 WTS Quality Assurance Manager

The WTS QA Manager is responsible for specific activities that relate to the CCP scope of work. These include:

- Performing independent assessments of CCP activities, in accordance with the CBFO-approved WTS QA Program and implementing procedures.

- Providing inspection services support for procurement, including source inspections.
- Providing vendor qualification and maintenance of the WTS Qualified Suppliers List for vendors used by CCP.

9.1.1.10 CCP Vendor Project Manager (VPM)

- Monitors the List of Qualified Individuals to confirm that only qualified personnel perform waste characterization activities.
- Ensures that in-process documents and the documents are transmitted to the CCP Site Project Office as soon as practicable per CCP-QP-008, *CCP Records Management*.
- Ensures applicable Material Safety Data Sheets are maintained and available to support operations.
- Notifies the CCP Project Manager of any abnormal events associated with safe operation of CCP characterization activities for reporting purposes.

9.1.1.11 LANL/CCP Project Manager

The LANL/CCP Project Manager is the primary liaison between LANL and CCP for successful implementation of the QA plan. Specific responsibilities include:

- Confirming that characterization activities are conducted at LANL per the Statement of Work requirements, the Interface Document, and the CCP schedule.
- Providing primary oversight responsibility for project safety and compliance for CCP personnel at LANL.
- Providing CCP personnel and equipment to support characterization, certification, and transportation, as required.
- Providing support to the CCP Site Project Manager (SPM).
- Receiving documentation of required LANL site-specific training.
- Providing weekly production reports to the DOE-CBFO and LANL Production Control as required.
- Receiving reports of LANL oversight activities and formally responding, as required.
- Interfacing with DOE-CBFO and DOE/Los Alamos Site Office (LASO) upon request.

9.1.1.12 LANL Director

- Retains the ultimate authority and accountability for the QuAP and its implementation at LANL.
- Ensures that overall institutional vision, values, standards, and management systems that define the QuAP are established and documented in policies and procedures.
- Ensures that resources necessary for effective implementation of the QuAP are provided.

- Fosters an environment that promotes and supports the identification of issues and resolution for continuous quality improvement.
- Appoints the Quality Steering Group Chair to administer the QuAP.
- Approves the QuAP and supports its implementation.

9.1.1.13 LANL Quality Steering Group

- Oversees and guides the development and implementation of the QuAP.
- Endorses the QuAP institutional support documents.
- Reviews and interprets quality documents and policy issues.
- Provides recommendations regarding quality assurance policy issues to support the Quality Steering Group Chair key decisions.

9.1.1.14 LANL Associate Directors

- Account for directorate compliance with quality assurance requirements [e.g., 10 CFR 830, Subpart A, DOE O 414.1 (current contractual version), and DOE/NNSA QC-1].
- Determine and provide resources (e.g., budget, personnel, materials) to accomplish required work activities.
- Serve as the directorate representative on the Quality Steering Group.
- Appoint directorate and/or division representatives to serve on the Quality Network.
- Ensure the flow down and effective implementation and enforcement of quality assurance requirements within their directorates.
- Ensure that applicable quality standards and quality requirements are identified for the work to be performed.
- Develop/approve directorate/division and program quality assurance supplemental documents (where applicable) and QuAP implementation plans within their directorates.
- Ensure that LANL customer and programmatic requirements are integrated into the scopes of work activities (e.g., ISM, Integrated Safeguards and Security Management, Conduct of Operations).
- Foster an environment that promotes identification and comprehensive correction of quality issues that support continuous quality improvement.
- Support the identification and recommendation for policy, process, or procedure changes that improve quality and efficiency within their directorates and/or throughout LANL.
- Perform and provide a summary management assessment report to the Quality Steering Group Chair and Laboratory Director annually that evaluates the adequacy, effectiveness, and implementation of management systems performance within their directorates.

9.1.1.15 LANL Performance Surety Division

- Provides formal operations and oversight for interdivisional and inter-directorate services.
- Develops and implements integrated management systems that document performance indicators, measure performance status through investigations, and regularly report results to LANL senior management (e.g., issues management, authorization basis).

9.1.1.16 LANL Division Leaders/Program, Project, and Office Directors

- Determine quality assurance program requirements based on work scopes and develop and/or approve quality assurance program documents and implementation plans within their divisions/programs/projects/offices.
- Approve quality assurance supplemental documents and implementation plans within their divisions/programs/projects/offices (where applicable).

9.1.1.17 LANL Institutional Quality Management Group

- Provides procedures, processes, tools, and quality training to assist organizations in implementation of the QuAP.
- Serves as a resource to systematically manage potential quality concerns, issues, and problems.
- Provides inspection, quality assurance compliance and performance assessments, and program development support services to LANL.
- Reviews directorate and/or division quality assurance supplemental documents and QuAP implementation plans for compliance with the QuAP requirements.
- Coordinates and chairs the Quality Network and disseminates quality-related information to Quality Network members.
- Independently assesses the QuAP implementation utilizing a risk-based process to determine assessment scope.

9.1.1.18 LANL Quality Network

- Assist in the development and implementation of the QuAP.
- Share quality-related information (e.g., defective items, product recalls) among workers within directorates, divisions, programs, and offices and identifies and helps to resolve multi-organizational quality issues.

9.1.1.19 Members of the LANL Workforce (at all levels)

- Implement their organization’s procedures to meet QA requirements.
- Comply with administrative and technical work control requirements.

- Identify and report issues to the responsible manager for resolution and continuous improvement for the work being performed.
- Seek, identify, and recommend work methods or procedural changes that would improve quality and efficiency.

9.2 Quality Assurance Program

9.2.1 General

The CBFO QAPD establishes the QA program requirements for programs, projects, and activities sponsored by the CBFO. CCP-PO-002, *Transuranic Waste Certification Plan*, Section 4.0, *Quality Assurance Plan* describes and implements the CBFO QAPD requirements for LANL/CCP. CCP-PO-002 is based on the CBFO QAPD as it applies to the characterization, certification, and transportation of TRU material and therefore incorporates the applicable requirements from the regulatory and committed QA source documents identified in the CBFO QAPD. Section 4.0 of CCP-PO-002, *Transuranic Waste Certification Plan*, fulfills the requirements for a transportation QA plan as required by 10 CFR 71, Subpart H for the S300 packaging.

The scope of the integrated Quality Assurance Program Requirements for Nuclear Facilities (NQA-1) Program is to ensure that all items and activities that are important to the safe containment of TRU Waste at WIPP comply with program objectives. Applicable criteria are identified in the individual element descriptions contained within the CCP-PO-002, *Transuranic Waste Certification Plan*, Section 4.0.

The LANL/CCP QA program is developed and maintained through an ongoing process that selectively applies QA criteria as appropriate to the function or work activity being performed. Applicable QA criteria consist of the following:

- Title 10 CFR Subpart 71, Packaging and Transportation of Radioactive Material
- Title 10 CFR Part 194, Criteria for the Certification and Re-Certification of Radioactive Material
- Title 10 CFR 830.120, Quality Assurance Requirements
- ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Application
- DOE O 414.1, Quality Assurance
- USDOE DOE-CBFO-94-1012, Quality Assurance Program Document

The LANL/CCP QAP is inclusive of applicable requirements from criteria noted above and addresses the following as applicable for this SAR:

- Organization
- Quality Assurance Program
- Implementation of the QA Program
- Personnel Qualification and Training
- Records
- Work Process
- Procurement
- Inspection and Testing

- Quality Improvement
- Documents
- Management Assessments
- Independent Assessment

Table 9.2-1 depicts how the requirements of 10 CFR 71, Subpart H are addressed within the LANL/CCP QA program.

The CCP Manager is responsible for ensuring implementation of requirements as defined within the QA program as well as the requirements of this SAR including design, procurement, fabrication, inspection, testing, maintenance, and modifications. Procurement documents are to reflect applicable requirements from 10 CFR 71, Subpart H, ASME NQA-1 and the QA program.

LANL and CCP management assesses the adequacy and effectiveness of the QA program to ensure effective implementation inclusive of objective evidence and independent verification, where appropriate, to demonstrate that specific project and regulatory objectives are achieved.

All LANL/CCP personnel and contactors are responsible for effective implementation of the QA program within the scope of their responsibilities. Personnel responsible for inspection and testing are to be qualified, as appropriate, through minimum education and/or experience, formal training, written examination and/or other demonstration of skill and proficiency. Objective evidence of qualifications and capabilities are to be maintained as required. As appropriate, the initial employee training should consist of the following:

- General employee indoctrination
- Program indoctrination
- Radiation/industrial training
- QA program training

Table 9.2-1 - QA Program Requirement Cross-mapping

10 CFR 71 Subpart H Requirement	Title	CCP QA Plan Section	Description	Application to CCP Implementation
1 (71.103)	QA Organization	4.1	Identifies organizations and their relationships in performance of activities affecting quality.	Applicable
2 (71.105)	QA Program	4.1	Describes basic methods for establishing a documented QA program that implements requirements of 10 CFR 71, Subpart H.	Applicable
3 (71.107)	Package Design Control	4.1	Describes design control measures established for structures, systems, and components.	Not Applicable
4 (71.109)	Procurement Document Control	4.7	Describes procedures for ensuring that applicable regulatory requirements, design bases, and other requirements necessary to ensure adequate quality are suitably included or referenced in documents for procurement of material and services.	Applicable
5 (71.111)	Instructions, Procedures, and Drawings	4.5	Describes documentation of instructions, procedures, or drawings to ensure that safety criteria have been met. Also describes QA review and concurrent processes.	Applicable
6 (71.113)	Document Control	4.4	Describes documents to be maintained by the QA program and how those documents may be changed, reviewed, approved, and issued.	Applicable
7 (71.115)	Control of Purchased Material, Equipment, and Services	4.7	Describes procurement planning, sources, bids, evaluations, awards, performance control, verification activities, control of nonconformances, and records.	Applicable

10 CFR 71 Subpart H Requirement	Title	CCP QA Plan Section	Description	Application to CCP Implementation
8 (71.117)	Identification and Control of Materials, Parts, and Components	4.6	Describes procedures to track materials to prevent the use of incorrect or defective items.	Applicable
9 (71.119)	Control of Special Processes	4.6	Describes procedures to monitor special processes such as welding, radiography, and heat-treating.	Applicable
10 (71.121)	Internal Inspection	4.8	Describes the planning and use of inspection procedures, instructions, and checklists.	Applicable
11 (71.123)	Test Control	4.8	Describes requirements and procedures for testing materials in accordance with original design and testing requirements. Also ensures that the test results are documented and evaluated by qualified individuals.	Applicable
12 (71.125)	Control of Measuring and Test Equipment	4.8	Describes procedures for ensuring that measuring and test equipment is properly calibrated and appropriate actions should the equipment be out of calibration.	Applicable
13 (71.127)	Handling, Storage, and Shipping Control	4.8	Describes procedures for ensuring that containers and packaging are preserved, prepared, released, and delivered in good condition.	Applicable
14 (71.129)	Inspection, Test, and Operating Status	4.8	Describes methods for the identification of the inspection, test, and operating status of items including the application/removal of tags, markings, or stamps.	Applicable
15 (71-131)	Inspection, Test, and Nonconforming Materials, Parts, or Components	4.7	Describes the identification, segregation, disposition, and evaluation of items that do not conform to design and construction criteria.	Applicable

10 CFR 71 Subpart H Requirement	Title	CCP QA Plan Section	Description	Application to CCP Implementation
16 (71-133)	Corrective Action	4.7	Described procedures for identifying, reporting, and obtaining corrective actions from suppliers for defective material.	Applicable
17 (71-135)	Quality Assurance Records	4.5	Describes the establishment of quality assurance records, content, indexing and classification, and appropriate methods for storage, preservation, and safekeeping.	Applicable
18 (71.137)	Audits	4.9	Describes internal and external audit programs applicable to both in-house and major suppliers.	Applicable

9.2.2 S300-Specific Program

The S300 was designed and tested as described in Chapter 2, *Structural Evaluation,* of this SAR. QA requirements are invoked in the design, procurement, fabrication, assembly, testing, maintenance, and use of the packaging to ensure established standards are maintained. Items and activities to be controlled and documented are described in this chapter.

9.2.3 QA Levels

Materials and components of the S300 are designed, procured, fabricated, assembled, and tested using a graded approach under a 10 CFR 71, Subpart H equivalent QA Program. Under that program, the categories critical to safety are established for all S300 packaging components. These defined quality categories consider the impact to safety if the component were to fail or perform outside design parameters.

Graded Quality Category A Items:

These items and services are critical to safe operation and include structures, components, and systems whose failure could directly result in a condition adversely affecting public health and safety. The failure of a single item could cause loss of primary containment leading to a release of radioactive material beyond regulatory requirements, loss of shielding beyond regulatory requirements, or unsafe geometry compromising criticality control.

Graded Quality Category B Items:

These items and services have a major impact on safety and include structures, components, and systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. The failure of a Category B item, in conjunction with the failure of an additional item, could result in an unsafe condition.

Graded Quality Category C Items:

These items and services have a minor impact on safety and include structures, components, and systems whose failure or malfunction would not significantly reduce the packaging effectiveness and would not be likely to create a situation adversely affecting public health and safety.

The CCP QAPD graded assessment results for the S300 are shown in Table 9.2-2. Table 9.2-3 identifies the level of effort for package activities appropriate for each quality category element.

Table 9.2-2 - QA Categories for Design and Procurement of S300 Subcomponents

Component	Subcomponent	Category
Shells and Heads	Pipe Flange	A
	Cylindrical Shell	A
	Pipe End Cap	A
Vessel Closure	Lid	A
	Closure Bolts	A
Seals	Containment O-Ring Seal	A
Pressure Relief Devices	Filter Vent	A
Neutron Shielding	Shield Insert Body	B
	Shield Insert Lid	B
Drum	55-Gallon Drum and Lid	B
Dunnage	Fiber board	B
	Plywood	B
Lifting Devices	Lifting Device	B
Package Hardware	Outer Rigid Polyethylene Drum Liner	C
Pressure Relief Devices	Drum Filter Vent	A
Miscellaneous	Weld Filler Metal	A
	Thread Locking Compound (optional)	C
	Vacuum Grease (optional)	C

Table 9.2-3 - Level of Quality Assurance Effort per QA Element

QA Element	Level of QA Effort	QA Category		
		A	B	C
1	QA Organization			
	• Organizational structure and authorities defined	X	X	X
	• Responsibilities defined	X	X	X
	• Reporting levels established	X	X	X
	• Management endorsement	X	X	X
2	QA Program			
	• Implementing procedures in place	X	X	
	• Trained personnel	X	X	
	• Activities controlled	X	X	
3	Design			
	• Control of design process and inputs	X	X	X
	• Control of design input	X	X	X
	• Software validated and verified	X	X	X
	• Design verification controlled	X	X	X
	• Quality category assessment performed	X	X	X
	• Definition of commercial or generic item (off-the-shelf) not related to A or B component			X
4	Procurement Document control			
	• Complete traceability	X	X	
	• Qualified suppliers list	X	X	
	• Commercial grade dedicated items acceptable	X	X	
	• Off-the-shelf item			X
5	Instructions, Procedures, and Drawings			
	• Must be written and controlled	X	X	
	• Qualitative or quantitative acceptance criteria	X	X	
6	Document Control			
	• Controlled issuance	X	X	
	• Controlled changes	X	X	
	• Procurement documents	X	X	X

QA Element	Level of QA Effort	QA Category		
		A	B	C
7	Control of Purchased Material, Equipment, and Services			
	• Source evaluation and selection plans	X	X	
	• Evidence of QA at supplier	X	X	
	• Inspections at supplier, as applicable	X	X	
	• Receiving inspection	X	X	
	• Objective proof that all specifications are met	X	X	
	• Audits/surveillances at supplier facility, as applicable	X	X	
	• Incoming inspection for damage only			X
8	Identification and Control of Material, Parts, and Components			
	• Positive identification and traceability of each item	X	X	
	• Identification and traceable to heats, lots, or other groupings	X	X	
	• Identification to end use drawings, etc.			X
9	Control of Special Processes			
	• All welding, heat treating, and nondestructive testing done by qualified personnel	X	X	
	• Qualification records and training of personnel	X	X	
	• No special processes			X
10	Inspection			
	• Documented inspection to all specifications required	X	X	
	• Examination, measurement, or test of material or processed product to assure quality	X	X	
	• Process monitoring if quality requires it	X	X	
	• Inspectors must be independent of those performing operations	X	X	X
	• Qualified inspectors only	X	X	X
	• Receiving inspection	X	X	X
11	Test Control			
	• Written test program	X	X	
	• Written test procedures for requirements in the package approval	X	X	
	• Documentation of all testing and evaluation	X	X	
	• Representative of buyer observes all supplier acceptance tests if specified in procurement documents	X		
	• No physical tests required			X

QA Element	Level of QA Effort	QA Category A	QA Category B	QA Category C
12	Control of Measuring and Test Equipment			
	• Tools, gauges, and instruments to be in a formal calibration program	X	X	
	• Only qualified inspectors	X	X	
	• No test required			X
13	Handling, Storage, and Shipping			
	• Written plans and procedures required	X	X	
	• Routine handling			X
14	Inspection, Test, and Operating Status			
	• Individual items identified as to status or condition	X	X	
	• Stamps, tags, labels, etc., must clearly show status	X	X	X
	• Visual examination only			X
15	Nonconforming Materials, Parts, or Components			
	• Written program to prevent inadvertent use	X	X	X
	• Nonconformance to be documented and closed	X	X	X
	• Disposal without records			X
16	Corrective Action			
	• Objective evidence of closure for conditions adverse to quality	X	X	X
17	QA Records			
	• Design and use records	X	X	
	• Results of reviews, inspections, test, audits, surveillance, and materials analysis	X	X	
	• Personnel qualifications	X	X	
	• Records of fabrication, acceptance, and maintenance retained throughout the life of package	X	X	X
	• Record of package use kept for three years after shipment	X	X	
	• All records managed by written plans for retention and disposal	X	X	
	• Procurement records	X	X	X
18	Audits			
	• Written plan of periodic audits	X	X	X
	• Lead auditor certified	X	X	

Upon custodianship of the S300 packages by LANL, functional classifications will be used for site operations and activities related to the S300. The method of classification is documented as follows.

The package-specific safety documents identify systems, structures, and components (SSCs) that are important to the safety functions for transportation. As appropriate, the hazard analysis and accident scenarios in the safety basis documents help identify SSCs that must function in order to prevent or mitigate these events. These SSCs are then identified using the classification system found in the NRC QA Category system provided in NRC Regulatory Guide (RG) 7.10. The categories as defined in RG 7.10, and listed below, are analogous to Safety Class, Safety Significant, and General Service that are identified for facility SSCs.

Quality Category A:

Critical impact on safety and associated functional requirements – items or components whose single failure or malfunction could directly result in an unacceptable condition of containment, shielding, or nuclear criticality control. This is functionally equivalent to “safety class” designation used for nuclear facility safety.

Quality Category B:

Impact on safety and associated functional requirement – components whose failure or malfunction in conjunction with one other independent failure or malfunction could result in an unacceptable condition of containment, shielding, or nuclear criticality control. This is functionally equivalent to “safety significant” designation used for nuclear facility safety.

Quality Category C:

Minor impact on safety and associated functional requirements – components whose failure or malfunction would not result in an unacceptable condition of containment, shielding, or nuclear criticality control regardless of other single failures. This is functionally equivalent to designations given to components that do not meet “safety class or safety significant” criteria used for nuclear facility safety.

The CCP shall assign a Design Authority (DA) who shall identify critical characteristics when they identify design attributes necessary to preserve the safety support function. As necessary, the DA also ensures critical characteristics are included in this SAR by the identification of SSCs and their QA Category designations. Additionally, this SAR shall include the safety function, design, and operational attributes necessary for reliable performance. The DA applies design criteria to the design, operation, and maintenance of each critical SSC including recommended codes and standards, as required by RG 7.10. QA requirements shall be applied as necessary to assure the SSCs can perform their function.

9.3 Package Design Control

As required by CCP-PO-002, *Transuranic Waste Certification Plan*, design processes shall be established and implemented to satisfy the requirements of CCP-PO-002, Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(f), *Criterion 6 – Performance/Design*[24]
- DOE Order 414C, CRD, Attachment 1, 2.b.(2), *Criterion 6 – Design*

Requirements are implemented to ensure processes and procedures are in place to ensure design features of packaging systems are appropriately translated into specifications, drawings, procedures, and instructions. Design control measures are established for criticality, shielding, thermal, and structural analyses under both normal and accident condition analyses as defined in DOT and NRC regulations.

The LANL/CCP will be responsible for maintaining the package and this SAR. The design documents (e.g., drawings and specifications) are controlled by incorporation into this SAR, which will be reviewed and approved by the U.S. Department of Energy – Packaging Certification Office and the NRC.

The design of the S300 will be performed under an NRC-approved QA Program as required by CCP, but is not applicable to this QA plan. Design inputs will consist of a CCP statement of work, applicable DOE orders, national standards, specifications, and drawings.

Procedures are established to control design activities to ensure that the following occur:

- Design activities will be planned, controlled, and documented.
- Regulatory requirements, design requirements, and appropriate quality standards will be correctly translated into specifications, drawings, and procedures.
- Competent engineering personnel, independent of design activities, perform design verification. Verification may include design reviews, alternate calculations, or qualification testing. Qualification tests are conducted in accordance with approved test programs or procedures.
- Design interface controls will be established and adequate.
- Design, specification, and procedure changes will be reviewed and approved in the same manner as the original issue. In a case where a proposed design change potentially affects licensed conditions, the Quality Assurance Program shall provide for ensuring that licensing considerations have been reviewed and are complied with or otherwise reconciled by amending the license.
- Design errors and deficiencies will be documented, corrected and corrective action to prevent recurrence is taken.
- Design organization(s) and their responsibilities and authorities will be delineated and controlled through written procedures.

Materials, parts, equipment, and processes essential to the function of items that are important to safety will be selected and reviewed for suitability of application.

[24] DOE, Code of Federal Regulations, 10 CFR 830.122, *Quality Assurance Criteria*, U.S. Department of Energy, Washington, D.C., 2006.

Computer programs used for design analysis or verification will be controlled in accordance with approved procedures. These procedures will provide for verification of the accuracy of computer results and for the assessment and resolution of reported computer program errors.

9.4 Procurement Document Control

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, procurement/acquisition processes and related document control activities shall be established and implemented to satisfy the requirements of CCP-PO-002, Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(d), Criterion 4 – Management/Documents and Records
- 10 CFR 830.122(g), Criterion 7 – Performance/Procurement
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), Criterion 4 – Documents and Records
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 7 – Procurement

Requirements are implemented to ensure processes and procedures are in place to ensure appropriate levels of quality are achieved in the procurement of material, equipment, and services. Quality Level and Quality Category designations assigned by the Design Authority are used to grade the application of QA requirements of procurements based on radiological material at risk, mission importance, safety of workers, public, environment, and equipment, and other differentiating criteria. Implementing procedures will provide the logic process for determining Quality Levels used in procurement of equipment and subcontracting of services. Procedures shall be in place to ensure processes address document preparation and document control, and management of records meeting regulatory requirements. Procurement records must be kept in a manner that satisfies regulatory requirements.

LANL/CCP will be responsible for initiating procurement actions for packaging and spare parts from a supplier with a 10 CFR 71, Subpart H QA Program.

Implementing procedures shall ensure that procurement documents are prepared to clearly define applicable technical and quality assurance requirements including codes, standards, regulatory requirements and commitments, and contractual requirements. These documents serve as the principal documents for the procurement of structures, systems and components, and related services for use in the design, fabrication, maintenance and operation, inspection and testing of storage and/or transportation systems. Procedures shall ensure that purchased material, components, equipment, and services adhere to the applicable requirements. Furthermore:

- The assignment of quality requirements through procurement documents is administered and controlled.
- Procurement activities are performed in accordance with approved procedures delineating requirements for preparation, review, approval, and control of procurement documents. Revisions to procurement documents are reviewed and approved by the same cognizant groups as the original document.
- Quality requirements are included in quality-related purchase orders as applicable to the scope of the procurement referencing 10 CFR 71, Subpart H or other codes and standards, as appropriate.

- LANL/CCP procurement documents will require suppliers to convey appropriate quality assurance program requirements to sub-tier suppliers.
- LANL/CCP procurement documents will include provisions that suppliers either maintain or supply those QA records which provide evidence of conformance to the procurement documents. Additionally, procurement documents shall designate the supplier documents required for submittal to LANL/CCP for review and/or approval.
- LANL/CCP shall maintain the right of access to supplier facilities and performance of source surveillance and/or audit activities, as applicable. A statement to this effect is to be included in procurement documents.

Procurement documents shall also address the applicability of the provisions of 10 CFR 21 for the Reporting of Defects and Noncompliances.

9.5 Instructions, Procedures, And Drawings

As required by the CCP-PO-002, *Transuranic Waste Certification Plan,* instructions, procedures, and drawing work processes and applicable quality improvement activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(c), Criterion 3 – Management/Quality Improvement
- 10 CFR 830.122(e), Criterion 5 – Performance/Work Processes
- DOE Order 414C, CRD, Attachment 1, 2.a.(3), Criterion 3 – Quality Improvement
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), Criterion 5 – Work Processes

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. The program shall ensure processes and procedures in place to identify and correct problems associated with transportation and packaging activities.

Implementing procedures shall be established to ensure that methods for complying with each of the applicable criteria of 10 CFR 71, Subpart H; 10 CFR 72, Subpart G; 10 CFR 50, Appendix B, or ASME Section III, as applicable, for activities affecting quality during design, fabrication, inspection, testing, use and maintenance are specified in instructions, procedures, and/or drawings. In addition:

- Instructions, procedures, and drawings shall be developed, reviewed, approved, utilized, and controlled in accordance with the requirements of approved procedures. These instructions, procedures, and drawings shall include appropriate quantitative and qualitative acceptance criteria.
- Changes to instructions, procedures and drawings, are developed, reviewed, approved, utilized and controlled using the same requirements and controls as applied to the original documents.
- Compliance with these approved instructions, procedures and drawings is mandatory for LANL/CCP personnel while performing activities affecting quality.

Specific activities by LANL/CCP regarding preparation of packaging for use, repair, rework, maintenance, loading contents, unloading contents, and transport, must be accomplished in accordance with written and approved instructions, procedures, specifications, and/or drawings. These documents must identify appropriate inspection and hold points and emphasize those characteristics that are important to safety and quality. Transportation package procedures are to be developed and reviewed by technical and quality staff and shall be approved by appropriate levels of management.

9.5.1 Preparation and Use

Activities concerning loading and shipping are performed in accordance with written operating procedures developed by the user and approved by the package custodian. Packaging first-time usage tests, sequential loading and unloading operations, technical constraints, acceptance limits, and references are specified in the procedures. A pre-planned and documented inspection will be conducted to ensure that each loaded package is ready for delivery to the carrier.

9.5.2 Operating Procedure Changes

Changes in operating procedures that affect the process must be approved at the same supervisory level as the initial issue.

9.5.3 Drawings

Controlled drawings are shown in Appendix 1.3.1, *Packaging General Arrangement Drawings*, of this SAR. Implementation of design revisions is discussed in SAR Section 9.3, *Package Design Control*.

9.6 Document Control

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, document control activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(d), Criterion 4 – Management/Documents and Records
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), Criterion 4 – Documents and Records

Requirements are implemented to ensure processes and procedures are in place to address document, document control, and for the management of records. Records (engineering, test reports, user instructions, etc.) must be maintained in a manner that conforms to regulatory requirements.

Document control activities related to the design, procurement, fabrication, and testing of S300 components; and SAR preparation shall be controlled.

Implementing procedures shall be established to control the issuance of documents that prescribe activities affecting quality and to assure adequate review, approval, release, distribution, use of documents and their revisions. Controlled documents may include, but are not limited to:

- Design specifications

- Design and fabrication drawings
- Special process specifications and procedures
- QA Program Manuals/Plans, etc.
- Implementing procedures
- Test procedures
- Operational test procedures and data.

Requirements shall ensure changes to documents, which prescribe activities affecting quality, are reviewed and approved by the same organization that performed the initial review and approval, or by qualified responsible organizations. Documents that prescribe activities affecting quality are to be reviewed and approved for technical adequacy and inclusion of appropriate quality requirements prior to approval and issuance. Measures are taken to ensure that only current documents are available at the locations where activities affecting quality are performed prior to commencing the work.

Package users are responsible for establishment, development, review, approval, distribution, revision, and retention of their documents. Documents requiring control, the level of control, and the personnel responsibilities and training requirements are to be identified.

Packaging documents to be controlled include as a minimum:

- Operating procedures
- Maintenance procedures
- Inspection and test procedures
- Loading and unloading procedures
- Preparation for transport procedures
- Repair procedures
- Specifications
- Fabrication records
- Drawings of packaging and components
- SAR and occurring supplements

Revisions are handled in a like manner as the original issue. Only the latest revisions must be available for use.

Documentation received from the supplier for each package must be filed by package serial number. These documents are to be retained in the user’s facility.

9.7 Control Of Purchased Material, Equipment And Services

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, the control of purchased material, equipment and services and applicable quality improvement activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(c), Criterion 3 – Management/Quality Improvement
- 10 CFR 830.122(g), Criterion 7 – Performance/Procurement
- 10 CFR 830.122(h), Criterion 8 – Performance/Inspection and Acceptance Testing
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 3 – Quality Improvement
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 7 – Procurement
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), Criterion 8 – Inspection and Acceptance Testing

Requirements are implemented to ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc. Requirements shall ensure processes and procedures are in place such that appropriate levels of quality are achieved in the procurement of material, equipment, and services. Quality Level and Quality Category designations by the Design Authority are used to grade the application of QA requirements of procurements based on radiological material at risk, mission importance, safety of workers, public, environment, and equipment, and other differentiating criteria. Requirements shall ensure processes and procedures in place to identify and correct problems associated with transportation and packaging activities.

Activities related to the control of purchased material, equipment and services shall be controlled. Control of purchased material, equipment, and services consist of the following elements:

- Implementing procedures shall be established to assure that purchased material, equipment and services conform to procurement documents.
- Procurement documents shall be reviewed and approved by authorized personnel for acceptability of proposed suppliers based on the quality requirements of the item/activity being purchased.
- As required, audits and/or surveys are conducted to determine supplier acceptability. These audits/surveys are based on one or all of the following criteria: the supplier's capability to comply with the requirements of 10 CFR 71, Subpart H; 10 CFR 50, Appendix B, or ASME Section III that are applicable to the scope of work to be performed; a review of previous records to establish the past performance of the supplier; and/or a survey of the supplier's facilities and review of the supplier's QA Program to assess adequacy and verify implementation of quality controls consistent with the requirements being invoked.

- Qualified personnel shall conduct audits and surveys. Audit/survey results are to be documented and retained as Quality Assurance Records. Suppliers are re-audited and/or re-evaluated at planned intervals to verify that they continue to comply with quality requirements and to assess the continued effectiveness of their QA Program. Additionally, interim periodic evaluations are to be performed of supplier quality activities to verify implementation of their QA Program.
- Suppliers are required to provide objective evidence that items or services provided meet the requirements specified in procurement documents. Items are properly identified to appropriate records that are available to permit verification of conformance with procurement documents. Any procurement requirements not met by suppliers shall be reported to LANL/CCP for assessment of the condition. These conditions are reviewed by technical and quality personnel to assure that they have not compromised the quality or service of the item.
- Periodic surveillance of supplier in-process activities is performed as necessary, to verify supplier compliance with the procurement documents. When deemed necessary, the need for surveillance is noted in approved quality or project planning documents. Surveillances are to be performed and documented in accordance with approved procedures. Personnel performing surveillance of supplier activities are to be trained and qualified in accordance with approved procedures.
- Quality planning for the performance of source surveillance, test, shipping and/or receiving inspection activities to verify compliance with approved design and licensing requirements, applicable 10 CFR 71, 10 CFR 50 criteria, procurement document requirements, or contract specifications is to be performed in accordance with approved procedures.
- For commercial "off-the-shelf" items, where specific quality controls appropriate for nuclear applications cannot be imposed in a practical manner, additional quality verification shall be performed to the extent necessary to verify the acceptability and conformance of an item to procurement document requirements. When dedication of a commercial grade item is required for use in a quality-related application, such dedication shall be performed in accordance with approved procedures.

To ensure compliance with procurement requirements, control measures shall include verification of supplier capability and verification of item or service quality. Procurements of S300 components are required to be placed with pre-qualified and selected vendors. The vendor's QA Plan must address the requirements of 10 CFR 71, Subpart H and defined requirements. A graded approach is used based on the QA Levels established in Table 9.2-2.

The approach used to control the procurement of items and services must include the following:

- Source evaluation and selection
- Evaluation of objective evidence of quality furnished by the supplier
- Source inspection
- Audit
- Examination of items or services upon delivery or completion.

9.8 Identification And Control Of Material, Parts And Components

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, activities concerning the identification and control of material, parts, and components shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(e), Criterion 5 – Performance/Work Processes
- 10 CFR 830.122(g), Criterion 7 – Performance/Procurement
- 10 CFR 830.122(h), Criterion 8 – Performance/Inspection and Acceptance Testing
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), Criterion 5 – Work Processes
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 7 – Procurement
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), Criterion 8 – Inspection and Acceptance Testing

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. The program also ensures processes and procedures are in place such that appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, and components. The program shall ensure processes and procedures are in place to ensure appropriate levels of quality are achieved in the procurement of material, equipment, and services.

Activities related to the identification and control of material, parts and components shall be controlled. The requirements for identification and control of material, parts, and components consist of the following elements:

- Implementing procedures are established to identify and control materials, parts, and components. These procedures assure identification of items by appropriate means during fabrication, installation, and use of the items and prevent the inadvertent use of incorrect or defective items.
- Requirements for identification are established during the preparation of procedures and specifications.
- Methods and location of identification are selected to not adversely affect the quality of the item(s) being identified.
- Items having limited shelf or operating life are controlled to prevent their inappropriate use.

Control and identification must be maintained either directly on the item or within documents traceable to the item to ensure that only correct and acceptable items are used. When physical identification is not practical, other appropriate means of control must be established such as bagging, physical separation, or procedural control. Each packaging unit shall be assigned a unique serial number after fabrication or purchase. All documentation associated with subsequent storage, use, maintenance, inspection, acceptance, etc., must refer to the assigned serial number. Verification of acceptance status is required prior to use. Items that are not acceptable must be controlled accordingly. Control of nonconforming items is addressed in SAR Section 9.15, *Nonconforming Parts, Materials, or Components*.

Each S300 package will be conspicuously and durably marked with information identifying the package owner, model number, unique serial number, and package gross weight, in accordance with 10 CFR 71.85(c).

Replacement parts must be identified to ensure correct application. Minute items must be individually packaged and marked with material certification, size, cure date, and shelf life, as appropriate. Replacement bolts must be source traceable, certified, marked to reflect their American Society for Testing and Materials (ASTM) or ASME designation, and segregated from other materials and fasteners to prevent misuse or installation of unacceptable bolts. Items that have limited calendar-life cycles, operating-life cycles, or shelf life must be controlled to preclude the use of expired items. Processes shall be in place to replace aging items before failure or expiration.

Assessment of the S300 packaging parts according to safety significance is shown in Table 9.2-2.

9.9 Control Of Special Processes

As required by the CCP-PO-002, *Transuranic Waste Certification Plan,* activities for the control of special processes shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CRF 830.122(b), Criterion 2 – Management/Personnel Training and Qualifications
- 10 CFR 830.122(e), Criterion 5 – Performance/Work Processes
- 10 CFR 830.122(g), Criterion 7 – Performance/Procurement
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), Criterion 2 - Personnel Training and Qualifications
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), Criterion 5 – Work Processes
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 7 – Procurement

Requirements will be implemented to ensure only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities related to the control of special processes shall be controlled. The requirements for control of special processes consist of the following elements:

- Implementing procedures shall be established to control special processes used in the fabrication and inspection of storage/transport systems. These processes may include welding, non-destructive examination, or other special processes as identified in procurement documents.

- Special processes are performed in accordance with approved procedures.
- Personnel who perform special processes are to be trained and qualified in accordance with applicable codes, standards, specifications, and/or other special requirements. Records of qualified procedures and personnel are to be maintained and kept current by the organization that performs the special processes.

Package users are responsible to ensure special processes for welding and nondestructive examination of the S300 during fabrication, use, and maintenance are controlled. Equipment used in conduct of special processes must be qualified in accordance with applicable codes, standards, and specifications. Special process operations must be performed by qualified personnel and accomplished in accordance with written process sheets or procedures with recorded evidence of verification when applicable. Qualification records of special process procedures, equipment, and personnel must be maintained.

Welders, weld procedures, and examination personnel are to be qualified in accordance with the appropriate articles of ASME BPVC, Section III,[25] Subsections NB (for containment components) and NG (for criticality control components); ASME BPVC, Section IX, "Welding and Brazing Qualifications";[26] and ASME BPVC, Section V, "Nondestructive Examination."[27]

Containment vessel and criticality control component structural welds must be examined by nondestructive methods using radiography and dye penetrant techniques and must meet the requirements of the ASME BPVC as cited on the design drawings.

Special processes for QA Level A and B items must be performed by qualified personnel in accordance with documented and approved procedures. Applicable special processes performed by an outside supplier such as welding, plating, anodizing, and heat treating, which are controlled by the suppliers' quality program, are reviewed and/or witnessed in accordance with procurement requirements.

9.10 Internal Inspection

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, internal inspection activities shall be established to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CRF 830.122(b), *Criterion 2 – Management/Personnel Training and Qualifications*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), *Criterion 2 - Personnel Training and Qualifications*

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[25] ASME, 2004, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Power Plant Components*, American Society of Mechanical Engineers, New York, NY

[26] ASME, 2004, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section IX, *Welding and Brazing Qualifications*, American Society of Mechanical Engineers, New York, NY

[27] ASME, 2004, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, American Society of Mechanical Engineers, New York, NY

- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing*

Requirements are implemented to ensure only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

Activities related to internal inspection shall be controlled. The program requirements for control of internal inspection consist of the following elements:

- Implementing procedures shall be established to assure that inspection or surveillance is performed to verify that materials, parts, processes, or other activities affecting quality conform to documented instructions, procedures, specifications, drawings, and/or procurement documents.
- Personnel performing inspection and surveillance activities shall be trained and qualified in accordance with written approved procedures.
- Inspections and surveillances are to be performed by individuals other than those who performed or supervised the subject activities.
- Inspection or surveillance and process monitoring are both required where either one, by itself, will not provide assurance of quality.
- Modifications and/or repairs to and replacements of safety-related and important-to-safety structures, systems, and components are inspected in accordance with the original design and inspection requirements or acceptable alternatives.
- Mandatory hold points, inspection equipment requirements, acceptance criteria, personnel qualification requirements, performance characteristics, variable and/or attribute recording instructions, reference documents, and other requirements are considered and included, as applicable, during inspection and surveillance planning.

9.10.1 Inspections During Fabrication

Specific inspection criteria are incorporated into the drawings (see Appendix 1.3.1, *Packaging General Arrangement Drawings* of this SAR) for the S300 packaging. Inspection requirements for fabrication are divided into two responsible areas that document that an accepted S300 package conforms to tested and certified design criteria. These two areas are:

- In-process inspections performed by the fabricator.
- Independent surveillance of fabrication activities performed by individuals acting on behalf of the purchaser.

The vendor (fabricator) is required to submit a Manufacturing/Fabrication Plan prior to the start of fabrication for approval by the customer. This plan shall be used as a tool for establishing witness and hold points. A review for compliance with procurement documents is normally performed as part of the surveillance function at the vendor's facility. The plan shall define how fabrications and inspections are to be performed, processes to be engaged, and qualification requirements for personnel. Inspections must be documented and records delivered in individual data packages accompanying the package in accordance with the procurement specification.

Independent surveillance activities will be performed by qualified personnel selected with approval of the customer.

9.10.2 Inspections During Initial Acceptance and During Service Life

Independent inspections are performed upon receipt of the S300 packaging prior to first usage (implemented by package user procedures) and on an annual basis. Post-loading inspections are also performed prior to shipment. Inspection to be implemented by the package user (by qualified independent inspection personnel) must include the following:

- Acceptance – Ensure compliance with procurement documents. Per Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR, perform (as applicable) first-time-usage inspections, weld examinations, pressure tests, structural tests, foam tests, and leakage rate tests with the use of approved procedures that implement the requirements of ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment.*[28]
- Operation – Verify proper assembly and verify that post-load leak testing (if applicable) is carried out as discussed in Chapter 7, *Package Operations*, of this SAR.
- Maintenance – Ensure adequate packaging maintenance to ensure that performance is not impaired as discussed in Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR.
- Final – Verify proper contents, assembly, marking, shipping papers, and implementation of any special instructions.

9.11 Test Control

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, test control activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities related to test control shall be controlled. The requirements for test control consist of the following elements:

[28] ANSI, ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standard Institute, Inc., New York, NY, 1998.

- Implementing procedures shall be established to assure that required proof, acceptance, and operational tests, as identified in design or procurement documents, are performed and appropriately controlled.
- Test personnel shall have appropriate training and shall be qualified for the level of testing which they are performing. Personnel shall be qualified in accordance with approved, written instructions, procedures, and/or checklists.
- Tests are performed by qualified personnel in accordance with approved, written instructions, procedures, and/or checklists. Test procedures are to contain or reference the following information, as applicable:
  - Acceptance criteria contained in the applicable test specifications, or design and procurement documents.
  - Instructions for performance of tests, including environmental conditions.
  - Test prerequisites such as test equipment, instrumentation requirements, personnel qualification requirements, fabrication, or operational status of the items to be tested.
  - Provisions for data recording and records retention.
- Test results are to be documented and evaluated to ensure that acceptance criteria have been satisfied.
- Tests to be conducted after modifications, repairs, or replacements of safety-related and important-to-safety structures, systems, or components are to be performed in accordance with the original design and testing requirements or acceptable alternatives.

Tests are required when it is necessary to demonstrate that an item or process will perform satisfactorily. Test procedures must specify the objectives of the tests, testing methods, required documentation, and acceptance criteria. Tests to be conducted by vendors at vendor facilities must be specified in procurement documents. Personnel conducting tests, test equipment, and procedures must be qualified and records attesting to qualification retained.

9.11.1 Acceptance and Periodic Tests

- The fabricator must supply QA documentation for the fabrication of each S300 packaging in accordance with applicable drawings, specifications, and/or other written requirements.
- The package user must ensure required S300 packaging pressure tests, structural tests, foam tests, or leakage rate tests, as applicable, are performed prior to first usage.
- Periodic testing, as applicable, will be performed to ensure the S300 packaging performance has not deteriorated with time and usage. The requirements for the periodic tests are given in the Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR. The results of these tests are required to be documented and maintained with the specific packaging records by the package user.

9.11.2 Packaging Nonconformance

Packaging that does not meet the inspection criteria shall be marked or tagged as nonconforming, isolated, and documented in accordance with Section 9.15, *Nonconforming Parts, Materials, or Components*. The packaging must not be used for shipment until the nonconformance report has been properly dispositioned in accordance with Section 9.15.

9.12 Control Of Measuring And Test Equipment

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, activities pertaining to the control of measuring and test equipment shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing*

Requirements are implemented to ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

Activities pertaining to the control of measuring and test equipment shall be controlled. The requirements for control of measuring and test equipment shall consist of the following elements:

- Implementing procedures shall be established to assure that tools, gages, instruments and other measuring and testing devices (M&TE) used in activities affecting quality are properly controlled, calibrated and adjusted to maintain accuracy within required limits.
- M&TE are calibrated at scheduled intervals against certified standards having known valid relationships to national standards. If no national standards exist, the basis for calibration shall be documented. Calibration intervals are based on required accuracy, precision, purpose, amount of use, stability characteristics and other conditions that could affect the measurements.
- Calibrations are to be performed in accordance with approved written procedures. Inspection, measuring and test equipment are to be marked to indicate calibration status.
- M&TE are to be identified, labeled or tagged indicating the next required calibration due date, and traceable to calibration records.
- If M&TE is found to be out of calibration, an evaluation shall be performed and documented regarding the validity of inspections or tests performed and the acceptability of items inspected or tested since the previous acceptable calibration. The current status of M&TE is to be recorded and maintained. Any M&TE that is consistently found to be out of calibration shall be repaired or replaced.

Special calibration and control measures on rules, tape measures, levels and other such devices are not required where normal commercial practices provide adequate accuracy.

9.13 Handling, Storage, And Shipping Control

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, handling, storage, and shipping control activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(e), Criterion 5 – Performance/Work Processes
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), Criterion 5 – Work Processes

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities pertaining to handling, storage, and shipping shall be controlled. The requirements for handling, storage, and shipping control consist of the following elements:

- Implementing procedures shall be established to assure that materials, parts, assemblies, spare parts, special tools, and equipment are handled, stored, packaged, and shipped in a manner to prevent damage, loss, loss of identity, or deterioration.
- When necessary, storage procedures address special requirements for environmental protection such as inert gas atmospheres, moisture control, temperature levels, etc.

Package users shall ensure that components associated with the S300 are controlled to prevent damage or loss, protected against damage or deterioration, and provide adequate safety of personnel involved in handling, storage, and shipment (outgoing and incoming) operations. Handling, storage, and shipping must be accomplished in accordance with written and approved instructions, procedures, specifications, and/or drawings. These documents must identify appropriate information regarding shelf life, environment, temperature, cleaning, handling, and preservation, as applicable, to meet design, regulatory, and/or DOE shipping requirements.

Preparation for loading, handling, and shipment will be done accordance with approved procedures to ensure that all requirements have been met prior to delivery to a carrier. A package ready for shipment must conform to its shipping paper. Specific handling precautions for the S300 are given in Chapter 7, *Package Operations* of this SAR.

Empty packages, following usage, must be checked and decontaminated if required. Each package must be inspected, reconditioned, or repaired, as appropriate, in accordance with approved written procedures before storing or loading. Empty S300 packagings are to be tagged with “EMPTY” labels and stored in designated protected areas in order to minimize environmental effects on the containers. New and unused S300 packagings do not require an “EMPTY” label.

Routine maintenance on the S300 packaging may be performed as deemed necessary by package users and is limited to cleaning, rust removal, painting, light metal working to restore the original contours and replacement of damaged, worn, or malfunctioning components. Spare components, such as bolts, will be placed in segregated storage to maintain proper identification and to avoid misuse. Specific maintenance precautions for the S300 are given in Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR.

9.14 Inspection, Test, And Operating Status

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, inspection, test, and operating status activities shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. In addition, processes and procedures shall be in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

Activities pertaining to inspection, test, and operating status activities shall be controlled. The requirements for inspection, test, and operating status consist of the following elements:

- Implementing procedures shall be established to assure that the inspection and test status of materials, items, structures, systems, and components throughout fabrication, installation, operation, and test are clearly indicated by suitable means, (e.g., tags, labels, cards, form sheets, check lists, etc.).
- Bypassing of required inspections, tests, or other critical operations is prevented through the use of approved instructions or procedures
- As appropriate, the operating status of nonconforming, inoperative or malfunctioning components of a storage/transport system (e.g., valves, switches, etc.) is indicated to prevent inadvertent operation. The application and removal of status indicators is performed in accordance with approved instructions and procedures.
- Any nonconforming items are identified and controlled in accordance with Section 9.15, *Nonconforming Parts, Materials, or Components*, of this SAR.

Package users shall ensure that the status of inspection and test activities are identified on the item or in documents traceable to the item to ensure that proper inspections or tests have been performed and that those items that do not pass inspection are not used. The status of fabrication, inspection, test, assembly, and refurbishment activities must be identified in documents traceable to the package components.

Measures established in specifications, procedures, and other instructions shall ensure that the following objectives are met:

- QA personnel responsible for oversight of packaging inspections can readily ascertain the status of inspections, tests, and/or operating conditions.
- No controlled items are overlooked.

- Inadvertent use or installation of unqualified items is prevented.
- Documentation is complete.

9.15 Nonconforming Materials, Parts, Or Components

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, control of nonconforming materials, parts, or components shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(c), Criterion 3 – Management/Quality Improvement
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 3 – Quality Improvement

Requirements are implemented to ensure that processes and procedures are in place to identify and correct problems associated with transportation and packaging activities.

Activities pertaining to the control of nonconforming materials, parts, or components shall be controlled. The requirements for nonconforming materials, parts, or components consist of the following elements:

- Implementing procedures shall be established to control materials, parts, and components that do not conform to requirements to prevent their inadvertent use during fabrication or during service.
- Nonconforming items include those items that do not meet specification or drawing requirements. Additionally, nonconforming items include items not fabricated or tested (1) in accordance with approved written procedures, (2) by qualified processes, or (3) by qualified personnel; where use of such procedures, processes, or personnel is required by the fabrication, test, inspection, or quality assurance requirements.
- Nonconforming items are identified and/or segregated to prevent their inadvertent use until properly dispositioned. The identification of nonconforming items is by marking, tagging, or other methods that do not adversely affect the end use of the item. The identification shall be legible and easily recognizable. When identification of each nonconforming item is not practical, the container, package, or segregated storage area, as appropriate, is identified.
- Nonconforming conditions are documented in NCRs and affected organizations are to be notified. The nonconformance report shall include a description of the nonconforming condition. Nonconforming items are dispositioned as use-as-is, reject, repair, or rework.
- Inspection or surveillance requirements for nonconforming items following rework, repair, or modification are detailed in the nonconformance reports and approved following completion of the disposition.
- Acceptability of rework or repair of nonconforming materials, parts, and components is verified by re-inspecting and/or re-testing the item to the original requirements or equivalent inspection/testing methods. Inspection, testing, rework, and repair methods are to be documented and controlled.

- The disposition of nonconforming items as use-as-is or repair shall include technical justification and independent verification to assure compliance with design, regulatory, and contractual requirements.
- Items dispositioned as rework or repair are reinspected and retested in accordance with the original inspection and test requirements or acceptable alternatives that comply with the specified acceptance criteria.
- When specified by contract requirements, nonconformances that result in a violation of client contract or specification requirements are to be submitted for client approval.
- Nonconformance reports are made part of the inspection records and are periodically reviewed to identify quality trends. Unsatisfactory quality trends are documented on a Corrective Action Report (CAR) as detailed in Section 9.16, *Corrective Action*, of this SAR. The results of these reviews are to be reported to management.
- Nonconformance reports relating to internal activities are issued to management of the affected organization. The appropriate Quality Assurance Manager shall approve the disposition and performs follow-up activities to assure proper closure.
- Compliance with the evaluation and reporting requirements of 10 CFR 21 related to defects and noncompliances are to be controlled by approved procedures.

9.16 Corrective Action

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, requirements for corrective action shall be established and implemented to satisfy the requirements Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(c), Criterion 3 – Management/Quality Improvement
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), Criterion 3 – Quality Improvement

Requirements are implemented to ensure that processes and procedures are in place to identify and correct problems associated with transportation and packaging activities.

Activities pertaining to corrective actions shall be controlled. The requirements for corrective action consist of the following elements:

- Implementing procedures shall be established to identify significant conditions adverse to quality. Significant and/or repetitive failures, malfunctions and deficiencies in material, components, equipment, and operations are to be promptly identified and documented on a Corrective Action Reports (CARs) and reported to appropriate management. The cause of the condition and corrective action necessary to prevent recurrence are identified, implemented, and followed up to verify corrective action is complete and effective.
- The SPQAO is responsible for ensuring implementation of the corrective action program, including follow up and closeout actions. The SPQAO may delegate certain activities in the Corrective Action process to others.

9.17 Quality Assurance Records

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, activities associated with QA records shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CRF 830.122(b), Criterion 2 – Management/Personnel Training and Qualifications
- 10 CFR 830.122(d), Criterion 4 – Management/Documents and Records
- 10 CFR 830.122(e), Criterion 5 – Performance/Work Processes
- 10 CFR 830.122(h), Criterion 8 – Performance/Inspection and Acceptance Testing
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), Criterion 2 - Personnel Training and Qualifications
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), Criterion 4 – Documents and Records
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), Criterion 5 – Work Processes
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), Criterion 8 – Inspection and Acceptance Testing

Requirements are implemented to ensure that only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place to address document preparation, document control, and management of records. In addition, the program ensures processes and procedures are in place which achieves quality objectives and appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. Finally, the program ensures processes and procedures are in place to identify appropriate inspections and tests are applied prior to acceptance or use of the package or component, and to identify the status of packaging items, components, etc.

Quality assurance records shall be controlled. The requirements for quality assurance records consist of the following elements:

- Implementing procedures shall be established to assure control of quality records. The purpose of the Quality Assurance Records system is to assure that documented evidence relative to quality related activities is maintained and available for use by LANL/CCP, its customers, and/or regulatory agencies, as applicable.
- Approved procedures identify the types of documents to be retained as QA records, as well as those to be retained by the originating organization. Lifetime and Non-Permanent records are retained by CCP or its customers, as appropriate. Records are identified, indexed, and stored in accessible locations.
- QA Records are maintained for periods specified to furnish evidence of activities affecting the quality of structures, systems, and components that are safety-related or important-to-safety. These records include records of design, procurement, fabrication, assembly, inspection, and testing.
- Maintenance, records shall include the use of operating logs; results of reviews, inspections, tests, and audits; results from monitoring of work performance and material

analyses; results of maintenance, modification, and repair activities; qualification of personnel, procedures, and equipment; records of calibration of measuring and test equipment; and related instructions, procedures, and drawings.

- Requirements for indexing, record retention period, storage method(s) and location(s), classification, preservation measures, disposition of nonpermanent records, and responsibility for safekeeping are specified in approved procedures. Record storage facilities are established to prevent destruction of records by fire, flood, theft, and deterioration due to environmental conditions (such as temperature, humidity, or vermin). As an alternative, two identical sets of records (dual storage) may be maintained at separate locations.
- LANL/CCP shall retain required records for at least three (3) years beyond the date of last engagement of activities.

9.17.1 General

Sufficient records must be maintained by package users to furnish evidence of quality of items and of activities affecting quality. QA records that must be retained for the lifetime of the packaging include:

- Appropriate production-related records that are generated throughout the package manufacturing and fabrication process
- Records demonstrating evidence of operational capability; e.g., completed acceptance tests and inspections
- Records verifying repair, rework, and replacement
- Audit reports, and corrective actions
- Records that are used as a baseline for maintenance
- Records showing evidence of delivery of packages to a carrier and proof that all DOT requirements were satisfied.

9.17.2 Generating Records

Package user documents designated as QA records must be:

- Legible
- Completed to reflect the work accomplished and relevant results or conclusions
- Signed and dated or otherwise authenticated by authorized personnel.

QA records should be placed in a records storage area as soon as is feasible to avoid loss or damage. Individual package QA records must be generated and maintained for each package by the package serial number.

9.17.3 Receipt, Retrieval, and Disposition of Records

The CCP has overall responsibility for records management for the S300. Package users are responsible for maintaining records while they are in process and for providing completed records to the CCP Document Control. A receipt control system shall be established, and records maintained in-house or at other locations are to be identifiable and retrievable and not disposed of until prescribed conditions are satisfied.

Records are to be available for inspection upon request.

Table 9.17-1 - Quality Assurance Records

Quality Assurance Record	Retention period
Design and Fabrication Drawings	LOP+
Test Reports	LOP+
Independent Design Review Comments	LOP+
Safety Analysis Report for Packaging	LOP+
Vendor Manufacturing and Inspection Plan	LOP+
Material Test Report of Certification of Materials	LOP+
Welding Specifications and Procedures	LOP+
Procedure Qualification Record	LOP+
Welder or Welding Operator Qualification Tests	LOP+
Record of Qualification of Personnel Performing Radiographic and PT Reports	LOP+
Weld Radiographs	LOP+
Liquid Penetrant Reports	LOP+
Dimensional Inspection Report for All Features	LOP+
Structural Test Reports (by Vendor)	LOP+
Leakage Test Reports (by Vendor and annual)	LOP+
Leakage Test Reports (Acceptance)	LOP+
Visual and Dimensional Inspection upon Receipt of Packaging	LOP+
Leak Testing Personnel Qualification Records	S+
Package Loading Procedure	S+
Leak Test Results (post loading)	S+
Unloading Procedure	S+
Preparation of Empty Package for Transport	S+
Maintenance Procedures	LOP+
Repair Procedures	LOP+
Procurement Specifications	LOP+
Audit Reports	LOP+
Personnel Training and Qualification Documentation	LOP+
Maintenance Log	LOP+

Corrective Action Reports	LOP+
Nonconformance Reports (and resolutions)	LOP+
Incident Reports per 10 CFR 71.95	LOP+
Preliminary Determinations per 10 CFR 71.85	S+
Routine Determinations per 10 CFR 71.87	S+
Shipment Records per 10 CFR 71.91(a), (b), (c), (d)	S+
LOP+ Lifetime of packaging plus 3 years S+ Shipping date plus 3 years	

9.18 Audits

As required by the CCP-PO-002, *Transuranic Waste Certification Plan*, audit requirements shall be established and implemented to satisfy the requirements of Section 4.0. These requirements are to be in accordance with:

- 10 CFR 830.122(i), Criterion 9 – Assessment/Management Assessment
- 10 CFR 830.122(j), Criterion 10 – Assessment/Independent Assessment
- DOE Order 414C, CRD, Attachment 1, 2.c.(1), Criterion 9 – Management Assessment
- DOE Order 414C, CRD, Attachment 1, 2.c.(2), Criterion 10 – Independent Assessment

Requirements are implemented to ensure management assessments are performed on a regular basis. Management assessments are planned and conducted in accordance with written procedures. In addition, the program will be independently assessed periodically in accordance with procedures.

Activities pertaining to audits and assessments shall be controlled. The requirements for audits and assessments consist of the following elements:

- Implementing procedures shall be established to assure that periodic audits verify compliance with all aspects of the Quality Assurance Program and determine its effectiveness. Areas and activities to be audited, such as design, procurement, fabrication, inspection, and testing of storage/transportation systems, are to be identified as part of audit planning.
- CCP audits supplier Quality Assurance Programs, procedures, and implementation activities to evaluate and verify that procedures and activities are adequate and comply with applicable requirements.
- Audits are planned and scheduled in a manner to provide coverage and coordination with ongoing Quality Assurance Program activities commensurate with the status and importance of the activities.
- Audits are performed by trained and qualified personnel not having direct responsibilities in the areas being audited and are conducted in accordance with written plans and checklists. Audit results are documented and reviewed by management having responsibility for the area audited. Corrective actions and schedules for implementation

are established and recorded. Audit reports include an objective evaluation of the quality-related practices, procedures, and instructions for the areas or activities being audited and the effectiveness of implementation.

- Responsible management shall undertake corrective actions as a follow-up to audit reports when appropriate. The SPQAO shall evaluate audit results for indications of adverse trends that could affect quality. When results of such assessments so indicate, appropriate corrective action will be implemented.

The SPQAO shall follow up on audit findings to assure that appropriate corrective actions have been implemented and directs the performance of re-audits when deemed necessary.