Department of Energy
Washington, DC 20585

SAFETY EVALUATION REPORT

for the SAFESHIELD 2999A Packaging

Docket 99-7-9519

Prepared by: James M. Shuler
James M. Shuler
Health Physicist
Office of Licensing, EM-24

Date: 10/5/5

Approved by:
Mark A. Gilbertson
Headquarters Certifying Official
Deputy Assistant Secretary for
Environmental Cleanup and Acceleration
Office of Environmental Management

Date: 10/12/05

SAFETY EVALUATION REPORT
for the SAFESHIELD 2999A Packaging

Docket 99-7-9519

SUMMARY

Based on the statements and representations in the Safety Analysis Report for Packaging (SARP) and the staff's confirmatory evaluation, the staff concludes that the design and performance of the SAFESHIELD 2999A package meets the requirements of DOE Order 460.1B, 10 CFR Part 71, and 49 CFR Part 173. ***Four issues identified at the end of Sections 1 and 7 of this Safety Evaluation Report (SER) should be addressed and documented in the next revision of the SARP.***

REFERENCE

"Safety Analysis Report for Packaging, SAFESHIELD 2999A, Package Docket 99-7-9519," SARP 2999A, Rev. 4, July 4, 2005, Los Alamos National Laboratory.

CONTAINER MODEL AND TYPE

The SAFESHIELD 2999A packaging consists of a lead-alloy-shielded containment vessel (Flask 2993) carried in an outer, double-skinned, insulated casket. The SAFESHIELD 2999A packaging is designed to transport radioactive material in special form capsules; welded capsules not classified as special form; accelerator targets containing solid, liquid metal, and gaseous radioactive material; stainless steel canister containing ion exchange resins with adsorbed radioactive material; and aluminum canister containing radioactive waste material. The packaging is classified as a Type B(U)-96, Category I container. Each fabricated SAFESHIELD 2999A packaging will be identified with a unique serial number that will be reported to the DOE Headquarters Certifying Official.

DRAWINGS

The SAFESHIELD 2999A packaging design is defined by the following Croft Associates Ltd. drawing lists, which in turn identify the individual design drawings:

DL-1C-4540, Sheet 1/1, Issue E	Drawing List for Packaging Design No. 2999A
DL-0C-4490, Sheet 1/3, Issue E	Drawing List for Flask Design No. 2993
DL-0C-4490, Sheet 2/3, Issue E	“ “
DL-0C-4490, Sheet 3/3, Issue D	“ “
DL-1C-4511, Sheet 1/3, Issue D	Drawing List for Casket GA Design No. 2999
DL-1C-4511, Sheet 2/3, Issue C	“ “
DL-1C-4511, Sheet 3/3, Issue D	“ “
DL-2C-5449, Sheet 1/1, Issue A	Drawing List for Target Capsule Design No. 3963

1. GENERAL INFORMATION AND DRAWINGS

The general information and drawings presented in the reference were reviewed by the staff and found acceptable. The SAFESHIELD 2999A package is adequately described by the above assembly and attendant drawings, which provide specifications for the materials of construction, component dimensions, location, size, and type of joints on the packaging.

The casket (Casket 2999) studs are provided with holes, which enable a wire security seal to be fitted through any pair of studs as a tamper indicating device in accordance with 10 CFR 71.43(b). In addition, the casket closure is provided with a welded pin that may be fitted with a padlock. The Casket 2999 contains an identification plate that complies with the requirements of 10 CFR 71.85(b) and 49 CFR 173.448.

The SAFESHIELD 2999A packaging is designed to be used as a general purpose container for the shipment of radioactive material in special form capsules; welded capsules not classified as special form; accelerator targets containing solid, liquid metal, and gaseous radioactive material; stainless steel canister containing ion exchange resins with adsorbed radioactive material; and aluminum canister containing radioactive waste material.

The permitted maximum heat generation of the contents is 250 watts. Exclusive use shipment is required whenever the contents heat output is greater than 200 watts.

The SAFESHIELD 2999A packaging is classified as a Type B(U)-96, Category I container and the inner containment vessel component of Flask 2993 is designed, fabricated, and examined to the requirements of Section III, Division 1, Subsection NB of the ASME Boiler & Pressure Vessel Code (B&PV). The Casket 2999 is designed, fabricated, and examined to the requirements of Section VIII, Division 1 of the ASME B&PV Code.

The nominal weight of the packaging is 3853 kg (8494 lb), excluding contents. The maximum contents weight is 100 kg (220 lb).

This SER provides details of the evaluation of the SARP with regard to the ability of the SAFESHIELD 2999A packaging to provide containment and radiation shielding protection of the contents during the Normal Conditions of Transport and Hypothetical Accident Conditions required by DOE Order 460.1B and 10 CFR Part 71.

1.1 Description

1.1.1 Packaging

The packaging consists of a lead-alloy-shielded containment vessel (Flask 2993) carried in an outer, double-skinned, insulated casket (Casket 2999). The packaging includes thermal insulation and lead-alloy (Pb-4 wt.% Sb) shielding. The containment vessel closure flange is secured by screws to a top flange welded to the containment cavity liner. The Casket 2999 is fitted with an identification plate that complies with the requirements in 10 CFR 71.85(b) and 49 CFR 173.448. Tie-down and lifting attachment points are provided on the casket.

1.1.1.1 Casket 2999

The casket consists of a double-skinned low-carbon steel overpack fastened to a double-skinned low-carbon steel base with stainless steel studs and nuts. The outer and inner shells of the casket are made of, respectively, 10-mm (0.39-in)- and 8-mm (0.32-in)-thick BS EN 10113: 1993, Grade S275 NL, ferritic steel. The overall dimensions of the casket are 839-mm (33.03-in) outside diameter [1,040-mm (40.95-in) to the outside of the tie-down and lifting plates] and 1,396-mm (54.96-in) high. The inside dimensions of the cavity for the flask 2993 are 727-mm (28.62-in) inside diameter and 945-mm (37.21-in) high. The components of the base are made of BS EN 10113: 1993, Grade S275 and Grade S355 NL. Four tie-down and lifting plates with bushings are attached on the side of the casket.

Impact protection for the containment vessel inside the casket is provided by pre-crushed aluminum honeycomb. The honeycomb is made of Type 5052, Grade 10-1/8-25 aluminum and provides 149-mm (5.87-in) impact mitigation over the top and bottom of the containment vessel (Flask 2993). Side support for the containment vessel (Flask 2993) is provided by a base-mounted, close-fitting steel sleeve with four nylon 66 guides attached.

The cavities between the double-skinned shell, cover, and base are filled with a cast-in-place Thermal Insulating and Shock Absorbing Foam (TISAF). The basic constituents of the foam are phenolic resin and mineral filler; it contains no chlorides. The foam has a mixture of open and closed porosity, and absorption of water or moisture in the open porosity will degrade its mechanical and thermal properties. Preventive steps have been taken to prevent intrusion of water and moisture into the region containing TISAF by using a Loctite thread sealant on the fuse plugs for the casket, and by storing the packaging dry when not in transit. The TISAF foam is unaffected by temperatures up to about 140°C (284°F). Above this temperature the foam starts to become more friable. Above 220°C (428°F), the TISAF begins to break down to a powder.

In the event of a hypothetical accident fire, the insulated cavities will vent through 12 vent holes, which are normally sealed with low-melting-point alloy plugs (drawing #3C-4533), in the cover and base of the casket.

The assembled casket has an overall height of 1,396 mm (54.96 in.) and an overall diameter of 1,040 mm (40.95 in.). The casket provides a cavity for the flask with internal dimensions of 698-mm (27.48-in) minimum diameter and 945-mm (37.21-in) height.

The approximate weight of the casket is 1,050 kg (2,315 lb).

1.1.1.2 Flask 2993 (Containment Vessel)

The containment vessel (Flask 2993) consists of a cylindrical outer shell with a truncated cone top to which a cylindrical containment cavity liner is welded. The material for both outer shell and containment cavity liner is ASTM A240/240M or A479/A479M Type 304L stainless steel. The overall diameter of the flask outer shell is 669-mm (26.34-in) with a height of 912-mm (35.91-in). The wall thickness of the flask outer shell is 6-mm (0.24-in). This outer shell is welded to the outer surface of the flange attached to the containment cavity liner. The shell of the containment cavity liner is machined from a solid billet and its wall thickness is 5-mm (0.20-in). This shell is welded to a flange that contains machined grooves for the O-rings and is sealed with a flat cover. The cover is secured to the flange by sixteen (16) M12 x 35 hex-head bolts made to ASTM A193, Grade B8M Class 1 stainless steel. The bolts are tightened to 25 ± 2 N-m (18 ± 1 ft-lb) torque. A lead-alloy-filled, stainless-steel plug fits inside the containment cavity liner and rests on a machined step in the upper part of the containment cavity. This plug provides radiation shielding directly above the containment vessel cover.

When assembled for transport, the cylindrical containment cavity for the radioactive contents is 220-mm (8.66-in) diameter by 400-mm (15.75-in) high.

The space between the flask outer shell and the containment cavity liner is filled with cast-in-place lead with 4% antimony to BS 3909:1965 (1989) Grade 3909/2. The lead-alloy filling is through filling holes, which are welded closed after completion of the filling procedure. The lead-alloy filling is performed in a controlled manner to avoid formation of voids during solidification or thermal shock on the flask and is non-destructively examined after filling by a gamma scintillation test. The thicknesses of the lead-alloy shielding are 213.5-mm (8.41-in) adjacent to the containment cavity, 218-mm (8.58-in) at the base of the cavity liner, and 228-mm (8.98-in) for the plug.

1.1.1.3 Containment boundary

The containment boundary for the radioactive material consists of the cavity liner of Flask 2993, top flange, weld between the cavity liner and top flange, closure flange, and the inner O-ring fitted to the top flange. The top flange and closure flange are also made from Type 304L SS. The cavity liner and the top flange form a cavity assembly whose overall height is 664 mm. The top flange is provided with grooves for inner and outer O-rings. The inner diameters of these grooves are, respectively, about 278 and 299 mm, and their width is about 5.1 mm. The top flange mates to the Type 304L SS closure flange having a deep spigot that fits into the top of the top flange. The closure flange contains a port for leak testing the space between the inner and outer O-rings. The closure flange is fastened to the top flange by 16 bolts.

1.1.1.4 O-rings

The O-rings used to seal the containment vessel (Flask 2993) are ethylene propylene (EPDM) that comply with the ASTM D2000 (2001) specification M3 BA710 A14 B13 F17 Z1. The size of the inner (primary) O-ring is 280 ± 1-mm (11.02 ± 0.04-in) ID x 4.0 ± 0.12-mm (0.157 ± 0.005-in) cross section (CS). The size of the outer O-ring is 301.96 ± 1.5-mm (11.89 ± 0.06-in) ID x 4.0 ± 0.12-mm (0.157 ± 0.005-in) CS. The flat cover provides the other sealing surface for the O-rings and also contains a leak test port between the inner and outer O-rings. This O-ring is made of a fluorocarbon elastomer, Viton, and complies with the ASTM D2000 (2001) specification M4 HK714 A1-11 B38 C12 C20 F17 Z1. The size of this O-ring is 3.6-mm (0.14-in) ID x 2.4-mm (0.09-in) CS. Another test port is provided in the flange to facilitate leak testing of the containment vessel body.

The approximate weight of the containment vessel (Flask 2993) is 2,803 kg (6,181 lb).

1.1.2 Operational Features

The packaging is loaded under ambient atmospheric pressure and temperature conditions. The containment vessel (Flask 2993) will not normally be pressurized, but internal heating of the enclosed gases may increase the pressure. The maximum normal operating pressure (MNOP) of the packaging is 37.2 kPa (5.4 psig). The serial numbers of the casket and the containment vessel (Flask 2993) are permanently marked on identification plates of these components. The marking system to be used is the design number followed by the serial number, e.g., 2999/0001.

The SAFESHIELD 2999A package is provided with four lifting attachments in the form of lifting plates on the sides of the casket (Casket 2999); each plate has holes strengthened by bosses. The tie-down is effected by attaching tie-down members to the bossed holes in the lifting plates.

1.2 Contents

The SAFESHIELD 2999A packaging is designed as a general-purpose Type B packaging for shipping radioactive material that emits gamma radiation and requires heavy shielding. The packaging may carry six different Contents Types as follows:

- **(I).** Special form sources, which are contained in capsules that meet the requirements of special form, consisting of solid metal discs or rods for Co-60 and I-192, or pressed pellets for Cs-137;
- **(II).** Encapsulated materials, which are not qualified as special form, consisting of solid metal discs or rods for Co-60 and Ir-192, or pressed pellets for Cs-137;
- **(III).** Irradiated solid accelerator targets;
- **(IV).** Stainless-steel canister containing solid ion exchange resins having adsorbed radioactive materials;
- **(V).** Aluminum canister containing solid radioactive waste material from handling irradiated targets; and
- **(VI).** Irradiated liquid metal accelerator targets.

Detailed descriptions of Contents Types I to VI are given in Tables 1.1-I to 1.1-VI of the SARP.

Other Permitted Contents:

The only pyrophoric material to be carried is rubidium in Contents Type VI. However, inerting of the containment vessel is not required since the rubidium is carried in a target cell within a target capsule. Other low-melting-point nuclides Na, P, S, I, and Hg could be present as products of accelerator irradiation in small quantities within the matrix of the accelerator target; they are thus unlikely to cause material compatibility concerns.

The contents may also include inorganic non-radioactive materials associated with the radioactive materials, such as content holders or fixtures and packing materials.

Contents Not Permitted:

Fissile materials and irradiated fissile materials containing fission products are not permitted. No organic/hydrogenous materials are allowed. No water may be present for any contents.

The shape of the contents (radioactive contents, product capsules or containers, all associated items such as target holders, and packing) inside the containment vessel (Flask 2993) shall not have any protrusions or sharp points that could damage or puncture the containment vessel liner.

Contents Limits:

Except for Contents Type VI, only dry solid contents are permitted, and loading shall take place in a dry environment.

The maximum weight of the contents, including all associated hardware and packing material, shall not exceed 100 kg (220 lb).

The radioactive contents shall be limited to a maximum internal heat generation of 250 watts. The 250 W limit results in an activity limit of 16,200, 55,000, and 43,900 Ci, respectively, for Co-60, Cs-137, and Ir-193 that are the three major radionuclides in the special form sources in Contents Type I, or encapsulated materials in non-special-form capsules in Contents Type II. Exclusive use shipment is required whenever the contents heat output is greater than 200 watts (Contents Types I and II). Nonexclusive use shipments are permitted for contents heat output less than 200 watts (Contents Types III, IV, V, and VI).

The radioactive contents shall be limited by the external radiation levels specified in 10 CFR 71.47, External radiation standards for all packages; 10 CFR 71.51, Additional requirements for Type B packages; and 49 CFR 173.441, Radiation level limitations. Exclusive use shipment is required whenever the radiation dose rates of the package exceed the external radiation standards in 10 CFR 71.47(a) for non-exclusive use shipment.

The bounding internal pressure that can occur within the containment vessel (Flask 2993) is 98.6 kPa (14.3 psig). The volume of gas within the contents is limited to 10 cc by the contents limits given in Table 1.2 of the SARP. The pressure caused by the release of this gas into the containment vessel would be insignificant.

The contents (radioactive contents, product capsules or containers, all associated items such as target holders, and packing) shall be packed such that they cannot move within the cavity of the containment vessel (Flask 2993) by more than 15-mm (0.59-in) in any direction.

1.3 Conclusion

Based on the statements and representations in Chapter 1 of the SARP and the staff's confirmatory evaluation, the staff concludes that the general information (and drawings) of the SAFESHIELD 2999 A packaging and contents has been adequately described. Evaluation of design and performance of the packaging in structural, thermal, containment, shielding, operating procedures, acceptance tests and maintenance, and quality assurance against regulatory requirements are given in the remainder sections of this SER.

Issues to be Corrected at the Next SARP Revision:

Issue 1.1: The type of Loctite sealant for the fuse plugs should be specified in Dwgs. 1C-4512 and 1C-4513 because there are many types of Loctite sealants with different performance characteristics. The Loctite sealant helps prevent intrusion of water and moisture into the region containing TISAF; water absorption by the open porosity in TISAF will change its properties and mechanical and thermal performance.

Issue 1.2: For Contents Type VI in Table 1.1-VI of the Rev. 4 SARP, include the statement "Co-60, Cs-137, and Ir-192 are excluded." This statement appears in Tables 1.1-III, 1.1-IV, and 1.1-V for Contents Types III, IV, and V of the Rev. 4 SARP and is essential to set the limit for the trace quantity of radionuclides in the contents.

Issue 1.3: In Table 1.1-III, Page 1-15 of the Rev. 4 SARP, the phrase "Compound only for Cs, Ga, Hg, I, Na, P, Rb, and S" under Chemical Form, and the phrase "excepting gallium and rubidium" under Radionuclides should be removed. The phrases conflict with each other. Also, radionuclides of gallium and rubidium can be formed by any number of proton irradiation reactions on several targets. Gallium and rubidium metal targets are already excluded by the General Form section of this table, which excludes LMP targets. Furthermore, page 1-12 of the Rev. 4 SARP has addressed the potential concern of material compatibility for the low-melting point radionuclides in the contents, and the staff has found it acceptable.

2. STRUCTURAL

2.1 Structural Design

2.1.1 Discussion

The SAFESHIELD 2999A packaging was designed and constructed as a Type B(U)-96, Category I packaging. Chapter 2 of the SARP documents compliance of the design and construction with the requirements of 10 CFR Part 71 and with the ASME Boiler and Pressure Vessel Code (hereinafter referred to as the "Code"). Compliance is demonstrated by physical tests on a prototype packaging, supplemented by various structural analyses and engineering evaluations. This section of the SER summarizes and documents the confirmatory review performed by the staff. It consists of a review and an evaluation of the material presented in Chapter 2 of the SARP. The structural evaluations presented in the reference were reviewed by the staff and found acceptable.

2.1.2 Design Criteria

The Design Criteria Section (Section 2.1.2) of the SARP states that the mechanical and environmental loadings that govern the design of the SAFESHIELD 2999A packaging are those specified as the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) requirements and given in 10 CFR 71.71 and 10 CFR 71.73. Since the packaging is qualified to the requirements of 10 CFR 71.41(a) by testing, the design criteria used for the containment boundary is that no portion of it should be stressed beyond the tensile yield strength, and the other components of the containment vessel (Flask 2993) should suffer only minor denting under these loadings under both NCT and HAC.

The containment vessel (Flask 2993) is shown in Dwg. 0C-4490, and the containment boundary for the radioactive material is defined in the SARP as the cavity liner, the top flange, the closure flange and the flask inner O-ring (Dwgs. 0C-4490, 2C-4492, and 1C4508).

The casket (Casket 2999) is shown in Dwg. 1C-4511. No components of the closure of the casket should be stressed beyond the yield stress under NCT and other parts should only suffer local denting or marking. The effects of the HAC should be confined to the components of the casket.

Section 1.1 in Chapter 1 of the SARP states that the components of the packaging are designed, fabricated, examined and tested to the applicable requirements of the ASME Code as specified in NUREG/CR-3019 and NUREG/CR-3854. The containment vessel of the flask meets the appropriate design criteria for a Category I packaging, including the applicable portions of Section III, Division 1, Subsection NB of the Code, Regulatory Guide 7.6, and Regulatory Guide 7.8. The casket meets the appropriate design criteria specified in the applicable portions of Section VIII, Division 1 of the Code.

Since the method chosen for demonstrating compliance with the requirements of 10 CFR Part 71 is primarily by prototype testing, limited analyses have been performed.

Structural failure modes such as brittle fracture and buckling are addressed in the SARP. Brittle fracture is not a consideration for the containment vessel (Flask 2993) because the structural components are made of austenitic stainless steel. These materials are not susceptible to brittle fracture at the minimum design and transport temperature of -40°C (-40°F). The casket falls within the "Other Safety" Category of Table 1.1 of NUREG/CR-3854; it must satisfy the low-temperature test rules in Section VIII, Division 1 of the Code.

Local buckling may be possible under the NCT 1.2-m (4-ft) and the HAC 9-m (30-ft) free drop, and the results of these tests and analysis are evaluated later in Sections 2.6 and 2.7 of this SER.

2.2 Weights and Centers of Gravity

Section 2.2.1 in the SARP provides a table that lists the weights of the components of the packaging. The nominal gross weight of the package including contents is 3,953 kg (8,715 lb). This includes the maximum contents weight of 100 kg (220 lb). The maximum package gross weight is 4,030 kg (8,885 lb). The actual packaging weight should be within ±2% of the total net weight of the packaging, i.e., 3,853 kg (8,496 lb). The location of the center of gravity is given in Section 2.2.2 of the SARP as 667-mm (26.3-in) above the base of the package.

2.3 Mechanical Properties of Material

The materials that affect the structural behavior of the SAFESHIELD 2999A packaging are the austenitic stainless steels used for the containment vessel (Flask 2993), the stainless steel for the closure screws, the lead-alloy (Pb-4 wt.%Sb) for shielding, the low-alloy carbon ferritic steels for the casket (Casket 2999), the phenolic resin foam (TISAF) poured between the inner and outer shells of the casket, and the aluminum load plates and honeycomb placed between the top and bottom of the containment vessel (Flask 2993) and the inside ends of the casket.

The phenolic resin foam and the aluminum plates and honeycomb packing are important components in distributing the loads during NCT and HAC impacts and in thermally insulating the containment vessel (Flask 2993) and O-rings during the HAC fire.

The mechanical properties for the materials that affect the structural behavior of the SAFESHIELD 2999A packaging are listed in the SARP. These materials include the stainless steels, the ferritic steels, the lead alloy, the TISAF phenolic resin foam, the aluminum plates and the aluminum honeycomb. The properties provided have been reviewed by the staff and have generally been found to be acceptable for the analysis of this packaging and consistent with values provided in the Code, technical reports, standards, or handbooks. Where there was concern about the values provided, conservative values were obtained and used for confirmatory analysis.

The prototype packaging was qualified by testing at an ambient temperature of approximately 20°C (68°F). Verification is required to show that the ferritic steels, welds, and heat-affected zone (HAZ) material used in the casket (Casket 2999) are not susceptible to brittle fracture during low-temperature service. This verification for ferritic steel base metal was obtained by Charpy impact testing to the requirements of Section VIII, Division 1 of the Code and is presented in CTR 2004/09 in Appendix B, Chapter 1 of the SARP. However, Charpy impact testing for ferritic steel welds and heat-affected zone as presented in CTR 2004/09 was not obtained to the requirements of Section VIII, Division 1 of the Code and, therefore, does not verify the low-temperature performance of the ferritic weld and HAZ used in the prototype casket.

Each heat of the ferritic steels used in the production packagings will also be qualified by impact testing to these requirements. (See LANL response, Q#1.5, Page 16 of CTR 2005/01, Issue B, "SAFESHIELD 2999A SARP Review – Q4 Response Matrix," July 31, 2005. The staff reviewed MSP 091, Issue E "Manufacturing Specification – Casket Design No 2999" in Appendix C, Chapter 1 of the SARP and finds the specifications acceptable. The specifications in MSP 091 do not address the use of full-size versus half-size specimens in the determination of low-temperature properties of S275 NL and S335 NL steels and their welds and heat-affected zones. Whereas -29°C is an acceptable temperature condition for full-size specimens based on 10 CFR 71.71(b), a reduction of temperature by 11°C, i.e., -40°C is necessary for half-size specimen according to Table UG-84.2, ASME Section VIII, Division 1 (2004 Edition).

The containment vessel (Flask 2993) bolting is made from ASTM A193, Grade B8M Class 1 stainless steel. The containment vessel (Flask 2993) liner shell is machined from ASTM

A479/A479M-04 Type 304L stainless steel. The top flange and cover are made from ASTM A240/A240M-04A or A479/A479M-04 Type 304L stainless steel plate. The containment vessel (Flask 2993) outer shell is also made from ASTM A240/A240M-04A Type 304L stainless steel. None of these materials are susceptible to brittle fracture at the minimum temperatures of -40°C (-40°F) expected during transport. Therefore, protection against brittle fracture of the components comprising the containment vessel (Flask 2993) is not necessary.

The casket (Casket 2999) is made from BS EN 10113:1993 Grade S275NL and Grade S355NL ferritic steel. These materials are susceptible to brittle fracture at the minimum temperatures of -40°C (-40°F) expected during transport. Therefore, protection against brittle fracture of the structural components comprising the casket is necessary. The studs used to attach the cover and base of the casket are made from BS EN3506-1:1998 Grade A2-70 stainless steel, and are therefore not susceptible to brittle fracture at the minimum temperatures of -40°C (-40°F) expected during transport.

The SARP does not provide mechanical properties data for the O-ring seals for the containment vessel (Flask 2993). However, these materials are common O-ring seal materials and are adequately identified by the ASTM D2000 specifications in CM 075, Issue A and CM 076, Issue B provided in Appendix C, Chapter 1 of the SARP.

The other materials comprising the SAFESHIELD 2999A packaging are adequately described by the information and specifications provided in the SARP. This includes the lead-alloy shielding (Table 2.4B: lead with 4% antimony to BS 3909:1965 Grade 3909/2), the thermal insulation (Table 2.4A: TISAF to specification CM 066, Issue A in Appendix C, Chapter 1 of the SARP), the impact mitigating aluminum honeycomb (Table 2.4A: specification CM 077, Issue A in Appendix C, Chapter 1 of the SARP), and the aluminum load sheets (BS 1470:1987, Grade 1050A/0).

2.4 General Standards

The SARP addresses the 10 CFR 71.43 general requirements such as minimum package size, 71.43(a); a tamperproof seal, 71.43(b); and protection against inadvertent opening of the containment system, 71.43(c). These requirements are met as follows: The smallest overall dimension is approximately 839-mm (33-in) which is larger than the 10-cm (4-in) minimum specified in 71.43(a). The twenty-four (24) casket cover studs have holes drilled in them so that tamper-indicating seals can be installed. In addition, the casket (Casket 2999) has one cover stud designed so that it can be secured with a padlock to satisfy 71.43(b). Positive closure for the containment vessel (Flask 2993) is provided by means of sixteen (16) M12 x 35 stainless steel, hex-head machine screws to prevent unintentional opening, as required by 71.43(c).

Paragraph 71.43(d) is addressed by assuring that the materials used in the construction of the SAFESHIELD 2999A packaging and the contents of this packaging are compatible with each other so no chemical or galvanic reactions can occur. For Contents Type VI, the liquid metal accelerator targets shall be encapsulated in the target cells used to perform irradiation. Target cells shall be fabricated from niobium for the gallium target and stainless steel for the rubidium target. Operating experience with gallium/niobium and rubidium/stainless-steel targets documented in C-INC-05-075 in Appendix C, Chapter 2 of the SARP indicates no failure either during irradiation, or under normal transportation conditions. Therefore, both gallium and rubidium are compatible with their target cell materials with no material compatibility concerns under NCT. Similarly, 71.43(e) is satisfied because the packaging does not incorporate any valve or other device which would allow release or escape of the contents. Also, the packaging design does not include any feature intended to allow continuous venting during transport as required by 71.43(h).

2.5 Lifting and Tie-down Devices

The SAFESHIELD 2999A packaging is provided with four lifting and tie-down plates with holes strengthened by bosses with 28-mm- (1.10-in)-diameter holes.

Calculation sheet CS 97/53, Issue C in Appendix C, Chapter 2 of the SARP provides an analysis of the stresses in the lifting plates. Confirmatory analysis has verified that the lifting attachments have been designed to meet the requirements of 71.45(a) when the package is being lifted in the manner intended.

Section 7.4 of the SARP requires that the package is tied down using the lower attachment points with the tie-downs aligned with the centerline of the packaging at 45 ± 5 degrees to the vertical. Calculation Sheet CS 97/54, Issue D in Appendix C, Chapter 2 of the SARP provides the analysis of the stresses in the lifting plates due to tie-down. Independent analysis performed by the staff has confirmed that the lifting attachments were designed to meet the requirements of 71.45(b) when used in the manner specified in Section 7.4 of the SARP.

The SAFESHIELD 2999A packaging has no tie-down devices or structural parts that could be used for unintended tie-down, thus meeting the additional requirements of 71.45(b).

2.6 Normal Conditions of Transport (NCT)

2.6.1 Regulatory Requirements

Section 2.6 in the SARP for the SAFESHIELD 2999A packaging addresses the ten conditions and tests associated with the evaluation of the packaging for the normal conditions of transport (NCT) stipulated in 10 CFR 71.71(c). These include heat, cold, reduced external pressure, increased external pressure, vibration, water spray, a 1.2-m (4.0-ft) free drop, corner drop, a compression test, and a penetration test. The SARP presents the results of tests and simplified analyses to show that the stresses generated in the packaging due to these test requirements are acceptable.

Staff confirmatory evaluation recognized that the structural members of the containment portion of this packaging are fabricated from austenitic stainless steel and therefore the material properties are relatively stable over the temperature range of approximately -40°C (-40°F) to 150°C (300°F). In addition, this material does not exhibit a transition from ductile to brittle behavior in this temperature range.

The casket (Casket 2999) of this packaging is fabricated from low-alloy carbon, i.e., ferritic, steel and is therefore susceptible to brittle fracture at low temperatures. Consequently, these materials were qualified to the low-temperature rules in Section VIII, Division 1 of the Code. The low-temperature Charpy impact energy data for ferritic steels used in the prototype casket along with their welds and heat-affected zone are presented in CTR 2004/09, Issue C in Appendix B, Chapter 1 of the SARP. Each heat of the ferritic steels used in the production packagings will also be qualified by impact testing to these requirements. In addition, no significant loading mechanisms are identified that would be expected to affect the performance of this packaging due to environmental temperature variations during normal conditions of transport.

71.71(c)(1) Heat is discussed in Section 2.6.1.1 of the SARP, and lists the MNOP within the containment vessel (Flask 2993) as 37.2 kPa (5.4 psig) and a maximum operating temperature of the packaging as 100°C (212°F). Section 3.4.2.1 of the SARP shows that the effect of solar heating is relatively small and Section 2.6.1.2 explains that because temperature gradients measured during steady-state tests were small, thermal stresses will not be significant. The results of the staff confirmatory evaluation of maximum NCT temperature and the associated thermal stress are given in Sections 3.4.2 and 3.4.5 of this SER.

71(c)(2) Cold is discussed in Section 2.6.2 of the SARP. The staff confirmatory evaluation verified the conclusions of this Section.

71.71(c)(3) Reduced external pressure is addressed in Section 2.6.3 of the SARP. The casket (Casket 2999) is not fitted with a seal and it is not designed to be leak tight. Therefore, the SARP explains that there can be no differential pressure across the shells of the casket, and the only source of a differential pressure would be between the containment cavity and the external surface of the packaging. The differential pressure across the primary containment vessel would then be the bounding internal pressure 199.9 kPa (29 psia) minus 24.1 kPa (3.5 psia) which is 175.8 kPa (25.5 psi). This is addressed in the bolting analysis in CTR 98/04, Issue B in Appendix C, Chapter 2 of the SARP and the results, summarized in Table 2.9 of the SARP, show that the resulting increase in bolt stress due to the reduced external pressure would be 9.4 MPa (1.36 ksi); and when added to the other stresses in the bolt, is below the Code allowable stress.

The staff concludes that the bounding pressure used in these analyses and the subsequent analysis is adequate to ensure that the containment vessels meet the requirements for reduced external pressure.

71.71(c)(4) Increased external pressure is discussed in Section 2.6.4 of the SARP. This case would reduce the effective internal pressure and the stresses in the containment vessel (Flask 2993) components would be below the design pressure stresses.

71.71(c)(5) Vibration is discussed in Section 2.6.5 of the SARP. This section describes the design precaution taken to assure that vibration normally expected during transport will not adversely affect any of the structural components of the packaging, nor the leaktightness of the containment boundary. In addition, this section of the SARP also addresses the effect of cyclic loadings on the fatigue behavior of the components. The conclusion in the SARP is that neither vibration nor cyclic loading would be detrimental to the safety of the packaging; the staff concurs with this conclusion.

71.71(c)(6) Water spray is discussed in Section 2.6.6 of the SARP. Because the casket (Casket 2999) is painted, a Loctite sealant will be used on the fuse plugs, and the packaging is subject to annual inspection, and because the containment vessel (Flask 2993) is fitted with O-ring seals and all of the containment components are made out of corrosion-resistant materials, the staff agrees that the water spray conditions will have no adverse effect on the packaging.

71.71(c)(7) Free drop is discussed in Section 2.6.7 of the SARP. The prototype SAFESHIELD 2999A packaging was dropped from a height of 1.2-m (4.0-ft) onto an unyielding concrete surface. The package was initially oriented in the position which was expected to produce the most damage with the center of mass directly above the top edge of the casket. Following this drop test the only damage found was that the top edge of the package was deformed 29-mm (1.1-in) below the original plane of the top of the rim. This meets the requirement of 10 CFR §71.51(a)(1) that there be no substantial reduction of the effectiveness of the packaging.

71.71(c)(8) Corner drop is discussed in Section 2.6.8 of the SARP. This test is not applicable to the SAFESHIELD 2999A packaging because it is of steel construction.

71.71(c)(9) Compression is discussed in Section 2.6.9 of the SARP. Buckling calculations are presented in CS 97/58 Issue B, and CS 2001/04 Issue A in Appendix C, Chapter 2 of the SARP. Independent calculations confirm that the packaging meets these requirements.

71.71(c)(10) Penetration is discussed in Section 2.6.10 of the SARP. Test results for the SAFESHIELD 2999A packaging show that the dropping of a vertical steel cylinder 3.2-cm (1.25- in.) in diameter and weighing 6 kg (13 lb) onto the package from a height of 1-m (40-in.) produced only a small dent approximately 0.5-mm (0.02-in.) deep in the outer shell of the casket (Casket 2999). The staff concurs that the results demonstrates that the packaging meets the requirements of the penetration test.

2.6.2 Summary of NCT Damage

The structural damage expected to result from the NCT test requirements is insignificant. The actual results from the NCT tests and analyses provided in the SARP show that there is little or no structural damage and no loss of containment when the packaging is subjected to the required loadings. The only detectable damage was minor denting of the external shell of the casket (Casket 2999). This damage is an acceptable consequence of the NCT requirements.

2.7 Hypothetical Accident Conditions (HAC)

2.7.1 Regulatory Requirements

Section 2.7 of the SARP for the SAFESHIELD 2999A packaging addresses the applicable tests associated with the hypothetical accident conditions (HAC) stipulated in 10 CFR 71.73(c). These tests include: (1) Free drop, (3) Puncture, (4) Thermal, and (6) Immersion – all packages.

The HAC tests that are not applicable to this packaging are: (2) Crush and (5) Immersion – fissile material. The crush test is not applicable because this test is restricted to packagings that weigh 500 kg (1,100 lb) or less, and the immersion – fissile material test is not applicable because the contents do not allow fissile materials.

The applicable tests were conducted on a prototype packaging at an ambient temperature of approximately 20°C (68°F) rather than at -29°C (-20°F) normally required by 71.73(b) because, as explained in Section 2.7 of the SARP, the materials of construction are not susceptible to brittle fracture at low temperatures, and the temperature-dependence of their mechanical properties is small enough to be insignificant. Although the casket (Casket 2999) is constructed from ferritic steel which is susceptible to brittle fracture at low temperatures, these materials were qualified for low-temperature service by the rules in Section VIII, Division 1, of the Code. The SARP, and the independent confirmatory review, has provided adequate demonstration that these assumptions are sufficient to justify ambient temperature testing.

The evaluations provided in the SARP for the HAC tests are primarily based on testing of a prototype packaging. The SARP lists the acceptance criteria for the packaging as follows:

(a) No plastic deformation of the containment vessel components of the flask,
(b) Some plastic deformation of the casket structural components,
(c) Some crushing of the TISAF, and
(d) Crushing to nominally 20% of the original thickness of the aluminum honeycomb.

71.73(c)(1) Free drop is addressed in Section 2.7.1 of the SARP. The packaging for the free drop was the fully assembled prototype loaded with 100 kg (220 lb) of lead shot to simulate the contents. The containment vessel (Flask 2993) was leak tested before and after the test to verify that the leak rates were less than 10^{-7} std cm^3/s. Two different 9-m (30-ft) drop tests were performed. The first drop test was with the center of gravity over the top edge of the package. This test resulted in the top edge of the casket (Casket 2999) being deformed 64-mm (2.52-in). The second was a drop with the center of gravity over the base edge of the package. This test resulted in the bottom edge being deformed 56-mm (2.20-in) and some of the studs in the region of impact were sheared off.

71.73(c)(3) Puncture is addressed in Section 2.7.2 of the SARP. A series of puncture tests was performed. The packaging was dropped 1-meter (40-in.) from three different orientations onto a vertical bar 15-cm (6-in.) in diameter. This first puncture test followed the free drop on the top edge of the package. In this test the puncture bar impacted the top edge of the packaging that had already been damaged. An additional permanent deformation of 5-mm (0.20-in) resulted. The next test followed the free drop on the base of the package. In this test the puncture bar also impacted the portion of the base edge that had already been previously damaged. The results of this test were that there was an additional permanent deformation of 2-mm (0.08-in) and more studs were sheared off in the area of the impact. The final puncture test was with the package oriented horizontally to impact the area in the region near the O-rings. This test resulted in a permanent deformation of 25-mm (1.0-in).

71.73(c)(4) Thermal is addressed in Section 2.7.3 of the SARP. This test was performed at the pool fire test facility operated by AEAT at Winfrith, Dorset, in England. The packaging was fully engulfed in the pool fire for 36.5 minutes. During this time the average temperature as indicated by flame thermocouples was more than 800°C (1472°F). The average temperature for the five thermocouples on the surface of the casket (Casket 2999) was 857°C (1575°F). After the fire was extinguished, gasses continued to escape from the holes of the casket. (These holes were sealed with fusible plugs before the fire.) When the packaging was disassembled, it was noted that the TISAF in the casket had shrunk from its original thickness of 42-mm (1.7-in) to 32-mm (1.3-in) and it had charred through its entire depth. The outermost 10-mm (0.40-in) of the shrunken TISAF was cracked and friable when handled. There was a loss of about 30 kg (66 lb) during the fire test. Most of this was presumed to be due to the loss of TISAF. Helium leak tests performed before and after the complete series of tests, including the thermal test, showed that the tests did not damage the containment vessel or the O-ring seals.

71.73(c)(6) Immersion – all packages is addressed in Section 2.7.5 of the SARP. The regulations require that an undamaged specimen of the packaging be subjected to water pressure equivalent to immersion in water to at least 15-m (50-ft). For test purposes, this relates to an external pressure of 150 kPa (21.7 psig). In terms of absolute pressure, this is 251 kPa (36.4 psia).

The explanation presented in Section 2.7.5 is that the containment vessel (Flask 2993) is designed for a maximum differential pressure of 200 kPa (29 psi), and using the worst case of reduced internal pressure of 47 kPa (6.8 psi) due to oxidation effects on the contents (SARP section 2.6.4), the maximum differential pressure across the O-ring seals would be 204 kPa (29.6 psi) [(251-47) kPa = 204 kPa] which is within 2% of the design value. Therefore, the SARP concludes that this satisfies the regulatory requirement. This explanation and conclusion is supported by the staff confirmatory evaluation.

For the liquid metal targets in Contents Type VI, the liquid metal (gallium or rubidium) is enclosed in a target cell made of niobium or stainless steel. The target cells are carried in a stainless steel target capsule which is designed to provide additional containment function of the contents. The target capsule is treated as a Special Form and qualified by tests specified in 10 CFR 71.75(b). The applicable tests include a 9-m drop test and a 1-m percussion test. The results of the tests, documented in TR 04/09/01 in Appendix B, Chapter 2 of the SARP, show that the stainless steel target capsule carrying dummy target cells suffered minimum damage, remained leak-tight after the tests, and maintained additional containment function.

2.7.2 Summary of HAC Damage

The SARP states that the damage to the packaging from the HAC tests is not sufficient to affect the containment of the contents or radiation shielding required by the regulations. The casket (Casket 2999) sustained significant deformations, some of the studs retaining the cover to the base of the overpack were sheared off, and there was a loss of thermal insulation due to the fire, but the containment vessel (Flask 2993) was not damaged and remained leaktight.

The SARP considers the closure bolts for the containment vessel (Flask 2993) the weakest component of the SAFESHIELD 2999A packaging. This is based on the results of the HAC tests and a stress analysis of the containment vessel (CTR 2001/06, Issue A) that show the stresses are well below the Code allowable. Section 2.7 presents the results of various analyses of the stresses in the bolts, including the HAC tests, prying due to flange rotations, pressure, and thermal stresses. A comparison of these analyses with Code allowable stresses leads to the conclusion that the stresses in the bolts are also well below the Code allowable.

2.8 Conclusion

Based on the statements and representations in Chapter 2 of the SARP and the staff's confirmatory evaluation, the staff concludes that the structural design has been adequately described and evaluated. The staff concludes that the structural performance of the SAFESHIELD 2999A package will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

3. THERMAL

3.1 Discussion

Tests and analyses are used in the SARP to evaluate the packaging temperatures under the normal transport and hypothetical accident test conditions specified in 10 CFR 71.71(c) and 71.73(c)(3), respectively. The staff confirmatory analyses agree with the SARP conclusion that the design of the SAFESHIELD packaging can provide adequate thermal protection to the containment boundary and that the packaging meets the regulatory thermal requirements of 10 CFR 71.43(g).

The maximum heat load in a SAFESHIELD shipping container is limited to 250 Watts. However, for non-exclusive use shipment, the maximum heat load allowed in a SAFESHIELD shipping container is 200 Watts. These conditions will limit the amount of content in the package that must be satisfied before shipment.

3.2 Summary of Thermal Properties of Materials

The thermal properties of the materials of all of the packaging components modeled in the analyses have been adequately listed in the SARP. The listed property values are in agreement with the values found in the published technical reports, standards, test reports, or handbooks. The references cited for the data are also provided in the SARP.

3.3 Technical Specifications of Components

The components that require attention from the perspective of thermal performance are the O-rings for the containment vessel flask 2993, the lead-alloy shielding, the aluminum honeycomb, and the TISAF (Croft proprietary phenolic resin foam) insulation that fills the space between the inner and the outer shell of the Casket 2999. The O-rings limit the leak rate of radioactive material and the phenolic resin foam provides thermal insulation. The O-rings are made of ethylene propylene to specification ASTM D2000 M3 BA710 A14 B13 F17 Z1. Material specification for the EPDM O-ring is provided in CM076. The phenolic resin foam (TISAF) and the aluminum honeycomb are manufactured to specifications CM066 and CM077, respectively. These specifications are provided in Section 1.3 of the SARP. The lead-alloy shielding contains 4% antimony and the lead-alloy filling procedure is described in CTN 2000/02, which is also provided in Section 1.3 of the SARP.

The maximum allowable temperature limits for the EPDM O-rings, specified in the SARP, are 125°C (257°F) for the normal conditions of transport, and 200°C (392°F) for the hypothetical accident conditions. These limits are acceptable because the results of the tests, reported in the supporting document CTR 97/28 in Section 4.5 (Appendix B) of the SARP, show that ethylene propylene O-rings can provide leak tight seals over a temperature range of -40°C (-40°F) to 125°C (257°F) for continuous operation, and to 200°C (392°F) for 4 hours and 10 minutes.

The maximum allowable temperature limit for the phenolic resin foam (TISAF), specified in the SARP for the normal conditions of transport, is greater than 140°C (284°F). This temperature limit is acceptable because the test results, presented in CTR 97/22 in Section 2.10, Appendix C, of the SARP, show that TISAF is unaffected by temperatures up to approximately 140°C (284°F) and pyrolysis of the foam begins at temperature approximately above 220°C (428°F).

The maximum temperature limit of the lead-alloy shielding is the solidus temperature of the lead with 4 wt.% antimony. This temperature is specified as 252°C (486°F) in the SARP, which is acceptable because it agrees with the solidus temperature in the literature, "Lead for Corrosion Resistant Applications-A Guide," published by the Lead Industries Association, and "Constitution of Binary Alloys," M. Hansen, 2nd Ed., 1958.

For the liquid metal targets in Contents Types VI, the thermal test specified in 10 CFR 71.75 is not required since the testing carried out on the complete SAFESHIELD 2999A packaging, as reported in Sections 2.7.3 and 3.5.3 of the SARP, showed that the maximum temperature of the contents of the package would be less than the design bounding temperature of 200°C (392°F).

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model

3.4.1.1 SARP Analysis

The SARP used tests and analyses to evaluate the thermal performance of the packaging during normal conditions of transport. The tests were used to determine the temperature rise due to internal heating of the contents. The effects of ambient temperature and solar heating on packaging temperatures were determined by analyses.

For the steady-state thermal test, the SAFESHIELD 2999A was modified according to drawing 2C-4576. The test plan and procedure is described in CP 216, Issue A in Chapter 2, Appendix B of the SARP. An electric heater was placed inside an aluminum housing located in the centerline of the flask. The assembled packaging was placed in an ambient environment at 23°C (73°F).

Temperature indicating labels and thermocouples were used to measure the temperatures at various locations inside and outside of the packaging with an internal heat load of 250 W. The thermocouples inside the packaging indicated that the packaging had reached thermal equilibrium with the environment at approximately 92 hours after the heater was turned on. The test was continued for another 48 hours during which the temperatures were stable. The maximum steady-state temperature rise due to internal heating was then measured.

The effect of combined solar and internal heating was estimated by using the finite element computer code FEAT. The temperatures at various locations of the packaging for an ambient condition of 38°C (100°F), internal heat source of 250 W, and various insolation rates on the external surfaces of the packaging were then calculated. Details of the finite-element model and results are described in the report SA/PSS/13942/W1, which is in Appendix B of Chapter 3 in the SARP.

3.4.1.2 Staff Evaluation

Since the packaging is axisymmetrical, the staff confirmatory analyses used a two-dimensional, radial versus axial, model to represent the geometry of the packaging. The analyses were performed for the ambient temperature of 38°C (100°F), with and without solar heat load as specified in 10 CFR 71.71(c)(1). Solar heating was imposed on the external surfaces of the packaging for 12 hours. Because the content heat generation is through gamma radiation, the internal heat generation was modeled by assuming that 90% of the internal heat (225 W) is deposited in the first 5 cm (2 in) of the lead-alloy shielding adjacent to the cavity of the flask. The rest of the 10% of the internal heat (25 W) is assumed deposited in the surrounding lead-alloy shielding. The results of the analysis was used to determine the maximum external surface temperature and provided the initial condition for the subsequent hypothetical accident event analysis. The analyses were performed using the HEATING7 module of the SCALE computer code.

3.4.2 Maximum Temperatures

The maximum temperatures from the SARP test data and analyses and the staff's confirmatory evaluation, together with the allowable temperature limits, are presented in Table 3.1. The allowable temperatures for various components are obtained from Section 3.2 of the SARP.

Table 3.1 shows relatively large differences in the calculated temperatures at various locations in the packaging between the SARP and the staff's confirmatory evaluation. Detailed evaluation of the finite element thermal analysis provided by the applicant is documented in a separate report (Y. S. Cha, Evaluation of the Report SA/PSS/13942/W1, SAFESHIELD 2999A - Thermal FEA for NCT and HAC, Argonne internal report, July, 2004). The main causes for the differences are the assumed values for the solar heating rate and the solar absorptivity. In the applicant's model, the insolation on the side surface of the package is assumed to be 200 W/m^2. However, the side surface is curved, and therefore a surface heat flux of 400 W/m^2 should be used irrespective of whether the surface is vertical or horizontal. The surface absorptivity of the packaging used in the SARP calculation is 0.2. This value is not justified because of the large uncertainty associated with the absorptivity, and it is usually conservative to assume a value close to unity.

Table 3.1 Summary of Calculated Temperatures during NCT

Component	SARP	Staff	Allowable
Max. surface temperature	54°C (129°F)	85°C (185°F)	---
Flask flange (O-ring) temperature	83°C (181°F)	120°C (248°F)	125°C (257°F)
Max. Pb-4 wt.% Sb temperature	91°C (196°F)	122°C (252°F)	252°C (486°F)
Max. TISAF temperature	66°C (151°F)	116°C (241°F)	≤ 140°C (284°F)
Max. Al honeycomb temperature	74°C (165°F)	117°C (243°F)	≤ 200°C (392°F)
Max. external surface temperature in the shade	49°C (120°F)	52°C (126°F)	50°C (122°F)*

*The allowable surface temperature of 50°C (122°F) for the package in the shade is for non-exclusive use shipment based on 10 CFR 71.43(g).

Table 3.1 also shows that even though there are significant differences in the results between the SARP and the staff's confirmatory calculations, the higher calculated temperatures for the various components in the package are still below the allowable limits. The closest one is between the calculated and the allowable temperatures, 120 and 125°C, respectively, for the O-ring seal of the flask. The rest of the calculated temperatures are well below the allowable temperatures under the NCT conditions (except the external surface temperature in the shade). The calculated maximum temperature of the lead-alloy shielding (122°C) is well below the solidus temperature of the Pb-4 wt.% Sb (252°C) shield. The calculated maximum temperature of the TISAF foam (116°C) is below the allowable temperature of 140°C under continuous operation. The calculated maximum aluminum honeycomb temperature is 117°C, which is well below the allowable temperature of 200°C under continuous operation.

The staff-calculated maximum external surface temperature of the packaging in the shade is 52°C, versus 49°C of the SARP. Since the staff's evaluation of 52°C is more conservative and exceeds the allowable maximum surface temperature (50°C) for non-exclusive use shipment per 10 CFR 71.43(g), the packaging must be shipped in exclusive use vehicles if no measure is taken to reduce the maximum surface temperature. Tables 1.1-I to 1.1-III for Contents Types I, II, and III in Chapter 1 of the SARP specify the requirement of exclusive use shipment whenever the contents heat output is greater than 200 W.

3.4.3 Minimum Temperatures

The minimum temperature of the package with no heat load will be –40°C (–40°F) when exposed to an ambient temperature of –40°C (–40°F) in still air and shade. This condition is the coldest regulatory environment specified in 10 CFR 71.71(c)(2). The tests conducted on the EPDM O-rings and presented in CTR 97/28 in Section 4.5 (Appendix B) of the SARP demonstrate that the O-rings provide leak tight seal at low temperature down to –40°C (–40°F).

3.4.4 Maximum Internal Pressures

The maximum internal pressure under NCT, calculated in CS 97/51, Issue B, Section 2.10, Appendix C of the SARP is 1.38 bar (20.1 psia) based on a maximum temperature of 100°C during NCT. Using the staff-calculated maximum temperature of 122°C during NCT, the maximum internal pressure is 1.47 bar (21.4 psia). The small difference in the maximum internal pressures during NCT would have no adverse effects on the containment vessel (Flask 2993).

3.4.5 Maximum Thermal Stresses

The maximum temperature drop across the lead-alloy shielding is 3°C from the analysis presented in the SARP and 4.4°C from the staff's confirmatory evaluation. This translates into a maximum temperature gradient of 20°C/m for the lead-alloy shielding. The relatively small temperature gradient in the flask is the result of fairly high thermal conductivity of the lead alloy. The body shell and the cavity liner of the flask are made of stainless steel which also has a very small temperature gradient because it is very thin and has relatively high thermal conductivity. These relatively small temperature gradients, i.e., ΔT over distance, are not likely to cause any significant thermal stresses [on the order of $(\alpha\Delta T)E$] for the flask containment (all the components have the same coefficient of thermal expansion, α, and Young's modulus, E).

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The results of the SARP test and analyses and the staff's confirmatory analyses show that the maximum temperatures of the safety-related components in a SAFESHIELD package during normal condition of transport do not exceed the allowable limits. The results also show that the package surface temperature exceeds the thermal requirements of 10 CFR 71.43(g) and requires exclusive use shipment for content heat load of 250 watts.

3.5 Hypothetical Accident Thermal Evaluation

3.5.1 Thermal Model

3.5.1.1 SARP Analysis

The SARP used a pool fire test (without internal heat source), internal heat test, and analyses to evaluate the thermal performance of the packaging during a hypothetical accident thermal event. The fire test was performed to determine the temperature rise due to external heat of a fire. The test procedures and results of the fire test are described in CTR 97/33, Section 2.10, Appendix B of the SARP. The effects of internal heating on packaging temperature rise were determined by test using an electric heater. The combination of internal heating and external fire are analyzed using a finite-element code and the results are documented in the report SA/PSS/13942/W1, which is in Appendix B of Chapter 3 in the SARP.

For the fire test, temperature-indicating labels were mounted on the inside and outside surfaces of the flask, and near the seals of the containment flask to record the maximum temperatures achieved during the test. Thermocouples were mounted on the outside surface of the casket to measure the surface temperatures during the test. The hypothetical accident tests were performed in a sequential order as specified in 10 CFR 71.73. The thermal test was performed after the packaging had been subjected to a 9-m (30-ft) drop and a 1-m (40-in) puncture test.

In the fire test, the packaging, with a simulated content but without internal heat source, was placed in a pool fire test facility at Winfrith, Dorset, U.K. The pool was flooded with 8,000 liters of kerosene. The pool test facility was instrumented with four digital flame thermocouples (DFTs) and a wind speed and direction monitor. The test packaging was then fully engulfed in the fire for 32 minutes after the start of the fire. During this period, the average wind speed was 1.21 m/s and the average temperature of the DFTs was 962°C, although one of the DFTs in the north indicated a temperature below 800°C over a portion of the test. The actual period that the average temperature of the DFTs was above 800°C was 36.5 minutes. The average temperature of the thermocouples mounted on the external surface of the casket was 857°C during the fire test, although one of the thermocouple near the bottom of the casket showed an average temperature of only 771°C. After the fire was extinguished, the packaging was allowed to stabilize and cool naturally overnight in an open environment.

The fire test was an overtest because the average temperature of all the DFTs and all the external thermocouples was above 800°C for more than 30 minutes. The actual period that the average DFT temperature remained above 800°C was 36.5 minutes. Therefore, it satisfies the requirements specified in 10 CFR 71.73(c)(4). This conclusion from the SARP is confirmed by the staff's analysis described in Sections 3.5.2 and 3.5.3 of this SER.

The packaging maximum temperatures for the hypothetical accident test conditions specified in 10 CFR 71.73(c)(4), were calculated by using the finite element code FEAT. Detailed model and results are described in the report SA/PSS/13942/W1, which is in Appendix B of Chapter 3 in the SARP.

3.5.1.2 Packaging Conditions and Environment

The thermal test on the packaging was performed after the packaging had been subjected to a 9-m (30-ft) drop and a 1-m (40-in) puncture test. The drop and puncture tests caused only minor denting in the impact region of the Casket 2999. The casket remained intact even though six studs were sheared off. There was no splitting of the casket skin and no cracking of the weld, and no visible signs of damage to the TISAF foam insulation. The aluminum honeycomb in the casket was partially crushed. The containment vessel (Flask 2993) suffered only a small dent near its base and the flask closure remained leak tight.

The examination of the packaging after the thermal test showed no visible signs of damage to the containment vessel (Flask 2993), the O-rings, and the O-ring grooves. In some locations, the TISAF foam was found to shrink from its original thickness of 42 mm to approximately 32 mm due to pyrolysis (chemical change induced by heat). There was a total weight loss of 30 kg for the packaging after the fire test. Cracks were found in the TISAF foam even though the foam was still largely intact and did not break down into small pieces or powder. Some charring and discoloring occurred in the TISAF foam. The containment flask remained leak tight after the fire test.

3.5.2 Staff Evaluation

For the hypothetical accident thermal event, the staff analyses used the same geometrical model that was used for the normal conditions of transport. The internal heat distribution used in the calculation was also the same as that in the NCT calculation, i.e., 90 % of the internal heat (225 W) was assumed to be deposited in the first 5 cm of the Pb-4 wt.% Sb shielding adjacent to the cavity of the flask and the rest of the 10% of the internal heat (25 W) was assumed to be deposited in the surrounding lead alloy. To account for the effect of loss of TISAF foam due to evaporation during the fire test, it was assumed that 10 mm (out of a total of 42 mm) of the TISAF foam was evaporated completely from the beginning. This is a conservative assumption because (1) it took finite time to evaporate the 10-mm-thick TISAF foam, and (2) the effect of latent heat of vaporization was neglected. During the hypothetical accident period of 30 minutes, the radiation environment temperature was set to 800°C (1475°F) with an emissivity coefficient of 0.9. The forced convective heat transfer coefficient of 20 $W/m^2 \, ^oC$ ($3.5 \, Btu/h \cdot ft^2 \, ^oF$), appropriate for a flow velocity of 10 m/s (32.8 ft/s), was applied at the packaging surface. The heat transfer coefficient appropriate for a flow velocity of 10 m/s (32.8 ft/s) was selected because the IAEA guidelines A-628.20 in Safety Series No. 37, Third Edition, suggest that the convective flow velocity is in the range of 5 to 10 m/s (16.4 to 32.8 ft/s) during the fire portion of the hypothetical accident thermal event.

For conservatism, the staff evaluation considered insolation during the post fire accident period. Also, during the pre- and post-fire accident periods, the packaging surface emissivity was reduced to 0.15 and the forced convection coefficient was set to zero. The analyses were performed using the HEATING7 module of the SCALE computer code.

3.5.3 Package Temperatures

The results of the SARP test and analyses and the staff's confirmatory evaluation are shown in Table 3.2, along with the allowable temperature limits. The allowable temperatures are obtained from Section 3.2 of the SARP.

There are minor differences between the analysis from the SARP and the staff's confirmatory analysis. More detailed evaluation of the SARP results can be found in reference 1 in Section 3.7 of this SER. The important results are that the calculated peak temperatures of the key components of the packaging, from the SARP and the staff's confirmatory analysis, are all lower than the allowable temperatures for the hypothetical accident conditions. Therefore, the O-ring will survive and the lead-antimony shielding will not melt under the hypothetical accident conditions. Furthermore, the pool fire test also demonstrated that these temperatures are within the acceptable levels. Therefore, it is concluded that the temperatures of various components in the SAFESHIELD package satisfy the requirements in 10 CFR 71.73 under HAC.

The staff's confirmatory analysis shows that the maximum temperature of the TISAF foam insulation is very high and well exceeds the pyrolysis temperature of 220°C. Therefore, the assumption that 10 mm (out of a total of 42 mm) of the TISAF foam was evaporated is appropriate.

Table 3.2 Summary of temperatures at various locations under HAC

Location	SARP	Staff	Allowable
O-ring seal temperature	132°C (270°F)	144°C (291°F)	200°C (392°F)
Max. lead temperature	139°C (282°F)	146°C (295°F)	252°C (486°F)
Max. casket surface temperature	752°C (1386°F)	782°C (1440°F)	---
Max. cavity temperature	148°C (298°F)	146°C (295°F)	---

3.5.4 Maximum Internal Pressures

The maximum internal pressure under NCT, calculated in CS 97/51, Issue B, Section 2.10, Appendix C of the SARP is 1.76 bar (25.5 psia) based on a maximum temperature of 200°C during HAC. Using the staff-calculated maximum temperature of 146°C during HAC, the maximum internal pressure is 1.56 bar (22.6 psia). The small difference in the maximum internal pressures during HAC would have no adverse effects on the containment vessel (Flask 2993).

3.5.5 Maximum Thermal Stresses

The maximum temperature gradient in the lead-antimony shielding is 66°C/m from the finite element analysis provided in the SARP. The staff's confirmatory analysis shows that the maximum temperature gradient in the lead-alloy shielding is less than 30°C/m. These temperature gradients are relatively small and neither should cause significant thermal stresses [on the order of $(\alpha\Delta T)E$] in the flask containment (all the components have the same coefficient of thermal expansion, α, and Young's modulus, E). These small temperature gradients are the results of relatively high thermal conductivity and large masses of the lead-alloy shielding. Furthermore, it was demonstrated that the SAFESHIELD packaging survived the pool fire test, which is an overtest that exceeded the requirements specified in 10 CFR 71.73(c)(4), with the containment flask intact and leak tight. The pool fire test also demonstrated that the thermal stress in the casket is insignificant because the casket also survived the test intact.

3.5.6 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

The SARP has demonstrated and the staff evaluation has confirmed that the SAFESHIELD packaging is able to maintain the containment boundary below the maximum allowable temperature limits and the SAFESHIELD packaging can provide adequate thermal protection under the hypothetical accident conditions.

3.6 Conclusion

Based on the statements and representations in Chapter 3 of the SARP and the staff's confirmatory evaluation, the staff concludes that the thermal design has been adequately described and evaluated. The staff concludes that the thermal performance of the SAFESHIELD 2999A package will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

4. CONTAINMENT

The SAFESHIELD 2999A packaging is designed to be used as a general purpose container for the shipment of radioactive material in special form capsules, welded capsules not classified as special form, capsules having a removable top, accelerator targets containing solid, liquid metal and gaseous radioactive material, stainless-steel canister containing ion exchange resins, and aluminum canister containing radioactive waste material. Content Types I to VI are described in Tables 1.1-I to 1.1-VI of the SARP. Except Contents Types VI, all other contents are solid with no presence of water and the loading shall take place in a dry environment. No organic materials are allowed in the cavity of Flask 2993. Fissile materials and irradiated materials containing fission products are not permitted. The only pyrophoric material to be carried is rubidium in the liquid metal target for Contents Types VI. However, no inerting is required as the rubidium is carried in a target cell with a target capsule as described in Page 2-26A of Chapter 2 of the SARP. The radionuclide limits are given in Tables 1.2 and 1.3 of the SARP.

4.1 Containment Boundary

The containment boundary of the packaging is the containment vessel of Flask 2993, the elements of which are the cavity liner, top flange, closure flange, sixteen (16) M12 ASTM SA193 Grade B8M Class 1 stainless-steel screws, and the inner O-ring fitted to the flask closure, together with the associated circumferential weld. The Flask 2993 has an overall height of 912 mm (35.91 in) and an overall diameter of 669 mm (26.3 in), and the cavity dimensions are an overall height of 400 mm (15.75 in) and an overall diameter of 220 mm (8.66 in). The containment vessel cavity liner (drawing 2C-4499, Issue D) is machined from a Type 304L (ASTM SA 479) solid stainless-steel billet and welded to a 220 mm (8.66 in) ID top flange body resulting in the cavity assembly (drawing 2C-4492, Issue D). This is the only weld in the containment boundary. The Type 304L (ASTM SA 240 or SA 479) stainless-steel top flange (drawing 2C-4500, Issue D) is provided with grooves for two O-ring seals and mates to the Type 304L (ASTM SA 240 or SA 479) stainless-steel closure flange (drawing 1C-4508, Issue D), having a deep spigot that fits into the top of the top flange. Access in the closure flange to the interspace between the two O-rings is provided by a test port for leak testing. The test port is not a part of the containment boundary. The outer O-ring of the containment vessel and the associated test port seals in the closure flange are also not part of the containment boundary.

The closure flange is fastened to the top flange by sixteen (16) M12 screws. The Flask 2993 is a pressure vessel designed, analyzed (using nominal dimensions for the vessel components), fabricated, examined, and tested in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB. The containment vessel is fabricated from Type 304L (ASTM SA 479) stainless steel. The containment vessel body is fabricated per manufacturing specification, MSP 083, Issue A, by welding together the two pieces with a full penetration circumferential weld. All containment welding consumables, their supply, certification, control during storage, and use, shall comply with the appropriate requirements of ASME III – Division 1, Subsection NB-2400. The containment boundary weld is dye-penetrant and radiographically inspected in accordance with Section III, Division I, Subsection NB-5000 of the ASME Boiler and Pressure Vessel Code. Two concentric grooves are machined in the face of the top flange for installation of the elastomer O-rings.

The closure flange (drawing 1C-4508) machined from a Type 304L (ASTM SA 240 or SA 479) stainless steel forging completes the assembly. The machined closure flange has a drilled hole providing a leak-check port between the elastomer O-rings. The sixteen M12 closure screws are torqued to 25 ± 2 N-m (17 ± 1.4 ft-lb) to close the containment boundary and satisfy the requirement in 10 CFR 71.43(c). There are no penetrations into the containment boundary. The closure flange is recessed into the containment body, thus reducing the vulnerability of the closure from impact damage.

The containment vessel O-rings are manufactured from ethylene propylene (EPM) specified to the requirements contained in ASTM D-2000 as follows: M3 BA710 A14 B13 F17 Z1 hardness 75 ± 5 IRHD (as described in CM 076). The seal materials of the O-rings in the containment vessel of the Flask 2993 have been shown to remain leaktight over the design temperature range of -40°C to 200°C (-40°F to 392°F). The effectiveness of the seals has been shown in a test program reported in CTR 97/28, Issue A, included in Appendix B of Chapter 4 of the SARP. The temperatures that the Flask 2993 O-ring seals might experience under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) are less than the design temperature range. Of the two O-rings, only the inner O-ring is part of the containment boundary.

The EPM O-rings have a nominal operating temperature range of -50°C to 135°C (122°F to 275°F) and retain adequate sealing properties during temperature excursions up to 150°C (302°F). Design seal compression is 20.5% (based upon worst-case tolerance) and 19.8% (based upon low-temperature effect), which are in the acceptable range found in the literature. Tests conducted on the EPM O-ring and presented in report CTR 97/28 in Section 4.5 of Appendix B demonstrated that the O-rings are leaktight over the temperature range -40°C to 200°C (-40°F to 392°F), which is greater than the operating temperature range of -40°C to 182°C (-40°F to 360°F). These tests included the effects of temperature cycling over the maximum temperature range that could be encountered during normal or hypothetical accident conditions of transport. The seal compression for the tests is 21.8% (21.1% including the low temperature effect).

Acceptability of these temperature specifications is demonstrated in Sections 3.4.2 and 3.5.3 of the SARP for NCT and HAC, respectively.

The containment boundary of the packaging defined for the packaging applies to all Contents Types described in Tables 1.1-I to 1.1-VI of the SARP. For Contents Type VI, the irradiated LMP metal accelerator targets are encapsulated in a target cell and carried in a target capsule. The target capsule provides additional containment function under HAC.

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of radioactive material

The release criteria for the containment boundary is that there shall be no loss or dispersal of radioactive contents - as demonstrated to a sensitivity of 10^{-6} A_2 per hour under the NCT per 10 CFR 71.51(a)(1). The release requirements under NCT have been shown to be satisfied by testing of a prototype packaging in the SARP (CTR 97/33, Section 2.10, Appendix B). The containment vessel of the Flask 2993 was tested for leakage after the test sequence and the results showed that the containment boundary was leaktight against the requirements in ANSI 14.5 American National Standard for radioactive materials – leakage tests on packages for shipment. The leakage rate requirements are 10^{-7} ref cm^3/s for design and fabrication verification, and 10^{-3} ref cm^3/s for assembly verification. The unit for the leakage rate, ref cm^3/s, refers to standard conditions of dry air at 1 atmosphere (atm) absolute pressure (101 kPa) and 298 K (25°C).

The SARP states "Containment of gaseous radioactive contents is shown in CS 2004/04, Issue B to be within the regulatory limit for NCT of 10^{-6} A_2/hr; these calculations are based on conservative assumptions." The staff reviewed CS 2004/04, Issue B and confirmed the basis and the results for the NCT calculations.

4.2.2 Pressurization of containment vessel

The SARP states "The only significant mechanism for pressurization of the cavity of the containment vessel of Flask 2993 is that due to temperature change." This statement is true if there are no other mechanisms of gas generation in the contents and from interaction with the environment. Hydrogen gas generation due to radiolysis of hydrogenous material, helium gas generation due to (n, α) reaction in the target material, and combustible gas generation from pyrophoric material are among the mechanisms of gas generation in the contents and from interaction with the environment. The SARP has addressed the issue of hydrogen gas generation by excluding hydrogenous/organic materials from the contents (Page 1-11 of the SARP); the issue of helium gas generation (Page 1-12 of the SARP) by the absence of (p, α) reactions in target irradiation by protons; and the issue of combustible gas generation (Page 1-12 of the SARP) by noting that rubidium is the only pyrophoric material present in Contents Type VI target cells, which are carried in target capsules. All the materials listed in Table 1.2 (except Co-60, Cs-137, and Ir-192) are present as products of accelerator irradiation (typically < 0.1% of the total contents) and therefore do not represent a pyrophoric concern.

4.3 Requirements for Hypothetical Accident Conditions

4.3.1 Fission gas products

All radioactive gasses listed in Table 1.2 of the SARP, including Kr and Xe, originate from irradiation of the accelerator targets, not by irradiation of fissile materials. Fissile materials and irradiated fissile materials containing fission products are not permitted in the package.

4.3.2 Containment of radioactive material

The release criteria for the containment boundary is that there would be no escape of krypton-85 exceeding 10 A_2 in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week. The release requirements under HAC have been shown to be satisfied by testing of a prototype packaging in the SARP (CTR 97/33, Section 2.10, Appendix B). The containment vessel of the Flask 2993 was tested for leak after the test sequence and the results showed that the containment boundary was leaktight against the requirements in ANSI 14.5 American National Standard for radioactive materials – leakage tests on packages for shipment. The leakage rate requirements are 10^{-7} ref cm^3/s for design and fabrication verification, and 10^{-3} ref cm^3/s for assembly verification. The unit for the leakage rate, ref cm^3/s, refers to standard conditions of dry air at 1 atmosphere (atm) absolute pressure (101 kPa) and 298 K (25°C).

The SARP states "Containment of gaseous radioactive contents is shown in CS 2004/04, Issue B to be within the regulatory limit for HAC of 10 A_2/week for Kr-85 or A_2/week for other radionuclides." The staff reviewed CS 2004/04, Issue B and confirmed the basis and the results of the calculations.

4.3.3 Maximum internal pressure

Section 4.2.2 of the SARP states "The only significant mechanism for pressurization of the cavity of the containment vessel of Flask 2993 is that due to temperature change." This statement is true if there are no other mechanisms of gas generation in the contents and from interaction with the environment. Hydrogen gas generation due to radiolysis of hydrogenous material, helium gas generation due to (n, α) reaction in the target material, and combustible gas generation from pyrophoric material are among the mechanisms of gas generation in the contents and from interaction with the environment. The SARP has addressed the issue of hydrogen gas generation by excluding hydrogenous/organic materials from the contents (Page 1-11 of the SARP); the issue of helium gas generation (Page 1-12 of the SARP) by the absence of (p, α) reactions in target irradiation by protons; and the issue of combustible gas generation (Page 1-12 of the SARP) by noting that rubidium is the only pyrophoric material present in Contents Type VI target cells, which are carried in target capsules. All the materials listed in Table 1.2 (except Co-60, Cs-137, and Ir-192) are present as products of accelerator irradiation (typically < 0.1% of the total contents) and therefore do not represent a pyrophoric concern.

For the liquid metal accelerator targets in Contents Type VI, the target cells are carried in target capsules which provide additional containment function under HAC. TR04/09/01 in Appendix

B, Chapter 2 of the SARP describes the procedures and test results for the LMP target capsules, and the staff's evaluation of TR04/09/01 is described in Section 2 of this SER.

4.4 Special Requirements

For Contents Type VI, the irradiated liquid metal target cells are carried in target capsules which provide additional containment function under HAC. The test results in TR04/09/01 of Appendix B, Chapter 2 of the SARP showed that the target capsule can provide additional containment function under HAC.

4.5 Conclusion

Based on the statements and representations in Chapter 4 of the SARP and the staff's confirmatory evaluation, the staff concludes that the containment boundary of the SAFESHIELD 2999A packaging will not release radioactive material in excess of the regulatory limits under NCT and HAC, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

5. SHIELDING

5.1. Discussion

Section 5.1 of the SARP describes the approach and the major assumptions of the shielding evaluation for Contents Types I to VI and presents a summary of maximum exposure rates calculated assuming a point source of 16.2 kCi Co-60 under NCT and HAC. The results showed that the exposure rates would exceed those allowed for non-exclusive use shipment per 10 CFR 71.47(a), but not for exclusive use shipement per 10 CFR 71.47(b). For all other radionuclides (excluding Co-60, Cs-137, and Ir-192) listed in Table 1.2 of the SARP that may be present in Contents Types III, IV, V, and VI, the activity limit set for the package for mixtures of radionuclides result in calculated exposure rates below those allowed under non-exclusive use shipment per 10 CFR 71.47(a).

Details of the shielding evaluation are documented in Appendix B, Chapter 5 of the SARP in (1) CS 2005/01, Issue A, "2999A Shielding Assessment – Dose Rate Calculations for 16.2 kCi Co60 Contents as a Point Source," May 31, 2005; (2) CTR 2004/03, Issue B, "SAFESHIELD 2999A – Activity Limits for individual Radionuclides," May 12, 2005; (3) CS 2004/06, Issue B, "2999A Shielding Assessment - NCT: Activity Limits for Photons by Energy Group," May 31, 2005; and (4) CS 2004/05, Issue A, "2999A Shielding Assessment – HAC: Streaming at Flask Plug," April 17, 2004. Microshield code (version 6.02) was used in all the shielding evaluations.

The staff evaluation of the shielding analysis and results is presented in subsections 5.1 to 5.4 of this SER.

5.2 Source Specification

5.2.1 Gamma Source

The activity limits of 16.2, 55, and 43.9 kCi for Co-60, Cs-137, and Ir-192, respectively, in Contents Types I and II are based on a decay heat limit of 250 W for the package (see Table 1.3 of the SARP and Page 3, CR 2004/03, Issue B, Appendix B, Chapter 5 of the SARP). The limiting gamma source assumed for shielding evaluation in Chapter 5 of the SARP is a point source of 16.2 kCi Co-60 located at the appropriate inner surface (side, top, and base) of the contaiment cavity (CS 2005/01, Issue A). The staff has confirmed that a point source of 16.2 kCi of Co-60 would bounnd the exposure rates of a point source of 55 kCi of Cs-137 or 43.9 kCi of Ir-192.

For Contents Types III, IV, V, and VI that do not contain Co-60, Cs-137, or Ir-192, the acitivty limit in Ci is specified for each radionuclide listed in Table 1.2 of the SARP. The activity limits for the majority of radionuclides in Table 1.2 are less than 1,000 Ci and are calculated based on a point source at the center of the containment cavity (CS 2004/06, Issue B, Appendix B, Chapter 5 of the SARP). The activity limits for tritium, argon, krypton, and xenon in Table 1.2 are calculated based on limits of user volume and leak rate (CTR 2004/03, Issue B, Appendix B, Chapter 5 of the SARP). For mixtures of radionuclides (excluding Co-60, Cs-137, and Ir-192), the total activity is limited such that the sum of the proportionate amounts of each radionuclide with repsect to its activity limit in Table 1.2 does not exceed unity, i.e.,

$$\{\sum (A_i / L_i)\} \leq 1, i = 1 \text{ to } n \qquad (1)$$

where A_i and L_i are the actual activity and the activity limit in Table 1.2, respectively, for radionuclide i. The summation rule ensures that the total activity for mixtures of any radionuclides will not exceed 1,000 Ci for Contents Types III, IV, V, and VI. The calculated exposure rates for these Contents Types, therefore, are bounded by the maximum exposure rates calculated for a point source of 16.2 kCi of Co-60. The staff has confirmed the calculation results provided in CS 2004/06, Issue B and CTR 2004/03, Issue B.

For radiation streaming calculations during HAC, the SARP assumed a point source of Co-60 positioned such that the calculated dose rate through any gaps within the shield plug/body interface is maximized. Details of the calculations and results are documented in CS 2004/05, Issue A in Appendix B, Chapter 5 of the SARP. The staff's confirmatory evaluation of radiation streaming is given in Section 5.4 of this SER.

5.2.2 Neutron Source

Contents Types I to VI do not include neutron-emitting radionuclides or neutron sources from the (α, n) reactions.

5.3 Model Specification

5.3.1 Description of the Radial and Axial Shielding Configuration

The Microshield models used in the calculations are idealized versions of the the SAFESHIELD 2999A packaging shown in Figs. 1-1 and 1-2 of the SARP, with components configured such that displacements and deformation appropriate for NCT and HAC are accounted for conservatively for the 16.2 kCi Co-60 point source located at appropriate inner surface of the containment cavity. Three shielding configurations are considered and the details are given in Tables 5.2, 5.3, and 5.4, respectively, for the top axial shielding model, the radial shielding model, and the base axial shielding model. Each model includes the various shield regions, dimensions under routine, NCT, and HAC conditions, and materials and densities assumed in the calculations.

5.3.2 Shielding Regional Densities

The dimensions, material, and density for the various shielding regions in the Microshield calculations are listed in Tables 5.2 to 5.4 for the three shielding configurations. Under NCT the air gaps due to normal clerances are assumed closed or removed, with no change in the external packaging dimensions because there was no significant damage to the packaging during the NCT tests (see Appendix B, Chapter 2 of the SARP). For HAC and based on the damage observed in the HAC tests (Appendix B, Chapter 2 of the SARP), the thickness of the aluminum honeycomb was reduced to account for the impact deformation; all TISAF was assumed to have burnt and replaced by air; the surface of the casket was assumed radially deformed inward by 25 mm (the depth of the dent caused by the puncture test); and the air gaps (including those resulting from the crush of the alumnum honeycomb) were assumed closed to minimize the distance between the source and the external surface of the casket.

For exclusive use shipment, the dose rates are calculated at the appropriate surface of the vehicle (top, side, and underside) and at 2 m away from the appropriate surface of the vehicle, with air assumed to be present between the surfaces. The vehicle gap distance was based on a SeaLand container (2.6 m high and 2.4 m wide), with the 2999A packaging (1.4 m high and 0.84 m diameter) centrally located in the SeaLand container (see Fig. 5.1 of the SARP).

5.3.3 Buildup Factors

Within the point kernel modeling approach in the Microshield code and other similar codes, the exposure buildup factor is a critical parameter because it is the ratio of the broad beam gamma flux to the narrow beam gamma flux that accounts for photon scattering and amplifies the calculated dose rates. The exposure buildup factors can vary over a wide range depending on the source-shield geometry, source energy, shield thickness, shield material, and detector response (See N. M. Shaeffer, "Reactor Shielding for Nuclear Engineers," USAEC, Office of Information Service, 1973, p. 284-286). The buildup factors employed in the Microshield calculatons in CS 2005/01, CS 2004/06, CTR 2004/03, and CS 2004/05 in Appendix B, Chapter 5 of the SARP were default values selected by the code. Tables 4, 5, and 7 in CS 2005/01 show that in calculations for a point source of Co-60 next to a 21.3-cm-thick side shield, the buildup factors for the dominant gamma photons (1.17 and 1.33 MeV) are 6.18 and 6.337, respectively, for a Pb-4%Sb alloy (Table 7), which are higher than the buildup factors (5.327 and 5.563) for pure Pb (Table 4), but lower than the buildup factors (7.596 and 7.041) for pure Sb (Table 5). These buildup factors are in the similar range (5.64 to 8.75) of the buildup factors for lead glass (55%PbO_2-34.5%SiO_2-5%BaO) listed in Table IV, "Interpolation of Gamma-Ray Buildup Factors for Point Isotropic Source with Respect to Atomc Number," Sakamoto et al., Nucl. Sci. & Engng, 100, 33-42 (1988).

The calculated maximum exposure rates will change with the buildup factors listed in CS 2005/01; however, the changes are not sufficient to alter the conclusions based on the results summarized in Table 5.1 of the SARP, i.e., the calculated exposure rates would exceed those allowed for non-exclusive use shipment per 10 CFR 71.47(a), but not for exclusive use shipment per 10 CFR 71.47(b).

5.4 Shielding Evaluation

5.4.1 NCT Shielding Evaluation

For non-exclusive use shipment per 10 CFR 71.47(a), the dose rates are limited to ≤ 200 mrem/h at the surface and ≤ 10 mrem/h (Transport Index TI = 10) at 1 m from the surface of the packaging (casket), with no significant increase in the dose rate duirng NCT. For exclusive use shipment per 10 CFR 71.47(b), the dose rates are limited to ≤ 1,000 mrem/h at the surface of the packaging (casket), ≤ 200 mrem/h at the side, top, and underside of the vehicle, and ≤ 10 mrem/h at 2 m from the side of the vehicle. The source geometry models employed in the Microshield calculations are summarized in Tables 5.2 to 5.4 of the SARP; the calculated maximum exposure rates are summarized in Table 5.1 of the SARP. The staff has confirmed the input parameters for the Microshield models and the maximaum exposure rates calculated based on a point source of 16.2 kCi of Co-60 located at the appropriate inner surface (top, side, and bottom) of the containment cavity. The staff has also confirmed that the limiting exposure rate occurs at the side, not at the top or bottom, of the package. The conclusion that the side configuration provides the limiting exposure rates applies to all other contents for the 2999A packaging.

The activity limits for all other radionuclides (except Co-60, Cs-137, Ir-192, and the gases tritium, argon, krypton, and xenon) listed in CTR 2004/03, Issue B in Appendix B, Chapter 5 and Table 1.2 of the SARP are determined in calculations by assuming a point source for each radionuclide located at the center of the containment cavity, and a limit for an exposure rate of 10 mrem/h at the side of the package at 1 m from the surface. The method utilized is summarized in the following steps:

(1) The abundance of photons resulting from the disintegration of each radionuclide are listed by the energy group in which they occur using data from the BNL data library. The abundance of photons resulting from the disintegration of each radionuclide is the probability per decay times 3.7×10^{10} disintegrations/s. The staff has confirmed the photon abundance values of randomly selected radionuclides listed in Table 1 of CTR 2004/03, using the Grove data library and the ICRP38 data library in RadDecay 2.0.

(2) The number of photons at the maximum energy for each group that results in an external exposure rate using the NCT model of 10 mrem/h at 1 m from the surface, has been calculated (CS 2004/06, Issue Isssue in Appendix B, Chapter 5 of the SARP). These calculations show a monotonically decreasing function that relates the photon energy to the allowable photon abundance for photons of that energy.

Table 2 in CS 2004/06 lists the permissible activities by photon energy where the values were calculated from a point source located at the cavity center of the flask. The permissible activity varied from 8.13 x 10^{24} Bq (2.20 x 10^{14} Ci) to 2.75 x 10^{12} Bq (74 Ci) for 0.5 and 6 MeV monoenergetic photons, respectively, for a limit of 10 mrem/h at 1 m based on the shield model for NCT described in Section 5.3 of the SARP. The staff has confirmed the results of these calculations.

(3) The allowable activity for each radionuclide is calculated by the following formula:

$$C = 1 / \sum (Ai / Gi),\ i = 1 \text{ to } n \qquad (2)$$

where C = allowable activity for each radionuclide; Gi = #/s of group i photons that result in external exposure rate of 10 mrem/hr at 1 m from the surface using the NCT model; Ai = photon abundance/s/Ci in each energy group; and n = number of energy groups (10).

Row 6 of Table 1, page 6 of CTR 2004/03 lists the values of the permissible activities (Bq) by energy groups calculated from a point-source model for NCT shield geometry described in CS 2004/06. (The permissible activities by energy groups are listed in Table 2 of CS 2004/06.) Using these values for Gi and the photon abundance values for Ai in Table 1 of CTR 2004/03, the staff has calculated the activity limits for selected radionuclides and compared them to those listed in Column T of Table 1 of CTR 2004/03. The comparison is summarized as follows:

(a) For element Be-7 that has a single photon in the energy range 300 to 500 keV, C = 1 / (Ai / Gi), i = 1, or Gi/Ai = (8.13e+24) / (3.84e+09) = 2.117e+15, which is in agreement with 2.12e+15 Ci listed in Column T of Table 1 of CTR 2004/03.

(b) For elements Na-24 or Al-26 that have photons in multiple energy ranges, the staff has confirmed the calculated limits for Na-24 (1.09e+2 Ci) and Al-26 (3.91e+2 Ci) listed in Columns T of Table 1 of CTR 2004/03.

(c) The package limits in Column U of Table 1 are set at 1,000 Ci for the majority of radionuclides for which the calculated limits in Column T for the radionuclides exceed 1,000 Ci. For cases where the calculated limits in Column T are less than 1,000 Ci, e.g., Na-24, S-37, Cl-34m, Cl-38, etc., the package limits in Column U for these radionuclides are set identical to the calculated limits in Column T. Exceptions are the package limits for Co-60, Cs-137, Ir-192; the gaseous radionuclides tritium, argon, krypton, and xenon; and Al-26 and Tc-97m which are based on other considerations. The staff has confirmed the basis for the calculations and the results of the activity limits for the radionuclides in Table 1 of CTR 2004/03, which are the same as those listed in Table 1.2 of the SARP.

The calculated activity limits for each radionuclide based on the photon energy groups in Page 5-7 of the SARP [and Eq. (2) in Section 5 of this SER] should not be confused with the total activity limits calculated for Contents III, IV, V, and VI, none of which contains Co-60, Cs-137, or Ir-192. The total activity limits for radionuclides in Contents Types III to VI are calculated based on the summation rule described in Tables 1.1-III to 1.1-VI of the SARP. The summation rule, which is shown as Eq. (1) in Section 5 of this SER, ensures that the total activity of the radionuclides in Contents Types III, IV, V, or VI will not exceed 1,000 Ci. The calculated dose rates for these Contents Types, therefore, are bounded by the maximum exposure rates calculated for a point source of 16.2 kCi of Co-60. The staff has confirmed the calculation results provided in CS 2004/06 and CTR 2004/03 in Appendix B, Chapter 5 of the SARP.

There is a requirement in Section 1.2.3.1 and Section 7.1.5 of the SARP that the contents inside the containment vessel shall be packed such that they cannot move within the cavity of the flask by more than 15 mm. Calculations based on displacing a point source of Co-60 from the center of the containment cavity by 15 mm produced a ≈7% change in the exposure rate at the surface of the packaging (casket). The variation of dose rates due to contents movement within the cavity during NCT is bounded by the maximum exposure rates summarized inn Table 5.1 under routine conditions and NCT.

Realistic gamma streaming calculations must use a Monte Carlo code that follows the trajectory of photons from the source and all subsequent transport paths through the shields and gaps. The staff has performed MCNP 4.2 calculations for a 3-D model of an undamaged SAFESHIELD packaging assuming a spherical source of 16.2 kCi Co-60 located at the center, bottom, and top corner of the cavity. The calculated surface exposure rate is the highest, i.e., 724 mrem/h ± 11% (1-σ), at the top surface of the package for the case where the source is located at the top corner of the cavity; the corresponding surface exposure rates at the side and bottom of the package are 519 mrem/h ± 13% (1-σ) and 20 mrem/h ±18% (1-σ), respectively. Thus the MCNP 4.2 calculated surface exposure rates at both the top and side of the package have exceeded the external surface dose rate limit (200 mrem/h) in 10 CFR 71.47(a) for non-exclusive use shipment; however, they are lower than the surface dose rate limit (1,000 mrem/h) in 10 CFR 71.47(b) for exclusive use shipment.

5.4.2 HAC Shielding Evaluation

Under HAC the dose rate at 1 m away from the external surface of the package is permitted up to 1,000 mrem/h per 10 CFR 71.51(a)(2).

The maximum exposure rates for HAC were calculated assuming a worst case contents of 16.2 kCi Co-60 as a point source located at the appropriate inner surface (side, top, and bottom) of the containment cavity (same as those assumed in the NCT calculations), and with maximum deformation of the packaging which could occur during the HAC tests. The flask was assumed displaced such that there are no clearances left between the flask and the casket. The aluminum shock absorber was assumed fully crushed, and the TISAF foam was assumed completely burnt and replaced by air. The casket surface was also assumed to deform radially inward by 25 mm, the displacement observed in the regulatory puncture test. The staff has confirmed the calculated maximum exposure rates under HAC in Cases 7, 8, and 9 of CS 2005/01, Appendix B, Chapter 5 of the SARP. The calculated maximum exposure rates at 1 m away from the side, top, and bottom surface of the package, 45.6, 2.3, and 32.4 mrem/h, respectively, are all significantly lower than 1,000 mrem/h permitted under 10 CFR 71.51(a)(2).

The possible effect of radiation streaming around the shielding plug assembly of Flask 2993 was evaluated in CS 2004/05 in Appendix B, Chapter 5 of the SARP. A point source model for 16,200 Ci of Co-60 was assumed present at five different locations at the side of the shield plug from near bottom to top of the cavity in the calculations of the exposure rates at the surface and at 1 m from the top of package, with the thickness of the aluminum honeycomb reduced by 120 mm. Table 5.1 shows the comparision of the calculated exposure rates from CS 2005/01 and CS 2004/05 for Line c and Line d, the two cases for which the point source of 16.2 kCi Co-60 was placed along the side of the shield plug near the top of the cavity. The calculated dose rates at 1 m away from the surface of the package, 49.2 and 74.4 mrem/h obtained from the Microshield radiation streaming calculations, while slightly higher than 45.6 mrem/h obtained for the standard HAC conditions, are still significantly lower than 1,000 mrem/h exposure rates permitted under 10 CFR 71.51(a)(2).

Table 5.1 Calculated dose rates at surface and 1m from surface
with a point source of 16.2 kCi Co-60

	Shield Thickness[3] (total/dominant), mm	Surface (mrem/h)	1 m (mrem/h)
Next to cavity wall[1]	(255.1/213.0)	1111	45.6
Line "c"[2]	(429.11/120.33)	548	49.2
Line "d"[2]	(430.17/116.64)	826.8	74.4

[1] Values from CS 2005/01, Issue A, May 31, 2005;
[2] Values from CS 2004/05, Issue A, April 17, 2004.
[3] Pb-4 wt.%Sb is the dominant shield in all cases; however, it is Shield #2 in "Next to cavity wall," Shield #4 in Line "c," and Shield #3 in Line "d" in the Microshield models for shields in these calculations.

The staff has also performed MCNP 4.2 calculation for a case assuming that the source of 16.2 kCi Co-60 is relocated and uniformly distributed in the gap space (≈8 mm in height) above the top plug and below the top flange of the flask. The calculated external exposure rate at the top surface is on the order of 10^7 mrem/h, indicating that the contents must not be a powder that might migrate to the gap space during NCT and HAC. Based on 14.7 g of Co-60 (calculated from 16.2 kCi of Co-60 and its specific acitivity of 1.1×10^3 Ci/g) and the Co density of 8.9 g/cc, the estimated particle size of Co-60 is 1.8 mm diameter with an avtivity of 40 Ci, which is much lower than 16,200 Ci. The special form sources in Contents Type I and the encapsulated materials in Contents Type II are to be carried in an outer carrier fittted to provide a means for handling, and the sources are to be packed so that they cannot move within the cavity of the flask by more than 15 mm under NCT, as required in Tables 1.1-I and 1.1-II of the SARP. The containment boundary of the flask is found to have remained leaktight after the HAC tests reported in Appendix B, Chapter 2 of the SARP. Given these considerations, the staff has concluded that it is highly unlikely that a sufficient quantity of Co-60 small particles will relocate and uniformly distribute in the gap space above the top plug and below the top flange of the flask.

5.5 Conclusion

Based on the statements and representations in Chapter 5 of the SARP and the staff's confirmatory evaluation, the staff concludes that the shielding design has been adequately described and evaluated. The staff concludes that the shielding performance of the SAFESHIELD 2999A package will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

6. CRITICALITY

Not applicable. The contents for SAFESHIELD 2999A do not include fissile materials.

7. OPERATING PROCEDURES

Chapter 7 of the SARP provides specific requirements in the operating procedures for loading and unloading the package, preparation of an empty package for transport, and tiedown of the package. When not in transit, the packaging shall be stored in conditions to protect the packaging from direct water impingement and standing water. The staff has reviewed the operating procedures and found them acceptable.

7.1 Procedures for loading the package

The requirements in the procedures for loading the package include preliminary checks (Section 7.1.1), disassembly for loading (Section 7.1.2), inspection before loading (Section 7.1.3), contents (Section 7.1.4), and assembly after loading (Section 7.1.5). Each of these sections in the SARP contains multiple steps which have been evaluated by staff as follows:

7.1.1 Preliminary checks

The requirements for the preliminary checks include proper Certificate of Compliance for the packaging, package serviceability, radiation survey, and approved operating procedures prepared according to the requirements enumerated in Chapter 7 of the SARP. The serviceability of the packaging is determined based on the criteria given in the maintenance program in Section 8.2 of the SARP.

7.1.2 Disassembly for loading

The requirements for disassembly of an empty package for loading address primarily the radiation levels due to potential contamination of the components and external surface of the package, and appropriate decontamination actions if the allowable radiation levels are exceeded. The contamination criteria are ≤ 0.41 Bq/cm^2 (10^{-5} μCi/cm^2) for beta/gamma emitting radionuclides and all radionuclides with half-lives less than 10 days, and ≤ 0.04 Bq/cm^2 (10^{-6} µCi/cm^2) for all other alpha emitting radionuclides.

7.1.3 Inspection before loading

The requirements for inspection before loading include the matching of model/serial numbers of the Flask 2993, plug assembly, closure flange, and the Casket 2999 cover and base assemblies; unacceptable defects on the outer surface of the casket; studs and nuts for the casket; assembly interferences; closure screws and threads for the flanges of the flask; and O-ring seals. The specifications for the materials required for operational use are listed in Appendix B, Chapter 7 of the SARP.

7.1.4 Contents

The requirements for contents refer to Section 1.2.3 of the SARP. The contents are required to be at least 26 mm (1.02 in) below the step in the containment vessel cavity on which the plug assembly sits in order to avoid interference with the plug assembly. Water is not permitted in the contents and loading shall take place in a dry environment. For Contents Type VI, the target cells (containing LMP metal) shall be carried within target capsules which are assembled to the specification in Table 1.1-VI of the SARP.

7.1.5 Assembly after loading

The requirements for assembly after loading include the loading environment (dry and ambient temperature), source holder, flask closure screws torque [25 ± 2 N-m (18.4 ± 1.5 lb-ft)], O-ring seals, leak testing, lifting, casket nuts/washers closure torque [100 ± 5 N-m (74 ± 4 lb-ft)], tamper-indicating device, radiation survey, and an evaluation to determine the internal heating of the contents and the radionuclide limits. Step 7 of Section 7.1.5 of the SARP states that inerting is not required where the contents are pyrophoric (Contents Type VI) because these contents are contained in target capsules. Step 10 of Section 7.1.5 of the SARP specifies the requirements for the preshipment leakage tests based on a go/no-go test sensitivity of 10^{-3} ref cm^3/s by the gas pressure rise or gas pressure drop methods per ANSI N14.5-1987..

Step 16 of Section 7.1.5 of the SARP specifies the requirements for a radiation survey: (1) the maximum radiation level shall not exceed 200 mrem/h at any point on the external surface of the package or a TI of 10, i.e., ≤10 mrem/h at 1 m away from any point on the external surface of the package per 10 CFR 71.47(a) for non-exclusive use shipment; (2) the maximum radiation levels for exclusive use shipment shall not exceed levels specified in 10 CFR 71.47(b); (3) the maximum level of removable radioactive contamination on the package surface shall be ≤ 0.4 Bq/cm^2 (10^{-5} µCi/cm^2) for beta/gamma emitting radionuclides and all radionuclides with half-lives less than 10 days, and ≤ 0.04 Bq/cm^2 (10^{-6} µCi/cm^2) for all other alpha emitting radionuclides per 49 CFR 173.443(a).

Step 18 of Section 7.1.5 of the SARP requires that an evaluation shall be conducted to determine the internal heating of the content; where this is determined to be > 200 W, the packaging shall be shipped under exclusive use, and shipper shall provide specific written instructions to the carrier for the maintenance of the exclusive use shipment controls. The instructions must be included with the shipping paper information and meet the requirement of 10 CFR 71.47(d).

7.2 Procedures for unloading the package

The procedural requirements for unloading the package are similar to those for loading the package except in a reverse order. The main concerns are the radiation levels and potential contamination during the unloading operation and the security indicated by the integrity of the tamper-indicating device.

7.3 Preparation of an empty package for transport

The requirements for preparation of an empty package for transport include the checking of the radiation levels and potential contamination, assembly according to the same procedural requirements as those in Section 7.1.5 of the SARP except for loading the contents (Step 4), and appropriate labeling per 10 CFR 71.129.

7.4 Tiedown of the package

The requirements for tiedown of the package consist of specifying the attachment points in the lifting plates of the casket and the angle 45 ± 5 degrees to the vertical for tie members arranged to be in line with the center of the package.

7.5 Conclusion

Based on the statements and representations in Chapter 7 of the SARP and the staff's confirmatory evaluation, the staff concludes that the operating procedure requirements presented in Chapter 7 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

Issues to be Corrected at the Next SARP Revision:

Issue 7.1: Section 7.1.4 of the Rev. 4 SARP should be revised to state that the decay heat generation rates in the contents may be determined through calculation, calorimetry, or process knowledge, and recorded. This information should be included as part of the shipping documentation. (This was agreed upon at the March 2005 meeting between the applicant and EM-24. There needs to be an action following the agreement. See CTR 2005/01, Issue B, July 31, 2005, "SARP Review - Q4 Response Matrix.")

8. ACCEPTANCE TESTS AND MAINTENANCE

The requirements for acceptance tests to be performed for each SAFESHIELD 2999A shipping package prior to initial use are presented in Section 8.1 of the SARP. These tests include visual inspections, structural and pressure tests, leakage tests, component tests, test for shielding integrity, thermal acceptance tests, and package identification. The maintenance program used to ensure continued performance of the packaging is described in Section 8.2 of the SARP. This program includes structural and pressure tests, leak tests, and subsystem maintenance. The results of the staff's evaluation of the acceptance tests and maintenance program are described below:

8.1 Acceptance tests

Inspection and acceptance tests are performed during fabrication of the packaging components, which include visual, dimensional verification, liquid penetrant testing, and radiography for the Flask 2993. The tests shall be in accordance with the ASME B&PV Code, Section III, Subsection NB-5000, as referenced in the appropriate design drawings. The fabrication of all the components of the packaging shall follow a quality assurance plan that meets the requirements of 10 CFR Part 71, Subpart H.

Pressure proof tests of the Flask 2993 shall be performed in accordance with the ASME B&PV Code, Section III, Subsection NB-6000, except that the pressure shall be at least 1.5 times the MNOP in accordance with 10 CFR 71.85(b).

Leakage tests for the containment boundary of the Flask 2993 shall be conducted in accordance with ANSI N14.5. The leakage tests are to be performed before first use and after the third use as part of the shakedown verification in accordance with Paragraphs 8.1.3.1 and 8.1.3.2 of the SARP. The leakage tests require sensitivities of 1×10^{-8} ref cm^3/s to assure that the containment criteria of 1×10^{-7} ref cm^3/s is satisfied.

Each packaging shall be weighed after fabrication and the weight plus the maximum allowable weight of the contents (100 kg) should be inscribed as the maximum gross weight on the certification plate attached to the packaging. If the as-built weight is different from the weight of the prototype (3853 kg) by more than 2%, the applicant shall notify the DOE Headquarters Certifying Official and provide a written explanation of the discrepancy.

Each flask shall be weighed after fabrication and that weight plus the maximum allowable weight of the contents (100 kg) should be inscribed as the maximum gross weight on the flask identification plate attached to the flask.

Test for shielding integrity during fabrication is performed according to CP 010 (Section 1.3, Appendix C of the SARP) and AESS 6067. The staff has reviewed these documents and found them acceptable. The staff also found package identification, per 10 CFR 71.85(c), as described in Section 8.1.7 of the SARP acceptable.

8.2 Maintenance program

The maintenance program for the packaging includes both pre-shipment and annual periodic maintenance. Pre-shipment maintenance includes preliminary check for serviceability as described in Section 7.1.1 of the SARP.

Annual leakage tests of the containment boundary of the Flask 2993 are to be performed in accordance with ANSI N14.5. Appendix B in Chapter 8 of the SARP lists the material specifications for parts such as O-rings, lubricant, flask closure screws and casket nut and washer that are required for operational use of the packaging. It is required that all replacement parts be exactly as specified in the drawings, and the specifications for the parts that may need to be replaced are exactly the same as the specifications on the drawings.

8.3 Conclusion

Based on the statements and representations in Chapter 8 of the SARP and the staff's confirmatory evaluation, the staff concludes that the acceptance tests and maintenance program requirements presented in Chapter 8 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

9. QUALITY ASSURANCE

9.1 Discussion

The requirements for a Quality Assurance (QA) Program presented in Chapter 9 of the SARP have been reviewed and found to satisfy the QA requirements of 10 CFR Part 71, Subpart H. These QA requirements provide sufficient control over all items and quality-affecting activities that are important-to-safety as applied to the design, fabrication, assembly, inspection, testing, operation, maintenance, modification, and repair of the SAFESHIELD 2999A packaging. The QA requirements are based on a graded approach as described in 10 CFR 71.101. The graded approach in the QA Chapter includes an important-to-safety Q-list for each significant item and activity and is graded based on the design function of the item relative to the safety and performance requirements for the complete shipping package. The quality assurance categories for each component are listed in Table 9.1 of the SARP. The Q-list uses three QA categories with associated definitions for each. The QA level of each important-to-safety item is based on specific criteria. The QA requirements assure that the SAFESHIELD 2999A packaging is designed, fabricated, tested, and operated in accordance with the drawings identified in the SARP. In addition, the QA Chapter requires the user to invoke the same level of QA requirements for the use, maintenance, and repair of the packaging, as is required for the procurement, fabrication, and acceptance testing of the original packaging. The QA categories for important-to-safety items and activities are based on the following definitions:

1. Category A (Critical)

   Category A items and activities shall be ones whose single failure or malfunction will result in an unacceptable condition of containment or shielding based upon federal regulations.

2. Category B (Major)

   Category B items and activities shall be ones whose single failure or malfunction could indirectly result in an unacceptable condition of containment or shielding. An unsafe condition could result only if the failure of a Category B item occurred in conjunction with the failure of another Category B item.

3. Category C (Minor)

   Category C items and activities shall be ones whose single failure or malfunction would not reduce packaging effectiveness and would not result in an unacceptable condition of containment or shielding regardless of other failures or malfunctions of items in the same QA category.

After determining the applicable QA category, the appropriate level of QA effort for design, procurement, fabrication, testing, operations, maintenance, modification, and repair activities is determined from the 18 QA requirements identified in 10 CFR Part 71, Subpart H. Specific QA requirements from Subpart H of 10 CFR Part 71 relative to packaging activities are categorized in Table 9.2 of the SARP. The 18 requirements identified in the SARP are as follows: organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, equipment, and services; identification and control of material, parts, and components; control of special processes; inspection control; test control; control of measuring and test equipment; handling, shipping, and storage control; inspection, test, and operating status; control of nonconforming materials, parts, or components; corrective action; QA records; and QA audits. Table 9.3 of the SARP specifies which documents are considered to be lifetime records; e.g., the SAFESHIELD SARP, contractor QA Manual, and maintenance records. The record retention program specifies that the licensee shall retain records for three years beyond the date when the licensee last engaged in a particular activity that is documented by the prescribed records.

The QA Chapter of the SARP includes independent verification of fabrication, operational, and maintenance activities considered to be critical in satisfying the regulatory requirements as identified in 10 CFR Part 71. Verification of critical activities is contained in Section 9.2.2 of the SARP. In Section 9.2.2.1, quality verification of procurement activities, assembly operations, welding requirements, and leakage criteria is specified. In Section 9.2.2.2, verification of important-to-safety maintenance activities is specified. In Sections 9.2.2.3, 9.2.2.4, and 9.2.2.5, verification of important-to-safety activities for package use, package unloading, and empty package shipment is specified.

The LANL Type B Packaging Program Management Quality Assurance Plan (QAP), P&T-Plan–028, Revision 0, and associated implementing procedures adequately address the 18 requirements in Subpart H of 10 CFR Part 71. Appendix D of Chapter 9 of the SARP provides a cross reference between each of the 18 QA requirements in Subpart H of 10 CFR Part 71 and the LANL Type B QA Packaging Program Management QAP. In addition, Appendix C contains the LANL Type B Program Management organizational chart that demonstrates the LANL Packaging and Transportation Group-Office of Institutional Coordination and Oversight for all LANL P&T activities report to senior laboratory management.

9.2 Conclusion

Based on the statements and representations in the SARP and the staff's confirmatory evaluation, the staff concludes that the Quality Assurance plan and requirements in Chapter 9 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B are met.