Department of Energy
Washington, DC 20585

AUG 0 8 2007

Attn: Document Control Desk
Director, Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

This is in response to the request of additional information on Certificate of Compliance (CoC) No. 9315, Revision 5 for the Model ES-3100 Package, Docket No. 71-9315, TAC No. L24063. In a letter dated May 9, 2007, the Department of Energy received a request for additional information concerning the application for revision to the definition of allowable pyrophoric forms uranium in the ES-3100 shipping package. These requests for additional information (RAI) were discussed during a public meeting with the Nuclear Regulatory Commission on May 10, 2007. Complete responses to these RAIs were submitted on June 27, 2007.

Subsequent to the RAI response, a conference call was held on July 31, 2007, between the NRC and the ES-3100 design agency, BWXT Y-12, for the purpose of clarifying two final items. One item requested that the oxidation process for pyrophoric uranium be detailed in the ES-3100 Safety Analysis Report (SAR). Rather than define the oxidation process in detail, the option was eliminated. The other item was a request that the method of determination of pyrophoric uranium used by operators, as described in Section 7 of the ES-3100 SAR, be added to the CoC. Section 12 of the CoC satisfies this request by requiring compliance with Section 7 of the SAR.

Attached you will find page changes to the ES-3100 SAR (Document No. Y/LF-717, R1). These affected SAR pages are identified with a "page change 4" in the footer. A guide for insertion of these page changes into the SAR is included.

The applicant has one additional request. This concerns the wording in the CoC Section 5.(b)(2). Oxides with high carbon concentrations are not to be shipped in the ES-3100 at this time. This was discussed at the public meeting on May 10, 2007. The applicant asked that the statement "carbide compounds are not authorized" be added to the CoC. That was done. In addition, the applicant would also like another statement directly following this one stating, "only trace amounts of carbon in oxides are authorized."

NMSS01

The original of this letter, with the attachment, is being sent to the Document Control Desk. Ten copies of this letter with the attachment are being delivered to Kimberly J. Hardin, Project Manager, Licensing Branch, Division of Spent Fuel Storage and Transportation, Office of Nuclear Material Safety and Safeguards.

If you have any questions, please contact me at 301-903-5513.

Sincerely,

James Shuler

James Shuler
Manager, Packaging Certification Program
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Enclosure

cc:
Kimberly J. Hardin, NRC
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ATTACHMENT

SAR PAGE CHANGES

GUIDE TO PAGE CHANGES

Y/LF-717, Rev. 1, page change #4

SAR SECTION	PAGE CHANGES
Volume 1, Front section	Replace pages i and xix
Volume 1, Section 1	Replace pages 1-11, 1-201, 1-203, and 1-211
Volume 1, Section 2	Replace page 2-25
Volume 2, Front section	Replace pages i and xix
Volume 2, Section 7	Replace page 7-3

SAFETY ANALYSIS REPORT, Y-12 NATIONAL SECURITY COMPLEX, MODEL ES-3100 PACKAGE WITH BULK HEU CONTENTS

Prepared by the
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Managed by
BWXT Y-12, L.L.C.
for the
U. S. Department of Energy
under contract DE-AC05-84OR21400

July 31, 2007

REVISION LOG

Date	SAR Revision No.	Description	Affected Pages
38407	0	Original issue	All
08/15/05	0, Page Change 1	Page changes resulting from *Responses to Request for Additional Information* #1, Y/LF-747.	title page, iv, xxiii, 1-4, 1-145, 2-2, 2-3, 2-6, 2-31, 2-32, 2-33, 2-34, 2-57, 2-59, 2-61, 2-107, 2-125, 2-131, 2-171, 2-173, 2-181, 2-183, 2-185, 2-186, 2-189, 2-367, 2-458, 2-675, 8-8, 8-9, 8-31
38753	0, Page Change 2	Page changes resulting from *Responses to Request for Additional Information #2*, Y/LF-761.	All Sections
38795	0, Page Change 3	Page changes resulting from *Responses to Request for Additional Information #3*, Y/LF-764.	1.38, 1.48, Appendix 1.4.1, 2-120, Table 6.4
38844	0, Page Change 4	Added polyethylene bottles and nickel alloy cans as convenience containers for authorized HEU contents. (CoC Revision 1)	Various pages in chapters 1, 2, 3 and 4.
08/21/06	0, Page Change 5	Revised equipment specifications for Kaolite and 277-4 neutron absorber. (CoC Revision 3)	Appendices 1.4.4 and 1.4.5.
11/15/06	1	Updated definition of pyrophoric uranium. Evaluated air transport. Revised criticality safety calculations to remove bias correct factors. Added a CSI option of 3.2. Increased mass of off-gassing material allowed in containment vessel. Increased carbon concentration in HEU contents. Increased Np-237 concentration is HEU contents. Added uranium zirconium hydride and uranium carbide as contents (TRIGA fuel). Revised equipment specifications for 277-4 neutron absorber. (CoC Revision 3)	All Sections

Date	SAR Revision No.	Description	Affected Pages
3/29/07	1, Page Change 1	Updated definition of TRIGA fuel for air transport and added TRIGA-related criticality safety cases.	title pages, viii, xi, xx, 1-12, 1-13, 1-20, 6-30, 6-54, 6-64, 6-66, 6-87, 6-119, 6-240 to 6-286, 6-385 to end
5/31/07	1, Page Change 2	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 4	title pages, xiii, xx, Section 1 and Section 6
6/30/07	1, Page Change 3	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 5	title pages, table of contents, Section 1, and Section 7
7/31/07	1, Page Change 4	Removed oxidation as an option for treating pyrphoric uranium metal	title pages, xx, 1-12, 1-201, 1-203, 1-212, 2-26,7-4

Note on revisions: Latest revision is shown as:

- Additions or changes are indicated by highlighted text
- Deletions are indicated by a mark in the margin

$\leq$0.040 μg^{232}U/gU, $\leq$50.0 μg^{233}U/gU with the balance of the uranium being ^{238}U).

Group 2 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and displays typical isotopic content ($\leq$0.977 g ^{235}U/g U, $\leq$0.014 g ^{234}U/g U, $\leq$0.010 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 3 oxides are contaminated with up to 40 μg Pu/g U and are in the form of UO_x. Material from this group contains at least 83.0% uranium by weight and displays typical isotopic content for uranium ($\leq$0.977 g ^{235}U/g U, $\leq$0.014 g ^{234}U/g U, $\leq$0.010 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 4 oxides are in the form of U_3O_8. Material from this group contains at least 83.0% uranium by weight and displays typical isotopic content ($\leq$0.977 g ^{235}U/g U, $\leq$0.014 g ^{234}U/g U, $\leq$0.010 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 5 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and displays typical isotopic content ($\leq$0.977 g ^{235}U/g U, $\leq$0.014 g ^{234}U/g U, $\leq$0.010 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U). This material may contain considerable activity in the form of unspecified beta emitters.

Group 6 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and may display unusually high isotopic concentrations of ^{233}U, ^{234}U, and ^{236}U ($\leq$0.977 g ^{235}U/g U, $\leq$0.020 g ^{234}U/g U, $\leq$0.40 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$200.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 7 oxides are in the form of U_3O_8. Material from this group is a mixture of graphite and U_3O_8. The uranium concentration is up to 84.5% by weight and the carbon concentration is up to 171,000 μg/gU. Enrichment is up to 93.2% by weight. Concentrations of other uranium isotopes are $\leq$0.014 g ^{234}U/g U, $\leq$0.010 g ^{236}U/g U, $\leq$0.040 μg ^{232}U/g U, $\leq$50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U. The same carbon concentration limit shall apply to any uranium carbide content such UC, UC_2, or U_2C_3.

The oxides in Groups 1, 3, 4 and 7 are high purity uranium oxide purity (the remainder is only trace impurities). Oxide Groups 2, 5, and 6 are listed to contain at least 20% uranium by weight, which allows up to 80% non-uranium material. As oxides, depending on the purity and chemical form, 3% to 17% of the total material composition will be oxygen, leaving up to 77% impurity or "filler". These three oxide groups include a range of scrap and recovered materials. For the least pure uranium oxides, the majority of the filler material is aluminum oxide (from recovered alumina traps or from oxidized uranium-aluminum alloys). Other materials that occur in appreciable quantities in some scrap materials are oxides and compounds of boron, calcium, iron, sodium, lead, zinc, magnesium, copper, molybdenum, and tungsten. These materials are essentially inert from the standpoint of criticality safety and chemical interaction with the ES-3100 convenience cans and bottles identified in this section for the shipment of oxides.

HEU Metal and Alloy

HEU metal and alloy (alloys of uranium with aluminum or molybdenum) may be in the form of solid geometric shapes. Solid shapes may include the following:

1. spheres are not included as a content shape;
2. cylinders having a diameter no larger than 4.25 in. (maximum of one cylinder per convenience can);

3. square bars having a cross section no larger than 2.29 in. × 2.29 in. (maximum of one bar per convenience can); and

4. slugs having dimensions of 1.5 in. diameter × 2 in. tall (maximum of 10 per convenience can).

With the exception of slug content, solid HEU metal and alloy content of specified geometric shapes shall be limited to one item per convenience container. HEU bulk metal and alloy contents not covered by the geometric shapes category specified above will be in the broken metal category, and will be so limited.

HEU bulk metal and alloy contents in the broken metal category may be of unspecified geometric form. HEU bulk metal and alloy in this category may also be of a specific shape where one or more of the characteristic dimensions vary from piece to piece (i.e., the height, width, length, radius, etc.).

For pyrophoric considerations, HEU metal and alloy must meet the following restrictions:

1. Uranium metal and alloy (broken) pieces must have a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve.

2. Particles and small shapes which do not pass the size restriction tests in #1, and powders, foils, turnings, and wires, are not permitted unless they are in a sealed, inerted container.

Metal and alloy may be shipped in tinned-carbon steel, stainless steel, or nickel-alloy convenience cans.

Uranyl Nitrate Crystals

Uranyl nitrate crystals (UNX) are formed by dissolving uranium metal or any of the uranium oxides in nitric acid. Uranyl nitrate hexahydrate (UNH) has a chemical formula of $UO_2(NO_3)_2 + 6\ H_2\ O$. This most reactive form is used as the bounding composition for uranyl nitrate crystals in the criticality evaluation. Therefore, for UNX contents, X must be less than or equal to 6. The theoretical density of UNH crystals is 2.79 g/cm^3; however, the working densities will be less.

The user of the ES-3100 for UNX shipments will be required to use non-metallic containers only (such as Teflon or polyethylene bottles) as the convenience container.

TRIGA Fuel Elements

Fuel pellets from Training, Research, Isotopes, and General Atomics (TRIGA) reactor elements are authorized to be shipped in the ES-3100. The fuel shall be unirradiated. The TRIGA fuel shall be in the form of uranium zirconium hydride (UZrHx), where $x \leq 2$. Fuel pellets from three types of TRIGA fuel elements are allowed; TRIGA Standard Fuel Elements (SFE), Instrumented TRIGA Standard Fuel Elements (FTC), and TRIGA Fuel Follower Control Rods (FFCR). These fuel elements have three fuel pellets (or sections) per element. The fuel pellets from the SFE's and FTC's to be shipped are 8.5 wt% uranium and 70% enriched. Fissile loading is 45.33 g ^{235}U per pellet (136 g ^{235}U per element) and the dimensions are 5 inches in length and 1.44 inches in diameter. The fuel pellets from the FFCR's to be shipped are 8.5 wt% uranium and 70% enriched. Fissile loading is 37.33 g ^{235}U per pellet (112 g ^{235}U per element) and the dimensions are 5 inches in length and 1.31 inches in diameter. Specific TRIGA fuel data is given in Table 1.4.

APPENDIX 1.4.10

PYROPHORICITY OF URANIUM METAL

I. Introduction

The ES-3100 is a new shipping container designed for safe and efficient transportation of highly enriched uranium in a wide range of material forms. The ES-3100 has been certified for use with a variety of contents, including enriched uranium metal and alloy. However, the current size limitations on uranium contents in the form of broken metal are unnecessarily restrictive. The size limits exist because under certain conditions uranium metal and some uranium alloys are pyrophoric – they have the potential to spontaneously ignite. The size restrictions are intended to eliminate the possibility of spontaneous ignition during transport.

The purpose of this analysis is to evaluate the potential for uranium metal pieces to spontaneously ignite under the conditions expected for shipment in the ES-3100 shipping container, and to identify limits on the uranium metal content that will prevent spontaneous ignition during transport, while still allowing a high degree of flexibility and utility.

It is important to remember that the content limits developed for the ES-3100 must be implemented in the field. Therefore the criteria derived from this evaluation must be simple, robust, and readily applied in all of the facilities using this package.

This evaluation does not include new laboratory tests of uranium metal ignition parameters. Such tests have been performed and well documented in the past. This evaluation draws on the extensive body of existing data and proven storage and transport practice to identify the bounds within which uranium metal and alloys can be safely transported in the ES-3100 shipping container.

II. Proposed Definition of Pyrophoricity

The Certificate of Compliance (CoC), gives the definition of broken metal in paragraph 5.(b)(1)(ii), as follows:

> *For metal or alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must have a mass not less than 50 g, whichever is most restrictive. Powders, foils, turnings, wires, and incidental small particles are not permitted, unless they are restricted to not more than 1 percent by weight of the content per convenience can, and they are either in a sealed, inerted container or are stabilized to an oxide prior to shipment.*

It is suggested that the definition of broken metal in paragraph 5.(b)(1)(ii) be revised to the following:

> ***For metal and alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must not pass freely through a 3/8-inch (0.0095m) mesh sieve. Particles and small shapes that do not pass this size restriction, as well as powders, foils, turnings, and wires, are not permitted, unless they are either in a sealed container under an inert cover gas.***

III. Rational for Proposed Changes

The proposed text makes the following changes:

- The 50 g minimum piece size is eliminated;
- A 3/8-in. mesh limit is added;
- The phrase "whichever is most restrictive" is deleted;
- Remove oxidation as a treatment for pyrophoric uranium, in this context
- The 1% limit on inerted material is eliminated.

The 1 cm^2/g maximum specific surface area limit is the most significant limit in the original text, and that limit is retained unchanged. Specific surface area is the most significant parameter in determining if a given piece of uranium is at risk of spontaneous ignition under a given set of conditions, and therefore it is appropriate that this restriction should control any other restrictions to the package contents. The discussion section below will demonstrate that the 1 cm^2/g maximum allowable specific surface area is adequate to prevent spontaneous ignition in the ES-3100.

The 50 g minimum piece size is overly restrictive and is inconsistent with the 1 cm^2/g upper limit on specific surface area. Smooth uranium metal pieces can have a mass of less than 0.5 g and still have a specific surface area less than 1 cm^2/g (see example 1). This makes the 50 g limit two orders of magnitude too large. The 50 g limit is nearly an order of magnitude too large even considering metal pieces with the rough surface of broken metal instead of a smooth cast or polished surface.

Example 1.
Consider a smooth uranium metal sphere with a diameter of 0.32 cm (0.126 in.).
The radius of the sphere is 0.16 cm. The density of uranium metal is 19 g/cm^3.
The volume is $V = (4/3) \cdot Pi \cdot r^3 = (4/3) \cdot Pi \cdot (0.16)^3 = 0.01716\ cm^3$
The mass is $M = Density \cdot V = 19\ g/cm^3 \cdot 0.01716\ cm^3 = 0.3260\ g$
The surface area is $A = 4 \cdot Pi \cdot r^2 = 4 \cdot Pi \cdot (0.16)^2 = 0.3217\ cm^2$
The specific surface area is $SA = A/M = 0.3217\ cm^2 / 0.3260\ g = 0.9868\ cm^2/g$
This specific surface area is just within the 1 cm^2/g upper limit.

If instead of a smooth surface the sphere has a rough surface characteristic of broken uranium metal, a larger size is needed to ensure that the 1 cm^2/g limit is maintained. For a roughness factor of three (meaning that the rough surface has an actual surface area that is three times the surface area calculated from the radius), the radius would need to be three times the above example to give the same specific area. In this case:
$r = 3*0.16\ cm = 0.48\ cm$; $V = (4/3) \cdot Pi \cdot (0.48)^3 = 0.463\ cm^3$;
$M = 19\ g/cm^3 \cdot 0.463\ cm^3 = 8.802\ g$; $A = 4 \cdot Pi \cdot (0.48)^2 \cdot 3$ (roughness factor) $= 8.686\ cm^2$
And so the specific surface area is $8.686\ cm^2/8.802 g = 0.9868\ cm^2/g$ as above.

Depending on the surface roughness, a sphere with a mass between 0.33 and 8.8 grams will meet the 1 cm^2/g specific surface area limit.

The 1 cm^2/g specific surface area limit controls the parameter that is most important in terms of preventing spontaneous ignition, but it is not easy to measure or to use in the field. A mass limit (similar to the 50 g limit in the existing certificate, but more consistent with the 1 cm^2/g specific area limit) could be used, but it is very time-consuming to weigh every piece of metal in a package. An approach that is both effective at enforcing the 1 cm^2/g specific surface area limit and quick and easy to use in the field is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

As demonstrated in example 1, rough-surfaced spheres 3/8 in. (0.95 cm) in diameter meet the 1 cm^2/g specific surface area limit (a smooth-surfaced sphere of this size has a specific surface area of 0.33 cm^2/g). Therefore, a sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere.

The phrase "whichever is most restrictive" has been deleted from the proposed text since the sieve test has been sized to effectively enforce the 1 cm^2/g specific surface area limit.

The option of converting pyrophoric uranium to an oxide is removed, since metals need to be shipped as metals for maximum usefulness at the receiver site. In addition, if oxides are produced, packing limits for oxides have been explicitly given in the certificate of compliance.

The final change in the proposed text is to eliminate the 1% of content weight limit on inerted material. This limit is unnecessary for uranium metal sealed in a container containing an inert atmosphere. If the metal has been sealed in a container containing an inert atmosphere, there is no oxygen available to the metal and therefore no chance of combustion.

Uranium metal packaged for transport in the ES-3100 is first placed inside a convenience can or other container. These cans are then placed into the ES-3100 containment vessel (CV). The convenience cans will displace most of the oxygen from the containment vessel, leaving only enough to react with a few grams of metal. If a sealed container containing an inert atmosphere somehow came open in transport (an unlikely scenario given the very limited amount of movement possible inside a properly loaded containment vessel), this small amount of oxygen is not enough to support spontaneous ignition. The containment vessel has been shown to retain its structural integrity and remain leak tight under hypothetical accident conditions, so no additional oxygen can enter.

IV. Discussion

In his 1995 review,[1] Terry Totemeier explains pyrophoricity this way: "Pyrophoricity refers to the tendency of certain metals to ignite and burn in a self-sustaining oxidation reaction. The pyrophoric nature of metals is usually defined in terms of an ignition temperature, which is the temperature at which a metal will ignite and burn in a self-sustained fashion for a given set of conditions." ASTM C-1454[2] defines pyrophoric as "capable of igniting spontaneously under temperature, chemical, or physical/mechanical conditions specific to the storage, handling, or transportation environment".

This evaluation will demonstrate that uranium metal with a specific surface area of 1 cm^2/g will not spontaneously ignite under the conditions existing in the ES-3100 during packaging and transport.

The primary factors determining if the conditions for spontaneous ignition exist are specific surface area and temperature. Totemeier explains, "Because oxidation is a surface reaction, the amount of area available for reaction is a critical factor in the determination of the heat generated in oxidation. Specific area is the best parameter to describe the effect of area, as it also accounts for the amount of material not reacting which can serve as a heat sink." Temperature is critical because the amount of heat generated by the reaction is a function of the reaction rate, which is in turn a function of the temperature. Higher temperatures give higher reaction rates.

An additional safety factor in the case of the ES-3100 is the small amount of oxygen available in the sealed inner containment vessel. This serves to limit the total amount of uranium that can oxidize, and therefore prevents any potential heat build-up from reaching the ignition point of uranium metal.

Ignition Temperature and Transport Conditions

In figures 4 and 5 of his review, Totemeier plots two separate tests of uranium ignition temperatures as a function of specific surface area. For a specific surface area of 1 cm^2/g these two plots give values of 390°C (663 K)[a] and 340°C (613 K), respectively. Using the lower value and rounding down gives a conservative value of 600 K for the ignition temperature of uranium metal in the ES-3100.

The ES-3100 thermal analysis determined that the temperature at the containment vessel wall would not exceed 190°F (361 K) for normal conditions of transport (NCT) and 255°F (397 K) for hypothetical accident conditions (HAC). These values, particularly the HAC temperature, are very conservative. The actual results from six separate package tests showed that the CV wall temperature was typically around 210 °F (372 K), with the highest recorded value of 241 °F (389 K). Note that all of these temperatures are well below the 600 K ignition temperature of the uranium metal contents.

Maximum Temperature from Oxidation – Basic Equations

Uranium metal readily reacts with oxygen to form uranium dioxide (UO_2). This reaction is exothermic. The heat released by the reaction warms the uranium metal, increasing the reaction rate. Under normal conditions for storage and transport, the reaction rate is slow enough that the small amount of heat generated by the reaction is lost to the environment, and a stable steady-state is achieved. If the reaction rate is fast enough, and the metal is relatively well insulated, the temperature of the uranium metal can build, slowly at first but at an increasing rate, until the ignition temperature is reached and the metal ignites and burns.

The task at hand is to evaluate the balance between heat generation and heat loss in the ES-3100 under hypothetical accident conditions to verify that a stable steady state is reached, and that the steady-state condition is safely below the ignition point of uranium metal. A recent paper by Epstein, Malinovic, and Plys[3] lays out a useful approach, which will be followed here without the approximations used in their paper.

For uranium metal packed in cylindrical cans, the generation of heat throughout the can and the associated transfer of heat to the can wall is mathematically identical to the generation of heat within a wire due to electrical resistance. In their text "Transport Phenomena"[4] Bird, Stewart & Lightfoot develop the desired relation (equation 9.2-14):

$$T_{center} - T_{wall} = (S \cdot R^2) / (4 \cdot K_{th}) \qquad \text{(Equation 1)}$$

where

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[a] The curve in Totemeier figure 4 is discontinuous, with a transition from a lower curve to an upper curve shown at a specific surface area of 6 cm^2/g. At a specific surface area of 1 cm^2/g the upper curve would give an ignition temperature of 550°C, while extrapolation of the lower curve gives 390°C. The original reference from which Totemeier drew figure 4 explains that the transition from the lower curve to the upper curve is influenced by many factors, including the metallurgy of the uranium, any alloying metals or impurities, and the oxygen content of the gas involved. Therefore this analysis uses the lower curve value of 390°C.

The actual metal contents of the ES-3100 will include both smooth-surfaced and rough-surfaced metal. The smooth-surfaced items include a variety of cast and machined shapes. The rough-surfaced items are "broken metal" – large castings that have been fractured into smaller pieces. These broken metal pieces will typically have two or three cast surfaces with the remaining 3 or 4 surfaces of fractured metal.

The 3/8-inch mesh recommendation is based on a surface roughness factor of three, meaning that the rough surface has an actual surface area available to react with oxygen that is three times that of a smooth-surface of the same gross dimensions. This roughness factor of three was derived from an evaluation of fracture surfaces for cast uranium metal. Roughness factors ranged from 1.1 to 2.7, with a mean value of 2.0. A roughness factor of three was selected to bound the highest value observed. The 3/8 inch mesh screening is therefore suitable for metal that is fractured on all surfaces. Since as noted above even broken metal will have several smooth faces the 3/8-inch mesh screening should be quite conservative.

As demonstrated above, a rough-surfaced sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packaged in an inert atmosphere. Attachment 2 shows the dimensions of a variety of shapes that have a specific surface area of 1 cm^2/g. All of these items will fall through a 3/8-in. sieve, demonstrating that the sieve will effectively enforce the 1 cm^2/g specific surface area limit.

Most foils and wires will not fall through a sieve of any reasonable size. The current 50 g test would likewise not reliably exclude these materials, which is why foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere. Operator training will be required under either the current or the proposed text to ensure that these items are properly packaged.

Operator Training

As part of the transition to using the new shipping container, training materials are being prepared to instruct the field operations personnel on the proper way to use the ES-3100. As noted above, the training for the operators packing uranium metal into the convenience cans for shipment in the ES-3100 will be important in ensuring that potentially pyrophoric materials are properly categorized and inerted as necessary. This training will cover the following points:

- All metal pieces must be evaluated to ensure that their smallest dimension is larger than the 3/8 inch mesh size.
    - Single solid-metal pieces that are clearly larger than the 3/8-inch mesh in every dimension do not require sieving.
    - Items which are obviously unacceptable, such as foils, wires, and turnings, may be removed before the sieving
    - Any item that is not obviously larger than the 3/8-inch mesh in every dimension and which has not been rejected must be sieved.
    - Any item that falls through the sieve must be rejected.
- Operators need to be alert to items which may not fall through the sieve but which are too small:
    - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.
    - Wires or turnings may form a tangled ball which will not fall through. The above criterion applies: if the wire or turning could be separated and poked through the mesh it must be rejected.

- o No distinction is made between wires and rods – if the item could be picked up and poked through the mesh it must be rejected.
- o Foils, thin chips or shards - any item less than 1/8 inch thick – must be rejected.
- o Metal showing visible moisture or signs of having been stored in water must be rejected.

- Rejected items must be separated for proper handling:
  - o Rejected items can be shipped if packed under an inert cover gas.
  - o An acceptable cover gas must be high-purity (≥ 99.997%) and dry (≤ 5 ppm moisture).

V. Conclusion

The evaluations performed show that uranium metal conforming to the 1 cm^2/g limit on specific surface area will not spontaneously ignite under any anticipated transport conditions. Spontaneous ignition is independently prevented by both the 1 cm^2/g limit on the uranium metal and by the limited amount of oxygen available in the sealed ES-3100 containment vessel.

The 3/8-in. sieve specified in the revised text effectively applies the 1 cm^2/g specific surface area limit to broken uranium metal in a manner that is quick and easy to use in the field.

Table 2.17. Mechanical properties of the cast neutron absorber

Material		Cat 277-4
Service temperature range, °C (°F)		−40 to 150 (−40 to 302)
Modulus of elasticity in tension, GPa (Mpsi) at temperatures [a]		
	−40°C (−40°F)	13.72 (1.991)
	21.11°C (70°F)	4.72 (0.684)
	37.78°C (100°F)	2.78 (0.403)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [b]		
	−40°C (−40°F)	12.700×10^{-6} (7.056×10^{-6})
	−20°C (−4°F)	13.000×10^{-6} (7.222×10^{-6})
	0°C (32°F)	13.000×10^{-6} (7.222×10^{-6})
	40°C (104°F)	12.600×10^{-6} (7.000×10^{-6})
	60°C (140°F)	11.599×10^{-6} (6.444×10^{-6})
	80°C (176°F)	10.400×10^{-6} (5.778×10^{-6})
	100°C (212°F)	9.700×10^{-6} (5.389×10^{-6})
	120°C (248°F)	9.101×10^{-6} (5.056×10^{-6})
Poisson Ratio		
	−40°C (−40°F)	0.33 [a]
	21.11°C (70°F)	0.28
	37.78°C (100°F)	0.25
Density, g/cm³ (lb/in.³)		1.682 (0.0608)

[a] *Mechanical Properties of 277-4* (Appendix 2.10.4).
[b] *Thermophysical Properties of Heat Resistant Shielding Material* (Appendix 2.10.4).

Analysis. Starting with the outer components, the packaging consists of the drum (austenitic type 304 stainless steel), weld studs (austenitic stainless steel), nuts (silicon bronze), insulation (cast refractory), neutron absorber (Cat 277-4), silicone support pads, containment vessel (austenitic type 304L stainless steel), closure nut (Nitronic 60), silicone support pads, can spacers (stainless steel and Cat 277-4), stainless-steel scrubbers, convenience cans (stainless steel, tin-plated carbon steel, or nickel-alloy [series 200, passivated]), polyethylene or Teflon FEP bottles, polyethylene bags, and the HEU contents.

The cast refractory insulation (Kaolite) is contained between the drum and mid liner and within the top plug assembly's stainless-steel sheet metal. Due to the alkaline nature of this material, greater permanence of the surrounding structure is assured. Also, this material has been used successfully for years as an insulation heat treatment liner adjacent to metal surfaces of furnaces.

The cast neutron absorber (Cat 277-4) is contained between the inner liner and mid liner. During the casting process, the chlorine content is limited to 100 parts per million. The small quantity of chlorine will not affect the stainless-steel liners.

The nuts used to attach the drum to the lid are silicon bronze. All other metal components of the packaging are either stainless steel, Nitronic 60, or tinned steel. All stainless-steel components are passivated per ASTM A380, Paragraph 6.4, and Table A2.1, Part II. Prior to assembly, the packaging will be kept inside a building or transported between buildings in an enclosed truck. The assembled components are protected from the weather and inspected at the time of packaging; therefore, the package will not contain any free water at the time it is loaded for transport. Under NCT, the only moisture present will be the relative humidity or moisture absorbed by the cast refractory or neutron absorber materials. When the package is subjected to a water-spray type environment, some water may leak into the cavity formed by the inner liner and occupied by the containment vessel. To minimize the possibility of any potentially corrosive situation, a visual examination of the interior surface of the inner liner and the exterior surface of the containment vessel shall be conducted prior to packing and following transport of the shipping package (see Sect. 7). Any free water present and any corrosion discovered shall be promptly removed.

During immersion under HAC, water can enter the holes at the top of the drum, be absorbed into the cast refractory material, and fill all void spaces within the drum and inner liner. The insulating value of the insulation material may be decreased, and an overall weight increase would occur. The most important consideration is that the containment boundary remain intact and leaktight. This situation has been evaluated by completely immersing the containment vessel in a tank simulating 0.9-m and 15-m (3- and 50-ft) immersion depths. The containment vessel remained intact and water tight, as demonstrated by the analysis and testing discussed in Sect. 2.7.

All physical contact between the convenience cans and the containment vessel wall, bottom, or top is minimized through the use of the silicone support pads. The polyethylene or Teflon FEP bottles may be in contact with the stainless steel of the containment vessel, but will not react. All cans and bottles will provide the necessary separation of the HEU contents from the containment vessel walls. The passivated Nickel-alloy cans are galvanically similar to the stainless steel of the containment vessel and thus will not react. Additionally, polyethylene bagging may be used around the convenience container (in some cases the HEU is bagged inside the convenience container) as required by packaging personnel. Therefore, galvanic corrosion between the containment vessel wall and convenience containers is highly unlikely. In addition, the environment inside the containment vessel is free of electrolytic solutions, further assuring there will be no galvanic reactions occurring inside the containment vessel.

For pyrophoric considerations, broken metal and alloy pieces shall be of a size that: a) the specific surface area does not exceed 1 cm^2/g, or b) will not pass freely through a mesh size of 3/8 in. (9.53 mm). Incidental small particles which do not pass the size restriction tests, and powders, foils, turnings, and wires may only be shipped if they are in a sealed, inerted container.

The containment boundary remains intact even when the drum and inner liner are filled with water; therefore, the package is acceptable to the maximum credible extent from the standpoint of chemical, galvanic, or other reactions.

2.2.3 Effects of Radiation on Materials

The HEU material is not irradiated. The neutron and photon dose rates (Sect. 5) are well below those required to damage any of the package materials by radiolytic interactions.

2.3 FABRICATION AND EXAMINATION

2.3.1 Fabrication

SAFETY ANALYSIS REPORT, Y-12 NATIONAL SECURITY COMPLEX, MODEL ES-3100 PACKAGE WITH BULK HEU CONTENTS

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REVISION LOG

Date	SAR Revision No.	Description	Affected Pages
38407	0	Original issue	All
08/15/05	0, Page Change 1	Page changes resulting from *Responses to Request for Additional Information* #1, Y/LF-747.	title page, iv, xxiii, 1-4, 1-145, 2-2, 2-3, 2-6, 2-31, 2-32, 2-33, 2-34, 2-57, 2-59, 2-61, 2-107, 2-125, 2-131, 2-171, 2-173, 2-181, 2-183, 2-185, 2-186, 2-189, 2-367, 2-458, 2-675, 8-8, 8-9, 8-31
38753	0, Page Change 2	Page changes resulting from *Responses to Request for Additional Information #2*, Y/LF-761.	All Sections
38795	0, Page Change 3	Page changes resulting from *Responses to Request for Additional Information #3*, Y/LF-764.	1.38, 1.48, Appendix 1.4.1, 2-120, Table 6.4
38844	0, Page Change 4	Added polyethylene bottles and nickel alloy cans as convenience containers for authorized HEU contents. (CoC Revision 1)	Various pages in chapters 1, 2, 3 and 4.
08/21/06	0, Page Change 5	Revised equipment specifications for Kaolite and 277-4 neutron absorber. (CoC Revision 3)	Appendices 1.4.4 and 1.4.5.
11/15/06	1	Updated definition of pyrophoric uranium. Evaluated air transport. Revised criticality safety calculations to remove bias correct factors. Added a CSI option of 3.2. Increased mass of off-gassing material allowed in containment vessel. Increased carbon concentration in HEU contents. Increased Np-237 concentration is HEU contents. Added uranium zirconium hydride and uranium carbide as contents (TRIGA fuel). Revised equipment specifications for 277-4 neutron absorber. (CoC Revision 3)	All Sections

Date	SAR Revision No.	Description	Affected Pages
3/29/07	1, Page Change 1	Updated definition of TRIGA fuel for air transport and added TRIGA-related criticality safety cases.	title pages, viii, xi, xx, 1-12, 1-13, 1-20, 6-30, 6-54, 6-64, 6-66, 6-87, 6-119, 6-240 to 6-286, 6-385 to end
5/31/07	1, Page Change 2	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 4	title pages, xiii, xx, Section 1 and Section 6
6/30/07	1, Page Change 3	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 5	title pages, table of contents, Section 1, and Section 7
7/31/07	1, Page Change 4	Removed oxidation as an option for treating pyrphoric uranium metal	title pages, xx, 1-12, 1-201, 1-203, 1-212, 2-26,7-4

Note on revisions: Latest revision is shown as:

- Additions or changes are indicated by highlighted text
- Deletions are indicated by a mark in the margin

7.1.2 Loading of Contents

The operating procedures for the ES-3100 package with HEU contents shall be specific regarding handling of all package components. Approved procedures shall clearly state all safety aspects or activities such as personnel protection (radiation, chemical, physical); surface contamination or radiation surveys; nuclear criticality safety; and environment temperature.

The detailed operating procedures for inserting the content into the packaging shall include, at a minimum, the process steps listed below:

1. the appropriate CV is positioned for packing and verify that the vessel was loaded according to these steps.

2. the HEU material has been verified as being within the limits specified in this SAR and the NRC CoC for material mass, material dimension, uranium content, and ^{235}U enrichment as required in Sect. 1.2.3. The content shall be verified using accountability records and weight measurements.

3. all contents and their associated cans, bottles and packing material are weighed and are within the allowable weights specified in Sect. 1.2.3.6.

4. the HEU material and associated packing material (convenience cans, spacers, bagging, pads, etc.) have been inserted as required by Sect. 1.2.3.

5. for proper handling of broken metal contents, pyrophoricity concerns must first be addressed. Operators have two options: 1) treat all broken metal as pyrophoric (in this case skip to procedure in Item #7 below) or, 2) determine whether or not the broken metal is pyrophoric (in this case go to procedure in Item #6 below).

6. for pyrophoric categorization of broken metal, first evaluate the specific surface area of the metal pieces (surface-area-to mass ratio). If that value is less than or equal to 1.00 cm²/g, then the metal pieces are not pyrophoric (and no further action is needed). If the specific surface area is greater than 1.00 cm²/g, or if the specific surface area can not be evaluated, perform the remainder of this procedure:

   a. Metal pieces must be physically evaluated to ensure that their smallest dimension is larger than a 3/8 inch mesh size.

      i. Single solid-metal pieces that are clearly larger than the 3/8-inch mesh in every dimension do not require sieving, and are acceptable.

      ii. Items which are unacceptable by definition (page 1-12), such as powders, foils, wires, and turnings, should be rejected before the sieving

      iii. Any items that are not obviously larger than the 3/8-inch mesh in every dimension and which have not been rejected must be sieved.

      iv. Any item that falls through the sieve must be rejected.

      v. Any rejected item must be handled according to the procedure in Item #7 below.

b. Operators need to be alert to items which may not fall through the sieve but still may be pyrophoric:

   i. Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.

   ii. Wires or turnings may form a tangled ball which will not fall through. The above criterion applies: if the wire or turning could be separated and poked through the mesh it must be rejected.

   iii. Foils, thin chips or shards - any item less than 1/8 inch thick – must be rejected.

   iv. Metal showing visible moisture or signs of having been stored in water must be rejected.

   v. Any rejected metal must be handled according to the procedure in Item #7 below.

7. Rejected items must be separated for proper handling:

   a. Rejected items can be shipped in the ES-3100 if packed in a sealed container under an inert cover gas.

   b. An acceptable cover must be high-purity (≥99.997%) and dry (≤5 ppm moisture).

7.1.2.1 CV Assembly and Leak Testing

The detailed operating procedures shall describe activities to prepare the packaging for final closure and shipment. They shall include, at a minimum, the process steps listed below when preparing the containment vessels for closure:

1. the containment vessel O-ring grooves and sealing surfaces are visually checked for scratches that may have occurred during insertion. If scratches are found, Sect. 8.2.2 should be reviewed for criteria for evaluating surface scratches, possible repair methods for minor scratches, and rejection criteria for significant scratches.

2. the O-rings and the containment vessel sealing surfaces are free from debris and have not been damaged during loading operations. Isopropyl alcohol and lint-free cotton cloth or swabs should be used to clean the grooves and sealing surfaces. The O-rings may be wiped with lint-free gloves, cloth, or swabs. Note that the O-rings shall be lubricated with a thin coat of Super O-Lube.

3. the containment vessel sealing lid is secured to the containment vessel body by the containment vessel closure nut.

4. the closure nut is tightened to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) of torque as specified in Drawing M2E801580A011 (Appendix 1.4.8). No impact wrench shall be used.