

**Safety Evaluation Report for the
Model ES-3100 Package with Bulk HEU Contents
SP-PKG-801940-A001, Revision 0**

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Summary

The National Nuclear Security Administration (NNSA) Office of Fissile Materials Disposition requested the revision of the Certificate of Compliance (CoC) for the Model ES-3100 Type B Package for the shipment of bulk highly-enriched uranium (HEU) by letter dated February 8, 2011.¹ The existing CoC identified as USA/9315/B(U)F-96 (DOE), Revision 2, was issued by the Department of Energy (DOE) Headquarters Certifying Official on November 23, 2010, with an expiration date of September 30, 2014.² Revision 2 of the subject CoC is based on the Safety Analysis Report for Packaging (SARP) SP-PKG-801940-A001, Revision 0, Page Change 1, dated November 10, 2010. The request for Revision 3 is based upon a page-change revision to that SARP.³

The request for revision of the CoC were for changes that the applicant deemed to be “administrative in nature,” where the request listed seven specific changes and noted that additional editorial changes were included in the request. In addition, the applicant provided a set of SARP change pages reflecting the above-noted requested changes to the CoC.

Based on the statements and representations in the request for revision of the CoC, including the proposed changes to the SARP, and the Department of Energy Packaging Certification Program (PCP) staff’s confirmatory evaluation as summarized in this Safety Evaluation Report (SER), the DOE PCP finds the request for revision of the CoC acceptable.

The DOE PCP is also adding a sunset condition to the CoC to conform to a similar process used by the Nuclear Regulatory Commission for its CoCs. The sunset condition allows time for the new revision of the CoC to be incorporated into operational procedures and allows shipments to be made under previous revisions for a limited period of time. The sunset condition for Revision 3 of the DOE CoC 9315 will allow the use of Revision 0 until October 1, 2011, and Revision 1 and Revision 2 until May 31, 2012.

Chapter 1: General Information and Drawings

1.1 Packaging Description

Detailed packaging descriptions, drawings and contents can be found in the SARP and CoC.^{2 3} The ES-3100 HEU shipping packaging is composed of an outer drum assembly and a containment vessel (CV).

Outer Drum Assembly

The outer drum assembly consists of (a) a reinforced stainless steel, standard military specification 30-gallon drum with an increased length; (b) a cylindrical layer of castable refractory material (Kaolite 1600™), which is a mixture of cement and vermiculite, and acts as both an impact limiting and thermal-insulating material; (c) a cylindrical layer of castable refractory (277-4 special dry mix) for neutron attenuation purposes; (d) an inner steel liner; and (e) a removable top plug that also has a layer of the castable refractory material (Kaolite 1600™) for impact limiting and thermal insulating.

The 30-gallon drum is manufactured from 16-gauge type 304 or 304L stainless steel. The fabrication was accomplished according to requirements specified in NUREG/CR-3854 (specifically, it is in accordance with the dimensional requirements of MIL-D-604F as modified

according to Drawing M2E801580A004). The inner liner is also manufactured from type 304 or type 304L stainless steel.

Containment Vessel

The CV is placed inside the outer drum assembly, surrounded by the neutron attenuating and impact limiting and thermal insulating materials. It is approximately 32 in. (82 cm) in overall height and 5 in. (13 cm) in overall diameter. The CV body is constructed of 304L stainless steel. The CV lid assembly consists of a sealing lid; a closure nut; an external retaining ring that holds both the assembly and closure nut together; and double ethylene-propylene elastomer O-rings. The CV lid is constructed of 304 stainless steel, and the closure nut is manufactured of Nitronic 60 stainless steel. The double O-rings in the top flange of the CV permit leak testing of the CV. The containment boundary consists of the 0.1 in. (0.254 cm) thick CV body, the CV sealing lid assembly, and the inner ethylene-propylene elastomer O-ring.

1.2 Contents

The contents to be shipped in the ES-3100 HEU package consist of bulk HEU in the form of (a) solid HEU metal or alloy of specified geometric shapes, (b) broken HEU metal or alloy, (c) HEU oxides (UO_2 , UO_3 , U_3O_8 , $\text{U}_3\text{O}_8\text{-Al}$, $\text{UO}_2\text{-Mg}$, and $\text{UO}_2\text{-ZrO}_2$), (d) research reactor fuel elements and components, (e) uranium compounds, and (f) uranyl nitrate crystals.

The radioactive materials are placed in convenience cans or bottles. Typical loading of the bulk HEU into the packaging, using convenience cans is depicted in Figure 1.2 of the SARP. Typical shipping configurations inside the CV are depicted in Figure 1.4 of the SARP.

The requests for the revision of the CoC for the Model ES-3100 Type B packaging proposed by NNSA are "administrative in nature," which are summarized as follows:

- Clarify the description of U-Zr oxide in the "HEU Oxide" category. The material will be noted as $\text{UO}_2\text{-ZrO}_2$ throughout the SARP.
- Add a physical form of oxide under "HEU Oxide" called, "pellets" in Section 1.2.2. of the SARP. There is no change to the density range given in the SARP.
- The entry for U-Zr under the category "Research Reactor Fuel Elements and Compounds" gives a loading equivalent to the loading for broken metal. For this entry to be consistent with the broken metal entry, the Criticality Safety Index (CSI) and can spacer notations had to be adjusted.
- Add a content description under the category "Research Reactor Fuel Elements and Components" called "Oxides of U-Zr." This includes $\text{UO}_2\text{-Zr}$ and $\text{UO}_2\text{-ZrO}_2$. The loading limits associated with this content are the same as HEU Oxide.
- Entry for TRIGA fuel in Table 1.3 is modified to change the <93% enrichment to $\leq 70\%$ enrichment. This is done for accuracy as TRIGA fuel does not have enrichments above 70%.
- The CSI for air transport in Table 1.3b has been adjusted to reference the CSI for the ground transport as the governing CSI for the container.
- In the Operations chapter (Chapter 7), Section 7.1.2.2, Drum Closure, Item 21 was clarified to insure the operator adds the appropriate DOE marking on the drum label.

These proposed changes are also included in Tables 1.3, 1.3a and 1.3b of the SARP, as shown below.

Table 1.3. Authorized Content and Fissile Mass Loading Limits for Ground Transport for the ES-3100 HEU Package. ^{a, b, c}

Content description		Enrichment	CSI	No Spacers, ²³⁵ U (kg)	Basis for limit	277-4 can Spacers, ²³⁵ U (kg)	Basis for limit
Solid HEU metal or alloy (specified geometric shape) ^e	Cylinder A	≤ 100%	0.0	15.000	Crit.	25.000	Crit.
	Cylinder B	≤ 100%	0.0	18.000	Crit.	30.000	Crit.
	Square bars	≤ 100%	0.0	30.000	Crit.	35.200 ^f	Struct.
	Slugs	≤ 95%	0.0	17.374	Crit.	-	-
	Slugs	≤ 80%	0.0	-	-	29.318	Crit.
	Slugs	> 80%, ≤ 95%	0.0	-	-	24.324	Crit.
	Slugs	> 80%, ≤ 95%	0.4	-	-	34.749	Crit.
Broken HEU metal or alloy ^e		> 95%, ≤ 100%	0.0	Spacers req'd ^d		2.774	Crit.
			0.4	Spacers req'd		5.549	Crit.
			0.8	Spacers req'd		9.248	Crit.
			2.0	Spacers req'd		13.872	Crit.
			3.2	Spacers req'd		24.969	Crit.
		> 90%, ≤ 95%	0.0	Spacers req'd		3.516	Crit.
			0.4	Spacers req'd		6.154	Crit.
			0.8	Spacers req'd		10.549	Crit.
			2.0	Spacers req'd		18.461	Crit.
			3.2	Spacers req'd		26.373	Crit.
		> 80%, ≤ 90%	0.0	Spacers req'd		3.333	Crit.
			0.4	Spacers req'd		7.500	Crit.
			0.8	Spacers req'd		12.500	Crit.
			2.0	Spacers req'd		20.000	Crit.
			3.2	Spacers req'd		28.334	Crit.
		> 70%, ≤ 80%	0.0	2.967	Crit.	4.450	Crit.
			0.4	5.192	Crit.	8.900	Crit.
			0.8	8.900	Crit.	16.317	Crit.
			2.0	17.059	Crit.	25.218	Crit.
			3.2	27.692	Crit.	28.184	Crit.
		> 60%, ≤ 70%	0.0	3.249	Crit.	5.198	Crit.
			0.4	5.848	Crit.	12.996	Crit.
			0.8	13.646	Crit.	20.793	Crit.
			2.0	21.444	Crit.	24.692	Crit.
			3.2	24.692	Crit.	24.692	Crit.
		≤ 60%	0.0	5.576 kg U	Crit.	11.154 kg U	Crit.
			0.4	14.872 kg U	Crit.	28.813 kg U	Crit.
			0.8	28.814 kg U	Crit.	35.20 kg U ^f	Struct.
		2.0	35.20 kg U ^f	Struct.	35.20 kg U ^f	Struct.	
		3.2	35.20 kg U ^f	Struct.	35.20 kg U ^f	Struct.	
HEU oxide ^{h, j} (UO ₂ , UO ₃ , U ₃ O ₈ , U ₃ O ₈ -Al, UO ₂ -Mg, UO ₂ -ZrO ₂)		≤ 100%	0.0	15.13 kg oxide 9.682 kg ²³⁵ U 921 g carbon	Crit. H ₂ gen.	Spacers not req'd	
Research reactor fuel elements and components ^k	UZrH _x (TRIGA)	≤ 20%	0.0	0.921 ^f	Crit.	Spacers not req'd	
		> 20%, ≤ 70%	0.0	0.408 ^f	Crit.	Spacers not req'd	
	UZrH _x	≥ 93%	0.0	0.857 ^f	Crit.	Spacers not	

Content description	Enrichment	CSI	No Spacers, ²³⁵ U (kg)	Basis for limit	277-4 can Spacers, ²³⁵ U (kg)	Basis for limit
(SNAP)					req'd	
U-Zr	≤ 100%	Varies	See limit for broken metal or alloy ^b	Crit.	Spacers as req'd	
U-Al	≤ 100%	0.0	7.333 kg U-Al 525 g U 473 g ²³⁵ U	Crit.	Spacers not req'd	
U ₃ O ₈ -Al	≤ 100%	0.0	15.13 kg oxide 9.682 kg ²³⁵ U ^l 921 g carbon	Crit.	Spacers not req'd	
UO ₂	≤ 100%	0.0	21.937 kg UO ₂ 19.308 kg ²³⁵ U	Crit.	Spacers not req'd	
Oxides of U-Zr ^m	≤ 100%	0.0	15.13 kg oxide 9.682 kg ²³⁵ U ^l 921 g carbon	Crit.	Spacers not req'd	
UO ₂ -Mg ⁿ	≤ 100%	0.0	15.13 kg oxide 9.682 kg ²³⁵ U ^l 921 g carbon	Crit.	Spacers not req'd	
Uranium compounds	UF ₄	≤ 100%	3 kg UF ₄ 2.267 kg ²³⁵ U	Crit.	Spacers not req'd	
	UO ₂ F ₂	≤ 100%	3 kg UO ₂ F ₂ 2.067 kg ²³⁵ U	Crit.	Spacers not req'd	
	UC	≤ 100%	2 kg UC 1.815 kg ²³⁵ U	Crit.	Spacers not req'd	
	UN	≤ 100%	2 kg UN 1.888 kg ²³⁵ U	Crit.	Spacers not req'd	
	TRISO	≤ 100%	0.0	2 kg TRISO 1.815 kg ²³⁵ U	Crit.	Spacers not req'd

- a With the exception of the UNX crystals (Section 1.2.2.2 of the SARP), which are loaded in crystalline solid form, HEU in solution form is not permitted for shipment in the ES-3100 HEU package.
- b All limits are expressed in kg ²³⁵U unless otherwise indicated.
- c Mass loadings cannot be rounded up.
- d 277-4 can spacers as described on Drawing No. M2E801580A043 (Appendix 1.3.7 of the SARP)
- e Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24 in. diameter but no larger than 4.25 in. diameter: maximum of 1 cylinder per can.
 - Cylinder B is no larger than 3.24 in. diameter: maximum of 1 cylinder per can.
 - Square bars are no larger than 2.29 in. × 2.29 in. (cross section): maximum of 1 bar per can.
 - Slugs are a maximum of 1.5 in. diameter × 2.0 in. tall: a maximum of 10 per convenience can where the actual number permitted is restricted by the stated loading limit.
- f Maximum planned content weight is 35.20 kg. Maximum analyzed for criticality safety is 35.32 kg.
- g Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is ²³⁵U.
- h Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 HEU package containment vessel is sealed that the shipment must be complete.
- i Evaluation limit based on specific fuel type as opposed to a maximum calculated limit for UZrH_x.
- j Allowable HEU bulk oxide densities are 2.0-6.54 g/cm³. Non-uranium metallic constituents must be counted as ²³⁵U. Moisture content in oxide is limited to 3 weight percent water.
- k For SNAP UZrH_x, x ≤ 2. For TRIGA UZrH_x, x ≤ 1.6.
- l Non-uranium metallic constituents must be counted as ²³⁵U
- m Oxides of U-Zr are UO₂-Zr and UO₂-ZrO₂.
- n UO₂-Mg shall be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

Table 1.3a. Loading Limits for Uranyl Nitrate Crystals for Ground Transport of the ES-3100 HEU Package.

Product ^{a, b}	Seal time ^c (months)	CSI	Loading limit ^{d, e} (kg UNX)	U content ^f (wt %)
UNX	2	0.4	11.90	52 < U ≤ 61
0 < X ≤ 3	4	0.4	6.70	52 < U ≤ 61
UNX	2	0.4	9.17	46 < U ≤ 52
X > 3	4	0.0	4.75	46 < U ≤ 52

- a UNX is uranyl nitrate hydrate $[\text{UO}_2(\text{NO}_3)_2 \cdot \text{XH}_2\text{O}]$ where $0 < X \leq 6$.
- b Must be shipped in Teflon bottles.
- c Seal Time – length of time after the ES-3100 HEU package containment vessel is sealed that the shipment must be complete. Seal times are conservative limits based on Table 3.5.4.1 in Appendix 3.5.4 of the SARP, and have been reduced for additional conservatism.
- d Total mass of UNX crystals. Spacers are not required for this content type.
- e Loading limits for uranyl nitrate crystals are based on hydrogen generation calculations presented in Appendix 3.5.4 of the SARP.
- f Enrichment up to 100%.

Table 1.3b. Authorized content and fissile mass loading limits for air transport of the ES-3100 HEU Package.^{a, b, c}

Content description	Enrichment	CSI	²³⁵ U (kg)
HEU metal or alloy ^d	≤ 100%	— ^g	7.00
Research reactor fuel elements and components (UZrH _x , ^e U-Zr, U-Al, U ₃ O ₈ -Al, UO ₂ , oxides of U-Zr, ^f UO ₂ -Mg)	≤ 20%	— ^g	0.921
	> 20%	— ^g	0.408

- a All limits are expressed in kg ²³⁵U unless otherwise indicated.
- b Mass loadings cannot be rounded up.
- c The loading limit for mixed-mode transportation is taken as the most restrictive limit for either ground or air mode of transportation (Table 1.3 or 1.3b).
- d Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is ²³⁵U.
- e For SNAP UZrH_x, x ≤ 2. For TRIGA UZrH_x, x ≤ 1.6.
- f Oxides of U-Zr are UO₂-Zr and UO₂-ZrO₂.
- g CSI is governed by ground transport mode.

On the basis of the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation of the request for revision of the existing CoC based upon the proposed "administrative in nature" and editorial changes. The DOE PCP finds the general information (and drawings) presented in Chapter 1 of the SARP acceptable, and the regulatory requirements of 10 CFR Part 71 remain satisfied. Evaluations of design and performance of the package for safety and regulatory compliance in structural, thermal, containment, shielding, criticality safety, operating procedures, acceptance tests and maintenance, and quality assurance are given in the remainder sections of this SER.

Chapter 2: Structural Evaluation

This section of the SER covers the Structural review.

Two administrative changes were proposed in Chapter 2 to clarify the description of U-Zr oxide in the "HEU Oxide" category. Neither of the changes affects the structural performance of the ES-3100 package and the structural safety analysis documented in the existing ES-3100 SARP remains valid.

On the basis of the review of the Page Change 2 for the ES-3100 SARP, the DOE PCP finds that the proposed changes presented in Chapter 2 of the Page Change 2 for the ES-3100 SARP, Rev. 0 are acceptable, and the regulatory requirements of 10 CFR Part 71 remain satisfied.

Chapter 3: Thermal Evaluation

This section of the SER covers the Thermal review.

On the basis of the review of the thermal-related information presented in Revision 0 of the SARP, Page Change 2, the DOE PCP finds that there are no thermal-related issues relative to this revision.

Chapter 4: Containment

This section of the SER covers the Containment review.

One administrative change was proposed in Chapter 4, specifically to clarify the description of U-Zr oxide in the "HEU Oxide" category. This proposed change does not affect the containment performance of the ES-3100 package and the containment safety analysis documented in the existing ES-3100 SARP is still valid.

On the basis of the review of the Page Change 2 for the ES-3100 SARP, the DOE PCP finds that the proposed change presented in Chapter 4 of the Page Change 2 for the ES-3100 SARP, Rev. 0 is acceptable, and the containment requirements of 10 CFR Part 71 remain satisfied.

Chapter 5: Shielding Evaluation

This section of the SER covers the Shielding review.

There are no shielding related changes included in the Page Change 2 pages for the ES-3100 SARP. All of the proposed changes are administrative in nature, encompassing various clarifications and editorial changes in other chapters. None of these changes affect the shielding evaluation in Revision 0 of the SARP and therefore the previous conclusion regarding the adequacy of shielding analysis remains valid.

On the basis of the review of the information presented in Revision 0 of the SARP, Page Change 2 for the ES-3100 SARP, Rev. 0, the DOE PCP finds that there is no shielding issue relative to this revision and that the ES-3100 SARP with the proposed page changes meets the shielding requirements of 10 CFR 71.

Chapter 6: Criticality Evaluation

This section of the SER covers the Criticality review.

All of the proposed changes are administrative in nature, encompassing various clarifications and editorial changes. No new analysis or calculations are included in the Page-Change 2 pages.

None of the changes affect the criticality safety analysis in the SARP or the previous conclusion regarding the adequacy of that analysis.

On the basis of the review of the page changes, the DOE PCP has concluded that the nuclear criticality aspects of the proposed changes have been adequately described and evaluated and that the package with the proposed page changes meets the nuclear criticality safety requirements of 10 CFR 71.

Chapter 7: Package Operations

This section of the SER covers the Package Operations review.

The proposed change is administrative in nature, and ensures that the DOE CoC identification tags use numbers at least ½- inch high. No new technical requirements are included in this Chapter 7 change. The change does not affect the operational requirements in the SARP or the previous conclusion regarding the adequacy of those requirements.

On the basis of the review of the page change, the DOE PCP has concluded that the operational procedure requirements of the proposed change have been adequately described and evaluated and that the package with the proposed change meets the operational requirements of 10 CFR 71.

Chapter 8: Acceptance Tests and Maintenance Program

This section of the SER covers the Acceptance Tests and Maintenance review.

On the basis of the review of the acceptance tests and maintenance program-related information presented in Revision 0 of the SARP, Page-Change 2, the DOE PCP finds that there are no acceptance tests and maintenance issues relative to this revision.

Chapter 9: Quality Assurance

This section of the SER covers the Quality Assurance review.

On the basis of the review of the quality assurance information presented in Revision 0 of the SARP, Page-Change 2, the DOE PCP finds that there are no quality assurance issues relative to this revision.

References

1. Tousley, D., DOE/NNSA. *Request for Revision 3 of USA/9315/B(U)F-96 (DOE)*, Docket No. 11-26-9315, letter to J. M. Shuler, DOE EM-45, dated February 8, 2011.
2. U.S. Department of Energy Certificate of Compliance, *USA/9315/B(U)F-96 (DOE), Revision 2, Certificate Number 9315*, issued November 23, 2010, expiration date of September 30, 2014.
3. Babcock & Wilcox Technical Services Y-12 LLC, Y-12 National Security Complex, Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents, SP-PKG-801940-A001, Rev. 0, dated August 2010; with Page Change 1, dated November 2010; and with Page Change 2, Docket 09-37-9315, dated February 10, 2011.