Safety Evaluation Report for Shipment of HEU Metal or Alloy Turnings, Fines, or Powders in the ES-3100 Package

Docket No. 13–20–9315

Prepared by: ________________ Date: 2/7/14

James M. Shuler
Manager, DOE Packaging Certification Program
Office of Packaging and Transportation

Approved by: ________________ Date: FEB 7, 2014

Stephen C. O'Connor
Headquarters Certifying Official
Director, Office of Packaging and Transportation

SUMMARY

The National Nuclear Security Administration (NNSA), Office of Defense Nuclear Nonproliferation (NA-20) submitted a letter[1] dated May 9, 2013, requesting that the Department of Energy (DOE) issue a Letter Amendment to the Certificate of Compliance (CoC) Number 9315, Rev 5., Package Identification No. USA/9315/B(U)F-96 (DOE), for the Model ES-3100.

In this letter, NA-20 requested a special authorization for a one-time shipment of enriched uranium (EU) in a powdered metal alloy form by air transport mode. DOE issued a Letter of Authorization on September 26, 2013 for this shipment, and was subsequently requested by NNSA to incorporate the Letter Amendment into a CoC revision in order to obtain a revision to the Department of Transportation Competent Authority Certification for a one-time shipment from the Republic of Korea. DOE issued Revision 6 of the CoC on November 19, 2013, to incorporate the conditions of the Letter of Authorization for air transport of up to eleven ES-3100 shipping packages to transport enriched uranium metal alloy powder.

During the review of the Letter Amendment, NNSA requested a CoC revision to include highly enriched uranium (HEU) metal or alloy in the form of turnings, fines or powders as an authorized content in the ES-3100 package for ground and air transport. The HEU metal or alloy turnings, fines or powders have a maximum enrichment of 80%. For ground transport, the amount of this content is limited depending on enrichment, on the basis of criticality safety or package loading limit; for air transport, the amount of this content is limited to a maximum of 7 kg U-235 per ES-3100 package (see Tables 1.3 and 1.3b of this SER for details). The existing criticality analyses in the SARP only analyzed small quantities of HEU metal and alloy powders in ES-3100 package for air transport; therefore, additional criticality safety analysis results[2] for HEU metal alloy turnings, fines or powders for air transport were provided in support of this letter amendment request. For pyrophoricity considerations, the convenience cans, the Teflon bottles and the ES-3100 containment vessel (CV) are all inerted with argon gas before closure of the CV for shipping HEU metal or alloy turnings, fines or powders.

The DOE Packaging Certification Program (PCP) staff reviewed the ES-3100 SARP Rev. 0, Page Change 4 and the additional criticality analysis results and generated four (4) Q1 questions on the nine (9) chapters. The applicant responded to all the questions and provided revisions to the SARP Rev. 0, Page Change 4, which were accepted by the PCP staff and incorporated by the applicant into the SARP Rev. 0, Page Change 5.[3]

SARP Rev.0, Page Change 5 includes changes to use aluminum convenience cans for the content of HEU metal or alloy. In order to clarify "HEU Metal and Alloy" and "HEU Oxide" shipping configurations including the use of aluminum convenience cans and Teflon bottles, applicable text throughout the SARP was revised. The HEU metal or alloy may be shipped in tin-plated carbon steel, stainless steel, aluminum, or nickel-alloy convenience cans; Teflon convenience bottles; or Teflon bottles inside metal convenience cans. HEU oxide may be shipped in tin-plated carbon steel, stainless steel, or nickel-alloy convenience cans; polyethylene or Teflon convenience bottles; or glass (UO_2-Mg oxide only), polyethylene, or Teflon bottles inside metal convenience cans.

The applicant also requested to change the revision level of Drawing M2E801580A043 from "0" to "A", which makes the "vibration absorbing silicone can pad" optional.

On the basis of the statements and representations in the ES-3100 SARP Rev.0 with Page Change 5 and the PCP staff's confirmatory evaluation as summarized in this Safety Evaluation Report (SER), the PCP staff finds shipping HEU metal or alloy turnings, fines or powders in ES-3100 packages in both ground and air transport modes are acceptable. In addition, based on this information the staff has reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71, subject to the conditions listed below.

1. *For transport of HEU metal or alloy turnings, fines or powders in the ES-3100 package, the Teflon bottles, the metal convenience cans and the CV shall be inerted with argon of high purity (>99%) and with low moisture (<5 ppm moisture).*

2. *The following issues in the SARP Rev. 0 Page Change 5 are still under review and are NOT authorized in this certificate:*

   a) *Use of the Viton fluorocarbon elastomer (Parker Compound VM835-75) O-rings,*

   b) *Extension of the periodic leakage rate test interval from 12 month to 2 years,*

   c) *Use of convenience can with a diameter greater than 4.25 inches along with off-gassing packing material,*

   d) *Use of empty convenience cans as spacers beneath loaded convenience cans, and*

   e) *Use of a bag instead of convenience can as an option in situations that currently require convenience cans.*

DOE CoC 9315 expires 9/30/2014; consequently, NNSA submitted a letter[4] dated December 3, 2013, requesting renewal of the CoC. NNSA has committed to submit a consolidated SARP to DOE for review of the CoC renewal. However, in order to allow sufficient time to review the consolidated SARP, Revision 7 of DOE CoC 9315 will be issued based on this SER with an expiration date of 9/30/2015.

1. GENERAL INFORMATION AND DRAWINGS

Detailed packaging descriptions, drawings and contents can be found in the SARP. The components of the packaging include a drum enhanced by impact-limiting and thermal-insulating materials, neutron-absorbing materials, and a containment vessel (CV) inside the drum. The payload in the CV is contained in tin-plated carbon steel, stainless steel, aluminum, or nickel-alloy convenience cans, polyethylene bottles, or Teflon bottles to prevent contamination of the interior surface of the CV.

The drawings that pertain to the ES-3100 package are listed in Table 1.0.

Table 1.0 List of Drawings Pertaining to the ES-3100 Package

Drawing No.	Revision	Title
M2E801580A001	C	Drum Assembly
M2E801580A002	B	Body Weldment
M2E801580A003	B	Inner Liner Weldment (2 sheets)
M2E801580A004	B	Double Open Head Reinforced Drum
M2E801580A005	D	Misc. Details
M2E801580A006	B	Drum Lid Weldment
M2E801580A007	B	18.25" Diameter Drum Lid
M2E801580A008	B	Top Plug Weldment
M2E801580A009	C	Pad Details
M2E801580A010	E	Data Plate Details
M2E801580A011	D	Containment Vessel Assembly
M2E801580A012	C	Containment Vessel Body Assembly (2 sheets)
M2E801580A013	C	Containment Vessel O-ring Details
M2E801580A014	B	Containment Vessel Lid Assembly
M2E801580A015	C	Containment Vessel Sealing Lid
M2E801580A016	B	Containment Vessel Closure Nut
M2E801580A023	C	Containment Vessel Leak Test Assemblies
M2E801580A024	B	Containment Vessel Vibration Absorbing Silicone 4.25" Can Pad
M2E801580A031	E	Main Assembly
M2E801580A037	D	Consolidated Assembly Drawing (3 sheets)
M2E801580A043	A	Heavy Can Spacer Assembly (SST)
T2E801827A008	A	Leak Check Flange Assembly

The content requested by NNSA and evaluated by the PCP staff is from Tables 1.3 and 1.3b of the SARP, and 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, [d] ^{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 [g]		>95%, ≤ 100%	0.0	Spacers req'd [d]	n/a	2.774	Crit.
			0.4	Spacers req'd	n/a	5.549	Crit.
			0.8	Spacers req'd	n/a	9.248	Crit.
			2.0	Spacers req'd	n/a	13.872	Crit.
			3.2	Spacers req'd	n/a	24.969	Crit.
		>90%, ≤ 95%	0.0	Spacers req'd	n/a	3.516	Crit.
			0.4	Spacers req'd	n/a	6.154	Crit.
			0.8	Spacers req'd	n/a	10.549	Crit.
			2.0	Spacers req'd	n/a	18.461	Crit.
			3.2	Spacers req'd	n/a	26.373	Crit.
Broken HEU metal or alloy [g] (cont.)		>80%, ≤ 90%	0.0	Spacers req'd	n/a	3.333	Crit.
			0.4	Spacers req'd	n/a	7.500	Crit.
			0.8	Spacers req'd	n/a	12.500	Crit.
			2.0	Spacers req'd	n/a	20.000	Crit.

Content Description	Enrichment	CSI	No Spacers, ^{235}U (kg)	Basis for limit	277-4 can Spacers, [d] ^{235}U (kg)	Basis for limit
	>80%, ≤ 90%	3.2	Spacers req'd	n/a	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	27.443	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 metal or alloy turnings, fines, or powders [g]	>70%, ≤ 80%	0.0	2.967	Crit.	Spacers not req'd	n/a
		0.4	5.192	Crit.	Spacers not req'd	n/a
		0.8	8.900	Crit.	Spacers not req'd	n/a
		2.0	17.059	Crit.	Spacers not req'd	n/a
		3.2	19.284	Crit.	Spacers not req'd	n/a
	>60%, ≤ 70%	0.0	3.249	Crit.	Spacers not req'd	n/a
		0.4	5.848	Crit.	Spacers not req'd	n/a
		0.8	13.646	Crit.	Spacers not req'd	n/a
		2.0	21.444	Crit.	Spacers not req'd	n/a
		3.2	24.692	Crit.	Spacers not req'd	n/a
	≤ 60%	0.0	5.576 kg U	Crit.	Spacers not req'd	n/a
		0.4	14.872 kg U	Crit.	Spacers not req'd	n/a
		0.8	28.814 kg U	Crit.	Spacers not req'd	n/a

Content Description		Enrichment	CSI	No Spacers, ^{235}U (kg)	Basis for limit	277-4 can Spacers, [d] ^{235}U (kg)	Basis for limit
HEU metal or alloy turnings, fines, or powders [g] (cont.)		≤ 60%	2.0	35.20 kg U [f]	Struct.	Spacers not req'd	n/a
			3.2	35.20 kg U [f]	Struct.	Spacers not req'd	n/a
HEU oxide [h, j] (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg,[n] 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	n/a
Research reactor fuel elements and components [k]	$UZrH_x$ (TRIGA)	≤ 20%	0.0	0.921 [i]	Crit.	Spacers not req'd	n/a
		> 20%, ≤ 70%	0.0	0.408 [i]	Crit.	Spacers not req'd	n/a
	$UZrH_x$ (SNAP)	≥ 93%	0.0	0.857 [i]	Crit.	Spacers not req'd	n/a
	U-Zr	≤ 100%	Varies	See limit for broken metal or alloy [g]	Crit.	Spacers as req'd	n/a
	U-Al	≤ 100%	0.0	7.333 kg U-Al 1.117 g U 1.050 kg ^{235}U	Crit.	Spacers not req'd	n/a
	U_3O_8-Al	≤ 100%	0.0	15.13 kg oxide 9.682 kg ^{235}U [l] 921 g carbon	Crit.	Spacers not req'd	n/a
	UO_2	≤ 100%	0.0	21.937 kg UO_2 19.308 kg ^{235}U	Crit.	Spacers not req'd	n/a
	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	n/a
	UO_2-Mg	≤ 100%	0.0	15.13 kg oxide 9.682 kg ^{235}U[l] 921 g carbon	Crit.	Spacers not req'd	n/a
	U_3Si_2-Al	19.7%	0.0	5.825 kg U_3Si_2-Al 2.227 kg U 450 g ^{235}U	Crit.	Spacers not req'd	n/a
Uranium compounds	UF_4	≤ 100%	0.0	3 kg UF_4 2.267 kg ^{235}U	Crit.	Spacers not req'd	n/a

Content Description		Enrichment	CSI	No Spacers, ^{235}U (kg)	Basis for limit	277-4 can Spacers,[d] ^{235}U (kg)	Basis for limit
Uranium compounds (cont).	UO_2F_2	≤ 100%	0.0	3 kg UO_2F_2 2.067 kg ^{235}U	Crit.	Spacers not req'd	n/a
	UC	≤ 100%	0.0	2 kg UC 1.815 kg ^{235}U	Crit.	Spacers not req'd	n/a
	UN	≤ 100%	0.0	2 kg UN 1.888 kg ^{235}U	Crit.	Spacers not req'd	n/a
	TRISO	≤ 100%	0.0	2 kg TRISO 1.815 kg ^{235}U	Crit.	Spacers not req'd	n/a
	U_3Si_2	≥19.7%, <40% ≥40%, ≤60%	0.0 0.0	13 kg U_3Si_2 7 Kg U_3Si_2	Crit. Crit.	Spacers not req'd Spacers not req'd	n/a

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.
b All limits are expressed in kg ^{235}U 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 HEU bulk metal and alloy not covered by these specific geometric shapes must be put into the broken metal category. Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24 inches diameter but no larger than 4.25 inches diameter: maximum of one cylinder per can.
- Cylinder B is no larger than 3.24 inches diameter: maximum of one cylinder per can.
- Square bars are no larger than 2.29 inches × 2.29 inches (cross section): maximum of one bar per can.
- Slugs are a maximum of 1.5 inches diameter × 2.0 inches 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 ^{235}U.
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/cm^3. Non-uranium metallic constituents must be counted as ^{235}U. Moisture content in oxide is limited to 3 weight percent water.
k For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
l Non-uranium metallic constituents must be counted as ^{235}U.
m Oxides of U-Zr are UO_2-Zr and UO_2-ZrO_2.
n UO_2-Mg shall be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

Table 1.3b Authorized content and fissile mass loading limits for air transport [a, b, c]

Content Description	Enrichment	CSI	^{235}U (kg)
HEU metal or alloy [d]	≤ 100%	— [g]	7.00
HEU metal or alloy turnings, fines, or powder [d]	≤ 80%	— [g]	7.00
Research reactor fuel elements and components ($UZrH_x$, [e] U-Zr, U-Al, U_3O_8-Al, UO_2, oxides of U-Zr, [f] UO_2-Mg, U_3Si_2-Al)	≤ 20%	— [g]	0.921
	> 20%	— [g]	0.408
HEU oxide [h], [i] (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, [j] UO_2-ZrO_2)	≤ 100%	— [g]	5.281

a All limits are expressed in kg ^{235}U 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 ^{235}U.
e For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
f Oxides of U-Zr are UO_2-Zr and UO_2-ZrO_2.
g CSI and spacer use are governed by ground transport mode.
h Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 containment vessel is sealed that the shipment must be complete.
i Allowable HEU bulk oxide densities are 2.0–6.54 g/cm^3. Non-uranium metallic constituents must be counted as ^{235}U. Moisture content in oxide is limited to 3 wt % water.
j UO_2-Mg will be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

Criticality Safety Index

On the basis of the results of the criticality safety analysis presented in the SARP, the PCP staff has confirmed, using the procedure in 10 CFR 71.59(b), that the Criticality Safety Index (CSI) values are 0.0, 0.4, 0.8, 2.0 and 3.2 for the ES-3100 package with HEU metal or alloy turnings, fines or powders and with the loading limits listed in Tables 1.3 and 1.3b of the SARP.

Radiation Level and Transport Index

The PCP staff has confirmed the maximum radiation transport index (TI) is 5.8, which is less than 10, the TI limit in 10 CFR 71.47(a) for non-exclusive use shipment. The actual TI of the ES-3100 package will be determined by measurement prior to shipment.

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the general information and drawings are acceptable for ground and air transport of HEU metal or alloy turnings, fines, or powders in ES-3100 package, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

The Applicant needs to revise Table 1.3b, footnote "g" in the next SARP submittal to include "and spacer use …". This information was added by the Applicant in Revision 5 of the CoC.

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 remaining sections of this SER.

2. STRUCTURAL

2.1 Discussion

The PCP staff reviewed the structural design and performance of the ES-3100 package for shipping HEU metal or alloy turnings, fines, or powders, as described in the ES-3100 SARP Rev.0, Page Change 5. The staff also reviewed the material compatibility between the HEU metal or alloy turnings, fines of powders, and the packaging components.

2.2 Structural Evaluation

The amount of HEU metal or alloy turnings, fines, or powders for transport is no greater than 35.2 kg per package, which is the radioactive content weight limit for the ES-3100 HEU package. Therefore, the structural evaluation in the original SARP remains valid. The enhanced structural tests described in 10 CFR 71.55(f)(1) and (2) for air transport of fissile material packages were not conducted for the ES-3100 package, which means the condition of the package following the tests cannot be determined. Therefore, worst-case assumptions regarding the geometric arrangement of the packaging and contents were made for criticality analysis, taking into account all moderating and structural components of the packaging (See Chapter 6 of this SER). This is consistent with the anticipated results in the mechanical and thermal tests specified in 10 CFR 71.55(f)(1) and (2).

For air transport, IAEA TS-R-1, Paragraph 618, requires that packages maintain integrity of the containment system when exposed to ambient temperatures ranging from -40^{o}C (-40^{o}F) to +55^{o}C (131^{o}F), and Paragraph 619 requires that packages be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than maximum normal operating pressure (MNOP) plus 95 kPa (13.78 psi). The condition for calculating MNOP for air transport is an ambient temperature of 55^{o}C (131^{o}F) in still air without solar insolation (IAEA TS-G-1.1, Paragraph 619.3). The calculated MNOP for air transport is 198.43 kPa (28.78 psi) at an ambient temperature of 55^{o}C (131^{o}F) and a CV temperature of 63.4^{o}C (146.11^{o}F). The CV was then evaluated at a pressure differential of 293.43 kPa (42.56 psi), and the results show that the structural integrity of the CV can be maintained.

The HEU metal or alloy powder is shipped in tin-plated carbon steel, stainless steel, aluminum, or nickel-alloy convenience cans; Teflon convenience bottles; or Teflon bottles inside metal convenience cans, and there is no material incompatibility between the contents and the packaging components.

2.3 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the structural design and performance of the ES-3100 package are acceptable for shipping HEU metal or alloy turnings, fines, or powders in either ground or air transport mode, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

3. THERMAL

3.1 Discussion

The PCP staff reviewed the thermal design and performance of the ES-3100 package for transport of the HEU metal or alloy turnings, fines or powders, as described in the SARP. The staff also reviewed Appendix 1.3.8 "Pyrophoricity of Uranium Metal" of the ES-3100 SARP. The review and evaluation focused on the potential pyrophoricity of ultrafine uranium metal powders for air shipment.

3.2 Thermal Evaluation

Uranium turnings, fines or powders can ignite easily. Moreover, spontaneous ignition of fine uranium powders is possible under water and even in a moist argon atmosphere (See page 534 in *Handbook of Non-Ferrous Metal Powders: Technologies and Applications*,O.D. Neikov et. al., 2009). Appendix 1.3.8 of the SARP on page 1-188 addresses this issue of pyrophoricity of fine uranium powders by inerting with a high-purity (>99%) argon cover gas containing low moisture (<5 ppm moisture). The PCP staff reviewed the information in the aforementioned handbook and found this inerting method is acceptable.

3.3 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the thermal design and performance of the ES-3100 package are acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71, subject to the condition listed below.

"For transport of HEU metal or alloy turnings, fines or powders in the ES-3100 package, the Teflon bottles, the metal convenience cans and the CV shall be inerted with argon of high purity (>99%) and with low moisture (<5 ppm moisture)."

4. CONTAINMENT

4.1 Discussion

The PCP staff reviewed the containment design and performance of the ES-3100 package for transport of HEU metal or alloy powder packed in Teflon bottles, as described in the SARP. The staff also reviewed Appendix 1.3.8 "Pyrophoricity of Uranium Metal" of the ES-3100 SARP. The review and evaluation was focused on the pyrophoricity of uranium metal powders in the presence of water (vapor).

4.2 Containment Evaluation

Appendix 1.3.8 of the SARP concludes that the thermal stability criterion as formulated (Equation 7, page 1-184, and associated discussion in the appendix) is satisfied for the ES-3100 package for temperatures at or above the ambient condition of T0. However, the ambient temperature for air transport within the cargo holds may be well below T0, depending on the altitude of the aircraft, e.g., -56.5^{o}C at 36,000 ft (11 km) [International Organization for

Standardization, Standard Atmosphere, ISO 2533:1975]. For these lower temperatures (but above 0^oC) and basing on the assumptions used in the appendix (relative humidity 100% at T0), liquid water may form by condensation on the internal material surfaces of the package including that of the U metal particles. The reaction of U metal particles with liquid water film on their surfaces at temperatures below 300K has not been included in the stability analysis presented in SARP Appendix 1.3.8.

The reaction of uranium metal with anoxic liquid water (i.e., free of dissolved oxygen) below 350°C forms uranium dioxide (UO_2) and H_2 [C.H. Delegard and A.J. Schmidt, "Uranium Metal Reaction Behavior in Water, Sludge, and Grout Matrices," PNNL-17815, 2008]. The UO_2 layer formed is not protective as it tends to spall off after a short time. The activation energy of the reaction rate of U metal with anoxic liquid water is 68.2 kJ/mol, which is significantly smaller than 95.5 kJ/mol — the activation energy of the reaction rate of U metal with unsaturated water vapor in Appendix 1.3.8. The difference in reaction rates becomes more significant as temperature decreases. The impact on thermal stability of the package arising from the potential presence of liquid water has not been addressed in Appendix 1.3.8. However, the potential presence of liquid water within the package is only relevant for a low temperature environment such as during air transport. These issues can be mitigated by inerting the CV with argon of high purity (>99%) and with low moisture (<5 ppm moisture).

4.3 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the containment design and performance of the ES-3100 package are acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71, subject to the condition listed below.

"For transport of HEU metal or alloy turnings, fines or powders in the ES-3100 package, the Teflon bottles, the metal convenience cans and the CV shall be inerted with argon of high purity (>99%) and with low moisture (<5 ppm moisture)."

5. SHIELDING

5.1 Discussion

The PCP staff reviewed the shielding design and performance of the ES-3100 package for transport of HEU metal or alloy turnings, fines or powders, as described in the SARP. The amount of HEU metal or alloy turnings, fines or powders is bounded by the radioactive content weight limit of the ES-3100 HEU package. Therefore, the shielding evaluation in the original SARP remains valid.

5.2 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the shielding design and performance of the ES-3100 package are acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

6. CRITICALITY

6.1 Discussion

The PCP staff reviewed the criticality design and performance of the ES-3100 package for transport of HEU metal or alloy turnings, fines or powders, as described in the ES-3100 SARP. The staff also performed Monte Carlo analyses to independently confirm the criticality safety under the most reactive conditions during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) for the shipment.

6.2 Package Description

The ES-3100 package design includes a stainless steel containment vessel (CV) inside a 30-gallon outer drum (See Figures 1.1 and 1.2 of the SARP). The HEU metal or alloy turnings, fines or powders are packed in tin-plated carbon steel or stainless steel convenience cans, or Teflon bottles which may be placed in convenience cans. The package includes two features intended for criticality control: neutron absorber that surrounds the CV and can spacers placed between convenience cans, both filled with alumina borated cement. The drawings included in the SARP provide the dimensions of the relevant packaging components. Chapter 2 of the SARP provides material specifications for the packaging components.

Descriptions of the ES-3100 package design features include the identification of packaging materials, densities and compositions of packaging materials, and the fissile/fissionable material forms, masses, and isotopic compositions of the payloads. The PCP staff confirmed that criticality-related information in the SARP is complete and representative of the actual materials specified for the ES-3100 package.

Contents

The contents of the ES-3100 package include various forms of uranium metal, uranium alloys, uranium oxides, uranyl nitrate hydrate, uranium compounds, and unirradiated TRIGA fuel elements (See SARP Tables 1.3, 1.3a, and 1.3b for loading limits). The content of the proposed shipment is HEU metal or alloy turnings, fines or powders.

Content in the form of HEU metal or alloy turnings, fines or powders requires a separate analysis because certain assumptions used to derive limits for other forms of HEU metal, such as broken pieces, are not applicable.

The results of criticality safety calculations for the proposed HEU metal or alloy turnings, fines or powders are listed in the SARP. The PCP staff confirmed that the models used in those criticality calculations are consistent with the drawings and the detailed package description given in the SARP.

6.3 Criticality Models

The single package, NCT and HAC array calculations for the proposed uranium metal alloy powder were based on detailed KENO V.a models of the ES-3100 package and payload and on a variety of array configurations.

The Standard Composition Library and the 238GROUPNDF5 nuclear data library in the SCALE code package were used for all KENO V.a calculations in the SARP and the confirmatory analyses. Section 6.8 in the SARP summarizes the determination of the minimum k_{safe} value. The lowest k_{safe} value determined from the validation is 0.925. Therefore, any configurations of ES-3100 packages with $k_{eff} + 2\sigma < k_{safe}$ are deemed subcritical. All calculations incorporated sufficient neutron histories to ensure statistical uncertainty (σ) less than 0.002 and adequate convergence. The PCP staff concurs that the benchmark experiments and corresponding bias value are applicable and conservative as applied to the ES-3100 package.

6.4 Summary of SARP Criticality Analysis and PCP Staff's Confirmatory Evaluation

6.4.1 Evaluation of a Single Package under NCT and HAC

The analyses in Section 6.4 of the SARP show that maximum reactivity occurs for a fully flooded, reflected package; therefore, the single package analysis is based on a fully flooded, reflected package. The SARP analyzed both a fully flooded, reflected containment vessel and a fully flooded, reflected package.

Table 6-1 of the SER shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Appendix 6.9.6 of the SARP and the PCP staff's confirmatory analyses for HEU metal or alloy turnings, fines or powders in the single package configuration. Single package configurations with uranium enrichments less than or equal to 80 wt.% and uranium mass less than or equal to 24.105 kg resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.925. Therefore, the ES-3100 single package containing HEU metal or alloy turnings, fines or powders with the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(b) related to a flooded single package.

6.4.2 Evaluation of Undamaged Package Arrays (NCT)

The NCT undamaged package array models for the HEU metal or alloy turnings, fines or powders corresponded to CSI values of 0.0, 0.4, 0.8, 2.0 and 3.2, with no can spacers. The analyses in the SARP show that maximum reactivity occurs in an array of ES-3100 packages when the containment vessel is flooded and the packaging is dry, referring to a configuration in which: (a) the neutron poison of the body weldment liner inner cavity and the impact absorbing insulation are dry, (b) recesses of the package external to the containment vessel do not contain any residual moisture, and (c) the interstitial space between packages in the array does not contain any residual moisture. The NCT array configurations are based on a flooded containment vessel and dry packaging to maximize the k_{eff} of the array.

Table 6.1 of the SER shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Table 6.9.6-1 of the SARP and the PCP staff's confirmatory analyses for the proposed HEU metal or alloy turnings, fines or powders under NCT. The NCT arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.925. Therefore, the ES-3100 package containing HEU metal or alloy turnings, fines or powders with the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(d) and 10 CFR 71.59(a)(1).

Table 6.1 Summary of SARP Criticality Analysis and the PCP Staff's Confirmatory Analysis

Case	Content	Case SARP	Maximum $k_{eff} + 2\sigma$[a]	
			SARP	Staff
Single Package				
S1	EU powder [b]	cvr3cha_25_1_5_15	0.92249	0.92007
NCT Array				
N1	EU powder [b]	nciabmt11_4_1_5_3	0.92133	0.92329
N2	EU powder [b]	nciabmt11_6_1_3_3	0.91515	0.91398
HAC Array				
H1	EU powder [b]	hciabmt12_4_1_5_3	0.92476	0.92386
H1	EU powder [b]	hciabmt12_6_1_3_3	0.91274	0.91412

a Upper subcritical limit (USL) k_{safe} value is 0.925.

b HEU turnings, fines and powder

6.4.3 Evaluation of damaged package arrays (HAC)

The HAC damaged package array model for the HEU metal or alloy turnings, fines or powders also corresponded to CSI values of 0.0, 0.4, 0.8, 2.0 and 3.2, with no can spacers. Each package had a flooded containment vessel and dry packaging to maximize the k_{eff} of the array. Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Table 6.9.6-11 of the SARP and the PCP staff's confirmatory analyses for HEU metal or alloy turnings, fines or powders under HAC. The HAC arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.925. Therefore, the ES-3100 package containing HEU metal or alloy turnings, fines or powders with the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(e) and the HAC-related requirements of 10 CFR 71.59(a)(2).

6.4.4 Air Transport of HEU Metal or Alloy Turnings, Fines, or Powders

The HEU metal or alloy turnings, fines, or powders in each ES-3100 package may be shipped by air transport. The six air transport models described in Section 6.3.1.4 of the SARP assume 7 kg of ^{235}U mixed with packaging materials and do not take any credit for the physical form of the payload. The proposed shipment falls within the existing criticality safety envelope for air transport and does not require any additional evaluation (see Sections 6.3.1.4 and 6.7 of the SARP). Therefore, the ES-3100 package with the HEU metal or alloy turnings, fines, or powders content described is subcritical and satisfies the requirements of 10 CFR 71.55(f) related to air transport.

6.5 Criticality Safety Index (CSI) for Nuclear Criticality Control

Based on the NCT/HAC array analyses, CSI values of 0.0, 0.4, 0.8, 2.0 and 3.2 are appropriate for the ES-3100 package with EU metal alloy powder and with the loading limits listed in SARP Tables 1.3 and 1.3b.

6.6 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5 and the PCP staff's confirmatory evaluation, the PCP staff finds the nuclear criticality safety design of the ES-3100 package is acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

7. PACKAGE OPERATIONS

7.1 Discussion

The PCP staff reviewed the package operations of the ES-3100 package for transport of HEU metal or alloy turnings, fines or powders, as described in the SARP. The staff finds no package operations-related issues that need to be addressed relative to this request except pyrophoricity of fine uranium metal alloy powders (see Section 3 of this SER for details).

7.2 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the package operations of the ES-3100 package are acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71, subject to the condition listed below.

"For transport of HEU metal or alloy turnings, fines or powders in the ES-3100 package, the Teflon bottles, the metal convenience cans and the CV shall be inerted with argon of high purity (>99%) and with low moisture (<5 ppm moisture)."

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Discussion

The PCP staff reviewed the acceptance tests and maintenance program of the ES-3100 package for transport of HEU metal or alloy turnings, fines or powders, as described in the SARP. The staff finds no acceptance tests and maintenance-related issues that need to be addressed relative to this request.

8.2 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and the PCP staff's confirmatory evaluation, the PCP staff finds the acceptance tests and maintenance program of the ES-3100 package are acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

9. QUALITY ASSURANCE

9.1 Discussion

The PCP staff reviewed the quality assurance of the ES-3100 package for transport of HEU metal or alloy turnings, fines or powders, as described in the SARP. The staff finds no quality assurance-related issues that need to be addressed relative to this request.

9.2 Conclusion

On the basis of the statements and representations in the SARP Revision 0 with Page Change 5, and PCP staff's confirmatory evaluation, the PCP staff finds the quality assurance of the ES-3100 package is acceptable for transport of HEU metal or alloy turnings, fines or powders, and will provide reasonable assurance that the package meets the regulatory requirements of 10 CFR Part 71.

REFERENCES

1. *Request for Letter Amendment to Ship HEU in Powered Metal Form in the ES-3100 Package, Docket 13-20-9315, CoC USA/9315/B(U)F-96 (DOE)*, submitted to James M. Shuler, Manager of Packaging Certification Program, Office of Packaging and Transportation of Department of Energy, by the National Nuclear Security Administration (NNSA), Office of Defense Nuclear Nonproliferation (NA-20), May 09, 2013.
2. SP-PKG-801940-A001, Rev. 0, Letter Amendment Calculations, ES-3100 HEU SARP Chapter 6 Criticality Evaluation, 04/18/2013.
3. *Safety Analysis Report for Packaging for Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001, Rev. 0, Page Change 5, Babcock & Wilcox Technical Services Y-12, LLC, Y-12 National Security Complex, September 30, 2013
4. *Request for Renewal of USA/9315/B(U)F-96 (DOE)*, submitted to James M. Shuler, Manager of Packaging Certification Program, Office of Packaging and Transportation of Department of Energy, by the National Nuclear Security Administration (NNSA), Office of Fissile Material Disposition (NA-261), December 3, 2013.