71-9315

**Department of Energy**
Washington, DC 20585

JUN 27 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 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 RAIs were discussed during a public meeting with the Nuclear Regulatory Commission on May 10, 2007. The attached document, Y/LF-782, prepared by BWXT Y-12, represents the response to these RAIs.

Key issues raised in the RAIs concerned the technical basis for the proposed re-definition of pyrophoric uranium. This response includes additional technical data to further back-up the definition. The final proposed definition is given on the attached ES-3100 Safety Analysis Report page 1-12.

In addition, a mark-up of the CoC for this revision is included for your consideration. This mark-up represents CoC Revision 5, and should have used Revision 4 as the base, but since that revision was not available at the time of this submittal, a mark-up of Revision 3 was used.

This submittal includes three attachments. The first is the RAI response document (Y/LF-782). The second is page changes to the ES-3100 SAR (Document No. Y/LF-717, R1). These affected SAR pages are identified with a "page change 3" in the footer. A guide to insertion of these page changes in the SAR is included. Third is a mark-up of the CoC with changes directly applicable to the revised definition of pyrophoric uranium.

The applicant respectfully requests that these responses be reviewed on an expedited schedule. A revised CoC is needed by mid-August to support a Naval Reactors shipment of HEU broken metal in September. The original of this letter with an attachment is being sent to the Document Control Desk. Ten copies of this letter with attachments 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.



NMSS01

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

Sincerely,

James Shuler
Manager, Packaging Certification Program
Safety Management and Operations
Office of Environmental Management

Enclosures

cc:
Kimberly J. Hardin, NRC
Joe Bozik, NNSA NA-261
Dana Willaford, DOE ORO
Jeff Arbital, BWXT Y-12
Steve Sanders, BWXT Y-12

# ATTACHMENT 1

# Y/LF-782

# RAI RESPONSE DOCUMENT

Plan by Period

Current data (06/28/2007 14:09:11)

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plan data | | | | | | | | | | | | |
| 4* PRJ PFWNARGE Argentina National Commission of Energy | 0 | 0 | 0 | 0 | 0 | 0 | 7,039 | 83,977 | 146,679 | 48,147 | 10,056 | 13,073 | 308,972 |
| *** WBS PFWNARGE Argentina National Commission of Energy | 0 | 0 | 0 | 0 | 0 | 0 | 7,039 | 83,977 | 146,679 | 48,147 | 10,056 | 13,073 | 308,972 |
| ** WBS 7ARGE002 ARGE 60 kgs L (FY07) | 0 | 0 | 0 | 0 | 0 | 0 | 7,039 | 83,977 | 146,679 | 48,147 | 10,056 | 13,073 | 308,972 |
| * WBS 7ARGE02A ARGE PM | 0 | 0 | 0 | 0 | 0 | 0 | 7,039 | 12,570 | 9,554 | 11,565 | 10,056 | 13,073 | 63,857 |
| * WBS 7ARGE02B ARGE Packaging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20,407 | 38,773 | 2,041 | 0 | 0 | 61,221 |
| * WBS 7ARGE02C ARGE Reimbursement | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51,000 | 57,000 | 18,000 | 0 | 0 | 126,000 |
| * WBS 7ARGE02D ARGE Staging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41,352 | 16,541 | 0 | 0 | 57,893 |
| 5* PFWNHANR South Korean Reactor | 0 | 0 | 0 | 0 | 0 | 0 | 6,063 | 24,955 | 80,694 | 115,977 | 39,551 | 15,151 | 282,391 |
| 4* PRJ PFWNHANR South Korean Reactor Projects | 0 | 0 | 0 | 0 | 0 | 0 | 6,063 | 24,955 | 80,694 | 115,977 | 39,551 | 15,151 | 282,391 |
| *** WBS PFWNHANR South Korean Reactor Projects | 0 | 0 | 0 | 0 | 0 | 0 | 6,063 | 24,955 | 80,694 | 115,977 | 39,551 | 15,151 | 282,391 |
| ** WBS 7HANR004 HANARO 180 Kgs L (FY06 & FY07 Cmb) | 0 | 0 | 0 | 0 | 0 | 0 | 6,063 | 24,955 | 80,694 | 115,977 | 39,551 | 15,151 | 282,391 |
| * WBS 7HANR04A HANARO Program Management | 0 | 0 | 0 | 0 | 0 | 0 | 6,063 | 10,826 | 8,228 | 9,960 | 8,661 | 11,259 | 54,996 |
| * WBS 7HANR04B HANARO Packaging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,129 | 15,791 | 19,116 | 3,324 | 0 | 52,361 |
| * WBS 7HANR04C HANARO Mat Reimburse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45,000 | 69,000 | 12,000 | 0 | 126,000 |
| * WBS 7HANR04D HANARO Staging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11,675 | 17,901 | 15,566 | 3,892 | 49,033 |
| 5* PGIR1205 GIRI Recoveries | 0 | 0 | 0 | 26,595 | 31,288 | 29,724 | 31,288 | 39,109 | 29,724 | 168,994 | 187,774 | 244,107 | 788,602 |
| 4* PRJ PGIR1205 GIRI Recoveries | 0 | 0 | 0 | 26,595 | 31,288 | 29,724 | 31,288 | 39,109 | 29,724 | 168,994 | 187,774 | 244,107 | 788,602 |
| *** WBS PGIR1205 GIRI Recoveries | 0 | 0 | 0 | 26,595 | 31,288 | 29,724 | 31,288 | 39,109 | 29,724 | 168,994 | 187,774 | 244,107 | 788,602 |
| ** WBS 7AECLMPL Project Maple Leaf | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 159,609 | 187,774 | 244,107 | 591,490 |
| * WBS 7AECLMLP Maple Leaf Planning | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40,839 | 48,045 | 62,459 | 151,344 |
| * WBS 7AECLMLE Maple Leaf Execution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28,322 | 33,320 | 43,315 | 104,957 |
| * WBS 7AECLMLR Maple Leaf Receipt & Storage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36,309 | 42,716 | 55,531 | 134,555 |
| * WBS 7AECLMLC Maple Leaf Closeout & Documentation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,021 | 16,495 | 21,444 | 51,960 |
| * WBS 7AECLMLF Maple Leaf Future Phase Planning | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40,118 | 47,198 | 61,358 | 148,674 |
| ** WBS 7AECLPHS Project High Stick | 0 | 0 | 0 | 26,595 | 31,288 | 29,724 | 31,288 | 39,109 | 29,724 | 9,385 | 0 | 0 | 197,112 |
| * WBS 7AECLHSP High Stick Planning | 0 | 0 | 0 | 6,939 | 8,164 | 7,756 | 8,164 | 10,204 | 7,756 | 2,449 | 0 | 0 | 51,431 |
| * WBS 7AECLHSE High Stick Execution | 0 | 0 | 0 | 5,724 | 6,734 | 6,397 | 6,734 | 8,417 | 6,397 | 2,020 | 0 | 0 | 42,424 |
| * WBS 7AECLHSR High Stick Receipt & Storage | 0 | 0 | 0 | 6,160 | 7,247 | 6,885 | 7,247 | 9,058 | 6,885 | 2,173 | 0 | 0 | 45,655 |
| * WBS 7AECLHSC High Stick Closeout & Documentation | 0 | 0 | 0 | 2,368 | 2,786 | 2,647 | 2,786 | 3,483 | 2,647 | 836 | 0 | 0 | 17,554 |
| * WBS 7AECLHSF High Stick Future Phase Planning | 0 | 0 | 0 | 5,403 | 6,357 | 6,039 | 6,357 | 7,946 | 6,039 | 1,907 | 0 | 0 | 40,049 |
| 5* PWNAECL1 Canadian Reactor Pro | 0 | 42,916 | 57,221 | 60,082 | 57,221 | 54,360 | 57,221 | 73,873 | 56,986 | 68,982 | 59,984 | 526,076 | 1,114,919 |
| 4* PRJ PWNAECL1 Canadian Reactor Projects L | 0 | 42,916 | 57,221 | 60,082 | 57,221 | 54,360 | 57,221 | 73,873 | 56,986 | 68,982 | 59,984 | 526,076 | 1,114,919 |
| *** WBS PWNAECL1 Canadian Reactor Projects L | 0 | 42,916 | 57,221 | 60,082 | 57,221 | 54,360 | 57,221 | 73,873 | 56,986 | 68,982 | 59,984 | 526,076 | 1,114,919 |
| ** WBS 7AECLL16 Canada 142 Kg - CY07 (Ship 1) | 0 | 42,916 | 57,221 | 60,082 | 57,221 | 54,360 | 57,221 | 22,886 | 0 | 0 | 0 | 0 | 351,905 |
| * WBS 7AECLL6A Program Management 142Kg LEU (1st CY07) | 0 | 6,881 | 9,174 | 9,633 | 9,174 | 8,715 | 9,174 | 3,670 | 0 | 0 | 0 | 0 | 56,421 |
| * WBS 7AECLL6B Material Packaging 142 Kg LEU (1st CY07) | 0 | 3,263 | 4,351 | 4,568 | 4,351 | 4,133 | 4,351 | 1,739 | 0 | 0 | 0 | 0 | 26,754 |
| * WBS 7AECLL6C Material Reimburement 142 Kg LEU (1st CY | 0 | 24,244 | 32,325 | 33,941 | 32,325 | 30,709 | 32,325 | 12,930 | 0 | 0 | 0 | 0 | 198,800 |
| * WBS 7AECLL6D Staging 142 Kg LEU (1st CY07) | 0 | 8,528 | 11,371 | 11,939 | 11,371 | 10,802 | 11,371 | 4,548 | 0 | 0 | 0 | 0 | 69,930 |
| ** WBS 7AESLL17 Canada MAPLE 60 Kg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 448,095 | 448,095 |
| * WBS 7AECLL7A Program Management 60 Kg MAPLE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43,627 | 43,627 |
| * WBS 7AECLL7B Material Packaging 60 Kg MAPLE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93,900 | 93,900 |
| * WBS 7AECLL7C Material Reimburement 60 Kg MAPLE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 252,000 | 252,000 |
| * WBS 7AECLL7D Staging 60 Kg MAPLE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 58,568 | 58,568 |
| ** WBS 7AECLL18 AECL CY08 Mat'l Supply | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50,987 | 56,986 | 68,982 | 59,984 | 77,980 | 314,919 |
| * WBS 7AECLL8A Proj Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,135 | 10,209 | 12,359 | 10,746 | 13,971 | 56,421 |
| * WBS 7AECLL8B Packaging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,332 | 4,842 | 5,860 | 5,096 | 6,625 | 26,754 |
| * WBS 7AECLL8C Mat'l Reimbursement | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32,187 | 35,973 | 43,547 | 37,867 | 49,227 | 198,800 |
| * WBS 7AECLL8D Staging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,334 | 5,962 | 7,216 | 6,275 | 8,158 | 32,944 |
| 5* PWNAECL2 Canadian Reactor Pro | 14,339 | 31,954 | 32,409 | 12,353 | 6,907 | 6,562 | 2,072 | 0 | 0 | 0 | 0 | 0 | 106,596 |
| 4* PRJ PWNAECL2 Canadian Reactor Projects H | 14,339 | 31,954 | 32,409 | 12,353 | 6,907 | 6,562 | 2,072 | 0 | 0 | 0 | 0 | 0 | 106,596 |
| *** WBS PWNAECL2 Canadian Reactor Projects H | 14,339 | 31,954 | 32,409 | 12,353 | 6,907 | 6,562 | 2,072 | 0 | 0 | 0 | 0 | 0 | 106,596 |
| ** WBS 7AECLH15 AECL 15 kg H (FY07) | 14,339 | 31,954 | 32,409 | 12,353 | 6,907 | 6,562 | 2,072 | 0 | 0 | 0 | 0 | 0 | 106,596 |
| * WBS 7AECLH5A Program Management | 5,180 | 7,943 | 6,907 | 7,252 | 6,907 | 6,562 | 2,072 | 0 | 0 | 0 | 0 | 0 | 42,824 |

Plan by Period | Current data (06/28/2007 14:09:11)

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| * WBS 7AECLH5B Packaging | 9,159 | 14,044 | 12,212 | 2,442 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37,856 |
| * WBS 7AECLH5C Material Reimburse | 0 | 1,737 | 2,316 | 463 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,515 |
| * WBS 7AECLH5D Staging | 0 | 8,231 | 10,975 | 2,195 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21,400 |
| 7* Y1060206 Global Threat Reduct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| 6* Y106020603 GTR Cash Work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| 5* PGNS2003 Sav River Future Mis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| 4* PRJ PGNS2003 Sav River Future Missions 64YE00411 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| *** WBS PGNS2003 Sav River Future Missions 64YE00411 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| ** WBS 7SWIZ100 Switzerland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| * WBS 7SWISR01 PM SWIZ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33,348 | 25,501 | 0 | 58,849 |
| 7* Y1060207 Non-Proliferation Te | 163,147 | 250,159 | 217,530 | 228,406 | 217,530 | 206,653 | 217,530 | 271,912 | 206,653 | 250,159 | 217,530 | 282,789 | 2,730,000 |
| 6* PINSG001 Tech Testbed Demo 61 | 163,147 | 250,159 | 217,530 | 228,406 | 217,530 | 206,653 | 217,530 | 271,912 | 206,653 | 250,159 | 217,530 | 282,789 | 2,730,000 |
| 5* PRJ PINSG001 Tech Testbed Demo 61YD00876 9/30/05*C* | 163,147 | 250,159 | 217,530 | 228,406 | 217,530 | 206,653 | 217,530 | 271,912 | 206,653 | 250,159 | 217,530 | 282,789 | 2,730,000 |
| 4* WBS PINSG001 Tech Testbed Demo 61YD00876 9/30/05*C* | 163,147 | 250,159 | 217,530 | 228,406 | 217,530 | 206,653 | 217,530 | 271,912 | 206,653 | 250,159 | 217,530 | 282,789 | 2,730,000 |
| 8* Y10603 International Non-Pr | 12,299 | 18,858 | 16,398 | 47,330 | 72,420 | 103,462 | 108,907 | 126,065 | 86,069 | 76,641 | 40,139 | 37,876 | 746,464 |
| 7* Y1060303 Work for Others | 12,299 | 18,858 | 16,398 | 47,330 | 72,420 | 103,462 | 108,907 | 126,065 | 86,069 | 76,641 | 40,139 | 37,876 | 746,464 |
| 6* PDCW9602 Eagle Eyes Air Fluor | 12,299 | 18,858 | 16,398 | 47,330 | 72,420 | 103,462 | 108,907 | 126,065 | 86,069 | 76,641 | 40,139 | 37,876 | 746,464 |
| 5* PRJ PDCW9602 Eagle Eyes Air Fluorescence Prototype | 12,299 | 18,858 | 16,398 | 47,330 | 72,420 | 103,462 | 108,907 | 126,065 | 86,069 | 76,641 | 40,139 | 37,876 | 746,464 |
| 4* WBS PDCW9602 Eagle Eyes Air Fluorescence Prototype | 12,299 | 18,858 | 16,398 | 47,330 | 72,420 | 103,462 | 108,907 | 126,065 | 86,069 | 76,641 | 40,139 | 37,876 | 746,464 |
| *** WBS 73119974 Eagle Eyes Testing and Verification | 12,299 | 18,858 | 16,398 | 21,896 | 21,322 | 20,256 | 21,322 | 16,584 | 5,540 | 6,707 | 5,832 | 8,044 | 175,058 |
| ** WBS SZCW3073 Eagle Eyes Project Mgmt | 4,374 | 6,707 | 5,832 | 6,123 | 5,832 | 5,540 | 5,832 | 7,290 | 5,540 | 6,707 | 5,832 | 7,581 | 73,191 |
| ** WBS SZCW3074 Eagle Eyes Test Plan | 7,925 | 12,151 | 10,566 | 1,057 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 463 | 32,162 |
| ** WBS SZCW3075 Eagle Eyes Field Testing | 0 | 0 | 0 | 14,716 | 15,490 | 14,716 | 15,490 | 9,294 | 0 | 0 | 0 | 0 | 69,706 |
| *** WBS 73119975 Eagle Eyes System Design (USM) | 0 | 0 | 0 | 0 | 15,299 | 36,334 | 38,247 | 47,808 | 36,334 | 43,984 | 27,538 | 29,832 | 275,376 |
| ** WBS SZCW3076 USM Design Subc | 0 | 0 | 0 | 0 | 15,299 | 36,334 | 38,247 | 47,808 | 36,334 | 43,984 | 27,538 | 29,832 | 275,376 |
| *** WBS 73119976 Eagle Eyes Lab & Model Integration (USM) | 0 | 0 | 0 | 25,434 | 35,799 | 46,871 | 49,338 | 61,673 | 44,194 | 25,951 | 6,770 | 0 | 296,030 |
| ** WBS SZCW3077 USM Lab Subc | 0 | 0 | 0 | 25,434 | 35,799 | 46,871 | 49,338 | 61,673 | 44,194 | 25,951 | 6,770 | 0 | 296,030 |
| Result | 6,321,557 | 9,501,696 | 8,356,882 | 8,942,147 | 8,609,308 | 8,330,805 | 8,779,103 | 11,031,853 | 8,652,212 | 10,374,816 | 8,982,734 | 11,839,039 | 109,722,153 |

Y/LF-782

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# REQUEST FOR ADDITIONAL INFORMATION MODEL ES-3100 PACKAGE

**Amendment 5**
**Docket No. 71-9315**
**TAC No. L24063**

**Reference: Letter Kimberly J. Hardin, U.S. NRC to James M. Shuler, U.S. DOE (dated May 9, 2007)**

BWXT Y-12, L.L.C.

June 30, 2007

MANAGED BY
BWXT Y-12, L.L.C.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-13672 (10-00)

Y/LF-782

# REQUEST FOR ADDITIONAL INFORMATION
# MODEL ES-3100 PACKAGE

**Amendment 5**
**Docket No. 71-9315**
**TAC No. L24063**

**Reference: Letter Kimberly J. Hardin, U.S. NRC to James M. Shuler, U.S. DOE (dated May 9, 2007)**

June 30, 2007


Prepared by the
Y-12 National Security Complex
Oak Ridge, Tennessee 37831



Managed by
BWXT Y-12, L.L.C.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

## 1.0 General Information

**Materials Review**

**1-1 Demonstrate that when considerations of the uncertainties in surface roughness, potential for hydride inclusions, packing densities, and measured ignition temperatures are evaluated, the maximum temperature reached by the canister stays below the lowest ignition temperature when uncertainties are considered, and that there is no pyrophoric potential for material that does not pass through the sieve.**

**Two curves in the Totemeier Study1 were used to propose ignition temperatures (340°C and the 550°C) for metal pieces with a surface area of 1 cm2/g. The plots did not consider the purity of the gas or condition of the sample given. Ignition temperature is uncertain and is not an intrinsic value of the metal. The previous history and conditions of the samples used in these studies need to be described and compared to the history of the samples intended to be shipped so that a safety determination can be made regarding these ignition temperatures.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

Uncertainties in surface roughness, potential for hydride inclusions, and packing densities are addressed in response to other questions below. In addressing the uncertainty in ignition temperature, the source reports for the Totemeier review article were consulted (Baker, Schnizlein, and Bingle,[a] and Tetenbaum, Mishler, and Schnizlein[b]), as well as an additional report by Baker et al in the same journal.[c] These three, particularly the two by Baker et al, examine variations in the gas composition, in the uranium composition, and the uranium metallurgy.

A key aspect of the burning curves for various uranium compositions and metallurgies, burned in a range of oxygen concentrations, is the tendency for the uranium to "thermocycle." Once the uranium temperature reaches a critical value around 400ºC the temperature increases rapidly, then falls off, and then increases again. This is demonstrated in a number of graphs in the two Baker reports (see for example figure 5 in footnote a). Baker, Schnizlein, and Bingle conclude (in both papers) that this is due to the transition from

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a Journal of Nuclear Materials, Volume 20, 1966, L. Baker, L. G. Schnizlein, and J. D. Bingle, The Ignition of Uranium, pp 22-38.

b Nuclear Science and Engineering, Volume 14, 1962, M. Tetenbaum , L. Mishler, and G. Schnizlein, Uranium Powder Ignition Studies, pp 230-238.

c Journal of Nuclear Materials, Volume 20, 1966, L. Baker, L. G. Schnizlein, and J. D. Bingle, The Ignition of Binary Alloys of Uranium, pp 39-40.

an autocatalytic oxide layer to a protective layer as the uranium heats up through the 400° to 500°C range. In some cases, the transition is enough to dampen the first temperature excursion, while in other cases it is not. This difference – whether ignition occurs at the first temperature excursion or the changing nature of the oxide layer dampens the first rise and ignition occurs later – is the source of the discontinuity in Baker (footnote a, figure 10), which is reproduced in Totemeier figure 4. The lower curve in this figure, nearly straight across at a value of approximately 390°C, represents ignition occurring at this first temperature excursion in the burning curve. As specific surface areas drop, the change in the nature of the oxide layer is enough to dampen the first temperature excursion and delay ignition. As Baker et al report, variations in metallurgy, metal composition, and gas composition could vary the point at which ignition is delayed beyond the first temperature excursion, particularly for specific surface areas in the range of 2 to 6 $cm^2/g$.

Because variations in metallurgy, metal composition, and gas composition can cause ignition to occur at the first temperature excursion (represented by the lower line in Totmeier, figure 4), the ES-3100 analysis used the value of 390°C from the lower line rather than 550°C from the upper curve. This value corresponds well with the 340°C value reported in Tetenbaum. A degree of conservatism was added by rounding these values down to 600 K (327 °C).

A footnote was added to the SAR text (page I-204) with a brief explanation of this.

**1-2 Revise the definition to state that shipment is limited to uranium metal that has not been stored in water. The operating instructions should include steps to ensure this condition is fulfilled.**

**According to the Totemeier review article, the ignition temperature is very dependent on the previous storage history, especially if the contents were in contact with water. As Totemeier indicates, if the samples had been exposed to a moist environment, UH3 has been consistently found to form as a secondary phase with significantly different ignition characteristics. Depending on the conditions used to determine the ignition temperature and the past history of the uranium metal, restrictions on past history might need be necessary.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

The proposed definition on SAR pages 1-12 and I-201 have been revised to state that if uranium metal or alloy has ever been stored in water, it must be converted to an oxide or shipped in an inert gas atmosphere. The new section on operating procedures (SAR pages 7-3 and 7-4) contains similar language.

**1-3 Demonstrate how Rho used in Equation 4 is a property of the can contents not the uranium metal.**

**Rho was used to convert surface reaction rates of the uranium to volumetric rates of the can contents in Equation 2. The reaction rates of the uranium metal should be used; otherwise Rho would have to be the density of the uranium fragment. Rho's definition should not change from the density of the uranium to the smear density of the container.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

To clarify the equations, the bulk density has been replaced with the metal density times a packing density. The requisite changes have been made in the SAR, specifically in equations 2 and 4, and in Table 1 (in SAR Appendix 1.4.10), as well as other places throughout SAR Appendix 1.4.10.

**1-4 Revise, to be technically correct, the last line on p. 1-205 to read "maximum allowable uranium heat generation rate" as indicated in Equation 6.**

**Complete and accurate information must be provided in the application in accordance with the 71.7(a) requirements.**

Applicant Response:

The paragraph in question (directly preceding equation 6) has been reworded to say that equation 6 calculates the "maximum possible uranium heat generation rate" from the configuration being evaluated. This paragraph is now the first paragraph on SAR page 1-206.

**1-5 Show how the packing density affects the conclusion that the system is stable against ignition. Describe how a change to a density of 10 g/cm3 would affect the results.**

**A bulk density of 5 g/cm3 is used on p. 1-207. This is only a 27% packing density. One fourth inch diameter beads should be able to be packed to a much higher density, probably 60-70%. The Epstein paper2 indicates that the ability to ignite, at temperatures even as low as ambient, depend on the density and size of the bed of materials.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

To show this affect, the bulk density has been replaced with the metal density times a packing density. A new section "Variation in Input Packing Density" has been added on SAR page I-209 to examine a range of packing densities.

1-6 **Interchange the phrases in the sentence in the definition starting with "Power..." on p. 1-201 to remove any ambiguity. The sentence should start with the phrase "Incidental small particles... size restrictions," to clarify that wire, foils, etc., are never permitted to be transported unless they are pre-oxidized or contained in an inert atmosphere.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

The sentence in question, in the proposed definition on the bottom of SAR page I-201 has been reworded for clarity, as requested by the reviewer.

1-7 **Establish definitions to distinguish between a wire and a rod.**

**Definitions are needed to distinguish a rod from a wire. The SA/M criterion is only met if any long wire or rod has a diameter greater than 0.4 cm. A ball of tangled shavings, rods, and wires, all with a diameter < 0.4 cm, can be formed into a ball that will not pass through the proposed one fourth inch mesh, yet the SA/M will be larger than the allowable limit of 1 cm2/g. A proper definition of both a "wire" and a "rod" will assure this ball is transported in an inert atmosphere.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

Attachment 2 of SAR Appendix 1.4.10 (page 1-215) shows that rods of infinite length with a diameter of at least 1/4 inch (0.63 cm) would meet the ≤1 $cm^2/g$ criteria. This item would pass through the 3/8-inch (0.95 cm) mesh and yet, if smooth, is clearly not pyrophoric. So, operators will be instructed to first evaluate the SA/M ratio, and if that can't be accomplished, their only recourse will be to use the 3/8-inch mesh screening process. This process has been addressed in the new section regarding operating procedures on SAR pages 7-3 and 7-4 (see also response to RAI 1-11). In this process, if the SA/M ratio can't be evaluated for a rod-shaped (or any other) item and it passes through the 3/8-inch mesh, it fails the test and must be considered pyrophoric.

Wire (and by inference balls of wire) is specifically called out in the pyrophoric definition in the CoC as requiring an inert atmosphere or be oxided prior to shipment. The operating procedures on SAR pages 7-3 and 7-4 expressly require wire and balls of wire to be treated as pyrophoric. The operating procedures on SAR pages 7-3 and 7-4 allow rod-shaped or any other broken metal shape (defined on SAR page 1-12) to be evaluated to determine if they are pyrophoric.

A ball, or tangled mass, of small items (such as wires, rods, and turnings) will not be treated as a solid shape. So even though the SA/M ratio can not be evaluated and the mass will not pass through the sieve, it will be treated as pyrophoric if any individual part of the mass is pyrophoric. The specialized operating procedures on SAR pages 7-3 and 7-4 address the treatment of a tangled mass of small items in this manner.

**1-8 Justify the roughness factor and be consistent in its use. Justification of the grid size for sieving should include a reasonable roughness factor for the metal.**

**Both examples on p. 1-202 should use the same roughness factor. Example #1 currently has a roughness factor of 1 and example #2 uses 2. A factor of two in the first example would drive the SA/M over the allowable limit of 1 cm2/g. Additionally, provide a justification for using the factor of 2. Most surface roughness factors range from 3 to 6.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

The roughness factor of two was based on a recommendation from Y-12 plant personnel. In response to this question, additional evaluations were made of fracture surfaces of cast uranium metal. Observed roughness factors ranged from 1.1 to 2.7, with a mean value of 2.0. This value is consistent with the recommendation from Y-12 experience, but since the maximum observed value was larger than 2, a roughness factor of three was selected to bound the highest value observed. The previous ¼ inch mesh definition was changed to 3/8 inch mesh throughout the text. A discussion of this was added to SAR pages I-210 and I-211. Example 1 (SAR page 1-202) was modified to compare the results for a smooth surface and a rough surface, and example 2 was deleted.

**1-9 Revise the proposed definition of pyrophoricity on p. 1-201 to state: "if an inert atmosphere is used, the cover gas will have a minimum of 99.999% purity," or include a section that warns the consignee that the convenience cans must be opened in an inert cell to avoid possible pyrophoric events. Include these in the operating procedures.**

**Totemeier indicated that for uranium metal sealed in an inert atmosphere, there was**

**sufficient moisture in the cover gas to produce UH3 and a UO2 surface layer. In addition, studies by Solbrig3 indicate that not all the hydrogen produced in the uranium/moisture reaction forms UH3 so there is free hydrogen in the canister; as much as 13%. When air is admitted to the canister, the 2UH3 + 2O2 2UO2 + 3H2 reaction can occur. This is a rapid and exothermic reaction. Totemeier states that; "The heat generated could either ignite any hydrogen gas present in the container or the uranium itself." Totemeier also discusses potential ways to avert this situation and the pros and cons of each.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

The revised definition of pyrophoricity on SAR page I-201 states "under an inert cover gas." In the new section on operating procedures (SAR pages 7-3 and 7-4), the cover gas specifications are given as argon with high purity (≥ 99.997%) and dry (≤ 5 ppm moisture). These values are Y-12's standard purchase specifications for argon, and sufficient to eliminate hydride formation.

**1-10 Clarify in Chapter 7 what steps are being taken to assure that the fines have been sufficiently oxidized so water vapor does not diffuse through the oxide layer to the metal underneath and establish the potential for hydride formation.**

**The operating instructions for pre-transport oxidation of fines (wires, etc.) should be revised to state the conversion of the metal to an oxide prior to transport must be complete enough to prevent diffusion of water vapor through the oxide to the metal surface over the maximum period of transport, i.e., one year.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

Any small particles which are oxidized (rather than packed in an inert atmosphere) will be "completely oxidized." This is noted in the revised definition of pyrophoricity, the new section regarding operating procedures on SAR pages 7-3 and 7-4, and in SAR Appendix 1.4.10 on pages I-211 and I-212.

**1-11 Include a section describing operator training and guidance for doing the sieving that is important to separating the size factions of the contents.**

**This information is needed to determine compliance with 10 CFR 71.43 (d), 10 CFR 71.55(d)(2), and 10 CFR 71.89.**

Applicant Response:

A new section has been included in Section 7, *Package Operations,* which include operating procedures for overall determination of pyrophority before loading the ES-3100 (SAR pages 7-3 and 7-4). This information is also in SAR Appendix 1.4.10 on pages I-211 and I-212.

**References**

1. Totemeier, Terry C., ANL/ED/95-2, "A Review of the Corrosion and Pyrophoricity Behavior of Uranium and Plutonium," June 1995, Argonne National Lab-West.

2. M. Epstein, B. Malinovic, M.G. Plys, SNF-6192-FP, "Uranium Pyrophoricity Phenomena and Prediction," April 2000, Flour Hanford, Richland, Washington.

3. C.W. Solbrig, J.R. Krsul, and D.N. Olsen, "Pyrophoricity of Uranium in Long-term Storage Environments," 1994, *DOE Spent Fuel Challenges and Initiatives*, American Nuclear Society.

# ATTACHMENT 2

# SAR PAGE CHANGES

# GUIDE TO PAGE CHANGES

## Y/LF-717, Rev. 1, page change #3

| SAR SECTION | PAGE CHANGES |
|---|---|
| Volume 1, Front section | Replace pages i to xx |
| Volume 1, Section 1 | Replace pages 1-11 to 1-12<br>Replace pages 1-199 to 1-218 |
| Volume 2, Front section | Replace pages i to xx |
| Volume 2, Section 6 | Replace page 6-239<br>*(page numbering fix from page change #2)* |
| Volume 2, Section 7 | Replace pages 7-1 to 7-14 |

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

Prepared by the
Oak Ridge Y-12 National Security Complex
Oak Ridge, Tennessee 37831
Managed by
BWXT Y-12, L.L.C.
for the
U. S. Department of Energy
under contract DE-AC05-84OR21400

June 30, 2007

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ALARA | as low as reasonably achievable |
| AM | as-manufactured |
| ANC | Average Net Count |
| ANSI | American National Standards Institute |
| AS | allowable stress |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| Cat 277-4 | Thermo Electron Corporation[1] Catalog No. 277-4™ (or Cat. No. 277-4) |
| CD | capacity discharge |
| CERCA | Compagnie pour l'Étude et la Realisation de Combustibles Atomiques |
| CFR | Code of Federal Regulations |
| CMTR | certified material test report |
| CoC | Certificate of Compliance |
| CSI | criticality safety index |
| CV | containment vessel |
| CVA | containment vessel arrangement |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| EPDM | ethylene-propylene-diene monomer |
| ETP | explicit triangular pack |
| FEA | finite element analysis |
| H/X ratio | hydrogen-to-fissile isotope ratio |
| HAC | Hypothetical Accident Conditions |
| HEU | highly enriched uranium |
| IAEA | International Atomic Energy Agency |
| $k_{eff}$ | calculated neutron multiplication factor |
| LOD | loss on drying |
| LTL | lower tolerance limit |
| M.S. | margin of safety |
| MNOP | maximum normal operating pressure |
| MOCFR | moisture fraction inside the containment vessel |
| MOIFR | moisture fraction of the package external to the containment vessel |
| NCT | Normal Conditions of Transport |
| NLF | neutron leakage fraction |
| NRC | U.S. Nuclear Regulatory Commission |
| NTRC | National Transportation Research Center |
| OECD | Organization for Economic Cooperation and Development |
| ORNL | Oak Ridge National Laboratory |
| PGNAA | Prompt Gamma-ray Neutron Activation Analysis |
| ppb | parts per billion |
| ppm | parts per million |
| QA | quality assurance |
| QCPI | Quality Certification and Procurement |
| RCSB | Rackable Can Storage Box |
| SAR | safety analysis report |

[1] Corporate name changed to Shieldwerx

| | |
|---|---|
| SCALE | Standardized Computer Analysis for Licensing Evaluation |
| $s_i$ | standard error |
| SRS | Savannah River Site |
| SS304 | type 304 stainless steel |
| SST/SGT | Safe-Secure Trailer/Safeguards Transporter |
| TGA | thermogravimetric analysis |
| TI | transport index |
| TID | tamper-indicating device |
| TS | test sample |
| UNH | uranyl nitrate hexahydrate |
| UNX | uranyl nitrate crystals |
| USL | upper subcritical limit |
| VF | Volume Fraction |
| Y-12 | Y-12 National Security Complex |

## 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.<br>Evaluated air transport.<br>Revised criticality safety calculations to remove bias correct factors.<br>Added a CSI option of 3.2.<br>Increased mass of off-gassing material allowed in containment vessel.<br>Increased carbon concentration in HEU contents.<br>Increased Np-237 concentration is HEU contents.<br>Added uranium zirconium hydride and uranium carbide as contents (TRIGA fuel).<br>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 |

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 either in a sealed, inerted container or are stabilized to an oxide prior to shipment (oxidation must be complete). If the uranium had been stored in water, it must be shipped in a sealed, inerted container or completely oxided prior to shipment.

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

Prepared by: Russell W. Schmidt
BWXT Y-12 L.L.C.
November 2006
Revised June 2007

Reviewed by: Sanford G. Bloom
BWXT Y-12 L.L.C.
November 2006
Re-reviewed June 2007

# 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 or are completely stabilized to an oxide prior to shipment. Uranium metal or alloy which has been stored in water must be shipped in a sealed container under an inert cover gas or completely oxided prior to shipment.*

## 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;
- 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 $8.686\ cm^2/8.802g = 0.9868\ cm^2/g$ 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 converted to an oxide or are packaged 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 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 or for uranium metal that is converted to an oxide. If the uranium metal is converted to an oxide, then it is in no danger of ignition under any conditions, and packing limits for oxides have been explicitly given in the certificate of compliance. 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

[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.

Tcenter is the temperature at the center of the can (K)
Twall is the temperature at the can wall (K)
S is the heat production per unit volume ($W/cm^3$)
R is the radius of the can (cm)
Kth is the thermal conductivity of the uranium contents (W/cm K)

The heat production per unit volume is a function of the reaction rate and the heat of reaction. Since the oxidation reaction occurs at the surface of the uranium, the reaction rate is typically stated as a mass reacted per second per unit area. The specific surface area, the uranium metal density, and the packing density are applied to convert the rate per unit uranium surface area to a rate per unit can volume. The result is:

$$S = Rho \bullet Phi \bullet SArea \bullet dHrxn \bullet RxnRate \qquad \text{(Equation 2)}$$

where
Rho is the density of the uranium metal ($g/cm^3$)
Phi is the packing density of the uranium in the can ($cm^3$ U/$cm^3$ can volume)
SArea is the specific surface area of the uranium ($cm^2/g$)
dHrxn is the heat of reaction (J/g uranium)
RxnRate is the reaction rate (g uranium / (s • $cm^2$))

The reaction rate of uranium metal with oxygen has been evaluated by many researchers over the years. The general form of the rate equation used is:

$$RxnRate = K0 \bullet P^n \bullet e^{(-Te/T)} \qquad \text{(Equation 3)}$$

where
K0 is the reaction rate coefficient (g uranium / (s • $cm^2$))
P is the partial pressure of water vapor (kPa)
n is the exponential coefficient on the partial pressure of water vapor
Te is the activation energy (K)
T is the temperature of the reactants (K)

For the case at hand, the temperature of the reactants is the highest at the can center (Tcenter) and the lowest at the can wall (Twall). The average temperature of the reactants is midway between these two values. For conservatism the reaction rate of the entire contents is evaluated at the maximum temperature, which occurs at the center of the can (Tcenter). This analysis considers heat transfer only through the can walls, and ignores heat transfer through the top and bottom of the can. This is also a conservative assumption.

Equations 1, 2, and 3 are combined to yield:

$$Tcenter - Twall = (R^2 \bullet Rho \bullet Phi \bullet SArea \bullet dHrxn \bullet K0 \bullet P^n \bullet e^{(-Te/Tcenter)}) / (4 \bullet Kth) \qquad \text{(Equation 4)}$$

Note that Kth is a property of the can contents (that is, for the bed of uranium metal particles with air in between), and not a property of solid uranium metal. The thermal conductivity of uranium metal is much higher than the thermal conductivity of a bed of uranium metal pieces.

P is the partial pressure of $H_2O$ present in the containment vessel at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 and 100%

relative humidity, which yields a water vapor pressure of P0. When the temperature in the containment vessel increases the partial pressure of water vapor increases according to the ideal gas law, which in this case reduces to:

$$P = P0 \cdot (Tcenter/T0) \qquad \text{(Equation 5)}$$

In this evaluation, the maximum possible rate of heat generation due to the oxidation of the uranium metal is also of interest since this heat must be carried away by the package, even at HAC. The maximum rate of heat generation is the heat generated by the oxidation of uranium metal at the highest temperature reached during HAC, assuming the maximum allowable load of uranium metal. This is:

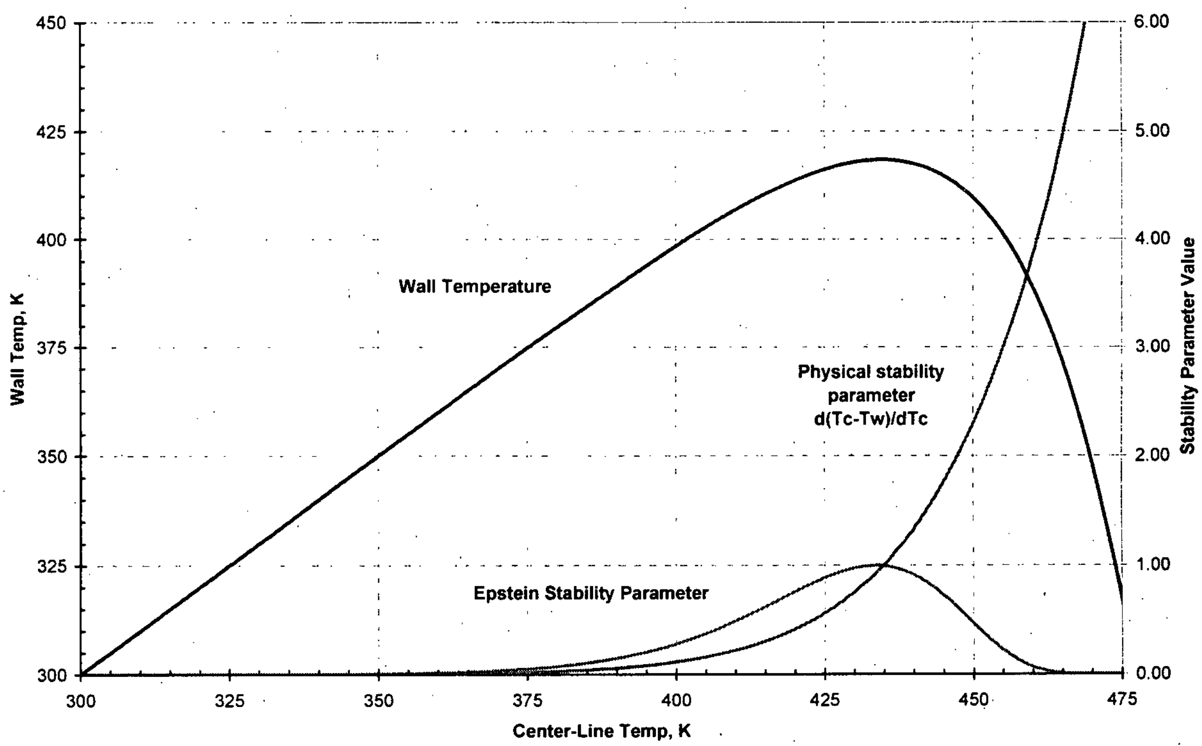
$$Qmax = Mmax \cdot SArea \cdot dHrxn \cdot K0 \cdot P^{n} \cdot e^{(-Te/Tcenter)} \qquad \text{(Equation 6)}$$

where
Qmax = the maximum rate of heat generation (W)
Mmax = the maximum uranium metal loading (g)

*Evaluation of Thermal Stability*
Equation 4 provides the means to evaluate the maximum temperature reached in the uranium metal. It does not by itself validate the stability of the system. This system does present a simple means to evaluate stability – both numerical stability and more importantly physical stability (meaning that the temperature cannot build to spontaneous ignition).

Solving equation 4 for Twall over a range of Tcenter values and plotting the results produces figure 1:

**Figure 1. Thermal Stability of Uranium Metal Package**



The wall temperature calculated from equation 4 and plotted here is the temperature needed in order to provide enough heat transfer to maintain the given center-line temperature. The wall temperature initially tracks the center-line temperature – the rate of heat generation is low, so a very small temperature difference is sufficient to remove that heat. As the center-line temperature (and therefore the amount of heat generated) increases, the temperature difference needed to keep the center-line temperature steady at the given value increases exponentially. At some point (about 435 K in figure 1) the required temperature difference gets so large that the wall temperature would have to decrease in order to maintain a stable center-line temperature. In an actual package there is no cooling mechanism to do this, and once the center-line temperature exceeds this point the amount of heat generated will exceed the ability to carry off that heat, and the center-line temperature will increase until either the reaction runs out of oxygen or the ignition point is reached. The point at which the required wall temperature stops increasing, marks the maximum stable center-line temperature for the package. The required wall temperature stops increasing at the point where the rate of increase in the needed temperature difference (d(Tcenter-Twall)) equals the rate of increase of the center-line temperature (dTcenter). Stated mathematically, when d(Tcenter-Twall)/dTcenter is less than 1 the required Twall increases along with Tcenter, and stability is maintained. When d(Tcenter-Twall)/dTcenter is greater than 1 Twall would have to drop to maintain stability as Tcenter increases. Since this is not possible in a real package, the temperature in the package would steadily increase to either ignition or consumption of all available oxygen. The value of d(Tcenter-Twall)/dTcenter = 1 marks the maximum stable point for a given package.

Equation 4 is

$$\text{Tcenter} - \text{Twall} = (R^2 \bullet \text{Rho} \bullet \text{Phi} \bullet \text{SArea} \bullet \text{dHrxn} \bullet \text{K0} \bullet P^n \bullet e^{(-\text{Te}/\text{Tcenter})}) / (4 \bullet \text{Kth})$$

Taking the first derivative of this equation with respect to Tcenter yields an equation for the stability parameter derived above:

$$\text{d(Tcenter-Twall)/dTcenter} = \text{(Tcenter-Twall)} \bullet \text{Te}/\text{Tcenter}^2 \qquad \text{(Equation 7)}$$

The thermal stability of the system is maintained as long as (Tcenter-Twall) • Te/Tcenter$^2$ ≤ 1. This parameter is equivalent to the stability parameter "B" developed in Epstein et al, without the simplifying assumptions made in that paper. The value of d(Tcenter-Twall)/dTcenter is plotted in Figure 1, along with the Epstein "B" parameter.

*Input Parameters*

The key values used to evaluate equations 4, 5, 6, and 7 are shown in Table 1.

**Table 1. Key input parameters**

| Parameter | Value | Units |
|---|---|---|
| R | 5.27 | cm |
| Rho | 19 | g/cm$^3$ |
| Phi | 0.26 | cm$^3$/cm$^3$ |
| SArea | 1 | cm$^2$/g |
| dHrxn | 4559 | J/g Uranium |
| K0 | 76086 | gU/(s • cm$^2$) |
| P0 | 3.53 | kPa |
| T0 | 300 | K |
| n | 0.3 | |
| Te | 11490 | K |
| Kth | 0.004 | W/(cm • K) |

The sources of these parameters are:

R is the inside radius of a convenience can. The typical can used has an outside diameter of 4.25 in, and an inside diameter of 4.15 in. (10.54 cm).

Rho is the density of uranium metal.

Phi is the packing density of uranium metal when packed into the convenience cans. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 $cm^3$. This yields a packing density of 0.26 $cm^3/cm^3$. The effects of variations on this value are discussed below.

SArea is the specific surface area, which is limited by the package certification to 1 $cm^2/g$.

dHrxn is the heat of reaction, on a uranium basis. This value came from Totemeier, page 17 (1089 cal/gU = 4559 J/gU).

K0, n, and Te are parameters for the reaction rate equation. As noted above, a number of researchers have analyzed the reaction rate of uranium metal with various combinations of oxygen and water vapor. Numerous models have been developed from this data. This analysis used the published model that best fit the conditions present. Many of the published rate models are only valid up to 100 to 130°C. This evaluation requires evaluation beyond 140°C. Many of the models are for either pure oxygen or pure water vapor. McGillivray[5] notes that the reaction rate at a given temperature varies with both the oxygen concentration and the partial pressure of water vapor. The published model that best matches the conditions of this evaluation (reaction in air at temperatures exceeding 140°C, with a small water vapor partial pressure) is the Pearce model (Pearce, < 100% RH, in Air, T < 192°C) as reported in the Epstein paper.

P0 and T0 are used to calculate P, the partial pressure of $H_2O$ vapor present in the containment vessel at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 = 300 K (80°F) and 100% relative humidity. P0 is therefore the vapor pressure of water at 300K, which is P0 = 3.53 kPa. When the temperature in the containment vessel increases, the partial pressure of water vapor increases according to equation 5.

Kth is the thermal conductivity of the uranium particle bed. The value here was taken from Epstein et al, page 6. Because of the air-filled void spaces, the bed thermal conductivity is much lower than the uranium metal value of 0.3 W/(cm • K).

*Results*
The set of equations (4, 5, 6, and 7) was evaluated using a commercial software package named Tk!Solver, which has the advantage of being able to automatically iterate to solutions as needed. This is necessary when solving equation 4 for a fixed wall temperature to determine Tcenter. Attachment 1 shows the rules, input and output for the TK!Solver model for the HAC and NCT cases.

The hypothetical accident condition evaluation gave a maximum containment vessel (CV) temperature (Twall) of 255°F (397 K). Evaluating equations 4 through 7 for these conditions yields a Tcenter of 398.4 K (257.5°F), with a maximum heat output (assuming a full load of 36 kgU) of 5.9 Watts, and a stability parameter d(Tcenter-Twall)/dTcenter of 0.102, well below the critical value of 1.0.

The 255°F HAC temperature was based on a uranium heat generation of 0.4 W. The 5.9 W maximum heat generated from the oxidation reaction under those conditions would heat the CV wall above that temperature. The thermal analysis evaluated the HAC for heat generation rates of 20 W and 30 W as well as the 0.4 W standard value. Table 3.7 in the thermal analysis shows that for an assumed 20 W heat generation in the uranium metal contents, the peak CV wall temperature is 277 °F (409.3 K). Using this value ensures that the heat transfer from the uranium contents to the CV wall and to the rest of the package is conservatively addressed.

For the revised HAC wall temperature of 277 °F (409.3 K), equations 4 through 7 yield the following results:

Tcenter = 413.3 K (284.4 °F) (well below the ignition temperature of 600 K)
MaxQ = 17.0 Watts (below the 20W assumption)
d(Tcenter-Twall)/dTcenter = 0.272 (well below the critical value of 1.0)

At the NCT wall temperature of 190°F (360.9 K) the results are:

Tcenter = 361.0 K (190.1 °F) (well below the ignition temperature of 600 K)
MaxQ = 0.289 Watts (below the 0.4W assumption)
d(Tcenter-Twall)/dTcenter = 0.006 (well below the critical value of 1.0)

These values clearly show that uranium metal with a specific surface area of no more than 1 $cm^2/g$ will not spontaneously ignite under any anticipated transport conditions.

*Variation in Input Packing Density*

The density with which uranium metal is packed into the convenience cans limits the surface area available to oxidize. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 $cm^3$. This yields a packing density of 0.26 $cm^3/cm^3$.

A search of the literature on packing densities reveals a lot of work on smooth spheres, and very little on anything else. Scott and Kilgour[6] experimented with packing smooth steel spheres in cylinders, and reported a maximum packing density of 0.6366 after extensive vibration to compact the steel spheres as much as possible. The steel balls used in this experiment had a coefficient of friction of 0.2, well below the value for smooth uranium metal of 1.0. Subsequent analysis by Kong and Lannutti[7] considering the effects of friction between particles gives packing fractions in the range of 0.41 to 0.46, with higher friction coefficients producing lower packing fractions.

The broken metal routinely packed at Y-12 consists of large, rough, irregular pieces. The reported packing density of 0.26 for this material is consistent with the literature reviewed, particularly Kong and Lannutti. Therefore the value of 0.26 was used as the base value in the analyses reported above.

To bound the metal contents of the ES-3100 two additional cases have been analyzed under hypothetical accident conditions: rough broken metal at a packing density of 0.46 (the upper end of the range reported by Kong & Lannutti); and smooth cast spheres at a packing density of 0.64 (consistent with Scott & Kilgour).

For rough broken metal at a packing density of 0.46 the maximum center temperature at HAC was 422 K, well below the ignition temperature of 600 K. For smooth cast 3/8" spheres at a packing density of 0.64 the maximum center temperature at HAC was 412 K, well below the ignition temperature of 600 K.

*Oxygen Limitation in the Containment Vessel*
The analysis above placed no restriction on the amount of oxygen available to react with the uranium metal contents. In reality, the ES-3100 containment vessel has a finite volume, which restricts the amount of oxygen available for reaction.

The CV is a cylinder with inside dimensions of 31.00 in. (78.74 cm) tall and 5.06 in. (12.85 cm) in diameter. This produces a volume of 10,215 $cm^3$, or 10.215 liters. At ambient conditions of 300 K (80.3°F) and 100% relative humidity, 10.215 liters of humid air contains 2.78 g of oxygen from the air, and another 0.23 grams of oxygen in the $H_2O$. These 3.01 grams of oxygen can react with 22.40 g of uranium metal. This is 0.06% of the ES-3100's capacity.

A mass of 22.4 g of U metal when reacted with 3.01 g of oxygen will produce a maximum total heat output of 102 kJ (96.8 BTU), spread out over the time required for the reaction to take place. This total amount of oxygen could sustain the NCT maximum heat output of 0.289 W for 4.1 days, or the HAC peak heat output for 1.7 hours. If somehow released all at once, the 102 kJ would only raise the temperature of 36 kg of uranium by 24.5 K. More realistically, as shown by the calculations above, any reaction will be slow, with enough time for the heat generated to flow to the CV and the rest of the package.

The ES-3100 CV is 15.1 kg of stainless steel, with a heat capacity of 0.515 J/(g •K). The 102 kJ maximum produced by the oxidation reaction could only raise the temperature of the CV (ignoring contents) by 13.1 K. This heat sink, plus the heat sinks offered by the CV contents, ensures that the oxidation reaction will not be able to build to the 600 K ignition temperature required for spontaneous ignition.

In practice there will less than 3 g of oxygen available to react with the uranium metal inside the closed CV. A full load of uranium will, by itself, displace nearly 20% of the air in the CV. The convenience cans, spacer cans, and other packing materials will displace even more air, further reducing the amount of uranium that could possibly react. Also, the uranium metal is packed inside closed convenience cans. These cans limit the oxygen available to react with the contents to the oxygen in the convenience can itself. Finally, part of the available oxygen will react with the uranium before the peak HAC conditions are reached. Figure 22b in section 3 shows that it will take about 4 hours for the CV wall to reach the maximum temperature in the HAC fire. During this four-hour temperature ramp-up 0.9 grams of oxygen would be consumed by reaction with the uranium, leaving only 2.1 grams available to react once the HAC temperature was reached. Even if the uranium surface area was uncontrolled, lack of oxygen would snuff out any increase in the uranium reaction rate before it could reach the ignition point.

*Specific Surface Area Implementation via Sieve*
As noted above, the 1 $cm^2/g$ specific surface area limit is not easy to measure or to use in the field. A screening method that is simple and easy to use in the field will reduce the potential for packaging mistakes. The recommended approach 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.

Example 1 above showed that the minimum size of a metal sphere meeting the 1 $cm^2/g$ specific surface area limit varies with the degree of surface roughness. In example 1 a smooth sphere 1/8 inch in diameter and a rough sphere 3/8 inch in diameter both had specific surface areas just below the 1 $cm^2/g$ limit. The 3/8-in. mesh is stipulated in the recommended text in order to accommodate both smooth and rough metal.

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 converted to an oxide or 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 converted to an oxide or are packaged 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.

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

- Rejected items must be separated for proper handling:
    - Rejected items can be shipped if packed under an inert cover gas or if converted to an oxide.
    - An acceptable cover gas must be high-purity (≥99.997%) and dry (≤5 ppm moisture).
    - For metal converted to an oxide, partial oxidation is not acceptable.

## 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.

## Attachment 1 TK!Solver Model and Results

Rules

-------

```
Tcenter-Twall=((R^2*rho*phi*SArea*dHrxn*K0*P^n)/(4*Kth))*exp(-Te/Tcenter)
P=P0*(Tcenter/T0)
Deriv=(Tcenter-Twall)*Te/Tcenter^2
HRate=SArea*dHrxn*K0*P^n*exp(-Te/Tcenter)
MaxQ=HRate*MaxM
RRate=SArea*MaxM*K0*P^n*exp(-Te/Tcenter)
ORate=RRate*32/238
OTime=MaxO/ORate
```

--------------------------------------------------------------------------------

HAC - 277 °F Wall Temperature

| Input | Name | Output | Unit | Comment |
|---|---|---|---|---|
| | Tcenter | 413.348 | K | Temperature at the center of the can |
| 409.3 | Twall | | K | Temp at the can wall |
| | HRate | .000472 | W/gU | Rate of heat production (w/unlimited O2) |
| | MaxQ | 16.9945 | W | Maximum heat production (from max KgU) |
| 36000 | MaxM | | gU | Maximum ES-3100 contents |
| 3.01 | MaxO | | gO | Maximum ES-3100 Oxygen Content |
| | RRate | .003728 | gU/s | Reaction Rate at given Conditions |
| | ORate | .000501 | gO/s | Oxygen Use rate at given conditions |
| | OTime | 1.66822 | hr | Oxygen time to run-out |
| 5.27 | R | | cm | Can radius |
| 1 | SArea | | cm^2/gU | Specific Surface Area of U particles |
| | Deriv | .272221 | | d(Tcenter-Twall)/dTcenter |
| 19 | rho | | gU/cm^3 | Density of uranium |
| .26 | phi | | | Packing density, U cm^3 / Can cm^3 |
| 4559 | dHrxn | | J/gU | Heat of Reaction |
| 76086 | K0 | | gU/(s*cm^2) | Reaction rate coefficient - Pearce <100% |
| 11490 | Te | | K | Reaction rate coefficient - Pearce <100% |
| .3 | n | | | Reaction rate coefficient - Pearce <100% |
| 3.53 | P0 | | kPa | Vapor pressure of water at T0 |
| 300 | T0 | | K | Temperature for P0 |
| | P | 4.86373 | kPa | Vapor Pressure of Water at Tcenter |
| .004 | Kth | | W/cm*K | Thermal Conductivity of U particle bed |

--------------------------------------------------------------------------------

NCT - 190 °F Wall Temperature

| Input | Name | Output | Unit | Comment |
|---|---|---|---|---|
| | Tcenter | 360.969 | K | Temperature at the center of the can |
| 360.9 | Twall | | K | Temp at the can wall |
| | HRate | 8.03E-6 | W/gU | Rate of heat production (w/unlimited O2) |
| | MaxQ | .288991 | W | Maximum heat production (from max KgU) |
| 36000 | MaxM | | gU | Maximum ES-3100 contents |
| 3.01 | MaxO | | gO | Maximum ES-3100 Oxygen Content |
| | RRate | 6.34E-5 | gU/s | Reaction Rate at given Conditions |
| | ORate | 8.52E-6 | gO/s | Oxygen Use rate at given conditions |
| | OTime | 98.1015 | hr | Oxygen time to run-out |
| | | | | |
| 5.27 | R | | cm | Can radius |
| 1 | SArea | | cm^2/gU | Specific Surface Area of U particles |
| | Deriv | .00607 | | d(Tcenter-Twall)/dTcenter |
| | | | | |
| 19 | rho | | gU/cm^3 | Density of uranium |
| .26 | phi | | | Packing density, U cm^3 / Can cm^3 |
| 4559 | dHrxn | | J/gU | Heat of Reaction |
| 76086 | K0 | | gU/(s*cm^2) | Reaction rate coefficient - Pearce <100% |
| 11490 | Te | | K | Reaction rate coefficient - Pearce <100% |
| .3 | n | | | Reaction rate coefficient - Pearce <100% |
| 3.53 | P0 | | kPa | Vapor pressure of water at T0 |
| 300 | T0 | | K | Temperature for P0 |
| | P | 4.2474 | kPa | Vapor Pressure of Water at Tcenter |
| .004 | Kth | | W/cm*K | Thermal Conductivity of U particle bed |

## Attachment 2. Pyrophoric Size Limits on Small Uranium Metal Pieces

Specific Surface Area: 1.0 cm^2/g
Uranium Metal Density: 19.0 g/cm^3
Surface Area Multiplier: 3.0

*The surface area multiplier is the ratio of the actual surface area divided by the simple geometeric surface area.*

**Spheres - Minimum Safe Diameter**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Limiting diameter | 0.9474 | cm | or | 0.3730 | in | 8.459 | grams |

**Rods - Minimum Safe Diameter**

| Length | Diameter | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.9 cm | 0.9474 | cm | or | 0.3730 | in | 12.688 | grams |
| 1.0 cm | 0.9231 | cm | or | 0.3634 | in | 12.715 | grams |
| 1.5 cm | 0.8000 | cm | or | 0.3150 | in | 14.326 | grams |
| 2.0 cm | 0.7500 | cm | or | 0.2953 | in | 16.788 | grams |
| 2.5 cm | 0.7229 | cm | or | 0.2846 | in | 19.495 | grams |
| Infinite | 0.6316 | cm | or | 0.2487 | in | | |

**Cubes - Minimum Safe Side Length**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Limiting side length | 0.9474 | cm | or | 0.3730 | in | 16.155 | grams |

**Square Cross-Section Rods - Minimum Safe Side Length**

| Length | Side | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.9 cm | 0.9474 | cm | or | 0.3730 | in | 16.155 | grams |
| 1.0 cm | 0.9231 | cm | or | 0.3634 | in | 16.189 | grams |
| 1.5 cm | 0.8000 | cm | or | 0.3150 | in | 18.240 | grams |
| 2.0 cm | 0.7500 | cm | or | 0.2953 | in | 21.375 | grams |
| 2.5 cm | 0.7229 | cm | or | 0.2846 | in | 24.822 | grams |
| Infinite | 0.6316 | cm | or | 0.2487 | in | | |

**Chips & Shards - Minimum Safe Thickness**

| Length | Width | Thickness | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.0 cm | 0.5 cm | 6.0000 | cm | or | 2.3622 | in | 57.000 | grams |
| 1.5 cm | 0.5 cm | 2.0000 | cm | or | 0.7874 | in | 28.500 | grams |
| 2.0 cm | 0.5 cm | 1.5000 | cm | or | 0.5906 | in | 28.500 | grams |
| 2.5 cm | 0.5 cm | 1.3043 | cm | or | 0.5135 | in | 30.978 | grams |
| 3.0 cm | 0.5 cm | 1.2000 | cm | or | 0.4724 | in | 34.200 | grams |
| Infinite | 0.5 cm | 0.8571 | cm | or | 0.3375 | in | | |
| | | | | | | | | |
| 1.0 cm | 0.6 cm | 2.0000 | cm | or | 0.7874 | in | 22.800 | grams |
| 1.5 cm | 0.6 cm | 1.2000 | cm | or | 0.4724 | in | 20.520 | grams |
| 2.0 cm | 0.6 cm | 1.0000 | cm | or | 0.3937 | in | 22.800 | grams |
| 2.5 cm | 0.6 cm | 0.9091 | cm | or | 0.3579 | in | 25.909 | grams |
| 3.0 cm | 0.6 cm | 0.8571 | cm | or | 0.3375 | in | 29.314 | grams |
| Infinite | 0.6 cm | 0.6667 | cm | or | 0.2625 | in | | |
| | | | | | | | | |
| Infinite | Infinite | 0.3158 | cm | or | 0.1243 | in | | |

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

Prepared by the
Oak Ridge Y-12 National Security Complex
Oak Ridge, Tennessee 37831
Managed by
BWXT Y-12, L.L.C.
for the
U. S. Department of Energy
under contract DE-AC05-84OR21400

June 30, 2007

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ALARA | as low as reasonably achievable |
| AM | as-manufactured |
| ANC | Average Net Count |
| ANSI | American National Standards Institute |
| AS | allowable stress |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| Cat 277-4 | Thermo Electron Corporation[1] Catalog No. 277-4™ (or Cat. No. 277-4) |
| CD | capacity discharge |
| CERCA | Compagnie pour l'Étude et la Realisation de Combustibles Atomiques |
| CFR | Code of Federal Regulations |
| CMTR | certified material test report |
| CoC | Certificate of Compliance |
| CSI | criticality safety index |
| CV | containment vessel |
| CVA | containment vessel arrangement |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| EPDM | ethylene-propylene-diene monomer |
| ETP | explicit triangular pack |
| FEA | finite element analysis |
| H/X ratio | hydrogen-to-fissile isotope ratio |
| HAC | Hypothetical Accident Conditions |
| HEU | highly enriched uranium |
| IAEA | International Atomic Energy Agency |
| $k_{eff}$ | calculated neutron multiplication factor |
| LOD | loss on drying |
| LTL | lower tolerance limit |
| M.S. | margin of safety |
| MNOP | maximum normal operating pressure |
| MOCFR | moisture fraction inside the containment vessel |
| MOIFR | moisture fraction of the package external to the containment vessel |
| NCT | Normal Conditions of Transport |
| NLF | neutron leakage fraction |
| NRC | U.S. Nuclear Regulatory Commission |
| NTRC | National Transportation Research Center |
| OECD | Organization for Economic Cooperation and Development |
| ORNL | Oak Ridge National Laboratory |
| PGNAA | Prompt Gamma-ray Neutron Activation Analysis |
| ppb | parts per billion |
| ppm | parts per million |
| QA | quality assurance |
| QCPI | Quality Certification and Procurement |
| RCSB | Rackable Can Storage Box |
| SAR | safety analysis report |

[1] Corporate name changed to Shieldwerx

| | |
|---|---|
| SCALE | Standardized Computer Analysis for Licensing Evaluation |
| $s_i$ | standard error |
| SRS | Savannah River Site |
| SS304 | type 304 stainless steel |
| SST/SGT | Safe-Secure Trailer/Safeguards Transporter |
| TGA | thermogravimetric analysis |
| TI | transport index |
| TID | tamper-indicating device |
| TS | test sample |
| UNH | uranyl nitrate hexahydrate |
| UNX | uranyl nitrate crystals |
| USL | upper subcritical limit |
| VF | Volume Fraction |
| Y-12 | Y-12 National Security Complex |

## 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.<br>Evaluated air transport.<br>Revised criticality safety calculations to remove bias correct factors.<br>Added a CSI option of 3.2.<br>Increased mass of off-gassing material allowed in containment vessel.<br>Increased carbon concentration in HEU contents.<br>Increased Np-237 concentration is HEU contents.<br>Added uranium zirconium hydride and uranium carbide as contents (TRIGA fuel).<br>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 |

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

Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model

| case name | SO (g) | $U_3O_8$ (g) | Sat. $H_2O$ (g) | SO h/x | U (g) | $^{235}U$ (g) | C (g) | mg C/ g $^{235}U$ | CV $H_2O$ (g) | CV h/x | Unident. (g) | $k_{eff}$ | σ | $k_{eff}+2σ$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hciask_9_7 | 21300 | 19865 | 760 | 2.36 | 16816 | 15673 | 921 | 58764 | 647 | 3.44 | 1 | 0.48912 | 0.00101 | 0.49114 |
| hciask_9_8 | 21300 | 19865 | 1140 | 3.00 | 16816 | 15673 | 921 | 58764 | 971 | 4.61 | 1 | 0.52104 | 0.00109 | 0.52322 |
| hciask_9_9 | 21300 | 19865 | 1521 | 3.63 | 16816 | 15673 | 921 | 58764 | 1294 | 5.79 | 1 | 0.55643 | 0.00104 | 0.55851 |
| hciask_9_10 | 21300 | 19865 | 1901 | 4.26 | 16816 | 15673 | 921 | 58764 | 1618 | 6.96 | 1 | 0.59193 | 0.00105 | 0.59403 |
| hciask_9_11 | 21300 | 19865 | 2281 | 4.90 | 16816 | 15673 | 921 | 58764 | 1941 | 8.13 | 1 | 0.62726 | 0.00109 | 0.62945 |
| hciask_9_12 | 21300 | 19865 | 2661 | 5.53 | 16816 | 15673 | 921 | 58764 | 2265 | 9.30 | 1 | 0.65952 | 0.00106 | 0.66163 |
| hciask_9_13 | 21300 | 19865 | 3041 | 6.16 | 16816 | 15673 | 921 | 58764 | 2588 | 10.47 | 1 | 0.69094 | 0.00127 | 0.69348 |
| hciask_9_14 | 21300 | 19865 | 3421 | 6.80 | 16816 | 15673 | 921 | 58764 | 2912 | 11.64 | [illegible] | [illegible] | [illegible] | [illegible] |
| hciask_9_15 | 21300 | 19865 | 3801 | 7.43 | 16816 | 15673 | 921 | 58764 | 3235 | 12.82 | 1 | 0.75757 | 0.00116 | 0.75989 |
| | | | | | | | | | | | | | | |
| hciask_10_1 | 21300 | 20786 | 0 | 1.05 | 17596 | 16399 | 0 | 0 | 0 | 1.05 | 1 | 0.43087 | 0.00111 | 0.43308 |
| hciask_10_6 | 21300 | 20786 | 391 | 1.67 | 17596 | 16399 | 0 | 0 | 324 | 2.19 | 1 | 0.46066 | 0.00092 | 0.46250 |
| hciask_10_7 | 21300 | 20786 | 781 | 2.29 | 17596 | 16399 | 0 | 0 | 647 | 3.32 | 1 | 0.49381 | 0.00097 | 0.49574 |
| hciask_10_8 | 21300 | 20786 | 1172 | 2.91 | 17596 | 16399 | 0 | 0 | 971 | 4.46 | 1 | 0.52679 | 0.00113 | 0.52906 |
| hciask_10_9 | 21300 | 20786 | 1562 | 3.54 | 17596 | 16399 | 0 | 0 | 1294 | 5.60 | 1 | 0.56200 | 0.00121 | 0.56442 |
| hciask_10_10 | 21300 | 20786 | 1953 | 4.16 | 17596 | 16399 | 0 | 0 | 1618 | 6.73 | 1 | 0.59673 | 0.00118 | 0.59908 |
| hciask_10_11 | 21300 | 20786 | 2343 | 4.78 | 17596 | 16399 | 0 | 0 | 1941 | 7.87 | 1 | 0.63042 | 0.00109 | 0.63260 |
| hciask_10_12 | 21300 | 20786 | 2734 | 5.40 | 17596 | 16399 | 0 | 0 | 2265 | 9.00 | 1 | 0.66502 | 0.00116 | 0.66735 |
| hciask_10_13 | 21300 | 20786 | 3124 | 6.02 | 17596 | 16399 | 0 | 0 | 2588 | 10.14 | 1 | 0.69780 | 0.00108 | 0.69997 |
| hciask_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.73223 | 0.00123 | 0.73470 |
| hciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76462 | 0.00131 | 0.76725 |
| nciask_10_14 | 21300 | 20786 | 3515 | 6.64 | 17596 | 16399 | 0 | 0 | 2912 | 11.28 | 1 | 0.72808 | 0.00150 | 0.73109 |
| nciask_10_15 | 21300 | 20786 | 3905 | 7.27 | 17596 | 16399 | 0 | 0 | 3235 | 12.41 | 1 | 0.76141 | 0.00140 | 0.76422 |

# 7. PACKAGE OPERATIONS

The ES-3100 shipping package shall be operated in accordance with applicable Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, workers, and the environment. Furthermore, the ES-3100 shall be operated according to a site-approved quality assurance plan.

Specific criteria for operating the ES-3100 package with highly enriched uranium (HEU) contents are presented in this section. The packaging user shall develop detailed site-specific operating procedures based on these criteria and on the NRC-issued Certificate of Compliance (CoC). These procedures shall be in accordance with 10 CFR 71, Subparts A, G, and H. The package operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) as required by 10 CFR 20.1101, "Standards for Protection Against Radiation."

## 7.1 PACKAGE LOADING

The user of the packaging shall:

1. have authorization to acquire, package, transport, or transfer radioactive, fissile, or special nuclear material;

2. have the latest NRC CoC and referenced SAR sections for the ES-3100 package with HEU contents;

3. comply with all actions and restrictions specified in the CoC;

4. be registered as a user of the packaging with the NRC; and

5. have an site-approved quality assurance program that meets the requirements of 10 CFR 71, Subpart H.

### 7.1.1 Preparation for Loading

The ES-3100 Containment Vessel (CV) may be loaded while inside or outside the drum. This decision is a site dependent. Detailed, written operating procedures shall include, at a minimum, the process steps listed below before the contents are placed in the ES-3100 package. These steps, initiated by the operating personnel and their supervisor, ensure that:

1. all appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. the radioactive material contents are authorized by the CoC, and the use of the package complies with all conditions in the CoC.

3. the packaging has been properly maintained and is in unimpaired condition. (All required refurbishment and periodic maintenance shall have been performed and documented within the scheduled requirements of the CoC, the SAR, and the maintenance program.)

4. A valid leak-test sticker must be present on the containment vessel to ensure that the required

acceptance leak test or the annual leak test has been performed.

5. packaging interior, nonfixed surface contamination levels are not high enough to significantly contaminate the contents. Nonfixed surface contamination limit requirements are given in 10 CFR 20.1906, 10 CFR 71.87(i), and 49 CFR 173.443 for alpha, beta, and gamma-emitting radionuclides.

6. all closure fasteners are those furnished with the packaging or are certified replacements and are acceptable for use.

7. all required parts of the packaging and all necessary equipment are available and ready for use.

8. the silicone rubber pads, if required, have been inspected prior to use.

The user may replace certain parts during loading. Parts that may be replaced by the user are identified in Table 7.1. The certification of all replacement parts must be traceable. The user must document the replacement.

**Table 7.1. Replacement parts for the ES-3100 packaging**

| Part | Description | Material | Specification/Drawing[a] |
|---|---|---|---|
| Containment vessel inner O-ring | 5.359-in. inner diam (ID) by 0.139-in. diam stock | Ethylene propylene | ASTM D-2000<br>M2E801580A013 |
| Containment vessel outer O-ring | 5.859-in. ID by 0.139-in. diam stock | Ethylene propylene | ASTM D-2000<br>M2E801580A013 |
| Drum lid washer | 0.844-in. ID by 1.375-in. outer diam (OD) × 0.25-in.-thick | Stainless steel | ASTM A240 or ASTM A276<br>M2E801580A005 |
| Drum lid hex nut | ⅝-in.-11 unified coarse thread (UNC) | Silicon bronze | ASTM F467 per ANSI B18.2.2<br>M2E801580A005 |
| Plug | (Plastic plug around circumference of drum assembly and top of top plug) | Nylon 6/6 | 62MP0312<br>Micro Plastic, Inc.<br>M2E801580A002<br>M2E801580A008 |
| Modified VCO Threaded Plug | Leak-test port plug | Brass | P/N 04-2126<br>M2E801580A011 |
| Silicone rubber pads | | Silicone rubber<br>22 ± 5 Shore A | M2E801580-A009-1<br>M2E801580-A009-2<br>M2E801580-A009-3 |

a. Drawings are available in Appendix 1.4.8.

### 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 $cm^2/g$, then the metal pieces are not pyrophoric (and no further action is needed). If the specific surface area is greater than 1.00 $cm^2/g$, 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, turnings, and other items may form a tangled mass which will not fall through the sieve. The above criterion applies: if the wire, turning, or other item could be separated and poked through the mesh it must be rejected (unless the specific surface area of the item can be evaluated and it is less than or equal to 1 $cm^2/g$).

   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 or if converted to an oxide.

   b. An acceptable cover gas is high-purity argon ($\geq$99.997%) and dry ($\leq$5 ppm moisture).

   c. For metal converted to an oxide, only complete oxidation is acceptable.

### 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.

5. the assembled and loaded containment vessel is prepared for leak testing.

6. the annulus between the O-rings shall be leak tested after the CV is loaded in accordance with ANSI N14.5-1997, Sect. 7.6, The user will perform the following steps:

   - ensure that equipment used to perform leak tests has been properly calibrated to ensure the accuracy of test measurements
   - ensure that all leak testing is performed in accordance with a quality assurance program, procedures, and documents the results
   - ensure that the test method used has a sensitivity of at least $1 \times 10^{-4}$ ref-cm$^3$/s air
   - use either the gas-pressure drop (ANSI N14.5-1997, Section A.5.1) or the gas-pressure rise (ANSI N14.5-1997, Section A.5.1) tests
   - remove the modified VCO threaded brass plug from the leak-test port opening
   - hook-up the leak test equipment into the leak-test port opening using an appropriate fitting
   - either pressurize or evacuate the annulus between the O-rings to a suitable pressure and measure the change in pressure and temperature within the test volume during a specified time period
   - pressure measurements must be accurate within1% or less and tests should be carried out in isothermal conditions.
   - calculate the total leakage rate, using the known test volume and test results and ensure that the measured leak rate is less than $1 \times 10^{-4}$ ref-cm$^3$/s air

7. the vacuum coupling is removed.

8. the modified VCO threaded brass plug is tightened into the leak-test port opening.

The user must ensure that their procedure meets the requirements of ANSI N14.5-1997.

If the inner O-ring requires replacement, the containment vessel must be retested per Sect. 8.2.2 prior to use. This requirement does not apply to the outer O-ring, as it is not part of the containment boundary.

Following a successful leak test, the containment vessel with its content is ready to be loaded into the drum assembly.

#### 7.1.2.2 Drum Closing

A radiation check of the contents may be conducted prior to loading to measure the content dose rate. The measured dose rate should be compared with known values for such a test. After loading is complete, radiation measurements shall be taken to determine the package dose rate, which establishes the transport index (TI).

The detailed operating procedures shall include, at a minimum, the process steps listed below when preparing the drum assembly for closing and sealing. The operating personnel and their supervisor shall ensure that:

1. the CV assembly with content is ready for loading into the drum assembly or lowering into the drum assembly, depending on whether it was loaded outside the drum or inside the drum.

2. the drum assembly (with top plug removed) is ready to receive the containment vessel assembly and that the containment vessel assembly, silicone rubber pads, drum lid, drum-lid nuts and washers, and tamper-indicating devices (TIDs) are available.

3. the approved lifting equipment is available and in place. For lifting equipment restrictions, see Sect. 7.1.3.1.

4. the CV swivel hoist ring is removed after the CV is positioned in the drum.

5. the CV flange pad is placed on top of the containment vessel and the plug pad is placed on the inner liner shelf.

6. the top plug is placed into position over the CV using eye bolts attached to the threaded holes provided on the top plug.

7. the eye bolts are removed from the top plug.

8. the drum lid, the drum washers and bronze drum nuts are installed.

9. the nuts are tightened to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) of torque with no sequence specified. No impact wrench shall be used.

10. the TIDs are attached through both TID lugs.

11. the gross package weight does not exceed 190.5 kg (420 lb).

12. surveys for nonfixed surface contamination and radiation dose rate measurements are conducted. The nonfixed surface contamination survey shall be conducted in accordance with the user's facility procedures. The survey shall use criteria that are derived from the surface radioactivity guidance of 10 CFR 20.1906, 10 CFR 71.87(i), or the user's site-specific criteria, whichever is the most stringent.

13. nonfixed surface contamination is removed as applicable.

14. all "empty" or inappropriate labels or tags are removed from the exterior surface of the package.

15. the package is labeled with the appropriate material description, nuclides, activity/mass, and TI in accordance with 49 CFR 172.403.

16. the package is marked with the minimum marking "Radioactive Material, Type B(U), Fissile, UN3328" in accordance with 49 CFR 172.310.

17. the package radiation dose rate at the surface is measured. The package radiation dose rate at 1 m from the surface shall be measured to establish the TI for the package and to ensure that content does not exceed the expected or allowable dose rates (see Sect. 5). The analysis presented in the containment evaluation (Sect. 4) has determined that this is a Type B, fissile material package.

### 7.1.3 Preparation for Transport

#### 7.1.3.1 Package Handling

Criticality Safety Index (CSI) values for the ES-3100 package with various payloads can be found in Table 1.3.

The ES-3100 is handled using industry-standard drum-handling equipment. Operating procedures shall include requirements to limit clamping pressures on forklift drum-handling equipment to prevent damage to the ES-3100 drum body (see Sect. 1.2.1.1 for limits on forklift gripping forces).

#### 7.1.3.2 Decontamination

The package may be placed onto areas that are covered by disposable covering, such as plastic or paper, to reduce the nonfixed surface contamination of physical structures.

The package must be shipped in an enclosed conveyance. Generally, the exterior surfaces of the package will remain relatively clean. However, each user shall prepare procedures to clean dirty packages. These procedures shall, at a minimum, consider the following:

1. The drum is austenitic stainless steel.

2. The drum nut is silicon bronze.

3. The drum vent holes are covered with plastic push-in plugs.

4. The labels and markings on the drum must remain legible.

5. The cleaning solution must be checked for contamination.

#### 7.1.3.3 Requirements Prior to Shipment

The shipper shall ensure that the quality control requirements of 49 CFR 173.475 and the routine determination requirements of 10 CFR 71.87 have been satisfied prior to each shipment. Detailed operating procedures [10 CFR 71.87(f)], shall provide evidence that these requirements are met and ensure that:

1. the package is proper for the content shipped and verified with the appropriate records by the user prior to content loading [10 CFR 71.87(a)];

2. the package is in unimpaired physical condition [10 CFR 71.87(b)];

3. the closure devices of the package are properly installed, secured, and free of defects [10 CFR 71.87(c)];

4. the containment vessel has been loaded properly and preparation for shipment has been followed, witnessed, and checked;

5. the internal pressure of the containment system does not exceed the design pressure during transportation [10 CFR 71.85(b)] as demonstrated by analysis (Appendix 2.10.1) and that there

are no pressure-relief devices [10 CFR 71.87(e)] in the package;

6. the external radiation levels for all transport conditions are within the allowable limits as measured for Normal Conditions of Transport (NCT) [10 CFR 71.87(j)];

7. the nonfixed external contamination levels are within the allowable limits as demonstrated by surface wipes prior to content insertion, containment vessel loading, and package closure [10 CFR 71.87(I)];

8. the contents are adequately sealed and have adequate space for expansion [10 CFR 71.87(d)];

9. all records for shipment are prepared and maintained; and

10. all lifting attachment features are either inoperative during transport [10 CFR 71.87(h)] or meet the requirements of 10 CFR 71.45(a).

#### 7.1.3.4 Leak Testing

Leak tests shall be conducted following the content loading and the containment vessel closure. The annulus between the O-rings shall be leak tested to an acceptable leak rate of $1 \times 10^{-4}$ ref-cm$^3$/s air (or equivalent) or lower in accordance with ANSI N14.5-1997, Subclause 7.6.

#### 7.1.3.5 Surveying

The radiation (gamma, neutron) emanating from the contents of the package shall be measured before the package is released for transport [10 CFR 71.47 and 71.87(j)]. The package radiation dose rate at the surface is measured to ensure that the content does not exceed the expected or allowable dose rates. The package radiation dose rate at 1 m from the surface is measured to establish the TI for the package. The package exterior surface contamination level limits are found in 10 CFR 71.87(i) and 49 CFR 173.443. The regulations present both fixed and nonfixed surface contamination level limits for the various radionuclides. In addition to these limits, the user may have more stringent surface contamination levels that shall also be followed.

A final visual survey of the package and loading paperwork shall be conducted to ensure that the package was assembled correctly and that it is ready for final shipment preparation. This survey may include a thorough review of the loading checklists by someone other than those who filled out the list to verify the loading operations. The area immediately surrounding the assembly operations should be surveyed, and all spare or extra parts should be identified. A final package survey may include weighing the package, hand-testing the closure nuts on the drum lid, and flexing the TIDs. The loading checklist should include a place for this final quality check to be properly recorded—including a signature and date—as being successfully completed.

#### 7.1.3.6 Marking

The user shall ensure detailed marking procedures are consistent with 10 CFR 71.85 and the applicable subsections of 49 CFR 172, Subpart D. Each shipper shall ensure that each package containing radioactive material is marked in the manner required.

Two electrochemically etched data plates are affixed to the exterior of the drum body in the locations, and with the methods, indicated on Drawing M2E801580A031 (Appendix 1.4.8).

The packaging components (drum assembly, containment vessel body, lid, and closure nut) are also marked with their serial numbers. The numbers are used to control these parts and to accumulate their respective histories.

### 7.1.3.7 Labeling

The user shall prepare labeling procedures that are consistent with the applicable subsections of 49 CFR 172, Subpart E. The procedures should include the following steps, to ensure that:

1. the proper label is affixed to the package and the TI is determined at the time of loading;

2. the correct label (White—I, Yellow—II, or Yellow-III) is determined using the table from 49 CFR 172.403(c);

3. the appropriate label is affixed to two places on opposite sides of the drum;

4. the content name, nuclides and activity/mass (49 CFR 173.435), and the TI are entered in the blank spaces on the radioactive label; and

5. the information is entered legibly using a durable, weather-resistant means of marking.

Additionally, two Fissile labels are required per 49 CFR 172.402(d)(2). These labels must be affixed two places on opposite sides of the drum adjacent to the radioactive labels. The CSI must be legibly entered on the Fissile label using a durable, weather-resistant means of marking.

### 7.1.3.8 Securing to Vehicle

The package shall be secured against movement within the vehicle in which it is being transported under conditions normally incident to transportation [49 CFR 177.834 and 177.842(d)]. The loading procedures shall include the following measures, at a minimum, to ensure that:

1. only an approved conveyance is used,

2. all reasonable precautions are taken to prevent motion of the vehicle during loading,

3. no tampering with packages occurs during transit,

4. no vehicle is loaded or unloaded unless a qualified person is in attendance at all times, and

5. no radioactive material package is loaded onto a vehicle also carrying Div. 1.1 or 1.2 explosives (49 CFR 177.848).

## 7.2 PACKAGE UNLOADING

### 7.2.1 Receipt of Package from Carrier

Prior to shipment, the user shall verify that the receiver has agreed to accept the special nuclear material. The user (shipper) shall ensure that appropriate documentation is submitted to the receiver to ensure that the physical characteristics and hazards of the material are conveyed to the receiver.

The user shipping the package shall provide any special instructions to the receiver to safely open the package (10 CFR 71.89), including special tools and precautions for handling or unloading. These instructions shall include special actions in the event that TIDs are not intact, or if surface contamination or radiation surveys are too high.

The receiver shall accept the radioactive material by surveying the conveyance and package surface for contamination and external radiation levels. The receiver's procedures shall clearly indicate that the contamination and radiation surveys and inspections be conducted upon receipt of the package. The receiver shall, at a minimum, include the following in their procedures (in compliance with 10 CFR 71.111):

1. receive the package when offered by the carrier for delivery and,

2. monitor external surfaces of the conveyance and package for radioactive contamination and radiation levels.

All users shall include provisions for reporting safety concerns associated with the packaging or its use. The user shall notify NRC in accordance with and 10 CFR 20.2202. Incidents requiring notification include:

1. removable radioactive surface contamination in excess of the limits provided by 10 CFR 71.87, and

2. external radiation levels in excess of the limits provided by 10 CFR 71.47.

The receiver shall compare the cargo with the list provided by the shipper. If a discrepancy appears between the cargo and the list, the receiver shall investigate and report to the NRC as required.

The package shall be removed from the conveyance prior to unloading the content. Unloading procedures shall, at a minimum, ensure that:

1. the package nonfixed surface contamination is below the minimum on-site or off-site requirements,

2. all appropriate package labels are affixed to the package exterior surface,

3. all lifting and handling equipment is certified for use,

4. all transfer equipment is certified for use,

5. the package is visually examined to ascertain surface damage that may have occurred during shipping or handling, and

6. the TIDs are examined to ensure that the package has not been tampered with during shipment.

If the package surface was damaged during handling or shipping, a nonconformance tag shall be completed and attached to the package for subsequent refurbishment (10 CFR 71.131). If the TIDs are found to be compromised, the receiver shall investigate and notify the NRC as required.

### 7.2.2 Removal of Contents

Detailed operating procedures shall describe activities required for content removal and shall identify any safety and health measures required to protect workers and the environment. The procedures shall include, at a minimum, the process steps listed below:

1. All appropriate labels for the material shipped are affixed to the exterior surface of the drum body.
2. Surveys for nonfixed surface contamination and radiation dose rate measurements are conducted.
3. As applicable, nonfixed surface contamination in excess of limits is addressed as required.
4. The TIDs remain intact until removal.
5. The weld stud nuts and washers are removed and controlled.
6. The drum lid is removed.
7. Visible portions of the interior of the drum body and top plug are still in good condition—no visible signs of damage, water damage, or tears.
8. The top plug is removed using eye bolts that can be attached to the threaded holes provided on the top plug.
9. The silicone rubber CV flange pad are removed from above the containment vessel.
10. The containment vessel top is in good condition—no visible signs of damage or loose closure nut.
11. A surface contamination check is conducted to discover any leak of radioactive material.
12. The containment vessel is removed from the drum assembly. The containment vessel is placed onto the work area. (This step may not be required if CV is unloaded while in the drum.)
13. The external retaining ring, containment vessel closure nut, and containment vessel sealing lid are removed and controlled. (No pressure buildup is expected under NCT.)
14. The O-rings and the O-ring grooves on the containment vessel flange are protected from damage during unloading.
15. The HEU content (convenience cans or bottles) and associated packing materials (can spacers, stainless-steel scrubbers, silicone can pads, etc.) are removed from the containment vessel in accordance with site-specific material-handling procedures.
16. The items removed and the inside of the containment vessel are checked for nonfixed surface contamination.

## 7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

The user shall develop detailed procedures to prepare an empty package for storage or transport.

These procedures shall, at a minimum, ensure that:

1. The package has been emptied of all radioactive contents.

2. The radiation level at any point on the external surface of the package does not exceed 0.5 mrem/h.

3. The nonfixed radioactive surface contamination on the external surface of the packaging does not exceed the limits specified in 49 CFR 173.443(a), and the internal contamination level does not exceed 100 times the limits in 49 CFR 173.443(a).

4. The package is not damaged, and there is no visible internal or external surface moisture or corrosion.

5. The package is closed.

6. No leakage of radioactive material under conditions normally incident to transportation can occur.

7. Any labels previously affixed in accordance with Subpart E of 49 CFR 172 are removed, obliterated, or covered. Leak-test labels should not be removed from the drum body.

8. The "EMPTY" label prescribed in 49 CFR 172.450 is affixed to the drum.

9. An appropriate notice is provided giving the name of the consignor or consignee. An example notice is, "This package conforms to the conditions and limitations specified in 49 CFR 173.428 for radioactive material, excepted package—empty packaging, UN2908."

## 7.4 OTHER OPERATIONS

None.

## SECTION 7 REFERENCES


10 CFR 71, *Packaging and Transportation of Radioactive Material*, Jan. 1, 2005.

49 CFR Pts. 100–180 and 393, *Transportation*, Oct. 1, 2004.

ANSI N14.5-1997, *Radioactive Materials—Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

# ATTACHMENT 3

# MARK-UP OF CoC

6/30/08 Mark-up for Rev 5

| NRC FORM 618 (8-2000) 10 CFR 71 | CERTIFICATE OF COMPLIANCE FOR RADIOACTIVE MATERIAL PACKAGES | | | U.S. NUCLEAR REGULATORY COMMISSION |
|---|---|---|---|---|
| 1. a. CERTIFICATE NUMBER | b. REVISION NUMBER | c. DOCKET NUMBER | d. PACKAGE IDENTIFICATION NUMBER | PAGE / PAGES |
| 9315 | 3 | 71-9315 | USA/9315/B(U)F-96 | 1 OF 6 |

2. PREAMBLE

a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."

b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION

a. ISSUED TO *(Name and Address)*
U.S. Department of Energy
Washington, DC 20585

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION
BWXT Y-12, L.L.C., application dated February 25, 2005, as supplemented

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No.: ES-3100

(2) Description

The ES-3100 package is a cylindrical container that is approximately 110 cm (43 in) in overall height and 49 cm (19 in) in overall diameter and is composed of an outer drum assembly and an inner containment vessel. The containment vessel is placed inside the drum and surrounded by a cement based borated neutron absorber, Catalog 277-4. The purpose of the ES-3100 is to transport bulk high enriched uranium in oxide form, uranium metal and alloy, and uranyl nitrate crystals.

The outer drum assembly consists of a reinforced stainless steel, standard mil spec 30-gal drum with an increased length. The volume formed between the drum and the attached inner liner is filled with an inorganic, castable refractory material, Kaolite 1600™, which is comprised of concrete and vermiculite. The Kaolite 1600™ acts as both a thermal insulating and an impact limiting material.

The containment vessel is approximately 82 cm (32 in) in overall height and 13 cm (5 in) in overall diameter and is constructed of 304L stainless steel. The containment boundary consists of the 0.1 in thick containment vessel body and the lid assembly. The lid assembly consists of a sealing lid, a closure nut, and external retaining ring, which holds both the assembly and closure nut together. The double ethylene-propylene elastomer O-rings in the top flange of the containment vessel permit leak testing of the containment vessel. The maximum gross weight of the package, including contents, is 190.5 kg (420 lb).

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5.(a) Packaging (continued)

(3) Drawings

The Model No. ES-3100 package is constructed and assembled in accordance with:

(i) BWXT Y-12, L.L.C., Drawing No. M2E801580A037, Sheets 1 through 6, Rev. A, "Consolidated Assembly Drawing."

(ii) BWXT Y-12, L.L.C., Drawing No. M2E801580A026, Rev. C, "Heavy Can Spacer Assembly."

(iii) Equipment Specification JS-YMN3-801580-A001, Rev. E, "ES-3100 Containment Vessel."

(iv) Equipment Specification JS-YMN3-801580-A002, Rev. D, "ES-3100 Drum Assembly."

(v) Equipment Specification JS-YMN3-801580-A003, Rev. C, "Manufacturing Process Specification for Casting Kaolite 1600™ into the ES-3100 Shipping Package."

(vi) Equipment Specification JS-YMN3-801580-A005, Rev. E, "Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package."

5.(b) Contents (Type and form of material, maximum quantity of material per package, and Criticality Safety Index (CSI)):

The weight of the radioactive contents, convenience containers, can lift attachments, polyethylene bags, spacers, and other material in the containment vessel shall not exceed 90 lb. The maximum mass of hydrogenous packaging materials in the containment vessel (e.g., polyethylene containers or bagging, silicone rubber pads, etc.) shall not exceed 500 grams. The maximum content decay heat load shall not exceed 0.4 watts.

The concentration limits of uranium and transuranic constituents shall be the following:

| Isotope | Maximum Concentration |
|---|---|
| U-232 | 0.040 μg/gU[a] |
| U-233 | 0.006 g/gU[b] |
| U-234 | 0.02 g/gU |
| U-235 | 1.00 g/gU |
| U-236 | 0.40 g/gU |
| Transuranics (except Np) | 40.0 μg/gU |
| Np-237 | 0.003 g/gU |

[a] μg/gU = $10^{-6}$ grams per gram of total uranium
[b] g/gU = grams per gram of total uranium

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5.(b) Contents (continued)

(1) Uranium as solid metal or alloy, packaged in stainless-steel or tin-plated carbon steel convenience cans.

The maximum uranium enrichment is 100 weight percent U-235.

For contents that must be shipped with spacers, the spacers must be in accordance with BWXT Y-12, L.L.C., Drawing No. M2E801580A026 and Equipment Specification JS-YMN3-801580-A005, as specified in Condition No. 5.(a)(3). The quantity of fissile material in any convenience can shall not exceed one-third of the mass loading limit per package for that content. Spacers must be positioned between every two convenience cans.

(i) For metal and alloy in the form of solid geometric shapes, meeting the following restrictions, mass limits are listed in Table 1. Contents not meeting the following restrictions must be shipped as broken metal (see Condition No. 5.(b)(1)(ii)).

(A) Spheres having a diameter no larger than 3.24 in (maximum of two spheres per convenience can)

(B) Cylinders having a diameter no larger than 3.24 in (maximum of one cylinder per convenience can)

(C) Square bars having a cross section no larger than 2.29 in × 2.29 in (maximum of one bar per convenience can)

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

Table 1: Loading Limits for Metal and Alloy in Solid Geometric Shapes

| Solid uranium metal or alloy (specified geometric shapes) | Uranium Enrichment (weight percent U-235) | CSI | With Spacers Maximum Mass U-235 (kg) | | No Spacers Maximum Mass U-235 Per Package (kg) |
|---|---|---|---|---|---|
| | | | Per Convenience Can | Per Package | |
| Spheres | ≤ 100 | 0.0 | 0.000 | 0.0 | 0.0 |
| Cylinders | ≤ 100 | 0.0 | 6.000 | 18.000 | 12.000 |
| Sq. Bars | ≤ 100 | 0.0 | 10.000 | 30.000 | 18.000 |
| Slugs | > 80 | 0.0 | 5.447 | 16.342 | Spacer req'd |
| Slugs | ≤ 80 | 0.0 | 8.738 | 26.213 | Spacer req'd |

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5.(b)(1) Contents (continued)

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(ii) 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 1.00 $cm^2/g$ 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.

Table 2: Loading Limits for Solid Metal or Alloy in the Form Defined as Broken Metal

| Uranium Enrichment (weight percent U-235) | CSI | With Spacers Maximum Mass U-235 (kg)[a] | | No Spacers Maximum Mass U-235 Per Package (kg)[a] |
|---|---|---|---|---|
| | | Per Convenience Can | Per Package | |
| > 95 and ≤ 100 | 0.0 | 0.925 | 2.774 | Spacer req'd |
| | 0.4 | 1.849 | 5.548 | Spacer req'd |
| | 0.8 | 2.774 | 8.323 | Spacer req'd |
| | 2.0 | 3.699 | 11.097 | Spacer req'd |
| > 90 and ≤ 95 | 0.0 | 0.879 | 2.637 | Spacer req'd |
| | 0.4 | 1.758 | 5.274 | Spacer req'd |
| | 0.8 | 3.516 | 10.549 | Spacer req'd |
| | 2.0 | 5.568 | 16.703 | Spacer req'd |
| > 80 and ≤ 90 | 0.0 | 0.833 | 2.500 | Spacer req'd |
| | 0.4 | 2.500 | 7.500 | Spacer req'd |
| | 0.8 | 3.333 | 10.000 | Spacer req'd |
| | 2.0 | 5.278 | 15.834 | Spacer req'd |
| > 70 and ≤ 80 | 0.0 | 0.742 | 2.225 | 2.225 |
| | 0.4 | 2.967 | 8.900 | 4.450 |
| | 0.8 | 0.000 | 0.0 | 0.0 |
| | 2.0 | 7.911 | 23.734 | 0.0 |

INSERT B

(ii) 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 $cm^2/g$ 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 or are completely stabilized to an oxide prior to shipment. Uranium metal or alloy which has been stored in water must be shipped in a sealed container under an inert cover gas or completely oxided prior to shipment.

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5.(b)(1) Contents (continued)

Table 2: Loading Limits for Solid Metal or Alloy in the Form Defined as Broken Metal (Continued)

| Uranium Enrichment (weight percent U-235) | CSI | With Spacers Maximum Mass U-235 (kg)[a] | | No Spacers Maximum Mass U-235 Per Package (kg)[a] |
|---|---|---|---|---|
| | | Per Convenience Can | Per Package | |
| > 60 and ≤ 70 | 0.0 | 0.000 | 0.0 | 1.949 |
| | 0.4 | 4.115 | 12.346 | 0.0 |
| | 0.8 | 6.931 | 20.793 | 16.245 |
| | 2.0 | 8.231 | 24.692 | 24.692 |
| ≤ 60 | 0.0 | 3.718 kgU | 11.153 kgU | 5.576 kgU |
| | 0.4 | 0.0 kgU | 0.0 kgU | 0.0 kgU |
| | 0.8 | 11.773 kgU | 35.320 kgU | 0.0 kgU |
| | 2.0 | 11.773 kgU | 35.320 kgU | 35.320 kgU |

[a] All limits are expressed in kg U-235 unless specified as kgU, which means kilograms of total uranium.

(2) Uranium as oxide, which may include $UO_2$, $UO_3$, and $U_3O_8$, packaged in stainless-steel, tin-plated carbon steel, or nickel alloy convenience cans, or polyethylene bottles. The physical form of all contents is dense, loose powder which may contain clumps and pellets. Moisture content in oxide is limited to 3 weight percent water. The mass limit shall be 24.0 kg of oxide, with a maximum mass of 21.124 kg U-235, with a CSI of 0.0. No spacers are required in the containment vessel.

(3) Solid uranyl nitrate in the form of uranyl nitrate crystals, $[UO_2(NO_3)_2{\cdot}xH_2O$, where x is $\leq 6]$. Uranyl nitrate crystals must be contained in a non-metallic convenience container (such as polyethylene bottles). The mass limit shall be 0.0 kg of uranyl nitrate crystals, with a maximum mass of 0.0 kg U-235, with a CSI of 0.0. No spacers are required in the containment vessel.

6. The vent holes on the outer steel drum shall be capped closed during transport and storage to preclude entry of rain water into the insulation cavity of the drum.

7. Content forms may not be mixed in a single ES-3100 containment vessel.

8. Any combination of convenience can sizes is allowed in a single package, as long as the total height of the can stack (including silicone rubber pads and spacers, if required) does not exceed the inside working height of the containment vessel (31 in). Any closure on the convenience can is allowed.

9. Empty convenience cans, spacers, silicone rubber pads, and/or stainless-steel scrubbers (i.e., stainless steel trimmings that act as dunnage) may be used to fill the void space in the containment vessel. Empty convenience cans must have a minimum 0.125 in diameter hole through the lid.

10. The contents and the convenience cans may be bagged or wrapped in polyethylene for contamination control provided the limits of Condition No. 5.(b) are met.

11. Transport by air is not authorized.

12. In addition to the requirements of Subpart G of 10 CFR Part 71:

    (a) The package shall be prepared for shipment and operated in accordance with the Package Operations in Section 7 of the application, as supplemented.

    (b) Each package must meet the Acceptance Tests and Maintenance Program of Section 8 of the application, as supplemented.

13. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

14. Expiration date: April 30, 2011.

## REFERENCES

BWXT Y-12, L.L.C., application dated February 25, 2005, as supplemented.

BWXT Y-12, L.L.C., supplements dated April 27, May 26, August 15, 2005; and January 9, February 6, March 20, May 8, June 6, July 18, August 21 and 24, October 26, 2006; and January 19 and April 26, 2007.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

[signature] for

Robert A. Nelson, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Date: May 8, 2007