71-3074

U.S. Department
of Transportation

Pipeline and
Hazardous Materials
Safety Administration

400 Seventh Street, S.W.
Washington, D.C. 20590

JUN 2 3 2005

Mr. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards (NMSS)
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Brach:

In accordance with the Memorandum of Understanding between our Agencies, we request that you review the enclosed revised Application for Exemption and provide your agency's recommendation to the DOT whether this application should be a candidate for a DOT exemption.

The applicant, the U.S. Department of Energy, originally requested an exemption from 49 CFR 173.453(d) fissile materials - exception requirements to ship low enriched uranium oxide (UO_3), exceeding a maximum of 1 percent of uranium-235 by weight, in 55-gallon drums (227 total) qualified as IP-1 packages, by highway, from the Savannah River Site to the Nevada Test Site, for disposal. Based on the DOT and NRC reviews of the original submittal, we requested additional information from DOE. DOE has responded to this request by revising their original Application for Exemption to request relief from the fissile materials packaging requirements in § 173.417(a)(1)(ii).

We have reviewed the revised application and noted the following items which we wish to point out to you for your review.

1) The applicant states that they may exchange a small number of drums from one shipping list to another to accommodate drums as they come from the storage building. We question the appropriateness of deviating from the attachment providing the proposed drum loading for each conveyance, as described on pages 9 and 136 of 140.

2) Note that the UO_3 will be confined in an inner plastic liner within the 55-gallon drum, as described on page 97 of 140.

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3) Note that boron will be added to each drum, as described on page 138 of 140.

To assist you in your review, we are providing a copy of:

- The original DOE application dated September 1, 2004.
- The initial DOT request for NRC review dated November 23, 2005
- The NRC response to our request dated March 15, 2005.
- The DOT request for additional information from the DOE dated April 14, 2005.
- The revised Application for Exemption from DOE dated May 12, 2005.

Since the applicant desires to use this exemption in upcoming shipments, we request you provide an estimate of the time needed to complete your review. If you have any questions or need any additional information, please contact Jim Williams at (202) 366-6177.

Sincerely,

Delmer F. Billings
Director, Office of Hazardous Material
Exemptions and Approvals

Enclosures

Cc: Meraj Rahimi (with enclosures)

May 12, 2005

R.M. Cutshall, Transportation Manager
Westinghouse Savannah River Company LLC
Savannah River Site
Building 706-N
Aiken, S.C. 29808
Phone: (803) 557-4617

OBU-TRA-2005-00037

Associate Administrator for Hazardous Materials Safety
Attn: Exemptions, DHM-31
Pipeline and hazardous Materials Safety Administration
U.S. Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590-0001

UNCLASSIFIED
DOES NOT CONTAIN
UNCLASSIFIED CONTROLLED
NUCLEAR INFORMATION
ADC & Reviewing Official: Christian W. Solum, Hazardous Material Shipping Advisor
(Name and Title)
Date: May 12, 2005

SUBJECT: Revision 1 to WSRC Request for a DOT Exemption (DOT-E 13962)

Ref: Letter, D. F. Billings, Office of Hazardous Materials Exemptions and Approvals, DOT to D. Y. Chung, Office of Environmental Management EM-24, DOE, April 14, 2005.

WSRC has revised the subject exemption application (see attachment) to address the reference request for additional information. This revised application for exemption completely replaces the original application. All relevant information from the original application plus the requested additional information is contained in the Revision 1 attachment.

Westinghouse Savannah River Company appreciates your assistance with this request.

Sincerely,

R.M. Cutshall
Manager, Transportation
Westinghouse Savannah River Company LLC

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Savannah River Site Request For Department of Transportation Exemption (U)

(DOT-E 13962)

WSRC Document No.: OBU-TRA-2004-00022

Revision 1

May 12, 2005

UNCLASSIFIED

DOES NOT CONTAIN
UNCLASSIFIED CONTROLLED NUCLEAR INFORMATION

ADC & Reviewing Official: Christian W. Solum, Hazardous Material Shipping Advisor
Date: MAY 12, 2005

Approval Signatures

Prepared By:

5/12/05

D. L. McWhorter
Closure Business Unit
F-Canyon Closure Engineering

Date

5/12/05

E. K. Opperman
Field Support Business Unit
Transportation Services

Date

5/12/05

K. R. Yates
Field Support Business Unit
Nuclear Safety

Date

Quality Assurance Reviewer

For Tim Tate

5/12/2005

T. W. Tate
Field Support Business Unit
Quality Services

Date

Approved By:

5/12/05

K. W. Stephens
Field Support Business Unit
Manager, Transportation Services

Date

SRS

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Savannah River Site Request For Department of Transportation Exemption (U)

(DOT-E 13962)

WSRC Document No.: OBU-TRA-2004-00022

Revision 1

May 12, 2005

UNCLASSIFIED

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ADC & Reviewing Official: ____________
Date: ____________

Approval Signatures

Prepared By:

D. L. McWhorter — Date
Closure Business Unit
F-Canyon Closure Engineering

E. K. Opperman — Date
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Transportation Services

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T. W. Tate — Date
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Approved By:

K. W. Stephens — Date
Field Support Business Unit
Manager, Transportation Services

****Approval Signatures on separate attachment****

Revision Summary

Rev. No.	Rev. Date	Affected Sections	Description of Revision
0	07/20/04	All	Initial Issue
1	05/13/05	Transmittal Letter	Revised the entire document to include additional information requested by the DOT. The document format was entirely changed.
		Attachment A1	Added Summary of Savannah River Site (SRS) Responses to DOT/NRC RAI Issues, 5/9/2005.
		Attachment 1	Revised Criticality Safety Index (CSI) and Loading Tables, 5/9/2005.
		Attachment 2D	Added *SRS Low-Enriched Uranium Analytical Results, Non-Radiological Elements*, July 22, 2003.
		Attachment 4	Replaced original issue with *Spherical Safe Mass Values – Low Enriched UO3*, Rev. 1 WSMS-CRT-04-0026, 4/29, 2005.
		Attachment 5C.	Added *LEU IP-1 Materials Compliance*, FSS-TS-2004-0001, 12/19/2003
		Attachment 6	Replaced original issue with *Array of UO3 Drums, Rev. 1*, N-CLC-F-00695, Rev. 1, 5/11/2005
		Attachment 7	Added *Evaluation of Type AF Packaging for Shipment of LEUO*, 2/8/2005.
		Attachment 8A.	Added *Instructions for Compliance with Alternative Packaging Requirements of 49 CFR 107.105(c)(9)*, 5/6/2005
		Attachment 8B	Added Drum Integrity Criteria, 5/6/2005

Table of Contents

List of Acronyms

CFR -	Code of Federal Regulations
DOE –	U. S. Department of Energy
DOT –	U. S. Department of Transportation
EPA –	U. S. Environmental Protection Agency
HMTR-	WSRC Hazardous Material Transportation Representative
LEUO -	Low-enriched uranium trioxide (UO_3)
QA –	Quality Assurance
SOW -	Statement of Work
SRS -	Savannah River Site
WSRC -	Westinghouse Savannah River Company

1.0 Purpose

SRS seeks relief from the fissile materials packaging requirements in 173.417(a)(1)(ii); specifically, "*Except as provided in 173.453, fissile materials containing not more than A1 or A2 as appropriate, must be packaged in one of the following packagings: (ii) Any Type AF, Type B(U)F, or Type B(M)F packaging that meets the applicable standards for fissile material packages in 10 CFR part 71.*" The exemption is sought from only the packaging requirements. All other requirements for fissile material shipments will be met (e.g. shipping papers, marking, labeling, and placarding). The packaging exemption is sought for the 227 drums containing low enriched uranium oxide (LEUO) with ^{235}U enrichments between 1 wt% and 1.098 wt% (includes uncertainty). The shipments will be transported by highway in exclusive use conveyances.

The drums are shown in Figure 1.

Figure 1
Array of UO_3 Drums

2.0 Justification

The consequence of not obtaining the packaging exemption (for the 227 drums) is that the LEUO would have no disposition path and the material would remain at SRS indefinitely. Shipment of the material, without a packaging exception, would require the material to be 1) repackaged or 2) downblended to reduce the enrichment, neither of which is considered viable. WSRC evaluated all known Type AF packages and could not identify any packages that were feasible for this application. The evaluation of Type AF package designs identified a total of 65 Type AF containers on RAMPAC. Of the 65, 53 were not approved for powder/oxide (e.g. approved for fuel, pellets, overpacks, import/export only, and liquids). Of the 12 remaining designs, 9 are unique and were evaluated in detail (see spreadsheet in Attachment 7). Evaluation of the 9 designs concluded: 4 can no longer be fabricated (are not -85 or -96); 3 are too small (22 lbs payload, requiring ~7800 packages); and 2 are high cost reusable containers that are not amenable for handling/disposal at NTS and would cost in excess of $2M to fabricate. Additionally, use of any of the 9 container designs would require extensive material handling with associated industrial hygiene, contamination control and ALARA concerns. Based on this, WSRC concluded that there are no viable Type AF packaging options that could be readily used.

The transportation of the SRS LEUO inventory in the current containers to a disposal site provides the minimum risk to the worker, public and environment. A SRS disposition pathway does not currently exist, nor is one planned. Therefore, any removal pathway necessitates offsite transportation. Continued storage is not a viable long-term option as the packages will eventually deteriorate over time. Continued storage is considered unacceptable to the public and regulatory agencies, both state and federal. Any process activities (i.e.; repackaging into a Type A Fissile Package or downblending the uranium enrichment) increase the potential for dose uptake, personnel contamination and/or an environmental release. In our engineering judgment, these risks would measurably exceed the risk reduction to the public and environment provided by a Type A Fissile Package as compared to the current containers.

Since alternative packages were not identified and the capability to downblend contents does not exist at SRS, WSRC has concluded that seeking a DOT exemption is the best option to achieve the permanent disposal of the material.

3.0 Background

3.1 Material Description

Savannah River Site (SRS) currently has an inventory of legacy low-enriched uranium oxide (LEUO) packaged in 227 55-gallon galvanized steel (IP-1) drums. The material, in the form of uranium trioxide (UO3), has been stored inside an SRS facility since 1985 (comment: material was produced a few years before it was processed) and the Nevada Test Site (NTS) has accepted the material for (future) disposition. The shipping campaign will involve one-time, one-way shipments, for permanent disposal. The total number of SRS LEUO drums was 382. It is noted that historic documents in this application refer to 380 and 381 drums because the inventory began with 380 drums and two additional drums were added over time. The LEUO material in 155 of the 382 drums met the 173.403 definition of LSA-II solid material with the 173.453(d) fissile materials exception (^{235}U enrichment <1%). This material has already been shipped to NTS for permanent disposal. The LEUO material in the remaining 227 drums (382–155=227) has ^{235}U enrichments slightly above 1%; with the maximum being 1.084 ± 0.014%. However, the maximum uncertainty in the enrichment is 1.3% of the analyzed value (e.g. 1.000 ± 0.013). Therefore, for the purpose of this request, the maximum enrichment is considered to be 1.084 + 0.014 = 1.098 wt % ^{235}U. If the exemption request is granted, the planned number of drums that will be shipped on each conveyance is given in Attachment 1. Attachment 1 lists: drum ID numbers, ^{235}U enrichment, and UO_3 weight; for each of the 227 drums. The ^{235}U enrichment values were determined by mass spectrometer measurements as described in Attachment 2. Attachment 2 also contains measurements of trace quantities of other constituents in the material (see Attachment 2D). The Pu and ^{233}U are excluded from the calculations as their concentrations were so low. Beryllium, graphite and hydrogenous materials were excluded based on process knowledge.

3.2 Production History

The Mark 15 campaign was a demonstration charge prepared, irradiated and processed at Savannah River Site. The purpose of the demonstration is unimportant. The reactor charge consisted of 112 metric tons of slightly enriched (1.100 +/- 0.006 wt. % U-235) aluminum clad uranium metal slugs. This material was irradiated from August 1 to September 7, 1983, a relatively short irradiation period. At discharge, the average post-irradiation enrichment of the charge was approximately 1.03 wt. % U-235, although the final enrichment of the slugs varied according to the axial and radial burnup profile in the reactor core.

Mark 15 slugs were reprocessed in the F-Canyon reprocessing facility. During the solvent extraction process, the fission products were separated from the fissile materials (U and Pu). Then the U and Pu were separated. The resulting product was a uranium-bearing nitric acid solution essentially free of fission products and other fissile materials.

Subsequent to reprocessing, the uranium-bearing solution was fed to A-line, a facility used to convert the uranium bearing solution into the final UO3 product. The denitration conversion process involves sufficiently high temperature such that any remaining traces of organic compounds were destroyed. The final step in A-Line is to store the UO3 product in an oxide storage bin.

It is important to understand that prior to the processing of the Mark 15 material in A-Line; the A-Line facility had been converting depleted uranium solutions to oxide. A-Line was not flushed prior to the introduction of the Mark 15 solution to the line. Some depleted uranium material remained in A-Line equipment. Therefore, as Mark 15 solution was introduced, the U-235 enrichment of the initial oxide product was in the depleted range. As more and more Mark15 material was fed to A-Line, the U-235 enrichment gradually approached the actual Mark 15 U-235 enrichment as discharged from the reactor. This explains the range of U-235 enrichment seen today in the drums awaiting disposal.

Mark 15 product from the A-Line oxide storage bin was loaded into 55-gallon drums. Because of the hold up of depleted material in A-Line and the expected axial and radial burnup distribution of the Mark 15 material, it is expected that there may be occasional very small but detectable enrichment variations in a drum. This explains why drum samples taken for duplicate mass spec analysis occasionally differ a little more than might be expected from such a sensitive analysis technique. The use of a 1.3 % relative uncertainty in the enrichment (e.g., 1.000 ± 0.013) is used to account for these slight variations. Otherwise, the typical mass spec uncertainty would be considerably less.

4.0 Discussion

WSRC has limited the total quantity of enriched uranium in each conveyance as shown in Attachment 1 so that criticality safety is ensured for a worst case accident scenario (total breach of drums where LEUO forms an optimally moderated sphere that is water reflected). Furthermore, the drums will be shipped one time from SRS directly to NTS for permanent disposal. When the 227 drums have been transported, there will be no additional shipments and the exemption shall expire.

The LEUO (UO_3) is an oxide that is stable well above the 800°C fire conditions of 10 CFR 71 (see Attachment 3). A criticality evaluation of the safe spherical mass of LEUO was completed and is provided in Attachment 4. The criticality evaluation considered a k_{safe} value of 0.934 and calculates $k_{eff} + 2\sigma < k_{safe}$. For this evaluation, σ is defined as the statistical uncertainty associated with the MCNP 4C calculations. The LEUO weight allowed in each conveyance is limited based on this criticality evaluation. Attachment 1 illustrates the proposed drum loading for each conveyance. WSRC may exchange a small number of drums from one shipping list to another in order to accommodate drums as-they-come from the storage building. This will minimize the need to handle drums multiple times.

The exemption is sought for the period of time required to ship the 227 drums from SRS to NTS. WSRC estimates the shipments will be completed within 9 months from the time the exemption is granted.

The basis for the exemption request is that the number of IP-1 LEUO drums with ^{235}U enrichments greater than 0.987% (1% minus uncertainty) will be limited on each conveyance to ensure sub-criticality. The safe spherical mass criticality evaluation provided in Attachment 4 establishes the worst-case, conservative, mass limits for the allowed LEUO weight. The mass limits (Attachment 4) are applied to each conveyance through the criticality safety index (CSI) values that are calculated in Attachment 1. If the drums were subjected to the hypothetical accident conditions in 10 CFR 71 (drop and fire), it is anticipated that the drums would fail and the contents would be distributed. Since the safe spherical mass evaluation considers a worst case geometry, any conceivable accident configuration is bounded. In reality the forces in an accident (30 foot drop onto unyielding surface) will tend to distribute the material (not form it into a sphere) making it safer from a criticality perspective. The 800°C fire has no adverse effect on the LEUO material. Normal condition transport containment is provided by the IP-1 packaging (per 173.411(b)(1)). Normal condition criticality safety is demonstrated by considering an array of undamaged drums in accordance with 10 CFR 71.59(a)(1). This evaluation is provided in Attachment 6. At the completion of the 227 drum one-time one-way shipping campaign, WSRC will have no further shipments of this LEUO material.

The LEUO material in the 227 drums meets the definition of "fissile material". Pending the approval of this exemption request, the shipping description of will be "RQ, Radioactive material transported under special arrangement, fissile, 7, UN3331".

The alternative packaging is an IP-1 drum-type packaging meeting the requirements of 49 CFR 173.411. The drum consists of a 16 gauge 55 gallon galvanized carbon steel drum with three rolling hoops, 16 gauge removable lid, 12 gauge closure ring with 5/8" diameter bolt and nut with locking nut, and an elastomer gasket. An IP-1 regulatory compliance summary is given in Attachment 5. The alternative packaging requirements in 49 CFR 107.105(c)(9) are addressed in Attachment 8.

5.0 Summary

WSRC is unaware of any shipping incidents relative to this application. The LEUO contents and corresponding number of drums per conveyance will be limited so that there is no increased probability of criticality under normal or accident conditions during the shipments. Normal condition containment is provided by the IP-1 packaging which is DOT authorized for LSA-II materials. The number of LEUO drums per conveyance (see Attachment 1) was determined by using the CSI calculated from the accident condition criticality analysis that considered a worst case arrangement (spherical geometry) of LEUO material with optimum moderation, and water reflection. A k_{safe} of 0.934 was used as the acceptance criteria for these calculations as explained in Attachment 4. The calculated values of $k_{eff} + 2\sigma < k_{safe}$ indicate configurations that are safely sub-critical.

Attachment A1. Summary of Savannah River Site (SRS) Responses to DOT/NRC RAI Issues. 5/10/2005

Reference: RAI Letter, D. F. Billings, DOT to D. Y. Chung, EM-24, dated April 14, 2005.

This attachment contains a summary of the responses to the 10 issues contained in the reference DOT/NRC RAI. The RAI issues are briefly paraphrased followed by the SRS response and its location in the revised exemption request (underlined). The revised application for exemption contains the relevant information from the original application plus the additional information. As such the revised report and attachments contain the complete application.

1. DOT/NRC believes it is more appropriate to request an exemption from the packaging requirements of 49CFR 173.417, rather than from the fissile material definition in 49CFR 173.453.

SRS Response. The revised application report now requests an exemption from the Type AF packaging requirements in 49CFR 173.417(a)(1)(ii) (see <u>report page 1</u>). Per issuance of the exemption, the shipments will be carried out as "RQ, Radioactive material transported under special arrangement, fissile, 7, UN3331" <u>(report page 5)</u>. The alternative packaging requirements in 49CFR 105.107(c)(9) are addressed in Attachment 8A.

2. The criticality analysis should be revised to include the appropriate uncertainty in establishing the maximum enrichment. The basis for the 1.3% measurement uncertainty is to be provided. There are no measurement uncertainties in ATT 2C, and ATT 2B indicates a 3.5% measurement uncertainty.

SRS Response. A table prepared by Savannah River National Lab mass spectrometry lab during July, 2003 was added to the submittal. The table shows the uncertainty (2 sigma) in the ^{235}U enrichment to be a maximum of +/- 1.3% relative to the enrichment (e.g., 1.000 +/- 0.013 ^{235}U). The uncertainty in the enrichment in many samples is considerably less. For drums with the highest enrichment (1.084 wt. % ^{235}U), the addition of the uncertainty (1.084 x 0.013 = 0.014 wt. % ^{235}U) raises the enrichment of these drums (1.084 + 0.014 = 1.098 wt. % ^{235}U), essentially to the pre-irradiation enrichment of 1.100 wt. % ^{235}U.

The pre-irradiation ^{235}U enrichment of the Mark 15 material that generated the subject UO_3 was verified to be 1.100 +/- 0.006 wt. % ^{235}U. The maximum enrichment of any remaining drum of UO_3 is clearly less than 1.10 wt. % ^{235}U due to burnup in the reactor. We added the uncertainty of 1.3% relative to the enrichment (e.g., 1.000 + 0.013 ^{235}U) to the enrichment listed for each drum.

Calculations for both the drum arrays and the homogeneous UO_3-water spheres were revised to include this uncertainty (1.3%).

The 3.5% value in attachment 2C was for two "duplicate" samples analyzed in 2003. The 3.5% difference is greater than normally expected in a mass spec analysis. In discussions with lab personnel, the difference may be explained by: minor contamination of one sample, minor variations in the enrichment of material in the drum (see report page 3), and typical mass spectrometer uncertainty. As explained in the paragraph immediately above, an uncertainty of 1.3% relative to the enrichment was added to the analyzed enrichment of each drum. If an uncertainty greater than 1.3% relative to the enrichment of each drum were used, the result would be that the enrichment for the maximally enriched drums would exceed the pre-irradiation enrichment.

3. The criticality analysis should be revised based on a bounding value of UO_3weight per drum. The criticality analysis for normal conditions of transport should be revised to bound the amount of material to be shipped.

SRS Response. The drum array calculations were revised to conservatively bound the maximum weight of UO_3 per drum. The maximum UO_3 weight is 796 pounds. The scales on which the drums are weighed are routinely calibrated to +/- 1 pound. To be conservative in the revised calculations, all drums were assumed to contain 803 pounds pure UO_3 per drum (i.e., 7 pounds extra) to ensure that the uncertainty in the drum weight is captured. The appropriate quantity of water will then be added to achieve the levels of moderation indicated.

Since UO_3 is a very hygroscopic material, the UO_3 weight per drum listed in the original submittal includes at least a few wt. % adsorbed water. The average weight of material per drum, assuming 100% UO_3, for the shipments planned in the original submittal, ranged from 735 pounds/drum to 763 pounds per drum. The original calculations assumed 750 pounds pure UO_3 per drum and added additional water to achieve the various levels of moderation indicated. Because there is only limited documentation of the adsorbed water content, the revised calculations were performed per the previous paragraph (i.e., 803 pounds UO_3, then add water).

4. The application should be revised to provide more information about how the range of applicability of the benchmark analysis was extrapolated down to 0.5 wt % from 2.0 wt %. Provide Ref. 5 and explain how guidance from Ref. 5 was applied to the benchmark data in the criticality analysis.

SRS Response. Reference 5 in the original submission was *Westinghouse Savannah River Company, Nuclear Criticality Safety Methods Manual, Chapter 7, Guidance for Determination and Documentation of Area of Applicability, 9/30/96.* This chapter was faxed to the NRC. The original submission used the ENDF/B-VI cross section library while the revised submission uses the ENDF/B-

V cross section library. The use of the ENDF/B-V library allows for application of a more recent validation specifically targeted to low enriched ^{235}U systems. Details of the revised Area of Applicability discussion are contained in Attachment 4, *Spherical Safe Mass Values - Low Enriched UO_3*, and Attachment 6, *Calculation: Arrays of UO_3 Drums.*

5. The criticality analysis should be revised to show how the 2.2% bias was determined. We do not agree that a 3% administrative margin on k_{eff} is appropriate; the analysis should include a 5% margin on k_{eff}.

SRS Response. In the original submission, the 2.2% bias for low enriched uranium compounds was extracted from "Compilation of WSMS MCNP 4C Validation (as of 7/1/01)," Revolinski, S. M., et. al., WSMS-CRT-01-0082, Westinghouse Safety Management Solutions, September, 2001. Two sections of the report are quoted below.

From WSMS-CRT-01-0082, section 5.3.2: "In support of this validation, one hundred sixteen low enriched uranium fuel experiments were marked as acceptable and extracted from the International Handbook of Evaluated Criticality Benchmark Experiments. Seventy one experiments with enrichments from 2-10% were used with the ENDF-/B-V library. All one hundred sixteen experiments were used with the ENDF/B-VI library to create two upper subcritical limits; one from 2 to 10 percent and the other from 2 to 30 percent."

From WSMS-CRT-01-0082, section 5.3.3.3, MCNP 4C with ENDF/B-VI (2% - 30%): "Tables 84 and 85 provide a breakdown of values of average Keff and corresponding statistical standard deviations by enrichment range and unit geometry for the 2-30% enrichment cases respectively. The distribution of the calculated Keff's was found to be non-normal using the chi-square test (chi-square value = 22.78 versus chi-square test = 15.51 for 11 bins) and the data are uncorrelated ($R^2 = 0.1065$). An attempt to fit this data to the curves specified in ref. 4 also failed. Therefore, the bias and bias uncertainty are represented by an upper subcritical limit. The data used and plot can be found in App. A, Table A-12, and App. B, Figure B-12, respectively. With a data set of 116, there is a 99.7% confidence that 95% of the data lies above the smallest value (see Equation 2). The non-parametric margin for this level of confidence is 0.00 (see section 2.91 of ref. 4). Case ieuslm 14 had the minimum Keff and was used to determine the upper subcritical limit using Equation 3.

$$0.9837 - [(0.0013)^2 + (0.005)^2]^{1/2} - 0.0 = 0.9785$$

The upper subcritical limit for the uranium compound systems for ENDF/B-VI with 2-30% enrichment is 0.978."

The 3% margin used in the original submission was replaced by a 5% margin in the revised submission.

The revised submission uses the ENDF/B-V cross section library instead of the ENDF/B-VI cross section library used in the original submission. The use of the ENDF/B-V cross section library allows for the application of a more recent validation specifically targeted to low enriched ^{235}U systems. Details of the revised bias discussion are contained in Attachment 4, *Spherical Safe Mass Values - Low Enriched UO_3*, and Attachment 6, *Calculation: Arrays of UO_3 Drums*.

6. The criticality analysis should be revised to consider 2N damaged packages according to the requirements of 10 CFR 71.59(a). The mass of the optimally moderated spherical configuration should be considered to represent a number of packages, 2N, for the determination of a Criticality Safety Index (CSI).

SRS Response. The revised application now includes the calculated CSI and the associated number of packages that will be shipped per exclusive use conveyance. The CSI is based on the number of damaged packages (2N) derived from the (worst case) spherical criticality analysis provided in Attachment 4. The CSI calculations and revised conveyance loading tables are given in Attachment 1.

7. Clarification of contradictory information should be provided on the total number of drums (380, 381, and 382) originally generated during the campaign.

SRS Response. The numbers are clarified in the revised application (report page 3). The total number of SRS LEUO drums was 382. Historic documents refer to 380 and 381 drums because the inventory began with 380 drums and two additional drums were added over time. The LEUO material in 155 of the 382 drums met the definition of LSA-II solid material (fissile exempt ^{235}U enrichment <1%). The LSA material in the 155 drums has already been shipped to NTS. The LEUO material in the remaining 227 drums (382–155=227) is addressed in the exemption request.

8. Further detail needs to be provided concerning other elements included in the UO_3 mixture as described in 173.453(d) (e.g. plutonium, uranium-233, beryllium, graphite or hydrogenous materials enriched in deuterium). If any of these materials are present, they need to be modeled in the criticality analysis.

SRS Response. Attachment 2C provides the results of composite sample results for Pu, which generally runs about 1 ppb, but 1 sample indicated 8 ppb. Thus, Pu was not included in the criticality analysis. This is consistent with the chemical separation of Pu from U during the reprocessing of the Mk 15 material.

A new attachment has been added (Attachment 2 D) showing that ^{233}U is no greater than approximately 3 x 10^{-7} atom percent. Thus, ^{233}U was not included in the criticality analysis.

The original material was aluminum clad uranium slugs. There was no deuterium, beryllium, or graphite originally in this material, and none was introduced during reprocessing. High temperature conversion from acidic solution to the oxide eliminated any organics that may have been present.

Attachment 2C provides the results of spectrographic analysis for Al, Ca, Cr, Cu, Fe, Mo, Na, Ni, P, Pb, and Si. In this analysis, these materials are present in the range of 5 - 300 ppm depending on the sample. None of these materials were included in the criticality analysis.

Attachment 2D also provides results of trace impurity analyses for Al, B, Ca, C, Cs, Cl, Cr, Dy, Eu, F, Gd, Hf, Fe, Li, Mn, Mo, P, K, Sm, Se, Si, Na, S, Ta, Sn, Ti, W, V, and Zr. The analysis indicates that these materials average about 30 - 1600 ppm. Due to their low concentrations, none of these materials were included in the criticality safety analysis.

9. The CSI instead of the Transport Index should be used per the revised regulations that became effective October 1, 2004.

SRS Response. The revised application includes the CSI evaluations in Appendix 1.

10. Specific clarification of whether the shipments will be made in exclusive use vehicles needs to be provided.

SRS Response. The revised application states that all shipments will be made in exclusive use conveyances (report page 1 and Attachment 1).

Group 1

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9421	1.084	1.098	766
2	9450	1.066	1.08	724
3	9451	1.064	1.078	764
4	9440	1.063	1.077	752
5	9378	1.063	1.077	765
6	9258	1.059	1.073	759
7	9427	1.057	1.071	764
8	9409	1.054	1.068	764

Total Weight	6058
Average drum weight in group	757

o Maximum enrichment in this conveyance group	=	1.098	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	2.76	MT
		6089	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	4.02	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	12.44	
CSI rounded up to first decimal place	=	**12.5**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**8.0**	

Group 2

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9449	1.052	1.066	761
2	9444	1.052	1.066	756
3	9426	1.052	1.066	763
4	9398	1.051	1.065	759
5	9377	1.051	1.065	768
6	9446	1.05	1.064	763
7	9374	1.05	1.064	763
8	9458	1.049	1.063	758
9	9452	1.049	1.063	771
10	9447	1.049	1.063	754

Total Weight	7616
Average drum weight in group	762

o Maximum enrichment in this conveyance group	=	1.066	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.62	MT
		7973	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.23	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	9.55	
CSI rounded up to first decimal place	=	9.6	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	10.4	

Group 3

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9443	1.049	1.063	763
2	9441	1.049	1.063	758
3	9436	1.049	1.063	756
4	9434	1.049	1.063	761
5	9432	1.049	1.063	758
6	9373	1.049	1.063	761
7	9448	1.048	1.063	765
8	9437	1.048	1.062	765
9	9433	1.048	1.062	764
10	9431	1.048	1.062	764
		Total Weight		7615
		Average drum weight in group		762

o Maximum enrichment in this conveyance group	=	1.063	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.70	MT
		8150	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.35	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	9.34	
CSI rounded up to first decimal place	=	9.4	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	10.6	

Group 4

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9420	1.048	1.062	763
2	9376	1.048	1.062	765
3	9337	1.048	1.062	764
4	9460	1.047	1.061	754
5	9438	1.047	1.061	752
6	9425	1.047	1.061	760
7	9360	1.047	1.061	760
8	9459	1.046	1.06	765
9	9457	1.046	1.06	758
10	9439	1.046	1.06	757
		Total Weight		7598
		Average drum weight in group		760

o Maximum enrichment in this conveyance group	=	1.062	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.72	MT
		8209	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.40	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	9.26	
CSI rounded up to first decimal place	=	9.3	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	10.8	

Group 5

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9430	1.046	1.060	770
2	9416	1.046	1.06	762
3	9412	1.046	1.06	754
4	9429	1.045	1.059	759
5	9424	1.045	1.059	760
6	9423	1.045	1.059	763
7	9422	1.045	1.059	764
8	9417	1.045	1.059	765
9	9415	1.045	1.059	757
10	9410	1.045	1.059	762
11	9462	1.011	1.025	515

Total Weight	8131
Average drum weight in group	739

o Maximum enrichment in this conveyance group	=	1.06	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.78	MT
		8326	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.63	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.88	
CSI rounded up to first decimal place	=	8.9	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	11.2	

Group 6

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9375	1.045	1.059	762
2	9414	1.044	1.058	759
3	9445	1.043	1.057	761
4	9413	1.043	1.057	757
5	9408	1.043	1.057	765
6	9341	1.043	1.057	764
7	9335	1.043	1.057	763
8	9411	1.042	1.056	764
9	9396	1.042	1.056	754
10	9336	1.042	1.056	761
11	9442	1.041	1.055	762
		Total Weight		8372
		Average drum weight in group		761

o Maximum enrichment in this conveyance group	=	1.059	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.80	MT
		8385	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.51	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	9.08	
CSI rounded up to first decimal place	=	**9.1**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**11.0**	

Group 7

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9419	1.041	1.055	757
2	9407	1.041	1.055	765
3	9406	1.041	1.055	759
4	9405	1.041	1.055	763
5	9391	1.041	1.055	758
6	9345	1.041	1.055	761
7	9402	1.04	1.054	756
8	9388	1.04	1.054	760
9	9386	1.04	1.054	762
10	9383	1.04	1.054	757
11	9428	1.039	1.053	674
		Total Weight		8272
		Average drum weight in group		752

o Maximum enrichment in this conveyance group	=	1.055	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.91	MT
		8621	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.73	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.72	
CSI rounded up to first decimal place	=	8.8	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	11.4	

Group 8

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9404	1.039	1.053	760
2	9403	1.039	1.053	762
3	9393	1.039	1.053	758
4	9392	1.039	1.053	759
5	9385	1.039	1.053	766
6	9435	1.038	1.052	761
7	9418	1.038	1.052	764
8	9387	1.038	1.052	759
9	9382	1.038	1.052	759
10	9372	1.038	1.052	764
11	9125	1.038	1.052	740
		Total Weight		8352
		Average drum weight in group		759

o Maximum enrichment in this conveyance group	=	1.053	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	3.96	MT
		8738	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.75	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.69	
CSI rounded up to first decimal place	=	**8.7**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**11.5**	

Group 9

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9122b	1.084	1.098	780
2	9399	1.037	1.051	759
3	9397	1.037	1.051	754
4	9390	1.037	1.051	763
5	9389	1.037	1.051	764
6	9338	1.037	1.051	760
7	9514	1.036	1.05	744
8	9395	1.036	1.05	757

Total Weight	6081
Average drum weight in group	760

o Maximum enrichment in this conveyance group	=	1.098	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	2.76	MT
		6089	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	4.01	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	12.48	
CSI rounded up to first decimal place	=	**12.5**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**8.0**	

Group 10

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9371	1.036	1.050	756
2	9370	1.036	1.05	767
3	9362	1.036	1.05	766
4	9361	1.036	1.05	758
5	9400	1.035	1.049	751
6	9384	1.035	1.049	757
7	9380	1.035	1.049	756
8	9379	1.035	1.049	752
9	9369	1.035	1.049	762
10	9363	1.035	1.049	748
11	9359	1.035	1.049	759
		Total Weight		8332
		Average drum weight in group		757

o Maximum enrichment in this conveyance group	=	1.05	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.04	MT
		8915	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	5.88	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.50	
CSI rounded up to first decimal place	=	**8.5**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**11.8**	

Group 11

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9394	1.034	1.048	757
2	9381	1.034	1.048	758
3	9364	1.034	1.048	760
4	9358	1.034	1.048	757
5	9356	1.034	1.048	758
6	9453	1.033	1.047	762
7	9352	1.033	1.047	756
8	9349	1.033	1.047	766
9	9287	1.033	1.047	762
10	9401	1.032	1.046	759
11	9365	1.032	1.046	763
12	9461	1.011	1.025	523

Total Weight	8881
Average drum weight in group	740

o Maximum enrichment in this conveyance group	=	1.048	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.10	MT
		9033	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.10	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.19	
CSI rounded up to first decimal place	=	8.2	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	12.2	

Group 12

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9357	1.032	1.046	754
2	9354	1.032	1.046	762
3	9348	1.031	1.045	756
4	9339	1.031	1.045	756
5	9456	1.03	1.044	763
6	9368	1.03	1.044	760
7	9355	1.03	1.044	760
8	9347	1.03	1.044	754
9	9344	1.03	1.044	761
10	9343	1.03	1.044	759
11	9334	1.03	1.044	763
12	9367	1.029	1.043	761

Total Weight	9109
Average drum weight in group	759

o Maximum enrichment in this conveyance group	=	1.046	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.15	MT
		9151	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.03	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.30	
CSI rounded up to first decimal place	=	**8.3**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**12.0**	

Group 13

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9350	1.029	1.043	759
2	9346	1.029	1.043	756
3	9454	1.028	1.042	763
4	9342	1.028	1.042	763
5	9333	1.027	1.041	763
6	9332	1.027	1.041	757
7	9327	1.027	1.041	755
8	9340	1.026	1.04	760
9	9331	1.025	1.039	754
10	9330	1.025	1.039	767
11	9314	1.024	1.038	758
12	9311	1.024	1.038	768
		Total Weight		9123
		Average drum weight in group		760

o Maximum enrichment in this conveyance group	=	1.043	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.23 9327	MT pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.13	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	8.15	
CSI rounded up to first decimal place	=	8.2	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	12.2	

Group 14

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9353	1.023	1.037	759
2	9351	1.023	1.037	763
3	9329	1.023	1.037	760
4	9310	1.023	1.037	758
5	9321	1.022	1.036	755
6	9320	1.022	1.036	756
7	9318	1.022	1.036	760
8	9317	1.022	1.036	755
9	9326	1.021	1.035	789
10	9316	1.021	1.035	796
11	9309	1.021	1.035	770
12	9308	1.021	1.035	767

Total Weight	9188
Average drum weight in group	766

o Maximum enrichment in this conveyance group	=	1.037	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.39	MT
		9680	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.32	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.91	
CSI rounded up to first decimal place	=	**8.0**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**12.5**	

Group 15

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9366	1.02	1.034	761
2	9323	1.02	1.034	743
3	9322	1.02	1.034	766
4	9319	1.02	1.034	765
5	9315	1.02	1.034	796
6	9301	1.02	1.034	751
7	9295	1.019	1.033	691
8	9303	1.019	1.033	756
9	9307	1.019	1.033	758
10	9313	1.019	1.033	762
11	9302	1.018	1.032	756
12	9304	1.018	1.032	756
13	9325	1.018	1.032	754
		Total Weight		9815
		Average drum weight in group		755

o Maximum enrichment in this conveyance group	=	1.034	wt %
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.47	MT
		9857	pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.53	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.66	
CSI rounded up to first decimal place	=	**7.7**	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	**13.0**	

Group 16

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9291	1.017	1.031	757
2	9296	1.017	1.031	758
3	9297	1.017	1.031	756
4	9299	1.017	1.031	757
5	9290	1.016	1.03	764
6	9298	1.016	1.03	765
7	9300	1.016	1.03	762
8	9324	1.016	1.03	750
9	9285	1.015	1.029	761
10	9455	1.015	1.029	759
11	9288	1.013	1.027	758
12	9289	1.013	1.027	757
13	9312	1.013	1.027	757
		Total Weight		9861
		Average drum weight in group		759

o Maximum enrichment in this conveyance group	=	1.033	wt %**
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.50 9916	MT pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.54	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.65	
CSI rounded up to first decimal place	=	**7.7**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**13.0**	

** 1.033 wt% is lowest calculated enrichment value and is used to determine safe mass for conveyances having maximum enrichment values below 1.033 wt%.

Group 17

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9286	1.012	1.026	757
2	9305	1.012	1.026	757
3	9328	1.012	1.026	768
4	9234	0.987	1.001	756
5	9236	0.987	1.001	754
6	9306	1.01	1.024	759
7	9278	1.007	1.021	756
8	9282	1.006	1.02	757
9	9273	1.005	1.019	759
10	9283	1.005	1.019	757
11	9292	1.005	1.019	753
12	9281	1.004	1.018	758
13	9294	1.004	1.018	755
		Total Weight		9846
		Average drum weight in group		757

o Maximum enrichment in this conveyance group	=	1.033	wt % **
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.50 9916	MT pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.55	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.64	
CSI rounded up to first decimal place	=	7.7	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	13.0	

** 1.033 wt% is lowest calculated enrichment value and is used to determine safe mass for conveyances having maximum enrichment values below 1.033 wt%.

Group 18

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9280	1.003	1.017	759
2	9269	1.002	1.016	766
3	9270	1.002	1.016	766
4	9279	1.002	1.016	757
5	9271	1.001	1.015	755
6	9272	1.001	1.015	761
7	9284	1.001	1.015	758
8	9276	1	1.014	757
9	9277	1	1.014	754
10	9262	0.999	1.013	758
11	9261	0.998	1.012	757
12	9268	0.997	1.011	759
13	9267	0.996	1.01	762
		Total Weight		9869
		Average drum weight in group		759

o Maximum enrichment in this conveyance group	=	1.033	wt % **
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.50 9916	MT pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.53	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.66	
CSI rounded up to first decimal place	=	7.7	CSI
o Calculated drums/exclusive use conveyance based on CSI	=	13.0	

** 1.033 wt% is lowest calculated enrichment value and is used to determine safe mass for conveyances having maximum enrichment values below 1.033 wt%.

Group 19

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9259	0.996	1.010	758
2	9266	0.995	1.009	757
3	9265	0.995	1.009	757
4	9264	0.995	1.009	756
5	9254	0.995	1.009	760
6	9260	0.994	1.008	757
7	9263	0.992	1.006	759
8	9257	0.99	1.004	758
9	9256	0.99	1.004	765
10	9244	0.99	1.004	756
11	9240	0.99	1.004	752
12	9221	0.99	1.004	753
13	9275	0.989	1.003	760
		Total Weight		9848
		Average drum weight in group		758

o Maximum enrichment in this conveyance group	=	1.033	wt % **
o Calculated safe mass (max. enrichment) from Attachment 4	=	4.50 9916	MT pounds
o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2)	=	6.54	N
o Criticality Safety Index (CSI) as per 71.59(b) (50/N)	=	7.64	
CSI rounded up to first decimal place	=	**7.7**	**CSI**
o Calculated drums/exclusive use conveyance based on CSI	=	**13.0**	

** 1.033 wt% is lowest calculated enrichment value and is used to determine safe mass for conveyances having maximum enrichment values below 1.033 wt%.

Group 20

Drum #	Drum ID	wt % U-235	wt % + 0.014	UO3 (Pounds)
1	9255	0.989	1.003	757
2	9242	0.989	1.003	753
3	9274	0.988	1.002	751
4	9237	0.988	1.002	756
5	9235	0.988	1.002	750
6	9233	0.988	1.002	754
7	9232	0.988	1.002	757
8	9227	0.988	1.002	753
9	9226	0.988	1.002	764
10	9225	0.988	1.002	752
11	9223	0.988	1.002	759
12	9293	0.987	1.001	743
13	9243	0.987	1.001	757
		Total Weight		9806
		Average drum weight in group		754

o Maximum enrichment in this conveyance group = 1.033 wt % **

o Calculated safe mass (max. enrichment) from Attachment 4 = 4.50 MT
9916 pounds

o Number damaged packages "N" based on safe mass/average drum weight in this group as per 10 CFR 71.59(a)(2) = 6.57 N

o Criticality Safety Index (CSI) as per 71.59(b) (50/N) = 7.61
CSI rounded up to first decimal place = 7.7 CSI

o Calculated drums/exclusive use conveyance based on CSI = 13.0

** 1.033 wt% is lowest calculated enrichment value and is used to determine safe mass for conveyances having maximum enrichment values below 1.033 wt%.

Westinghouse
Savannah River Company
Aiken, SC 29808

Attachment 2A.

BNFL

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D. L. McWhorter, 707-7F

Sampling Plan for Low Enriched Uranium Trioxide (U)

SRS has 381 drums of low-enriched uranium trioxide ($LEUO_3$) drums stored in Building 221-21F. The $LEUO_3$ was produced by the Mark 15 campaign in the early 1980s. WSRC needs the $LEUO_3$ characterization data to perform a disposition alternatives study to fulfill our DOE commitment for a recommended disposition pathway by September 30, 2003.

SRTC will analyze the $LEUO_3$ for radionuclides, elemental impurities, organic compounds and physical properties as identified in Tables 2-6. The analytical requirements are based on 10 CFR 61.55, the applicable RCRA and DOT requirements, potential vendor waste acceptance criteria (WAC) and the TVA Low Enriched Uranyl Nitrate Specification.

The ^{235}U content by drum is available from the analyses performed during the production campaign (D. R. Barton, Jr. to D. C. Bonfer, March 17, 1986). Analytical data for some radionuclides and chemical impurities based on 10-drum composites is available in the same document. The RCRA, DOT, WAC and TVA requirements necessitate lower levels of detection than were performed for this data to achieve the safest, most cost effective disposition pathway.

The available analytical data shows that the ^{235}U content steadily increases during the production run. The ^{235}U content exceeds the natural uranium concentration (0.711%) by the 33rd drum and the eversafe concentration (0.90% ^{235}U) in the 78th drum. The ^{235}U content remains above the eversafe concentration until the last 10 drums, but never drops under the natural uranium concentration. One drum is identified as $LEUO_3$ material from the secondary dust collector.

Based on our knowledge of the source material and the process, the $LEUO_3$ is considered homogeneous within each drum for radionuclide and chemical impurity content. WSRC is disposing other uranium materials via the same potential disposition vendors. These vendors accepted these materials with a minimal amount of analytical data with the WSRC assurance that the materials are homogeneous. Therefore, this sample plan assumes that each drum is a homogeneous mixture. Between drums, the ^{235}U content will vary. The drums will be sampled by a scoop from the top of each drum. A statistically representative set of samples shall be pulled from the 381 drums.

The sample material will be obtained by removing 20 grams of oxide from the top of each drum. Operations will arrange the transportation of 1-gram samples from each drum to SRTC for the characterization analyses. The remaining sample material will retained for possible recheck, and the RCRA-certified laboratory analyses. Each sample will be identified by drum number, and stored in a cool dry location away from sunlight until needed. The RCRA analyses will be held pending the outcome of the disposition alternatives study.

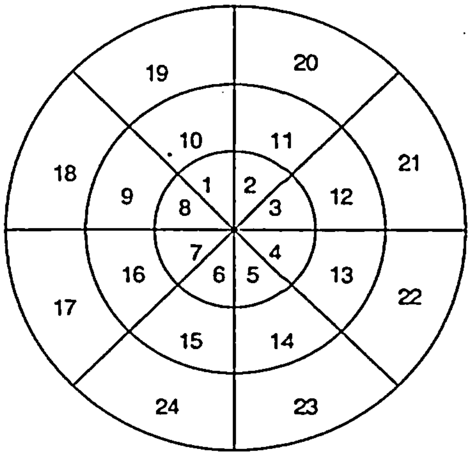
The sample material shall be taken from the drums identified in Table 1. The drum numbers for the entire LEUO inventory are 9092-9471, and 9514. In addition to the statistical sampling, the following drums will be sampled:

Drum 9433 - previous results indicated 4.0% ^{235}U content,
Drums 9341 & 9462 - no recorded ^{235}U content,
Drums 9124,9125,9169 & 9170 - ^{235}U content transitions, and
Drum 9514 – contains material removed from the secondary dust collector.

Table 1
Drums for Analysis

Specific Drums	Statistical Set	Drum Grid Position
9124	9138	16
9125	9150	18
9169	9162	2
9170	9174	8
9341	9186	9
9433	9198	14
	9210	20
9514	9222	21
	9234	1
	9246	5
	9258	9
	9270	11
	9282	13
	9294	16
	9306	17
	9318	20
	9330	23
	9342	24
	9354	1
	9366	3
	9378	4
	9390	5
	9402	8
	9414	12
	9426	15
	9438	17
	9450	18
	9462	20
	9474	21
	9468 ~~9486~~	22

The drum grid position is an imaginary grid, as shown, below:



SRTC will analyze the $LEUO_3$ for the following radionuclides:

Table 2
Radionuclides from DOT and Potential Vendor Waste Acceptance Criteria

Radionuclide	Threshold Value	Radionuclide	Threshold Value
U-232	100 nCi/M^3	I-129	0.08 Ci/M^3
U-233	100 nCi/M^3	Pu-238	100 nCi/M^3
U-234	100 nCi/M^3	Pu-239	100 nCi/M^3
U-235	100 nCi/M^3	Pu-240	100 nCi/M^3
U-236	100 nCi/M^3	Pu-241	3500 nCi/M^3
U-238	100 nCi/M^3	Pu-242	100 nCi/M^3
Np-237	100 nCi/M^3	Ra-226	100 nCi/M^3
Am-241	100 nCi/M^3	Sr-90	0.04 Ci/M^3
Cs-137	1.0 Ci/M^3	Tc-99	3.0 Ci/M^3

SRTC will analyze for the following elements from the TVA LEU Specification:

Table 3
TVA LEU Specification

Element	TVA Specification, µg/g U	Element	TVA Specification, µg/g U
Aluminum	≤150	Molybdenum	≤200
Boron	≤1	Phosphorus	≤200
Calcium	≤250	Potassium	≤50
Carbon	≤400	Samarium	≤100
Cesium	≤100	Selenium	≤10
Chlorine	≤200	Silicon	≤200
Chromium	≤150	Sodium	≤50
Dysprosium	≤100	Sulfur	≤200
Europium	≤100	Tantalum	≤200
Fluorine	≤100	Thorium	≤20
Gadolinium	≤100	Tin	≤200
Hafnium	≤100	Titanium	≤200
Iron	≤400	Tungsten	≤200
Lithium	≤100	Vanadium	≤200
Manganese	≤200	Zirconium	≤100

If the LEUO$_3$ is disposed as waste, an independent, certified[1] laboratory may be required to analyze for these RCRA constituents.

Table 4
RCRA Constituents

Constituent	RCRA Limit ,ppm[1]	Constituent	RCRA Limit ,ppm[1]
Arsenic	5.000	Hexachlorobenzene	0.130
Barium	100.000	Hexachlorobutadiene	0.500
Benzene	0.500	Hexachloroethane	3.000
Cadmium	1.000	Lead	5.000
Carbon tetrachloride	0.500	Lindane	0.400
Chlordane	0.030	Mercury	0.200
Chlorobenzene	100.000	Methoxychlor	10.000
Chloroform	6.000	Methyl ethyl ketone	200.000
Chromium	5.000	Nitrobenzene	2.000
o-Cresol[2]	200.000	Pentachlorophenol	100.000
m-Cresol[2]	200.000	Pyridine	5.000
p-Cresol[2]	200.000	Selenium	1.000
Cresol[2]	200.000	Silver	5.000
2,4-D	10.000	Tetrachloroethylene	0.700
1,4-Dichlorobenzene	7.500	Toxaphene	0.500
1,2-Dichloroethane	0.500	Trichloroethylene	0.500
1,1-Dichloroethylene	0.700	2,4,5-Trichlorophenol	400.000
2,4-Dinitrotoluene	0.130	2,4,6-Trichlorophenol	2.000
Endrin	0.020	2,4,5-TP (Silvex)	1.000
Heptachlor (and its epoxide)	0.008	Vinyl chloride	0.200

[1] Results reported as *parts per million* (ppm) are "mg/L" for liquids, and "mg/kg" for solids.
[2] If o-, m-, and p-Cresol concentrations cannot be differentiated, the total cresol concentration is used. The total cresol limit is 200 mg/L.

The following analytical requirements are included in the potential vendors' waste acceptance criteria:

Table 5
Vendor Waste Acceptance Criteria Constituents

Constituent	Typical Vendor's WAC Limit
Copper	Not Applicable
Zinc	9000 mg/L
Cyanide	25 ppm
Hydrogen sulfide	25 ppm
Paint Filter Test	No Free Liquids
pH (soil pH-method 9045)	Not Applicable
Is it an oxidizer or reducer?	Not Applicable
Photo-ionizing sniffer (gross organic)	Not Applicable
Density	± 0.1 g/cc

Potential constituents identified in the previously noted regulatory documents and/or waste acceptance criteria were excluded from the characterization analysis based on the provided reasoning:

Table 6
Excluded Analyses

Constituent	Exclusion Reasoning
Pesticides and herbicides	None used in the production process
Volatile organic compounds[3]	Removed by the production process
C-14	Process knowledge
Ni-59	Process knowledge
Radionuclides with less than 5-year half-lives[4]	Process knowledge and isotope half-lives
H-3	Process knowledge
Co-60	Process knowledge and isotope half-life
Ni-63	Process knowledge
Nb-94	Process knowledge
Pu-244	Process knowledge
Am-242m	Process knowledge
Am-243	Process knowledge
Cm-242	Process knowledge and isotope half-life
Cm-243	Process knowledge
Cm-244	Process knowledge
Cm-245	Process knowledge
Cm-246	Process knowledge
Cm-247	Process knowledge
Cm-248	Process knowledge
Cm-250	Process knowledge
Bk-247	Process knowledge
Cf-249	Process knowledge
Cf-250	Process knowledge
Cf-251	Process knowledge

[3] The LEU stream was processed through 4 high-heat manufacturing steps that eliminated any volatile organic compounds.
[4] The Mark 15 campaign was conducted in the mid-1980s. Isotopes with less than a 5-year half-life will have been reduced by radioactive decay (+3 cycles) to less-than-detectable concentrations. In addition, the LEU stream was processed through 2 solvent extraction cycles that either entirely removed or initially reduced these radionuclide concentrations to trace levels.

Please sign in the designated space to acknowledge your approval of this sample plan to characterize the $LEUO_3$.

Approvals:

[signature] for SJR — 6-2-03
S. J. Robertson, Manager, F-Canyon Complex Technical Support — Date

[signature] — 6/3/03
S. J. Howell, Manager, F-Canyon Complex Engineering — Date

[signature] — 6/4/03
M. E. Logan, Manager, F-Canyon Complex Deactivation — Date

Table B-1
Analytical Results

	Statistical Mean	Upper Confidence Level		Statistical Mean	Upper Confidence Level
TCLP Metals:			**TCLP Semivolatiles:**		
Arsenic			o-Cresol		
Barium			p-Cresol		
Cadmium			m-Cresol		
Chromium			Cresol		
Lead			Dinitrotoluene		
Mercury			Hexachlorobenzene		
Selenium			Hexachloro-1,3-butadiene		
Silver			Nitrobenzene		
TCLP Volatiles:			Pentachlorophenol		
Benzene			2,4,5-Trichlorophenol		
Carbon Tetrachloride			2,4,6-Trichlorophenol		
Chlorobenzene			Hexachloroethane		
Chloroform			**TCLP Pesticides and Herbicides:**		
1,4-Dichlorobenzene			Chlordane		
1,2-Dichloroethane			2,4 – D		
Methyl ethyl ketone			Endrin		
Pyridine			Heptachlor and Hydroxide		
Tetrachloroethelyne			Lindane		
Trichloroethylene			Methoxychlor		
Vinyl chloride			Toxaphene		
Dichloroethylene			2,4,5 - TP (Silvex)		

Attachment 2B.

SRS
savannah river site

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

MAR 2 5 2004

OBU-SWO-2004-00007

To:	Dave Collins	724-7E
	Mary Granade	724-20E
	Mark Kokovich	724-7E
	Don McWhorter	707-7F
	Jacob Nims	707-7F
	Howard Pope	704-S
	Glenn Siry	705-3C
	SW&I Document Control	642-E

From: Bernie Mayancsik *Bm* 724-21E

SUBJECT: RADIOCHEMISTRY DATA VALIDATION FOR LOW ENRICHED URANIUM OXIDE

Validation of the Low Enriched Uranium Oxide radiochemistry data analyzed by SRTC was completed with no anomalies noted. The process was performed to meet Nevada Test Site waste acceptance criteria to validate a portion of the chemical and radiological data for characterization purposes. Attached are copies of the case narrative report, completed validation checklist/summary sheet, and data validation worksheet.

Chemical analyses and subsequent validation of that data were performed by an independent source at General Engineering Laboratories, Inc.

If there are any questions regarding this information or process, please call me at 2-2271.

[illegible]

Radiochemistry Case Narrative
Westinghouse Savannah River Company
Low Enriched Uranium Oxide

Method/Analysis Information

Analytical Method

Gas Flow Proportional Counting
Liquid Scintillation
Gamma Spectroscopy
Alpha Spectrometry
Mass Spectrometry

Procedure

[illegible]	Thermal Ionization Mass Spectrometer Measurement Control Program
1-NTS-MS-010	Sample Changing Procedure for 3 Stage Thermal Ionization Mass Spec
RG B10-1	Pu TIMS Bioassay: Quality Assurance Plan
RG B10-3	Pu TIMS Bioassay: Measurement Control Program
RG B10-9	Pu TIMS Bioassay: TIMS Operations
ETSPMR-6	Underground Counting Facilities Measurement Control Program
WSRC-IM-97-00024	Conduct of Research & Development Savannah River Technology Center

Analytical Method	Batch Number	Sample Number	QC Sample Number
Gas Flow Proportional Counting	Batch 1 (Sr-90), 6-25-03	9124, 9150, 9170, 9198, 9258, 9306, 9366, 9414	blank-1
	Batch 2 (Sr-90), 7-3-03	9174, 9234, 9330, 9342, 9390, 9433, 9450, 9486	blank-2
Liquid Scintillation	Batch 1 (Tc-99), 7-23-03	9124, 9170, 9433, 9150, 9174, 9198, 9234, 9258.	blank-1, 9258 dup
	Batch 2 (Tc-99), 7-23-03	9306, 9330, 9342, 9366, 9390, 9414, 9450, 9486	blank-2, 9414 spike
Gamma Spectroscopy	Batch 1 (Np-237), 9-19-03	9124, 9150, 9170, 9174, 9198, 9234, 9258, 9306, 9330, 9342, 9366, 9390, 9414, 9433, 9450, 9486	N/A
	Batch 1(Cs-137, Ra-226, Am-241), 6-25-03	9124, 9150, 9170, 9198, 9258, 9306, 9366, 9414	blank-1, 9150 spike-1
	Batch 2 (Cs-137, Ra-226, Am-241), 7-3-03	9174, 9234, 9330, 9342, 9390, 9433, 9450, 9486	blank-2, 9450 spike-2
	Batch 1 (I-129), 8-18-03	9124, 9170, 9150, 9198, 9258, 9306, 9366, 9414	blank
Mass Spectrometry	Batch (U), 6-25-03	9124, 9125, 9150, 9169, 9170, 9174, 9198, 9258, 9282, 9306, 9341, 9366, 9414, 9433, 9438, 9514	9124 dup, 9125 dup, 9174 dup, 9198 dup, 9341 dup, 9366 dup
	Batch (Pu-238 by alpha, all other Pu's by mass). 6-25-03	9124, 9170, 9433, 9150, 9174, 9198, 9234, 9258, 9306, 9330, 9342, 9366, 9390, 9414, 9450, 9486	9366 dup

Attachment 2B.

Alpha Spectrometry	Batch (U). 6-25-03	9174. 9234. 9342. 9433. 9450. 9486. 9390. 9330	Q34
	Batch (Pu-238 by alpha. all other Pu's by mass). 6-25-03	9124. 9170. 9433. 9150. 9174. 9198. 9234. 9258. 9306. 9330. 9342. 9366. 9390. 9414. 9450. 9486	9366 dup

Calibration Information:

Calibration Information
All initial and continuing calibration requirements have been met.

Standards Information
Applicable standard solution(s) for analyses are traceable to NIST and used before the expiration date(s).

Sample Geometry
All counting sources were prepared in the same geometry as the calibration standards.

Quality Control (QC) Information:

Blank Information
Information fell within the acceptance criteria for method blanks.

QC Information
All of the QC samples (spikes, duplicates, and laboratory control samples) met the required acceptance limits for %R and RPD.

Technical Information:

Holding Time
All samples were analyzed within the required holding time.

Preparation Information
All preparation criteria have been met for these analyses.

Sample Re-prep/Re-analysis
Two samples did not agree with the historical record (9125 and 9198) during mass spectrometry for uranium. A second aliquot was dissolved and diluted and reanalyzed. The result of 9125 agreed with the initial preparation. The first result for 9198 was 0.24at% U-235 while the reanalysis resulted in 0.51at% U-235. A third aliquot for sample 9198 was therefore prepared, starting with 230 mg and diluting from there. The third result agreed with the first analysis giving 0.26at% U-235. After discussing this with the generator, another aliquot of each sample

was reanalyzed. Sample 9198 was still significantly depleted while the historical record indicates it should be very slightly enriched. The analysis of the resubmitted sample 9125 indicates that it is nearly natural in its U-235 content, agreeing with the historical record.

Miscellaneous Information:

NCR Documentation
No NCR was generated for the preparation and analysis of this sample set.

This validation was completed using *Environmental Geochemistry Group Operating Handbook Section 1.800 Analytical Data Qualification* and *LEHR Environmental Restoration/Waste Management Standard Operating Procedure* SOP NO. 21.1.

The following reviewer validated the information presented in this data narrative.

Signature: BAMayancsik Date: 3-25-04

Attachment 2B.

VALIDATION OF RADIOCHEMISTRY DATA

Sample ID: 9124, 9125, 9169, 9170, 9341, 9433, 9514, 9158, 9174, 9198, 9486, 9234, 9258, 9282, 9306, 9330, 9342, 9366, 9390, 9414, 9438, 9450
Laboratory: Analytical Development Section of SRTC
Analysis: gas flow proportional counting, liquid scintillation, gamma/mass/alpha spec
Date:
Review completed by:

HOLDING TIMES

Have all samples been analyzed within 180 days? Yes [X] No [ ] N/A [ ]

If any sample fails this criterion, apply "J" qualifier to all sample results.

LABORATORY CONTROL SAMPLE

Are all laboratory control sample (LCS) recoveries (%R) within QC limits? Yes [X] No [ ] N/A [ ]

If any LCS compound fails this criterion, apply qualifiers to the failed compound in all samples associated with that LCS, according to the following guidelines:

Condition	Positives	Non-Detects
Gross Alpha, Beta: ± 30% < %R ≤ ± 90% Upper/Lower Limit	"J"	"UJ"
%R > ± 90% Upper/Lower Limit	"J"	"R"
All others: ± 25% < %R ≤ ± 75% Upper/Lower Limit	"J"	"UJ"
%R > ± 75% Upper/Lower Limit	"J"	"R"

MATRIX SPIKE/MATRIX SPIKE DUPLICATE

Are all matrix spike (MS)/matrix spike duplicate (MSD) recoveries (%R) within QC limits? Yes [X] No [ ] N/A [ ]

Review MS recoveries and apply qualifiers to failed compounds in all associated samples.

Condition	Positives	Non-Detects
Gross Alpha, Beta: ± 30% < %R ≤ ± 90% Upper/Lower Limit	"J"	"UJ"
%R > ± 90% Upper/Lower Limit	"J"	"R"
All others: ± 25% < %R ≤ ± 75% Upper/Lower Limit	"J"	"UJ"
%R > ± 75% Upper/Lower Limit	"J"	"R"

BLANKS

	Yes	No	N/A
Are all Blank results below Reporting Limits?	☐	☒	☐

only applies to Tc-99, all others were below reporting limits. All Tc-99 results should have a "J" code.

	Yes	No	N/A
Are Field/Rinsate Blanks, if present, below Reporting Limits?	☐	☐	☒

If the blank results fall outside the appropriate limits, qualify the results for all associated samples that are less than 10 times the blank value as estimated. "J" or "UJ".

CALIBRATIONS

	Yes	No	N/A
Has the laboratory identified in the case narrative report that calibration was completed on the instrument prior to analysis?	☒	☐	☐

Discussed with laboratory personnel and was acceptable for methods that used calibration standards.

FIELD DUPLICATES (IF APPLICABLE)

	Yes	No	N/A
Do field duplicate values generally look similar?	☐	☐	☒

Field duplicate samples may be taken and analyzed as an indication of overall precision. These analyses measure both field and lab precision; therefore, the results may have more variability than lab duplicates that measure only lab performance. It is expected that soil duplicate results will have a greater variance than water matrices due to difficulties associated with collecting identical field samples. Any evaluation of field duplicates shall be provided with the reviewer's comments.

Sample Result Verification

	Yes	No	N/A
Analytes and results are expected or typical for that waste stream based on historical data or past sampling and analysis activities.	X		
Any anomalies in raw data (e.g., baseline shifts, negative absorbances, omissions, and legibility).		X	
Any transcription or calculation errors on one or more samples.		X	

Overall Validation Summary

Reference:
WSRC-TR-2003-00513 Determination of Trace radionuclides and Elements in SRS Low-Enriched Uranium from the MK-15 Campaign
Environmental Geochemistry Group Operating Handbook, Section 1.800 Analytical Data Qualification

Holding Times
within 180 days from collection

Sample date: Jun-03

Blanks

Element	Blank$_1$	Blank$_2$	Blank$_1$ x 5	Blank$_2$ x 5
Cs-137	<0.55	n/a pCi/g	n/a	n/a
Ra-226	<0 23	n/a pCi/g	n/a	n/a
Am-241	<0.63	n/a pCi/g	n/a	n/a
I-129	<28	n/a pCi/g	n/a	n/a
Tc-99	0.0056	0.026 nCi/g	0.028	0.13
Sr-90	<5	<5 pCi/g	n/a	n/a

[illegible]
detected analytes' concentration is > 5x the concentration in the blank

Duplicates
Relative percent differences (RPD) = (absolute x - y /(x + y)/2) x 100
0 - 20%

Element		x	y	absolute x-y	x+y/2	RPD
Tc-99	9258 dup	36	43	7.0000	39.5	17.7
Pu-238	9366 dup	10.6	8.8	1.8000	9.7	18.6
U-238	9125 dup	98.89	98.92	0 0300	98.91	0.0
U-236	9125 dup	0.062	0 061	0.0007	0.06	1.1
U-235	9125 dup	1.042	1.006	0.0360	1.02	3.5
U-234	9125 dup	0.008	0 008	0.0002	0.01	2.5
U-238	9198 dup	99.73	99.73	0.0000	99.73	0.0
U-236	9198 dup	0.010	0.010	0.0000	0.01	0.0
U-235	9198 dup	0.260	0.258	0.0020	0.26	0.8
U-234	9198 dup	0.001	0.001	0.0000	0.00	0.0
U-238	9124 dup	99.350	99.350	0.0000	99.35	0.0
U-236	9124 dup	0.036	0.036	0.0004	0.04	1.1
U-235	9124 dup	0.605	0.607	0.0020	0.61	0.3
U-234	9124 dup	0.005	0.005	0.0000	0.00	0.0
U-238	9174 dup	98.990	98.990	0.0000	98.99	0.0
U-236	9174 dup	0.062	0.061	0.0005	0.06	0.8
U-235	9174 dup	0.945	0.940	0.0050	0.94	0.5
U-234	9174 dup	0.008	0.008	0.0002	0.01	2.6
U-238	9341 dup	98.890	98.900	0.0100	98.90	0.0
U-236	9341 dup	0.062	0.061	0.0003	0.06	0.5
U-235	9341 dup	1.043	1.036	0.0070	1.04	0.7
U-234	9341 dup	0.008	0 008	0.0002	0.01	2.5
U-238	9366 dup	98.920	98.920	0.0000	98.92	0 0
U-236	9366 dup	0.065	0.064	0.0006	0.06	0.9
U-235	9366 dup	1.011	1.007	0.0040	1.01	0.4
U-234	9366 dup	0.008	0.008	0.0002	0.01	2.5

Laboratory Control Samples

laboratory control samples (LCS) percent recoveries = (sample results / known value) * 100

75 - 125%

Element	Known Value	Sample	%R
U-234	47.8	47.5	99
U-235-236	2.4	2.7	113
U-238	49.8	49.8	100

Spikes

% recovery (%R) = (Spike added sample results / known value of spike added) x 100

75 - 125%

Element		Spike Added	Sample Results	Units	%R
Cs-137	9150 spike	46	46	pCi/g	100
Ra-226	9150 spike	70	72	pCi/g	103
Am-241	9150 spike	115	111	pCi/g	97
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ra-226	9450 spike	70	71	pCi/g	101
Am-241	9450 spike	115	118	pCi/g	103
Tc-99	9414 spike	3 2	3.58	nCi/g	112

DU PONT

Attachment 2C

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
ATOMIC ENERGY DIVISION
SAVANNAH RIVER PLANT
AIKEN, SOUTH CAROLINA 29801

March 17, 1986

Mr. D. C. Bonfer
Westinghouse Materials Company of Ohio
P. O. Box 398704
Cincinnati, Ohio 45239

Mr. Bonfer:

The recent enriched uranium (Mark 15) productivity campaign generated 380 drums of uranium trioxide (UO_3) that were packaged as slightly enriched uranium. The majority of our sample analyses for the Mark 15 campaign have been completed. Uranium trioxide analyses are contained in Table I (^{235}U isotopic by weight for individual drums) and Table II (ten drum composite sample analyses). The transuranic alpha activity and total beta activity analyses are not yet complete.

As you indicated, composite sample 9335-9344 was mistakenly not shipped to your site. If needed, we will send this sample with our first shipment of enriched UO_3.

Please contact me at (803) 557-4263 (FTS 227-4263) if I can be of further assistance.

Very truly yours,

D. R. Barton, Jr., Engineer
Separations Technology Dept.

DRB/d
att

cc: D. C. Witt, 221-F
G. E. Barrow, 221-F
M. L. Cowen, 221-F
L. D. Olson \ C. D. Davis, 707-1F
J. T. Buckner, 703-F
C. W. Jenkins, 221-F
T. G. Campbell,221-F

TABLE I

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%	Drum #	235U wt%
9092	0.215	9142	0.734	9192	0.971
9093	0.500	9143	0.793	9193	0.967
9094	0.463	9144	0.793	9194	0.968
9095	0.479	9145	0.740	9195	0.975
9096	0.494	9146	0.807	9196	0.975
9097	0.461	9147	0.830	9197	0.977
9098	0.470	9148	0.835	9198	0.963
9099	0.486	9149	0.835	9199	0.967
9100	0.498	9150	0.837	9200	0.964
9101	0.503	9151	0.843	9201	0.965
9102	0.501	9152	0.890	9202	0.980
9103	0.503	9153	0.892	9203	0.980
9104	0.509	9154	0.893	9204	0.981
9105	0.502	9155	0.890	9205	0.941
9106	0.500	9156	0.893	9206	0.978
9107	0.581	9157	0.892	9207	0.976
9108	0.620	9158	0.893	9208	0.976
9109	0.599	9159	0.906	9209	0.981
9110	0.596	9160	0.916	9210	0.981
9111	0.598	9161	0.903	9211	0.980
9112	0.587	9162	0.868	9212	0.978
9113	0.595	9163	0.868	9213	0.929
9114	0.723	9164	0.868	9214	0.915
9115	0.581	9165	0.835	9215	0.958
9116	0.595	9166	0.829	9216	0.974
9117	0.575	9167	0.829	9217	0.975
9118	0.570	9168	0.837	9218	0.980
9119	0.507	9169	0.540	9219	0.980
9120	0.570	9170	0.923	9220	0.976
9121	0.571	9171	0.927	9221	0.990
9122	0.587	9172	0.928	9222	0.985
9123	0.589	9173	0.933	9223	0.988
9124	0.550	9174	0.934	9224	0.984
9125	0.725	9175	0.936	9225	0.963
9126	0.725	9176	0.918	9226	0.988
9127	0.725	9177	0.911	9227	0.988
9128	0.756	9178	0.913	9228	0.986
9129	0.766	9179	0.911	9229	0.951
9130	0.756	9180	0.920	9230	0.923
9131	0.727	9181	0.925	9231	0.981
9132	0.728	9182	0.925	9232	0.988
9133	0.721	9183	0.924	9233	0.985
9134	0.703	9184	0.953	9234	0.987
9135	0.702	9185	0.955	9235	0.983
9136	0.701	9186	0.959	9236	0.987
9137	0.666	9187	0.964	9237	0.983
9138	0.689	9188	0.971	9238	0.962
9139	0.745	9189	0.971	9239	0.981
9140	0.779	9190	0.970	9240	0.990
9141	0.785	9191	0.971	9241	0.984

Attachment 2C

TABLE I (cont'd)

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%	Drum #	235U wt%
9242	0.989	9292	1.005	9342	1.028
9243	0.987	9293	0.987	9343	1.030
9244	0.990	9294	1.004	9344	1.030
9245	0.969	9295	1.019	9345	1.041
9246	0.970	9296	1.017	9346	1.029
9247	0.966	9297	1.017	9347	1.030
9248	0.965	9298	1.016	9348	1.031
9249	0.970	9299	1.017	9349	1.033
9250	0.986	9300	1.016	9350	1.029
9251	0.985	9301	1.020	9351	1.023
9252	0.985	9302	1.018	9352	1.033
9253	0.986	9303	1.019	9353	1.023
9254	0.995	9304	1.018	9354	1.032
9255	0.989	9305	1.012	9355	1.030
9256	0.990	9306	1.010	9356	1.034
9257	0.990	9307	1.019	9357	1.032
9258	0.990	9308	1.021	9358	1.034
9259	0.996	9309	1.021	9359	1.035
9260	0.994	9310	1.023	9360	1.047
9261	0.998	9311	1.024	9361	1.036
9262	0.999	9312	1.013	9362	1.036
9263	0.992	9313	1.019	9363	1.035
9264	0.995	9314	1.024	9364	1.034
9265	0.995	9315	1.020	9365	1.032
9266	0.995	9316	1.021	9366	1.020
9267	0.996	9317	1.022	9367	1.029
9268	0.997	9318	1.022	9368	1.030
9269	1.002	9319	1.020	9369	1.035
9270	1.002	9320	1.022	9370	1.036
9271	1.001	9321	1.022	9371	1.036
9272	1.001	9322	1.020	9372	1.038
9273	1.005	9323	1.020	9373	1.049
9274	0.988	9324	1.016	9374	1.050
9275	0.989	9325	1.018	9375	1.045
9276	1.000	9326	1.021	9376	1.046
9277	1.000	9327	1.027	9377	1.051
9278	1.007	9328	1.012	9378	1.063
9279	1.002	9329	1.023	9379	1.035
9280	1.003	9330	1.025	9380	1.035
9281	1.004	9331	1.025	9381	1.034
9282	1.006	9332	1.027	9382	1.036
9283	1.005	9333	1.027	9383	1.040
9284	1.001	9334	1.030	9384	1.035
9285	1.015	9335	1.043	9385	1.039
9286	1.012	9336	1.042	9386	1.040
9287	1.033	9337	1.048	9387	1.038
9288	1.017	9338	1.037	9388	1.040
9289	1.017	9339	1.031	9389	1.037
9290	1.016	9340	1.026	9390	1.037
9291	1.017	9341	[illegible] 1.043	9391	1.041

Attachment 2C

TABLE I (cont'd)

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%
9392	1.039	9442	1.041
9393	1.039	9443	1.049
9394	1.034	9444	1.052
9395	1.036	9445	1.043
9396	1.042	9446	1.050
9397	1.037	9447	1.049
9398	1.051	9448	1.048
9399	1.037	9449	1.052
9400	1.035	9450	1.066
9401	1.032	9451	1.064
9402	1.040	9452	1.049
9403	1.039	9453	1.033
9404	1.039	9454	1.028
9405	1.041	9455	1.015
9406	1.041	9456	1.030
9407	1.041	9457	1.046
9408	1.043	9458	1.049
9409	1.054	9459	1.046
9410	1.045	9460	1.047
9411	1.042	9461	1.011
9412	1.046	9462	[illegible]
9413	1.043	9463	0.940
9414	1.044	9464	0.889
9415	1.045	9465	0.895
9416	1.046	9466	0.903
9417	1.045	9467	0.900
9418	1.038	9468	0.894
9419	1.041	9469	0.885
9420	1.048	9470	0.896
9421	1.054	9471	0.566
9422	1.045	9514	1.036 --- Light powder from secondary dust collector
9423	1.045		
9424	1.045		
9425	1.047		
9426	1.052		
9427	1.057		
9428	1.039		
9429	1.045		
9430	1.046		
9431	1.048		
9432	1.049		
9433	~~[illegible]~~ 1.048		
9434	1.049		
9435	1.038		
9436	1.049		
9437	1.048		
9438	1.047		
9439	1.046		
9440	1.063		
9441	1.049		

Attachment 2C

TABLE II

Mark 15 UO3 Composite Sample Results

Drum Numbers	9092-9102	9103-9112	9113-9122	9123-9132	9133-9142	9143-9142	9153-9162	9163-9172	9173-9181
wt % UO3	97.91	96.26	95.71	94.69	95.17	96.38	96.83	95.82	97.00
wt % U	81.48	80.11	79.65	78.80	79.20	80.21	80.58	79.74	80.72
PARTICLE SIZE									
%Past 40	88.4	97.1	98.2	97.1	98.0	96.6	99.0	98.7	96.7
%Past 80	22.8	80.2	87.3	83.3	90.5	87.8	90.5	90.8	82.3
%Past 325	0.4	7.7	4.8	11.4	11.4	2.9	17.0	10.6	0.4
SPECTOGRAPHIC, ppm									
Al	100	100	100	100	100	100	100	100	100
Ca	5	10	5	5	5	5	5	5	5
Cr	50	75	50	30	30	50	35	25	50
Cu	15	2	2	10	5	2	2	2	15
Fe	190	167	167	133	154	124	89	113	147
Mo	10	10	10	10	10	10	10	10	10
Na	250	300	250	150	175	75	75	90	45
Ni	30	25	25	15	25	25	25	25	25
P	25	25	100	50	100	50	50	25	100
Pb	5	5	5	5	5	5	5	5	5
Si	40	50	40	50	50	75	75	50	75
Pu - ppb	4.51	6.41	4.87	4.85	5.44	7.49	3.44	3.18	1.9
Gross %	122000	107000	37200	68000	65700	54700	50400	56600	51200

Drum Numbers	9182-9190	9192-9201	9202-9211	9212-9221	9222-9231	9232-9241	9242-9251	9252-9261	9262-9270
wt % UO3	96.68	95.95	96.64	95.30	94.29	96.68	95.64	97.40	97.48
wt % U	80.46	79.35	80.42	79.31	78.47	80.46	79.59	81.06	81.12
PARTICLE SIZE									
%Past 40	97.5	97.8	99.5	97.1	99.4	95.5	99.2	98.1	98.6
%Past 80	82.8	81.7	86.1	77.0	89.8	85.9	84.8	84.7	79.3
%Past 325	18.0	11.5	17.1	38.0	18.6	9.9	8.0	11.0	14.4
SPECTOGRAPHIC, ppm									
Al	100	50	100	100	30	20	50	50	[illegible]
Ca	5	5	5	5	5	5	5	5	5
Cr	50	25	40	100	30	30	40	75	25
Cu	2	2	25	2	2	2	5	2	[illegible]
Fe	72	100	36	152	111	323	80	100	[illegible]
Mo	10	10	10	10	10	10	10	10	[illegible]
Na	20	10	10	20	10	10	10	10	[illegible]
Ni	25	25	10	30	15	20	20	40	[illegible]
P	100	100	150	100	100	100	150	150	[illegible]
Pb	5	5	5	5	5	5	5	5	[illegible]
Si	75	100	10	10	10	10	10	50	[illegible]
Pu - ppb	2.56	1.95	1.86	3.33	1.90	9.52	1.14	1.86	2.95
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Attachment 2C

TABLE II (cont'd)

Mark 15 UO3 Composite Sample Results

Drum Numbers	9271-9277	9278-9287	9288-9297	9298-9317	9308-9314	9315-9324	9325-9334	9335-9344	9345-9354
wt % UO3	96.67	98.83	96.55	96.64	96.01	95.02	96.38	97.44	97.18
wt % U	81.5	90.00	85.70	80.42	79.90	79.08	80.21	81.09	80.87
PARTICLE SIZE									
%Past 40	98.4	98.9	98.6	97.0	99.0	97.2	96.7	98.4	99.1
%Past 80	81.5	90.0	85.7	79.1	89.4	83.3	78.6	84.7	83.5
%Past 325	10.1	31.0	28.7	20.9	30.5	22.0	19.5	27.1	13.2
SPECTOGRAPHIC, ppm									
Al	---	40	40	50	40	20	100	100	70
Ca	---	8	10	5	8	5	5	5	5
Cr	---	50	50	75	25	50	40	25	50
Cu	---	2	2	2	2	5	2	2	2
Fe	---	97	92	180	56	85	86	48	80
Mo	---	10	10	10	10	10	10	10	10
Na	---	10	10	10	10	10	10	10	20
Ni	---	15	25	50	15	15	15	15	25
P	---	100	100	100	100	100	100	100	90
Pb	---	5	5	5	5	5	5	5	5
Si	---	10	10	150	10	10	10	10	75
Pu - ppb	1.95	2.24	1.48	0.95	1.95	1.05	0.33	1.24	1.62
Gross %	46500	47500	48500	47200	46400	44700	45300	47800	40600

Drum Numbers	9355-9364	9365-9370	9371-9380	9381-9390	9391-9400	9401-9410	9411-9420	9421-9430	9431-9440
wt % UO3	96.45	96.83	96.66	97.02	97.28	97.40	96.79	97.16	97.1[illegible]
wt % U	80.27	80.58	80.44	80.74	80.96	81.06	80.55	80.86	80.8[illegible]
PARTICLE SIZE									
%Past 40	99.4	97.8	97.2	96.8	98.7	97.3	99.2	92.7	98.[illegible]
%Past 80	95.9	77.2	78.2	75.8	77.5	78.5	83.6	72.4	85.[illegible]
%Past 325	15.6	1.2	5.3	1.5	2.3	4.3	4.9	1.2	9.4
SPECTOGRAPHIC, ppm									
Al	100	20	50	25	50	---	100	100	[illegible]
Ca	5	5	10	5	5	---	5	5	[illegible]
Cr	30	20	30	40	40	---	25	25	[illegible]
Cu	2	2	5	2	2	---	2	2	
Fe	60	50	49	38	35	---	34	29	[illegible]
Mo	10	10	40	10	10	---	10	10	[illegible]
Na	10	10	10	10	10	---	10	10	[illegible]
Ni	10	25	10	10	10	---	15	10	
P	100	90	100	100	100	---	100	50	[illegible]
Pb	5	5	5	5	5	---	5	5	[illegible]
Si	100	75	10	10	10	---	10	10	[illegible]
Pu - ppb	8.57	2.48	7.76	1.28	1.71	0.62	1.19	0.95	0.4[illegible]
Gross [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				

Attachment 2C

TABLE II (cont'd)

Mark 15 UO3 Composite Sample Results

Drum Numbers	9441-9450	9451-9460
wt % UO3	97.10	97.16
wt % U	80.81	80.86
PARTICLE SIZE		
%Past 40	99.2	98.4
%Past 80	81.8	77.5
%Past 325	12.4	2.4
SPECTOGRAPHIC, ppm		
Al	30	100
Ca	5	5
Cr	25	50
Cu	2	5
Fe	31	200
Mo	10	10
Na	10	20
Ni	10	30
P	50	100
Pb	5	5
Si	10	100
Pu - ppb	1.09	0.80
Gross %	45600	46500

SRS Low-Enriched Uranium Analytical Results
Non-Radiologocal Elements

(all units are microgram per gram uranium oxide)

sample #	ADS #	Al	B	Ca	C	Cs	Cl	Cr	Dy	Eu	F	Gd	Hf	Fe	Li	Mn	Mo	P	K
9124	742	1077	1436	1179	664	100	<74	308	53	60	<74	34	59	162	2205	158	89	3538	76.92
9125	743	599	386	317	613	100	<72	267	30	60	<72	34	43	134	593	204	89	952	103.4
9150	744	596	233	192	385	100	<71	258	43	60	<71	34	15	140	358	210	89	575	62.5
9169	745	612	224	184	774	100	<61	274	8	60	<61	28	69	150	344	214	89	552	60
9170	746	645	467	383	1070	100	<72	278	36	60	<72	34	69	144	717	213	89	1150	125
9174	747	633	311	256	240	35	<77	279	30	60	<77	34	80	161	478	218	91	767	83.33
9198	748	596	243	200	169	100	<59	290	35	60	<59	34	13	247	374	205	89	600	65.22
9234	749	596	249	204	244	100	<70	271	14	60	<70	36	69	204	382	214	89	613	66.67
9258	750	618	249	204	176	100	<60	256	30	60	<60	25	58	103	382	214	89	613	66.67
9282	751	588	229	188	123	72	<76	264	28	60	<76	34	37	167	351	214	89	563	61.22
9306	752	634	273	224	214	100	<69	286	59	60	<69	34	69	200	420	215	89	673	73.17
9330	753	592	224	184	228	100	<85	264	40	60	<85	34	72	152	344	214	89	552	60
9341	754	576	350	288	489	100	<71	248	28	60	<71	80	61	126	538	196	89	863	93.75
9342	755	595	287	236	316	100	<74	271	21	60	<74	46	38	141	441	211	40	708	76.92
9366	756	628	260	214	245	23	<71	247	15	60	<71	34	69	112	400	213	89	642	69.77
9390	757	613	233	192	261	9	<70	273	30	60	<70	20	69	147	358	224	89	575	62.5
9414	758	868	238	196	321	121	<78	344	30	60	<78	31	69	604	366	217	152	587	63.83
9433	759	615	273	224	595	100	<58	258	20	60	<58	34	12	111	420	215	89	673	73.17
9438	760	571	273	224	277	100	<72	255	30	60	<72	34	69	135	420	208	40	673	73.17
9450	761	581	267	219	497	39	<78	259	30	60	<78	51	53	219	410	208	136	657	71.43
9486	762	620	229	188	350	100	<64	276	30	60	<64	34	21	147	351	224	89	563	61.22
9514	763	617	320	263	559	100	<66	274	64	60	<66	59	21	143	491	219	89	789	85.71

Note: a (<) indicates less than detection limit result

SRS Low-Enriched Uranium Analytical Results
Non-Radiologocal Elements

(all units are microgram per gram uranium oxide)

sample #	ADS #	Sm	Se	Si	Na	S	Ta	Th	Sn	Ti	W	V	Zr
9124	742	24	12.8	856	1549	7026	52	n/a	155	395	61	199	82
9125	743	59	17.2	518	1703	1890	52	n/a	157	106	212	82.8	88
9150	744	29	10.4	550	1604	1142	52	n/a	32	92.1	63	56.3	88
9169	745	20	10	600	1720	1096	52	n/a	55	98.8	92	58	88
9170	746	37	20.8	588	1750	2283	105	n/a	277	128	114	100	88
9174	747	13	13.9	594	1633	1522	52	n/a	65	96.1	71	66.7	88
9198	748	13	10.9	530	1561	1191	52	n/a	76	88.3	78	54.8	88
9234	749	59	11.1	591	1649	1218	52	n/a	84	106	77	56	88
9258	750	30	11.1	560	1564	1218	51	n/a	54	95.1	54	56.9	88
9282	751	59	10.2	596	1657	1118	52	n/a	50	105	43	56.7	88
9306	752	19	12.2	590	1517	1337	52	n/a	23	98.5	63	58.5	88
9330	753	36	10	576	1592	1096	52	n/a	54	103	161	57.2	88
9341	754	34	15.6	533	1544	1713	52	n/a	50	96.3	133	75	88
9342	755	31	12.8	590	1636	1405	52	n/a	121	103	22	61.5	88
9366	756	76	11.6	591	1493	1274	52	n/a	95	88.8	49	57.7	32
9390	757	37	10.4	621	1646	1142	52	n/a	52	110	58	58.8	88
9414	758	13	10.6	617	1672	1166	52	n/a	217	102	61	54.9	88
9433	759	11	12.2	546	1634	1337	52	n/a	148	89.3	85	58.5	88
9438	760	59	12.2	566	1566	1337	52	n/a	72	106	78	58.5	88
9450	761	51	11.9	567	1529	1305	52	n/a	93	92.4	73	57.1	88
9486	762	59	10.2	604	1637	1118	52	n/a	43	103	90	58.4	88
9514	763	59	14.3	606	1760	1566	52	n/a	52	104	62	68.6	88

Note: a (<) indicates less than detection limit result

SRS Low-Enriched Uranium Analytical Results
Uranium Isotopics

sample #	filament # and run date	238	2 sigma	236	2 sigma	235	2 sigma	234	2 sigma	233	232/238	U-234	2s error	U-235+6	2s error	U-238	2s error
9124	LEU 9124 f74 02Jul03	99.35at%	0.33at%	0.0362at%	0.0005at%	0.605at%	0.006at%	0.0045at%	0.0002at%	-3.E-08	5.E-07						
	LEU 9124 f92 15Jul03	99.35at%	0.22at%	0.0358at%	0.0003at%	0.607at%	0.004at%	0.0045at%	0.0001at%	6.E-08	1.E-06						
9125	LEU 9125 f179 10Jul03	98.90at%	0.21at%	0.0612at%	0.0004at%	1.033at%	0.007at%	0.0081at%	0.0001at%	1.E-07	3.E-07						
	LEU 9125 f66 23Jul03	98.89at%	0.27at%	0.0615at%	0.0006at%	1.042at%	0.008at%	0.0081at%	0.0002at%	1.E-07	3.E-07						
	LEU 9125R f69 23Jul03	98.92at%	0.25at%	0.0608at%	0.0005at%	1.006at%	0.008at%	0.0079at%	0.0002at%	1.E-07	8.E-08						
	LEU 9125R f13 24Jul03	98.93at%	0.23at%	0.0603at%	0.0005at%	1.007at%	0.007at%	0.0078at%	0.0002at%	6.E-08	6.E-08						
9150	LEU 9150 f130 02Jul03	99.11at%	0.33at%	0.0528at%	0.0006at%	0.833at%	0.008at%	0.0066at%	0.0002at%	8.E-08	4.E-07						
9169	LEU 9169 f121 10Jul03	99.07at%	0.20at%	0.0560at%	0.0004at%	0.865at%	0.006at%	0.0067at%	0.0001at%	1.E-07	1.E-07						
9170	LEU 9170 f162 02Jul03	99.00at%	0.28at%	0.0602at%	0.0006at%	0.932at%	0.009at%	0.0074at%	0.0002at%	1.E-07	9.E-08						
9174	LEU 9174 f19 07Jul03	98.99at%	0.28at%	0.0616at%	0.0007at%	0.945at%	0.010at%	0.0077at%	0.0002at%	1.E-07	7.E-08	53.5	4.8	6.9	1.6	39.6	3.9
	LEU 9174 f96 14Jul03	98.99at%	0.20at%	0.0611at%	0.0004at%	0.940at%	0.006at%	0.0075at%	0.0001at%	4.E-08	1.E-07						
9198	LEU 9198 f16 02Jul03	99.75at%	0.23at%	0.0090at%	0.0002at%	0.239at%	0.003at%	0.0012at%	0.0001at%	1.E-07	2.E-06						
	LEU 9198 f67 23Jul03	99.75at%	0.25at%	0.0091at%	0.0002at%	0.240at%	0.003at%	0.0012at%	0.0001at%	1.E-07	3.E-07						
	LEU 9198R f160 23Jul03	99.45at%	0.27at%	0.0293at%	0.0004at%	0.518at%	0.005at%	0.0037at%	0.0001at%	1.E-07	4.E-08						
	LEU 9198R f72 24Jul03	99.46at%	0.21at%	0.0291at%	0.0003at%	0.510at%	0.004at%	0.0036at%	0.0001at%	5.E-08	7.E-08						
	LEU 9198 R2 f9 28Jul03	99.73at%	0.22at%	0.0104at%	0.0002at%	0.260at%	0.003at%	0.0014at%	0.0001at%	2.E-08	1.E-08						
	LEU 9198 R2 f88 28Jul03	99.73at%	0.23at%	0.0104at%	0.0002at%	0.258at%	0.003at%	0.0014at%	0.0001at%	6.E-08	5.E-08						
9234												54.3	3.8	7.7	1.2	38.0	3.0
9258	LEU 9258 f124 03Jul03	98.87at%	0.30at%	0.0612at%	0.0007at%	1.059at%	0.011at%	0.0084at%	0.0002at%	7.E-08	1.E-07						
9282	LEU 9282 f108 07Jul03	98.91at%	0.26at%	0.0644at%	0.0006at%	1.022at%	0.011at%	0.0082at%	0.0002at%	1.E-07	2.E-07						
9306	LEU 9306 f40 03Jul03	98.90at%	0.30at%	0.0636at%	0.0007at%	1.026at%	0.011at%	0.0083at%	0.0002at%	1.E-07	2.E-07						
9330												55.8	3.7	6.4	1.1	37.8	2.9
9341	LEU 9341 f14 10Jul03	98.89at%	0.40at%	0.0615at%	0.0008at%	1.043at%	0.010at%	0.0080at%	0.0003at%	3.E-07	1.E-07						
	LEU 9341 f97 14Jul03	98.90at%	0.18at%	0.0612at%	0.0004at%	1.036at%	0.007at%	0.0082at%	0.0001at%	2.E-07	1.E-06						
9342												56.4	4.1	6.9	1.3	36.7	3.1
9366	LEU 9366 f135 03Jul03	98.92at%	0.45at%	0.0647at%	0.0010at%	1.011at%	0.013at%	0.0078at%	0.0003at%	2.E-07	3.E-07						
	LEU 9366 f86 14Jul03	98.92at%	0.30at%	0.0641at%	0.0006at%	1.007at%	0.008at%	0.0080at%	0.0002at%	7.E-08	1.E-07						
9390												56.8	3.0	6.5	0.9	36.7	2.3
9414	LEU 9414 f106 03Jul03	98.91at%	0.28at%	0.0585at%	0.0006at%	1.024at%	0.011at%	0.0080at%	0.0002at%	2.E-07	2.E-07						
9433	LEU 9433 f119 10Jul03	98.89at%	0.21at%	0.0581at%	0.0004at%	1.048at%	0.007at%	0.0080at%	0.0002at%	1.E-07	9.E-07	54.8	3.4	6.7	1.1	38.5	2.7
9438	LEU 9438 f26 07Jul03	98.87at%	0.22at%	0.0592at%	0.0006at%	1.061at%	0.011at%	0.0083at%	0.0002at%	9.E-08	5.E-07						
9450												53.9	3.3	7.7	1.1	38.5	2.6
9486												52.7	3.3	7.5	1.0	39.8	2.7
9514	LEU 9514 f167 07Jul03	98.89at%	0.23at%	0.0612at%	0.0006at%	1.042at%	0.011at%	0.0082at%	0.0002at%	8.E-08	4.E-07						
Standards run concurrently																	
	U005a f11 02Jul03	99.49at%	0.33at%	0.0012at%	0.0001at%	0.506at%	0.006at%	0.0035at%	0.0001at%	-2.E-07	-2.E-07	47.5	2.8	2.7	0.6	49.8	2.9
	U005a f118 03Jul03	99.49at%	0.41at%	0.0011at%	0.0001at%	0.506at%	0.007at%	0.0034at%	0.0002at%	0.E+00	2.E-07						
	U005a f27 07Jul03	99.49at%	0.42at%	0.0014at%	0.0001at%	0.506at%	0.007at%	0.0036at%	0.0002at%	5.E-07	5.E-07						
	U005a f2 10Jul03	99.49at%	0.25at%	0.0012at%	0.0001at%	0.506at%	0.004at%	0.0034at%	0.0001at%	1.E-07	3.E-07						
	U005a f21 14Jul03	99.49at%	0.24at%	0.0012at%	0.0001at%	0.506at%	0.004at%	0.0035at%	0.0001at%	9.E-08	4.E-07						
	U005a f112 23Jul03	99.49at%	0.28at%	0.0012at%	0.0001at%	0.506at%	0.005at%	0.0033at%	0.0001at%	9.E-08	2.E-07						
	U005a f95 24Jul03	99.49at%	0.26at%	0.0012at%	0.0001at%	0.506at%	0.004at%	0.0034at%	0.0001at%	2.E-08	1.E-07						
	U005a f81 28Jul03	99.49at%	0.41at%	0.0012at%	0.0001at%	0.506at%	0.007at%	0.0035at%	0.0002at%	-2.E-08	1.E-07						
Reference values of standards																	
	NBL U005a	99.49at%	0.00at%	0.0012at%	0.0000at%	0.506at%	0.000at%	0.0034at%	0.0001at%			47.8	0.3	2.4	0.5	49.8	0.6
	IUPAC U natural	99.27at%	0.01at%	0.0000at%	0.0000at%	0.720at%	0.005at%	0.0055at%	0.0002at%								

SRS Low-Enriched Uranium Analytical Results
Radiological Elements

sample #	Sr-90 pCi/g	Tc-99 nCi/g	I-129 pCi/g	Cs-137 pCi/g	Ra-226 pCi/g	Np-237	Pu-238 pCi/g	Pu-239 pCi/g	Pu-240 pCi/g	Pu-241 pCi/g	Pu-242 pCi/g	Am-241 pCi/g
9124	<36	36	<22	<16	<470	21	50	364	85	1216		47
9125												
9169						25						
9170	<10	28	<37	<29	<730		12					<36
9341						56						
9433	<7	39		<14	<410	57	1.8	25	5.9	87		<18
9514						<14						
9150	<14	35	<30	<24	<620	64	24	174	41	567	0.026	49
9174	<6	36		<16	<430	<16	11	109	25	361		<19
9198	<6	33	<19	<9	<210		41	310	74	1041		36
9234	<4	17		<4.6	<150	36	7.2	115	27	412		18
9258	<11	36	<32	<26	<640	27	5.4	81	18	299		<31
9282												
9306	<16	47	<25	<10	<300	21	8.1	134	30	412		24
9330	<8	44		<12	<330	65	5.4	84	20	289		21
9342	<6	53		<19	<480	<15	5.4	81	19	289		<24
9366	<8	57	<24	11	<340	<10	11	138	32	505		<18
9390	<8	23		<17	<420	<31	3.8	62	15	223		<18
9414	<18	20	<25	<29	<700		3.9	40	9.3	134		<34
9438						46						
9450	<12	55		<23	<620	66	13	62	14	258		34
9486	<5	14		<8	<210		9.1	73	19	618	0.007	23

OCCUPATIONAL SAFETY AND HEALTH GUIDELINE FOR URANIUM AND INSOLUBLE COMPOUNDS

INTRODUCTION

This guideline summarizes pertinent information about uranium and insoluble uranium compounds (measured as uranium) for workers and employers as well as for physicians, industrial hygienists, and other occupational safety and health professionals who may need such information to conduct effective occupational safety and health programs. Recommendations may be superseded by new developments in these fields; readers are therefore advised to regard these recommendations as general guidelines and to determine periodically whether new information is available.

APPLICABILITY

This guideline applies to metallic uranium and all insoluble uranium compounds; examples of such compounds include triuranium octaoxide, uranium dioxide, uranium hydride, uranium tetrafluoride, and uranium trioxide. The physical and chemical properties of uranium and of some insoluble uranium compounds are presented below for illustrative purposes.

SUBSTANCE IDENTIFICATION

Metallic uranium

* Formula

U

* Structure

(For Structure, see paper copy)

* Synonyms

U; Uranium metal, pyrophoric; uranium.

* Identifiers

1. CAS 7440-61-1.

2. RTECS YR3490000.

3. DOT UN: 2979 65 (for the pyrophoric forms of the metal).

4. DOT labels: Radioactive and Flammable Solid.

* Appearance and odor

Elemental uranium is a heavy, malleable, silvery white, lustrous, radioactive metal that is pyrophoric when finely divided. When uranium is obtained by reduction, it takes the form of a black powder. In its natural state, uranium has three isotopes: (234)U, (235) U, and (238)U. U-238 has a half life of 4,510,000,000 years.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Atomic number: 92.

2. Atomic weight: 238.03.

3. Boiling point (760 torr): 3818 degrees C (6904 degrees F).

4. Specific gravity (water = 1): 19.05 + 0.02 at 20 degrees C (68 degrees F).

5. Vapor density: Not applicable.

6. Melting point: 1132.3 degrees C (2070 degrees F).

7. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

8. Solubility: Insoluble in water, alcohol, and alkalies; soluble in acids.

9. Evaporation rate: Not applicable.

Triuranium Octaoxide

* Formula

U(3)O(8)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranium oxide, pitchblende, nasturan, uraninite.

* Identifiers

1. CAS 1317-99-3.

2. RTECS YR3400000.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Triuranium octaoxide is an olive green to black, odorless solid.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 842.1.

2. Boiling point: Not applicable.

3. Specific gravity (water = 1): 8.30 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 1300 degrees C (2372 degrees F) (decomposes to uranium dioxide).

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water; soluble in nitric and sulfuric acids.

8. Evaporation rate: Not applicable.

Uranium dioxide

* Formula

UO(2)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranous oxide, black uranium oxide, uranium oxide, uranic oxide, urania, yellow cake.

* Identifiers

1. CAS 1344-57-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium dioxide is a pyrophoric, black, crystalline solid. It occurs naturally in various minerals including uraninite, pitchblende, and tyuyamunite. The latter is the most important mineral commercially.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 270.03.

2. Boiling point: Data not available.

3. Specific gravity (water = 1): 10.96 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 2858-2898 degrees C (5176-5248 degrees F).

6. Vapor pressure: Not applicable.

7. Solubility: Insoluble in water; soluble in concentrated sulfuric acid and nitric acid.

8. Evaporation rate: Not applicable.

Uranium hydride

* Formula

UH(3)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranium trihydride.

* Identifiers

1. CAS 13598-56-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium hydride is a brownish-black or brownish-gray, pyrophoric powder.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 241.05.

2. Boiling point (760 torr): Not applicable.

3. Specific gravity (water = 1): 10.95 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: Decomposes.

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water, alcohol, acetone, or liquid ammonia; slightly soluble in dilute hydrogen chloride; decomposes in nitric acid.

8. Evaporation rate: Not applicable.

Uranium tetrafluoride

* Formula

UF(4)

* Structure

(For Structure, see paper copy)

* Synonyms

Green salt.

* Identifiers

1. CAS 10049-14-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium tetrafluoride is a nonvolatile, green, odorless, crystalline solid.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 314.

2. Boiling point (760 torr): 1417 degrees C (2582 degrees F).

3. Specific gravity (water = 1): 6.7 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 955-965 degrees C (1751-1769 degrees F).

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water; soluble (decomposes) in concentrated acids and alkalies.

8. Evaporation rate: Not applicable.

* Reactivity

1. Conditions contributing to instability: Heat, flame, or exposure to air. Uranium metal reacts with nearly all nonmetals. Uranium turnings and fines stored out-of-doors in closed containers under water or water-soluble oil will convert partially to the hydride and will eventually ignite during hot weather.

2. Incompatibilities: Pure uranium is very reactive and is a strong reducing agent. Clean uranium turnings or chips oxidize readily in air. Contact of uranium with carbon dioxide,

carbon tetrachloride, or nitric acid causes fires or explosions. Uranium hydride is spontaneously flammable in air, and contact of the hydride with strong oxidizers may cause fires and explosions. Contact of uranium hydride with water forms flammable and explosive hydrogen gas, and contact of the hydride with halogenated hydrocarbons can cause violent reactions. In finely divided form, uranium dioxide ignites spontaneously in air.

3. Hazardous decomposition products: Toxic particulates, gases, and vapors (such as uranium metal fume, oxides of uranium, hydrogen fluoride, carbon monoxide, and dangerous radioactive materials) may be released when uranium or an insoluble uranium compound decomposes.

4. Special precautions: Uranium is radioactive and highly reactive and should be handled with extreme caution at all times. Uranium tetrafluoride is highly corrosive.

* Flammability

The National Fire Protection Association has not assigned a flammability rating to uranium or the insoluble uranium compounds. Other sources rate uranium in solid or powder form as a very dangerous fire hazard when this substance is exposed to heat or open flame.

1. Flash point: Data not available.

2. Autoignition temperature: The ignition temperature depends on the extent to which the metal is subdivided. The ignition temperature of the metal is 170 degrees C (338 degrees F) (if oxygen is present); finely divided uranium metal (dust) ignites at room temperature (20 degrees C (68 degrees F)).

3. Flammable limits in air: Not applicable.

4. Minimum explosive concentration: 60 g/m(3).

5. Extinguishant: Use graphite chips, carbon dust, asbestos blankets, or flooding with water to extinguish small uranium fires. There is no effective way to extinguish large uranium fires.

Fires involving uranium or an insoluble uranium compound should be fought upwind and from the maximum distance possible. Keep unnecessary people away; isolate hazard area and deny entry. Emergency personnel should stay out of low areas and ventilate closed spaces before entering. Finely divided uranium (chips, turnings, shavings, etc.) are much more reactive than uranium in bulk form. If these are present during a fire, do not disperse them into a dust cloud, which may be explosive. Uranium metal may ignite spontaneously if exposed to air or other substances, may burn rapidly with a flare-burning effect, and may re-ignite after the fire has been extinguished. Containers of uranium or an insoluble uranium compound may explode in the heat of the fire and should be moved from the fire area if it is possible to do so safely. If this is not possible, cool containers from the sides with water until well after the fire is out. Stay away from the ends of containers. Personnel should withdraw immediately if a rising sound from a venting safety device is heard or if there is discoloration of a container due to fire. Dikes should be used to contain fire-control water for later disposal. If a tank car or truck is involved in a fire, personnel should isolate an area of a half a mile in all directions. Delay cleanup until arrival of, or instruction from, a qualified radiation authority. Firefighters should wear a full set of protective clothing, including a self-contained breathing apparatus, when fighting fires involving uranium or an insoluble uranium compound. Firefighters' protective clothing may provide limited protection against fires involving uranium or an insoluble uranium compound.

* Warning properties

No quantitative data are available on the odor threshold for uranium or insoluble uranium compounds; several of these substances are odorless. For the purpose of selecting appropriate respiratory protection, these substances are therefore considered to have inadequate odor warning properties.

* Eye irritation properties

No quantitative data are available on the eye irritation threshold for uranium or the insoluble uranium compounds.

EXPOSURE LIMITS

The current Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) for uranium and the insoluble uranium compounds (measured as uranium) are 0.2 milligram per cubic meter (mg/m(3)) of air as an 8-hour time-weighted average (TWA) concentration and 0.6 mg/m(3) as a 15-minute TWA short-term exposure limit (STEL). A STEL is the maximum 15-minute concentration to which workers may be exposed during any 15-minute period of the working day [29 CFR 1910.1000, Table Z-1-A]. The National Institute for Occupational Safety and Health (NIOSH) has not issued a recommended exposure limit (REL) for uranium or its insoluble uranium compounds; however, NIOSH concurs with the PEL established for this substance by OSHA [NIOSH 1988]. The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned uranium and the insoluble uranium compounds a threshold limit value (TLV) of 0.2 mg/m(3) as a TWA for a normal 8-hour workday and a 40-hour workweek and a short-term exposure limit (STEL) of 0.6 mg/m(3) for periods not to exceed 15 minutes [ACGIH 1988, p. 37]. The OSHA and ACGIH limits are based on the risk of kidney and blood disorders and on the radiological damage associated with exposure to uranium or an insoluble uranium compound.

HEALTH HAZARD INFORMATION

* Routes of exposure

Exposure to uranium or an insoluble uranium compound can occur via inhalation, ingestion, and eye or skin contact. Exposure to uranium trioxide can occur by absorption through the skin, eyes, and mucous membranes.

* Summary of toxicology

1. Effects on Animals: Metallic uranium and insoluble uranium compounds may produce both chemical poisoning and radiation injury to the kidneys and lungs of exposed animals [Clayton and Clayton 1981, p. 1996]. The insoluble uranium compounds are less toxic chemically than the soluble compounds, but uranium and all uranium compounds have the potential to cause radiation damage [Clayton and Clayton 1981, p. 2000; Klaassen, Amdur, and Doull 1986, p. 695]. The inhalation toxicity of uranium and the insoluble compounds of uranium is much greater than their oral toxicity [Clayton and Clayton 1981, p. 2000]. No dietary amount of insoluble uranium compounds acceptable to rats was lethal, and no evidence of systemic poisoning developed after the application of an insoluble compound to rabbit skin [Clayton and Clayton 1981, p. 2000]. However, uranium trioxide is lethal when placed in the conjunctival sac of rabbits' eyes, and uranium tetrafluoride causes direct eye injury [Grant 1986, p. 965]. Acute inhalation exposure to 20-mg/m(3) concentrations of uranium tetrafluoride, uranium dioxide, or high-grade uranium ore was occasionally fatal to some laboratory animals; exposure to a 2.5-mg/m(3) concentration of uranium tetrafluoride, uranium dioxide, or high-grade uranium ore caused mild or no renal damage and no fatalities in these animals [Clayton and Clayton 1981, p. 2001]. Chronic inhalation exposure to an insoluble uranium compound may produce radiation injury. In dogs and monkeys exposed to 5 mg/m(3) uranium dioxide for 6 hours/day, 5 days/week for up to 5 years, fibrotic changes suggestive of radiation injury were found in the tracheobronchial lymph nodes of both species and in the lungs of monkeys. No kidney damage was observed in these animals [Clayton and Clayton 1981, p. 2002]. Dogs tolerated inhalation of a 10-

mg/m(3) concentration of uranium dioxide every day for 1 year and dietary exposure to 10 g/kg/day for 1 year [Clayton and Clayton 1981, pp. 2001-2002]. Rats injected with metallic uranium in the femoral bone marrow and chest wall developed site-of-contact sarcomas; in these cases, the effects of chemical injury could not be distinguished from those of radiation damage [Clayton and Clayton 1981, p. 2003].

2. Effects on Humans: Metallic uranium and insoluble uranium compounds may produce both chemical poisoning and radiation injury [Clayton and Clayton 1981, p. 1996]. The insoluble uranium compounds are less toxic chemically than the soluble compounds, but uranium and all uranium compounds have the potential to cause radiation damage [Clayton and Clayton 1981, p. 2000; Klaassen, Amdur, and Doull 1986, p. 695]. Exposure to the dusts of uranium or to an insoluble uranium compound may cause respiratory irritation, cough, and shortness of breath [Genium MSDS 1988, No. 238]. Dermatitis has also been reported, and prolonged skin contact causes radiation injury to the basal cells [Proctor, Hughes, and Fischman 1988, p. 502]. Studies have shown that uranium workers are at increased risk of death from respiratory, lymphatic, and hematopoietic cancers; these deaths are presumed to be caused by radiation injury from radon gas, a byproduct of uranium decay [Rom 1983, p. 688]. A study of the risk of respiratory deaths among uranium miners in the United States showed the following dose-response: miners exposed occupationally for 5 to 9.9 years had a 2-fold increase in risk; miners exposed for 10 to 24.9 years had a 3.6-fold increase in risk; and those exposed for greater than 24.9 years had a 3.75-fold increase in risk. Smoking was shown both to increase the risk of death from respiratory disease and to shorten the neoplastic latency period [Clayton and Clayton 1981, pp. 2010-2011].

* Signs and symptoms of exposure

1. Acute exposure: The signs and symptoms of acute exposure to uranium or an insoluble uranium compound include respiratory irritation, cough, and shortness of breath.

2. Chronic exposure: The signs and symptoms of chronic exposure to uranium or an insoluble uranium compound include those of lung damage: shortness of breath, dry or productive cough, rales, cyanosis, and clubbing of the fingers. Long-term exposure also may cause cancer of the blood-forming system, the lymph system, and the respiratory tract, as well as anemia and leukopenia. The signs and symptoms of uranium-induced dermatitis may include irritation, redness, blistering, thickening, or hyperpigmentation of the skin.

* Emergency procedures:

In the event of an emergency, remove the victim from further exposure, send for medical assistance, and initiate the following emergency procedures:

1. Eye exposure: If uranium or an insoluble uranium compound gets into the eyes, immediately flush the eyes with large amounts of water for a minimum of 15 minutes, lifting the lower and upper lids occasionally. If irritation persists, get medical attention as soon as possible.

2. Skin exposure: If uranium or an insoluble uranium compound contacts the skin, the contaminated skin should be washed with soap and water. Contaminated body surfaces should immediately be decontaminated in accordance with radiation procedures. Get medical attention.

3. Inhalation: If uranium or an insoluble uranium compound is inhaled, move the victim at once to fresh air and get medical care as soon as possible. If the victim is not breathing, perform cardiopulmonary resuscitation; if breathing is difficult, give oxygen. Keep the victim warm and quiet until medical help arrives.

4. Ingestion: If uranium or an insoluble uranium compound is ingested, give the victim several glasses of water to drink and then induce vomiting by having the victim touch

the back of the throat with the finger or by giving syrup of ipecac as directed on the package. Do not force an unconscious or convulsing person to drink liquids or to vomit. Get medical help immediately. Keep the victim warm and quiet until medical help arrives.

5. Rescue: Remove an incapacitated worker from further exposure and implement appropriate emergency procedures (e.g., those listed on the Material Safety Data Sheet required by OSHA's Hazard Communication Standard, 29 CFR 1910.1200). All workers should be familiar with emergency procedures and the location and proper use of emergency equipment.

EXPOSURE SOURCES AND CONTROL METHODS

The following operations may involve uranium and insoluble uranium compounds and lead to worker exposures to these substances:

- Mining, grinding, and milling of uranium ores
- Use in nuclear reactors as fuel and to pack nuclear fuel rods and in the production of nuclear weapons
- Burning of uranium metal chips and smelting operations
- Use in the ceramics industry for pigments, coloring porcelain, painting on porcelain, and enamelling
- Use as catalysts for many reactions, in gas manufacture, and in production of fluorescent glass
- Use in photographic processes, for alloying steel, in radiation shielding, and in aircraft counterweights
- Use as a source of plutonium and radium salts

Uranium hydride:

* Use as a lab source for pure hydrogen, for separation of hydrogen isotopes, and as a reducing agent

Methods that are effective in controlling worker exposures to uranium and insoluble uranium compounds, depending on the feasibility of implementation, are

- Process enclosure,
- Local exhaust ventilation,
- General dilution ventilation, and
- Personal protective equipment.

The following publications are good sources of information on control methods:

1. ACGIH [1986]. Industrial ventilation--a manual of recommended practice. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

2. Burton DJ [1986]. Industrial ventilation--a self study companion. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

3. Alden JL, Kane JM [1982]. Design of industrial ventilation systems. New York, NY: Industrial Press, Inc.

4. Wadden RA, Scheff PA [1987]. Engineering design for control of workplace hazards. New York, NY: McGraw-Hill.

5. Plog BA [1988]. Fundamentals of industrial hygiene. Chicago, IL: National Safety Council.

Workers who may be exposed to chemical and radiation hazards should be monitored in a systematic program of medical surveillance that is intended to prevent occupational injury and disease. The program should include education of employers and workers about work-related hazards, placement of workers in jobs that do not jeopardize their safety or health, early detection of adverse health effects, and referral of workers for diagnosis and treatment. The occurrence of disease or other work-related adverse health effects should prompt immediate evaluation of primary preventive measures (e.g., industrial hygiene monitoring, engineering controls, and personal protective equipment). A medical monitoring program is intended to supplement, not replace, measures. To place workers effectively and to detect and control work-related health effects, medical evaluations should be performed (1) before job placement, (2) periodically during the period of employment, and (3) at the time of job transfer or termination.

* Preplacement medical evaluation

Before a worker is placed in a job with a potential for exposure to uranium or an insoluble uranium compound, the examining physician should evaluate and document the worker's baseline health status with thorough medical, environmental, and occupational histories, a physical examination, and physiologic and laboratory tests appropriate for the anticipated occupational risks. These should concentrate on the function and integrity of the kidneys, respiratory system, blood, liver, bone marrow, skin, and lymphatics. Medical monitoring for respiratory disease should be conducted using the principles and methods recommended by NIOSH and the American Thoracic Society.

A preplacement medical evaluation is recommended to assess an individual's suitability for employment at a specific job and to detect and assess medical conditions that may be aggravated or may result in increased risk when a worker is exposed to uranium or an insoluble uranium compound at or below the prescribed exposure limit. The examining physician should consider the probable frequency, intensity, and duration of exposure as well as the nature and degree of any applicable medical condition. Such conditions (which should not be regarded as absolute contraindications to job placement) include a history and other findings consistent with diseases of the kidneys, respiratory system, blood, liver, bone marrow, skin, or lymphatics.

* Periodic medical examinations and biological monitoring

Occupational health interviews and physical examinations should be performed at regular intervals during the employment period, as mandated by any applicable State, or local standard. Where no standard exists and the hazard is minimal, evaluations should be conducted every 3 to 5 years or as frequently as recommended by an experienced occupational health physician. Additional examinations may be necessary if a worker develops symptoms attributable to uranium exposure. The interviews, examinations, and medical screening tests should focus on identifying the adverse effects of uranium on the kidneys, respiratory system, blood, liver, bone marrow, skin, or lymphatics. Current health status should be compared with the baseline health status of the individual worker or with expected values for a suitable reference population.

Biological monitoring involves sampling and analyzing body tissues or fluids to provide an index of exposure to a toxic substance or metabolite. Urinary uranium concentrations correlate well with airborne uranium levels. Some sources report that urinary concen-trations of 50 þg uranium per liter of urine or 100 þg uranium per liter of urine correspond to constant daily exposures of approximately 0.05 mg/m(3) or 0.25 mg/m(3), respectively. Because there is great interindividual and intraindividual variability in urinary uranium concentrations, a pattern of urinary uranium excretion should be established for every exposed worker by sampling individuals at the same time on several different shifts and by sampling frequently.

* Medical examinations recommended at the time of job transfer or termination

The medical, environmental, and occupational history interviews, the physical examination, and selected physiologic or laboratory tests that were conducted at the time of placement should be repeated at the time of job transfer or termination to determine the worker's medical status at the end of his or her employment. Any changes in the worker's health status should be compared with those expected for a suitable reference population. Because occupational exposure to uranium or an insoluble uranium compound may cause diseases with prolonged latent periods, the need for medical monitoring may extend well beyond the termination of employment.

WORKPLACE MONITORING AND MEASUREMENT PROCEDURES

Determination of a worker's exposure to airborne uranium or an insoluble uranium compound (measured as uranium) is made using a mixed cellulose ester filter (0.8 micron). Samples are collected at a maximum flow rate of 2 liters per minute until a maximum air volume of 960 liters is collected. Analysis is conducted by neutron activation. This method is included in the OSHA In-House Methods File.

PERSONAL HYGIENE PROCEDURES

If uranium or an insoluble uranium compound contacts the skin, workers should immediately wash the affected areas with soap and water. Contaminated body surfaces should immediately be decontaminated in accordance with radiation procedures.

Clothing contaminated with uranium or an insoluble uranium compound should be removed immediately, and provisions should be made for the safe removal of the chemical from the clothing. Persons laundering the clothes should be informed of the toxic and radioactive hazards of uranium.

A worker who handles uranium or an insoluble uranium compound should thoroughly wash hands, forearms, and face with soap and water before eating, using tobacco products, or using toilet facilities.

Workers should not eat, drink, or use tobacco products in areas where uranium or an insoluble uranium compound is handled, processed, or stored.

STORAGE

Uranium and insoluble uranium compounds should be stored in a cool, dry, well-ventilated area in tightly sealed containers that are labeled in accordance with OSHA's Hazard Communication Standard [29 CFR 1910.1200]. Containers of uranium or of insoluble uranium compounds should be protected from physical damage and should be stored separately from carbon dioxide, carbon tetra-chloride, nitric acid, air, nonmetals, heat, sparks, and open flame. Uranium hydride should not be allowed to contact air, water, strong oxidizers, or halogenated hydrocarbons. Because empty containers that formerly contained uranium or a uranium compound may still hold product residues, they should be handled appropriately.

SPILLS AND LEAKS

In the event of a spill or leak involving uranium or an insoluble uranium compound, persons not wearing protective equipment and clothing should be restricted from contaminated areas until cleanup has been completed. A clean-up plan must be available to address an accidental leak or spill of uranium or an insoluble uranium compound because special radiation procedures are required and professional assistance is needed. The following steps should be undertaken following a spill or leak:

1. Do not touch the spilled material; stop the leak if it is possible to do so without risk.

2. Notify safety personnel.

3. Remove all sources of heat and ignition.

4. Ventilate the area of the spill or leak.

5. Protect cleanup personnel from contact with or inhalation of uranium dust.

EMERGENCY PLANNING, COMMUNITY RIGHT-TO-KNOW, AND HAZARDOUS WASTE MANAGEMENT REQUIREMENTS

The Environmental Protection Agency's (EPA's) regulatory requirements for emergency planning, community right-to-know, and hazardous waste management may vary over time. Users are therefore advised to determine periodically whether new information is available.

* Emergency planning requirements

Uranium and insoluble uranium compounds are not subject to EPA emergency planning requirements under the Superfund Amendments and Reauthorization Act (Title III).

* Reportable quantity requirements (releases of hazardous substances)

Employers are not required by the emergency release notification provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [40 CFR Part 355.40] to notify the National Response Center of an accidental release of uranium or an insoluble uranium compound; there is no reportable quantity for these substances.

* Community right-to-know requirements

Employers are not required by Section 313 of the Superfund Amendments and Reauthorization Act (SARA) to submit a Toxic Chemical Release Inventory form (Form R) to EPA reporting the amount of uranium or an insoluble uranium compound emitted or released from their facility annually.

* Hazardous waste management requirements

EPA considers a waste to be hazardous if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity, or toxicity, as defined in 40 CFR 261.21-261.24. Under the Resource Conservation and Recovery Act (RCRA), EPA has specifically listed many chemical wastes as hazardous. Although uranium and insoluble uranium compounds are not specifically listed as a hazardous waste under RCRA, EPA requires employers to treat any waste as hazardous if it exhibits any of the characteristics discussed above.

Providing more information about the removal and disposal of specific chemicals is beyond the scope of this guideline. EPA, U.S. Department of Transportation, and State and local regulations should be followed to ensure that removal, transport, and disposal of this substance are conducted in accordance with existing regulations. To be certain that chemical waste disposal meets EPA regulatory requirements, employers should address any questions to the RCRA hotline at (202) 382-3000 (in Washington, D.C.) or toll-free at (800) 424-9346 (outside Washington, D.C.). In addition, relevant State and local authorities should be contacted for information on any requirements they may have for the waste removal and disposal of this substance.

RESPIRATORY PROTECTION

* Conditions for respirator use

Good industrial hygiene practice requires that engineering controls be used where feasible to reduce workplace concentrations of hazardous materials to the prescribed

exposure limit. However, some situations may require the use of respirators to control exposure. Respirators must be worn if the ambient concentration of uranium or an insoluble uranium compound exceeds prescribed exposure limits. Respirators may be used (1) before engineering controls have been installed, (2) during work operations such as maintenance or repair activities that involve unknown exposures, (3) during operations that require entry into tanks or closed vessels, and (4) during emergency situations. If the use of respirators is necessary, the only respirators permitted are those that have been approved by NIOSH and the Mine Safety and Health Administration (MSHA).

* Respiratory protection program

Employers should institute a complete respiratory protection program that, at a minimum, complies with the requirements of OSHA's Respiratory Protection Standard [29 CFR 1910.134]. Such a program must include respirator selection (see Table 1), an evaluation of the worker's ability to perform the work while wearing a respirator, the regular training of personnel, fit testing, periodic workplace monitoring, and regular respirator maintenance, inspection, and cleaning. The implementation of an adequate respiratory protection program (including selection of the correct respirator) requires that a knowledgeable person be in charge of the program and that the program be evaluated regularly. For additional information on the selection and use of respirators and on the medical screening of respirator users, consult the **NIOSH Respirator Decision Logic** and the **NIOSH Guide to Industrial Respiratory Protection.**

Table 1 lists the respiratory protection that NIOSH recommends for workers exposed to uranium or an insoluble uranium compound. The recommended protection may vary over time because of changes in the exposure limit for uranium or the insoluble uranium compounds or in respirator certification requirements. Users are therefore advised to determine periodically whether new information is available.

PERSONAL PROTECTIVE EQUIPMENT

Protective clothing should be worn to prevent skin contact with uranium or an insoluble uranium compound. Impervious gloves, boots, and aprons should be worn as appropriate when handling any of these substances. Chemical protective clothing should be selected on the basis of available performance data, manufacturers' recommendations, and evaluation of the clothing under actual conditions of use. No reports have been published on the resistance of various protective clothing materials to permeation by uranium or an insoluble uranium compound; however, one source recommends natural rubber, neoprene, or polyvinyl chloride as a protective clothing material. If permeability data are not readily available, protective clothing manufacturers should be requested to provide information on the best chemical protective clothing for workers to wear when they are exposed to uranium or an insoluble uranium compound.

If uranium or an insoluble uranium compound is dissolved in an organic solvent, the permeation properties of both the solvent and the mixture must be considered when selecting personal protective equipment and clothing.

Safety glasses, goggles, or faceshields should be worn during operations in which uranium or an insoluble uranium compound might contact the eyes. Eyewash fountains and emergency showers should be available within the immediate work area whenever the potential exists for eye or skin contact with uranium or its insoluble compounds. Contact lenses should not be worn if the potential exists for exposure to any of these substances.

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Table 1
NIOSH recommended respiratory protection for workers exposed to uranium or an insoluble uranium compound*

Condition	Minimum respiratory protection**
Airborne concentration of uranium or an insoluble uranium compound:	
0.2 to 2 mg/m(3) (10 X PEL)	Any air-purifying, half-mask respirator equipped with a fume or high-efficiency filter approved for radon daughters or radionuclides, or
	Any air-purifying, full-facepiece respirator equipped with a fume filter approved for radon daughters, or
	Any supplied-air respirator equipped with a half mask and operated in a demand (negative-pressure) mode
0.2 to 5 mg/m(3) (25 X PEL)	Any powered, air-purifying respirator equipped with a hood or helmet and a fume or high-efficiency filter approved for radon daughters or radio-nuclides, or
	Any supplied-air respirator equipped with a hood or helmet and operated in a continuous-flow mode
0.2 to 10 mg/m(3) (50 X PEL)	Any air-purifying, full-facepiece respirator equipped with a high-efficiency filter approved for radon daughters or radio-nuclides, or
	Any powered, air-purifying respirator equipped with a tight-fitting facepiece and a high-efficiency filter approved for

	radon daughters or radio-nuclides, or
	Any supplied-air respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode, or
	Any supplied-air respirator equipped with a tight-fitting facepiece and operated in a continuous-flow mode, or
	Any self-contained respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode
0.2 to 30 mg/m(3) (150 X PEL)	Any supplied-air respirator operated in a pressure-demand or other positive-pressure mode
Entry into IDLH(+) or unknown concentrations	Any self-contained respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode, or
	Any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode
Firefighting	Any self-contained respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode
Escape	Any air-purifying, full-facepiece respirator equipped with a high-efficiency filter approved for radon daughters or radionuclides, or
	Any escape-type, self-contained breathing apparatus with a suitable service life (number of minutes required to escape the environment)

* The OSHA PEL is 0.2 mg/m(3) as an 8-hour TWA. No NIOSH REL has been issued.

** Only NIOSH/MSHA-approved equipment should be used. Also note the following:

1. Respirators accepted for use at higher concentrations may be used at lower concentrations; respirators must not, however, be used at concentrations higher than those for which they are approved.

2. Air-purifying respirators may not be used in oxygen-deficient atmospheres or in airborne concentrations that are immediately dangerous to life or health (IDLH).

(+) The uranium or an insoluble uranium compound concentration that is immediately dangerous to life and health (IDLH) is 30 mg/m(3) [NIOSH 1987b].

April 29, 2005

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FROM: S. M. Revolinski, CCC-2
S M Revolinski 4/29/05

Technical Reviewer: L. M. Gundy,
L.M. Gundy 4-29-05

Spherical Safe Mass Values – Low Enriched UO_3

Distribution

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Introduction

While performing the nuclear criticality safety evaluation (NCSE) for disposal of drums of UO_3 currently stored in F-Area [1], safe spherical mass values for several different ^{235}U enrichments were calculated. This information was not included in the NCSE, but is documented in this memorandum in the event that it could be of use at some future time.

Revision 1 evaluates ^{235}U enrichments up to 1.098 wt. percent, and includes a 0.05 minimum subcritical margin within the k_{SAFE} derivation. Revision 0 used the ENDF/B-VI cross-section library while this revision uses the ENDF/B-V cross-section library. The use of the ENDF/B-V library allows for the application of a more recent validation specifically targeted to low enriched ^{235}U systems.

Methodology

Monte Carlo calculations were used to perform the calculations for the UO_3 spherical safe mass calculations. A configuration controlled version of MCNP 4C was used to perform these calculations. MCNP 4C is a general purpose Monte Carlo radiation transport code that numerically simulates neutral and charged particle transport histories, using continuous energy cross-section libraries and general three-dimensional geometry. The MCNP code was developed by, and is maintained at, the Los Alamos National Laboratory. Configuration control of MCNP 4C is documented for the Washington Safety Management Solutions (WSMS) LINUX workstation cluster in Reference 2. A sample input file for the calculations is provided in Appendix A.

UO_3/water mixtures in spherical geometry are modeled in these calculations. The water content of the mixture is varied from 0 to 40 weight percent so that the point of optimum moderation can be determined. Each sphere is reflected with 30 cm of water. Calculations were performed for ^{235}U enrichment values of 1.098 (the maximum for the stored UO_3), 1.084, 1.050, and 1.033 weight percent ^{235}U. The mass values reported in the results section of this document were determined with the assistance of scoping calculations that are not reported here.

As recommended in Reference 3, k_{SAFE} will be determined from the following equations.

$k_{SAFE} = 1 + (\text{bias - bias uncertainty}) - \text{AOA Margin} - \text{MSM}$
$k_{bc} = 1 + (\text{bias - bias uncertainty})$

where:

AOA	=	Area of Applicability
MSM	=	Minimum Subcritical Margin
k_{bc}	=	Best estimate of the uppermost calculated neutron multiplication for which a system is not expected to be critical.

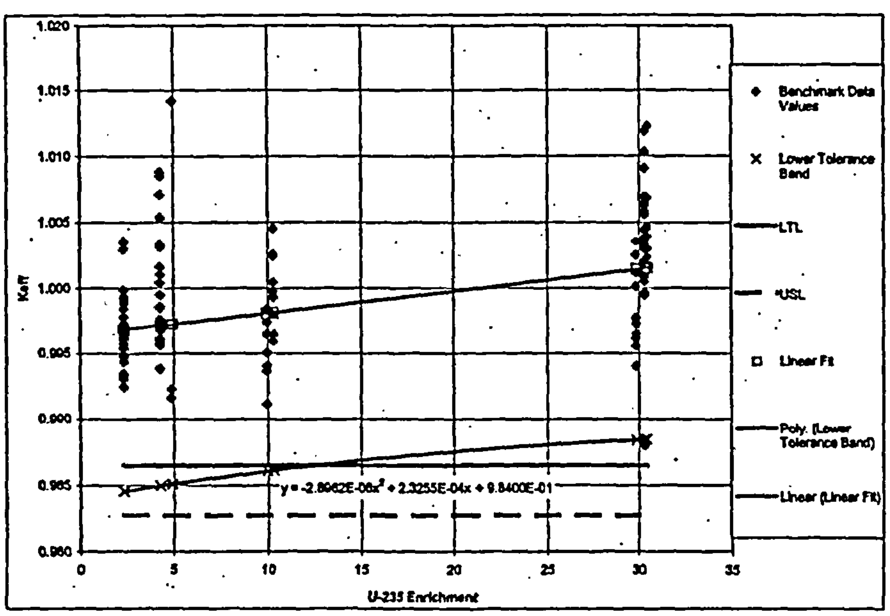
Rearranging the terms gives the following equation:

$k_{SAFE} = k_{bc}$ - AOA Margin - MSM

Calculated values of $k_{eff} + 2\sigma < k_{SAFE}$ will indicate configurations that are safely subcritical. Configurations with calculated $k_{eff} + 2\sigma \geq k_{SAFE}$ will be considered unacceptable. For this evaluation, σ is defined as the statistical uncertainty associated with the MCNP 4C calculations.

The MCNP code and cross section validation used herein was derived in Reference 4 using the Nuclear Regulatory Guidance (NRC) methodology specified in Reference 5[1]. Reference 4 provides k_{bc} for uranium systems in which the enrichment is between 2 and 30 wt. % with MCNP 4C (ENDF/B-V cross-section library) as a Lower Tolerance Limit (LTL) of 0.986. However, the uranium systems modeled herein have enrichments as low as 1.033 wt. % ^{235}U. While the LTL is the recommended expression of the bias and bias uncertainty, Reference 4 includes a discussion of the trend in the bias and bias uncertainty as a function of ^{235}U enrichment. The calculated Lower Tolerance Band (LTB) from the fit to the k_{eff} vs. ^{235}U trend was not recommended [4] because of the absence of experimental data with ^{235}U enrichments between 10 and 30 wt. %. However, for the application herein, the LTB is conservative relative to the LTL and there are sufficient data near the region of interest. Figure 1 is copied from Reference 4 and shows the relationship between the LTL and LTB for this data.

Figure 1, MCNP 4C ENDF/B-V LEU / IEU k_{bc} [4]



[1] References 3 and 5 specify identical validation methodology.

The equation for the LTB is shown on Figure 1 [4]:

$$k_{bc} = -2.8962E\text{-}06 * x^2 + 2.3255E\text{-}04 * x + 9.8400E\text{-}01,$$

where x is the ^{235}U enrichment. For an ^{235}U enrichment of 1.033 wt. % the value of k_{bc} = 0.9840. Note that extension of the LTB beyond the range of experiments is permitted [3,5].

An Area of Applicability (AOA) comparison was performed in Table 1, between the benchmark experiments documented in Reference 4 and the modeled $LEUO_3$ configurations. Specifications for the comparison provided in Table 1 were extracted from Section 4.1 of Reference 4.

Table 1: Area of Applicability Comparison

Parameter	Reference 8 System	Modeled System
Fuel	UO_2 rods, UO_2F_2, $UO_2(NO_3)_4$ solutions, and UF_4-polytetraflouroethylene cubes	UO_3
Enrichment	2 to 30 wt % ^{235}U	1.033 to 1.098 wt % ^{235}U
Moderation	$H/^{235}U$: 75 to 1400	$H/^{235}U$: Range: 0 to 1240, 413 for bounding case
Moderating Material	Water	Water
Reflecting Material	None, Water, Steel, Lead, and Paraffin	Water
Geometry	Thin Rod Lattices, Spheres, Cylinders, and Cubes	Spheres
Neutron Spectrum	Intermediate to Thermal	Intermediate to Thermal

From Table 1, the areas of applicability for the Reference 4 analyses and the analyses documented herein do not match up exactly. In terms of the $H/^{235}U$ ratio, some of the modeled systems are outside the benchmark system range on the lower end, although the bounding cases are all within the validated range. Since Reference 4 does not provide any evidence that there is any bias related trend with $H/^{235}U$ ratio on either end of the range and since the calculated k_{eff} values for the cases that are outside the range are very much lower than k_{SAFE}, no AOA margin adjustment is required. In terms of enrichment, the modeled system is slightly outside the benchmark system on the lower end; however, the use of the LTB allows for extension into the modeled range. Therefore, no AOA margin is required. In terms of the fuel form, the reference systems model a combination of uranium, fluorine, oxygen, nitrogen, carbon, and hydrogen. Fluorine and nitrogen are only minor neutron poisons and O is only a minor scatterer. Thus, the effect on the neutron flux for these constituents would be negligible.

The modeled system contains some of these elements but in different proportions. Since MCNP does not model a specific chemical formula (but rather the individual nuclei), these slight differences do not require an AOA margin adjustment. In terms of moderating material, reflecting material, geometry, and neutron spectrum the modeled system is within the range of the benchmark experiments. Therefore, it is concluded that the AOA of the Reference 4 system is similar enough to the systems analyzed in this evaluation that information from Reference 4 may be used here.

As stated above, no additional AOA margin is required. An MSM of 5% is set to account for system uncertainties. This MSM is deemed adequate, given the conservative nature of the $LEUO_3$ calculations. Using these parameters, a k_{SAFE} of 0.934 is calculated for the uranium systems modeled in this evaluation.

The ENDF/B-V cross sections supplied with MCNP 4C are used exclusively in these calculations. The following materials are used in the MCNP calculations for the UO_3 safe mass calculations:

1) Various uranium trioxide (UO_3) solutions are modeled with an isotopic enrichment up to 1.098% ^{235}U (cross sections 92235.50c, 92238.50c, 1001.50c, and 8016.50c). The mass density of UO_3 used is 7.29 g/cm^3 [6] and the mass density of water used is 1.0 g/cm^3. Thermal scattering from the hydrogen in these mixtures is modeled with the 300 K light water S(α,β) table (lwtr.01t).

2) Plain water is modeled as 2 atoms of H and 1 atom of O. Cross sections 1001.50c, and 8016.50c and a mass density of 1.0 g/cm^3 are used. Thermal scattering from the hydrogen in water is modeled with the 300 K light water S(α,β) table (lwtr.01t).

Results

The results of the spherical safe mass calculations are provided in Table 2.

Table 2: Spherical Safe Mass Calculation Results

Case ID	Internal H_2O Content, Wt% H_2O	k_{eff}	σ	k_{eff} + 2σ
2.81 metric tons of UO_3 @ ^{235}U Enrichment 1.084 + 0.014 = 1.098 wt%				
ud81	0	0.4685	0.0005	0.4695
ud82	5	0.7871	0.0006	0.7883
ud83	10	0.9028	0.0006	0.9040
ud84	12.5	0.9234	0.0006	0.9246
ud85	15	0.9314	0.0006	0.9325
ud86	17.5	0.9313	0.0005	0.9324

Table 2: Spherical Safe Mass Calculation Results

Case ID	Internal H_2O Content, Wt% H_2O	k_{eff}	σ	$k_{eff} + 2\sigma$
ud87	20	0.9265	0.0005	0.9275
ud88	30	0.8648	0.0004	0.8656
ud89	40	0.7693	0.0004	0.7700
3.07 metric tons of UO_3 @ ^{235}U Enrichment 1.070 + 0.014 = 1.084 wt%				
ud39	0	0.4679	0.0005	0.4688
ud40	5	0.7906	0.0006	0.7918
ud41	10	0.9051	0.0006	0.9064
ud42	12.5	0.9254	0.0006	0.9266
ud37	15	0.9318	0.0006	0.9329
ud43	17.5	0.9325	0.0005	0.9335
ud44	20	0.9254	0.0005	0.9264
ud45	30	0.8616	0.0004	0.8624
ud46	40	0.7662	0.0004	0.7669
4.06 metric tons of UO_3 @ ^{235}U Enrichment 1.035 + 0.014 = 1.05 wt%				
ud57	0	0.4646	0.0005	0.4656
ud58	5	0.7999	0.0006	0.8011
ud59	10	0.9092	0.0006	0.9104
ud60	12.5	0.9271	0.0006	0.9282
ud50	15	0.9323	0.0005	0.9333
ud61	17.5	0.9297	0.0005	0.9307
ud62	20	0.9228	0.0005	0.9237
ud63	30	0.8547	0.0004	0.8555
ud64	40	0.7569	0.0003	0.7576
4.50 metric tons of UO_3 @ ^{235}U Enrichment 1.020 +0.013 = 1.033 wt%				
ud67	0	0.4633	0.0005	0.4642
ud68	5	0.8015	0.0006	0.8027
ud69	10	0.9087	0.0006	0.9099
ud70	12.5	0.9263	0.0006	0.9274
ud66	15	0.9313	0.0005	0.9323
ud71	17.5	0.9280	0.0005	0.9290
ud72	20	0.9192	0.0005	0.9202
ud73	30	0.8501	0.0004	0.8509
ud74	40	0.7512	0.0004	0.7519

Conclusions

As shown in the results above, the safe spherical mass values for UO_3 at different enrichments are as follows:

Table 3, Safe Mass for Various Enrichments

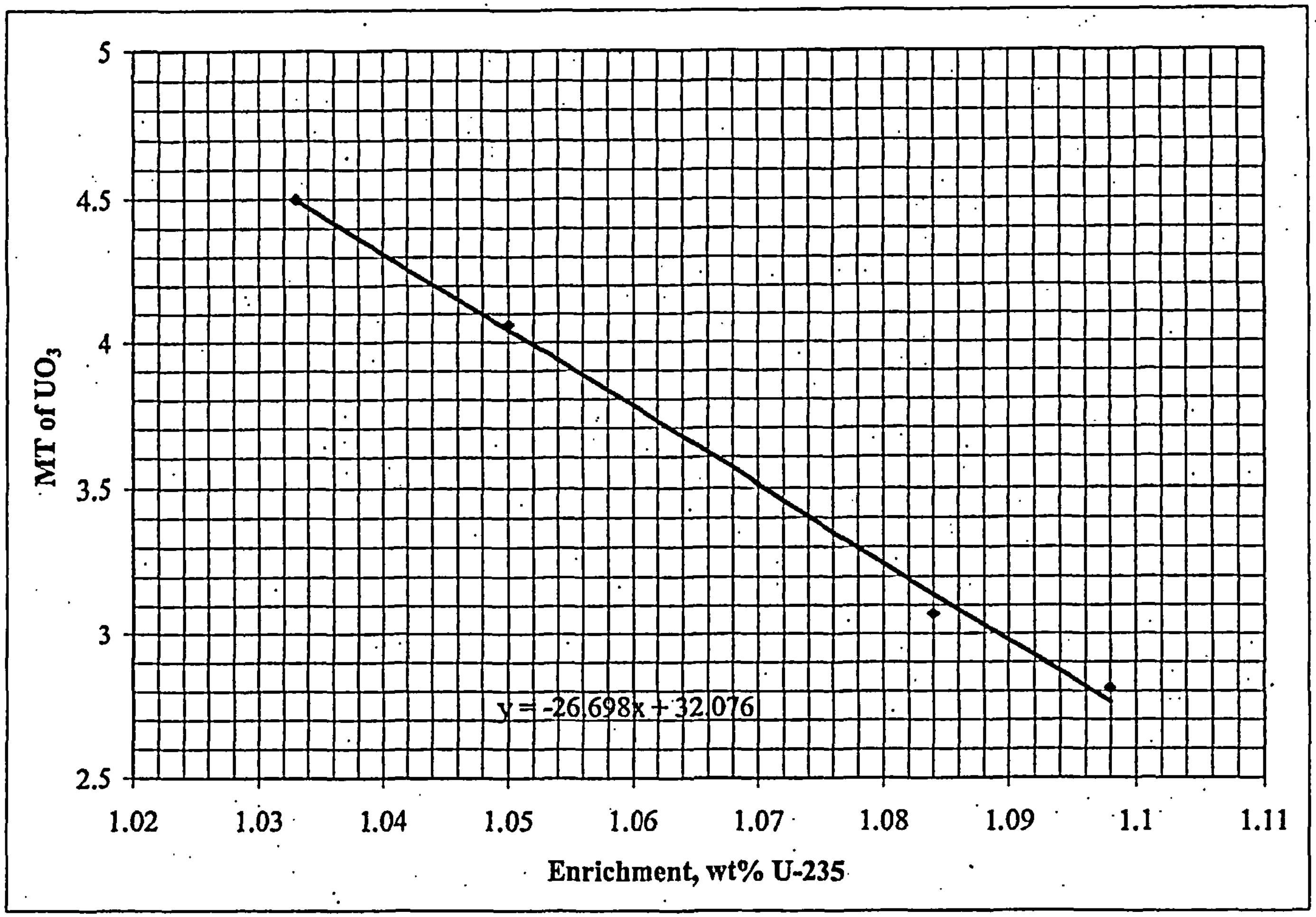
1.098 Wt%	2.81 MT
1.084 Wt%	3.07 MT
1.050 Wt%	4.06 MT
1.033 Wt%	4.50 MT

The results are shown graphically in Figure 2. The data have been fitted to a line and interpolation between the data points can be made using this fit:

$$UO_3 \text{ Mass (MT)} = -26.698 \text{ (wt. \% } U^{235}) + 32.076 \qquad \text{(Equation 1)}$$

The safe mass at enrichments between the calculated points may be obtained from Table 3 or Equation 1, in order to optimize drum loading per shipment.

Figure 2: Enrichment vs Safe Mass



References

1. Taylor, R. P., _Nuclear Criticality Safety Evaluation: Disposal Of Drums Containing UO_3 From F-Area_, N-NCS-F-00108, Revision 0, March 2004.

2. _Software Quality Assurance Implementation Checklist for MCNP 4C_, WSMS-CRT-01-0101, August 2001.

3. WSMS-CRT-01-0116, _Nuclear Criticality Safety Methods Manual_, Revision 3, October 2003.

4. Revolinski, S. M., _MCNP 4C Validation for Low and Intermediate Enriched Uranium On WSMS Linux Workstations (U)_, WSMS-CRT-04-0035, Revision 0, April, 28, 2004.

5. _Guide for Validation of Nuclear Criticality Safety Calculation Methodology_, NUREG/CR-6698, January 2001.

6. Petrie, L. M., Fox, P. B., and Lucius, K., _Standard Composition Library_, NUREG/CR-0200, Revision 5, SCALE Computer System, Volume 3, Section M8, Oak Ridge National Laboratory, Oak Ridge, TN, March, 1997.

Appendix A Sample MCNP 4C Input File

One of the MCNP 4C input files used in the spherical safe mass calculations is provided below. This basic input file was used for all drum calculations with necessary changes to material composition depending on the requirements of the case. File *ud37* models a sphere containing 3.07 metric tons of UO_3 at a ^{235}U enrichment of 1.084 weight percent with sufficient water such that the water content of the sphere is 15 wt% water. The sphere is reflected with 30 cm of water.

File ud37

```
UO3 Disposal,  Evaluator = R. P. Taylor, 3/8/04; SMR 4/26/05
c
c      3.07 MT UO3, 1.084% U-235
c      Sphere, 15 wt% H2O, full reflection
1      1  -3.7509    -1                                        imp:n=1
2      2  -1.0000    -2 #1                                     imp:n=1
999    0              2                                        imp:n=0

1     so     61.3
2     so     91.3

kcode 2000 1.0 50 575 50000
ksrc   0 0 0
prdmp  3j  1
c     UO3 mixture
m1       92238.50c    -0.699667
         92235.50c    -0.007689
          8016.50c    -0.275860
          1001.50c    -0.016784
mt1      lwtr.01t
c     water
m2        1001.50c     2
          8016.50c     1
mt2      lwtr.01t
```

Attachment 5A. LEUO 55 Gallon Drum IP-1 Container

The information in this report documents the LEUO 55 Gallon Drum IP-1 Container design compliance with 49 CFR requirements for IP-1 packaging. The document contains a 1) Regulatory Compliance Summary and Shipper Duties, and 2) Closing Instructions (Attachment 5B).

REGULATORY REQUIREMENT	ACTION REQUIRED AND BY WHOM	COMPLIANCE BY LEUO 55 GALLON DRUM CONTAINER
PART 173--SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart B—Preparation of Hazardous Materials for Transportation Sec. 173.24 General requirements for packagings and packages.		
(a) Applicability. Except as otherwise provided in this subchapter, the provisions of this section apply to— (1) Bulk and non-bulk packagings; (2) New packagings and packagings which are reused; and (3) Specification and non-specification packagings. (b) Each package used for the shipment of hazardous materials under this subchapter shall be designed, constructed, maintained, filled, its contents so limited, and closed, so that under conditions normally incident to transportation—	Shipper to ensure.	This packaging has been evaluated herein and meets DOT IP-1 packaging criteria of 173.411(b). The packaging consists of a 16 gauge 55 gallon galvanized carbon steel drum with three rolling hoops manufactured to the DOT 17C construction specification, 16 gauge removable lid, 12 gauge closure ring with 5/8" diameter bolt and nut, and an elastomer gasket (see Attachment 5C, FSS-TS-2004-0001 for gasket materials evaluation).
(1) Except as otherwise provided in this subchapter, there will be no identifiable (without the use of instruments) release of hazardous materials to the environment;	Shipper to ensure. To be considered during package design evaluagtion.	This packaging meets this requirement by confining contents within a carbon steel drum, with elastomer gasket and lid held together by a ring closure with 5/8" bolt and nut.
(2) The effectiveness of the package will not be substantially reduced; for example, impact resistance, strength, packaging compatibility, etc. must be maintained for the minimum and maximum temperatures encountered during transportation;	Shipper to ensure. To be considered during design evaluation.	This packaging meets this requirement by incorporating a commercially supplied, vibration resistant, 55 gallon open head drum.
(3) There will be no mixture of gases or vapors in the package, which could, through any credible spontaneous increase of heat or pressure, significantly reduce the effectiveness of the packaging.	Shipper to ensure.	Shipper to ensure that contents loaded into package conform to the appropriate content category (e.g. LSA content).
(c) Authorized packagings. A packaging is authorized for a hazardous material only if		

(1) The packaging is prescribed or permitted for the hazardous material in a packaging section specified for that material in Column 8 of the Sec. 172.101 table and conforms to applicable requirements in the special provisions of Column 7 of the Sec. 172.101 table and, for specification packagings (but not including UN standard packagings manufactured outside the United States), the specification requirements in parts 178 and 179 of this subchapter; or (2) The packaging is permitted under, and conforms to, provisions contained in Secs. 171.11, 171.12, 171.12a, 173.3, 173.4, 173.5, 173.7, 173.27, or 176.11 of this subchapter.	Shipper to ensure. Shipper is responsible to ensure that the packaging used is in compliance with this design	This packaging has been qualified herein to meet the IP-1 requirements specified in 49 CFR 173.411(b).
(d) Specification packagings and UN standard packagings manufactured outside the U.S. (1) Specification packagings. A specification packaging, including a UN standard packaging manufactured in the United States, must conform in all details to the applicable specification or standard in part 178 or part 179 of this subchapter.	Shipper responsible to ensure that the packaging hardware used is in compliance with the packaging design.	This packaging has been qualified to meet the IP-1 requirements specified in 49 CFR 173.411(b).
(2) UN standard packagings manufactured outside the United States. A UN standard packaging manufactured outside the United States, in accordance with national or international regulations based on the UN Recommendations (see Sec. 171.7 of this subchapter), may be imported and used and is considered to be an authorized packaging under the provisions of paragraph ©(1) of this section, subject to the following conditions and limitations: (i) The packaging fully conforms to applicable provisions in the UN Recommendations and the requirements of this subpart, including reuse provisions; (ii) The packaging is capable of passing the prescribed tests in part 178 of this subchapter applicable to that standard; and (iii) The competent authority of the country of manufacture provides reciprocal treatment for UN standard packagings manufactured in the U.S.	NA	NA

(e) Compatibility.		
(1) Even though certain packagings are specified in this part, it is, nevertheless, the responsibility of the person offering a hazardous material for transportation to ensure that such packagings are compatible with their lading. This particularly applies to corrosivity, permeability, softening, premature aging and embrittlement.	Shipper to ensure.	Shipper responsible to ensure that the packaging is loaded with contents that are compatible with packaging materials (galvanized steel drum and lid, and elastomer gasket). The packaging materials are durable for many content forms. Shipper to follow QC requirements in 49 CFR 173.475.
(2) Packaging materials and contents must be such that there will be no significant chemical or galvanic reaction between the materials and contents of the package.	Shipper to ensure.	Shipper to ensure chemical compatibility between contents and packaging.
(3) Plastic packagings and receptacles.		
(i) Plastic used in packagings and receptacles must be of a type compatible with the lading and may not be permeable to an extent that a hazardous condition is likely to occur during transportation, handling or refilling.	Shipper to ensure.	NA.
(ii) Each plastic packaging or receptacle which is used for liquid hazardous materials must be capable of withstanding without failure the procedure specified in appendix B of this part ("Procedure for Testing Chemical Compatibility and Rate of Permeation in Plastic Packagings and Receptacles"). The procedure specified in appendix B of this part must be performed on each plastic packaging or receptacle used for Packing Group I materials. The maximum rate of permeation of hazardous lading through or into the plastic packaging or receptacles may not exceed 0.5 percent for materials meeting the definition of a Division 6.1 material according to Sec. 173.132 and 2.0 percent for other hazardous materials, when subjected to a temperature no lower than—	NA	NA
(A) 18 deg.C (64 deg.F) for 180		

days in accordance with Test Method 1 in appendix B of this part; (B) 50 deg.C (122 deg.F) for 28 days in accordance with Test Method 2 in appendix B of this part; or (C) 60 deg.C (140 deg.F) for 14 days in accordance with Test Method 3 in appendix B of this part. (iii) Alternative procedures or rates of permeation are permitted if they yield a level of safety equivalent to or greater than that provided by paragraph (e)(3)(ii) of this section and are specifically approved by the Associate Administrator.		
(4) Mixed contents. Hazardous materials may not be packed or mixed together in the same outer packaging with other hazardous or nonhazardous materials if such materials are capable of reacting dangerously with each other and causing— (i) Combustion or dangerous evolution of heat; (ii) Evolution of flammable, poisonous, or asphyxiant gases; or (iii) Formation of unstable or corrosive materials.	Shipper to ensure.	Shipper to ensure.
(5) Packagings used for solids, which may become liquid at temperatures likely to be encountered during transportation, must be capable of containing the hazardous material in the liquid state. (f) Closures. (1) Closures on packagings shall be so designed and closed that under conditions (including the effects of temperature and vibration) normally incident to transportation—	Shipper to ensure.	Shipper to ensure. This packaging is designed for solids only. Damp contents may be loaded into packaging, but shall not result in free standing water.
(i) Except as provided in paragraph (g) of this section, there is no identifiable release of hazardous materials to the environment from the opening to which the closure is applied; and	Shipper to ensure.	Shipper to ensure proper closure instructions are followed. See Attachment 5B for closure instructions.

(ii) The closure is secure and leakproof. (2) Except as otherwise provided in this subchapter, a closure (including gaskets or other closure components, if any) used on a specification packaging must conform to all applicable requirements of the specification.	<u>Shipper to ensure.</u>	Shipper to ensure proper closure instructions are followed. Note: Shipper to follow closure instructions provided in Attachment 5B
(g) Venting. Venting of packagings, to reduce internal pressure which may develop by the evolution of gas from the contents, is permitted only when— (1) Transportation by aircraft is not involved; (2) Except as otherwise provided in this subchapter, the evolved gases are not poisonous, likely to create a flammable mixture with air or be an asphyxiant under normal conditions of transportation; (3) The packaging is designed so as to preclude an unintentional release of hazardous materials from the receptacle; and (4) For shipments in bulk packagings, venting is authorized for the specific hazardous material by a special provision in the Sec. 172.101 table or by the applicable bulk packaging specification in part 178 of this subchapter. (h) Outage and filling limits—	<u>NA</u>	There are no vents on this packaging design.
(1) General. When filling packagings and receptacles for liquids, sufficient ullage (outage) must be left to ensure that neither leakage nor permanent distortion of the packaging or receptacle will occur as a result of an expansion of the liquid caused by temperatures likely to be encountered during transportation. Requirements for outage and filling limits for non-bulk and bulk packagings are specified in Secs. 173.24a(d) and 173.24b(a), respectively.	<u>NA</u>	This packaging is not designed for liquids.

(2) Compressed gases and cryogenic liquids. Filling limits for compressed gases and cryogenic liquids are specified in Secs. 173.301 through 173.306 for cylinders and Secs. 173.314 through 173.319 for bulk packagings.		
(i) Air transportation. Packages offered or intended for transportation by aircraft must conform to the general requirements for transportation by aircraft in Sec. 173.27, except as provided in Sec. 171.11 of this subchapter.	NA	This packaging is not designed for air transport.
PART 173—SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart B—Preparation of Hazardous Materials for Transportation Sec. 173.24a Additional general requirements for non-bulk packagings and packages. (a) Packaging design. Except as provided in Sec. 172.312 of this subchapter:		
(1) Inner packaging closures. A combination packaging containing liquid hazardous materials must be packed so that closures on inner packagings are upright.	NA	This packaging not designed for liquid contents.
(2) Friction. The nature and thickness of the outer packaging must be such that friction during transportation is not likely to generate an amount of heat sufficient to alter dangerously the chemical stability of the contents.	Designer to do and shipper to ensure.	The LEUO 55 Gallon Drum contents will not be affected by friction induced heat generation. The oxide material (much like sand) is chemically stable and at equilibrium in the drum. There will be minimal friction generated heat. No measurable temperature increase due to friction induced heat generation will occur because of the 1) large thermal mass of the LEUO contents, 2) good conductivity of the metal drum, and 3) relatively small motion that will occur between the contents and metal packaging materials.

(3) Securing and cushioning. Inner packagings of combination packagings must be so packed, secured and cushioned to prevent their breakage or leakage and to control their movement within the outer packaging under conditions normally incident to transportation. Cushioning material must not be capable of reacting dangerously with the Contents of the inner packagings or having its protective properties significantly weakened in the event of leakage.	Designer to do and shipper to ensure.	The LEUO will be confined in an inner 3-6 mil plastic liner within the LEUO 55 gallon drum. The liner is constrained between the contents and the drum so movement is minimal. No containment credit is taken for the liner.
(4) Metallic devices. Nails, staples and other metallic devices shall not protrude into the interior of the outer packaging in such a manner as to be likely to damage inner packagings or receptacles.	Designer to do and shipper to ensure.	The 55 gallon galvanized steel drum has a smooth interior. The LEUO content conforms to the inside of the container and has no metallic feature likely to damage the drum.
(4) Vibration. Each non-bulk package must be capable of withstanding, without rupture or leakage, the vibration test procedure specified in Sec. 178.608 of this subchapter.	Designer to do and shipper to ensure.	Fifty five gallon open head drum packages have been used for decades in transportation and have proven vibration resistance.
(b) Non-bulk packaging filling limits. (1) A single or composite non-bulk packaging may be filled with a liquid hazardous material only when the specific gravity of the material does not exceed that marked on the packaging, or a specific gravity of 1.2 if not marked, except as follows: (i) A Packing Group I packaging may be used for a Packing Group II material with a specific gravity not exceeding the greater of 1.8, or 1.5 times the specific gravity	NA	This packaging is not designed for liquid contents.

marked on the packaging, provided all the performance criteria can still be met with the higher specific gravity material; (ii) A Packing Group I packaging may be used for a Packing Group III material with a specific gravity not exceeding the greater of 2.7, or 2.25 times the specific gravity marked on the packaging, provided all the performance criteria can still be met with the higher specific gravity material; and (iii) A Packing Group II packaging may be used for a Packing Group III material with a specific gravity not exceeding the greater of 1.8, or 1.5 times the specific gravity marked on the packaging, provided all the performance criteria can still be met with the higher specific gravity material.		
(2) Except as otherwise provided in this section, a non-bulk packaging may not be filled with a hazardous material to a gross mass greater than the maximum gross mass marked on the packaging.	Shipper to ensure.	Gross mass shall not exceed the 900 pound capacity of the IP-1 package.
(3) A single or composite non-bulk packaging which is tested and marked for liquid hazardous materials may be filled with a solid hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. In addition: (i) A single or composite non-bulk packaging which is tested and marked for Packing Group I liquid hazardous materials may be filled with a solid Packing Group II hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 1.5, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. (ii) A single or composite non-bulk packaging which is tested and	NA	This packaging is not designed nor tested for liquids.

marked for Packing Group I liquid hazardous materials may be filled with a solid Packing Group III hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 2.25, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. (iii) A single or composite non-bulk packaging which is tested and marked for Packing Group II liquid hazardous materials may be filled with a solid Packing Group III hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 1.5, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked.		
(4) Packagings tested as prescribed in Sec. 178.605 of this subchapter and marked with the hydrostatic test pressure as prescribed in Sec. 178.503(a)(5) of this subchapter may be used for liquids only when the vapor pressure of the liquid conforms to one of the following: (i) The vapor pressure must be such that the total pressure in the packaging (i.e., the vapor pressure of the liquid plus the partial pressure of air or other inert gases, less 100 kPa (15 psia)) at 55 deg.C (131 deg.F), determined on the basis of a maximum degree of filling in accordance with paragraph (d) of this section and a filling temperature of 15 deg.C (59 deg.F)), will not exceed two-thirds of the marked test pressure; (ii) The vapor pressure at 50 deg.C (122 deg.F) must be less than four-sevenths of the sum of the marked test pressure plus 100 kPa (15 psia); or (iii) The vapor pressure at 55 deg.C (131 deg.F) must be less than two-thirds of the sum of the marked test pressure plus 100 kPa (15	<u>NA</u>	This packaging is not designed for liquid contents.

psia).		
(5) No hazardous material may remain on the outside of a package after filling.	Shipper to ensure.	Shipper responsible to ensure that instructions are followed to prevent contamination of the outside of the package. Shipper is responsible to ensure that packaging is loaded with appropriate contents and that the drum is closed in accordance with closure instruction.
(c) Mixed contents. (1) An outer non-bulk packaging may contain more than one hazardous material only when— (i) The inner and outer packagings used for each hazardous material conform to the relevant packaging sections of this part applicable to that hazardous material; (ii) The package as prepared for shipment meets the performance tests prescribed in part 178 of this subchapter for the packing group indicating the highest order of hazard for the hazardous materials contained in the package; (iii) Corrosive materials (except ORM-D) in bottles are further packed in securely closed inner receptacles before packing in outer packagings; and	NA	This packaging is not a combination packaging.
(iv) For transportation by aircraft, the total net quantity does not exceed the lowest permitted maximum net quantity per package as shown in Column 9a or 9b, as appropriate, of the Sec. 172.101 table. The permitted maximum net quantity must be calculated in kilograms if a package contains both a liquid and a solid. (2) A packaging containing inner packagings of Division 6.2 materials may not contain other hazardous materials, except dry ice.	NA	This packaging is not designed for air transport.

(d) Liquids must not completely fill a receptacle at a temperature of 55 deg.C (131 deg.F) or less.	NA	This packaging is not designed for liquids.
PART 173—SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart I—Class 7 (Radioactive) Materials Sec. 173.410 General design requirements. In addition to the requirements of subparts A and B of this part, each package used for the shipment of Class 7 (radioactive) materials must be designed so that—		
(a) The package can be easily handled and properly secured in or on a conveyance during transport.	Designer to do and shipper to ensure.	This drum packaging is of standard commercial design and can be handled with commercially available, or appropriate, drum handling equipment. The drum package can be secured in the conveyance by standard blocking/bracing/tie-down methods
(b) Each lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting attachment under excessive load would not impair the ability of the package to meet other requirements of this subpart. Any other structural part of the package which could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport or must be designed with strength equivalent to that required for lifting attachments.	Designer to do and shipper to ensure.	The packaging (drum) is not equipped with lifting attachments. The drum is to be handled/lifted using standard industrial, or appropriate, drum handling methods.
(c) The external surface, as far as practicable, will be free from protruding features and will be easily decontaminated.	Designer to do and shipper to ensure.	The external surfaces are galvanized carbon steel which can be decontaminated. The drum closure ring system is removable to accommodate decontamination

(d) The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect.	Designer to do and shipper to ensure.	This packaging meets the intent of this requirement. The drum design has clean vertical members and a domed lid that enhances water run off and minimizes water collection.
(e) Each feature that is added to the package will not reduce the safety of the package.	Shipper to ensure.	It is a shipper responsibility to contact the CTF (WSRC/Transportation Services) if features need to be added to the current packaging design.
(f) The package will be capable of withstanding the effects of any acceleration, vibration or vibration resonance that may arise under normal conditions of transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use (see Secs. 173.24, 173.24a, and 173.24b).	Designer to do, shipper to ensure.	Extensive transportation experience with 17C drums has demonstrated that single bolt drum closures are vibration resistant.
(h) The materials of construction of the packaging and any components or structure will be physically and chemically compatible with each other and with the package contents. The behavior of the packaging and the package contents under irradiation will be taken into account.	Designer to do, shipper to ensure.	The shipper must ensure application of quality assurance during package closing to ensure compliance. The packaging components (carbon steel drum and lid, elastomer gasket, and ring closure) are physically and chemically compatible with each other. The LEUO contents are furthermore enveloped within a plastic liner. All package materials shall be chemically compatible. Radiation will have no adverse effect on the carbon steel. The elastomer gasket will not degrade due to radiation because of the low LEUO dose rates (typical ~1 mrad/hr vs. typical elastomer 1E3 rad dose limit).

(h) All valves through which the package contents could escape will be protected against unauthorized operation.	NA	This packaging design has no valves.
(i) For transport by air *[this section NA]*—	NA	This packaging is not designed for air transport.

Open Head Drum Tested for Solids Only Application
FSS-TS-2004-0004, 1/07/2004

OPEN HEAD DRUM

STEP 1 Ensure the gasket is properly fitted in lid groove. (Fig.1 &2)

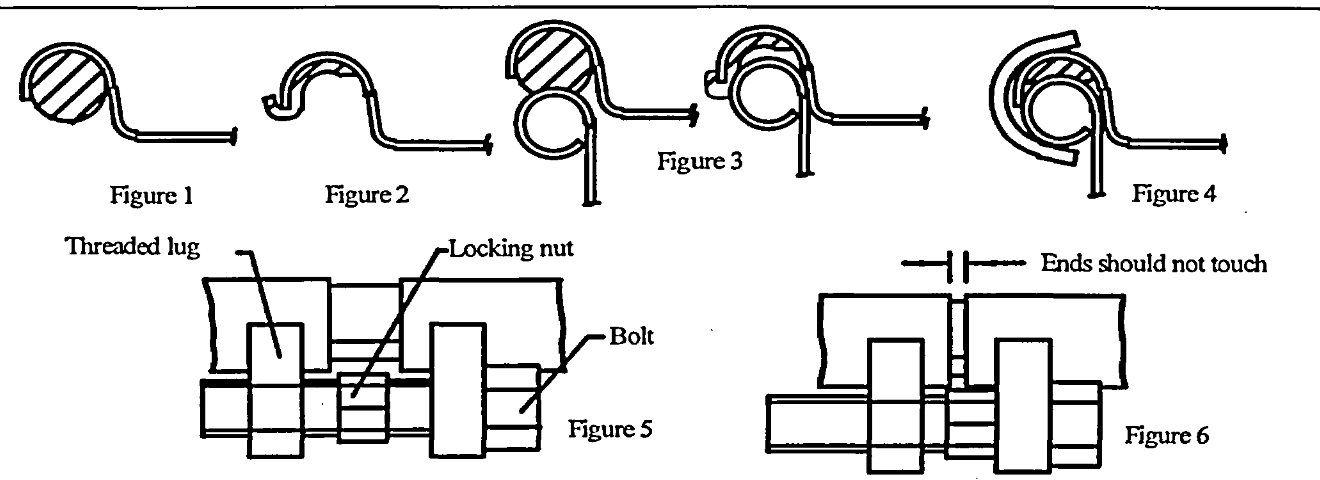
STEP 2 Position lid onto drum curl. (Fig.3) being careful to seat gasket around bead

STEP 3 Align bolt closure ring onto drum. Ensure the inner channel engages periphery of the entire drum cover. (Fig.4)

STEP 4 Insert bolt through ring unthreaded lug with bored end. Screw bolt into locking nut, then into threaded ring lug. (Fig.5)

STEP 5 Tighten bolt while tapping ring until a gap of 1" is achieved. The 1" gap is an indicator that the ring has been properly seated and the remainder of the closing process may be initiated. Torque until a minimum torque of 25 ft. lbs. (as in Fig. 6) is achieved noting that the ring ends should not touch.

STEP 6 For previously closed drums with ring ends that touch, complete steps 6A & 6B to ensure ring is tight and uniformly installed. A. Ensure ring does not rotate on drum by tapping end of ring bolt with rubber mallet. If ring rotates go to step 6C. B. Inspect ring/lid for uniformity.. The distance from top of drum lid to ring should not vary by more than 1/16". If ring/lid is not aligned, go to step 6C. C. Remove ring, cut approximately 1/8" from end of ring and go to STEP 3 above to reinstall and tighten ring.



Please contact CTF in WSRC Transportation Services with questions regarding this information.
Revised January 7, 2004 by WSRC Transportation Services

Erich Opperman/WSRC/Srs
01/29/04 10:33 AM

To Gwen Lynch/WSRC/Srs@Srs
cc Ken Stephens
bcc
Subject FSS-TS-2004-0001, LEU IP-1 Materials Compliance (U)

Gwen - please print this transmittal and place in our group correspondence file under the number/title above.

Thanks,

Erich
----- Forwarded by Erich Opperman/WSRC/Srs on 01/29/04 10:30 AM -----

Eric Skidmore/WSRC/Srs
12/19/03 10:05 AM

To Erich Opperman/WSRC/Srs@Srs
cc
Subject LEU oxide drums (U)

Erich,

Based on the visual examination we made together in 221-21F and Richard Redd's input on the gasket material/drum condition, MTS recommends that the subject LEU oxide drums (galvanized) are suitable for movement and transportation. The drums examined appear to be in excellent condition with no external signs of significant corrosion or even direct moisture exposure. The bottom of the drums were not directly examined, but there was no evidence of corrosion product (white or reddish/brown) at the base of the drums or on the exposed concrete where drums had previously sat.

As previously discussed, the composition and properties of the drum gasket are unknown. For this application, one of several materials could have been used. However, based on the nature of the material being stored (solid oxide/powder), storage conditions and condition of the drum (dry/no external corrosion), and the observations by others (gaskets exhibited elasticity and recovery after long-term compression, no evidence of deterioration or chemical attack), the existing gaskets are considered suitable for transportation purposes. The gaskets have remained out of direct exposure to solar heating, UV radiation, ozone, and other environmental factors that would otherwise degrade the material.

Let me know if you need a more formal response or if additional assistance is required.

Eric Skidmore
Westinghouse Savannah River Company
SRTC/Materials NDE & Consultation Group
Phone: 803-725-2236
FAX: 803-725-1744
----- Forwarded by Eric Skidmore/WSRC/Srs on 12/19/03 09:51 AM -----

Eric Skidmore

To: Erich Opperman/WSRC/Srs
cc:
Subject: Re: Fw: Answers to THE Questions

12/09/03 06:20 AM

See you around 9:00 this morning.

Eric Skidmore
Westinghouse Savannah River Company
SRTC/Materials NDE & Consultation Group
Phone: 803-725-2236
FAX: 803-725-1744
Erich Opperman

Erich Opperman
To: Eric Skidmore/WSRC/Srs@Srs
cc: Richard Redd/WSRC/Srs@Srs
Subject: Fw: Answers to THE Questions

12/05/03 11:45 AM

Eric - answers the questions you asked in your 12/02 LEU drum e-mail are given below.

I would suggest we go and look at the drums next week - and then hopefully, draw some conclusions on the drum integrity and narrow down the gasket material.

I could pick you up at **09:00 next Tuesday (12/09)** & we can go out to F-Area.

Let me know,

Erich

----- Forwarded by Erich Opperman/WSRC/Srs on 12/05/03 11:25 AM -----

Richard Redd
To: Erich Opperman/WSRC/Srs@Srs
cc: Donald Mcwhorter/WSRC/Srs@Srs
Subject: Answers to THE Questions

12/04/03 04:26 PM

1. Do they remain at the compressed thickness upon load removal?
No, they did expand some during the time the lid was off. The gasket was not brittle and did have some elasticity.

2. Were there any stains observed on or near the gasket, or on any visible interior drum surface?
May be a few specks, but no large or obvious, glaring spots were noted.

3. Moisture?
There were no obvious signs of moisture on the lids or on the interior of the liner that could be seen.

4. Do the drum bottoms appear corroded?

The bottoms of the drums showed no corrosion (red rust). They were dusty from what appeared to be dirt from the floor. The concrete where the drums sat showed signs of moisture, but no droplet patterns were evident on the drum bottoms.

Richard D. Redd
952-4267
pager# 17991

Project	Calculation Number	Project Number
N/A	N-CLC-F-00695	N/A
Title Arrays of UO_3 Drums	Functional Classification SS	Page 1 of 27
	Discipline Nuclear	

☐ Preliminary ☒ Confirmed

Computer Program No.	Version/Release No.
MCNP	4C

Purpose and Objective

Calculate the reactivity of arrays of UO_3-containing drums, with various degrees of internal and interstitial moderation.

Summary of Conclusion

The results confirm that the reactivity of optimally moderated drums is decreased by interstitial water and by increased surface-to-surface spacing. All of the cases requested in Reference 1 are shown to be safely subcritical.

	Revisions
Rev No.	Revision Description
0	Initial issue
1	Revise to address NRC question considering higher uranium enrichment

Sign Off (signatures of previous revision on file)

Rev No.	Originator (Print) Sign/Date	Verification/Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
1	Original signed by: S. M. Revolinski 5/6/05	Document Review	Original signed by: L. M. Gundy 5/6/05	Original signed by: L. A. Hedlund 5/6/05

Design Authority – (Print) D. L. McWhorter	Signature - Original signed by: D. L. McWhorter	Date 5/6/05
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DISCLAIMER

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1.0 INTRODUCTION

Reference 1 requests that criticality calculations be performed for arrays of UO_3-containing drums, with varying degrees of internal and interstitial moderation, in order to support a Department of Transportation (DOT) exemption for the transport of drums containing Low-enriched Uranium Oxide (LEUO).

The calculations performed herein serve to supplement previous calculations involving the same LEUO material, modeled as optimally-moderated spheres reflected by water [9]. The calculations contained in Reference 9, in combination with the calculations contained herein, address hypothetical accident conditions to which the UO_3 drums may be subjected.

Revision 1 includes evaluation of drums containing 803 lbs of UO_3 at a ^{235}U enrichment of 1.098 wt. percent, and includes a 0.05 minimum subcritical margin within the k_{SAFE} derivation [10]. Revision 0 used the ENDF/B-VI cross-section library while this revision uses the ENDF/B-V cross-section library. The use of the ENDF/B-V library allows for the application of a more recent validation specifically targeted to low enriched ^{235}U systems.

2.0 REFERENCES

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4. *Software Quality Assurance Implementation Checklist for MCNP 4C*, WSMS-CRT-01-0101, August 2001.

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7. Walker, F. W., et al., *Chart of the Nuclides*, 14th Edition, General Electric Company, San Jose, CA, 1989.

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10. Isom, W. L., *Low Enriched Uranium Oxide Disposition Project Cost and Schedule Estimate for Nuclear Criticality Safety Calculations (U)*, CBU-FCP-2005-0101, Rev. 1, April 21, 2005.

11. *Guide for Validation of Nuclear Criticality Safety Calculation Methodology*, NUREG/CR-6698, January 2001.

3.0 INPUT

Per Reference 1, two different drum arrays are modeled. The first array contains five layers, with 24 drums in each layer, for a total of 120 drums. Each layer is a 4-5-6-5-4 triangular-pitch array. The second array is a 5 by 5 by 5 square-pitch array, for a total of 125 drums. For all arrays, at least 12" of water reflection is present at all external boundaries.

Per Reference 1, each drum of the modeled arrays contains 750 lb of UO_3, at an enrichment of 1.084 wt% ^{235}U, with 3 to 24 wt% water. The fissile solution in each drum is modeled as a cylinder filling the internal radius of the drum. In the drums in the top two layers of the arrays, the fissile solution cylinders are modeled at the bottoms of the drums. In the drums on the bottom two layers of the arrays, the fissile solution cylinders are modeled at the tops of the drums. In the drums in the middle layer of the arrays, the fissile solution cylinders are modeled in the middle of the drums. This configuration is not really achievable, but provides optimum interaction between drum layers of the arrays.

Additional configurations with drums containing 803 lb of UO_3, at an enrichment of 1.098 wt% ^{235}U, specified in Reference 10, are included in Section 5.2.

Each drum is modeled with an internal diameter of 55.88 cm, and an internal height of 83.82 cm [2]. The walls, tops, and bottoms of the drums are modeled as 16 gauge carbon steel (0.1519 cm thick) [1-2].

4.0 ANALYTICAL METHODS AND COMPUTATIONS

4.1 Nuclear Criticality Safety Codes

In performing the criticality calculations in this report, the MCNP 4C code is used [3]. MCNP is a general purpose Monte Carlo radiation transport code that numerically simulates neutron transport histories, using continuous energy cross-section libraries and general three-dimensional geometry. The MCNP code was developed, and is maintained, by the Los Alamos National Laboratory (LANL).

4.2 MCNP Code Bias, Statistical Uncertainty, and Acceptance Criteria

Results documented in this report are obtained from the MCNP 4C code, which is under configuration control on the Washington Safety Management Solutions Linux workstation cluster [4]. As recommended in Reference 5, k_{SAFE} will be determined from the following equations.

$k_{SAFE} = 1 + (\text{bias} - \text{bias uncertainty}) - \text{AOA Margin} - \text{MSM}$
$k_{be} = 1 + (\text{bias} - \text{bias uncertainty})$

where:

AOA	=	Area of Applicability
MSM	=	Minimum Subcritical Margin
k_{be}	=	Best estimate of the uppermost calculated neutron multiplication for which a system is not expected to be critical.

Rearranging the terms gives the following equation:

$k_{SAFE} = k_{be} - \text{AOA Margin} - \text{MSM}$

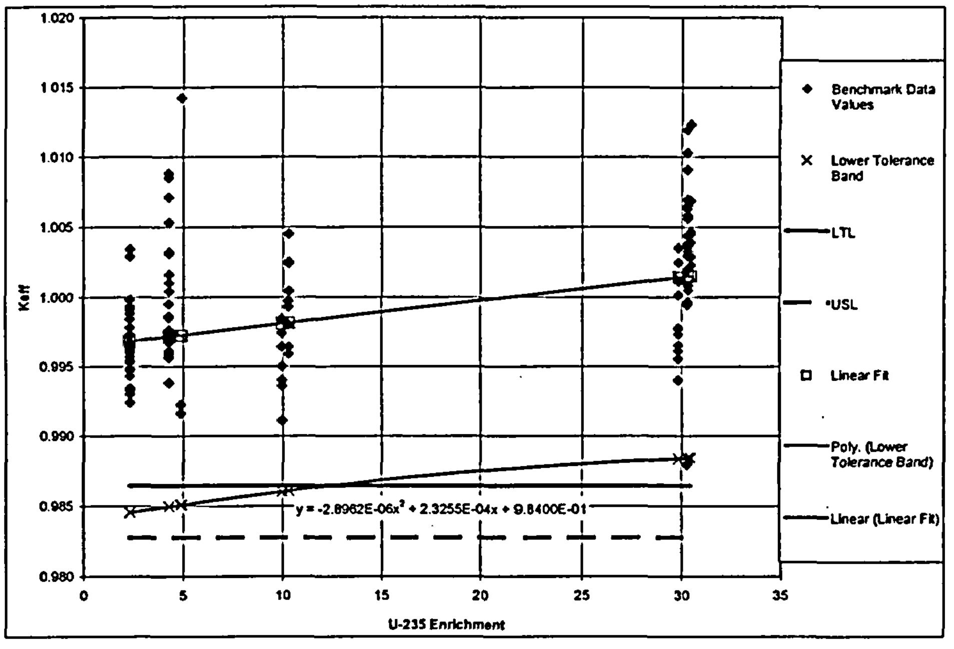
Calculated values of $k_{eff} + 2\sigma < k_{SAFE}$ will indicate configurations that are safely subcritical. Configurations with calculated $k_{eff} + 2\sigma \geq k_{SAFE}$ will be considered unacceptable. For this evaluation, σ is defined as the statistical uncertainty associated with the MCNP 4C calculations.

The MCNP code and cross section validation used herein was derived in Reference 6 using the Nuclear Regulatory Guidance (NRC) methodology specified in Reference 11[a]. Reference 6 provides k_{be} for uranium systems in which the enrichment is between 2 and 30 wt. % with MCNP 4C (ENDF/B-V cross-section library) as a Lower Tolerance Limit (LTL) of 0.986. However, the uranium systems modeled herein have enrichments as low as 1.084 wt. % ^{235}U. While the LTL is the recommended expression of the bias and bias uncertainty, Reference 6 includes a discussion of the trend in the bias and bias uncertainty as a function of ^{235}U enrichment. The calculated Lower Tolerance Band (LTB) from the fit to the k_{eff} vs. ^{235}U trend

[a] References 5 and 11 specify identical validation methodology , which are consistent with slight differences in terminology.

was not recommended [6] because of the absence of experimental data with ^{235}U enrichments between 10 and 30 wt. %. However, for the application herein, the LTB is conservative relative to the LTL and there are sufficient data near the region of interest. Figure 1 is copied from Reference 6 and shows the relationship between the LTL and LTB for this data.

Figure 1, MCNP 4C ENDF/B-V LEU / IEU k_{be} [6]



The equation for the LTB is shown on Figure 1 [6]:

$$k_{be} = -2.8962E\text{-}06 * x^2 + 2.3255E\text{-}04 * x + 9.8400E\text{-}01,$$

where x is the ^{235}U enrichment. For an ^{235}U enrichment of 1.084 wt. % the value of k_{be} = 0.9840. Note that extension of the LTB beyond the range of experiments is permitted [6,11].

An Area of Applicability (AOA) comparison was performed in Table 1, between the benchmark experiments documented in Reference 6 and the modeled $LEUO_3$ configurations. Specifications for the comparison provided in Table 1 were extracted from Section 4.1 of Reference 4.

Table 1: Area of Applicability

Parameter	Reference 6	Present System
Fissile Material	UO_2 rods, UO_2F_2, uranyl nitrate solutions, and UF4-polytetrafluoroethylene cubes	UO_3
Enrichment	2 – 30 wt% ^{235}U	1.084 – 1.098 wt% ^{235}U
Moderator	water ($H/^{235}U$): 75 to 1400	water ($H/^{235}U$): ~90 to 900
Reflector	steel, lead, water, paraffin, or none	water
Geometry	thin rod lattices, spheres, cylinders, and cubes	cylinders
Neutron Spectrum	intermediate to thermal	intermediate to thermal

From Table 1, the key parameters defining the analyses documented herein are all within the AOA of the Reference 6 analyses, with the exception of enrichment and fissile material. In terms of enrichment, the modeled system is slightly outside the benchmark system on the lower end; however, the use of the LTB allows for extension into the modeled range. Therefore, no AOA margin is required for this parameter.

In terms of the fissile material, the Reference 6 analyses model a wide variety of LEU compounds including UO_2, while the analyses herein model UO_3. Since MCNP does not model a specific chemical formula (but rather the individual nuclei), the inclusion of UO_2 in the Reference 6 analyses is judged to adequately represent the UO_3 modeled herein. Therefore, no AOA margin is required for this parameter.

Using the MSM value of 0.05[b] with the bias discussed above results in a k_{SAFE} of 0.934.

4.3 Material Cards and Cross-section Libraries

In performing the calculations presented herein, the ENDF/B-V default cross-sections supplied with MCNP 4C are used exclusively.

The fissile solutions in these analyses are modeled as mixtures of UO_3 and water, at varying $H/^{235}U$ ratios. In calculating specific mixtures, the maximum theoretical density of UO_3 (7.29 g/cm^3 [1]) is employed, and the mass density of water is assumed to be 1.0 g/cm^3. The isotopic composition of the uranium is assumed to be 1.084 wt% ^{235}U and 98.916 wt% ^{238}U, or 1.098 wt% ^{235}U and 98.902 wt% ^{238}U. Thermal scattering from hydrogen in these mixtures is modeled with the 300 K light water $S(\alpha,\beta)$ table (lwtr.01t).

Carbon steel is modeled using the data provided in References 7 and 8. The mass density of the steel is assumed to be 7.82 g/cm^3 [8].

[b] As noted in Reference 10, Nuclear Regulatory Commission reviewers requested the use of MSM=0.05.

Light water is modeled assuming a mass density of 1.0 g/cm^3. Thermal scattering from hydrogen is modeled with the 300 K light water S(α,β) table (lwtr.01t).

5.0 RESULTS

5.1 Scoping Calculations for Typical UO_3 Drums to Determine Most Reactive Drum-to-Drum Spacing and Interstitial Water Density

This section contains the results for the configurations identified in Reference 1. Each drum contains 750 lb of UO_3, at an enrichment of 1.084 wt% ^{235}U, with 3 to 24 wt% water.

5.1.1 Triangular-pitch Arrays

In this section, triangular-pitch arrays are modeled, as described in Section 3.0. Seven different water contents are modeled for the drums: 3, 6, 12, 15, 18, 21, and 24 wt% water. For each water content, at least six cases are executed. The first three cases model the drum array at surface-to-surface (S/S) separations of 0, 2, and 4 cm, with no interstitial water modeled. The second three cases model the most reactive spacing determined from the first three cases[c], with 10, 20, and 100 wt% interstitial water. Additional cases are executed as deemed necessary. A representative model is depicted in Figures 1 and 2, and the results are presented in Tables 2 through 8. Note that the "Problem #" column in the tables refers to the task description in Reference 1.

Figure 1: Triangular-pitch Array Top View (12 wt% water, 2 cm S/S, no interstitial H_2O)

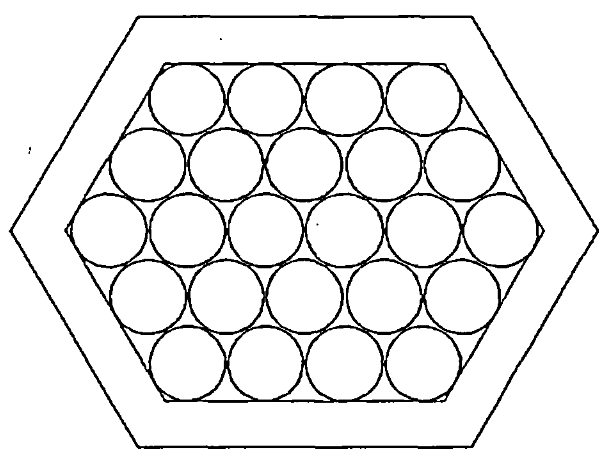


Figure 2: Triangular-pitch Array Side View (12 wt% water, 2 cm S/S, no interstitial H_2O)

[c] It is expected that the most reactive spacing will always be when the drums are touching, since increasing the spacing of an array without interstitial moderation can only increase neutron leakage.

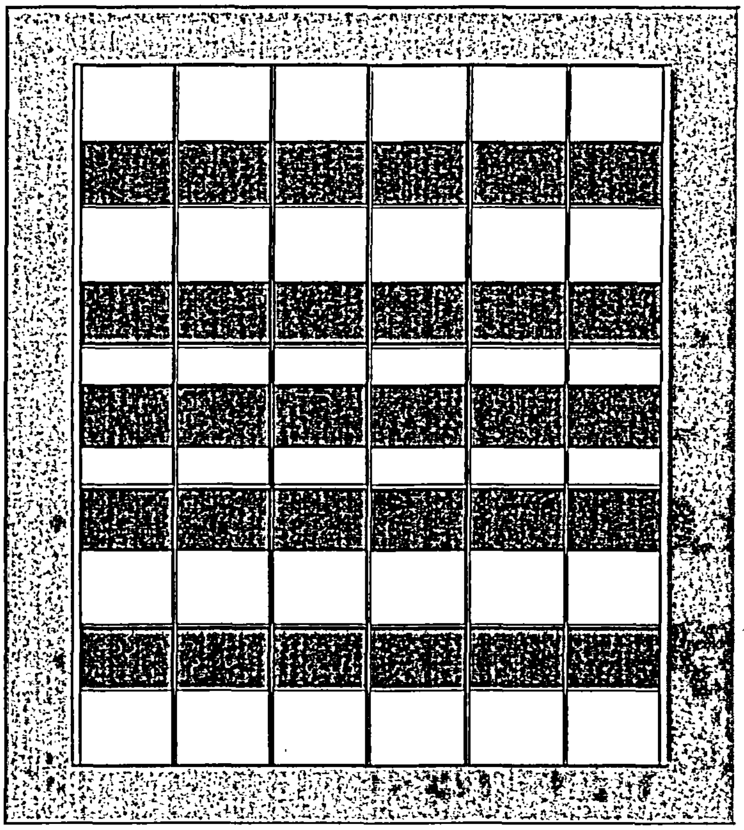


Table 2: Triangular-pitch Array, 3 wt% Water in Drums ($\rho = 6.1328$ g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
1	anl001	0%	0	0.645	0.0005
2	anl002	0%	2	0.634	0.0005
3	anl003	0%	4	0.624	0.0005
4	anl004	100%	0	0.687	0.0005
5	anl005	10%	0	0.666	0.0005
6	anl006	20%	0	0.684	0.0005
N/A	anl100	60%	0	0.686	0.0005

Table 3: Triangular-pitch Array, 6 wt% Water in Drums (ρ = 5.2926 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
7	anl007	0%	0	0.792	0.0005
8	anl008	0%	2	0.781	0.0005
9	anl009	0%	4	0.770	0.0005
10	anl010	100%	0	0.783	0.0005
11	anl011	10%	0	0.801	0.0005
12	anl012	20%	0	0.781	0.0005
N/A	anl101	60%	0	0.783	0.0005

Table 4: Triangular-pitch Array, 12 wt% Water in Drums (ρ = 4.1543 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
13	anl013	0%	0	0.904	0.0005
14	anl014	0%	2	0.896	0.0005
15	anl015	0%	4	0.888	0.0005
16	anl016	100%	0	0.871	0.0005
17	anl017	10%	0	0.905	0.0005
18	anl018	20%	0	0.872	0.0005

Table 5: Triangular-pitch Array, 15 wt% Water in Drums (ρ = 3.7510 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
31	anl031	0%	0	0.920	0.0005
32	anl032	0%	2	0.913	0.0005
33	anl033	0%	4	0.904	0.0005
34	anl034	100%	0	0.884	0.0005
35	anl035	10%	0	0.920	0.0005
36	anl036	20%	0	0.883	0.0005

Table 6: Triangular-pitch Array, 18 wt% Water in Drums (ρ = 3.4190 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
19	anl019	0%	0	0.922	0.0005
20	anl020	0%	2	0.915	0.0005
21	anl021	0%	4	0.908	0.0005
22	anl022	100%	0	0.886	0.0005
23	anl023	10%	0	0.921	0.0005
24	anl024	20%	0	0.884	0.0005

Table 7: Triangular-pitch Array, 21 wt% Water in Drums (ρ = 3.1410 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
N/A	anl111	0%	0	0.914	0.0004
N/A	anl112	0%	2	0.910	0.0005
N/A	anl113	0%	4	0.903	0.0005
N/A	anl114	100%	0	0.876	0.0005
N/A	anl115	10%	0	0.914	0.0004
N/A	anl116	20%	0	0.878	0.0005

Table 8: Triangular-pitch Array, 24 wt% Water in Drums (ρ = 2.9048 g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
25	anl025	0%	0	0.899	0.0004
26	anl026	0%	2	0.894	0.0004
27	anl027	0%	4	0.890	0.0004
28	anl028	100%	0	0.863	0.0004
29	anl029	10%	0	0.898	0.0004
30	anl030	20%	0	0.863	0.0004

5.1.2 Square-pitch Arrays

In this section, square-pitch arrays are modeled, as described in Section 3.0. Four cases are executed for the most reactive water content calculated in Section 5.1 (18 wt% water). The first two cases model the drum array at surface-to-surface (S/S) separations of 0 and 2 cm, with no interstitial water modeled. The second two cases model the most reactive spacing determined from the first two cases, with 10 and 20 wt% interstitial water. A representative model is depicted in Figure 3, and the results are presented in Table 9.

Figure 3: Square-pitch Array Top View (18 wt% water, 2 cm S/S, no interstitial H_2O)

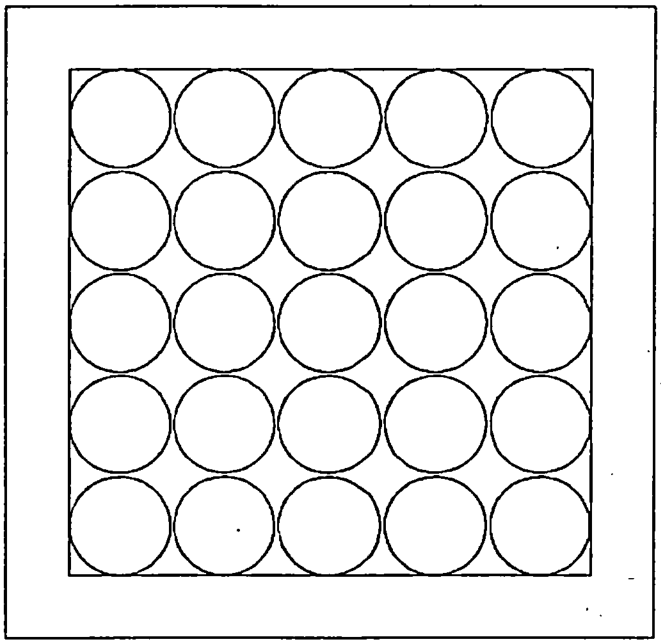


Table 9: Square-pitch Array, 18 wt% Water in Drums ($\rho = 3.4190\ g/cm^3$)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
37	anl037	0%	0	0.912	0.0005
38	anl038	0%	2	0.906	0.0005
39	anl039	10%	0	0.910	0.0005
40	anl040	20%	0	0.901	0.0005

5.2 Maximally Enriched and Maximally Loaded UO_3 Drums at Most Reactive Spacing and Interstitial Water Density

This section contains the results for the configurations identified in Reference 10. Each drum contains 803 lb of UO_3, at an enrichment of 1.098 wt% ^{235}U, with 12 to 21 wt% water. The purpose of this section is to recalculate the most reactive case from Tables 4, 5, 6, and 7 using the higher mass of UO_3 per drum and higher enrichment.

5.2.1 Triangular-pitch Arrays

In this section, triangular-pitch arrays are modeled, as described in Section 3.0. Four different water contents are modeled for the drums: 12, 15, 18, and 21 wt% water. For each water content, two cases are executed. The first case models the drum array at zero surface-to-surface separation with no interstitial water modeled. The second case models the drum array at zero surface-to-surface separation with 10 wt% interstitial water. The results are presented in Table 10.

Table 10: Triangular-pitch Array

Problem #	Case	Internal Water Density	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
N/A	anl120	12%	0%	0	0.916	0.0005
N/A	anl121	12%	10%	0	0.918	0.0005
N/A	anl122	15%	0%	0	0.931	0.0005
N/A	anl123	15%	10%	0	0.931	0.0005
N/A	anl124	18%	0%	0	0.931	0.0005
N/A	anl125	18%	10%	0	0.930	0.0005
N/A	anl126	21%	0%	0	0.925	0.0005
N/A	anl127	21%	10%	0	0.922	0.0004

5.2.2 Square-pitch Arrays

In this section, square-pitch arrays are modeled, as described in Section 3.0. Two cases are executed for the most reactive water content calculated in Section 5.1 (18 wt% water). The first case models the drum array at zero surface-to-surface separations with no interstitial water. The second case models the drum array at zero surface-to-surface separations with 10 wt% interstitial water. The results are presented in Table 11.

Table 11: Square-pitch Array

Problem #	Case	Internal Water Density	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
N/A	anl128	18%	0%	0	0.923	0.0005
N/A	anl129	18%	10%	0	0.922	0.0005

6.0 CONCLUSIONS

The triangular-pitch array calculations presented in Section 5.1.1 demonstrate, for cases with 750 lbs UO_3 per drum, 1.084 wt% ^{235}U, and no interstitial water, that the reactivity of the modeled arrays decreased when the spacing between the drums increased. In addition, for cases with no interstitial water, reactivity was maximized at a water content of 18 wt% in the drums ($H/^{235}U$ = 635). At this water content, interstitial water at the modeled densities (10, 20, and 100%) decreased the reactivity of the array.

Therefore, the maximum adjusted k_{EFF} ($k_{eff} + 2\sigma$) calculated in Section 5.1.1 (0.923 for case anl019) is for an array with the drums in physical contact, with no interstitial water, and with a water content of 18 wt% in the drums. Since this maximum adjusted k_{EFF} is below k_{SAFE}, the array configurations modeled in Section 5.1.1 are safely subcritical.

The square-pitch array calculations presented in Section 5.1.2 demonstrate that the square-pitch array with 750 lbs UO_3 per drum, 1.084 wt% ^{235}U is less reactive than the triangular-pitch array, at a water content of 18 wt%. In addition, for a water content of 18 wt%, the results demonstrate that the square-pitch array behaves similarly to the triangular-pitch array: increasing the array spacing or adding interstitial water both decrease array reactivity.

For the maximally enriched (1.098 wt% ^{235}U) and mass loaded (803 lbs UO_3 per drum) cases in Section 5.2, the triangular pitch cases containing 15 and 18 wt% water (for both 0 and 10 wt% interstitial water) were all equivalent within the calculational uncertainty. The maximum adjusted k_{EFF} calculated in Section 5.2.1 is 0.932 for case anl123. The square pitch arrays in Section 5.2.2 were slightly less. Consequently, the array sizes modeled (see Section 3.0) are safe for up to 803 lb of UO3 per drum and up to 1.098 wt% ^{235}U with optimum water moderation and reflection.

7.0 ATTACHMENTS AND APPENDICES

Numerous MCNP cases are executed as part of this engineering calculation. However, these cases are represented in this attachment by a subset of MCNP models, with all other cases requiring only minor modifications of the models in this subset.

Case *anl001* (Problem 1, 3 wt% water, no interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -6.1328         -100      -110            u=1  imp:n=1
102   0                   -100  110                 u=1  imp:n=1
103   2   -7.82       100                           u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -6.1328         -100  111 -112            u=2  imp:n=1
111   0                   -100      -111            u=2  imp:n=1
112   0                   -100  112                 u=2  imp:n=1
113   2   -7.82       100                           u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -6.1328         -100  113                 u=3  imp:n=1
121   0                   -100      -113            u=3  imp:n=1
123   2   -7.82       100                           u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                         fill=3  u=4  imp:n=1
201   0     -101        trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202   0     -101        trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                u=4  imp:n=1
c     Center Row
210   0     -150  trcl=(-140.4845 0 0)        fill=4 u=5 imp:n=1
211   0     -150  trcl=( -84.2907 0 0)        fill=4 u=5 imp:n=1
212   0     -150  trcl=( -28.0969 0 0)        fill=4 u=5 imp:n=1
213   0     -150  trcl=(  28.0969 0 0)        fill=4 u=5 imp:n=1
214   0     -150  trcl=(  84.2907 0 0)        fill=4 u=5 imp:n=1
215   0     -150  trcl=( 140.4845 0 0)        fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
```

```
          #240 #241 #242 #243
          #250 #251 #252 #253
                                                    u=5 imp:n=1
301   0     -200:-201                        fill=5 u=9 imp:n=1
302   3 -1.0   #301                                 u=9 imp:n=1

303   0     -300:-301                        fill=9     imp:n=1
999   0     #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  23.4702                     $ bottom fuel
111   pz  30.4027                     $ middle fuel
112   pz  53.7211                     $ middle fuel
113   pz  60.6536                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.50c  -3.3568E-03
      92235.50c  -8.7502E-03
      92238.50c  -7.9847E-01
       8016.50c  -1.8942E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl008* (Problem 8, 6 wt% water, no interstitial water, triangular pitch, S/S = 2 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -5.2926         -100      -110              u=1  imp:n=1
102   0                   -100  110                   u=1  imp:n=1
103   2   -7.82        100                            u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -5.2926         -100  111 -112              u=2  imp:n=1
111   0                   -100      -111              u=2  imp:n=1
112   0                   -100  112                   u=2  imp:n=1
113   2   -7.82        100                            u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -5.2926         -100  113                   u=3  imp:n=1
121   0                   -100      -113              u=3  imp:n=1
123   2   -7.82        100                            u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                            fill=3  u=4  imp:n=1
201   0     -101        trcl=(0 0  86.1238) fill=3  u=4  imp:n=1
202   0     -101        trcl=(0 0 172.2476) fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 258.3714) fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 344.4952) fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                u=4  imp:n=1
c
```

```
c     Center Row
210   0      -150  trcl=(-145.4595 0 0)         fill=4 u=5 imp:n=1
211   0      -150  trcl=( -87.2757 0 0)         fill=4 u=5 imp:n=1
212   0      -150  trcl=( -29.0919 0 0)         fill=4 u=5 imp:n=1
213   0      -150  trcl=(  29.0919 0 0)         fill=4 u=5 imp:n=1
214   0      -150  trcl=(  87.2757 0 0)         fill=4 u=5 imp:n=1
215   0      -150  trcl=( 145.4595 0 0)         fill=4 u=5 imp:n=1
c     One Up
220   0      -150  trcl=(-116.3676  50.3886 0)  fill=4 u=5 imp:n=1
221   0      -150  trcl=( -58.1838  50.3886 0)  fill=4 u=5 imp:n=1
222   0      -150  trcl=(   0.0000  50.3886 0)  fill=4 u=5 imp:n=1
223   0      -150  trcl=(  58.1838  50.3886 0)  fill=4 u=5 imp:n=1
224   0      -150  trcl=( 116.3676  50.3886 0)  fill=4 u=5 imp:n=1
c     One Down
230   0      -150  trcl=(-116.3676 -50.3886 0)  fill=4 u=5 imp:n=1
231   0      -150  trcl=( -58.1838 -50.3886 0)  fill=4 u=5 imp:n=1
232   0      -150  trcl=(   0.0000 -50.3886 0)  fill=4 u=5 imp:n=1
233   0      -150  trcl=(  58.1838 -50.3886 0)  fill=4 u=5 imp:n=1
234   0      -150  trcl=( 116.3676 -50.3886 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0      -150  trcl=( -87.2757  100.7773 0)   fill=4 u=5 imp:n=1
241   0      -150  trcl=( -29.0919  100.7773 0)   fill=4 u=5 imp:n=1
242   0      -150  trcl=(  29.0919  100.7773 0)   fill=4 u=5 imp:n=1
243   0      -150  trcl=(  87.2757  100.7773 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0      -150  trcl=( -87.2757 -100.7773 0)   fill=4 u=5 imp:n=1
251   0      -150  trcl=( -29.0919 -100.7773 0)   fill=4 u=5 imp:n=1
252   0      -150  trcl=(  29.0919 -100.7773 0)   fill=4 u=5 imp:n=1
253   0      -150  trcl=(  87.2757 -100.7773 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
            #240 #241 #242 #243
            #250 #251 #252 #253
                                                       u=5 imp:n=1
301   0     -200:-201                           fill=5 u=9 imp:n=1
302   3 -1.0   #301                                    u=9 imp:n=1
303   0      -300:-301                          fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  28.0342                     $ bottom fuel
111   pz  28.1207                     $ middle fuel
112   pz  56.0031                     $ middle fuel
113   pz  56.0896                     $ top fuel
150   rcc 0 0 -0.001 0 0 428.6210 28.0929
c     Drum Boundaries
200   rhp -29.0919 0 -0.002 0 0 428.6230 0 128.8702 0
201   rhp  29.0919 0 -0.002 0 0 428.6230 0 128.8702 0
c     Reflector
300   rhp -29.0919 0 -35 0 0 499 0 163.8702 0
301   rhp  29.0919 0 -35 0 0 499 0 163.8702 0

c     Fissile Solution
m1     1001.50c  -6.7137E-03
      92235.50c  -8.4796E-03
      92238.50c  -7.7377E-01
       8016.50c  -2.1103E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
```

```
prdmp   3j 2
```

Case *anl015* (Problem 15, 12 wt% water, no interstitial water, triangular pitch, S/S = 4 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -4.1543         -100       -110             u=1  imp:n=1
102   0                   -100  110                   u=1  imp:n=1
103   2   -7.82       100                             u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -4.1543         -100  111 -112              u=2  imp:n=1
111   0                   -100      -111              u=2  imp:n=1
112   0                   -100  112                   u=2  imp:n=1
113   2   -7.82       100                             u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -4.1543         -100  113                   u=3  imp:n=1
121   0                   -100      -113              u=3  imp:n=1
123   2   -7.82       100                             u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                          fill=3  u=4  imp:n=1
201   0     -101        trcl=(0 0  88.1238)  fill=3  u=4  imp:n=1
202   0     -101        trcl=(0 0 176.2476)  fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 264.3714)  fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 352.4952)  fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                u=4  imp:n=1
c
c     Center Row
210   0     -150  trcl=(-150.4595 0 0)        fill=4 u=5 imp:n=1
211   0     -150  trcl=( -90.2757 0 0)        fill=4 u=5 imp:n=1
212   0     -150  trcl=( -30.0919 0 0)        fill=4 u=5 imp:n=1
213   0     -150  trcl=(  30.0919 0 0)        fill=4 u=5 imp:n=1
214   0     -150  trcl=(  90.2757 0 0)        fill=4 u=5 imp:n=1
215   0     -150  trcl=( 150.4595 0 0)        fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-120.3676  52.1207 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -60.1838  52.1207 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  52.1207 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  60.1838  52.1207 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 120.3676  52.1207 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-120.3676 -52.1207 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -60.1838 -52.1207 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -52.1207 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  60.1838 -52.1207 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 120.3676 -52.1207 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=( -90.2757  104.2414 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=( -30.0919  104.2414 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=(  30.0919  104.2414 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=(  90.2757  104.2414 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=( -90.2757 -104.2414 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=( -30.0919 -104.2414 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=(  30.0919 -104.2414 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=(  90.2757 -104.2414 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
            #240 #241 #242 #243
            #250 #251 #252 #253
                                                 u=5 imp:n=1
301   0      -200:-201                    fill=5 u=9 imp:n=1
302   3 -1.0    #301                             u=9 imp:n=1
303   0      -300:-301                    fill=9     imp:n=1
999   0     #303 imp:n=0
```

```
100    rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101    rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110    pz  38.0958                     $ bottom fuel
111    pz  23.0900                     $ middle fuel
112    pz  61.0338                     $ middle fuel
113    pz  46.0280                     $ top fuel
150    rcc 0 0 -0.001 0 0 436.6210 28.0929
c      Drum Boundaries
200    rhp -30.0919 0 -0.002 0 0 436.6230 0 132.3343 0
201    rhp  30.0919 0 -0.002 0 0 436.6230 0 132.3343 0
c      Reflector
300    rhp -30.0919 0 -35 0 0 507 0 167.3343 0
301    rhp  30.0919 0 -35 0 0 507 0 167.3343 0

c      Fissile Solution
m1      1001.50c  -1.3427E-02
       92235.50c  -7.9384E-03
       92238.50c  -7.2438E-01
        8016.50c  -2.5425E-01
mt1     lwtr.01t
c      Carbon Steel
m2     26000.50c  -0.95000
        6000.50c  -0.00500
c      Water
m3      1001.50c   2.0
        8016.50c   1.0
mt3     lwtr.01t
mode   n
totnu
kcode 2000 1.0 100 700
ksrc  -30 0 218 30 0 218
print 128
prdmp   3j 2
```

Case *anl022* (Problem 22, 18 wt% water, 100% interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1   -3.4190         -100      -110                u=1  imp:n=1
102    0                   -100  110                     u=1  imp:n=1
103    2   -7.82       100                               u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -3.4190         -100  111 -112                u=2  imp:n=1
111    0                   -100      -111                u=2  imp:n=1
112    0                   -100  112                     u=2  imp:n=1
113    2   -7.82       100                               u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -3.4190         -100  113                     u=3  imp:n=1
121    0                   -100      -113                u=3  imp:n=1
123    2   -7.82       100                               u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                              fill=3  u=4  imp:n=1
201    0     -101        trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202    0     -101        trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203    0     -101        trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204    0     -101        trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205    3 -1.0 #200 #201 #202 #203 #204                 u=4  imp:n=1
C      Center Row
210    0     -150  trcl=(-140.4845 0 0)          fill=4 u=5 imp:n=1
211    0     -150  trcl=( -84.2907 0 0)          fill=4 u=5 imp:n=1
212    0     -150  trcl=( -28.0969 0 0)          fill=4 u=5 imp:n=1
213    0     -150  trcl=(  28.0969 0 0)          fill=4 u=5 imp:n=1
214    0     -150  trcl=(  84.2907 0 0)          fill=4 u=5 imp:n=1
215    0     -150  trcl=( 140.4845 0 0)          fill=4 u=5 imp:n=1
c      One Up
220    0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221    0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
```

```
222   0      -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0      -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0      -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0      -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0      -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0      -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0      -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0      -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0      -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0      -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0      -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0      -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0      -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0      -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0      -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0      -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   3 -1.0    #210 #211 #212 #213 #214 #215
           #220 #221 #222 #223 #224
           #230 #231 #232 #233 #234
           #240 #241 #242 #243
           #250 #251 #252 #253
                                                       u=5 imp:n=1
301   0      -200:-201                          fill=5 u=9 imp:n=1
302   3 -1.0    #301                                   u=9 imp:n=1
303   0      -300:-301                          fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  49.6298                     $ bottom fuel
111   pz  17.3230                     $ middle fuel
112   pz  66.8008                     $ middle fuel
113   pz  34.4940                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.50c  -2.0141E-02
      92235.50c  -7.3971E-03
      92238.50c  -6.7499E-01
       8016.50c  -2.9747E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl111* (21 wt% water, no interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -3.1410         -100      -110              u=1  imp:n=1
```

```
102   0                   -100  110                      u=1  imp:n=1
103   2   -7.82       100                                u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -3.1410         -100  111 -112                 u=2  imp:n=1
111   0                   -100      -111                 u=2  imp:n=1
112   0                   -100  112                      u=2  imp:n=1
113   2   -7.82       100                                u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -3.1410         -100  113                      u=3  imp:n=1
121   0                   -100      -113                 u=3  imp:n=1
123   2   -7.82       100                                u=3  imp:n=1
c
c     Stack of Five Drums
200   0      -101                             fill=3  u=4  imp:n=1
201   0      -101        trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202   0      -101        trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203   0      -101        trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204   0      -101        trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205   0      #200 #201 #202 #203 #204                 u=4  imp:n=1
C     Center Row
210   0      -150  trcl=(-140.4845 0 0)          fill=4 u=5 imp:n=1
211   0      -150  trcl=( -84.2907 0 0)          fill=4 u=5 imp:n=1
212   0      -150  trcl=( -28.0969 0 0)          fill=4 u=5 imp:n=1
213   0      -150  trcl=(  28.0969 0 0)          fill=4 u=5 imp:n=1
214   0      -150  trcl=(  84.2907 0 0)          fill=4 u=5 imp:n=1
215   0      -150  trcl=( 140.4845 0 0)          fill=4 u=5 imp:n=1
c     One Up
220   0      -150  trcl=(-112.3876  48.6653 0)   fill=4 u=5 imp:n=1
221   0      -150  trcl=( -56.1938  48.6653 0)   fill=4 u=5 imp:n=1
222   0      -150  trcl=(   0.0000  48.6653 0)   fill=4 u=5 imp:n=1
223   0      -150  trcl=(  56.1938  48.6653 0)   fill=4 u=5 imp:n=1
224   0      -150  trcl=( 112.3876  48.6653 0)   fill=4 u=5 imp:n=1
c     One Down
230   0      -150  trcl=(-112.3876 -48.6653 0)   fill=4 u=5 imp:n=1
231   0      -150  trcl=( -56.1938 -48.6653 0)   fill=4 u=5 imp:n=1
232   0      -150  trcl=(   0.0000 -48.6653 0)   fill=4 u=5 imp:n=1
233   0      -150  trcl=(  56.1938 -48.6653 0)   fill=4 u=5 imp:n=1
234   0      -150  trcl=( 112.3876 -48.6653 0)   fill=4 u=5 imp:n=1
c     Two Up
240   0      -150  trcl=(-84.2907  97.3305 0)    fill=4 u=5 imp:n=1
241   0      -150  trcl=(-28.0969  97.3305 0)    fill=4 u=5 imp:n=1
242   0      -150  trcl=( 28.0969  97.3305 0)    fill=4 u=5 imp:n=1
243   0      -150  trcl=( 84.2907  97.3305 0)    fill=4 u=5 imp:n=1
c     Two Down
250   0      -150  trcl=(-84.2907 -97.3305 0)    fill=4 u=5 imp:n=1
251   0      -150  trcl=(-28.0969 -97.3305 0)    fill=4 u=5 imp:n=1
252   0      -150  trcl=( 28.0969 -97.3305 0)    fill=4 u=5 imp:n=1
253   0      -150  trcl=( 84.2907 -97.3305 0)    fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
            #240 #241 #242 #243
            #250 #251 #252 #253
                                                        u=5 imp:n=1
301   0      -200:-201                           fill=5 u=9 imp:n=1
302   3 -1.0    #301                                    u=9 imp:n=1

303   0      -300:-301                           fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  56.0537                     $ bottom fuel
111   pz  14.1110                     $ middle fuel
112   pz  70.0128                     $ middle fuel
113   pz  28.0701                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
```

```
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.50c  -2.3498E-02
      92235.50c  -7.1265E-03
      92238.50c  -6.5030E-01
       8016.50c  -3.1908E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl029* (Problem 29, 24 wt% water, 10% interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -2.9048         -100      -110              u=1  imp:n=1
102   0                   -100  110                   u=1  imp:n=1
103   2   -7.82       100                             u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -2.9048         -100  111 -112              u=2  imp:n=1
111   0                   -100      -111              u=2  imp:n=1
112   0                   -100  112                   u=2  imp:n=1
113   2   -7.82       100                             u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -2.9048         -100  113                   u=3  imp:n=1
121   0                   -100      -113              u=3  imp:n=1
123   2   -7.82       100                             u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                             fill=3  u=4  imp:n=1
201   0     -101         trcl=(0 0  84.1338) fill=3  u=4  imp:n=1
202   0     -101         trcl=(0 0 168.2676) fill=2  u=4  imp:n=1
203   0     -101         trcl=(0 0 252.4014) fill=1  u=4  imp:n=1
204   0     -101         trcl=(0 0 336.5352) fill=1  u=4  imp:n=1
205   3 -0.1 #200 #201 #202 #203 #204                u=4  imp:n=1
C     Center Row
210   0     -150  trcl=(-140.4845 0 0)         fill=4 u=5 imp:n=1
211   0     -150  trcl=( -84.2907 0 0)         fill=4 u=5 imp:n=1
212   0     -150  trcl=( -28.0969 0 0)         fill=4 u=5 imp:n=1
213   0     -150  trcl=(  28.0969 0 0)         fill=4 u=5 imp:n=1
214   0     -150  trcl=(  84.2907 0 0)         fill=4 u=5 imp:n=1
215   0     -150  trcl=( 140.4845 0 0)         fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
```

```
240   0     -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   3 -0.1    #210 #211 #212 #213 #214 #215
           #220 #221 #222 #223 #224
           #230 #231 #232 #233 #234
           #240 #241 #242 #243
           #250 #251 #252 #253
                                                      u=5 imp:n=1
301   0     -200:-201                          fill=5 u=9 imp:n=1
302   3 -1.0   #301                                   u=9 imp:n=1
303   0     -300:-301                          fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  62.9849                     $ bottom fuel
111   pz  10.6454                     $ middle fuel
112   pz  73.4784                     $ middle fuel
113   pz  21.1389                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.50c  -2.6855E-02
      92235.50c  -6.8559E-03
      92238.50c  -6.2560E-01
       8016.50c  -3.4069E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl037* (Problem 37, 18 wt% water, no interstitial water, square pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -3.4190         -100      -110            u=1  imp:n=1
102   0                   -100  110                 u=1  imp:n=1
103   2   -7.82       100                           u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -3.4190         -100  111 -112            u=2  imp:n=1
111   0                   -100      -111            u=2  imp:n=1
112   0                   -100  112                 u=2  imp:n=1
113   2   -7.82       100                           u=2  imp:n=1
c
c     Drum - Fuel in Top
```

```
120   1   -3.4190        -100  113                  u=3  imp:n=1
121   0                  -100      -113             u=3  imp:n=1
123   2   -7.82       100                           u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                            fill=3  u=4  imp:n=1
201   0     -101        trcl=(0 0  84.1338) fill=3  u=4  imp:n=1
202   0     -101        trcl=(0 0 168.2676) fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 252.4014) fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 336.5352) fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                u=4  imp:n=1
C     Center Row
210   0     -150  trcl=(-112.3876 0 0)        fill=4 u=5 imp:n=1
211   0     -150  trcl=( -56.1938 0 0)        fill=4 u=5 imp:n=1
212   0     -150  trcl=(   0.0000 0 0)        fill=4 u=5 imp:n=1
213   0     -150  trcl=(  56.1938 0 0)        fill=4 u=5 imp:n=1
214   0     -150  trcl=( 112.3876 0 0)        fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-112.3876  56.1938 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -56.1938  56.1938 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  56.1938 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  56.1938  56.1938 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 112.3876  56.1938 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -56.1938 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
c     Two Up

240   0     -150  trcl=(-112.3876  112.3876 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=( -56.1938  112.3876 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=(   0.0000  112.3876 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=(  56.1938  112.3876 0)   fill=4 u=5 imp:n=1
244   0     -150  trcl=( 112.3876  112.3876 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=(-112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=( -56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=(   0.0000 -112.3876 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=(  56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
254   0     -150  trcl=( 112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0    #210 #211 #212 #213 #214
           #220 #221 #222 #223 #224
           #230 #231 #232 #233 #234
           #240 #241 #242 #243 #244
           #250 #251 #252 #253 #254
                                               u=5 imp:n=1
301   0        -200                     fill=5 u=9 imp:n=1
302   3 -1.0    #301                           u=9 imp:n=1
303   0        -300                     fill=9     imp:n=1
999   0     #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  49.6298                     $ bottom fuel
111   pz  17.3230                     $ middle fuel
112   pz  66.8008                     $ middle fuel
113   pz  34.4940                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6610 28.0929
c     Drum Boundaries
200   rpp -140.4805 140.4805 -140.4805 140.4805 -0.002 420.6630
c     Reflector
300   rpp -176 176 -176 176 -35 456

c     Fissile Solution
m1     1001.50c  -2.0141E-02
      92235.50c  -7.3971E-03
      92238.50c  -6.7499E-01
       8016.50c  -2.9747E-01
mt1    lwtr.01t
c     Carbon Steel
```

```
m2     26000.50c  -0.95000
        6000.50c  -0.00500
c      Water
m3      1001.50c   2.0
        8016.50c   1.0
mt3     lwtr.01t
mode   n
totnu
kcode 2000 1.0 100 700
ksrc   0 0 210
print 128
prdmp    3j 2
```

Case *anl128* (Problem 37, 1.098 wt% U^{235}, 803 lbs UO_3 per drum, 18 wt% water, no interstitial water, square pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough; SMR 5/02/05
c  w/ 1.098 wt % U-235 and 803 lbs
c      Drum - Fuel in Bottom
100    1   -3.4190          -100      -110              u=1  imp:n=1
102    0                    -100  110                   u=1  imp:n=1
103    2   -7.82       100                              u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -3.4190          -100  111 -112              u=2  imp:n=1
111    0                    -100      -111              u=2  imp:n=1
112    0                    -100  112                   u=2  imp:n=1
113    2   -7.82       100                              u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -3.4190          -100  113                   u=3  imp:n=1
121    0                    -100      -113              u=3  imp:n=1
123    2   -7.82       100                              u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                             fill=3  u=4  imp:n=1
201    0     -101         trcl=(0 0  84.1338) fill=3  u=4  imp:n=1
202    0     -101         trcl=(0 0 168.2676) fill=2  u=4  imp:n=1
203    0     -101         trcl=(0 0 252.4014) fill=1  u=4  imp:n=1
204    0     -101         trcl=(0 0 336.5352) fill=1  u=4  imp:n=1
205    0     #200 #201 #202 #203 #204                 u=4  imp:n=1
C      Center Row
210    0     -150  trcl=(-112.3876 0 0)         fill=4 u=5 imp:n=1
211    0     -150  trcl=( -56.1938 0 0)         fill=4 u=5 imp:n=1
212    0     -150  trcl=(   0.0000 0 0)         fill=4 u=5 imp:n=1
213    0     -150  trcl=(  56.1938 0 0)         fill=4 u=5 imp:n=1
214    0     -150  trcl=( 112.3876 0 0)         fill=4 u=5 imp:n=1
c      One Up
220    0     -150  trcl=(-112.3876  56.1938 0)  fill=4 u=5 imp:n=1
221    0     -150  trcl=( -56.1938  56.1938 0)  fill=4 u=5 imp:n=1
222    0     -150  trcl=(   0.0000  56.1938 0)  fill=4 u=5 imp:n=1
223    0     -150  trcl=(  56.1938  56.1938 0)  fill=4 u=5 imp:n=1
224    0     -150  trcl=( 112.3876  56.1938 0)  fill=4 u=5 imp:n=1
c      One Down
230    0     -150  trcl=(-112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
231    0     -150  trcl=( -56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
232    0     -150  trcl=(   0.0000 -56.1938 0)  fill=4 u=5 imp:n=1
233    0     -150  trcl=(  56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
234    0     -150  trcl=( 112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
c      Two Up
240    0     -150  trcl=(-112.3876  112.3876 0)   fill=4 u=5 imp:n=1
241    0     -150  trcl=( -56.1938  112.3876 0)   fill=4 u=5 imp:n=1
242    0     -150  trcl=(   0.0000  112.3876 0)   fill=4 u=5 imp:n=1
243    0     -150  trcl=(  56.1938  112.3876 0)   fill=4 u=5 imp:n=1
244    0     -150  trcl=( 112.3876  112.3876 0)   fill=4 u=5 imp:n=1
c      Two Down
250    0     -150  trcl=(-112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
251    0     -150  trcl=( -56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
252    0     -150  trcl=(   0.0000 -112.3876 0)   fill=4 u=5 imp:n=1
```

```
253   0     -150  trcl=(  56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
254   0     -150  trcl=( 112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
            #240 #241 #242 #243 #244
            #250 #251 #252 #253 #254
                                                        u=5 imp:n=1
301   0        -200                            fill=5 u=9 imp:n=1
302   3 -1.0   #301                                   u=9 imp:n=1
303   0        -300                            fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110  pz  53.126196334886    $ bottom fuel
111  pz  15.574751832557    $ middle fuel
112  pz  68.549048167443    $ middle fuel
113  pz  30.997603665114    $ top fuel
150   rcc 0 0 -0.001 0 0 420.6610 28.0929
c     Drum Boundaries
200   rpp -140.4805 140.4805 -140.4805 140.4805 -0.002 420.6630
c     Reflector
300   rpp -176 176 -176 176 -35 456

c     Fissile Solution
m1     1001.50c  -2.0141E-02
      92235.50c  -7.4926E-03
      92238.50c  -6.7489E-01
       8016.50c  -2.9747E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26000.50c  -0.95000
       6000.50c  -0.00500
c     Water
m3     1001.50c   2.0
       8016.50c   1.0
mt3    lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  0 0 210
print 128
prdmp   3j 2
```

Attachment 7. Evaluation of Type AF Packagings for Shipment of LEUO

Total LEUO 172,520 lbs #packages 227 Currently packaged in 55 gal drums

Ave UO3 weight/drum	760	lbs
Fraction of drum filled with UO3	0.66	
Volume of drum	55	gal
	7.6	ft3
	13,114	in3
	214,240	cm3
	214	liter
Ave density of UO3	151.5	lbs/ft3
	0.088	lbs/in3
	5.4	lbs/liter

Evaluation

65 Type AF packaging designs from RAMPAC
- 53 are for fuel/overpacks/pellets/liquids/import-export only
- 12 are approved for compounds/powder (see listing below)
  - 9 of the 12 are unique designs (listed below)
    - o 2 are 6M like (6357&9203): can no longer fabricate
    - o 2 are 6M like/rectangle (9217/9251): can no longer fabricate
    - o 3 carry only ~22 lbs; requires > 7800 packages (not viable)
    - o 2 boxes wi inner containers; not for disposal & cost >$2M

Units: in/in3/lbs

Identification #	Features	ID	Length	volume	content limit from volume	content weight limit	Smaller of the two content limits	#packages to ship total LEUO	Estimated Cost of one Container	Total container cost
USA/6357/AF	6M-like	5	22	395	35		35	4929	$ 800	$ 3,943,314
USA/9217/AF	6M/rect	11.5	57	5900	518	310	310	557	$ 1,200	$ 667,819
USA/9294/AF-85	* box/inner	8.5	32	1800	158	1190	158	1092	$ 3,500	$ 3,821,646
USA/9203/AF	6M-like	9.5	17.5	1240	109	275	109	1583	$ 800	$ 1,266,202
USA/9251/AF	6M/rect			3500		370	307	561	$ 1,200	$ 673,625
USA/9280/AF-85	drum					22	22	7842	$ 100	$ 784,182
USA/9281/AF-85	drum					22	22	7842	$ 100	$ 784,182
USA/9285/AF-85	drum					23	23	7501	$ 100	$ 750,087
USA/9301/AF-85	**box/inner				232	660	232	744	$ 2,800	$ 2,083,815
IP-1/55 GAL Drum	Average UO3 weight in current content container.						760	227	$ 100.00	$ 22,700

**12-1gal paint cans
*9-8"diax32'Lcans

Compliance with 49 CFR 107.105(c)(9)

In lieu of using Type AF packaging, the alternative proposed is that normal condition transport safety (containment) be provided by the 17C/IP-1/Type A 55 gallon drum packaging. Shielding is not required for the LEUO material and the drum packaging has no specific shielding incorporated. Accident condition safety is provided by 1) limiting contents to less than 1 A2 Curies per packaging, and 2) subcriticality is assured by limiting the number of packagings per conveyance to a small number (as per Attachment 1).

The following steps will be followed by WSRC to document compliance with the Alternative Packaging requirements of 49 CFR 107.105(c)(9).

Packaging Background and Summary. As detailed in the IP-1 Compliance Summary and Closure Instructions (Attachment 5B), the drums to be used to ship the LEUO were manufactured in 1985 to the DOT 17C construction specification. The WSRC initial exemption request had categorized the LEUO contents as LSA-II (assumed fissile exempt); which requires an excepted, or IP-1 packaging in accordance with 49 CFR 173.427(b)(4). The 17C/IP-1 packaging design also meets the more robust requirements for a DOT 7A Type A packaging. The DOT 7A Type 7A compliance testing was carried out by the DOE Type A testing program and is documented in the "Test and Evaluation Document for the U.S. Department of Transportation Specification 7A Type A Packaging" (DOE/RL-96-57, Rev. 0-F, Vol. 1). This information is available on the RAMPAC data base at http://www.rampac.com/dot7a/rl96-57/ch1-2/chap2.htm#2.7.

Compliance Summary. This revised exemption request is now seeking a "packaging exemption" which invokes the additional requirements of 49 CFR 107.105(c)(9). The requirements and compliance summary are provided in Table A8 below.

Table A8. Compliance Summary

49 CFR 107.105(c)(9) Requirements	Compliance
Quality assurance controls	Prior to shipment the drum integrity will be independently verified. Any drum failing any of the criteria shall be overpacked into an 85 gallon DOT 7A Type A drum. The Quality Control requirements prior to each shipment in 49 CFR 173.475 shall be met.

Package design	The packaging design consists of a 16 gauge 55 gallon galvanized carbon steel drum with three rolling hoops manufactured to the DOT 17C construction specification, 16 gauge removable lid, 12 gauge closure ring with 5/8" diameter bolt and locking nut, and an elastomer gasket. The drum design meets the requirements for a DOT 7A Type A packaging as well as the lesser requirements of an IP-1 packaging.
Manufacture	The drums were manufactured to the DOT 17C construction specification as per 49 CFR 178.115 (pre-1987 regulations). The drums were procured and marked as DOT 17C and DOT 7A Type A drums. Testing documentation from the manufacturer is unavailable; however the markings on the drum bottom confirm the drums meet the DOT 17C specification. The Type A performance of the DOT 17C drums is documented in the DOE Type A testing program (DOE/RL -96-57, Rev. 0-F, Vol. 1). Compliance with the IP-1 requirements is documented in Attachment 5.
Performance test criteria	<u>17C Specification.</u> The drum is designed to withstand the following tests without leakage: 1) test by dropping, filled with water to 98 percent capacity, from height of 4 feet onto solid concrete so as to strike diagonally on chime, 2) hydrostatic pressure test of 20 pounds per square inch sustained for 5 minutes, and 3) leakage tested with soapsuds by interior air pressure of at least 15 pounds per square inch. <u>DOT 7A Type A.</u> The 17C drum meets the performance criteria of DOT 7A Type A as documented in DOE/RL 56-97, Rev 0-F, Vol. 1)). For this exemption application the packaging is to provide normal condition of transport containment of the LEUO material.

In-service performance	The 227 drums will be shipped one-time, one-way, on exclusive use trucks to the Nevada Test Site (NTS) for permanent disposal. The integrity of each drum will be verified in accordance with the drum integrity criteria provided in Attachment 8B. NTS waste disposal criteria requires that a 29-31 pound bag of boron be placed into each drum (on top of the LEUO). This necessitates removal of each drum lid and subsequent re-closure by WSRC. WSRC will use this opportunity to further verify drum integrity by completion of the following: 1) visual inspection of the interior of the drum (above the level of LEUO), 2) inspection of the gasket, and 3) re-closure of the drum in accordance with the closure instructions (Attachment 5B). The interior inspection of the drum and gasket shall be carried out in accordance with the drum integrity criteria in Attachment 8B.
Service-life limitations	The drums which have been stored inside since loading in 1985 are in good condition with no visible degradation and only minimal surface corrosion in limited locations (see photo in Attachment 8B and materials evaluation in Attachment 5C). The drum integrity check list will ensure the condition of each drum, and gasket. The drum lid and ring assembly shall be installed in accordance with the closure instructions in Attachment 5B.

Attachment 8B. Drum Integrity Criteria

Operations personnel will inspect the drums as they are prepared for shipment. The drum integrity will be independently verified by Operations QA and Hazardous Materials Transportation personnel.. Any drum that does not meet the criteria shall be overpacked in an 85 gallon drum meeting DOT 7A Type A requirements and shipped accordingly. See photo of drums in Figure 8B-1.

EXAMINATION CRITERIA	DISCUSSION OF CRITERIA
1. Is there evidence that the drum is, or has been, pressurized?	Pressurization can be indicated by a fairly uniform expansion of the sidewalls, bottom or top. Past pressurization can be indicated by a notable outward deflection of the bottom or top. Verify that the drum is not warped.
2. Is there any potentially significant rust or corrosion such that wall thinning, pin holes, or breaches are likely or the load bearing capacity is suspect?	Rust shall be assessed in terms of its type, extent, and location. Pitting, pocking, flaking, or dark coloration characterizes potentially significant rust or corrosion. This includes the extent of the drum surface area covered, thickness, and, if it occurs in large flakes or built-up (caked) areas. Rusted drums shall not be accepted if: • Rust is present in caked layers or deposits • Rust is present in the form of deep metal flaking, or built-up areas of corrosion products In addition, the location of rust should be noted: for example on a drum: top lid; locking chime top one-third, above the second rolling hoop; middle one-third, between the first and second rolling hoops; bottom one-third, below the second rolling hoop; and on the bottom. Drums may still be considered acceptable if the signs of rust show up as: • Some discoloration on the drum. • If rubbed would produce fine grit or dust or minor flaking (such that wall thinning does not occur)
3. Are there any split seams, tears, obvious holes, punctures (of any size), creases broken welds, or cracks?	Drums with obvious leaks, holes or openings, cracks, deep crevices, creases, tears, broken welds, sharp edges or pits, are either breached or on the verge of being breached and shall be overpacked.
4. Is the drum improperly closed?	Drum is to be closed in accordance with closure instructions in Attachment 5B.

Figure 8B-1. LEUO Drums stored at SRS awaiting shipment to NTS.

U.S. Department
of Transportation

Pipeline and
Hazardous Materials
Safety Administration

400 Seventh Street, S.W.
Washington, D.C. 20590

APR 14 2005

Dae Y. Chung
Director, Licensing Office, EM-24
Environmental Cleanup and Acceleration
Office of Environmental Management
Department of Energy
Washington, D.C. 20585

Dear Mr. Chung:

We have received your September 1, 2004 application for exemption (13962N) requesting relief from the 49 CFR 173.453(d) fissile materials - exception requirements to ship low enriched uranium trioxide (UO_3), exceeding a maximum of 1 percent of uranium-235 by weight, in 55-gallon drums (227 total) qualified as IP-1 packages, by highway, from the Savannah River Site to the Nevada Test Site, for disposal.

In accordance with the Memorandum of Understanding between the Department of Transportation and the Nuclear Regulatory Commission (NRC), we requested the NRC to review the application for exemption and provide their recommendations. Their recommendations, which we concur with, were recently received by us and forwarded to the members of your staff identified in the application for exemption. Based on these recommendations, we request you provide additional information on the following issues:

1. We believe it would be more appropriate to request an exemption (with sufficient justification and demonstration of equivalent safety) from the packaging requirements of 49 CFR 173.417, Authorized fissile material packages, rather than from the material definition in 49 CFR 173.453, Fissile material - exceptions. Therefore, the exemption application should be revised or withdrawn/resubmitted to request a packaging requirement exemption rather than a fissile material definition exemption.

APR 1 4 2005

2. The criticality analysis should be revised to include the appropriate uncertainty in establishing the maximum enrichment. It is not clear from the criticality evaluation whether or not the measurement uncertainty was included in the maximum enrichment considered in the calculations. The enrichment value for the material considered in the calculation should be the measured value plus the measurement uncertainty. Furthermore, the basis for the 1.3% measurement uncertainty is not known. There are no measurement uncertainties indicated in Attachment 2C which includes the initial measurements for U-235 for all the drums except one in March 1986. Attachment 2B, which includes measurements of U-235 on selected drums for validation purposes, indicates 3.5% as the measurement uncertainty.

3. The criticality analysis should be revised based on a bounding value of UO_3 weight per drum. The criticality analysis under normal conditions of transport assumed 750 pounds of UO_3 per drum. Attachment 1 shows the majority of drums to be shipped exceed 750 pounds. The criticality analysis for normal conditions of transport should be revised to bound the amount of material to be shipped.

4. The application should be revised to provide more information about how the range of applicability of the benchmark analysis was extrapolated down to 0.5 weight-percent from 2.0 weight-percent. Reference 5 should be provided, as well as an explanation of how the guidance from this document was applied to the benchmark data in the criticality analysis.

5. The criticality analysis should be revised to show how the 2.2% bias for the calculations using MCNP was determined. We do not agree that a 3% administrative margin on k_{eff} is appropriate for the criticality analysis, considering the magnitude of the code bias and the fact that the enrichment for the material to be shipped lies outside of the range of applicability of the benchmark analysis. We believe a revised analysis should include a 5% administrative margin on k_{eff}.

6. The criticality analysis should be revised to consider 2N damaged packages according to the requirements of 10 CFR 71.59(a). The criticality analysis for damaged packages considers the maximum subcritical mass of UO_3 optimally moderated in a spherical configuration. This mass should be considered to represent a number of packages, 2N, for the determination of a Criticality Safety Index (CSI). For instance, the application calculated that 5,250 kg of 1.084%

APR 1 4 2005

enriched UO_3 would be safely subcritical under hypothetical accident conditions. At 340 kg per package, this mass represents approximately 15 packages, and N = 7.5 packages. Therefore, CSI = 50/7.5 = 6.7, meaning that up to 7 packages could be shipped in a non-exclusive use vehicle, and up to 14 could be shipped in an exclusive use vehicle.

7. Clarification of contradictory information should be provided on the total number of drums (380, 381, and 382) originally generated during the campaign.

8. Further detail needs to be provided concerning other elements included in the UO_3 mixture, and whether they include plutonium, uranium-233, beryllium, graphite, or hydrogenous material enriched in deuterium, as described in 49 CFR 173.453(d). If any of these specific materials are present, they need to be modeled in the criticality analysis.

9. The CSI instead of the Transport Index should be used per the revised regulations that became effective October 1, 2004.

10. Specific clarification of whether the shipments will be made in exclusive use vehicles needs to be provided.

The additional information requested is necessary for further consideration of your application. If you are unable to submit this information within 30 days, please consider withdrawing your application and reapplying at a later date. Failure to respond within 30 days from the date of this letter may result in a denial of your application.

Please contact James Williams at 202 366-6177 or James.Williams@dot.gov if you have any questions concerning our position on these ten issues.

Sincerely,

Delmer F. Billings
Director, Office of Hazardous Materials
Exemptions and Approvals

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 15, 2005

Mr. Delmar F. Billings, Director
Office of Hazardous Materials
Exemptions and Approvals
U.S. Department of Transportation
400 Seventh Street, S.W.
Washington, D.C. 20590

SUBJECT: U. S. DEPARTMENT OF ENERGY'S EXEMPTION REQUEST

Dear Mr. Billings:

This is in response to your letter dated November 23, 2004, requesting our recommendation regarding the U.S. Department of Energy's (DOE's) request for an exemption from 49 CFR 173.453(d) requirement in order to ship 227 55-gallon drums containing uranium trioxide (UO_3), enriched in U-235 up to 1.084 wt%, as a fissile-exempt shipment.

Based upon our review, the statements and representations contained in the request and in the supporting documents, we recommend that DOE provide responses to the attached Request for Additional Information (RAI). Most of the issues raised in your letter are also included as part of the RAI. With respect to your question regarding "Whether there is no Type A fissile packaging that could be used to achieve full regulatory compliance," there are only a few U.S. certified Type A fissile packages which would not have to have a revised certificate of compliance in order to ship UO_3. However, using any of these packagings would require significant repackaging of the proposed content. For example, one particular Type A fissile package is authorized to carry up to 1423 lbs of UO_2 pellets or powder enriched up to 4.5%, but the material would have to be repackaged in four separate inner containers that make up the package. Additionally, the certificate would need to be revised to allow UO_3. There are some DOT-revalidated foreign packages for shipping similar materials, but they are similar to U.S. approved packages with respect to the amount of material which can be shipped, and would also require significant repackaging.

In general, the NRC staff believes it is more appropriate to request an exemption (with sufficient justification and demonstration of equivalent safety) from the packaging requirements than from material definition. It appears to be more appropriate for DOE to request exemption from 49 CFR 173.417, "Authorized fissile materials packages" instead of a request for an exemption from the "Fissile material - exception." NRC staff does not recommend calling UO_3 with U-235 enrichment above 1 percent a fissile-excepted material.

If you have any questions regarding this matter, please contact me at (301) 415-8500.

Sincerely,

Meraj Rahimi, Senior Project Manager
Licensing Section
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

TAC No.: L23787

Enclosure: Request for Additional Information

DOE Request for Exemption from 49 CFR 173.453(d)

Request for Additional Information

1. Revise the criticality analysis to include the appropriate uncertainty in establishing the maximum enrichment.

   It is not clear from the criticality evaluation whether or not the measurement uncertainty was included in the maximum enrichment considered in the calculations. The enrichment value for the material considered in the calculation should be the measured value plus the measurement uncertainty. Furthermore, the basis for the 1.3% measurement uncertainty is not known. There are no measurement uncertainties indicated in Attachment 2C which includes the initial measurements for U-235 for all the drums except one in March 1986. Attachment 2B, which includes measurements of U-235 on selected drums for validation purposes, indicate 3.5% as the measurement uncertainty.

2. Revise the criticality analysis based on a bounding value for UO_3 weight per drum.

   The criticality analysis under normal conditions of transport assumed 750 lbs of UO_3 per drum. Attachment 1 shows that the majority of drums to be shipped exceed 750 lbs. The criticality analysis for normal conditions of transport should be revised to bound the amount of material to be shipped.

3. Revise the application to provide more information about how the range of applicability of the benchmark analysis was extrapolated down to 0.5 weight-percent from 2.0 weight-percent. Reference 5 should be provided as well as an explanation of how the guidance from this document was applied to the benchmark data in the criticality analysis.

4. Revise the criticality analysis to show how the 2.2% bias for the calculations using MCNP was determined. Additionally, the staff does not agree that a 3% administrative margin on k_{eff} is appropriate for the criticality analysis, considering the magnitude of the code bias and the fact that the enrichment for the material to be shipped lies outside of the range of applicability of the benchmark analysis. A revised analysis should include a 5% administrative margin on k_{eff}.

5. Revise the criticality analysis to consider 2N damaged packages according to the requirements of 10 CFR 71.59(a). The criticality analysis for damaged packages considers the maximum subcritical mass of UO_3, optimally moderated in a spherical configuration. This mass should be considered to represent a number of packages, 2N, for the determination of a CSI. For instance, the applicant calculated that 5,250 kg of 1.084% enriched UO_3 would be safely subcritical under hypothetical accident conditions. At 340 kg per package, this mass represents approximately 15 packages, and N = 7.5 packages. Therefore, CSI = 50/7.5 = 6.7, meaning that up to 7 packages could be shipped in a non-exclusive use vehicle, and up to 14 could be shipped in an exclusive use vehicle.

6. Specify the total number of drums. Contradictory information is provided on the total numbers (380, 381, and 382) in the attached reports.

7. Specify other elements included in the UO_3 mixture, and whether they include plutonium, uranium-233, beryllium, graphite, or hydrogenous material enriched in deuterium as described in 49 CFR 173.453(d). If any of these elements are present, they need to be modeled in the criticality analyses.

8. Use the Criticality Safety Index (CSI) instead of Transport Index (TI) per revised regulations effective October 1, 2004.

9. State explicitly that the shipments will be made in exclusive use vehicles.

U.S. Department
of Transportation

**Research and
Special Programs
Administration**

400 Seventh Street, S.W.
Washington, D.C. 20590

NOV 2 3 2004

Mr. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards (NMSS)
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Brach:

In accordance with the Memorandum of Understanding between our Agencies, I request that you review the attached Application for Exemption and supplemental material and provide your agency's recommendation to the DOT whether this application should be a candidate for a DOT exemption.

The applicant, the U.S. Department of Energy, is requesting an exemption from 49 CFR § 173.453(d) fissile materials - exception requirements to ship low enriched uranium oxide (UO_3), exceeding a maximum of 1 percent of uranium-235 by weight, in 55-gallon drums (227 total) qualified as IP-1 packages, by highway, from the Savannah River Site to the Nevada Test Site, for disposal.

To assist you in your review, I am providing two copies of the Application for Exemption and supplemental material as well as the following potential issues identified by us pertaining to the request.

1) Contradictory information is provided on the total number of drums (380, 381, and 382) originally generated during the campaign.

2) Whether there is no Type A fissile packaging that could be used to achieve full regulatory compliance.

3) The request for exemption from the fissile material – exception requirement in 49 CFR 173.453(d) that does not address all requirements of the subject paragraph, such as plutonium, uranium-233, beryllium, graphite, or hydrogenous material enriched in deuterium content.

Tracking Number: 2004100032

NOV 2 3 2004

4) The enclosed Safety Evaluation Report that references transport index rather than criticality safety index to demonstrate compliance with 10 CFR § 71.59(b).

5) Whether the applicant is proposing to ship exclusive use.

Since the applicant desires to use this exemption in upcoming shipments, we request you provide an estimate of the time needed to complete your review. If you have any questions or need any additional information, please contact Jim Williams at (202) 366-6177.

Sincerely,

Delmer F. Billings
Director, Office of Hazardous Materials
Exemptions and Approvals

Enclosures

13962-N

20041?0032

Cureton, Sandra

From: Shuler, James [James.Shuler@em.doe.gov]
Sent: Wednesday, September 08, 2004 11:20 AM
To: 'Sandra.Cureton@rspa.dot.gov'
Cc: Steve Primeau (sprimeau@rampac.com)
Subject: DOT Exemption Application

Per your telephone request, I have amended our request below to add the information required. This info is shown in bold.

ATTN: Exemptions, DHM-31

Associate Administrator for Hazardous Materials Safety

Research and Special Programs Administration

U.S. Department of Transportation

400 7th Street, SW

Washington, DC 20590-0001

Dear Associate Administrator:

The U.S. Department of Energy requests an exemption from the requirements of 49 CFR 173.453(d) to permit the one-time, one-way shipment of certain IP-1 drums containing low-enriched uranium oxide from the Savannah River Site to the Nevada Test Site **by highway**. Full details of our exemption request are included in the enclosed documents. Also enclosed is a copy of our Safety Evaluation Report detailing our independent review and evaluation of the Savannah River Site contractor's criticality safety analysis.

If you have any questions, please call Dr. James Shuler at 301-903-5513.

Dr. James M. Shuler

Health Physicist

U.S. Department of Energy

EM-24, CLV-1081

1000 Independence Ave., SW

Washington, DC 20585

Department of Energy
Washington, DC 20585

DOT/RSPA/OHMS UNIT

SEP 01 2004

04 SEP -7 PM 5:21

ATTN: Exemptions, DHM-31
Associate Administrator for Hazardous Materials Safety
Research and Special Programs Administration
U.S. Department of Transportation
400 7th Street, SW
Washington, D.C. 20590-0001

Dear Associate Administrator:

The U.S. Department of Energy requests an exemption from the requirements of 49 CFR 173.453(d) to permit the one-time, one-way shipment of certain IP-1 drums containing low-enriched uranium oxide from the Savannah River Site (SRS) to the Nevada Test Site. Full details of our exemption request are included in the enclosed documents. Also enclosed is a copy of our Safety Evaluation Report detailing our independent review and evaluation of the SRS contractor's criticality safety analysis.

If you have any questions, please call Dr. James Shuler at 301-903-5513.

Sincerely,

Dae Y. Chung
Director, Licensing Office, EM-24
Environmental Cleanup and Acceleration
Office of Environmental Management

Enclosures

cc w/o enclosure(s):
Paul Golan, EM-1
James Shuler, EM-24
Jeffrey Allison, DOE-SR

DOE F 1325.8

United States Government | Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE: AUG 0 5 2004

REPLY TO ATTN OF: NMPD (Dawn Gillas, (803) 208-3976)

SUBJECT: Request for Exemption from the Department of Transportation (DOT) Requirement for Low Enriched Uranium (LEU) Shipments

TO: Paul M. Golan, Acting Assistant Secretary for Environmental Management (EM-1), HQ

The Savannah River Site (SRS) has the opportunity to dispose of 382 drums of low enriched uranium oxide (LEUO) as low level waste at the Nevada Test Site. When determining the packaging requirements for this material, SRS determined that 227 drums contain uranium enriched to a level slightly higher than is allowed by DOT for material to be shipped in an Industrial Package. The 49 CFR 173.453 describes fissile material exceptions such that materials meeting these requirements are not required to be shipped in "fissile packages." Paragraph (c) of this section applies to LEU with a maximum enrichment of one percent. The 227 drums slightly exceed this limit (including uncertainty) to a maximum of 1.084 percent, which would require these drums to be shipped in Type A Fissile packages. No such packages are available for this material form and development of a compliant package would be a multi-million dollar, multi-year project. Allowing the exemption would allow all of the drums to be dispositioned within nine months of granting the exemption and at a cost of less than $100K.

The attached Exemption Request follows all of the requirements of 49 CFR 107.105, Application for Exemption, and details the reasons SRS feels this is a safe and appropriate action. To summarize the major reasons: 1) this is a one-way, one-time shipment of a very limited amount of material, 2) the criticality analysis shows equivalent safety by limiting the amount of material in each shipment, and 3) the cost and time necessary to develop and implement an approved package is prohibitive. The only other option that is currently available is continued storage for an indefinite period, which is contrary to risk-managed accelerated cleanup.

We have communicated with your staff regarding the exemption request and have provided them with an advance copy of the nuclear criticality safety evaluation to support the justification. Please forward this request to the appropriate DOT office for approval. Two original request packages are attached since two originals are required to be submitted to DOT.

If you have any questions, please contact me or have your staff contact Dawn Gillas at (803) 208-3976.

Jeffrey M. Allison
Manager

NMPD:DLG:mag

FC-04-074

Attachment:
Request for DOT Exemption

cc w/o attach:
I. Triay (EM-3), HQ
Dae Y. Chung (EM-24), HQ

cc w/attach:
J. Shuler (EM-24), HQ

Westinghouse
Savannah River Company
Aiken, SC 29808

SRS
savannah river site

July 20, 2004

OBU-TRA-2004-00022

R.M. Cutshall, Transportation Manager
Westinghouse Savannah River Company LLC
Savannah River Site
Building 706-N
Aiken, S.C. 29808
Phone: (803) 557-4617

UNCLASSIFIED
DOES NOT CONTAIN
UNCLASSIFIED CONTROLLED
NUCLEAR INFORMATION
ADC & Reviewing Official: Christopher W. Sohn Hazardous Material Shipping Advisor
(Name and Title)
Date: July 26, 2004

Associate Administrator for Hazardous Materials Safety
Attn: Exemptions, DHM-31
Research and Special Programs Administration
U.S. Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590-0001

REQUEST FOR DEPARTMENT OF TRANSPORTATION EXEMPTION

Savannah River Site (SRS) currently has an inventory of legacy low enriched uranium oxide (LEUO) packaged in 382 55-gallon galvanized steel (Excepted) drums. The material has been stored inside an SRS facility since 1982 and is destined for shipment to the Nevada Test Site (one-time, campaign) for permanent disposal. The LEUO material in 155 of the drums meets the 173.403 definition of LSA-II solid material with the 173.453(d) fissile materials exception (uranium-235 enrichment < 1%). The LEUO material in the remaining 227 drums has uranium-235 enrichments slightly above 1%; with the maximum being 1.084%. For each planned conveyance, a listing of the 227 drum ID numbers, corresponding uranium-235 enrichment, and UO_3 weight is given in Attachment 1. The uranium-235 enrichment values were determined by mass spectrometer measurements with an uncertainty of +/- 1.3% (or approximately 1.000 +/- 0.013) as described in Attachment 2.

SRS seeks relief from the 173.453(d) requirement that limits uranium-235 enrichment to a maximum of 1%; specifically, "Uranium enriched in U-235 to a maximum of 1 percent by weight" as stated in 49 CFR effective October 1, 2004. The exemption is sought so that the fissile materials exemption will still apply to shipments of a total of 227 drums containing low enriched uranium oxide (LEUO). The shipments will be transported by highway.

The consequence of not meeting the fissile materials exception for the 227 drums is that the packaging category increases from excepted package to Type A fissile. There is a limited number of approved Type A fissile package designs for materials other than non-irradiated fuel in the United States. WSRC reviewed certificates for the Type A fissile packages listed on RAMPAC and did not identify any viable options that could be readily used. WSRC also explored adding/mixing depleted uranium with the LEUO contents to reduce the enrichment below 1%. WSRC determined that mixing operations involve considerable radiological risk and costs; and the capability does not currently exist to carry out the mixing. Since alternative packagings were not identified and the capability to modify contents does not exist at SRS, WSRC has concluded that seeking a DOT exemption is the only viable option.

Westinghouse
Savannah River Company
Aiken, SC 29808

SRS
savannah river site

Proposed Alternative: WSRC will strictly limit the total content weight and corresponding number of drums in each conveyance so that criticality safety is ensured for a worst case accident scenario (total breach of drums where LEUO forms an optimally moderated sphere that is water reflected). Transport safety under normal conditions of transport is also demonstrated. The drums will be shipped from SRS to NTS for permanent disposal. When the 227 drums have been transported, there will be no additional shipments.

The LEUO (UO_3) is an oxide that is stable well above the 800°C fire conditions of 10 CFR 71 [see Attachment 3]. A criticality evaluation of the safe spherical mass of LEUO was completed and is provided in Attachment 4. The criticality evaluation considered a k_{safe} value of 0.948 and calculates $k_{eff} + 2\sigma < k_{safe}$. For this evaluation, σ is defined as the statistical uncertainty associated with the MCNP 4C calculations. Based on the evaluation, the weight of LEUO determined to be safe under any conditions was determined to be 7.5 MT or 16,534 lbs for an enrichment of 1.05% and 5.25 MT or 11,574 lbs for an enrichment of 1.084%. The content weight in each conveyance will be limited to these conservative weight limits. Normal condition of transportation safety was demonstrated by considering an array of undamaged packages in accordance with 10 CFR 71.59. This criticality evaluation is provided in Attachment 6. The conveyance loading plans for all of the drums are given in Attachment 1.

In Attachment 1, the drums listed in Group 1 loading plans were selected with U-235 wt% enrichments ranging from 0.987% to 1.036%. This considers the 1.3% uncertainty in the enrichment measurements (i.e. 1.00 – 0.013 = 0.987 and 1.05 – 0.014 = 1.036). The Group 2 loading plans were selected with enrichments from 1.037% to 1.084%.

The exemption is sought for the period of time required to ship the 227 drums from SRS to NTS. WSRC estimates the shipments will be completed within 9 months from the time the exemption is granted.

The basis for the exemption request is that the number of excepted LEUO drums with uranium-235 enrichments greater than 0.987% (1% minus uncertainty) will be limited on each conveyance to ensure sub-criticality. The safe spherical mass criticality evaluation provided in Attachment 4 establishes worst case, conservative, mass limits for the allowed LEUO. The Attachment 4 mass limits are used to limit the number of drums in each conveyance. If the drums were subjected to the hypothetical accident conditions in 10 CFR 71 (drop and fire), it is anticipated that the drums would fail and the contents would be distributed. Since the safe spherical mass evaluation considers a worst case geometry, any conceivable accident configuration should be bounded. In reality the forces in an accident (30 foot drop onto unyielding surface) will tend to distribute the material (not form it into a sphere) making it safer from a criticality perspective. The 800°C fire has no adverse effect on the LEUO material. Normal condition transport containment and shielding are provided by the excepted packaging (per 173.427(b)(4)) for LSA-II material meeting the fissile materials exception of 173.453(d). Criticality safety under normal conditions of transport is demonstrated in Attachment 6 which considers an array of packages in accordance with 10 CFR 71.59 (a)(1). The calculations in Attachment 6 demonstrate that more than five times the number of packages planned for shipment in each conveyance is safe. At the completion of the shipping campaign, WSRC will have no further shipments of this LEUO material.

The LEUO material meets the definition of LSA-II. Pending the approval of this exemption request, the shipping description of will be "RQ, Radioactive Material Low Specific Activity (LSA-II), 7, UN3321".

The packaging is an excepted drum-type packaging meeting the requirements of 49 CFR 173.24, 173.24a, and 173.410. The drum consists of a 16 gauge 55 gallon galvanized carbon steel drum with three rolling hoops, 16 gauge removable lid, 12 gauge closure ring with 5/8" diameter bolt and nut with locking nut, and an elastomer gasket. A compliance summary given in Attachment 5 demonstrates packages meet IP-1 and excepted package requirements.

WSRC is not aware of any shipping or incident experiences relative to this application. The LEUO contents and corresponding number of drums per conveyance will be limited so that there is no increased likelihood of criticality under normal or accident conditions during the shipments. Normal condition containment and shielding are provided by the excepted packaging which is DOT authorized for LSA-II materials.

Westinghouse Savannah River Company appreciates your assistance with this request.

Sincerely,

R.M. Cutshall
Transportation Manager
Westinghouse Savannah River Company LLC

Attachments:

Attachment 1. Conveyance Loading Plan for LEUO (13 Tables of Loading Details, 13 pages).

Attachment 2. Radiochemistry Validation of LEUO (3 memos; "Sampling Plan for Low Enriched Uranium Trioxide", NMM-ETS-2002-00195, May 28, 2003 (8 pages); "Radiochemistry Data Validation for Low Enriched Uranium Oxide", OBU-SWO-2004-00007, March 25, 2004 (9 pages); Memo D. R. Barton to D. C. Bonfer, March 17, 1986 (7 pages).

Attachment 3. Occupational Safety and Health Guideline for Uranium and Insoluble Compounds (OSHA Guideline 16 pages).

Attachment 4. Criticality Evaluation of Spherical Safe Mass Values for LEUO (Memo; "Spherical Safe Mass Values - Low Enriched UO3", WSMS-CRT-04-0026, April 5, 2004, 6 pages).

Attachment 5. IP-1 Compliance Summary and Closure Instructions ("LEUO 55 Gallon IP-1 Container", FSS-TS-2004-0003, January 7, 2004 (14 pages); "Closing Instructions for 55 Gallon LEU Drum IP-1 Container", FSS-TS-2004-0004, January 7, 2004 (1 page)

Attachment 6. Arrays of UO3 Drums (S.P. Gough Report, N-CLC-F-00695, July 14, 2004)

Department of Energy
Washington, DC 20585

SAFETY EVALUATION REPORT

Request for Exemption from the Department of Transportation Requirement for Low Enriched Uranium Shipments

Docket 04-10-0000

INTRODUCTION

The Department of Energy Savannah River Operations Office (DOE-SR) has submitted a request for exemption (Reference 1) from a Department of Transportation (DOT) requirement for low-enriched uranium oxide (LEUO) shipments in 227 of 382 fifty-five-gallon galvanized steel drums. The LEUO material in 155 of the drums meets the 49 CFR 173.403 definition of LSA-II solid material with the 173.453(d) fissile materials exception; i.e., U-235 enrichment less than 1%. The LEUO material in the remaining 227 drums has U-235 enrichment slightly above 1%, with the maximum being 1.084%. DOE is seeking relief from the 173.453(d) requirement that limits the U-235 enrichment to a maximum of 1%, specifically "Uranium enriched in U-235 to a maximum of one percent by weight" as stated in 49 CFR that will become effective on October 1, 2004. The exemption is sought for the period-of-time required to ship the 227 drums from the Savannah River Site (SRS) to the Nevada Test Site. It has been estimated that the shipments will be completed within nine months from the time the exemption is granted.

DOE-SR has considered options for shipment of this LEUO material with U-235 enrichment greater than 1 wt.% (but ≤1.084 wt.%), including developing a Type A fissile package, or mixing depleted uranium with LEUO to reduce the average U-235 enrichment in the drums. The cost and the additional radiological risk associated with these options, however, has been found difficult to justify, given the one-way, one-time-only shipment of the rather limited amount of the LEUO material. The continued indefinite storage of the material at the SRS is also contrary to the objective of a risk-managed accelerated cleanup.

A request for exemption from the DOT requirement appears to be the only viable option, and the proposed alternative by DOE-SR is one that will strictly limit the total content mass (weight) in the corresponding number of drums in each conveyance so that criticality safety is ensured for the worst-case accident scenario; i.e., total breach of drums where LEUO forms an optimally moderated sphere that is water reflected. Array analysis of drums has also been conducted to demonstrate criticality safety under normal conditions of transport (NCT) in accordance with the requirements in 10 CFR 71.59(a)(1). The criticality safety analyses performed by Westinghouse Savannah River Company (WSRC) are documented in Attachments 4 and 6 of Reference 2.

In its early interaction with DOE on the exemption request, DOT indicated that a separate, independent confirmatory review of the criticality safety analyses of the LEUO shipments is to be conducted by the DOE Office of Licensing (EM-24). This Safety Evaluation Report contains EM-24's technical evaluation of the approach and results of WSRC's criticality safety analyses, which is described in the following sections of the report.

TECHNICAL EVALUATION

Spherical safe mass values for the LEUO material

For a given amount of fissile material, the most reactive configuration is one that achieves optimal moderation, minimizes leakage, and attains full reflection of neutrons emitted from the fissile material, e.g., U-235, for subsequent chain reactions. A UO_3/H_2O mixture in spherical geometry with water surrounding the sphere is generally regarded as the most reactive configuration that can be achieved at a certain intermediate ratio (H/U) of the moderator content in the mixture.

Monte Carlo calculations were performed using the MCNP-4C code to obtain the safe spherical mass of LEUO and the results are given in Attachment 4 of Reference 2. MCNP-4C is a general-purpose Monte Carlo radiation transport code developed and maintained by Los Alamos National Laboratory and used widely by members of the criticality safety community. UO_3/H_2O mixtures in spherical geometry surrounded by 30-cm water were modeled in the MCNP calculations with the water content in the mixtures varying from 0 to 40 wt.% (to determine the optimum moderation), and with U-235 enrichments of 1.084, 1.05, 1.0, and 0.99 wt.%. The criticality safety criterion used is a k_{safe} value of 0.948 such that the calculated $k_{eff} + 2\sigma \leq k_{safe}$, where k_{eff} is the effective neutron multiplication factor and σ is the standard deviation associated with the statistical uncertainty of the MCNP-4C calculations. Table 1 below lists the values of the spherical safe mass thus obtained with optimum moderation and full reflection.

Table 1: MCNP-4C calculated spherical safe mass for UO_3/H_2O mixtures with optimum moderation and full reflection by water

U-235 enrichment (wt%)	0.99	1.0	1.05	1.084
Spherical safe mass (metric tons, MT)	17.1	14.5	7.5	5.25

The spherical safe mass values of 7.5 and 5.25 metric tons in Table 1 are used to generate the conveyance loading plans for the LEUO drums listed in Attachment 1 of Reference 2. There are two groups of planned shipments. The drums listed in the Group 1 loading plan were selected with U-235 enrichments ranging from 0.987 to 1.036 wt.% that incorporated the 1.3% uncertainty in the enrichment measurements (i.e., 1.00 - 0.013 = 0.987 and 1.05 - 0.014 = 1.036, Attachment 2A, Reference 2). The drums listed in the Group 2 loading plan were selected with U-235 enrichments ranging from 1.037 to 1.084 wt.%.

There are seven shipments in Group 1 for drums of LEUO with U-235 enrichment less than 1.05 wt.%. Each shipment in Group 1 contains fewer than or equal to 21 drums with a total mass of $UO_3 < 7.5$ MT. There are six shipments in Group 2 for drums of LEUO with U-235 enrichment less than 1.08 wt.%. Each shipment in Group 2 contains either 15 or 14 drums with a total mass of $UO_3 < 5.25$ MT. The total UO_3 mass in each conveyance shipment limits the amount of fissile material to a value below that of the spherical safe mass, with a margin of safe mass varying from at least 3.4% for any of the Group 1 shipments to at least 1.1% for any of the Group 2 shipments listed in Attachment 1 of Reference 2.

<u>EM-24 Evaluation</u> - The spherical safe mass values in Table 1 for UO_3/H_2O mixtures agree very well with the results of independent calculations documented in Reference 3 for UO_2-H_2O homogeneous mixtures; the extra oxygen atom in UO_3 is not expected to have any significant effect on the criticality calculations. The use of a criticality safety criterion, $k_{safe} = 0.948$, is slightly more conservative than the usual value of 0.95 with a safety margin of 5%. The assumption of a UO_3/H_2O mixture in spherical geometry with optimum moderation and full reflection is the most conservative case and, therefore, the limits placed on the number of LEUO drums in the shipment plan (Attachment 1 of Reference 2) should ensure criticality safety, even for the worst-case hypothetical accident.

<u>Criticality analysis for arrays of UO_3 drums</u>

10 CFR 71.59 defines standards for arrays of fissile material packages that are applicable to the LEUO drums. Part (a) of 71.59 states "... the designer of a fissile material package shall derive a number N based on all of the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:

(1) Five times N undamaged packages with nothing between the packages would be subcritical;

(2) Two times N damaged packages, if each package were subjected to the tests specified in §71.73 (Hypothetical accident conditions) would be subcritical with optimum interspersed hydrogeneous moderation; and

(3) The value of N cannot be less than 0.5."

Criticality calculations were performed for arrays of UO_3 drums using the MCNP-4C code and the details of the models and results are given in Attachment 6 of Reference 2. Based on the drum-loading plan described above, two 3-D array configurations were modeled, one with five rows of 24 drums in each row and arranged with a triangular pitch (4-5-6-5-4), for a total of 120 drums; and the other a 5 x 5 x 5 square-pitch array for a total of 125 drums. The total number of drums in either configuration bounds the "5N" undamaged packages that vary from 80 to 105 (i.e., 16 to 21 drums) in the LEUO Group 1 shipments and 70 to 75 (i.e., 14 or 15 drums) in the LEUO Group 2 shipments.

In all of the array calculations, each drum was modeled as a cylinder (55.88-cm ID x 83.82-cm internal height) with wall, top and bottom treated as 16-gauge (0.1519-cm thickness) carbon steel. Each drum was assumed to contain 750 lb of UO_3 with a maximum U-235 enrichment of 1.084 wt.%, and with 3 to 24 wt.% H_2O. The fissile solution in each drum was modeled as a cylinder filling the internal radius of the drum; other parameters considered in the 3-D array models included the gap, i.e., surface-to-surface separation, between drums (0, 2, 4 cm), interstitial water density (0, 10, 20, and 100 wt.%), and full reflection on all sides of the arrays by water. The criticality safety criterion, $k_{eff} + 2\sigma \leq k_{safe}$, where $k_{safe} = 0.948$ and k_{eff} and σ are from the MCNP calculations for the arrays, is the same as that used for the determination of the spherical safe mass.

Altogether 48 MCNP-4C cases were studied covering the stated parameter space. The two cases that have the highest values of $k_{eff}(\sigma) = 0.9161\,(0.0005)$ and 0.9058 (0.0005) are, respectively, Problem #19 for a triangular-pitch array of 120 drums and Problem #37 for a square-pitch array of 125 drums, both with 18 wt.% H_2O in the UO_3/H_2O mixture inside each drum, zero gap, and no interstitial moderation between drums. In both cases, the values of $k_{eff} + 2\sigma$ are less than $k_{safe} = 0.948$.

<u>**EM-24 Evaluation**</u> - Highly conservative assumptions were employed in the MCNP-4C calculations for arrays of drums that exceed the actual number of the LEUO drums in the shipment plan described in Attachment 1 of Reference 2. Even though water is <u>not</u> present inside an undamaged drum or outside between drums during normal conditions of transport, its presence was not only assumed, but also varied, along with other parameters (gap width and pitch) in the MCNP calculations to determine the most reactive configuration for the 3D array of the LEUO drums. The calculated $k_{eff} + 2\sigma$ for the most reactive array configuration is 0.91710, which is significantly less than $k_{safe} = 0.948$, thus ensuring criticality safety for the planned shipments of the LEUO drums under normal conditions of transport. EM-24 has performed independent MCNP calculations that confirmed the results for the most reactive, bounding configurations of the arrays shown in Table 2.

With regard to the requirements in 10 CFR 71.59(a), it should be noted that the array analysis only applies to 5N "undamaged" packages (or drums) where N is either 24 or 25 for the triangular or square pitch arrays, respectively. The 2N "damaged" package is not invoked here because the worst case damaged configuration, i.e., UO_3/H_2O mixture in spherical geometry with optimum moderation and full reflection, has already been assumed and analyzed to obtain the spherical safe mass for the LEUO shipments. Therefore, it is <u>not</u> necessary to perform criticality calculations for 2N "damaged" packages where N is either 24 or 25, which is greater than 0.5 in 10 CFR 71.59(a)(3).

The transport index (TI) for nuclear criticality control defined in 10 CFR 71.59(b), TI = 50/N, with N derived in the manner described in 10 CFR 71.59(a)(1), is TI = 2 for N = 25, and TI = 2.1 for N = 24, which means the drums may be shipped by any carrier, and that the carrier provides adequate criticality control by limiting the sum of TI to 50 in a non-exclusive use vehicle, and to

100 in an exclusive use vehicle, according to 10 CFR 71.59(c). For a non-exclusive use vehicle, the sum of TI of 50 limits the number of packages (drums) in a conveyance to 25 or 24, which bounds the number of the LEUO drums in any of the shipments listed in Attachment 1, Reference 2.

Table 2: Comparison of results in the MCNP calculations for the most reactive, bounding configurations of arrays of drums

	H_2O (mixture / interstitial, wt.%)	Gap (cm)	k_{eff} (σ)	$k_{eff} + 2\sigma$
Triangular pitch				
WSRC	(18 / 0)	0	0.9161 (0.0005)	0.91710
EM-24	(18 / 0)	0	0.91691 (0.00044)	0.91779
Square pitch				
WSRC	(18 / 0)	0	0.9058 (0.0005)	0.90680
EM-24	(18 / 0)	0	0.90528 (0.00046)	0.90620

CONCLUSION

The basis for the exemption request is the number of excepted LEUO drums with uranium-235 enrichments greater than 0.987 wt.% (1% minus uncertainty) will be limited on each conveyance to ensure criticality safety. The safe spherical mass criticality analysis provided in Attachment 4 of Reference 2 established the most conservative mass limits for the allowed number of the LEUO drums in the shipments listed in Attachment 1 of Reference 2. If the drums were subjected to the hypothetical accident conditions in 10 CFR Part 71 (drop and fire), it is anticipated that the drums would breach and the LEUO contents disperse, rather than conglomerate into a sphere with optimum moderation and full reflection. The calculations for arrays containing up to 120-125 drums of LEUO material that bound the number of drums in the conveyance-loading plan (Attachment 1, Reference 2) have also demonstrated criticality safety conservatively for the most reactive array configurations under NCT. These statements and conclusions are confirmed in EM-24's independent confirmatory evaluation.

References

1. DOE memorandum, J. M. Allison to P. M. Golan, August 5, 2004, "Request for Exemption from the Department of Transportation (DOT) Requirement for Low Enriched Uranium (LEU) Shipments."

2. R. M. Cutshall (WSRC) to Associate Administrator for Hazardous Material Safety, DOT, July 20, 2004, "Request for Department of Transportation Exemption."

3. NUREG/CR-0095 and ORNL/NUEG/CSD-6, "Nuclear Safety Guide/TID-7016/Revision 2," June 1978.

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Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 1, Shipment 1

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9234	0.987	754
2	9236	0.987	756
3	9243	0.987	757
4	9293	0.987	743
5	9223	0.988	759
6	9225	0.988	752
7	9226	0.988	764
8	9227	0.988	753
9	9232	0.988	757
10	9233	0.988	754
11	9235	0.988	750
12	9237	0.988	756
13	9274	0.988	751
14	9242	0.989	753
15	9255	0.989	757
16	9275	0.989	760
17	9221	0.990	753
18	9240	0.990	752
19	9244	0.990	756
20	9256	0.990	765
21	9257	0.990	758
Total			15,860

Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 1, Shipment 2

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9263	0.992	759
2	9260	0.994	757
3	9254	0.995	760
4	9264	0.995	756
5	9265	0.995	757
6	9266	0.995	757
7	9259	0.996	758
8	9267	0.996	762
9	9268	0.997	759
10	9261	0.998	757
11	9262	0.999	758
12	9277	1.000	754
13	9276	1.000	757
14	9284	1.001	758
15	9272	1.001	761
16	9271	1.001	755
17	9279	1.002	757
18	9270	1.002	766
19	9269	1.002	766
20	9280	1.003	759
21			
Total			15,173

LEUO Group 1, Shipment 3

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9294	1.004	755
2	9281	1.004	758
3	9292	1.005	753
4	9283	1.005	757
5	9273	1.005	759
6	9282	1.006	757
7	9278	1.007	756
8	9306	1.010	759
9	9462	1.011	515
10	9461	1.011	523
11	9328	1.012	768
12	9305	1.012	757
13	9286	1.012	757
14	9312	1.013	757
15	9289	1.013	757
16	9288	1.013	758
17	9455	1.015	759
18	9285	1.015	761
19	9324	1.016	750
20	9300	1.016	762
21	9298	1.016	765
Total			15,443

Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 1, Shipment 4

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9290	1.016	764
2	9299	1.017	757
3	9297	1.017	756
4	9296	1.017	758
5	9291	1.017	757
6	9325	1.018	754
7	9304	1.018	756
8	9302	1.018	756
9	9313	1.019	762
10	9307	1.019	758
11	9303	1.019	756
12	9295	1.019	691
13	9301	1.020	751
14	9315	1.020	796
15	9319	1.020	765
16	9322	1.020	766
17	9323	1.020	743
18	9366	1.020	761
19	9308	1.021	767
20	9309	1.021	770
21	9316	1.021	796
Total			15,940

LEUO Group 1, Shipment 5

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9326	1.021	789
2	9317	1.022	755
3	9318	1.022	760
4	9320	1.022	756
5	9321	1.022	755
6	9310	1.023	758
7	9329	1.023	760
8	9351	1.023	763
9	9353	1.023	759
10	9311	1.024	768
11	9314	1.024	758
12	9330	1.025	767
13	9331	1.025	754
14	9340	1.026	760
15	9327	1.027	755
16	9332	1.027	757
17	9333	1.027	763
18	9342	1.028	763
19	9454	1.028	763
20	9346	1.029	756
21	9350	1.029	759
Total			15,978

Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 1, Shipment 6

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9367	1.029	761
2	9334	1.030	763
3	9343	1.030	759
4	9344	1.030	761
5	9347	1.030	754
6	9355	1.030	760
7	9368	1.030	760
8	9456	1.030	763
9	9339	1.031	756
10	9348	1.031	756
11	9354	1.032	762
12	9357	1.032	754
13	9365	1.032	763
14	9401	1.032	759
15	9287	1.033	762
16	9349	1.033	766
17	9352	1.033	756
18	9453	1.033	762
19	9356	1.034	758
20	9358	1.034	757
21			
Total			15,192

Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 1, Shipment 7

(UO_3 < 7.5 MT/16,534 lbs.)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9364	1.034	760
2	9381	1.034	758
3	9394	1.034	757
4	9359	1.035	759
5	9363	1.035	748
6	9369	1.035	762
7	9379	1.035	752
8	9380	1.035	756
9	9384	1.035	757
10	9400	1.035	751
11	9361	1.036	758
12	9362	1.036	766
13	9370	1.036	767
14	9371	1.036	756
15	9395	1.036	757
16	9514	1.036	744
17			
18			
19			
20			
21			
Total			12,108

LEUO Group 2, Shipment 1

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9338	1.037	760
2	9389	1.037	764
3	9390	1.037	763
4	9397	1.037	754
5	9399	1.037	759
6	9125	1.038	740
7	9372	1.038	764
8	9382	1.038	759
9	9387	1.038	759
10	9418	1.038	764
11	9435	1.038	761
12	9385	1.039	766
13	9392	1.039	759
14	9393	1.039	758
15	9403	1.039	762
Total			11,392

LEUO Group 2, Shipment 2

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9404	1.039	760
2	9428	1.039	674
3	9383	1.040	757
4	9386	1.040	762
5	9388	1.040	760
6	9402	1.040	756
7	9345	1.041	761
8	9391	1.041	758
9	9405	1.041	763
10	9406	1.041	759
11	9407	1.041	765
12	9419	1.041	757
13	9442	1.041	762
14	9336	1.042	761
15	9396	1.042	754
Total			11,309

LEUO Group 2, Shipment 3

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9411	1.042	764
2	9335	1.043	763
3	9341	1.043	764
4	9408	1.043	765
5	9413	1.043	757
6	9445	1.043	761
7	9414	1.044	759
8	9375	1.045	762
9	9410	1.045	762
10	9415	1.045	757
11	9417	1.045	765
12	9422	1.045	764
13	9423	1.045	763
14	9424	1.045	760
15	9122b	1.084	780
Total			11,446

Attachment 1. Conveyance Loading Plans for LEUO, 7/06/2004

LEUO Group 2, Shipment 4

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9429	1.045	759
2	9412	1.046	754
3	9416	1.046	762
4	9430	1.046	770
5	9439	1.046	757
6	9457	1.046	758
7	9459	1.046	765
8	9360	1.047	760
9	9425	1.047	760
10	9438	1.047	752
11	9460	1.047	754
12	9337	1.048	764
13	9376	1.048	765
14	9420	1.048	763
Total			10,643

LEUO Group 2, Shipment 5

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9431	1.048	764
2	9433	1.048	764
3	9437	1.048	765
4	9448	1.048	765
5	9373	1.049	761
6	9432	1.049	758
7	9434	1.049	761
8	9436	1.049	756
9	9441	1.049	758
10	9443	1.049	763
11	9447	1.049	754
12	9452	1.049	771
13	9458	1.049	758
14	9374	1.050	763
Total			10,661

LEUO Group 2, Shipment 6

(UO_3 <5.25 MT/11,574 lbs)

Drum #	Drum ID	% Enrichment	UO_3 Weight (pounds)
1	9446	1.050	763
2	9377	1.051	768
3	9398	1.051	759
4	9426	1.052	763
5	9444	1.052	756
6	9449	1.052	761
7	9409	1.054	764
8	9427	1.057	764
9	9258	1.059	759
10	9378	1.063	765
11	9440	1.063	752
12	9451	1.064	764
13	9450	1.066	724
14	9421	1.084	766
Total			10,628

Attachment 2H

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Sampling Plan for Low Enriched Uranium Trioxide (U)

SRS has 381 drums of low-enriched uranium trioxide ($LEUO_3$) drums stored in Building 221-21F. The $LEUO_3$ was produced by the Mark 15 campaign in the early 1980s. WSRC needs the $LEUO_3$ characterization data to perform a disposition alternatives study to fulfill our DOE commitment for a recommended disposition pathway by September 30, 2003.

SRTC will analyze the $LEUO_3$ for radionuclides, elemental impurities, organic compounds and physical properties as identified in Tables 2-6. The analytical requirements are based on 10 CFR 61.55, the applicable RCRA and DOT requirements, potential vendor waste acceptance criteria (WAC) and the TVA Low Enriched Uranyl Nitrate Specification.

The ^{235}U content by drum is available from the analyses performed during the production campaign (D. R. Barton, Jr. to D. C. Bonfer, March 17, 1986). Analytical data for some radionuclides and chemical impurities based on 10-drum composites is available in the same document. The RCRA, DOT, WAC and TVA requirements necessitate lower levels of detection than were performed for this data to achieve the safest, most cost effective disposition pathway.

The available analytical data shows that the ^{235}U content steadily increases during the production run. The ^{235}U content exceeds the natural uranium concentration (0.711%) by the 33rd drum and the eversafe concentration (0.90% ^{235}U) in the 78th drum. The ^{235}U content remains above the eversafe concentration until the last 10 drums, but never drops under the natural uranium concentration. One drum is identified as $LEUO_3$ material from the secondary dust collector.

Based on our knowledge of the source material and the process, the $LEUO_3$ is considered homogeneous within each drum for radionuclide and chemical impurity content. WSRC is disposing other uranium materials via the same potential disposition vendors. These vendors accepted these materials with a minimal amount of analytical data with the WSRC assurance that the materials are homogeneous. Therefore, this sample plan assumes that each drum is a homogeneous mixture. Between drums, the ^{235}U content will vary. The drums will be sampled by a scoop from the top of each drum. A statistically representative set of samples shall be pulled from the 381 drums.

The sample material will be obtained by removing 20 grams of oxide from the top of each drum. Operations will arrange the transportation of 1-gram samples from each drum to SRTC for the characterization analyses. The remaining sample material will retained for possible recheck, and the RCRA-certified laboratory analyses. Each sample will be identified by drum number, and stored in a cool dry location away from sunlight until needed. The RCRA analyses will be held pending the outcome of the disposition alternatives study.

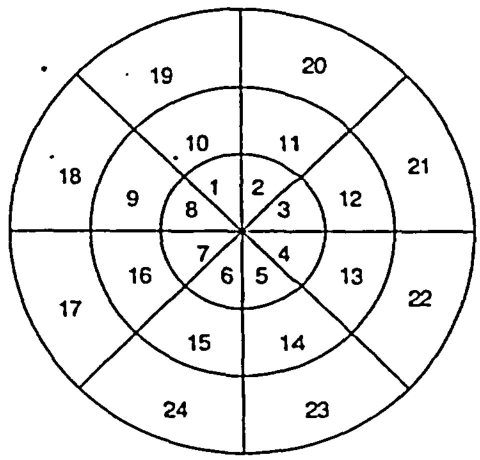
The sample material shall be taken from the drums identified in Table 1. The drum numbers for the entire LEUO inventory are 9092-9471, and 9514. In addition to the statistical sampling, the following drums will be sampled:

Drum 9433 - previous results indicated 4.0% ^{235}U content,
Drums 9341 & 9462 - no recorded ^{235}U content,
Drums 9124,9125,9169 & 9170 - ^{235}U content transitions, and
Drum 9514 – contains material removed from the secondary dust collector.

Table 1
Drums for Analysis

Specific Drums	Statistical Set	Drum Grid Position
9124 ✓	9138	16
9125 ✓	9150 ✓	18
9169 ✓	9162	2
9170 ✓	9174 ✓	8
9341 ✓	9186	9
9433 ✓	9198 ✓	14
	9210	20
9514 ✓	9222	21
	9234 ✓	1
	9246	5
	9258 ✓	9
	9270	11
	9282 ✓	13
	9294	16
	9306 ✓	17
	9318	20
	9330 ✓	23
	9342 ✓	24
	9354	1
	9366 ✓	3
	9378	4
	9390 ✓	5
	9402	8
	9414 ✓	12
	9426	15
	9438 ✓	17
	9450 ✓	18
	9462	20
	9474	21
	9468 ~~9486~~ ✓	22

The drum grid position is an imaginary grid, as shown, below:



SRTC will analyze the $LEUO_3$ for the following radionuclides:

Table 2
Radionuclides from DOT and Potential Vendor Waste Acceptance Criteria

Radionuclide	Threshold Value	Radionuclide	Threshold Value
U-232	100 nCi/M^3	I-129	0.08 Ci/M^3
U-233	100 nCi/M^3	Pu-238	100 nCi/M^3
U-234	100 nCi/M^3	Pu-239	100 nCi/M^3
U-235	100 nCi/M^3	Pu-240	100 nCi/M^3
U-236	100 nCi/M^3	Pu-241	3500 nCi/M^3
U-238	100 nCi/M^3	Pu-242	100 nCi/M^3
Np-237	100 nCi/M^3	Ra-226	100 nCi/M^3
Am-241	100 nCi/M^3	Sr-90	0.04 Ci/M^3
Cs-137	1.0 Ci/M^3	Tc-99	3.0 Ci/M^3

SRTC will analyze for the following elements from the TVA LEU Specification:

Table 3
TVA LEU Specification

Element	TVA Specification, µg/g U	Element	TVA Specification, µg/g U
Aluminum	≤150	Molybdenum	≤200
Boron	≤1	Phosphorus	≤200
Calcium	≤250	Potassium	≤50
Carbon	≤400	Samarium	≤100
Cesium	≤100	Selenium	≤10
Chlorine	≤200	Silicon	≤200
Chromium	≤150	Sodium	≤50
Dysprosium	≤100	Sulfur	≤200
Europium	≤100	Tantalum	≤200
Fluorine	≤100	Thorium	≤20
Gadolinium	≤100	Tin	≤200
Hafnium	≤100	Titanium	≤200
Iron	≤400	Tungsten	≤200
Lithium	≤100	Vanadium	≤200
Manganese	≤200	Zirconium	≤100

If the $LEUO_3$ is disposed as waste, an independent, certified[1] laboratory may be required to analyze for these RCRA constituents.

Table 4
RCRA Constituents

Constituent	RCRA Limit ,ppm[1]	Constituent	RCRA Limit ,ppm[1]
Arsenic	5.000	Hexachlorobenzene	0.130
Barium	100.000	Hexachlorobutadiene	0.500
Benzene	0.500	Hexachloroethane	3.000
Cadmium	1.000	Lead	5.000
Carbon tetrachloride	0.500	Lindane	0.400
Chlordane	0.030	Mercury	0.200
Chlorobenzene	100.000	Methoxychlor	10.000
Chloroform	6.000	Methyl ethyl ketone	200.000
Chromium	5.000	Nitrobenzene	2.000
o-Cresol[2]	200.000	Pentachlorophenol	100.000
m-Cresol[2]	200.000	Pyridine	5.000
p-Cresol[2]	200.000	Selenium	1.000
Cresol[2]	200.000	Silver	5.000
2,4-D	10.000	Tetrachloroethylene	0.700
1,4-Dichlorobenzene	7.500	Toxaphene	0.500
1,2-Dichloroethane	0.500	Trichloroethylene	0.500
1,1-Dichloroethylene	0.700	2,4,5-Trichlorophenol	400.000
2,4-Dinitrotoluene	0.130	2,4,6-Trichlorophenol	2.000
Endrin	0.020	2,4,5-TP (Silvex)	1.000
Heptachlor (and its epoxide)	0.008	Vinyl chloride	0.200

[1] Results reported as *parts per million* (ppm) are "mg/L" for liquids, and "mg/kg" for solids.
[2] If o-, m-, and p-Cresol concentrations cannot be differentiated, the total cresol concentration is used. The total cresol limit is 200 mg/L.

The following analytical requirements are included in the potential vendors' waste acceptance criteria:

Table 5
Vendor Waste Acceptance Criteria Constituents

Constituent	Typical Vendor's WAC Limit
Copper	Not Applicable
Zinc	9000 mg/L
Cyanide	25 ppm
Hydrogen sulfide	25 ppm
Paint Filter Test	No Free Liquids
pH (soil pH-method 9045)	Not Applicable
Is it an oxidizer or reducer?	Not Applicable
Photo-ionizing sniffer (gross organic)	Not Applicable
Density	± 0.1 g/cc

Potential constituents identified in the previously noted regulatory documents and/or waste acceptance criteria were excluded from the characterization analysis based on the provided reasoning:

Table 6
Excluded Analyses

Constituent	Exclusion Reasoning
Pesticides and herbicides	None used in the production process
Volatile organic compounds[3]	Removed by the production process
C-14	Process knowledge
Ni-59	Process knowledge
Radionuclides with less than 5-year half-lives[4]	Process knowledge and isotope half-lives
H-3	Process knowledge
Co-60	Process knowledge and isotope half-life
Ni-63	Process knowledge
Nb-94	Process knowledge
Pu-244	Process knowledge
Am-242m	Process knowledge
Am-243	Process knowledge
Cm-242	Process knowledge and isotope half-life
Cm-243	Process knowledge
Cm-244	Process knowledge
Cm-245	Process knowledge
Cm-246	Process knowledge
Cm-247	Process knowledge
Cm-248	Process knowledge
Cm-250	Process knowledge
Bk-247	Process knowledge
Cf-249	Process knowledge
Cf-250	Process knowledge
Cf-251	Process knowledge

[3] The LEU stream was processed through 4 high-heat manufacturing steps that eliminated any volatile organic compounds.

[4] The Mark 15 campaign was conducted in the mid-1980s. Isotopes with less than a 5-year half-life will have been reduced by radioactive decay (+3 cycles) to less-than-detectable concentrations. In addition, the LEU stream was processed through 2 solvent extraction cycles that either entirely removed or initially reduced these radionuclide concentrations to trace levels.

Please sign in the designated space to acknowledge your approval of this sample plan to characterize the $LEUO_3$.

Approvals:

S. J. Robertson, Manager, F-Canyon Complex Technical Support — 6-2-03 Date

S. J. Howell, Manager, F-Canyon Complex Engineering — 6/3/03 Date

M. E. Logan, Manager, F-Canyon Complex Deactivation — 6/4/03 Date

Table B-1
Analytical Results

	Statistical Mean	Upper Confidence Level		Statistical Mean	Upper Confidence Level
TCLP Metals:			**TCLP Semivolatiles:**		
Arsenic			o-Cresol		
Barium			p-Cresol		
Cadmium			m-Cresol		
Chromium			Cresol		
Lead			Dinitrotoluene		
Mercury			Hexachlorobenzene		
Selenium			Hexachloro-1,3-butadiene		
Silver			Nitrobenzene		
TCLP Volatiles:			Pentachlorophenol		
Benzene			2,4,5-Trichlorophenol		
Carbon Tetrachloride			2,4,6-Trichlorophenol		
Chlorobenzene			Hexachloroethane		
Chloroform			**TCLP Pesticides and Herbicides:**		
1,4-Dichlorobenzene			Chlordane		
1,2-Dichloroethane			2,4 – D		
Methyl ethyl ketone			Endrin		
Pyridine			Heptachlor and Hydroxide		
Tetrachloroethelyne			Lindane		
Trichloroethylene			Methoxychlor		
Vinyl chloride			Toxaphene		
Dichloroethylene			2,4,5 - TP (Silvex)		

ATTACHMENT 2B

SRS
savannah river site

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

MAR 25 2004

OBU-SWO-2004-00007

To:	Dave Collins	724-7E
	Mary Granade	724-20E
	Mark Kokovich	724-7E
	Don McWhorter	707-7F
	Jacob Nims	707-7F
	Howard Pope	704-S
	Glenn Siry	705-3C
	SW&I Document Control	642-E

From: Bernie Mayancsik *Bm* 724-21E

SUBJECT: RADIOCHEMISTRY DATA VALIDATION FOR LOW ENRICHED URANIUM OXIDE

Validation of the Low Enriched Uranium Oxide radiochemistry data analyzed by SRTC was completed with no anomalies noted. The process was performed to meet Nevada Test Site waste acceptance criteria to validate a portion of the chemical and radiological data for characterization purposes. Attached are copies of the case narrative report, completed validation checklist/summary sheet, and data validation worksheet.

Chemical analyses and subsequent validation of that data were performed by an independent source at General Engineering Laboratories, Inc.

If there are any questions regarding this information or process, please call me at 2-2271.

Radiochemistry Case Narrative
Westinghouse Savannah River Company
Low Enriched Uranium Oxide

Method/Analysis Information

Analytical Method

Gas Flow Proportional Counting
Liquid Scintillation
Gamma Spectroscopy
Alpha Spectrometry
Mass Spectrometry

Procedure

[illegible]	Thermal Ionization Mass Spectrometer Measurement Control Program
1-NTS-MS-010	Sample Changing Procedure for 3 Stage Thermal Ionization Mass Spec
RG B10-1	Pu TIMS Bioassay: Quality Assurance Plan
RG B10-3	Pu TIMS Bioassay: Measurement Control Program
RG B10-9	Pu TIMS Bioassay: TIMS Operations
ETSPMR-6	Underground Counting Facilities Measurement Control Program
WSRC-IM-97-00024	Conduct of Research & Development Savannah River Technology Center

Analytical Method	Batch Number	Sample Number	QC Sample Number
Gas Flow Proportional Counting	Batch 1 (Sr-90), 6-25-03	9124, 9150, 9170, 9198, 9258, 9306, 9366, 9414	blank-1
	Batch 2 (Sr-90), 7-3-03	9174, 9234, 9330, 9342, 9390, 9433, 9450, 9486	blank-2
Liquid Scintillation	Batch 1 (Tc-99), 7-23-03	9124, 9170, 9433, 9150, 9174, 9198, 9234, 9258,	blank-1, 9258 dup
	Batch 2 (Tc-99), 7-23-03	9306, 9330, 9342, 9366, 9390, 9414, 9450, 9486	blank-2, 9414 spike
Gamma Spectroscopy	Batch 1 (Np-237), 9-19-03	9124, 9150, 9170, 9174, 9198, 9234, 9258, 9306, 9330, 9342, 9366, 9390, 9414, 9433, 9450, 9486	N/A
	Batch 1(Cs-137, Ra-226, Am-241), 6-25-03	9124, 9150, 9170, 9198, 9258, 9306, 9366, 9414	blank-1, 9150 spike-1
	Batch 2 (Cs-137, Ra-226, Am-241), 7-3-03	9174, 9234, 9330, 9342, 9390, 9433, 9450, 9486	blank-2, 9450 spike-2
	Batch 1 (I-129), 8-18-03	9124, 9170, 9150, 9198, 9258, 9306, 9366, 9414	blank
Mass Spectrometry	Batch (U), 6-25-03	9124, 9125, 9150, 9169, 9170, 9174, 9198, 9258, 9282, 9306, 9341, 9366, 9414, 9433, 9438, 9514	9124 dup, 9125 dup, 9174 dup, 9198 dup, 9341 dup, 9366 dup
	Batch (Pu-238 by alpha, all other Pu's by mass), 6-25-03	9124, 9170, 9433, 9150, 9174, 9198, 9234, 9258, 9306, 9330, 9342, 9366, 9390, 9414, 9450, 9486	9366 dup

Alpha Spectrometry	Batch (U). 6-25-03	9174, 9234, 9342, 9433, 9450, 9486, 9390, 9330	Q34
	Batch (Pu-238 by alpha, all other Pu's by mass), 6-25-03	9124, 9170, 9433, 9150, 9174, 9198, 9234, 9258, 9306, 9330, 9342, 9366, 9390, 9414, 9450, 9486	9366 dup

Calibration Information:

Calibration Information

All initial and continuing calibration requirements have been met.

Standards Information

Applicable standard solution(s) for analyses are traceable to NIST and used before the expiration date(s).

Sample Geometry

All counting sources were prepared in the same geometry as the calibration standards.

Quality Control (QC) Information:

Blank Information

Information fell within the acceptance criteria for method blanks.

QC Information

All of the QC samples (spikes, duplicates, and laboratory control samples) met the required acceptance limits for %R and RPD.

Technical Information:

Holding Time

All samples were analyzed within the required holding time.

Preparation Information

All preparation criteria have been met for these analyses.

Sample Re-prep/Re-analysis

Two samples did not agree with the historical record (9125 and 9198) during mass spectrometry for uranium. A second aliquot was dissolved and diluted and reanalyzed. The result of 9125 agreed with the initial preparation. The first result for 9198 was 0.24at% U-235 while the reanalysis resulted in 0.51at% U-235. A third aliquot for sample 9198 was therefore prepared, starting with 230 mg and diluting from there. The third result agreed with the first analysis giving 0.26at% U-235. After discussing this with the generator, another aliquot of each sample

was reanalyzed. Sample 9198 was still significantly depleted while the historical record indicates it should be very slightly enriched. The analysis of the resubmitted sample 9125 indicates that it is nearly natural in its U-235 content, agreeing with the historical record.

Miscellaneous Information:

NCR Documentation
No NCR was generated for the preparation and analysis of this sample set.

This validation was completed using *Environmental Geochemistry Group Operating Handbook Section 1.800 Analytical Data Qualification* and *LEHR Environmental Restoration/Waste Management Standard Operating Procedure* SOP NO. 21.1.

The following reviewer validated the information presented in this data narrative.

Signature: BA Mayercik Date: 3-25-04

VALIDATION OF RADIOCHEMISTRY DATA

Sample ID: 9124, 9125, 9169, 9170, 9341, 9453, 9514, 9150, 9174, 9198, 9486, 9234, 9258, 9282, 9306, 9330, 9342, 9366, 9390, 9414, 9438, 9450
Laboratory: Analytical Development Section of SRTC
Analysis: gas flow proportional counting, liquid scintillation, gamma/mass/alpha spec
Date:
Review completed by:

HOLDING TIMES

	Yes	No	N/A
Have all samples been analyzed within 180 days?	X		

If any sample fails this criterion, apply "J" qualifier to all sample results.

LABORATORY CONTROL SAMPLE

	Yes	No	N/A
Are all laboratory control sample (LCS) recoveries (%R) within QC limits?	X		

If any LCS compound fails this criterion, apply qualifiers to the failed compound in all samples associated with that LCS, according to the following guidelines:

Condition	Positives	Non-Detects
Gross Alpha, Beta: $\pm$ 30% < %R $\leq \pm$ 90% Upper/Lower Limit	"J"	"UJ"
%R > $\pm$ 90% Upper/Lower Limit	"J"	"R"
All others: $\pm$ 25% < %R $\leq \pm$ 75% Upper/Lower Limit	"J"	"UJ"
%R > $\pm$ 75% Upper/Lower Limit	"J"	"R"

MATRIX SPIKE/MATRIX SPIKE DUPLICATE

	Yes	No	N/A
Are all matrix spike (MS)/matrix spike duplicate (MSD) recoveries (%R) within QC limits?	X		

Review MS recoveries and apply qualifiers to failed compounds in all associated samples.

Condition	Positives	Non-Detects
Gross Alpha, Beta: ± 30% < %R ≤ ± 90% Upper/Lower Limit	"J"	"UJ"
%R > ± 90% Upper/Lower Limit	"J"	"R"
All others: ± 25% < %R ≤ ± 75% Upper/Lower Limit	"J"	"UJ"
%R > ± 75% Upper/Lower Limit	"J"	"R"

BLANKS

	Yes	No	N/A
Are all Blank results below Reporting Limits?	☐	☒	☐

only apples to Tc-99, all others were below reporting limits. All Tc-99 results should have a "J" code.

	Yes	No	N/A
Are Field/Rinsate Blanks, if present, below Reporting Limits?	☐	☐	☒

If the blank results fall outside the appropriate limits, qualify the results for all associated samples that are less than 10 times the blank value as estimated, "J" or "UJ".

CALIBRATIONS

	Yes	No	N/A
Has the laboratory identified in the case narrative report that calibration was completed on the instrument prior to analysis?	☒	☐	☐

Discussed with laboratory personnel and was acceptable for methods that used calibration standards.

FIELD DUPLICATES (IF APPLICABLE)

	Yes	No	N/A
Do field duplicate values generally look similar?	☐	☐	☒

Field duplicate samples may be taken and analyzed as an indication of overall precision. These analyses measure both field and lab precision; therefore, the results may have more variability than lab duplicates that measure only lab performance. It is expected that soil duplicate results will have a greater variance than water matrices due to difficulties associated with collecting identical field samples. Any evaluation of field duplicates shall be provided with the reviewer's comments.

Sample Result Verification

	Yes	No	N/A
Analytes and results are expected or typical for that waste stream based on historical data or past sampling and analysis activities.	X		
Any anomalies in raw data (e.g., baseline shifts, negative absorbances, omissions, and legibility).		X	
Any transcription or calculation errors on one or more samples.		X	

Overall Validation Summary

LEUO Radiochemistry
Data Validation Worksheet

Reference.
WSRC-TR-2003-00513 Determination of Trace radionuclides and Elements in SRS Low-Enriched Uranium from the MK-15 Campaign
Environmental Geochemistry Group Operating Handbook, Section 1 800 Analytical Data Qualification

Holding Times
within 180 days from collection

Sample date: Jun-03

Blanks

Element	$Blank_1$	$Blank_2$		$Blank_1$ x 5	$Blank_2$ x 5
Cs-137	<0.55	n/a	pCi/g	n/a	n/a
Ra-226	<0 23	n/a	pCi/g	n/a	n/a
Am-241	<0.63	n/a	pCi/g	n/a	n/a
I-129	<28	n/a	pCi/g	n/a	n/a
Tc-99	0.0056	0 026	nCi/g	0 028	0.13
Sr-90	<5	<5	pCi/g	n/a	n/a

[illegible]
detected analytes' concentration is > 5x the concentration in the blank

Duplicates
Relative percent differences (RPD) = (absolute x - y /(x + y)/2) x 100
0 - 20%

Element		x	y	absolute x-y	x+y/2	RPD
Tc-99	9258 dup	36	43	7.0000	39.5	17.7
Pu-238	9366 dup	10.6	8.8	1.8000	9.7	18.6
U-238	9125 dup	98.89	98.92	0.0300	98.91	0.0
U-236	9125 dup	0.062	0.061	0.0007	0.06	1.1
U-235	9125 dup	1.042	1.006	0.0360	1.02	3.5
U-234	9125 dup	0.008	0.008	0.0002	0.01	2.5
U-238	9198 dup	99.73	99.73	0.0000	99.73	0.0
U-236	9198 dup	0.010	0 010	0.0000	0.01	0.0
U-235	9198 dup	0.260	0.258	0 0020	0.26	0.8
U-234	9198 dup	0.001	0 001	0.0000	0.00	0.0
U-238	9124 dup	99.350	99.350	0 0000	99.35	0.0
U-236	9124 dup	0 036	0 036	0 0004	0.04	1.1
U-235	9124 dup	0.605	0 607	0.0020	0.61	0.3
U-234	9124 dup	0 005	0.005	0.0000	0.00	0.0
U-238	9174 dup	98.990	98.990	0.0000	98.99	0.0
U-236	9174 dup	0.062	0.061	0.0005	0.06	0.8
U-235	9174 dup	0.945	0.940	0.0050	0.94	0.5
U-234	9174 dup	0.008	0.008	0.0002	0.01	2.6
U-238	9341 dup	98.890	98.900	0.0100	98.90	0.0
U-236	9341 dup	0 062	0.061	0.0003	0.06	0.5
U-235	9341 dup	1.043	1.036	0.0070	1.04	0.7
U-234	9341 dup	0 008	0.008	0.0002	0.01	2.5
U-238	9366 dup	98.920	98.920	0.0000	98.92	0.0
U-236	9366 dup	0.065	0 064	0.0006	0.06	0.9
U-235	9366 dup	1.011	1.007	0.0040	1.01	0.4
U-234	9366 dup	0 008	0.008	0.0002	0 01	2.5

Laboratory Control Samples

laboratory control samples (LCS) percent recoveries = (sample results / known value) * 100

75 - 125%

Element	Known Value	Sample	%R
U-234	47.8	47.5	99
U-235-236	2.4	2.7	113
U-238	49.8	49.8	100

Spikes

% recovery (%R) = (Spike added sample results / known value of spike added) x 100

75 - 125%

Element		Spike Added	Sample Results	Units	$\%R_1$
Cs-137	9150 spike	46	46	pCi/g	100
Ra-226	9150 spike	70	72	pCi/g	103
Am-241	9150 spike	115	111	pCi/g	97
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ra-226	9450 spike	70	71	pCi/g	101
Am-241	9450 spike	115	118	pCi/g	103
Tc-99	9414 spike	3.2	3.58	nCi/g	112

ATTACHMENT 2C

DUPONT

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
ATOMIC ENERGY DIVISION
SAVANNAH RIVER PLANT
AIKEN, SOUTH CAROLINA 29801
(TWX 810-771-2670, TEL 803-725-6211, WU AUGUSTA, GA)

March 17, 1986

Mr. D. C. Bonfer
Westinghouse Materials Company of Ohio
P. O. Box 398704
Cincinnati, Ohio 45239

Mr. Bonfer:

The recent enriched uranium (Mark 15) productivity campaign generated 380 drums of uranium trioxide (UO_3) that were packaged as slightly enriched uranium. The majority of our sample analyses for the Mark 15 campaign have been completed. Uranium trioxide analyses are contained in Table I (^{235}U isotopic by weight for individual drums) and Table II (ten drum composite sample analyses). The transuranic alpha activity and total beta activity analyses are not yet complete.

As you indicated, composite sample 9335-9344 was mistakenly not shipped to your site. If needed, we will send this sample with our first shipment of enriched UO_3.

Please contact me at (803) 557-4263 (FTS 227-4263) if I can be of further assistance.

Very truly yours,

D. R. Barton, Jr.

D. R. Barton, Jr., Engineer
Separations Technology Dept.

DRB/d
att

cc: D. C. Witt, 221-F
G. E. Barrow, 221-F
M. L. Cowen, 221-F
L. D. Olson \ C. D. Davis, 707-1F
J. T. Buckner, 703-F
C. W. Jenkins, 221-F
T. G. Campbell, 221-F

TABLE I

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%	Drum #	235U wt%
9092	0.215	9142	0.734	9192	0.971
9093	0.500	9143	0.793	9193	0.967
9094	0.463	9144	0.793	9194	0.968
9095	0.479	9145	0.740	9195	0.975
9096	0.494	9146	0.807	9196	0.975
9097	0.461	9147	0.830	9197	0.977
9098	0.470	9148	0.835	9198	0.963
9099	0.486	9149	0.835	9199	0.967
9100	0.498	9150	0.837	9200	0.964
9101	0.503	9151	0.843	9201	0.965
9102	0.501	9152	0.890	9202	0.980
9103	0.503	9153	0.892	9203	0.980
9104	0.509	9154	0.893	9204	0.981
9105	0.502	9155	0.890	9205	0.941
9106	0.500	9156	0.893	9206	0.978
9107	0.581	9157	0.892	9207	0.976
9108	0.620	9158	0.893	9208	0.976
9109	0.599	9159	0.906	9209	0.981
9110	0.596	9160	0.916	9210	0.981
9111	0.598	9161	0.903	9211	0.980
9112	0.587	9162	0.868	9212	0.978
9113	0.595	9163	0.868	9213	0.929
9114	0.723	9164	0.868	9214	0.915
9115	0.581	9165	0.835	9215	0.958
9116	0.595	9166	0.829	9216	0.974
9117	0.575	9167	0.829	9217	0.975
9118	0.570	9168	0.837	9218	0.980
9119	0.507	9169	0.540	9219	0.980
9120	0.570	9170	0.923	9220	0.976
9121	0.571	9171	0.927	9221	0.990
9122	0.583	9172	0.928	9222	0.985
9123	0.589	9173	0.933	9223	0.988
9124	0.550	9174	0.934	9224	0.984
9125	0.725	9175	0.936	9225	0.988
9126	0.725	9176	0.918	9226	0.988
9127	0.725	9177	0.911	9227	0.988
9128	0.756	9178	0.913	9228	0.986
9129	0.766	9179	0.911	9229	0.951
9130	0.756	9180	0.920	9230	0.929
9131	0.727	9181	0.925	9231	0.981
9132	0.725	9182	0.925	9232	0.988
9133	0.721	9183	0.924	9233	0.988
9134	0.703	9184	0.953	9234	0.987
9135	0.702	9185	0.955	9235	0.988
9136	0.701	9186	0.959	9236	0.987
9137	0.666	9187	0.964	9237	0.988
9138	0.689	9188	0.971	9238	0.962
9139	0.745	9189	0.971	9239	0.981
9140	0.739	9190	0.970	9240	0.990
9141	0.785	9191	0.971	9241	0.984

TABLE I (cont'd)

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%	Drum #	235U wt%
9242	0.989	9292	1.005	9342	1.028
9243	0.987	9293	0.987	9343	1.030
9244	0.990	9294	1.004	9344	1.030
9245	0.969	9295	1.019	9345	1.041
9246	0.970	9296	1.017	9346	1.029
9247	0.966	9297	1.017	9347	1.030
9248	0.965	9298	1.016	9348	1.031
9249	0.970	9299	1.017	9349	1.033
9250	0.986	9300	1.016	9350	1.029
9251	0.985	9301	1.020	9351	1.023
9252	0.985	9302	1.018	9352	1.033
9253	0.986	9303	1.019	9353	1.023
9254	0.995	9304	1.018	9354	1.032
9255	0.989	9305	1.012	9355	1.030
9256	0.990	9306	1.010	9356	1.034
9257	0.990	9307	1.019	9357	1.032
9258	0.990	9308	1.021	9358	1.034
9259	0.996	9309	1.021	9359	1.035
9260	0.994	9310	1.023	9360	1.047
9261	0.998	9311	1.024	9361	1.036
9262	0.999	9312	1.013	9362	1.036
9263	0.992	9313	1.019	9363	1.035
9264	0.995	9314	1.024	9364	1.034
9265	0.995	9315	1.020	9365	1.032
9266	0.995	9316	1.021	9366	1.020
9267	0.996	9317	1.022	9367	1.029
9268	0.997	9318	1.022	9368	1.030
9269	1.002	9319	1.020	9369	1.035
9270	1.002	9320	1.022	9370	1.036
9271	1.001	9321	1.022	9371	1.036
9272	1.001	9322	1.020	9372	1.038
9273	1.005	9323	1.020	9373	1.049
9274	0.988	9324	1.016	9374	1.050
9275	0.989	9325	1.018	9375	1.045
9276	1.000	9326	1.021	9376	1.048
9277	1.000	9327	1.027	9377	1.051
9278	1.007	9328	1.012	9378	1.063
9279	1.002	9329	1.023	9379	1.035
9280	1.003	9330	1.025	9380	1.035
9281	1.004	9331	1.025	9381	1.034
9282	1.006	9332	1.027	9382	1.038
9283	1.005	9333	1.027	9383	1.040
9284	1.001	9334	1.030	9384	1.035
9285	1.015	9335	1.043	9385	1.039
9286	1.012	9336	1.042	9386	1.040
9287	1.033	9337	1.048	9387	1.038
9288	1.013	9338	1.037	9388	1.040
9289	1.013	9339	1.031	9389	1.037
9290	1.016	9340	1.026	9390	1.037
9291	1.017	9341	[illegible] 1.043	9391	1.041

TABLE I (cont'd)

Mark 15 Individual Drum 235U Isotopics

Drum #	235U wt%	Drum #	235U wt%
9392	1.039	9442	1.041
9393	1.039	9443	1.049
9394	1.034	9444	1.052
9395	1.036	9445	1.043
9396	1.042	9446	1.050
9397	1.037	9447	1.049
9398	1.051	9448	1.048
9399	1.037	9449	1.052
9400	1.035	9450	1.066
9401	1.032	9451	1.064
9402	1.040	9452	1.049
9403	1.039	9453	1.033
9404	1.039	9454	1.028
9405	1.041	9455	1.015
9406	1.041	9456	1.030
9407	1.041	9457	1.046
9408	1.043	9458	1.049
9409	1.054	9459	1.046
9410	1.045	9460	1.047
9411	1.042	9461	1.011
9412	1.046	9462	1.0[illegible]
9413	1.043	9463	0.940
9414	1.044	9464	0.889
9415	1.045	9465	0.895
9416	1.046	9466	0.903
9417	1.045	9467	0.900
9418	1.038	9468	0.894
9419	1.041	9469	0.885
9420	1.048	9470	0.896
9421	1.054	9471	0.866
9422	1.045	9514	1.036 --- Light powder from secondary dust collector
9423	1.045		
9424	1.045		
9425	1.047		
9426	1.052		
9427	1.057		
9428	1.039		
9429	1.045		
9430	1.046		
9431	1.048		
9432	1.049		
9433	~~1.045~~ 1.048		
9434	1.049		
9435	1.038		
9436	1.049		
9437	1.048		
9438	1.047		
9439	1.046		
9440	1.063		
9441	1.049		

TABLE II

Mark 15 UO3 Composite Sample Results

Drum Numbers	9092-9102	9103-9112	9113-9122	9123-9132	9133-9142	9143-9142	9153-9162	9163-9172	9173-9181
wt % UO3	97.91	96.26	95.71	94.69	95.17	96.38	96.83	95.82	97.00
wt % U	81.48	80.11	79.65	78.80	79.20	80.21	80.58	79.74	80.72
PARTICLE SIZE									
%Pass 40	88.4	97.1	98.2	97.1	98.0	96.6	99.0	98.7	96.7
%Pass 80	22.8	80.2	87.3	83.3	90.5	87.8	90.5	90.8	82.3
%Pass 325	0.4	7.7	4.8	11.4	11.4	2.9	17.0	10.6	0.4
SPECTOGRAPHIC, ppm									
Al	100	100	100	100	100	100	100	100	100
Ca	5	10	5	5	5	5	5	5	5
Cr	50	75	50	30	30	50	35	25	50
Cu	15	2	2	10	5	2	2	2	15
Fe	190	167	167	133	154	124	89	113	147
Mo	10	10	10	10	10	10	10	10	10
Na	250	300	250	150	175	75	75	90	45
Ni	30	25	25	15	25	25	25	25	25
P	25	25	100	50	100	50	50	25	100
Pb	5	5	5	5	5	5	5	5	5
Si	40	50	40	50	50	75	75	50	75
Pu - ppb	4.51	6.41	4.87	4.85	5.44	3.49	3.44	3.18	1.9
Gross %	122000	107000	87200	68000	65700	54700	50400	56600	51200

Drum Numbers	9182-9190	9192-9201	9202-9211	9212-9221	9222-9231	9232-9241	9242-9251	9252-9261	9262-9270
wt % UO3	96.68	95.95	96.64	95.30	94.29	96.68	95.64	97.40	97.48
wt % U	80.46	79.25	80.42	79.31	78.47	80.46	79.59	81.06	81.12
PARTICLE SIZE									
%Pass 40	97.5	97.8	99.5	97.1	99.4	98.5	99.2	98.1	98.[illegible]
%Pass 80	82.6	81.7	86.1	77.0	89.8	85.9	84.8	84.7	79.[illegible]
%Pass 325	18.0	11.5	17.1	38.0	18.6	9.9	8.0	11.0	14.[illegible]
SPECTOGRAPHIC, ppm									
Al	100	50	100	100	30	20	50	50	20
Ca	5	5	5	5	5	5	8	5	5
Cr	50	35	40	100	30	30	40	75	25
Cu	2	2	25	2	2	2	5	2	2
Fe	72	100	36	152	111	323	80	100	[illegible]
Mo	10	10	10	10	10	10	10	10	[illegible]
Na	20	10	10	20	10	10	10	10	[illegible]
Ni	25	25	10	30	15	20	20	40	25
P	100	100	150	100	100	100	150	150	10[illegible]
Pb	5	5	5	5	5	5	5	5	[illegible]
Si	75	100	10	10	10	10	10	50	[illegible]
Pu - ppb	2.56	1.95	1.86	3.33	1.90	9.52	1.14	1.86	2.95
Gross %	51200	48100	46500	54400	45700	46700	49200	45800	472[illegible]

TABLE II (cont'd)

Mark 15 UO3 Composite Sample Results

Drum Numbers	9271-9277	9278-9287	9288-9297	9298-9317	9308-9314	9315-9324	9325-9334	9335-9344	9345-9354
wt % UO3	96.67	98.83	96.55	96.64	96.01	95.02	96.38	97.44	97.18
wt % U	81.5	90.00	85.70	80.42	79.90	79.08	80.21	81.09	80.87
PARTICLE SIZE									
%Past 40	98.4	98.9	98.6	97.0	99.0	97.2	96.7	98.4	99.1
%Past 80	81.5	90.0	85.7	79.1	89.4	83.3	78.6	84.7	83.5
%Past 325	10.1	31.0	28.7	20.9	30.5	22.0	19.5	27.1	13.2
SPECTOGRAPHIC, ppm									
Al	---	40	40	50	40	20	100	100	70
Ca	---	8	10	5	8	5	5	5	5
Cr	---	50	50	75	25	50	40	25	50
Cu	---	2	2	2	2	5	2	2	2
Fe	---	97	92	180	56	85	86	48	80
Mo	---	10	10	10	10	10	10	10	10
Na	---	10	10	10	10	10	10	10	20
Ni	---	15	25	50	15	15	15	15	25
P	---	100	100	100	100	100	100	100	90
Pb	---	5	5	5	5	5	5	5	5
Si	---	10	10	150	10	10	10	10	75
Pu - ppb	1.95	2.24	1.48	0.95	1.95	1.05	0.33	1.24	1.62
Gross %	46500	47500	48500	47200	46400	44700	45300	47800	40600

Drum Numbers	9355-9364	9365-9370	9371-9380	9381-9390	9391-9400	9401-9410	9411-9420	9421-9430	9431-9440
wt % UO3	96.45	96.83	96.66	97.02	97.28	97.40	96.79	97.16	97.1[illegible]
wt % U	60.27	90.58	80.44	80.74	80.96	81.06	80.55	80.86	80.8[illegible]
PARTICLE SIZE									
%Past 40	99.4	97.8	97.2	96.8	98.7	97.3	99.2	92.7	98.[illegible]
%Past 80	95.9	77.2	78.2	75.8	77.5	78.5	83.6	72.4	85.[illegible]
%Past 325	15.6	1.2	5.3	1.5	2.3	4.3	4.9	1.2	[illegible]
SPECTOGRAPHIC, ppm									
Al	100	20	50	25	50	---	100	100	[illegible]
Ca	5	5	10	5	5	---	5	5	[illegible]
Cr	30	20	30	40	40	---	25	25	[illegible]
Cu	2	2	5	2	2	---	2	2	[illegible]
Fe	60	50	49	38	35	---	34	29	[illegible]
Mo	10	10	40	10	10	---	10	10	[illegible]
Na	10	10	10	10	10	---	10	10	[illegible]
Ni	10	25	10	10	10	---	15	10	[illegible]
P	100	90	100	100	100	---	100	50	[illegible]
Pb	5	5	5	5	5	---	5	5	[illegible]
Si	100	75	10	10	10	---	10	10	[illegible]
Pu - ppb	8.57	2.48	7.76	1.28	1.71	0.62	1.19	0.95	[illegible]
Gross %	45000	45300	48000	41100	46200	44600	44900	45200	[illegible]

TABLE II (cont'd)

Mark 15 UO3 Composite Sample Results

Drum Numbers	9441-9450	9451-9460
wt % UO3	97.10	97.16
wt % U	80.81	80.86
PARTICLE SIZE		
%Past 40	99.2	98.4
%Past 80	81.8	77.5
%Past 325	12.4	2.4
SPECTOGRAPHIC, ppm		
Al	30	100
Ca	5	5
Cr	25	50
Cu	2	5
Fe	31	200
Mo	10	10
Na	10	20
Ni	10	30
P	50	100
Pb	5	5
Si	10	100
Pu - ppb	1.09	0.80
Gross %	45600	46500

ATTACHMENT 3

OCCUPATIONAL SAFETY AND HEALTH GUIDELINE FOR URANIUM AND INSOLUBLE COMPOUNDS

INTRODUCTION

This guideline summarizes pertinent information about uranium and insoluble uranium compounds (measured as uranium) for workers and employers as well as for physicians, industrial hygienists, and other occupational safety and health professionals who may need such information to conduct effective occupational safety and health programs. Recommendations may be superseded by new developments in these fields; readers are therefore advised to regard these recommendations as general guidelines and to determine periodically whether new information is available.

APPLICABILITY

This guideline applies to metallic uranium and all insoluble uranium compounds; examples of such compounds include triuranium octaoxide, uranium dioxide, uranium hydride, uranium tetrafluoride, and uranium trioxide. The physical and chemical properties of uranium and of some insoluble uranium compounds are presented below for illustrative purposes.

SUBSTANCE IDENTIFICATION

Metallic uranium

* Formula

U

* Structure

(For Structure, see paper copy)

* Synonyms

U; Uranium metal, pyrophoric; uranium.

* Identifiers

1. CAS 7440-61-1.

2. RTECS YR3490000.

3. DOT UN: 2979 65 (for the pyrophoric forms of the metal).

4. DOT labels: Radioactive and Flammable Solid.

* Appearance and odor

Elemental uranium is a heavy, malleable, silvery white, lustrous, radioactive metal that is pyrophoric when finely divided. When uranium is obtained by reduction, it takes the form of a black powder. In its natural state, uranium has three isotopes: (234)U, (235) U, and (238)U. U-238 has a half life of 4,510,000,000 years.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Atomic number: 92.

2. Atomic weight: 238.03.

3. Boiling point (760 torr): 3818 degrees C (6904 degrees F).

4. Specific gravity (water = 1): 19.05 + 0.02 at 20 degrees C (68 degrees F).

5. Vapor density: Not applicable.

6. Melting point: 1132.3 degrees C (2070 degrees F).

7. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

8. Solubility: Insoluble in water, alcohol, and alkalies; soluble in acids.

9. Evaporation rate: Not applicable.

Triuranium Octaoxide

* Formula

U(3)O(8)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranium oxide, pitchblende, nasturan, uraninite.

* Identifiers

1. CAS 1317-99-3.

2. RTECS YR3400000.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Triuranium octaoxide is an olive green to black, odorless solid.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 842.1.

2. Boiling point: Not applicable.

3. Specific gravity (water = 1): 8.30 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 1300 degrees C (2372 degrees F) (decomposes to uranium dioxide).

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water; soluble in nitric and sulfuric acids.

8. Evaporation rate: Not applicable.

Uranium dioxide

* Formula

UO(2)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranous oxide, black uranium oxide, uranium oxide, uranic oxide, urania, yellow cake.

* Identifiers

1. CAS 1344-57-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium dioxide is a pyrophoric, black, crystalline solid. It occurs naturally in various minerals including uraninite, pitchblende, and tyuyamunite. The latter is the most important mineral commercially.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 270.03.

2. Boiling point: Data not available.

3. Specific gravity (water = 1): 10.96 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 2858-2898 degrees C (5176-5248 degrees F).

6. Vapor pressure: Not applicable.

7. Solubility: Insoluble in water; soluble in concentrated sulfuric acid and nitric acid.

8. Evaporation rate: Not applicable.

Uranium hydride

* Formula

UH(3)

* Structure

(For Structure, see paper copy)

* Synonyms

Uranium trihydride.

* Identifiers

1. CAS 13598-56-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium hydride is a brownish-black or brownish-gray, pyrophoric powder.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 241.05.

2. Boiling point (760 torr): Not applicable.

3. Specific gravity (water = 1): 10.95 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: Decomposes.

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water, alcohol, acetone, or liquid ammonia; slightly soluble in dilute hydrogen chloride; decomposes in nitric acid.

8. Evaporation rate: Not applicable.

Uranium tetrafluoride

* Formula

$UF(4)$

* Structure

(For Structure, see paper copy)

* Synonyms

Green salt.

* Identifiers

1. CAS 10049-14-6.

2. RTECS: None.

3. Specific DOT number: None.

4. Specific DOT label: None.

* Appearance and odor

Uranium tetrafluoride is a nonvolatile, green, odorless, crystalline solid.

CHEMICAL AND PHYSICAL PROPERTIES

* Physical data

1. Molecular weight: 314.

2. Boiling point (760 torr): 1417 degrees C (2582 degrees F).

3. Specific gravity (water = 1): 6.7 at 20 degrees C (68 degrees F).

4. Vapor density: Not applicable.

5. Melting point: 955-965 degrees C (1751-1769 degrees F).

6. Vapor pressure at 20 degrees C (68 degrees F): Nearly zero.

7. Solubility: Insoluble in water; soluble (decomposes) in concentrated acids and alkalies.

8. Evaporation rate: Not applicable.

* Reactivity

1. Conditions contributing to instability: Heat, flame, or exposure to air. Uranium metal reacts with nearly all nonmetals. Uranium turnings and fines stored out-of-doors in closed containers under water or water-soluble oil will convert partially to the hydride and will eventually ignite during hot weather.

2. Incompatibilities: Pure uranium is very reactive and is a strong reducing agent. Clean uranium turnings or chips oxidize readily in air. Contact of uranium with carbon dioxide,

carbon tetrachloride, or nitric acid causes fires or explosions. Uranium hydride is spontaneously flammable in air, and contact of the hydride with strong oxidizers may cause fires and explosions. Contact of uranium hydride with water forms flammable and explosive hydrogen gas, and contact of the hydride with halogenated hydrocarbons can cause violent reactions. In finely divided form, uranium dioxide ignites spontaneously in air.

3. Hazardous decomposition products: Toxic particulates, gases, and vapors (such as uranium metal fume, oxides of uranium, hydrogen fluoride, carbon monoxide, and dangerous radioactive materials) may be released when uranium or an insoluble uranium compound decomposes.

4. Special precautions: Uranium is radioactive and highly reactive and should be handled with extreme caution at all times. Uranium tetrafluoride is highly corrosive.

* Flammability

The National Fire Protection Association has not assigned a flammability rating to uranium or the insoluble uranium compounds. Other sources rate uranium in solid or powder form as a very dangerous fire hazard when this substance is exposed to heat or open flame.

1. Flash point: Data not available.

2. Autoignition temperature: The ignition temperature depends on the extent to which the metal is subdivided. The ignition temperature of the metal is 170 degrees C (338 degrees F) (if oxygen is present); finely divided uranium metal (dust) ignites at room temperature (20 degrees C (68 degrees F)).

3. Flammable limits in air: Not applicable.

4. Minimum explosive concentration: 60 g/m(3).

5. Extinguishant: Use graphite chips, carbon dust, asbestos blankets, or flooding with water to extinguish small uranium fires. There is no effective way to extinguish large uranium fires.

Fires involving uranium or an insoluble uranium compound should be fought upwind and from the maximum distance possible. Keep unnecessary people away; isolate hazard area and deny entry. Emergency personnel should stay out of low areas and ventilate closed spaces before entering. Finely divided uranium (chips, turnings, shavings, etc.) are much more reactive than uranium in bulk form. If these are present during a fire, do not disperse them into a dust cloud, which may be explosive. Uranium metal may ignite spontaneously if exposed to air or other substances, may burn rapidly with a flare-burning effect, and may re-ignite after the fire has been extinguished. Containers of uranium or an insoluble uranium compound may explode in the heat of the fire and should be moved from the fire area if it is possible to do so safely. If this is not possible, cool containers from the sides with water until well after the fire is out. Stay away from the ends of containers. Personnel should withdraw immediately if a rising sound from a venting safety device is heard or if there is discoloration of a container due to fire. Dikes should be used to contain fire-control water for later disposal. If a tank car or truck is involved in a fire, personnel should isolate an area of a half a mile in all directions. Delay cleanup until arrival of, or instruction from, a qualified radiation authority. Firefighters should wear a full set of protective clothing, including a self-contained breathing apparatus, when fighting fires involving uranium or an insoluble uranium compound. Firefighters' protective clothing may provide limited protection against fires involving uranium or an insoluble uranium compound.

* Warning properties

No quantitative data are available on the odor threshold for uranium or insoluble uranium compounds; several of these substances are odorless. For the purpose of selecting appropriate respiratory protection, these substances are therefore considered to have inadequate odor warning properties.

* Eye irritation properties

No quantitative data are available on the eye irritation threshold for uranium or the insoluble uranium compounds.

EXPOSURE LIMITS

The current Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) for uranium and the insoluble uranium compounds (measured as uranium) are 0.2 milligram per cubic meter (mg/m(3)) of air as an 8-hour time-weighted average (TWA) concentration and 0.6 mg/m(3) as a 15-minute TWA short-term exposure limit (STEL). A STEL is the maximum 15-minute concentration to which workers may be exposed during any 15-minute period of the working day [29 CFR 1910.1000, Table Z-1-A]. The National Institute for Occupational Safety and Health (NIOSH) has not issued a recommended exposure limit (REL) for uranium or its insoluble uranium compounds; however, NIOSH concurs with the PEL established for this substance by OSHA [NIOSH 1988]. The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned uranium and the insoluble uranium compounds a threshold limit value (TLV) of 0.2 mg/m(3) as a TWA for a normal 8-hour workday and a 40-hour workweek and a short-term exposure limit (STEL) of 0.6 mg/m (3) for periods not to exceed 15 minutes [ACGIH 1988, p. 37]. The OSHA and ACGIH limits are based on the risk of kidney and blood disorders and on the radiological damage associated with exposure to uranium or an insoluble uranium compound.

HEALTH HAZARD INFORMATION

* Routes of exposure

Exposure to uranium or an insoluble uranium compound can occur via inhalation, ingestion, and eye or skin contact. Exposure to uranium trioxide can occur by absorption through the skin, eyes, and mucous membranes.

* Summary of toxicology

1. Effects on Animals: Metallic uranium and insoluble uranium compounds may produce both chemical poisoning and radiation injury to the kidneys and lungs of exposed animals [Clayton and Clayton 1981, p. 1996]. The insoluble uranium compounds are less toxic chemically than the soluble compounds, but uranium and all uranium compounds have the potential to cause radiation damage [Clayton and Clayton 1981, p. 2000; Klaassen, Amdur, and Doull 1986, p. 695]. The inhalation toxicity of uranium and the insoluble compounds of uranium is much greater than their oral toxicity [Clayton and Clayton 1981, p. 2000]. No dietary amount of insoluble uranium compounds acceptable to rats was lethal, and no evidence of systemic poisoning developed after the application of an insoluble compound to rabbit skin [Clayton and Clayton 1981, p. 2000]. However, uranium trioxide is lethal when placed in the conjunctival sac of rabbits' eyes, and uranium tetrafluoride causes direct eye injury [Grant 1986, p. 965]. Acute inhalation exposure to 20-mg/m(3) concentrations of uranium tetrafluoride, uranium dioxide, or high-grade uranium ore was occasionally fatal to some laboratory animals; exposure to a 2.5-mg/m(3) concentration of uranium tetrafluoride, uranium dioxide, or high-grade uranium ore caused mild or no renal damage and no fatalities in these animals [Clayton and Clayton 1981, p. 2001]. Chronic inhalation exposure to an insoluble uranium compound may produce radiation injury. In dogs and monkeys exposed to 5 mg/m(3) uranium dioxide for 6 hours/day, 5 days/week for up to 5 years, fibrotic changes suggestive of radiation injury were found in the tracheobronchial lymph nodes of both species and in the lungs of monkeys. No kidney damage was observed in these animals [Clayton and Clayton 1981, p. 2002]. Dogs tolerated inhalation of a 10-

mg/m(3) concentration of uranium dioxide every day for 1 year and dietary exposure to 10 g/kg/day for 1 year [Clayton and Clayton 1981, pp. 2001-2002]. Rats injected with metallic uranium in the femoral bone marrow and chest wall developed site-of-contact sarcomas; in these cases, the effects of chemical injury could not be distinguished from those of radiation damage [Clayton and Clayton 1981, p. 2003].

2. Effects on Humans: Metallic uranium and insoluble uranium compounds may produce both chemical poisoning and radiation injury [Clayton and Clayton 1981, p. 1996]. The insoluble uranium compounds are less toxic chemically than the soluble compounds, but uranium and all uranium compounds have the potential to cause radiation damage [Clayton and Clayton 1981, p. 2000; Klaassen, Amdur, and Doull 1986, p. 695]. Exposure to the dusts of uranium or to an insoluble uranium compound may cause respiratory irritation, cough, and shortness of breath [Genium MSDS 1988, No. 238]. Dermatitis has also been reported, and prolonged skin contact causes radiation injury to the basal cells [Proctor, Hughes, and Fischman 1988, p. 502]. Studies have shown that uranium workers are at increased risk of death from respiratory, lymphatic, and hematopoietic cancers; these deaths are presumed to be caused by radiation injury from radon gas, a byproduct of uranium decay [Rom 1983, p. 688]. A study of the risk of respiratory deaths among uranium miners in the United States showed the following dose-response: miners exposed occupationally for 5 to 9.9 years had a 2-fold increase in risk; miners exposed for 10 to 24.9 years had a 3.6-fold increase in risk; and those exposed for greater than 24.9 years had a 3.75-fold increase in risk. Smoking was shown both to increase the risk of death from respiratory disease and to shorten the neoplastic latency period [Clayton and Clayton 1981, pp. 2010-2011].

* Signs and symptoms of exposure

1. Acute exposure: The signs and symptoms of acute exposure to uranium or an insoluble uranium compound include respiratory irritation, cough, and shortness of breath.

2. Chronic exposure: The signs and symptoms of chronic exposure to uranium or an insoluble uranium compound include those of lung damage: shortness of breath, dry or productive cough, rales, cyanosis, and clubbing of the fingers. Long-term exposure also may cause cancer of the blood-forming system, the lymph system, and the respiratory tract, as well as anemia and leukopenia. The signs and symptoms of uranium-induced dermatitis may include irritation, redness, blistering, thickening, or hyperpigmentation of the skin.

* Emergency procedures:

In the event of an emergency, remove the victim from further exposure, send for medical assistance, and initiate the following emergency procedures:

1. Eye exposure: If uranium or an insoluble uranium compound gets into the eyes, immediately flush the eyes with large amounts of water for a minimum of 15 minutes, lifting the lower and upper lids occasionally. If irritation persists, get medical attention as soon as possible.

2. Skin exposure: If uranium or an insoluble uranium compound contacts the skin, the contaminated skin should be washed with soap and water. Contaminated body surfaces should immediately be decontaminated in accordance with radiation procedures. Get medical attention.

3. Inhalation: If uranium or an insoluble uranium compound is inhaled, move the victim at once to fresh air and get medical care as soon as possible. If the victim is not breathing, perform cardiopulmonary resuscitation; if breathing is difficult, give oxygen. Keep the victim warm and quiet until medical help arrives.

4. Ingestion: If uranium or an insoluble uranium compound is ingested, give the victim several glasses of water to drink and then induce vomiting by having the victim touch

the back of the throat with the finger or by giving syrup of ipecac as directed on the package. Do not force an unconscious or convulsing person to drink liquids or to vomit. Get medical help immediately. Keep the victim warm and quiet until medical help arrives.

5. Rescue: Remove an incapacitated worker from further exposure and implement appropriate emergency procedures (e.g., those listed on the Material Safety Data Sheet required by OSHA's Hazard Communication Standard, 29 CFR 1910.1200). All workers should be familiar with emergency procedures and the location and proper use of emergency equipment.

EXPOSURE SOURCES AND CONTROL METHODS

The following operations may involve uranium and insoluble uranium compounds and lead to worker exposures to these substances:

- Mining, grinding, and milling of uranium ores
- Use in nuclear reactors as fuel and to pack nuclear fuel rods and in the production of nuclear weapons
- Burning of uranium metal chips and smelting operations
- Use in the ceramics industry for pigments, coloring porcelain, painting on porcelain, and enamelling
- Use as catalysts for many reactions, in gas manufacture, and in production of fluorescent glass
- Use in photographic processes, for alloying steel, in radiation shielding, and in aircraft counterweights
- Use as a source of plutonium and radium salts

Uranium hydride:

* Use as a lab source for pure hydrogen, for separation of hydrogen isotopes, and as a reducing agent

Methods that are effective in controlling worker exposures to uranium and insoluble uranium compounds, depending on the feasibility of implementation, are

- Process enclosure,
- Local exhaust ventilation,
- General dilution ventilation, and
- Personal protective equipment.

The following publications are good sources of information on control methods:

1. ACGIH [1986]. Industrial ventilation--a manual of recommended practice. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

2. Burton DJ [1986]. Industrial ventilation--a self study companion. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

3. Alden JL, Kane JM [1982]. Design of industrial ventilation systems. New York, NY: Industrial Press, Inc.

4. Wadden RA, Scheff PA [1987]. Engineering design for control of workplace hazards. New York, NY: McGraw-Hill.

5. Plog BA [1988]. Fundamentals of industrial hygiene. Chicago, IL: National Safety Council.

MEDICAL MONITORING

Workers who may be exposed to chemical and radiation hazards should be monitored in a systematic program of medical surveillance that is intended to prevent occupational injury and disease. The program should include education of employers and workers about work-related hazards, placement of workers in jobs that do not jeopardize their safety or health, early detection of adverse health effects, and referral of workers for diagnosis and treatment. The occurrence of disease or other work-related adverse health effects should prompt immediate evaluation of primary preventive measures (e.g., industrial hygiene monitoring, engineering controls, and personal protective equipment). A medical monitoring program is intended to supplement, not replace, measures. To place workers effectively and to detect and control work-related health effects, medical evaluations should be performed (1) before job placement, (2) periodically during the period of employment, and (3) at the time of job transfer or termination.

* Preplacement medical evaluation

Before a worker is placed in a job with a potential for exposure to uranium or an insoluble uranium compound, the examining physician should evaluate and document the worker's baseline health status with thorough medical, environmental, and occupational histories, a physical examination, and physiologic and laboratory tests appropriate for the anticipated occupational risks. These should concentrate on the function and integrity of the kidneys, respiratory system, blood, liver, bone marrow, skin, and lymphatics. Medical monitoring for respiratory disease should be conducted using the principles and methods recommended by NIOSH and the American Thoracic Society.

A preplacement medical evaluation is recommended to assess an individual's suitability for employment at a specific job and to detect and assess medical conditions that may be aggravated or may result in increased risk when a worker is exposed to uranium or an insoluble uranium compound at or below the prescribed exposure limit. The examining physician should consider the probable frequency, intensity, and duration of exposure as well as the nature and degree of any applicable medical condition. Such conditions (which should not be regarded as absolute contraindications to job placement) include a history and other findings consistent with diseases of the kidneys, respiratory system, blood, liver, bone marrow, skin, or lymphatics.

* Periodic medical examinations and biological monitoring

Occupational health interviews and physical examinations should be performed at regular intervals during the employment period, as mandated by any applicable State, or local standard. Where no standard exists and the hazard is minimal, evaluations should be conducted every 3 to 5 years or as frequently as recommended by an experienced occupational health physician. Additional examinations may be necessary if a worker develops symptoms attributable to uranium exposure. The interviews, examinations, and medical screening tests should focus on identifying the adverse effects of uranium on the kidneys, respiratory system, blood, liver, bone marrow, skin, or lymphatics. Current health status should be compared with the baseline health status of the individual worker or with expected values for a suitable reference population.

Biological monitoring involves sampling and analyzing body tissues or fluids to provide an index of exposure to a toxic substance or metabolite. Urinary uranium concentrations correlate well with airborne uranium levels. Some sources report that urinary concen-trations of 50 þg uranium per liter of urine or 100 þg uranium per liter of urine correspond to constant daily exposures of approximately 0.05 mg/m(3) or 0.25 mg/m(3), respectively. Because there is great interindividual and intraindividual variability in urinary uranium concentrations, a pattern of urinary uranium excretion should be established for every exposed worker by sampling individuals at the same time on several different shifts and by sampling frequently.

* Medical examinations recommended at the time of job transfer or termination

The medical, environmental, and occupational history interviews, the physical examination, and selected physiologic or laboratory tests that were conducted at the time of placement should be repeated at the time of job transfer or termination to determine the worker's medical status at the end of his or her employment. Any changes in the worker's health status should be compared with those expected for a suitable reference population. Because occupational exposure to uranium or an insoluble uranium compound may cause diseases with prolonged latent periods, the need for medical monitoring may extend well beyond the termination of employment.

WORKPLACE MONITORING AND MEASUREMENT PROCEDURES

Determination of a worker's exposure to airborne uranium or an insoluble uranium compound (measured as uranium) is made using a mixed cellulose ester filter (0.8 micron). Samples are collected at a maximum flow rate of 2 liters per minute until a maximum air volume of 960 liters is collected. Analysis is conducted by neutron activation. This method is included in the OSHA In-House Methods File.

PERSONAL HYGIENE PROCEDURES

If uranium or an insoluble uranium compound contacts the skin, workers should immediately wash the affected areas with soap and water. Contaminated body surfaces should immediately be decontaminated in accordance with radiation procedures.

Clothing contaminated with uranium or an insoluble uranium compound should be removed immediately, and provisions should be made for the safe removal of the chemical from the clothing. Persons laundering the clothes should be informed of the toxic and radioactive hazards of uranium.

A worker who handles uranium or an insoluble uranium compound should thoroughly wash hands, forearms, and face with soap and water before eating, using tobacco products, or using toilet facilities.

Workers should not eat, drink, or use tobacco products in areas where uranium or an insoluble uranium compound is handled, processed, or stored.

STORAGE

Uranium and insoluble uranium compounds should be stored in a cool, dry, well-ventilated area in tightly sealed containers that are labeled in accordance with OSHA's Hazard Communication Standard [29 CFR 1910.1200]. Containers of uranium or of insoluble uranium compounds should be protected from physical damage and should be stored separately from carbon dioxide, carbon tetra-chloride, nitric acid, air, nonmetals, heat, sparks, and open flame. Uranium hydride should not be allowed to contact air, water, strong oxidizers, or halogenated hydrocarbons. Because empty containers that formerly contained uranium or a uranium compound may still hold product residues, they should be handled appropriately.

SPILLS AND LEAKS

In the event of a spill or leak involving uranium or an insoluble uranium compound, persons not wearing protective equipment and clothing should be restricted from contaminated areas until cleanup has been completed. A clean-up plan must be available to address an accidental leak or spill of uranium or an insoluble uranium compound because special radiation procedures are required and professional assistance is needed. The following steps should be undertaken following a spill or leak:

1. Do not touch the spilled material; stop the leak if it is possible to do so without risk.

2. Notify safety personnel.

3. Remove all sources of heat and ignition.

4. Ventilate the area of the spill or leak.

5. Protect cleanup personnel from contact with or inhalation of uranium dust.

EMERGENCY PLANNING, COMMUNITY RIGHT-TO-KNOW, AND HAZARDOUS WASTE MANAGEMENT REQUIREMENTS

The Environmental Protection Agency's (EPA's) regulatory requirements for emergency planning, community right-to-know, and hazardous waste management may vary over time. Users are therefore advised to determine periodically whether new information is available.

* Emergency planning requirements

Uranium and insoluble uranium compounds are not subject to EPA emergency planning requirements under the Superfund Amendments and Reauthorization Act (Title III).

* Reportable quantity requirements (releases of hazardous substances)

Employers are not required by the emergency release notification provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [40 CFR Part 355.40] to notify the National Response Center of an accidental release of uranium or an insoluble uranium compound; there is no reportable quantity for these substances.

* Community right-to-know requirements

Employers are not required by Section 313 of the Superfund Amendments and Reauthorization Act (SARA) to submit a Toxic Chemical Release Inventory form (Form R) to EPA reporting the amount of uranium or an insoluble uranium compound emitted or released from their facility annually.

* Hazardous waste management requirements

EPA considers a waste to be hazardous if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity, or toxicity, as defined in 40 CFR 261.21-261.24. Under the Resource Conservation and Recovery Act (RCRA), EPA has specifically listed many chemical wastes as hazardous. Although uranium and insoluble uranium compounds are not specifically listed as a hazardous waste under RCRA, EPA requires employers to treat any waste as hazardous if it exhibits any of the characteristics discussed above.

Providing more information about the removal and disposal of specific chemicals is beyond the scope of this guideline. EPA, U.S. Department of Transportation, and State and local regulations should be followed to ensure that removal, transport, and disposal of this substance are conducted in accordance with existing regulations. To be certain that chemical waste disposal meets EPA regulatory requirements, employers should address any questions to the RCRA hotline at (202) 382-3000 (in Washington, D.C.) or toll-free at (800) 424-9346 (outside Washington, D.C.). In addition, relevant State and local authorities should be contacted for information on any requirements they may have for the waste removal and disposal of this substance.

RESPIRATORY PROTECTION

* Conditions for respirator use

Good industrial hygiene practice requires that engineering controls be used where feasible to reduce workplace concentrations of hazardous materials to the prescribed

exposure limit. However, some situations may require the use of respirators to control exposure. Respirators must be worn if the ambient concentration of uranium or an insoluble uranium compound exceeds prescribed exposure limits. Respirators may be used (1) before engineering controls have been installed, (2) during work operations such as maintenance or repair activities that involve unknown exposures, (3) during operations that require entry into tanks or closed vessels, and (4) during emergency situations. If the use of respirators is necessary, the only respirators permitted are those that have been approved by NIOSH and the Mine Safety and Health Administration (MSHA).

* Respiratory protection program

Employers should institute a complete respiratory protection program that, at a minimum, complies with the requirements of OSHA's Respiratory Protection Standard [29 CFR 1910.134]. Such a program must include respirator selection (see Table 1), an evaluation of the worker's ability to perform the work while wearing a respirator, the regular training of personnel, fit testing, periodic workplace monitoring, and regular respirator maintenance, inspection, and cleaning. The implementation of an adequate respiratory protection program (including selection of the correct respirator) requires that a knowledgeable person be in charge of the program and that the program be evaluated regularly. For additional information on the selection and use of respirators and on the medical screening of respirator users, consult the **NIOSH Respirator Decision Logic** and the **NIOSH Guide to Industrial Respiratory Protection.**

Table 1 lists the respiratory protection that NIOSH recommends for workers exposed to uranium or an insoluble uranium compound. The recommended protection may vary over time because of changes in the exposure limit for uranium or the insoluble uranium compounds or in respirator certification requirements. Users are therefore advised to determine periodically whether new information is available.

PERSONAL PROTECTIVE EQUIPMENT

Protective clothing should be worn to prevent skin contact with uranium or an insoluble uranium compound. Impervious gloves, boots, and aprons should be worn as appropriate when handling any of these substances. Chemical protective clothing should be selected on the basis of available performance data, manufacturers' recommendations, and evaluation of the clothing under actual conditions of use. No reports have been published on the resistance of various protective clothing materials to permeation by uranium or an insoluble uranium compound; however, one source recommends natural rubber, neoprene, or polyvinyl chloride as a protective clothing material. If permeability data are not readily available, protective clothing manufacturers should be requested to provide information on the best chemical protective clothing for workers to wear when they are exposed to uranium or an insoluble uranium compound.

If uranium or an insoluble uranium compound is dissolved in an organic solvent, the permeation properties of both the solvent and the mixture must be considered when selecting personal protective equipment and clothing.

Safety glasses, goggles, or faceshields should be worn during operations in which uranium or an insoluble uranium compound might contact the eyes. Eyewash fountains and emergency showers should be available within the immediate work area whenever the potential exists for eye or skin contact with uranium or its insoluble compounds. Contact lenses should not be worn if the potential exists for exposure to any of these substances.

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Table 1
NIOSH recommended respiratory protection for workers exposed to uranium or an insoluble uranium compound*

Condition	Minimum respiratory protection**
Airborne concentration of uranium or an insoluble uranium compound:	
0.2 to 2 mg/m(3) (10 X PEL)	Any air-purifying, half-mask respirator equipped with a fume or high-efficiency filter approved for radon daughters or radionuclides, or
	Any air-purifying, full-facepiece respirator equipped with a fume filter approved for radon daughters, or
	Any supplied-air respirator equipped with a half mask and operated in a demand (negative-pressure) mode
0.2 to 5 mg/m(3) (25 X PEL)	Any powered, air-purifying respirator equipped with a hood or helmet and a fume or high-efficiency filter approved for radon daughters or radio-nuclides, or
	Any supplied-air respirator equipped with a hood or helmet and operated in a continuous-flow mode
0.2 to 10 mg/m(3) (50 X PEL)	Any air-purifying, full-facepiece respirator equipped with a high-efficiency filter approved for radon daughters or radio-nuclides, or
	Any powered, air-purifying respirator equipped with a tight-fitting facepiece and a high-efficiency filter approved for

	radon daughters or radio-nuclides, or Any supplied-air respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode, or Any supplied-air respirator equipped with a tight-fitting facepiece and operated in a continuous-flow mode, or Any self-contained respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode
0.2 to 30 mg/m(3) (150 X PEL)	Any supplied-air respirator operated in a pressure-demand or other positive-pressure mode
Entry into IDLH(+) or unknown concentrations	Any self-contained respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode, or Any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode
Firefighting	Any self-contained respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode
Escape	Any air-purifying, full-facepiece respirator equipped with a high-efficiency filter approved for radon daughters or radionuclides, or Any escape-type, self-contained breathing apparatus with a suitable service life (number of minutes required to escape the environment)

* The OSHA PEL is 0.2 mg/m(3) as an 8-hour TWA. No NIOSH REL has been issued.

** Only NIOSH/MSHA-approved equipment should be used. Also note the following:

1. Respirators accepted for use at higher concentrations may be used at lower concentrations; respirators must not, however, be used at concentrations higher than those for which they are approved.

2. Air-purifying respirators may not be used in oxygen-deficient atmospheres or in airborne concentrations that are immediately dangerous to life or health (IDLH).

(+) The uranium or an insoluble uranium compound concentration that is immediately dangerous to life and health (IDLH) is 30 mg/m(3) [NIOSH 1987b].

April 5, 2004

ATTACHMENT 4

TO: D. L. McWhorter, 707-7F

FROM: R. P. Taylor, Jr., CCC-2

Technical Reviewer: G. A. McGehee, CCC-2
4-5-04

Spherical Safe Mass Values – Low Enriched UO_3

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Introduction

While performing the nuclear criticality safety evaluation (NCSE) for disposal of drums of UO_3 currently stored in F-Area [1], safe spherical mass values for several different ^{235}U enrichments were calculated. This information was not included in the NCSE, but is documented in this memorandum in the event that it could be of use at some future time.

Methodology

Monte Carlo calculations were used to perform the calculations for the UO_3 spherical safe mass calculations. A configuration controlled version of MCNP 4C was used to perform these calculations. MCNP 4C is a general purpose Monte Carlo radiation transport code that numerically simulates neutral and charged particle transport histories, using continuous energy cross-section libraries and general three-dimensional geometry. The MCNP code was developed by, and is maintained at, the Los Alamos National Laboratory. Configuration control of MCNP 4C is documented for the Washington Safety Management Solutions (WSMS) LINUX workstation cluster in Reference 2. A sample input file for the calculations is provided in Appendix A.

A k_{SAFE} of 0.948 was used as the acceptance criteria for these calculations. The derivation of this k_{SAFE} value and discussion of Area of Applicability (AOA) for this material is documented in Reference 1. Calculated values of $k_{eff} + 2\sigma < k_{SAFE}$ will indicate configurations that are safely subcritical. Configurations with calculated $k_{eff} + 2\sigma \geq k_{SAFE}$ will be considered unacceptable. For this evaluation, σ is defined as the statistical uncertainty associated with the MCNP 4C calculations.

UO_3/water mixtures in spherical geometry are modeled in these calculations. The water content of the mixture is varied from 0 to 40 weight percent so that the point of optimum moderation can be determined. Each sphere is reflected with 30 cm of water. Calculations were performed for ^{235}U enrichment values of 1.084 (the maximum for the stored UO_3), 1.05, 1.0, and 0.99 weight percent ^{235}U. The mass values reported in the results section of this document were determined with the assistance of scoping calculations that are not reported here.

The ENDF/B-VI cross sections supplied with MCNP 4C are used exclusively in these calculations except for the $S(\alpha,\beta)$ cross section for hydrogen in water which is based on ENDF/B-V. The following materials are used in the MCNP calculations for the UO_3 safe mass calculations:

1) Various uranium trioxide (UO_3) solutions are modeled with an isotopic enrichment of 1.084% U-235 (cross sections 92235.60c, 92238.60c, 1001.60c, and 8016.60c). The mass density of UO_3 used is 7.29 g/cm^3 [3] and the mass density of water used is 1.0 g/cm^3. Thermal scattering from the hydrogen in these mixtures is modeled with the 300 K light water $S(\alpha,\beta)$ table (lwtr.01t).

2) Plain water is modeled as 2 atoms of H and 1 atom of O. Cross sections 1001.60c, and 8016.60c and a mass density of 1.0 g/cm^3 are used. Thermal scattering from the hydrogen in water is modeled with the 300 K light water S(α,β) table (lwtr.01t).

Results

The results of the spherical safe mass calculations are provided in Table 1.

Table 1: Spherical Safe Mass Calculation Results

Case ID	Internal H_2O Content, Wt% H_2O	k_{eff}	σ	$k_{eff} + 2\sigma$
5.25 metric tons of UO_3 @ ^{235}U Enrichment = 1.084 wt%,				
ud39	0	0.4736	0.0004	0.4745
ud40	5	0.8142	0.0006	0.8153
ud41	10	0.9235	0.0006	0.9246
ud42	12.5	0.9410	0.0006	0.9421
ud37	15	0.9466	0.0006	0.9477
ud43	17.5	0.9450	0.0005	0.9461
ud44	20	0.9374	0.0005	0.9384
ud45	30	0.8684	0.0004	0.8692
ud46	40	0.7708	0.0004	0.7715
7.5 metric tons of UO_3 @ ^{235}U Enrichment = 1.05 wt%,				
ud57	0	0.4700	0.0005	0.4710
ud58	5	0.8240	0.0006	0.8252
ud59	10	0.9286	0.0005	0.9297
ud60	12.5	0.9440	0.0005	0.9451
ud50	15	0.9451	0.0005	0.9461
ud61	17.5	0.9439	0.0005	0.9449
ud62	20	0.9319	0.0005	0.9329
ud63	30	0.8618	0.0004	0.8627
ud64	40	0.7608	0.0004	0.7615
14.5 metric tons of UO_3 @ ^{235}U Enrichment = 1.00 wt%,				
ud67	0	0.4658	0.0004	0.4667
ud68	5	0.8364	0.0006	0.8375
ud69	10	0.9335	0.0005	0.9346

Table 1: Spherical Safe Mass Calculation Results

Case ID	Internal H_2O Content, Wt% H_2O	k_{eff}	σ	$k_{eff} + 2\sigma$
ud70	12.5	0.9455	0.0005	0.9465
ud66	15	0.9460	0.0005	0.9470
ud71	17.5	0.9387	0.0005	0.9397
ud72	20	0.9287	0.0005	0.9296
ud73	30	0.8514	0.0004	0.8522
ud74	40	0.7471	0.0004	0.7478
17.1 metric tons of UO_3 @ ^{235}U Enrichment = 0.99 wt%,				
ud75	0	0.4639	0.0006	0.4651
ud76	5	0.8415	0.0007	0.8430
ud20	10	0.9341	0.0007	0.9355
ud77	12.5	0.9453	0.0007	0.9467
ud21	15	0.9463	0.0007	0.9476
ud78	17.5	0.9383	0.0007	0.9396
ud22	20	0.9264	0.0006	0.9276
ud79	30	0.8475	0.0005	0.8485
ud80	40	0.7426	0.0005	0.7435

Conclusions

As shown in the results above, the safe spherical mass values for UO_3 at different enrichments are as follows:

1.084 Wt%	5.25 MT
1.05 Wt%	7.5 MT
1.00 Wt%	14.5 MT
0.99 Wt%	17.1 MT

References

1. Taylor, R. P., *Nuclear Criticality Safety Evaluation: Disposal Of Drums Containing UO_3 From F-Area*, N-NCS-F-00108, Revision 0, March 2004.

2. *Software Quality Assurance Implementation Checklist for MCNP 4C*, WSMS-CRT-01-0101, August 2001.

3. Petrie, L. M., Fox, P. B., and Lucius, K., *Standard Composition Library*, NUREG/CR-0200, Revision 5, SCALE Computer System, Volume 3, Section M8, Oak Ridge National Laboratory, Oak Ridge, TN, March, 1997.

Appendix A Sample MCNP 4C Input File

One of the MCNP 4C input files used in the spherical safe mass calculations is provided below. This basic input file was used for all drum calculations with necessary changes to material composition depending on the requirements of the case. File *ud37* models a sphere containing 5.25 metric tons of UO_3 at a ^{235}U enrichment of 1.084 weight percent with sufficient water such that the water content of the sphere is 15 wt% water. The sphere is reflected with 30 cm of water.

File ud37

```
UO3 Disposal,  Evaluator = R. P. Taylor, 3/8/04
c
c     5.25 MT UO3, 1.084% U-235
c     Sphere, 15 wt% H2O, full reflection
1     1  -3.7509     -1                                    imp:n=1
2     2  -1.0000     -2 #1                                 imp:n=1
999   0               2                                    imp:n=0

1    so    73.2551
2    so   103.2551

kcode 2000 1.0 50 575 50000
ksrc   0 0 0
prdmp  3j  1
c    UO3 mixture
m1      92238.60c   -0.699687
        92235.60c   -0.007668
         8016.60c   -0.275861
         1001.60c   -0.016784
mt1      lwtr.01t
c    water
m2       1001.60c    2
         8016.60c    1
mt2      lwtr.01t
```

ATTACHMENT 5

LEUO 55 Gallon Drum IP-1 Container

The information in this report documents the LEUO 55 Gallon Drum IP-1 Container design compliance with 49 CFR requirements for IP-1 packaging. The document contains a 1) Regulatory Compliance Summary and Shipper Duties, and 2) Closing Instructions (Attachment 1).

REGULATORY REQUIREMENT	ACTION REQUIRED AND BY WHOM	COMPLIANCE BY LEUO 55 GALLON DRUM CONTAINER
PART 173--SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart B—Preparation of Hazardous Materials for Transportation Sec. 173.24 General requirements for packagings and packages.		
(a) Applicability. Except as otherwise provided in this subchapter, the provisions of this section apply to— (1) Bulk and non-bulk packagings; (2) New packagings and packagings which are reused; and (3) Specification and non-specification packagings. (b) Each package used for the shipment of hazardous materials under this subchapter shall be designed, constructed, maintained, filled, its contents so limited, and closed, so that under conditions normally incident to transportation—	Shipper to ensure.	This packaging has been evaluated herein and meets DOT IP-1 packaging criteria of 173.411(b). The packaging consists of a 16 gauge 55 gallon galvanized carbon steel drum with three rolling hoops manufactured to the DOT 17C construction specification, 16 gauge removable lid, 12 gauge closure ring with 5/8" diameter bolt and nut, and an elastomer gasket (see FSS-TS-2004-0001 for gasket/materials evaluation).
(1) Except as otherwise provided in this subchapter, there will be no identifiable (without the use of instruments) release of hazardous materials to the environment;	Shipper to ensure. To be considered during package design evaluagtion.	This packaging meets this requirement by confining contents within a carbon steel drum, with elastomer gasket and lid held together by a ring closure with 5/8" bolt and nut.
(2) The effectiveness of the package will not be substantially reduced; for example, impact resistance, strength, packaging compatibility, etc. must be maintained for the minimum and maximum temperatures encountered during transportation;	Shipper to ensure. To be considered during design evaluation.	This packaging meets this requirement by incorporating a commercially supplied, vibration resistant, 55 gallon open head drum.
(3) There will be no mixture of gases or vapors in the package, which could, through any credible spontaneous increase of heat or pressure, significantly reduce the effectiveness of the packaging. (c) Authorized packagings. A packaging is authorized for a hazardous material only if	Shipper to ensure.	Shipper to ensure that contents loaded into package conform to the appropriate content category (e.g. LSA content).

(1) The packaging is prescribed or permitted for the hazardous material in a packaging section specified for that material in Column 8 of the Sec. 172.101 table and conforms to applicable requirements in the special provisions of Column 7 of the Sec. 172.101 table and, for specification packagings (but not including UN standard packagings manufactured outside the United States), the specification requirements in parts 178 and 179 of this subchapter; or (2) The packaging is permitted under, and conforms to, provisions contained in Secs. 171.11, 171.12, 171.12a, 173.3, 173.4, 173.5, 173.7, 173.27, or 176.11 of this subchapter.	Shipper to ensure. Shipper is responsible to ensure that the packaging used is in compliance with this design	This packaging has been qualified herein to meet the IP-1 requirements specified in 49 CFR 173.411(b).
(d) Specification packagings and UN standard packagings manufactured outside the U.S. (1) Specification packagings. A specification packaging, including a UN standard packaging manufactured in the United States, must conform in all details to the applicable specification or standard in part 178 or part 179 of this subchapter.	Shipper responsible to ensure that the packaging hardware used is in compliance with the packaging design.	This packaging has been qualified to meet the IP-1 requirements specified in 49 CFR 173.411(b).
(2) UN standard packagings manufactured outside the United States. A UN standard packaging manufactured outside the United States, in accordance with national or international regulations based on the UN Recommendations (see Sec. 171.7 of this subchapter), may be imported and used and is considered to be an authorized packaging under the provisions of paragraph ©(1) of this section, subject to the following conditions and limitations: (i) The packaging fully conforms to applicable provisions in the UN Recommendations and the requirements of this subpart, including reuse provisions; (ii) The packaging is capable of passing the prescribed tests in part 178 of this subchapter applicable to that standard; and (iii) The competent authority of the country of manufacture provides reciprocal treatment for UN standard packagings manufactured in the U.S.	NA	NA
(e) Compatibility.		

(1) Even though certain packagings are specified in this part, it is, nevertheless, the responsibility of the person offering a hazardous material for transportation to ensure that such packagings are compatible with their lading. This particularly applies to corrosivity, permeability, softening, premature aging and embrittlement.	Shipper to ensure.	Shipper responsible to ensure that the packaging is loaded with contents that are compatible with packaging materials (galvanized steel drum and lid, and elastomer gasket). The packaging materials are durable for many content forms. Shipper to follow QC requirements in 49 CFR 173.475.
(2) Packaging materials and contents must be such that there will be no significant chemical or galvanic reaction between the materials and contents of the package.	Shipper to ensure.	Shipper to ensure chemical compatibility between contents and packaging.
(3) Plastic packagings and receptacles.		
(i) Plastic used in packagings and receptacles must be of a type compatible with the lading and may not be permeable to an extent that a hazardous condition is likely to occur during transportation, handling or refilling.	Shipper to ensure.	NA.
(ii) Each plastic packaging or receptacle which is used for liquid hazardous materials must be capable of withstanding without failure the procedure specified in appendix B of this part ("Procedure for Testing Chemical Compatibility and Rate of Permeation in Plastic Packagings and Receptacles"). The procedure specified in appendix B of this part must be performed on each plastic packaging or receptacle used for Packing Group I materials. The maximum rate of permeation of hazardous lading through or into the plastic packaging or receptacles may not exceed 0.5 percent for materials meeting the definition of a Division 6.1 material according to Sec. 173.132 and 2.0 percent for other hazardous materials, when subjected to a temperature no lower than—	NA	NA
(A) 18 deg.C (64 deg.F) for 180 days in accordance with Test		

Method 1 in appendix B of this part; (B) 50 deg.C (122 deg.F) for 28 days in accordance with Test Method 2 in appendix B of this part; or (C) 60 deg.C (140 deg.F) for 14 days in accordance with Test Method 3 in appendix B of this part. (iii) Alternative procedures or rates of permeation are permitted if they yield a level of safety equivalent to or greater than that provided by paragraph (e)(3)(ii) of this section and are specifically approved by the Associate Administrator.		
(4) Mixed contents. Hazardous materials may not be packed or mixed together in the same outer packaging with other hazardous or nonhazardous materials if such materials are capable of reacting dangerously with each other and causing— (i) Combustion or dangerous evolution of heat; (ii) Evolution of flammable, poisonous, or asphyxiant gases; or (iii) Formation of unstable or corrosive materials.	<u>Shipper to ensure.</u>	Shipper to ensure.
(5) Packagings used for solids, which may become liquid at temperatures likely to be encountered during transportation, must be capable of containing the hazardous material in the liquid state. (f) Closures. (1) Closures on packagings shall be so designed and closed that under conditions (including the effects of temperature and vibration) normally incident to transportation—	<u>Shipper to ensure.</u>	Shipper to ensure. This packaging is designed for solids only. Damp contents may be loaded into packaging, but shall not result in free standing water.
(i) Except as provided in paragraph (g) of this section, there is no identifiable release of hazardous materials to the environment from the opening to which the closure is applied; and	<u>Shipper to ensure.</u>	Shipper to ensure proper closure instructions are followed. See Attachment 1 for closure instructions.

(ii) The closure is secure and leakproof. (2) Except as otherwise provided in this subchapter, a closure (including gaskets or other closure components, if any) used on a specification packaging must conform to all applicable requirements of the specification.	<u>Shipper to ensure.</u>	Shipper to ensure proper closure instructions are followed. Note: Shipper to follow closure instructions provided in Attachment 1
(g) Venting. Venting of packagings, to reduce internal pressure which may develop by the evolution of gas from the contents, is permitted only when— (1) Transportation by aircraft is not involved; (2) Except as otherwise provided in this subchapter, the evolved gases are not poisonous, likely to create a flammable mixture with air or be an asphyxiant under normal conditions of transportation; (3) The packaging is designed so as to preclude an unintentional release of hazardous materials from the receptacle; and (4) For shipments in bulk packagings, venting is authorized for the specific hazardous material by a special provision in the Sec. 172.101 table or by the applicable bulk packaging specification in part 178 of this subchapter. (h) Outage and filling limits—	<u>NA</u>	There are no vents on this packaging design.
(1) General. When filling packagings and receptacles for liquids, sufficient ullage (outage) must be left to ensure that neither leakage nor permanent distortion of the packaging or receptacle will occur as a result of an expansion of the liquid caused by temperatures likely to be encountered during transportation. Requirements for outage and filling limits for non-bulk and bulk packagings are specified in Secs. 173.24a(d) and 173.24b(a), respectively.	<u>NA</u>	This packaging is not designed for liquids.

(2) Compressed gases and cryogenic liquids. Filling limits for compressed gases and cryogenic liquids are specified in Secs. 173.301 through 173.306 for cylinders and Secs. 173.314 through 173.319 for bulk packagings.		
(i) Air transportation. Packages offered or intended for transportation by aircraft must conform to the general requirements for transportation by aircraft in Sec. 173.27, except as provided in Sec. 171.11 of this subchapter.	NA	This packaging is not designed for air transport.
PART 173—SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart B—Preparation of Hazardous Materials for Transportation Sec. 173.24a Additional general requirements for non-bulk packagings and packages. (a) Packaging design. Except as provided in Sec. 172.312 of this subchapter:		
(1) Inner packaging closures. A combination packaging containing liquid hazardous materials must be packed so that closures on inner packagings are upright.	NA	This packaging not designed for liquid contents.
(2) Friction. The nature and thickness of the outer packaging must be such that friction during transportation is not likely to generate an amount of heat sufficient to alter dangerously the chemical stability of the contents.	Designer to do and shipper to ensure.	The LEUO 55 Gallon Drum contents will not be affected by friction induced heat generation. The oxide material (much like sand) is chemically stable and at equilibrium in the drum. There will be minimal friction generated heat. No measurable temperature increase due to friction induced heat generation will occur because of the 1) large thermal mass of the LEUO contents, 2) good conductivity of the metal drum, and 3) relatively small motion that will occur between the contents and metal packaging materials.

(3) Securing and cushioning. Inner packagings of combination packagings must be so packed, secured and cushioned to prevent their breakage or leakage and to control their movement within the outer packaging under conditions normally incident to transportation. Cushioning material must not be capable of reacting dangerously with the Contents of the inner packagings or having its protective properties significantly weakened in the event of leakage.	Designer to do and shipper to ensure.	The LEUO will be confined in an inner 3-6 mil plastic liner within the LEUO 55 gallon drum. The liner is constrained between the contents and the drum so movement is minimal. No containment credit is taken for the liner.
(4) Metallic devices. Nails, staples and other metallic devices shall not protrude into the interior of the outer packaging in such a manner as to be likely to damage inner packagings or receptacles.	Designer to do and shipper to ensure.	The 55 gallon galvanized steel drum has a smooth interior. The LEUO content conforms to the inside of the container and has no metallic feature likely to damage the drum.
(4) Vibration. Each non-bulk package must be capable of withstanding, without rupture or leakage, the vibration test procedure specified in Sec. 178.608 of this subchapter.	Designer to do and shipper to ensure.	Fifty five gallon open head drum packages have been used for decades in transportation and have proven vibration resistance.
(b) Non-bulk packaging filling limits. (1) A single or composite non-bulk packaging may be filled with a liquid hazardous material only when the specific gravity of the material does not exceed that marked on the packaging, or a specific gravity of 1.2 if not marked, except as follows: (i) A Packing Group I packaging may be used for a Packing Group II material with a specific gravity not exceeding the greater of 1.8, or 1.5 times the specific gravity marked on the packaging,	NA	This packaging is not designed for liquid contents.

provided all the performance criteria can still be met with the higher specific gravity material; (ii) A Packing Group I packaging may be used for a Packing Group III material with a specific gravity not exceeding the greater of 2.7, or 2.25 times the specific gravity marked on the packaging, provided all the performance criteria can still be met with the higher specific gravity material; and (iii) A Packing Group II packaging may be used for a Packing Group III material with a specific gravity not exceeding the greater of 1.8, or 1.5 times the specific gravity marked on the packaging, provided all the performance criteria can still be met with the higher specific gravity material.		
(2) Except as otherwise provided in this section, a non-bulk packaging may not be filled with a hazardous material to a gross mass greater than the maximum gross mass marked on the packaging.	Shipper to ensure.	Gross mass shall not exceed the 900 pound capacity of the IP-1 package.
(3) A single or composite non-bulk packaging which is tested and marked for liquid hazardous materials may be filled with a solid hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. In addition: (i) A single or composite non-bulk packaging which is tested and marked for Packing Group I liquid hazardous materials may be filled with a solid Packing Group II hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 1.5, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. (ii) A single or composite non-bulk packaging which is tested and marked for Packing Group I	NA	This packaging is not designed nor tested for liquids.

liquid hazardous materials may be filled with a solid Packing Group III hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 2.25, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked. (iii) A single or composite non-bulk packaging which is tested and marked for Packing Group II liquid hazardous materials may be filled with a solid Packing Group III hazardous material to a gross mass, in kilograms, not exceeding the rated capacity of the packaging in liters, multiplied by 1.5, multiplied by the specific gravity marked on the packaging, or 1.2 if not marked.		
(4) Packagings tested as prescribed in Sec. 178.605 of this subchapter and marked with the hydrostatic test pressure as prescribed in Sec. 178.503(a)(5) of this subchapter may be used for liquids only when the vapor pressure of the liquid conforms to one of the following: (i) The vapor pressure must be such that the total pressure in the packaging (i.e., the vapor pressure of the liquid plus the partial pressure of air or other inert gases, less 100 kPa (15 psia)) at 55 deg.C (131 deg.F), determined on the basis of a maximum degree of filling in accordance with paragraph (d) of this section and a filling temperature of 15 deg.C (59 deg.F)), will not exceed two-thirds of the marked test pressure; (ii) The vapor pressure at 50 deg.C (122 deg.F) must be less than four-sevenths of the sum of the marked test pressure plus 100 kPa (15 psia); or (iii) The vapor pressure at 55 deg.C (131 deg.F) must be less than two-thirds of the sum of the marked test pressure plus 100 kPa (15 psia).	NA	This packaging is not designed for liquid contents.

(5) No hazardous material may remain on the outside of a package after filling.	Shipper to ensure.	Shipper responsible to ensure that instructions are followed to prevent contamination of the outside of the package. Shipper is responsible to ensure that packaging is loaded with appropriate contents and that the drum is closed in accordance with closure instruction.
(c) Mixed contents. (1) An outer non-bulk packaging may contain more than one hazardous material only when— (i) The inner and outer packagings used for each hazardous material conform to the relevant packaging sections of this part applicable to that hazardous material; (ii) The package as prepared for shipment meets the performance tests prescribed in part 178 of this subchapter for the packing group indicating the highest order of hazard for the hazardous materials contained in the package; (iii) Corrosive materials (except ORM-D) in bottles are further packed in securely closed inner receptacles before packing in outer packagings; and	NA	This packaging is not a combination packaging.
(iv) For transportation by aircraft, the total net quantity does not exceed the lowest permitted maximum net quantity per package as shown in Column 9a or 9b, as appropriate, of the Sec. 172.101 table. The permitted maximum net quantity must be calculated in kilograms if a package contains both a liquid and a solid. (2) A packaging containing inner packagings of Division 6.2 materials may not contain other hazardous materials, except dry ice.	NA	This packaging is not designed for air transport.

(d) Liquids must not completely fill a receptacle at a temperature of 55 deg.C (131 deg.F) or less.	NA	This packaging is not designed for liquids.
PART 173—SHIPPERS—GENERAL REQUIREMENTS FOR SHIPMENTS AND PACKAGINGS—Table of Contents Subpart I—Class 7 (Radioactive) Materials Sec. 173.410 General design requirements. In addition to the requirements of subparts A and B of this part, each package used for the shipment of Class 7 (radioactive) materials must be designed so that—		
(a) The package can be easily handled and properly secured in or on a conveyance during transport.	Designer to do and shipper to ensure.	This drum packaging is of standard commercial design and can be handled with commercially available, or appropriate, drum handling equipment. The drum package can be secured in the conveyance by standard blocking/bracing/tie-down methods
(b) Each lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting attachment under excessive load would not impair the ability of the package to meet other requirements of this subpart. Any other structural part of the package which could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport or must be designed with strength equivalent to that required for lifting attachments.	Designer to do and shipper to ensure.	The packaging (drum) is not equipped with lifting attachments. The drum is to be handled/lifted using standard industrial, or appropriate, drum handling methods.
(c) The external surface, as far as practicable, will be free from protruding features and will be easily decontaminated.	Designer to do and shipper to ensure.	The external surfaces are galvanized carbon steel which can be decontaminated. The drum closure ring system is removable to accommodate decontamination

(d) The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect.	Designer to do and shipper to ensure.	This packaging meets the intent of this requirement. The drum design has clean vertical members and a domed lid that enhances water run off and minimizes water collection.
(e) Each feature that is added to the package will not reduce the safety of the package.	Shipper to ensure.	It is a shipper responsibility to contact the CTF (WSRC/Transportation Services) if features need to be added to the current packaging design.
(f) The package will be capable of withstanding the effects of any acceleration, vibration or vibration resonance that may arise under normal conditions of transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use (see Secs. 173.24, 173.24a, and 173.24b).	Designer to do, shipper to ensure.	Extensive transportation experience with 17C drums has demonstrated that single bolt drum closures are vibration resistant.
(h) The materials of construction of the packaging and any components or structure will be physically and chemically compatible with each other and with the package contents. The behavior of the packaging and the package contents under irradiation will be taken into account.	Designer to do, shipper to ensure.	The shipper must ensure application of quality assurance during package closing to ensure compliance. The packaging components (carbon steel drum and lid, elastomer gasket, and ring closure) are physically and chemically compatible with each other. The LEUO contents are furthermore enveloped within a plastic liner. All package materials shall be chemically compatible. Radiation will have no adverse effect on the carbon steel. The elastomer gasket will not degrade due to radiation because of the low LEUO dose rates (typical ~1 mrad/hr vs. typical elastomer 1E3 rad dose limit).

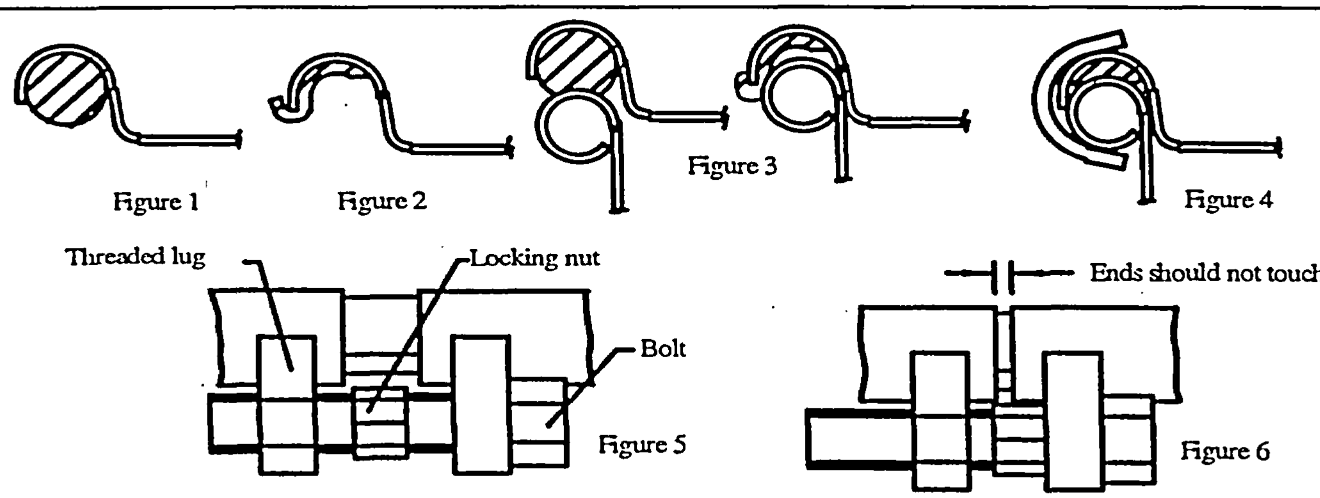
(h) All valves through which the package contents could escape will be protected against unauthorized operation.	NA	This packaging design has no valves.
(i) For transport by air [this section NA]—	NA	This packaging is not designed for air transport.

Attachment 1. CLOSING INSTRUCTIONS FOR 55 GALLON LEU DRUM IP-1 CONTAINER

Open Head Drum Tested for Solids Only Application

FSS-TS-2004-0004, 1/07/2004

OPEN HEAD DRUM	
STEP 1	Ensure the gasket is properly fitted in lid groove. (Fig.1&2)
STEP 2	Position lid onto drum curl. (Fig.3) being careful to seat gasket around bead
STEP 3	Align bolt closure ring onto drum. Ensure the inner channel engages periphery of the entire drum cover. (Fig.4)
STEP 4	Insert bolt through ring unthreaded lug with bored end. Screw bolt into locking nut, then into threaded ring lug. (Fig.5)
STEP 5	Tighten bolt while tapping ring until a gap of 1" is achieved. The 1" gap is an indicator that the ring has been properly seated and the remainder of the closing process may be initiated. Torque until a minimum torque of 25 ft. lbs. (as in Fig. 6) is achieved noting that the ring ends should not touch.
STEP 6	For previously closed drums with ring ends that touch, complete steps 6A & 6B to ensure ring is tight and uniformly installed. A. Ensure ring does not rotate on drum by taping end of ring bolt with rubber mallet. If ring rotates go to step 6C. B. Inspect ring/lid for uniformity. The distance from top of drum lid to ring should not vary by more than 1/16". If ring/lid is not aligned, go to step 6C. C. Remove ring, cut approximately 1/8" from end of ring and go to STEP 3 above to reinstall and tighten ring.



Please contact CTF in WSRC Transportation Services with questions regarding this information.
Revised January 7, 2004 by WSRC Transportation Services

ATTACHMENT 6

Project N/A	Calculation Number N-CLC-F-00695	Project Number N/A
Title Arrays of UO_3 Drums	Functional Classification SS	Page 1 of 23
	Discipline Nuclear	

☐ Preliminary ☒ Confirmed

Computer Program No. MCNP	Version/Release No. 4C

Purpose and Objective

Calculate the reactivity of arrays of UO_3-containing drums, with various degrees of internal and interstitial moderation.

Summary of Conclusion

The results confirm that the reactivity of optimally moderated drums is decreased by interstitial water and by increased surface-to-surface spacing. All of the cases requested in Reference 1 are shown to be safely subcritical.

	Revisions
Rev No.	Revision Description
0	Initial issue

Sign Off (signatures of previous revision on file)

Rev No.	Originator (Print) Sign/Date	Verification/Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
0	S. T. Gough [signature] 7/14/04	Document Review	S. M. Revolinski [signature] 7/15/04	M. A. Rosser [signature] 7/14/04

Design Authority – (Print)	Signature	Date
Release to Outside Agency – (Print)	Signature	Date

Classification

UNCLASSIFIED
DOES NOT CONTAIN
UNCLASSIFIED CONTROLLED
NUCLEAR INFORMATION

ADC & Reviewing Official: [signature] S JNATHAN, WSMS

Date: 7/15/04

IG-SR-2, 4/98

TABLE OF CONTENTS

1.0 INTRODUCTION

Reference 1 requests that criticality calculations be performed for arrays of UO_3-containing drums, with varying degrees of internal and interstitial moderation, in order to support a Department of Transportation (DOT) exemption for the transport of drums containing Low-enriched Uranium Oxide (LEUO).

The calculations performed herein serve to supplement previous calculations involving the same LEUO material, modeled as optimally-moderated spheres reflected by water [9]. The calculations contained in Reference 9, in combination with the calculations contained herein, address hypothetical accident conditions to which the UO_3 drums may be subjected.

2.0 REFERENCES

1. McWhorter, D. L., *Perform Criticality Calculations to Support the DOT Exemption for LEUO Transportation*, NNMD-FTS-2004-1842, Rev. 0, June 17, 2004.

2. Taylor, R. P. Jr., *Disposal of Drums Containing UO_3 From F-Area*, N-NCS-F-00108, April 2004.

3. Briesmeister, J. F, ed., *MCNP - A General Monte Carlo Code N-Particle Transport Code*, Version 4C, LA-13709-M, Los Alamos National Laboratory, Los Alamos, New Mexico, March 2000.

4. *Software Quality Assurance Implementation Checklist for MCNP 4C*, WSMS-CRT-01-0101, August 2001.

5. *Nuclear Criticality Safety Methods Manual*, WSMS-CRT-01-0116, Rev. 3, October 1, 2003.

6. Revolinski, S. M., et. al., *Compilation of WSMS MCNP 4C Validation (as of 7/1/01)*, WSMS-CRT-01-0082, September 2001.

7. Walker, F. W., et al., *Chart of the Nuclides*, 14th Edition, General Electric Company, San Jose, CA, 1989.

8. Harmon, C. D. II, Busch, R. D., Briesmeister, J. F., and Forster, R. A., *Criticality Calculations with MCNP: A Primer*, LA-12827-M, Los Alamos National Laboratory, Los Alamos, New Mexico, August 1994.

9. Taylor, R. P. Jr., *Spherical Safe Mass Values – Low Enriched UO_3*, WSMS-CRT-04-0026, April 5, 2004.

3.0 INPUT

Per Reference 1, two different drum arrays are modeled. The first array contains five layers, with 24 drums in each layer, for a total of 120 drums. Each layer is a 4-5-6-5-4 triangular-pitch array. The second array is a 5 by 5 by 5 square-pitch array, for a total of 125 drums. For all arrays, at least 12" of water reflection is present on all sides.

Per Reference 1, each drum contains 750 lb of UO_3, at an enrichment of 1.084 wt% ^{235}U, with 3 to 24 wt% water. The fissile solution in each drum is modeled as a cylinder filling the internal radius of the drum. In the drums in the top two layers of the arrays, the fissile solution cylinders are modeled at the bottoms of the drums. In the drums in the bottom two layers of the arrays, the fissile solution cylinders are modeled at the tops of the drums. In the drums in the middle layer of the arrays, the fissile solution cylinders are modeled in the middle of the drums.

Each drum is modeled with an internal diameter of 55.88 cm, and an internal height of 83.82 cm [2]. The walls, tops, and bottoms of the drums are modeled as 16 gauge carbon steel (0.1519 cm thick) [1-2].

4.0 ANALYTICAL METHODS AND COMPUTATIONS

4.1 Nuclear Criticality Safety Codes

In performing the criticality calculations in this report, the MCNP 4C code is used [3]. MCNP is a general purpose Monte Carlo radiation transport code that numerically simulates neutral and charged particle transport histories, using continuous energy cross-section libraries and general three-dimensional geometry. The MCNP code was developed, and is maintained, by the Los Alamos National Laboratory (LANL).

4.2 MCNP Code Bias, Statistical Uncertainty, and Acceptance Criteria

Results documented in this report are obtained from the MCNP 4C code, which is under configuration control on the Washington Safety Management Solutions Linux workstation cluster [4]. To account for the statistical uncertainty in the MCNP calculations, the calculated k_{EFF} is adjusted as follows [5]:

$$adjusted\ k_{EFF} = k_{EFF}^{MCNP} + 2\sigma_S$$

where σ_S is the statistical uncertainty (standard deviation) calculated by the MCNP code. The standard deviation is multiplied by a factor of two to achieve the 95.4% confidence level, assuming a normal distribution.

For nuclear criticality limits derivations, the adjusted k_{EFF} values are compared to the k_{SAFE} reactivity limit. The k_{SAFE} acceptance criterion is defined as [5]:

$$k_{SAFE} = 1.0 - \sigma_B - \sigma_M - \sigma_A$$

where σ_B is the MCNP code bias (which includes the bias uncertainty) for a particular fuel, and σ_M and σ_A are margins ensuring sub-criticality. The first margin, σ_M, is the Minimum Subcritical Margin (MSM). It is an arbitrary margin used to ensure sub-criticality against system uncertainties. The second margin, σ_A, is the Area of Applicability (AOA) margin. It is used if it is necessary to account for any extensions to the benchmark area of applicability for the analyzed fissile system.

Reference 6 provides a bias and bias uncertainty analysis for LEU compounds, resulting in σ_B = 0.022. Key parameters of this analysis and the analyses performed herein are presented in Table 1.

Table 1: Area of Applicability

Parameter	Ref. 6	Present System
Fissile Material	UO_2 rods, UO_2F_2, uranyl nitrate solutions, and UF4-polytetrafluoroethylene cubes	UO_3
Enrichment	2 – 30 wt% ^{235}U	1.084 wt% ^{235}U
Moderator	water ($H/^{235}U$): 75 to 1400 polyethylene ($H/^{235}U$): 8 to 64	water ($H/^{235}U$): ~90 to 900
Reflector	steel, lead, water, paraffin, or none	water
Geometry	thin rod lattices, spheres, cylinders, and cubes	cylinders
Neutron Spectrum	intermediate to thermal	intermediate to thermal

From Table 1, the key parameters defining the analyses documented herein are all within the AOA of the Reference 6 analyses, with the exception of enrichment and fissile material. In terms of enrichment, the validation AOA covers a range of 2 to 30 wt%. Based on the guidance of Reference 5, the lower end of this range may be extended to 0.5 wt%, which bounds the 1.084 wt% modeled herein. Therefore, no AOA margin is required for this parameter.

In terms of the fissile material, the Reference 6 analyses model a wide variety of LEU compounds including UO_2, while the analyses herein model UO_3. Since MCNP does not model a specific chemical formula (but rather the individual nuclei), the inclusion of UO_2 in the Reference 6 analyses is judged to adequately represent the UO_3 modeled herein. Therefore, no AOA margin is required for this parameter.

Given the simplicity of the calculations performed herein, as well as the conservative fissile density and water content, an MSM of 0.03 is judged to be adequate. Using this MSM with the bias discussed above results in a k_{SAFE} of 0.948.

4.3 Material Cards and Cross-section Libraries

In performing the calculations presented herein, the ENDF/B-VI default cross-sections supplied with MCNP 4C are used exclusively, with the exception that thermal neutron scattering $S(\alpha,\beta)$ cross-sections are based on ENDF/B-V.

The fissile solutions in these analyses are modeled as mixtures of UO_3 and water, at varying $H/^{235}U$ ratios. In calculating specific mixtures, the maximum theoretical density of UO_3 (7.29 g/cm^3 [1]) is employed, and the mass density of water is assumed to be 1.0 g/cm^3. The isotopic composition of the uranium is assumed to be 1.084 wt% ^{235}U and 98.916 wt% ^{238}U. Thermal scattering from hydrogen in these mixtures is modeled with the 300 K light water $S(\alpha,\beta)$ table (lwtr.01t).

Carbon steel is modeled using the data provided in References 7 and 8. The mass density of the steel is assumed to be 7.82 g/cm^3 [8].

Light water is modeled assuming a mass density of 1.0 g/cm^3. Thermal scattering from hydrogen is modeled with the 300 K light water $S(\alpha,\beta)$ table (lwtr.01t).

5.0 RESULTS

5.1 Triangular-pitch Arrays

In this section, triangular-pitch arrays are modeled, as described in Section 3.0. Seven different water contents are modeled for the drums: 3, 6, 12, 15, 18, 21, and 24 wt% water. For each water content, at least six cases are executed. The first three cases model the drum array at surface-to-surface (S/S) separations of 0, 2, and 4 cm, with no interstitial water modeled. The second three cases model the most reactive spacing determined from the first three cases[a], with 10, 20, and 100 wt% interstitial water. Additional cases are executed as deemed necessary. A representative model is depicted in Figures 1 and 2, and the results are presented in Tables 2 through 8. Note that the "Problem #" column in the tables refers to the task description in Reference 1.

[a] It is expected that the most reactive spacing will always be when the drums are touching, since increasing the spacing of an array without interstitial moderation can only increase neutron leakage.

Figure 1: Triangular-pitch Array Top View (12 wt% water, 2 cm S/S, no interstitial H_2O)

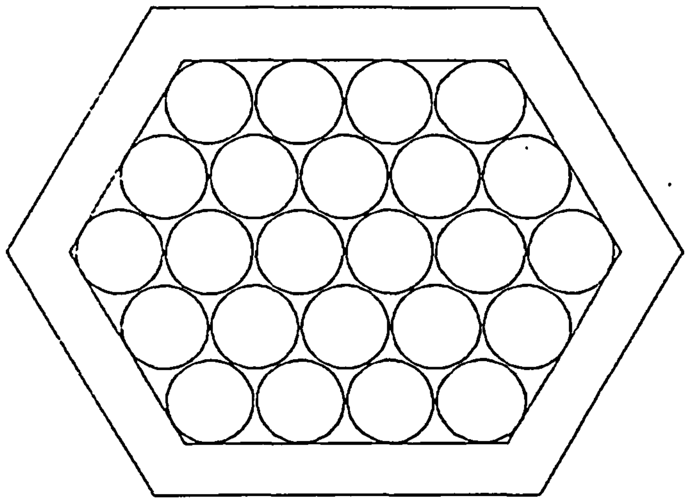


Figure 2: Triangular-pitch Array Side View (12 wt% water, 2 cm S/S, no interstitial H_2O)

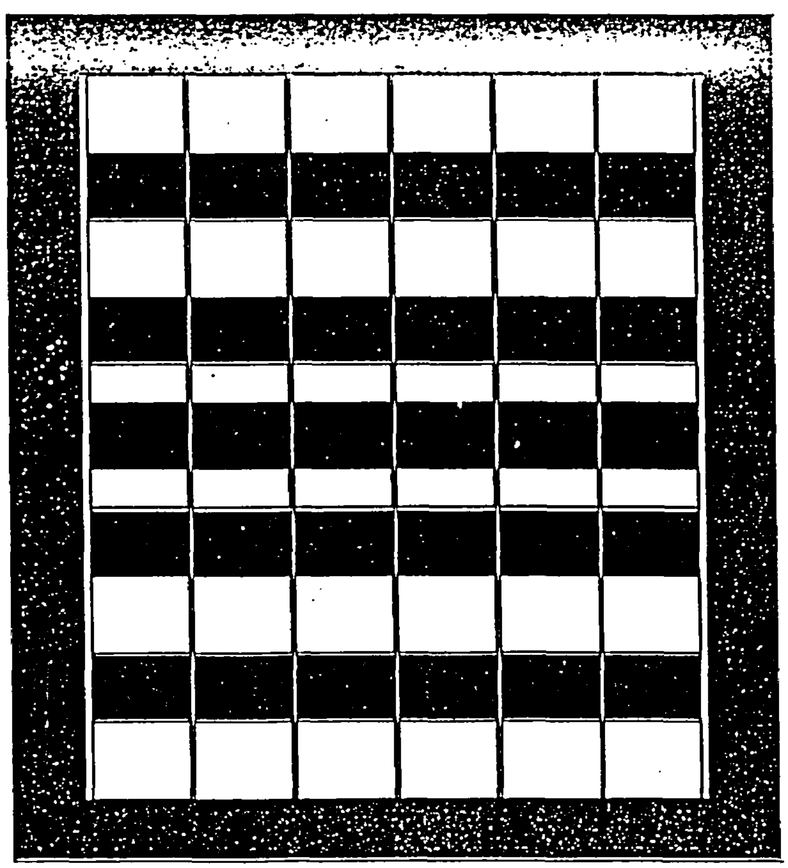


Table 2: Triangular-pitch Array, 3 wt% Water in Drums ($\rho = 6.1328\ g/cm^3$)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
1	anl001	0%	0	0.6431	0.0005
2	anl002	0%	2	0.6319	0.0005
3	anl003	0%	4	0.6220	0.0005
4	anl004	100%	0	0.6827	0.0005
5	anl005	10%	0	0.6621	0.0005
6	anl006	20%	0	0.6809	0.0005
N/A	anl100	60%	0	0.6822	0.0005

Table 3: Triangular-pitch Array, 6 wt% Water in Drums ($\rho = 5.2926\ g/cm^3$)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
7	anl007	0%	0	0.7865	0.0006
8	anl008	0%	2	0.7742	0.0006
9	anl009	0%	4	0.7631	0.0006
10	anl010	100%	0	0.7778	0.0005
11	anl011	10%	0	0.7949	0.0005
12	anl012	20%	0	0.7758	0.0005
N/A	anl101	60%	0	0.7769	0.0005

Table 4: Triangular-pitch Array, 12 wt% Water in Drums ($\rho = 4.1543\ g/cm^3$)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
13	anl013	0%	0	0.8983	0.0005
14	anl014	0%	2	0.8904	0.0005
15	anl015	0%	4	0.8802	0.0005
16	anl016	100%	0	0.8659	0.0005
17	anl017	10%	0	0.9002	0.0005
18	anl018	20%	0	0.8638	0.0005

Table 5: Triangular-pitch Array, 15 wt% Water in Drums ($\rho = 3.7510$ g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
31	anl031	0%	0	0.9150	0.0005
32	anl032	0%	2	0.9061	0.0005
33	anl033	0%	4	0.8986	0.0005
34	anl034	100%	0	0.8753	0.0005
35	anl035	10%	0	0.9136	0.0005
36	anl036	20%	0	0.8780	0.0005

Table 6: Triangular-pitch Array, 18 wt% Water in Drums ($\rho = 3.4190$ g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
19	anl019	0%	0	0.9161	0.0005
20	anl020	0%	2	0.9096	0.0005
21	anl021	0%	4	0.9023	0.0005
22	anl022	100%	0	0.8788	0.0005
23	anl023	10%	0	0.9143	0.0005
24	anl024	20%	0	0.8799	0.0005

Table 7: Triangular-pitch Array, 21 wt% Water in Drums ($\rho = 3.1410$ g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
N/A	anl111	0%	0	0.9074	0.0004
N/A	anl112	0%	2	0.9031	0.0005
N/A	anl113	0%	4	0.8973	0.0005
N/A	anl114	100%	0	0.8715	0.0004
N/A	anl115	10%	0	0.9048	0.0004
N/A	anl116	20%	0	0.8725	0.0005

Table 8: Triangular-pitch Array, 24 wt% Water in Drums ($\rho = 2.9048$ g/cm^3)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
25	anl025	0%	0	0.8945	0.0004
26	anl026	0%	2	0.8892	0.0004
27	anl027	0%	4	0.8835	0.0004
28	anl028	100%	0	0.8586	0.0004
29	anl029	10%	0	0.8935	0.0004
30	anl030	20%	0	0.8588	0.0004

5.2 Square-pitch Arrays

In this section, square-pitch arrays are modeled, as described in Section 3.0. Four cases are executed for the most reactive water content calculated in Section 5.1 (18 wt% water). The first two cases model the drum array at surface-to-surface (S/S) separations of 0 and 2 cm, with no interstitial water modeled. The second two cases model the most reactive spacing determined from the first two cases, with 10 and 20 wt% interstitial water. A representative model is depicted in Figure 3, and the results are presented in Table 9.

Figure 3: Square-pitch Array Top View (18 wt% water, 2 cm S/S, no interstitial H_2O)

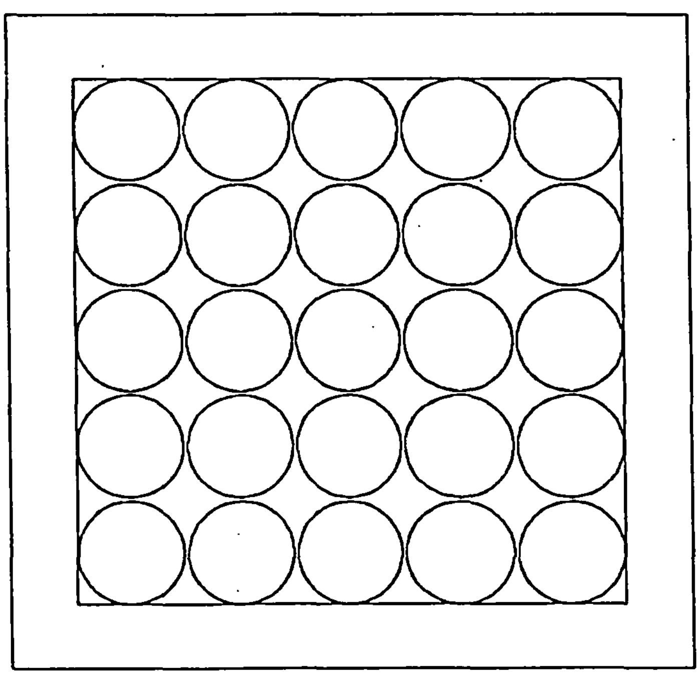


Table 9: Square-pitch Array, 18 wt% Water in Drums ($\rho = 3.4190\ g/cm^3$)

Problem #	Case	Interstitial Water Density	S/S (cm)	k_{EFF}	σ_S
37	anl037	0%	0	0.9058	0.0005
38	anl038	0%	2	0.9014	0.0005
39	anl039	10%	0	0.9039	0.0005
40	anl040	20%	0	0.8965	0.0005

6.0 CONCLUSIONS

The triangular-pitch array calculations presented in Section 5.1 demonstrate, for cases with no interstitial water, that the reactivity of the modeled arrays decreased when the spacing between the drums increased. In addition, for cases with no interstitial water, reactivity was maximized at a water content of 18 wt% in the drums ($H/^{235}U = 635$). At this water content, interstitial water at the modeled densities (10, 20, and 100%) decreased the reactivity of the array.

Therefore, the maximum adjusted k_{EFF} calculated in Section 5.1 (0.9170) is for an array with the drums in physical contact, with no interstitial water, and with a water content of 18 wt% in the drums. Since this maximum adjusted k_{EFF} is below k_{SAFE}, the array configurations modeled in Section 5.1 are safely subcritical.

The square-pitch array calculations presented in Section 5.2 demonstrate that the square-pitch array is less reactive than the triangular-pitch array, at a water content of 18 wt%. In addition, for a water content of 18 wt%, the results demonstrate that the square-pitch array behaves similarly to the triangular-pitch array: increasing the array spacing or adding interstitial water both decrease array reactivity.

7.0 ATTACHMENTS AND APPENDICES

Numerous MCNP cases are executed as part of this engineering calculation. However, these cases are represented in this attachment by a subset of MCNP models, with all other cases requiring only minor modifications of the models in this subset.

Case *anl001* (Problem 1, 3 wt% water, no interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -6.1328          -100      -110             u=1  imp:n=1
102   0                    -100  110                  u=1  imp:n=1
103   2   -7.82       100                             u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -6.1328          -100  111 -112             u=2  imp:n=1
111   0                    -100      -111             u=2  imp:n=1
112   0                    -100  112                  u=2  imp:n=1
113   2   -7.82       100                             u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -6.1328          -100  113                  u=3  imp:n=1
121   0                    -100      -113             u=3  imp:n=1
123   2   -7.82       100                             u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                              fill=3  u=4  imp:n=1
201   0     -101         trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202   0     -101         trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203   0     -101         trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204   0     -101         trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                  u=4  imp:n=1
c     Center Row
210   0     -150  trcl=(-140.4845 0 0)          fill=4 u=5 imp:n=1
211   0     -150  trcl=( -84.2907 0 0)          fill=4 u=5 imp:n=1
212   0     -150  trcl=( -28.0969 0 0)          fill=4 u=5 imp:n=1
213   0     -150  trcl=(  28.0969 0 0)          fill=4 u=5 imp:n=1
214   0     -150  trcl=(  84.2907 0 0)          fill=4 u=5 imp:n=1
215   0     -150  trcl=( 140.4845 0 0)          fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
```

```
          #240 #241 #242 #243
          #250 #251 #252 #253
                                                        u=5 imp:n=1
301    0     -200:-201                         fill=5 u=9 imp:n=1
302    3 -1.0   #301                                  u=9 imp:n=1

303    0     -300:-301                         fill=9     imp:n=1
999    0     #303 imp:n=0

100    rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101    rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110    pz  23.4702                     $ bottom fuel
111    pz  30.4027                     $ middle fuel
112    pz  53.7211                     $ middle fuel
113    pz  60.6536                     $ top fuel
150    rcc 0 0 -0.001 0 0 420.6710 28.0929
c      Drum Boundaries
200    rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201    rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c      Reflector
300    rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301    rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c      Fissile Solution
m1      1001.60c  -3.3568E-03
       92235.60c  -8.7502E-03
       92238.60c  -7.9847E-01
        8016.60c  -1.8942E-01
mt1     lwtr.01t
c      Carbon Steel
m2     26054.60c  -0.05670
       26056.60c  -0.91405
       26057.60c  -0.02130
       26058.60c  -0.00289
        6000.60c  -0.00500
c      Water
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode   n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl008* (Problem 8, 6 wt% water, no interstitial water, triangular pitch, S/S = 2 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1    -5.2926          -100      -110              u=1  imp:n=1
102    0                     -100  110                   u=1  imp:n=1
103    2    -7.82       100                              u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1    -5.2926          -100  111 -112              u=2  imp:n=1
111    0                     -100      -111              u=2  imp:n=1
112    0                     -100  112                   u=2  imp:n=1
113    2    -7.82       100                              u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1    -5.2926          -100  113                   u=3  imp:n=1
121    0                     -100      -113              u=3  imp:n=1
123    2    -7.82       100                              u=3  imp:n=1
c
c      Stack of Five Drums
200    0      -101                          fill=3  u=4  imp:n=1
201    0      -101         trcl=(0 0  86.1238)  fill=3  u=4  imp:n=1
```

```
202   0     -101        trcl=(0 0 172.2476)  fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 258.3714)  fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 344.4952)  fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                 u=4  imp:n=1
c
c     Center Row
210   0     -150  trcl=(-145.4595 0 0)          fill=4 u=5 imp:n=1
211   0     -150  trcl=( -87.2757 0 0)          fill=4 u=5 imp:n=1
212   0     -150  trcl=( -29.0919 0 0)          fill=4 u=5 imp:n=1
213   0     -150  trcl=(  29.0919 0 0)          fill=4 u=5 imp:n=1
214   0     -150  trcl=(  87.2757 0 0)          fill=4 u=5 imp:n=1
215   0     -150  trcl=( 145.4595 0 0)          fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-116.3676  50.3886 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -58.1838  50.3886 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  50.3886 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  58.1838  50.3886 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 116.3676  50.3886 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-116.3676 -50.3886 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -58.1838 -50.3886 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -50.3886 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  58.1838 -50.3886 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 116.3676 -50.3886 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=( -87.2757  100.7773 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=( -29.0919  100.7773 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=(  29.0919  100.7773 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=(  87.2757  100.7773 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=( -87.2757 -100.7773 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=( -29.0919 -100.7773 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=(  29.0919 -100.7773 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=(  87.2757 -100.7773 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0     #210 #211 #212 #213 #214 #215
            #220 #221 #222 #223 #224
            #230 #231 #232 #233 #234
            #240 #241 #242 #243
            #250 #251 #252 #253
                                                     u=5 imp:n=1
301   0      -200:-201                       fill=5 u=9 imp:n=1
302   3 -1.0   #301                                 u=9 imp:n=1
303   0      -300:-301                       fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  28.0342                     $ bottom fuel
111   pz  28.1207                     $ middle fuel
112   pz  56.0031                     $ middle fuel
113   pz  56.0896                     $ top fuel
150   rcc 0 0 -0.001 0 0 428.6210 28.0929
c     Drum Boundaries
200   rhp -29.0919 0 -0.002 0 0 428.6230 0 128.8702 0
201   rhp  29.0919 0 -0.002 0 0 428.6230 0 128.8702 0
c     Reflector
300   rhp -29.0919 0 -35 0 0 499 0 163.8702 0
301   rhp  29.0919 0 -35 0 0 499 0 163.8702 0

c     Fissile Solution
m1     1001.60c  -6.7137E-03
      92235.60c  -8.4796E-03
      92238.60c  -7.7377E-01
       8016.60c  -2.1103E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26054.60c  -0.05670
      26056.60c  -0.91405
      26057.60c  -0.02130
      26058.60c  -0.00289
       6000.60c  -0.00500
c     Water
```

```
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl015* (Problem 15, 12 wt% water, no interstitial water, triangular pitch, S/S = 4 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c     Drum - Fuel in Bottom
100   1   -4.1543          -100      -110              u=1  imp:n=1
102   0                    -100  110                   u=1  imp:n=1
103   2   -7.82        100                             u=1  imp:n=1
c
c     Drum - Fuel in Middle
110   1   -4.1543          -100  111 -112              u=2  imp:n=1
111   0                    -100      -111              u=2  imp:n=1
112   0                    -100  112                   u=2  imp:n=1
113   2   -7.82        100                             u=2  imp:n=1
c
c     Drum - Fuel in Top
120   1   -4.1543          -100  113                   u=3  imp:n=1
121   0                    -100      -113              u=3  imp:n=1
123   2   -7.82        100                             u=3  imp:n=1
c
c     Stack of Five Drums
200   0     -101                              fill=3  u=4  imp:n=1
201   0     -101        trcl=(0 0  88.1238)   fill=3  u=4  imp:n=1
202   0     -101        trcl=(0 0 176.2476)   fill=2  u=4  imp:n=1
203   0     -101        trcl=(0 0 264.3714)   fill=1  u=4  imp:n=1
204   0     -101        trcl=(0 0 352.4952)   fill=1  u=4  imp:n=1
205   0     #200 #201 #202 #203 #204                  u=4  imp:n=1
c
c     Center Row
210   0     -150  trcl=(-150.4595 0 0)          fill=4 u=5 imp:n=1
211   0     -150  trcl=( -90.2757 0 0)          fill=4 u=5 imp:n=1
212   0     -150  trcl=( -30.0919 0 0)          fill=4 u=5 imp:n=1
213   0     -150  trcl=(  30.0919 0 0)          fill=4 u=5 imp:n=1
214   0     -150  trcl=(  90.2757 0 0)          fill=4 u=5 imp:n=1
215   0     -150  trcl=( 150.4595 0 0)          fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-120.3676  52.1207 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -60.1838  52.1207 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  52.1207 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  60.1838  52.1207 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 120.3676  52.1207 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-120.3676 -52.1207 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -60.1838 -52.1207 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -52.1207 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  60.1838 -52.1207 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 120.3676 -52.1207 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=( -90.2757  104.2414 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=( -30.0919  104.2414 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=(  30.0919  104.2414 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=(  90.2757  104.2414 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=( -90.2757 -104.2414 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=( -30.0919 -104.2414 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=(  30.0919 -104.2414 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=(  90.2757 -104.2414 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   0    #210 #211 #212 #213 #214 #215
```

```
          #220 #221 #222 #223 #224
          #230 #231 #232 #233 #234
          #240 #241 #242 #243
          #250 #251 #252 #253
                                                      u=5 imp:n=1
301    0      -200:-201                        fill=5 u=9 imp:n=1
302    3 -1.0    #301                                 u=9 imp:n=1
303    0      -300:-301                        fill=9     imp:n=1
999    0      #303 imp:n=0

100    rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101    rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110    pz  38.0958                     $ bottom fuel
111    pz  23.0900                     $ middle fuel
112    pz  61.0338                     $ middle fuel
113    pz  46.0280                     $ top fuel
150    rcc 0 0 -0.001 0 0 436.6210 28.0929
c      Drum Boundaries
200    rhp -30.0919 0 -0.002 0 0 436.6230 0 132.3343 0
201    rhp  30.0919 0 -0.002 0 0 436.6230 0 132.3343 0
c      Reflector
300    rhp -30.0919 0 -35 0 0 507 0 167.3343 0
301    rhp  30.0919 0 -35 0 0 507 0 167.3343 0

c      Fissile Solution
m1      1001.60c  -1.3427E-02
       92235.60c  -7.9384E-03
       92238.60c  -7.2438E-01
        8016.60c  -2.5425E-01
mt1     lwtr.01t
c      Carbon Steel
m2     26054.60c  -0.05670
       26056.60c  -0.91405
       26057.60c  -0.02130
       26058.60c  -0.00289
        6000.60c  -0.00500
c      Water
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode   n
totnu
kcode 2000 1.0 100 700
ksrc  -30 0 218 30 0 218
print 128
prdmp   3j 2
```

Case *anl022* (Problem 22, 18 wt% water, 100% interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1   -3.4190          -100      -110            u=1  imp:n=1
102    0                    -100  110                 u=1  imp:n=1
103    2   -7.82       100                            u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -3.4190          -100  111 -112            u=2  imp:n=1
111    0                    -100      -111            u=2  imp:n=1
112    0                    -100  112                 u=2  imp:n=1
113    2   -7.82       100                            u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -3.4190          -100  113                 u=3  imp:n=1
121    0                    -100      -113            u=3  imp:n=1
123    2   -7.82       100                            u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                            fill=3  u=4  imp:n=1
```

```
201   0     -101         trcl=(0 0  84.1338)   fill=3   u=4   imp:n=1
202   0     -101         trcl=(0 0 168.2676)   fill=2   u=4   imp:n=1
203   0     -101         trcl=(0 0 252.4014)   fill=1   u=4   imp:n=1
204   0     -101         trcl=(0 0 336.5352)   fill=1   u=4   imp:n=1
205   3 -1.0 #200 #201 #202 #203 #204                   u=4   imp:n=1
c     Center Row
210   0     -150   trcl=(-140.4845 0 0)         fill=4 u=5 imp:n=1
211   0     -150   trcl=( -84.2907 0 0)         fill=4 u=5 imp:n=1
212   0     -150   trcl=( -28.0969 0 0)         fill=4 u=5 imp:n=1
213   0     -150   trcl=(  28.0969 0 0)         fill=4 u=5 imp:n=1
214   0     -150   trcl=(  84.2907 0 0)         fill=4 u=5 imp:n=1
215   0     -150   trcl=( 140.4845 0 0)         fill=4 u=5 imp:n=1
c     One Up
220   0     -150   trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221   0     -150   trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222   0     -150   trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0     -150   trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0     -150   trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150   trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0     -150   trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0     -150   trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0     -150   trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0     -150   trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150   trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0     -150   trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0     -150   trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0     -150   trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150   trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0     -150   trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0     -150   trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0     -150   trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   3 -1.0    #210 #211 #212 #213 #214 #215
           #220 #221 #222 #223 #224
           #230 #231 #232 #233 #234
           #240 #241 #242 #243
           #250 #251 #252 #253
                                                    u=5 imp:n=1
301   0     -200:-201                         fill=5 u=9 imp:n=1
302   3 -1.0   #301                                  u=9 imp:n=1
303   0     -300:-301                         fill=9     imp:n=1
999   0     #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  49.6298                     $ bottom fuel
111   pz  17.3230                     $ middle fuel
112   pz  66.8008                     $ middle fuel
113   pz  34.4940                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.60c  -2.0141E-02
      92235.60c  -7.3971E-03
      92238.60c  -6.7499E-01
       8016.60c  -2.9747E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26054.60c  -0.05670
      26056.60c  -0.91405
      26057.60c  -0.02130
      26058.60c  -0.00289
       6000.60c  -0.00500
c     Water
```

```
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl111* (21 wt% water, no interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1   -3.1410          -100      -110               u=1  imp:n=1
102    0                    -100  110                    u=1  imp:n=1
103    2   -7.82        100                              u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -3.1410          -100  111 -112               u=2  imp:n=1
111    0                    -100      -111               u=2  imp:n=1
112    0                    -100  112                    u=2  imp:n=1
113    2   -7.82        100                              u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -3.1410          -100  113                    u=3  imp:n=1
121    0                    -100      -113               u=3  imp:n=1
123    2   -7.82        100                              u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                               fill=3  u=4  imp:n=1
201    0     -101          trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202    0     -101          trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203    0     -101          trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204    0     -101          trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205    0     #200 #201 #202 #203 #204                   u=4  imp:n=1
C      Center Row
210    0     -150  trcl=(-140.4845 0 0)           fill=4 u=5 imp:n=1
211    0     -150  trcl=( -84.2907 0 0)           fill=4 u=5 imp:n=1
212    0     -150  trcl=( -28.0969 0 0)           fill=4 u=5 imp:n=1
213    0     -150  trcl=(  28.0969 0 0)           fill=4 u=5 imp:n=1
214    0     -150  trcl=(  84.2907 0 0)           fill=4 u=5 imp:n=1
215    0     -150  trcl=( 140.4845 0 0)           fill=4 u=5 imp:n=1
c      One Up
220    0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221    0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222    0     -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223    0     -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224    0     -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c      One Down
230    0     -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231    0     -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232    0     -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233    0     -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234    0     -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c      Two Up
240    0     -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241    0     -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242    0     -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243    0     -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c      Two Down
250    0     -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251    0     -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252    0     -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253    0     -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c      Boundaries
300    0     #210 #211 #212 #213 #214 #215
             #220 #221 #222 #223 #224
```

```
          #230 #231 #232 #233 #234
          #240 #241 #242 #243
          #250 #251 #252 #253
                                                  u=5 imp:n=1
301    0     -200:-201                     fill=5 u=9 imp:n=1
302    3 -1.0   #301                              u=9 imp:n=1

303    0     -300:-301                     fill=9     imp:n=1
999    0     #303 imp:n=0

100    rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101    rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110    pz  56.0537                     $ bottom fuel
111    pz  14.1110                     $ middle fuel
112    pz  70.0128                     $ middle fuel
113    pz  28.0701                     $ top fuel
150    rcc 0 0 -0.001 0 0 420.6710 28.0929
c      Drum Boundaries
200    rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201    rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c      Reflector
300    rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301    rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c      Fissile Solution
m1      1001.60c  -2.3498E-02
       92235.60c  -7.1265E-03
       92238.60c  -6.5030E-01
        8016.60c  -3.1908E-01
mt1     lwtr.01t
c      Carbon Steel
m2     26054.60c  -0.05670
       26056.60c  -0.91405
       26057.60c  -0.02130
       26058.60c  -0.00289
        6000.60c  -0.00500
c      Water
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl029* (Problem 29, 24 wt% water, 10% interstitial water, triangular pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1   -2.9048         -100      -110           u=1  imp:n=1
102    0                   -100  110                u=1  imp:n=1
103    2   -7.82       100                          u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -2.9048         -100  111 -112           u=2  imp:n=1
111    0                   -100      -111           u=2  imp:n=1
112    0                   -100  112                u=2  imp:n=1
113    2   -7.82       100                          u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -2.9048         -100  113                u=3  imp:n=1
121    0                   -100      -113           u=3  imp:n=1
123    2   -7.82       100                          u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                          fill=3   u=4  imp:n=1
```

```
201   0     -101          trcl=(0 0  84.1338)  fill=3  u=4   imp:n=1
202   0     -101          trcl=(0 0 168.2676)  fill=2  u=4   imp:n=1
203   0     -101          trcl=(0 0 252.4014)  fill=1  u=4   imp:n=1
204   0     -101          trcl=(0 0 336.5352)  fill=1  u=4   imp:n=1
205   3 -0.1 #200 #201 #202 #203 #204                  u=4   imp:n=1
c     Center Row
210   0     -150  trcl=(-140.4845 0 0)          fill=4 u=5 imp:n=1
211   0     -150  trcl=( -84.2907 0 0)          fill=4 u=5 imp:n=1
212   0     -150  trcl=( -28.0969 0 0)          fill=4 u=5 imp:n=1
213   0     -150  trcl=(  28.0969 0 0)          fill=4 u=5 imp:n=1
214   0     -150  trcl=(  84.2907 0 0)          fill=4 u=5 imp:n=1
215   0     -150  trcl=( 140.4845 0 0)          fill=4 u=5 imp:n=1
c     One Up
220   0     -150  trcl=(-112.3876  48.6653 0)  fill=4 u=5 imp:n=1
221   0     -150  trcl=( -56.1938  48.6653 0)  fill=4 u=5 imp:n=1
222   0     -150  trcl=(   0.0000  48.6653 0)  fill=4 u=5 imp:n=1
223   0     -150  trcl=(  56.1938  48.6653 0)  fill=4 u=5 imp:n=1
224   0     -150  trcl=( 112.3876  48.6653 0)  fill=4 u=5 imp:n=1
c     One Down
230   0     -150  trcl=(-112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
231   0     -150  trcl=( -56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
232   0     -150  trcl=(   0.0000 -48.6653 0)  fill=4 u=5 imp:n=1
233   0     -150  trcl=(  56.1938 -48.6653 0)  fill=4 u=5 imp:n=1
234   0     -150  trcl=( 112.3876 -48.6653 0)  fill=4 u=5 imp:n=1
c     Two Up
240   0     -150  trcl=(-84.2907  97.3305 0)   fill=4 u=5 imp:n=1
241   0     -150  trcl=(-28.0969  97.3305 0)   fill=4 u=5 imp:n=1
242   0     -150  trcl=( 28.0969  97.3305 0)   fill=4 u=5 imp:n=1
243   0     -150  trcl=( 84.2907  97.3305 0)   fill=4 u=5 imp:n=1
c     Two Down
250   0     -150  trcl=(-84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
251   0     -150  trcl=(-28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
252   0     -150  trcl=( 28.0969 -97.3305 0)   fill=4 u=5 imp:n=1
253   0     -150  trcl=( 84.2907 -97.3305 0)   fill=4 u=5 imp:n=1
c     Boundaries
300   3 -0.1    #210 #211 #212 #213 #214 #215
           #220 #221 #222 #223 #224
           #230 #231 #232 #233 #234
           #240 #241 #242 #243
           #250 #251 #252 #253
                                                       u=5 imp:n=1
301   0      -200:-201                         fill=5 u=9 imp:n=1
302   3 -1.0   #301                                   u=9 imp:n=1
303   0      -300:-301                         fill=9     imp:n=1
999   0      #303 imp:n=0

100   rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101   rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110   pz  62.9849                     $ bottom fuel
111   pz  10.6454                     $ middle fuel
112   pz  73.4784                     $ middle fuel
113   pz  21.1389                     $ top fuel
150   rcc 0 0 -0.001 0 0 420.6710 28.0929
c     Drum Boundaries
200   rhp -28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
201   rhp  28.0969 0 -0.002 0 0 420.6730 0 125.4284 0
c     Reflector
300   rhp -28.0969 0 -35 0 0 491 0 160.4284 0
301   rhp  28.0969 0 -35 0 0 491 0 160.4284 0

c     Fissile Solution
m1     1001.60c  -2.6855E-02
      92235.60c  -6.8559E-03
      92238.60c  -6.2560E-01
       8016.60c  -3.4069E-01
mt1    lwtr.01t
c     Carbon Steel
m2    26054.60c  -0.05670
      26056.60c  -0.91405
      26057.60c  -0.02130
      26058.60c  -0.00289
       6000.60c  -0.00500
c     Water
```

```
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  -28 0 210 28 0 210
print 128
prdmp   3j 2
```

Case *anl037* (Problem 37, 18 wt% water, no interstitial water, square pitch, S/S = 0 cm)

```
Arrays of UO3 Drums; Evaluator: S.T.Gough
c
c      Drum - Fuel in Bottom
100    1   -3.4190        -100      -110          u=1  imp:n=1
102    0                  -100  110               u=1  imp:n=1
103    2   -7.82       100                        u=1  imp:n=1
c
c      Drum - Fuel in Middle
110    1   -3.4190        -100  111 -112          u=2  imp:n=1
111    0                  -100      -111          u=2  imp:n=1
112    0                  -100  112               u=2  imp:n=1
113    2   -7.82       100                        u=2  imp:n=1
c
c      Drum - Fuel in Top
120    1   -3.4190        -100  113               u=3  imp:n=1
121    0                  -100      -113          u=3  imp:n=1
123    2   -7.82       100                        u=3  imp:n=1
c
c      Stack of Five Drums
200    0     -101                        fill=3  u=4  imp:n=1
201    0     -101      trcl=(0 0  84.1338)  fill=3  u=4  imp:n=1
202    0     -101      trcl=(0 0 168.2676)  fill=2  u=4  imp:n=1
203    0     -101      trcl=(0 0 252.4014)  fill=1  u=4  imp:n=1
204    0     -101      trcl=(0 0 336.5352)  fill=1  u=4  imp:n=1
205    0     #200 #201 #202 #203 #204              u=4  imp:n=1
c      Center Row
210    0     -150  trcl=(-112.3876 0 0)       fill=4 u=5 imp:n=1
211    0     -150  trcl=( -56.1938 0 0)       fill=4 u=5 imp:n=1
212    0     -150  trcl=(   0.0000 0 0)       fill=4 u=5 imp:n=1
213    0     -150  trcl=(  56.1938 0 0)       fill=4 u=5 imp:n=1
214    0     -150  trcl=( 112.3876 0 0)       fill=4 u=5 imp:n=1
c      One Up
220    0     -150  trcl=(-112.3876  56.1938 0)  fill=4 u=5 imp:n=1
221    0     -150  trcl=( -56.1938  56.1938 0)  fill=4 u=5 imp:n=1
222    0     -150  trcl=(   0.0000  56.1938 0)  fill=4 u=5 imp:n=1
223    0     -150  trcl=(  56.1938  56.1938 0)  fill=4 u=5 imp:n=1
224    0     -150  trcl=( 112.3876  56.1938 0)  fill=4 u=5 imp:n=1
c      One Down
230    0     -150  trcl=(-112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
231    0     -150  trcl=( -56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
232    0     -150  trcl=(   0.0000 -56.1938 0)  fill=4 u=5 imp:n=1
233    0     -150  trcl=(  56.1938 -56.1938 0)  fill=4 u=5 imp:n=1
234    0     -150  trcl=( 112.3876 -56.1938 0)  fill=4 u=5 imp:n=1
c      Two Up

240    0     -150  trcl=(-112.3876  112.3876 0)   fill=4 u=5 imp:n=1
241    0     -150  trcl=( -56.1938  112.3876 0)   fill=4 u=5 imp:n=1
242    0     -150  trcl=(   0.0000  112.3876 0)   fill=4 u=5 imp:n=1
243    0     -150  trcl=(  56.1938  112.3876 0)   fill=4 u=5 imp:n=1
244    0     -150  trcl=( 112.3876  112.3876 0)   fill=4 u=5 imp:n=1
c      Two Down
250    0     -150  trcl=(-112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
251    0     -150  trcl=( -56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
252    0     -150  trcl=(   0.0000 -112.3876 0)   fill=4 u=5 imp:n=1
253    0     -150  trcl=(  56.1938 -112.3876 0)   fill=4 u=5 imp:n=1
254    0     -150  trcl=( 112.3876 -112.3876 0)   fill=4 u=5 imp:n=1
c      Boundaries
```

```
300    0     #210 #211 #212 #213 #214
             #220 #221 #222 #223 #224
             #230 #231 #232 #233 #234
             #240 #241 #242 #243 #244
             #250 #251 #252 #253 #254
                                                             u=5 imp:n=1
301    0         -200                                 fill=5 u=9 imp:n=1
302    3 -1.0    #301                                        u=9 imp:n=1
303    0         -300                                 fill=9     imp:n=1
999    0      #303 imp:n=0

100    rcc 0 0 0.1519 0 0 83.82 27.94  $ inner drum
101    rcc 0 0 0 0 0 84.1238 28.0919   $ outer drum
110    pz  49.6298                     $ bottom fuel
111    pz  17.3230                     $ middle fuel
112    pz  66.8008                     $ middle fuel
113    pz  34.4940                     $ top fuel
150    rcc 0 0 -0.001 0 0 420.6610 28.0929
c      Drum Boundaries
200    rpp -140.4805 140.4805 -140.4805 140.4805 -0.002 420.6630
c      Reflector
300    rpp -176 176 -176 176 -35 456

c      Fissile Solution
m1      1001.60c  -2.0141E-02
       92235.60c  -7.3971E-03
       92238.60c  -6.7499E-01
        8016.60c  -2.9747E-01
mt1     lwtr.01t
c      Carbon Steel
m2     26054.60c  -0.05670
       26056.60c  -0.91405
       26057.60c  -0.02130
       26058.60c  -0.00289
        6000.60c  -0.00500
c      Water
m3      1001.60c   2.0
        8016.60c   1.0
mt3     lwtr.01t
mode  n
totnu
kcode 2000 1.0 100 700
ksrc  0 0 210
print 128
prdmp   3j 2
```