CHANGES NEEDED IN ^{233}U SAFEGUARDS AND SECURITY RULES

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Outline

- Uranium-233, an 'Orphan' weapons-usable material
- Definition of weapons-usable ^{233}U
  - Need
  - Nuclear equivalence by isotopic dilution
  - Actions to define weapons-usable ^{233}U
- Definitions of ^{233}U safeguards and security categories
- Conclusions

Uranium-233 Is An Orphan Weapons-Usable Fissile Material

- ! There are three major fissile materials: ^{235}U, ^{239}Pu, and ^{233}U
- ! Large quantities of high-enriched uranium (HEU) and plutonium were produced to manufacture weapons and to be used for other purposes
- ! Only small quantities (<1 ton) of separated ^{233}U exist in the United States and there have been only limited uses of ^{233}U
- ! Treaties, laws, and U.S. Department of Energy (DOE) orders are developed and implemented as needs appear
  - — Rules were established for HEU, plutonium, and various mixtures
  - — In many cases, no equivalent rules exist for ^{233}U

Need For A Definition Of Weapons-Usable ^{233}U

There Is No Official Definition Of Non-Weapons-Usable Or Weapons-Usable ^{233}U. There Were Few Incentives To Create Such A Definition

- In the case of ^{235}U, by definition, only HEU is weapons-usable ^{235}U
  - HEU is >20 wt % ^{235}U in ^{238}U
  - No equivalent definition exists for weapons-usable ^{233}U
- Uranium-233 is made by the neutron irradiation of ^{232}Th
  - Production process yields weapons-usable ^{233}U—unlike the production if ^{235}U, during which the enrichment process is capable of producing all enrichments of ^{235}U
  - An added step is required to down-blend ^{233}U with ^{238}U
- Changing conditions have created strong incentives to define weapons-usable and non-weapons-usable ^{233}U

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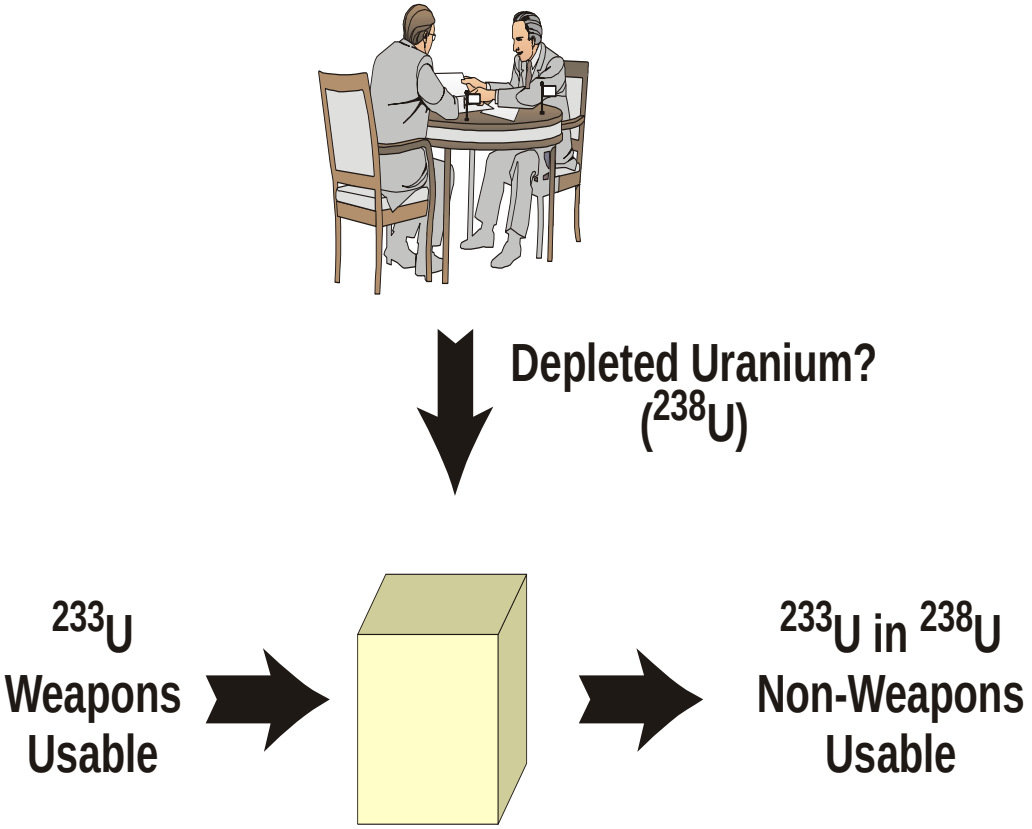

Arms Control Programs to Reduce the Inventory of Weapons-Usable Fissile Materials Require a Definition of Non-Weapons-Usable ^{233}U

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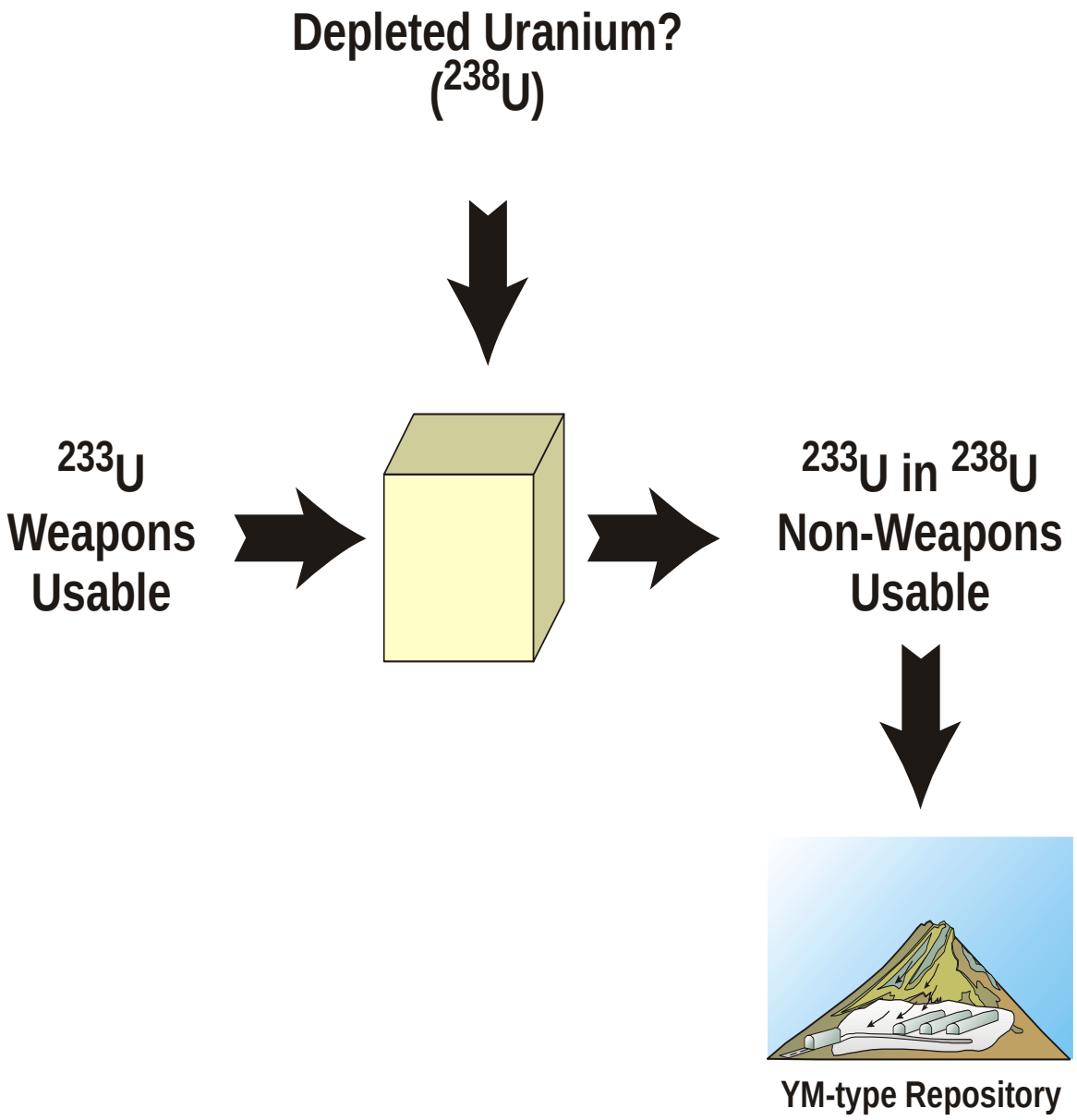

Disposal Of Excess ^{233}U As A Waste Requires Conversion To A Non-Weapons Usable Form. A Definition Of Non-Weapons Usable ^{233}U Is Required

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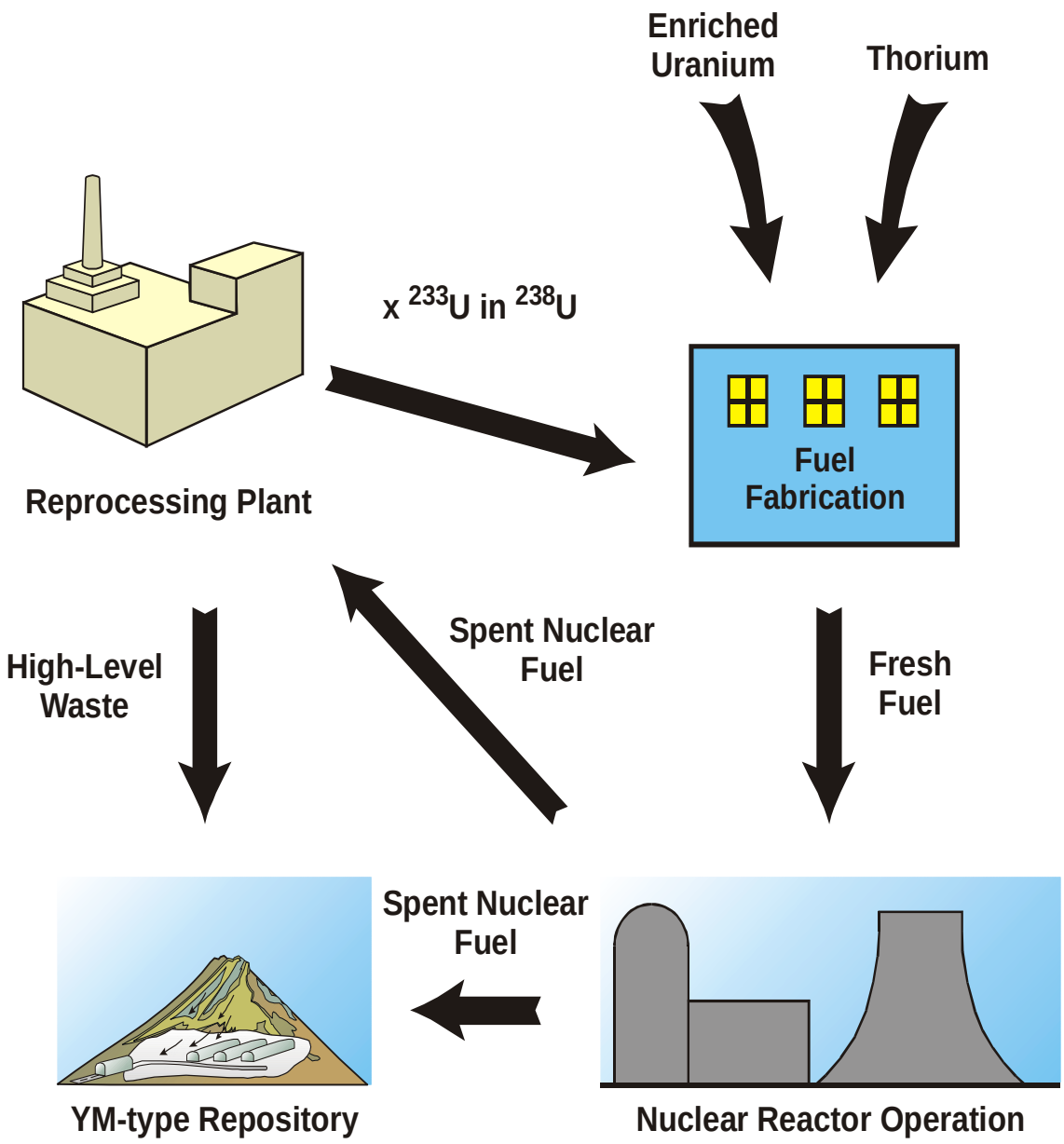

Development of Once-Through and Recycle Proliferation-Resistant Nuclear Power Fuel Cycles Requires a Definition of Non-Weapons-Usable ^{233}U

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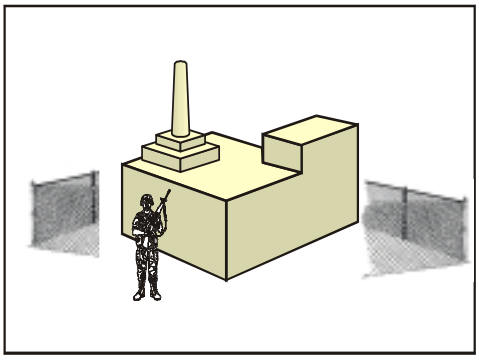
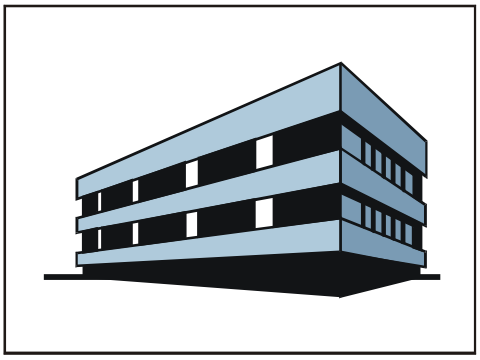
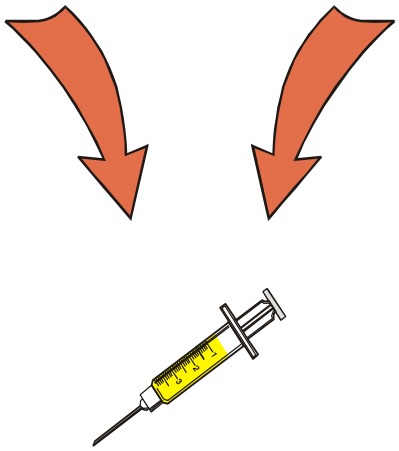
Processing Weapons-Usable ^{233}U



Processing Nonweapons-Usable ^{233}U





Medical (Cancer Treatment)

Clinical Trials Are Evaluating ^{213}Bi (a Decay Product of ^{233}U) for Treatment of Cancer: Processing Costs Depend upon Security Requirements and the Definition of Non-Weapons-Usable ^{233}U

There Is A Need For A Definition Of Non-Weapons-Usable ^{233}U

- Fissile materials cutoff treaty
  - Contact: Hans Chi [U.S. Department of State (DOS)]
- Fissile materials disposition (define end points and allow disposal as a waste)
  - Contact: Martin Newdorf [DOE-Materials Disposition (MD)]
- Proliferation-resistant fuel cycles (thorium—^{233}U fuel cycles). DOE is sponsoring research and development on such fuel cycles in the United States and Russia
  - Contacts (IPP Program): Andrie Gakh, Peter Green, and Bill Desmond [DOE-Nuclear Nonproliferation (NN)]
  - Contacts (Reactors Programs): Bill Magwood, John Herczeg, Madeline Feltus, Charles Thompson [DOE-Nuclear Energy (NE)]

Definition Of Weapons-Usable ^{233}U

Nuclear Equivalence By Isotopic Dilution

An Approach[a] Was Developed To Define The Boundary Between Weapons-Usable And Non-Weapons-Usable ^{233}U When The ^{233}U Is Isotopically Diluted With ^{238}U

- The boundary between weapons-usable and non-weapons-usable ^{235}U in ^{238}U is 20 wt % ^{235}U in ^{238}U
- The boundary between weapons-usable and non-weapons-usable ^{233}U should be chosen so that a weapons designer would have no preference in using 20% ^{235}U in ^{238}U in or *X* wt % ^{233}U in ^{238}U
- There are several methods to calculate what *X* is

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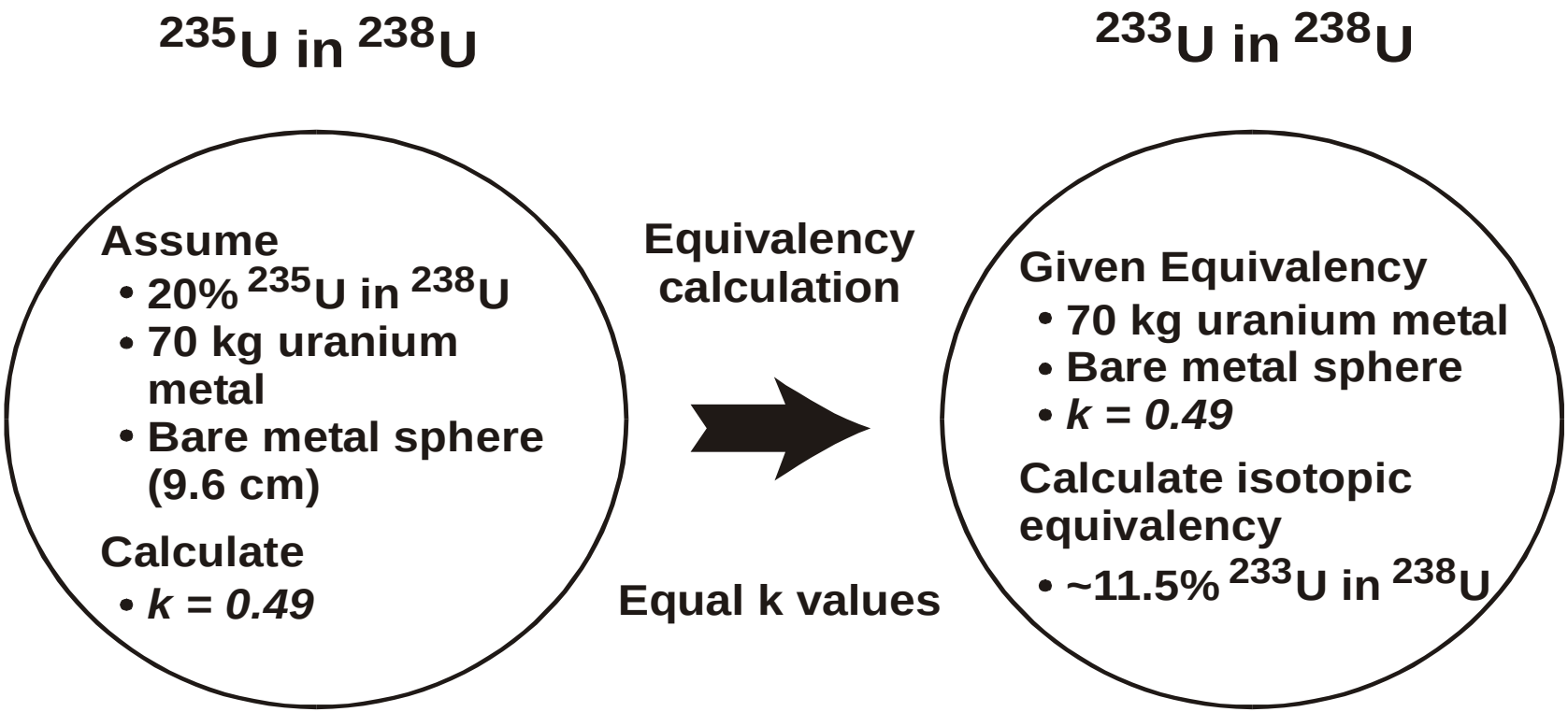
[a]C. W. Forsberg [Oak Ridge National Laboratory (ORNL)], C. M. Hopper (ORNL), J. L. Richter (Los Alamos National Laboratory), and H. C. Vantine (Lawrence Livermore National Laboratory), March 1998. *Definition of Weapons-Usable Uranium-233*, ORNL/TM-13517, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

ORNL DWG 99C-448



Nuclear Equivalency of Different Isotopic Mixtures Can Be Determined by Assuming a Set of Conditions and Matching the Value of k

Nuclear Equivalence Can Be Calculated For An Assumed Spherical Form

- Assume uranium metal sphere
  - 70 kg uranium[a]
  - 20 wt % ^{235}U in ^{238}U (boundary between weapons- and non-weapons-usable ^{235}U)
- Calculate the neutron multiplication ratio (k_{eff}):k_{eff} ~0.49
- Calculate the ^{233}U concentration in ^{238}U required for k_{eff} = 0.49
  - Assume same conditions: 70 kg uranium metal sphere
  - Same k_{eff} for ~11.5 wt % ^{233}U in ^{238}U

[a]Seber, R. 1992. *The Los Alamos Primer*, University of California Press, Berkeley, California (originally published as L.A. 1 by the Los Alamos National Laboratory, Los Alamos, New Mexico).

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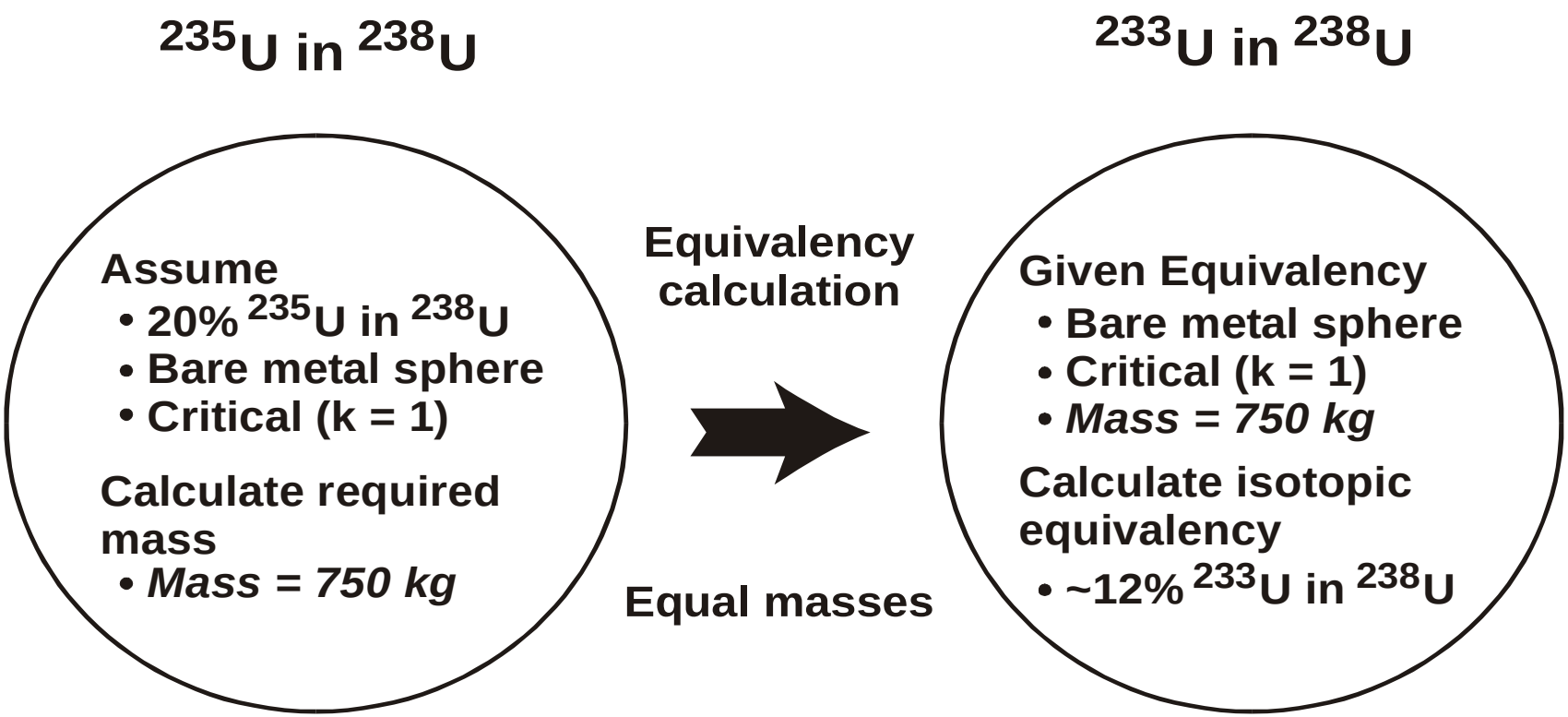
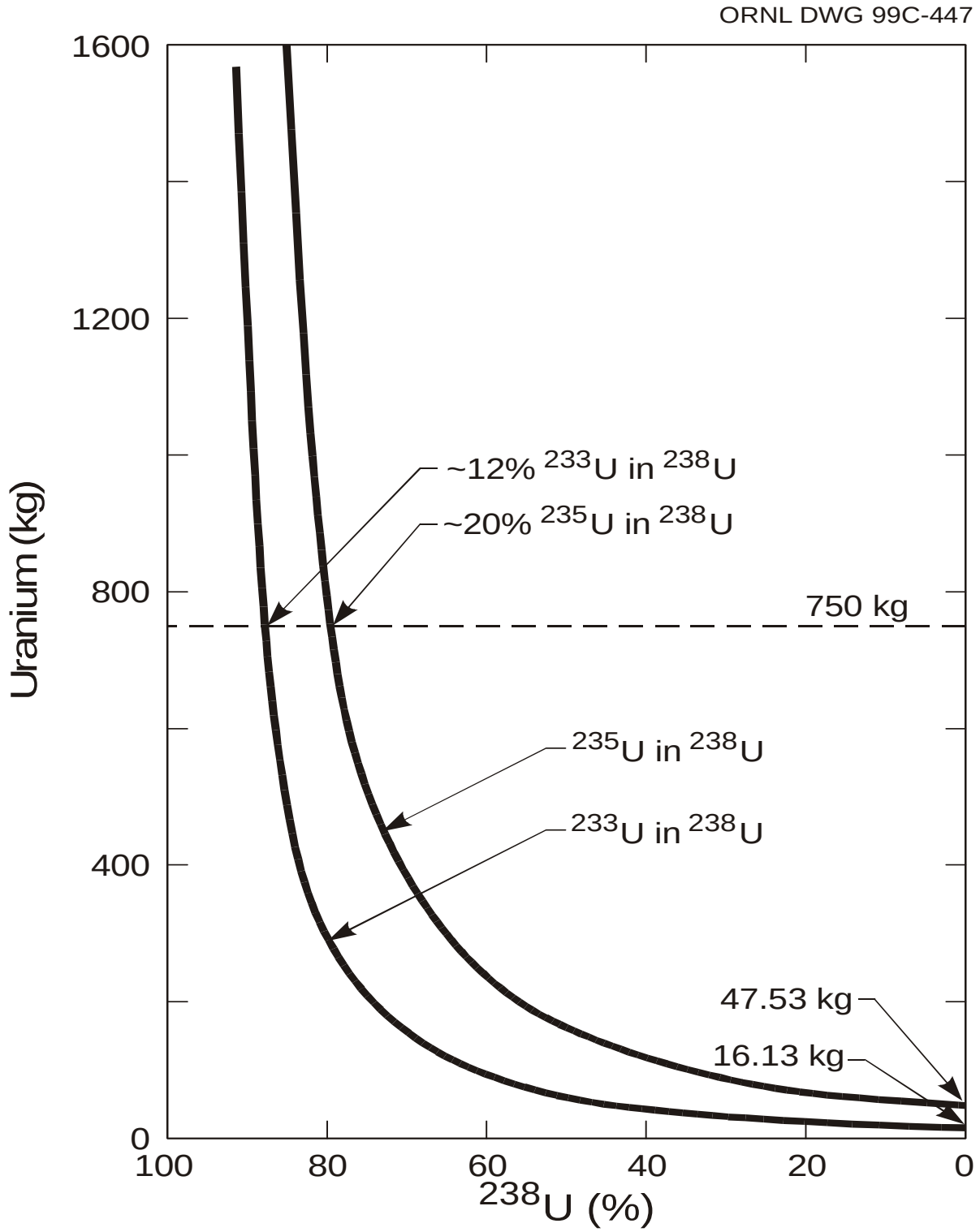


Nuclear Equivalency of Different Isotopic Mixtures Can Be Determined by Assuming a Set of Conditions and Matching Total Mass



Critical Masses of ^{233}U in ^{238}U and ^{235}U in ^{238}U for a Bare Metal Sphere

Nuclear Equivalence Can Be Calculated By Comparing The Spherical Masses Of Uranium Required For Nuclear Criticality

- Assume a uranium metal sphere with 20 wt % ^{235}U in ^{238}U (boundary between weapons-usable and non-weapons-usable ^{235}U)
- Calculate the mass of uranium to achieve nuclear criticality: ~750 kg
- Calculate the ^{233}U concentration in ^{238}U required to achieve nuclear criticality under parallel conditions
  - Assume a uranium metal sphere of 750 kg
  - Criticality occurs with ~12 wt % ^{233}U in ^{238}U

Definition Of Weapons-Usable ^{233}U

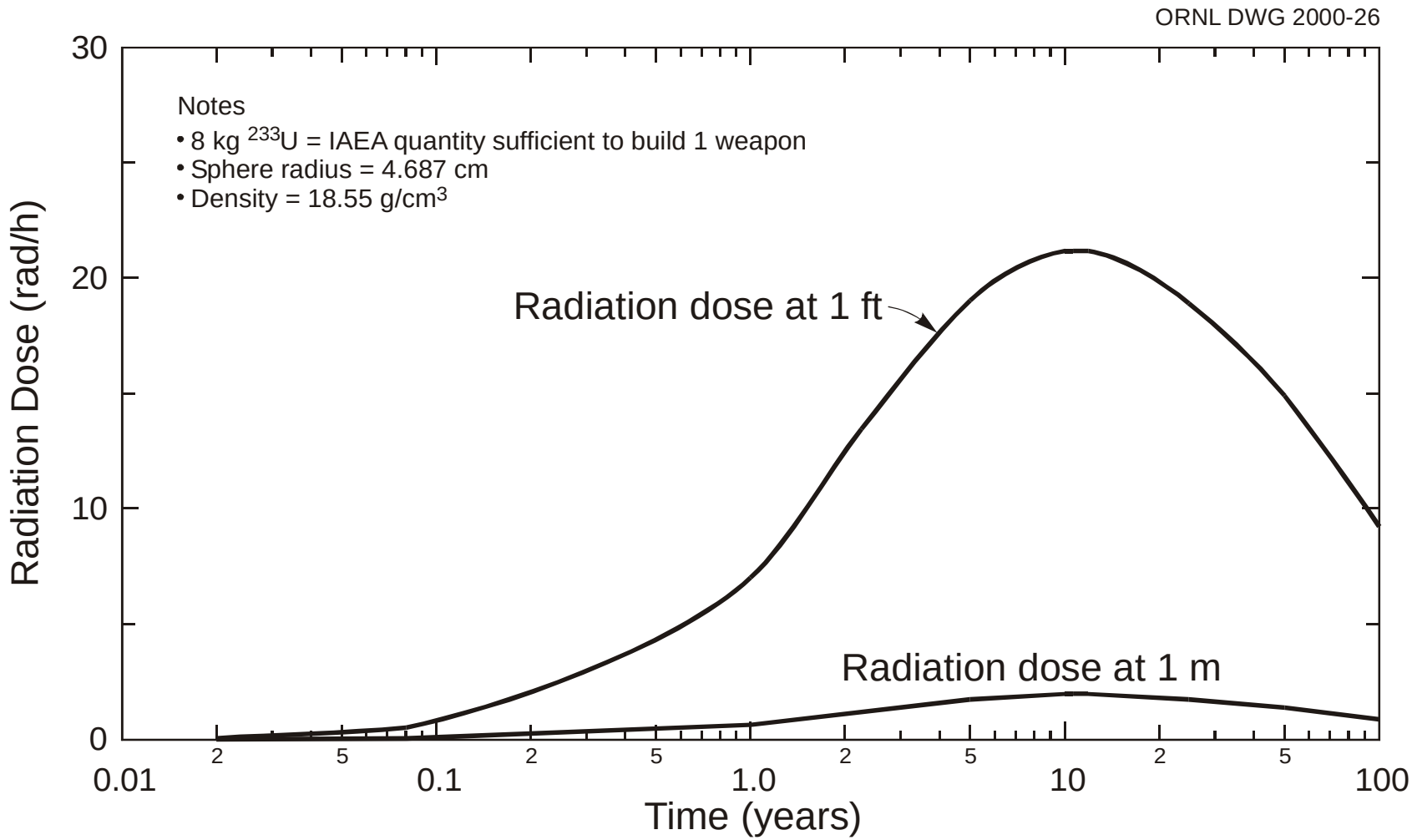
Actions To Define Weapons-Usable ^{233}U

It Is Recommended That 12 wt % ^{233}U In ^{238}U Become The Dividing Line Between Weapons-Usable And Non-Weapons-Usable ^{233}U

- **Different neutronic calculations all yield the result that ~12 wt % ^{233}U in ^{238}U is equal to 20 wt % ^{235}U in ^{238}U**

- **Informal (undocumented) use assumes 12 wt % ^{233}U in ^{238}U as the dividing line between weapons-usable and non-weapons-usable ^{233}U**

- **Additional conservatism is that ^{233}U (except that produced under very unusual circumstances) is typically contaminated with ^{232}U and ^{232}U decay products, which create significant radiation fields as compared to those created by HEU**



Radiation Dose from a Metal Sphere with 100 ppm ^{232}U and 8 kg ^{233}U

The Following Definition Of *Non-Weapons-Usable* ^{233}U Is Recommended For Mixtures Containing Multiple Uranium Isotopes

$$\frac{1.67 \times \textit{Weight Of } {}^{233}U + \textit{Weight Of } {}^{235}U}{\textit{Weight Of Total Uranium}} < 0.20$$

[a]It is recommended that this relationship be added to DOE M 474.1-1, *Manual for Control and Accountability of Nuclear Materials*, pp.1–7, "Table 1–4. Graded Safeguards," at the end of the entry, "ALL OTHER MATERIALS . . . any quantity), U-233, where [(1.67 × weight of U-233 + weight of U-235/weight of total uranium) <0.2 (any form, any quantity)].

Path Forward For Definition Of Non-Weapons-Usable ^{233}U

- DOE-NN agreement on the definition
- Interagency Working Group [DOE, Department of Defense, Nuclear Regulatory Commission (NRC), DOS] reaches an agreement on the definition
  - DOE-NN grants a variance recognizing the definition of non-weapons-usable ^{233}U
  - DOE-NN includes the new definition when DOE orders and guidance are updated[a]
  - NRC and DOE include the new definition when changes are made in the appropriate sections of the Code of Federal Regulations
  - DOS includes the definition in future treaties and when other agreements are updated

[a]It is recommended that the following relationship be added to DOE M 474.1–1, *Manual for Control and Accountability of Nuclear Materials*, pp. 1–7, "Table 1–4. Graded Safeguards," at the end of the entry, "ALL OTHER MATERIALS . . . any quantity), U-233 where [1.67 × weight of U-233 + weight of U-235/weight of total uranium <0.2 (any form, any quantity)].

Definitions Of ^{233}U Safeguards And Security Categories

Appropriate Safeguards And Security Rules Are Needed For ^{233}U To Ensure Efficient Use Of Government Funds. For The First Time In Several Decades, There Will Be Significant Handling Of ^{233}U

- **DOE-Environmental Management (EM) safe storage program**
  - **DOE-EM is initiating a ^{233}U multiyear inspection and repackaging program for ^{233}U**
  - **Contact: Hoyt Johnson (DOE-EM)**
- **Fissile materials disposition**
  - **Disposition activities may include processing of ^{233}U to convert the ^{233}U to non-weapons-usable material**
  - **Contact: Martin Newdorf (DOE-MD)**

DOE's Security And Safeguards Requirements For ^{233}U Are Far More Restrictive Than Those For HEU And Plutonium Because They Do Not Account For Isotopic Dilution Of ^{233}U With Other Uranium Isotopes

- During the cold war, there was no consideration of isotopically diluting weapons-usable uranium isotopes

- The existing ^{233}U rules, defining the categories that determine the security requirements, are identical to those for plutonium

  — Categories for plutonium depend upon the plutonium mass[a]
  — Categories for ^{233}U depend upon the *total* uranium mass[a]

- If 1 kg of ^{233}U oxide (Category III) is diluted with 6 kg of ^{238}U, the product is a Category I quantity of material (treated as 7 kg of ^{233}U)—isotopics are not accounted for and thus dilution increases security requirements

- If 3 kg of ^{235}U oxide (Category III) is diluted with 20 kg of ^{238}U, the product is a Category III quantity—isotopics are accounted for

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[a]DOE M 474.1–1, *Manual for Control and Accountability of Nuclear Materials*, p. 1–8, Sect. 2.b, line 9: "Material quantities are element weights for plutonium and ^{233}U and isotopic weights for ^{235}U."

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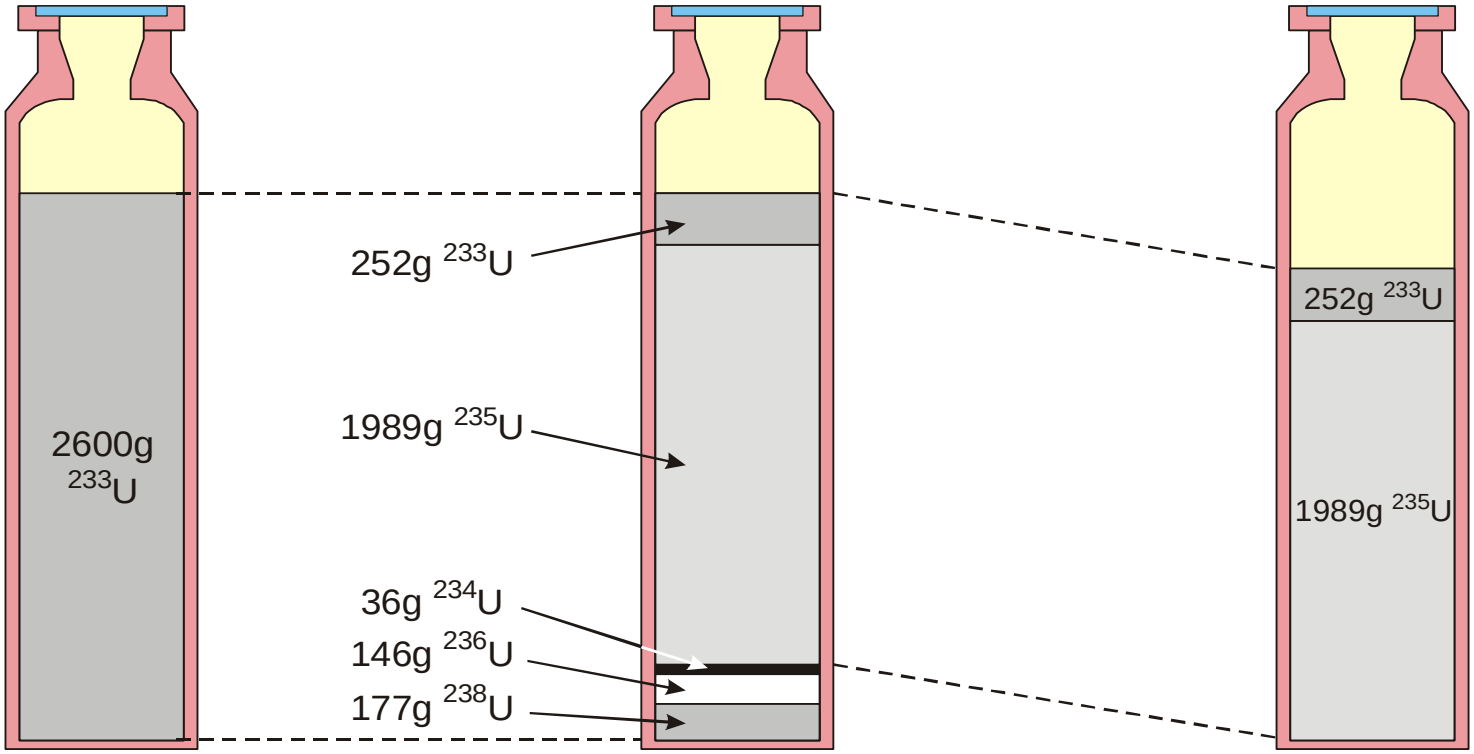

As Viewed By Current Rules (Category II)

Actual Can Content

Proposed Changes In Rules (Category III)

Categorization of CEUSP ^{233}U Can With Uranium Oxides

The Current Rules Directly Impact The Handling Of The 403 Cans Of Consolidated Edison Uranium Solidification Program (CEUSP) ^{233}U—Half The ^{233}U Inventory. Most Operations Involve 1 CEUSP Can

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- **Typical contents of 1 CEUSP can of uranium oxides**

  - **252 g ^{233}U**
  - **1,989 g ^{235}U**
  - **36 g ^{234}U**
  - **146 g ^{236}U**
  - **177 g ^{238}U**

  2,600 g U_{total}

- **One can is a Category II quantity because it is treated as 2.6 kg of ^{233}U**

- **One can would be a Category III quantity if:**

  - **The ^{233}U were plutonium**
  - **The uranium were treated by isotopes (like ^{235}U)**

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[a]DOE M 474.1–1 Manual for Control and Accountability of Nuclear Materials, pg. 1–8, Sect. 2.b, line 9: "Material quantities are element weights for plutonium and ^{233}U and isotopic weights for ^{235}U."

Implications And Actions

- **Treatment of a CEUSP can as a Category II quantity increases security costs by ~$2.5 × 10^6/year when handling these cans**
  - **Planned inspections of CEUSP cans will require several years**
  - **If CEUSP ^{233}U is processed for disposition, the processing will require several years**
- **Costs can be avoided by treating ^{233}U like other weapons-usable materials**
- **Modify DOE M 474.1–1, *Manual for Control and Accountability of Nuclear Materials*, pp. 1–8, Sect. 2.b, Line 9**
  - **Current: "Material quantities are element weights for plutonium and U-233 and isotopic weights for U-235"**
  - **Modification: "Material quantities are element weights for plutonium and isotopic weights for U-233 and U-235"**

Path Forward For Changes In The Categorization Of ^{233}U Quantities

- **DOE-NN agrees to treat ^{233}U on an isotopic basis**
- **DOE-NN grants a variance to treat ^{233}U isotopically**
- **DOE-NN modifies the DOE orders and guidance when the documents are updated[a]**

[a]DOE M 474.1–1, *Manual for Control and Accountability of Nuclear Materials*, pp. 1–8, Sect. 2.b, Line 9 states: "Material quantities are element weights for plutonium and U-233 and isotopic weights for U-235." It is proposed that this be changed to "Material quantities are element weights for plutonium and isotopic weights for U-233 and U-235."

Near-Term Actions

- ORNL is preparing a formal request for changes to the rules
  - Request will be sent to DOE/Oak Ridge Operations and then DOE/NN
  - Request is being coordinated with other sites
  - DOE/NN review committees are being notified of proposed changes and the proposal changes are being placed on committee calendars
- DOE/MD is coordinating activities with DOE/NN and other DOE/Headquarters organizations

Conclusions

- **Uranium-233 is the orphan fissile material. Isotopic dilution of ^{233}U with ^{238}U was not considered for any application during the cold war**

- **To advance nonproliferation goals and reduce costs, the rules should be modified to account for the effect of other uranium isotopes on the usability of ^{233}U for weapons purposes**

- **A set of changes are proposed so that the rules for ^{233}U will be consistent with the rules for plutonium and ^{235}U**