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Recommended Representative Isotopic Compositions for Potential VTR Pu Supplies

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Introduction

This document recommends isotopic compositions to represent selected Pu supplies that might be made available for use in VTR driver fuel. These compositions are intended to be conservative representations suitable for determination of environmental impacts associated with use of the selected Pu supplies, but not upper bounds of all possible compositions. The selected Pu supplies under consideration are themselves representations of a more complicated set of possibilities, defined in a manner to allow efficient but conservative analysis of impacts.[1]

The source definitions to be considered are as follows:

1. Foreign sources of reactor-grade plutonium. This material would be provided as polished material in an oxide form and is assumed to be transported from Europe (France or England).
2. Domestic, non-weapon sources of plutonium such as unused FFTF fuel, Hanford metal (stored at SRS), and various oxides.
3. Domestic sources of weapons-grade plutonium, including metal from dismantled pits and otherwise excess to stockpile needs.

Assumptions and Simplifications

The following were applied in determining representative isotopic compositions:

- The intent is to recommend representative isotopic compositions that conservatively (with respect to environmental impact) represent the average of selected plutonium sources, rather than compositions that bound all compositions but are not representative of the bulk of the material.
- Because impurity contents in the potential plutonium supplies varies, and because information is not available uniformly, it is convenient to assume those impurities to not add appreciably to the environmental impact of processing that material into VTR fuel. This is justifiable because the greatest radiological exposure and ingestion hazards result from plutonium and americium isotopes, which are addressed here.
- Because amounts of plutonium in stored in specific places are classified, impressionistic quantities of different sources are provided here based on unclassified sources. These values are not accurate but judged sufficient for evaluation of environmental impacts.
- Information from selected sources has been consolidated into a single representative source, to simplify evaluation and to avoid need for specific quantities that might be classified.
- The following definitions of plutonium grade are used here[2]
    - Weapons grade (WG): $^{240}Pu \leq 8\%$ of total Pu
    - Fuels grade (FG): $^{240}Pu > 8\%$ and $\leq 18\%$ of total Pu
    - Reactor grade (RG): $^{240}Pu > 18\%$ of total Pu
- Although VTR use of each potential Pu sources is not equally likely, no distinction is used here among Pu sources to define representative compositions. The details and content of policy decisions and international agreements that would allow use of any particular Pu supply cannot be helpfully predicted at this time.

Recommended Isotopic Compositions

1. French and UK reactor-grade plutonium
    a. UK reactor-grade plutonium

The Pu recovered from AGR and MAGNOX comprises the largest portion of the UK Pu inventory. [3,4] It is assumed here, based on the present author's judgment, that the as-discharged isotopic compositions for those sources are best represented by Pu recovered from medium burnup fuel, which is defined as 5.6 GWd/MTHM for Magnox fuel and 18 GWd/MTHM for AGR-1 fuel.[5] This assumption is support by other sources that report representative UK Pu isotopic compositions using these similar burnup designations.[6,7,8] It is further assumed that the bulk material can be represented, for the present purpose, by a 5-year time between discharge from the reactor and separation of plutonium, followed by a 25-year storage time to the present date. (Shorter pre-separations times and longer post-separations storage times allow more decay for ^{241}Pu to ^{241}Am and presumably would bring greater radiological/environmental impact in subsequent use. Otherwise, isotopic composition of Pu and associated impact depend on reactor-discharge composition and subsequent total decay time.) The representative isotopic compositions for each Pu source are tabulated below.

Table 1.

	Pu from AGR Fuel at 18 GWd/MTHM[5]					
0.5 yrs after discharge[5]	**^{238}Pu g/MTHM**	**^{239}Pu g/MTHM**	**^{240}Pu g/MTHM**	**^{241}Pu g/MTHM**	**^{242}Pu g/MTHM**	**^{241}Am g/MTHM**
	32	2700	1540	673	309	39.7
	^{238}Pu % of Pu	**^{239}Pu % of Pu**	**^{240}Pu % of Pu**	**^{241}Pu % of Pu**	**^{242}Pu % of Pu**	**^{241}Am % of Pu+Am**
0.5 yrs after discharge	0.6%	51.4%	29.3%	12.8%	5.9%	0.75%
After separation 5 yrs after discharge*	0.6%	52.8%	30.1%	10.4%	6.0%	0.0%
After 25-yrs post-separation storage*	0.5%	57%	33%	3.4%	6.5%	7.9%

* Calculated using:

14.4 years for the half-life of ^{241}Pu decay to ^{241}Am
87.7 years for the half-life of ^{238}Pu decay to ^{234}U
432.7 years for the half-life of ^{241}Am decay to ^{237}Np

Table 2.

	Pu from Magnox Fuel at 5.6 GWd/MTHM[5]					
0.5 yrs after discharge[5]	^{238}Pu g/MTHM	^{239}Pu g/MTHM	^{240}Pu g/MTHM	^{241}Pu g/MTHM	^{242}Pu g/MTHM	^{241}Am g/MTHM
	6.96	2060	728	199	43.4	17.1
	^{238}Pu % of Pu	^{239}Pu % of Pu	^{240}Pu % of Pu	^{241}Pu % of Pu	^{242}Pu % of Pu	^{241}Am % of Pu+Am
0.5 yrs after discharge	0.2%	67.8%	24.0%	6.6%	1.4%	0.56%
After separation 5 yrs after discharge*	0.2%	68.8%	24.3%	5.2%	1.4%	0.0%
After 25-yrs post-separation storage*	0.2%	71%	25%	1.6%	1.5%	3.8%

* Calculated using:

14.4 years for the half-life of ^{241}Pu decay to ^{241}Am
87.7 years for the half-life of ^{238}Pu decay to ^{234}U
432.7 years for the half-life of ^{241}Am decay to ^{237}Np

The total UK Pu inventory of these and other sources is expected to be around 140 MT, most of which is UK-owned and derived from AGR and Magnox fuel (anecdotally), so the UK inventory would be a sufficient single source for VTR supply.[9] Because information regarding the relative amounts of AGR-derived Pu and Magnox-derived are not known, it might be helpful to represent the UK inventory with the following single isotopic composition based on the AGR- and Magnox-derived inventory.[10,11]

Table 3.

	Estimated Pu for Combined AGR & Magnox Fuel[11*]					
Year	^{238}Pu % of Pu	^{239}Pu % of Pu	^{240}Pu % of Pu	^{241}Pu % of Pu	^{242}Pu % of Pu	^{241}Am % of Pu+Am
2025	0.25%	68.77%	26.70%	1.76%	2.52%	3.91%
2040	0.22%	69.42%	26.96%	0.86%	2.54%	4.68%

* Pu isotopic composition adjusted from source document values of Pu isotope fraction of Pu + Am.

b. French reactor-grade plutonium

The Pu inventory in France includes roughly 81 MT of Pu in oxide form (including some in unirradiated MOX powder, pellets and fuel products) and another 287 MT in used nuclear fuel.[10] The separated Pu inventory in France is comprised of 65 MT of material of French origin and 15.5 MT of material that is foreign-owned.[12] So, the French inventory alone would be sufficient to supply VTR needs, provided VTR core design accommodates lower Pu fissile contents (^{239}Pu + ^{241}Pu). Because the French nuclear reactor fleet is comprised of PWRs, it is assumed here that the French inventory is sufficiently represented by isotopic composition of Pu in PWR fuel of moderately high burnup (mean value of 42 GWd/MTHM).[13] As with the UK inventory, the representative time between reactor discharge and separations is assumed to be 5 years, and the representative post-separations storage time is assumed to 25 years.

Table 4.

	Pu from PWR Fuel at 42 GWd/MTHM[13]					
	^{238}Pu % of Pu	^{239}Pu % of Pu	^{240}Pu % of Pu	^{241}Pu % of Pu	^{242}Pu % of Pu	^{241}Am % of Pu+Am
0.5 yrs after discharge	2.3%	55%	22%	15%	5.8%	0.30%
After separation 5 yrs after discharge*	2.3%	57%	23%	12%	6.0%	0
After 25-yrs post-separation storage*	2.1%	62%	25%	4.0%	6.6%	8.4%

* Calculated using:

14.4 years for the half-life of ^{241}Pu decay to ^{241}Am
87.7 years for the half-life of ^{238}Pu decay to ^{234}U
432.7 years for the half-life of ^{241}Am decay to ^{237}Np

Recommendation for VTR EIS evaluation of foreign-sourced Pu:

- If a distinction is to be made between French and UK Pu supply
  - The combined composition for AGR and Magnox Pu (2025 composition) to represent the UK source
  - The composition for PWR fuel at 42 GWd/MTHM (Table 4, 25 years post-separation) to represent the French supply
- If all potential foreign Pu is to be addressed in a single composition, the composition for PWR fuel at 42 GWd/MTHM (Table 4, 25 years post-separation) would provide conservative assessment of radiological/environmental impact.

2. Domestic sources of non-weapons plutonium

The U.S. excess Pu inventory of 57.2 MT includes roughly 13 MT of Pu in metal and oxide forms, managed by DOE-EM and up to 4MT (now less than 4 MT) of Pu in ZPPR fuel and other forms managed by DOE-NE. [14,15] These DOE-EM and DOE-NE sources would not be sufficient to meet fueling needs for the VTR lifetime, but they could be used to supplement or back up other supply options should those other supplies be interrupted or delayed.

a. DOE-EM non-weapons Pu at SRS and other locations[16]

Details of the DOE-EM Pu inventory are not available in public documents, but information available in several documents appears to be sufficient to identify a representative isotopic composition.

- Some portion of the material is known to be in the form of mixed fuel intended for use in the Fast Flux Test Facility (FFTF), shipped to SRS from Hanford. Fresh FFTF driver fuel is reported to have isotopic composition containing 87% ^{239}Pu, 11.7% ^{240}Pu, and 1% ^{241}Pu.[17]
- Other material is documented to be metal and mixed oxide Pu also shipped from Hanford, with ^{240}Pu contents either greater than or less than 10%.[18]

- The isotopic composition used for safety and environmental analysis of some Pu stored in the SRS K area is reported to include 0.4% ^{238}Pu, 88% ^{239}Pu, and 6.25% ^{241}Am (the isotopes with greatest radiological and environmental impact).[19]
- The DOE standard for packaging and long-term storage of Pu-bearing materials provides a set of representative isotopic compositions for Pu in the DOE inventory, which is shown below in Table.

Table 5

	Isotopic Compositions of Different Pu types in the U.S. Inventory[16]					
	^{238}Pu % of Pu	**^{239}Pu % of Pu**	**^{240}Pu % of Pu**	**^{241}Pu % of Pu**	**^{242}Pu % of Pu**	**^{241}Am % of Pu+Am**
Weapon Grade	0.05%	93.50%	6.00%	0.40%	0.05%	
Fuel Grade	0.10%	86.10%	12.00%	1.60%	0.20%	
Power Grade	1.00%	63.00%	22.00%	12.00%	3.00%	
Hanford 4-7%	0.01%	93.77%	6.00%	0.20%	0.03%	0.14%
Hanford 10-13%	0.09%	86.94%	11.81%	1.00%	0.17%	0.86%
Hanford 16-19%	0.24%	80.66%	16.98%	1.44%	0.69%	2.80%

Given the information available, it seems best to consider the DOE-EM Pu inventory of metal and oxides as having the "Hanford 10%-13%" composition from Table 5, with ^{238}Pu content or 0.4% and ^{241}Am content of 6.25% of the total Pu and Am. These seems to be overestimates of the ^{238}Pu and ^{241}Am in this material, but given the uncertainties in composition assuming the larger values should bound radiological and environmental impacts from VTR use of this material.

Table 6.

Representative Isotopic Composition for DOE-EM Non-Weapons Pu					
^{238}Pu % of Pu	**^{239}Pu % of Pu**	**^{240}Pu % of Pu**	**^{241}Pu % of Pu**	**^{242}Pu % of Pu**	**^{241}Am % of Pu+Am**
0.4%	86.6%	11.8%	1.0%	0.17%	6.25%
* Composition shown is derived from the "Hanford 10%-13%" composition of reference 16, with ^{239}Pu content adjusted for the ^{238}Pu and ^{241}Am from reference 19, to reflect maximal radiological and environmental impact.					

Recommendation for VTR EIS evaluation of DOE-EM Pu:

- The portions of the VTR fuel supply assumed to come from 13 MT of DOE-EM Pu can be represented by the isotopic composition in Table 6.

b. DOE-NE non-weapons Pu at INL

According to the 2015 Surplus Plutonium Disposition EIS and a GAO report, the surplus inventory includes 4 MT of DOE-NE-managed Pu in as ZPPR fuel (metal and oxide) and other forms.[14,15] As suggested by the 2015 EIS, some portion of that inventory less than 4 MT remains

and could possibly be used in VTR fuel. The inventory contains a mix of fuels-grade and reactor-grade Pu, with MT amounts of fuels grade and 100s-of-kgs amounts of reactor grade material.[20] Unweighted average compositions for the fuels-grade and reactor-grade metals and oxides are tabulated below, as updated to incorporate decay as of April 1, 2020. [21]

Table 7.

	Unweighted average Composition* for Fuels-Grade ZPPR U-Pu-Mo[21]	**Unweighted average Composition* for Reactor-Grade ZPPR U-Pu-Mo[21]**
U	72.6%	63.5%
Pu	24.8%	34.0%
Mo	2.5%	2.5%
^{238}Pu % of Pu	0.0%	0.1%
^{239}Pu % of Pu	89.2%	70.8%
^{240}Pu % of Pu	10.5%	27.3%
^{241}Pu % of Pu	0.1%	0.4%
^{242}Pu % of Pu	0.1%	1.5%
^{241}Am % of (Pu+Am)	1.2%	4.8%
^{235}U	0.2%	0.2%
^{238}U	99.8%	99.8%

* Compositions shown are unweighted averages of composition of like materials as reported in reference 21, with ^{238}Pu, ^{241}Pu, and ^{241}Am amounts listed as of 1/1/1977 adjusted for radioactive decay to 4/1/2020. Note that reference 21 reports the composition date as 7/1/1983, but the correct date is 1/1/1977.[22]

Table 8.

	Unweighted average Composition* for Fuels-Grade ZPPR MOX[21]	**Composition for Reactor-Grade ZPPR MOX[21]**
U	68.3%	72.4%
Pu	19.9%	15.7%
O	11.8%	11.9%
^{238}Pu % of Pu	0.0%	0.1%
^{239}Pu % of Pu	87.9%	72.3%
^{240}Pu % of Pu	11.7%	27.0%
^{241}Pu % of Pu	0.2%	0.5%
^{242}Pu % of Pu	0.2%	0.1%
^{241}Am % of (Pu+Am)	1.5%	4.0%
^{235}U	0.2%	0.2%
^{238}U	99.8%	99.8%

* Compositions shown are unweighted averages of composition of like materials as reported in reference 21, with ^{238}Pu, ^{241}Pu, and ^{241}Am amounts listed as of 1/1/1977 adjusted for radioactive decay to 4/1/2020. Note that reference 21 reports the composition date as 7/1/1983, but the correct date is 1/1/1977.[22]

A single representative Pu and Am composition, based on the present author's judgment, that can be used to represent the DOE-NE Pu at INL is given in Table 9, along with values to represent a single U-Pu-Mo composition and a single MOX composition.

Table 9.

Representative Isotopic Composition for DOE-NE Non-Weapons Pu						
	^{238}Pu % of Pu	^{239}Pu % of Pu	^{240}Pu % of Pu	^{241}Pu % of Pu	^{242}Pu % of Pu	^{241}Am % of Pu+Am
All DOE-NE Pu at INL	0.1%	85.4%	14.1%	0.2%	0.3%	2%
All ZPPR U-Pu-Mo	0.1%	86.3%	13.0%	0.2%	0.3%	2%
All ZPPR MOX	0.05%	75.4%	23.9%	0.4%	0.2%	3%
* Compositions shown are derived by the author based in part on non-public information about quantities and in part on the present author's judgment.						

Recommendation for VTR EIS evaluation of DOE-NE Pu at INL:

- If a single composition is desired to represent the portions of DOE-NE Pu at INL used for VTR, the values in the top line of Table 9 above can be used.
- If a U-Pu-Mo/metal-specific isotopic composition and a MOX-specific composition are desired to represent the portions of DOE-NE Pu at INL used for VTR, the values so labeled in Table 9 above can be used.

3. Domestic excess weapons-grade plutonium

The U.S. excess Pu inventory of 57.2 MT includes 33.3 MT of metallic weapons-grade Pu in pit form, managed by NNSA.[14] This source alone would be sufficient to meet VTR needs. The isotopic compositions of U.S. weapons grade plutonium supplies are classified, but unclassified compositions for use in safety and environmental assessments can be found in public documents. The "Weapon Grade" composition in Table 5 in the preceding section is an example.[16] The composition provided for evaluation in the Surplus Plutonium Disposition Supplemental Environmental Impact Statement for and in the Environment Assessment for Pit Disassembly and Conversion is provided and recommended here, for consistency with these other recent DOE NEPA actions.[23]

Table 10.

Representative Composition for U.S. Weapons Pu[16,23*]					
^{238}Pu % of Pu	^{239}Pu % of Pu	^{240}Pu % of Pu	^{241}Pu % of Pu	^{242}Pu % of Pu	^{241}Am % of Pu+Am
0.05%	92.3	6.6%	0.0%	0.1	1.0%
* Composition shown differs from that of reference 23, because Pu isotopic values shown here are provided as % of Pu only, rather than as percent of Pu + Am. As with other values in this document, only the ^{241}Am content is provided as % of Pu + Am.					

Recommendation for VTR EIS evaluation of domestic excess weapons-grade Pu:

- The portions of the VTR fuel supply assumed to come from U.S. weapons-grade Pu supply can be represented by the isotopic composition in Table 10 above.

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