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Title: **American National Standard ANSI/ANS-8.12-1987: Criticality Control of Plutonium-Uranium Mixtures**

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AMERICAN NATIONAL STANDARD ANSI/ANS-8.12-1987: CRITICALITY CONTROL OF PLUTONIUM-URANIUM MIXTURES

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American National Standard ANSI/ANS-8.12-1987 (Ref. 1) was approved for use on September 11, 1987. The history of the development of the standard is discussed in Ref. 2. The first version of this standard, which only included subcritical limits on homogeneous plutonium-uranium fuel mixtures, was approved July 17, 1978. The current version was revised to include limits on heterogeneous systems as well (Ref. 3). This paper provides additional information on the limits presented in the standard.

As stated in its forward, the standard "... provides guidance for the prevention of criticality accidents in the handling, storing, processing, and transporting of plutonium-uranium fuel mixtures outside reactors and is applicable to all operations involving mixtures of plutonium and natural uranium. It constitutes an extension of the American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANSI/ANS-8.1-1983 (Ref. 4).

The standard includes subcritical limits[1] for both homogeneous mixtures and heterogeneous lattices of plutonium and uranium. The uranium is assumed to be natural or depeleted. Limits

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[1]The limiting value assigned to a controlled parameter that results in a system known to be subcritical, provided the limiting value of no other controlled parameter of the system is violated. The subcritical limit allows for uncertainties in the calculations used in its derivation, but not for contingencies, e.g., double batching or failure of analytical techniques to yield accurate values of process variables.

are provided for a variety of mixtures, including aqueous solutions, dry [H/(Pu + U) = 0] mixed oxides at theoretical density, and damp [H/(Pu + U) $\leq$ 0.45] mixed oxides at both theoretical and one-half theoretical density. The limits for homogeneous mixtures shown in Table I cover four different plutonium contents (3, 8, 15, and 30 wt% PuO_2 in $PuO_2 + UO_2$) and three different isotopic compositions ($^{240}Pu > ^{241}Pu$; $^{240}Pu \geq 15$ wt% and $^{241}Pu \leq 6$ wt%; and $^{240}Pu \geq 25$ wt% and $^{241}Pu \leq 15$ wt%).

Heterogeneous lattice limits for mass, spherical volume, cylinder diameter, and slab thickness are also presented in the standard. Figure 1 shows one such set of limits: the limiting volume curves for heterogeneous systems. Anomalous behavior was noted for the heterogeneous cases with 30 wt% plutonium in $PuO_2 + UO_2$ with 25 wt% ^{240}Pu and 15 wt% ^{241}Pu. For these cases, the minima calculated for the lattices were greater than the minima for dry theoretical oxide. The lattice minima occurred with very small rod diameters, and it is believed that the resonance absorption treatment employed could not adequately handle the unusual geometry (Ref 5). Thus, the standard does not extrapolate beyond 15 wt% plutonium in the mixed oxide for the isotopic mixture of 25 wt% ^{240}Pu and 15 wt% ^{241}Pu.

The current version of the standard has now been available for 13 years. The last reaffirmation was on February 17, 1993. The standard provides useful subcritical limits for mixed-oxide systems in the range of 3 to 30 wt% PuO_2 in $PuO_2 + UO_2$. To cover interest in metal fuels (such as the uranium, plutonium, and zirconium fuel used in the integral fast reactor concept [Ref. 6]), a work group is likely to be formed to establish limits applicable to these fuel types.

1. "Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors," ANSI/ANS-8.12-1987, American Nuclear Society (1987).

2. R. A. LIBBY, E. D. CLAYTON, "American National Standard ANSI/ANS-8.12-1987 -- History and Limits," *Trans. Am. Nucl. Soc.*, **62**, 335 (1990).

3. E. D. CLAYTON, H. K. CLARK, G. WALKER, "Basis for Extending Limits in ANSI Standard for Mixed Oxides to Heterogeneous Systems," *Nuc. Tech.*, **75**, (November (1986).

4. "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1983 (reaffirmed 1988), American Nuclear Society (1988).

5. E. D. CLAYTON, "Safety Implications of Anomalous Effects of Neutron Absorbers on Criticality," *Proc. Int. Seminar Nuclear Criticality Safety*, Tokyo, Japan, October 19-23, 1987, p. 194.

6. D. R. PEDERSEN, B. R. SEIDEL, "A Status Report on the Integral Fast Reactor Fuels and Safety Program," *Trans. Am. Nucl. Soc.*, **61**, 300 (1990).

TABLE I

Subcritical Limits for Uniform Aqueous Mixtures of the Oxides of Plutonium and Natural Uranium*

	PuO_2 in (PuO_2 + UO_2) (wt%)											
	3			8			15			30[a]		
	Plutonium Isotopic Composition[b]											
	I	II	III	I	II	III	I	II	III	I	II	III
Mass of plutonium in oxide mixture (kg)	0.73	1.35	2.00	0.61	1.06	1.53	0.54	0.94	1.28	0.50	0.87	1.16
Mass of (PuO_2 + UO_2) (kg)	27.5	51.3	75.9	8.6	15.1	21.7	4.1	7.1	9.7	1.9	3.3	4.4
Diameter of infinite cylinder (cm)	24.3	30.8	34.8	19.8	24.9	27.5	17.8	22.5	24.8	16.2	21.0	23.4
Thickness of infinite slab (cm)	11.0	14.9	17.4	8.2	11.2	12.9	6.9	9.6	11.0	5.9	8.7	9.9
Volume of oxide mixture (ℓ)	23.5	44.8	63.4	14.0	25.9	34.4	11.0	20.4	26.6	8.5	16.8	21.6
Concentration of plutonium (g Pu/ℓ)	6.8[c]	8.1	9.3	6.9	8.2	9.4	7.0	8.2	9.4	7.0	8.1	9.3
Concentration of oxides [g(PuO_2 + UO_2)/ℓ]	257[c]	305	351	97.3	116	134	52.9	61.7	71.0	26.5	30.7	35.2
H:Pu atomic ratio	3780	3203	2780	3780	3210	2790	3780	3237	2818	3780	3253	2848
Areal density of plutonium (g Pu/cm^2)	0.27	0.38	0.47	0.25	0.34	0.42	0.25	0.33	0.41	0.24	0.32	0.37
Areal density of oxides [g(PuO_2 + UO_2)/cm^2]	10.2	14.4	17.7	3.5	4.8	5.9	1.9	2.5	3.1	0.9	1.2	1.4

*All values are upper limits except atomic ratios, which are lower limits.

[a]Dimensional and volume limits do not apply for isotopic compositions II and III unless, for II, the concentration of oxides is < 5700 g/ℓ and, for III, < 4500 g/ℓ.

[b]Plutonium isotopic composition: I -- $^{240}Pu > ^{241}Pu$, II -- $^{240}Pu \geq 15$ wt% and $^{241}Pu \leq 6$ wt%, and III -- $^{240}Pu \geq 25$ wt% and $^{241}Pu \leq 15$ wt%.

[c]This concentration limit is not applicable to oxide mixtures in which the PuO_2/(PuO_2 + UO_2) ratio is < 3 wt% because of the increased relative importance of ^{235}U in high-uranium-bearing materials.

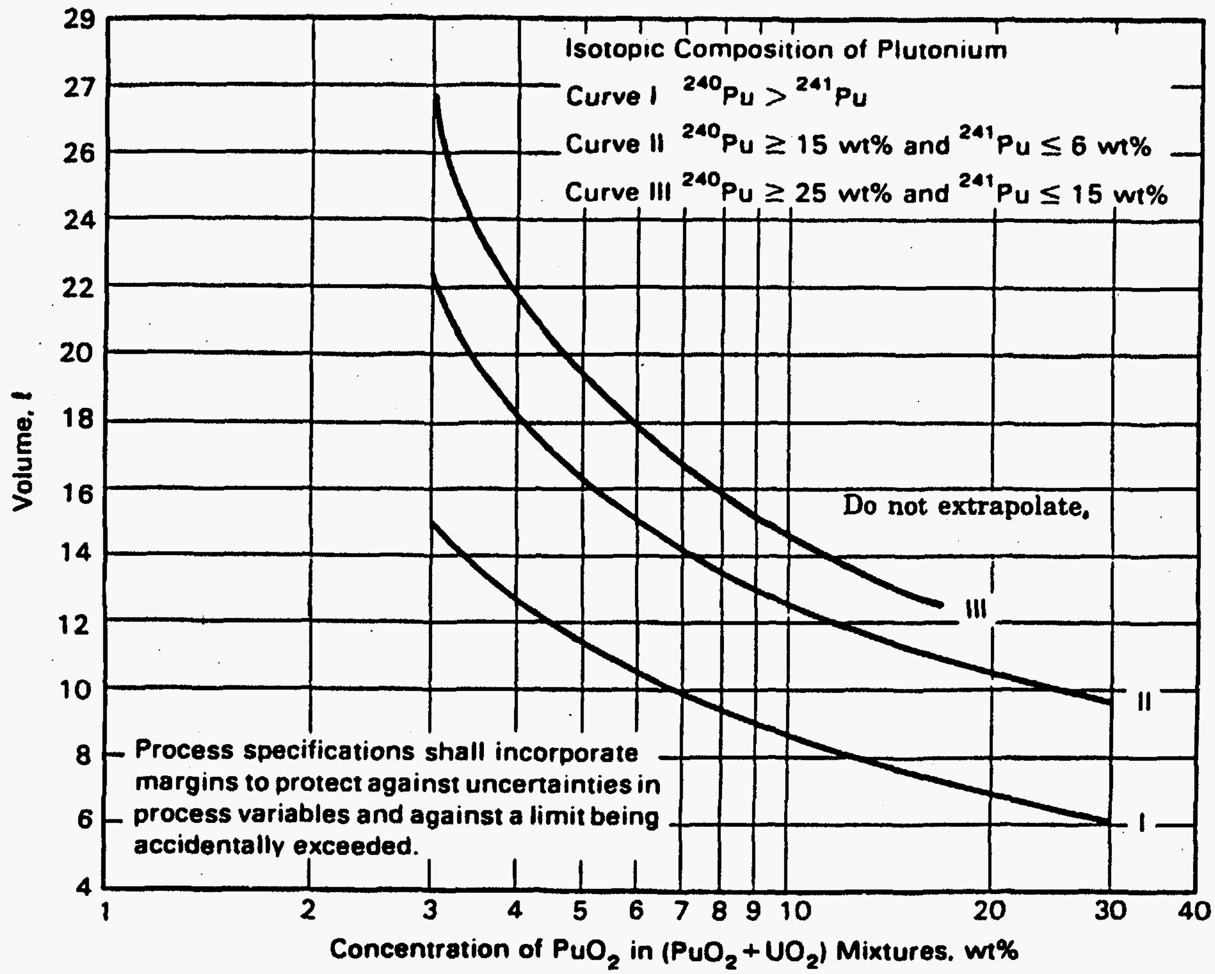

Fig. 1. Limiting volume of heterogeneous mixtures of the oxides of plutonium and natural uranium in water as a function of the plutonium oxide content.