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Title: Fraction Critical Arguments in Criticality Safety

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Fraction Critical Arguments in Criticality Safety

Presented by:
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Background

- “Fraction Critical” is a term used in some hand calculations (typically for arrays)
- Defined as $\boldsymbol{f} = \frac{\boldsymbol{m_i}}{\boldsymbol{m_c}}$
- Used in Surface Density Method and Density Analog Method to determine unit spacing based on fraction critical of individual units

Relation to k_{eff}

- $F \neq k_{eff}$, but there is a relationship between the two which may be useful to determining margins
- Can be empirically approximated by $k_{eff} = (F)^n$
  - n may be 0.25 or 0.3 depending on the system (bare/reflected metal or bare/reflected solutions)
  - Refer to ESH-6-96-092 for derivation of the exponent n
  - F^n gives a rough approximation of k_{eff}, but is not necessarily conservative
- From ESH-6-96-092:

"Perhaps the most notable result of these analyses is the extreme nonlinearity of k_{eff} as a function of F. In particular, for low values of F (less than 1/5 of a critical mass), k_{eff} rises very quickly to values of 0.5 to 0.7. Note also that a k_{eff} of 0.9 is obtained with less than 70% of a critical mass."

Relation to k_{eff} (continued)

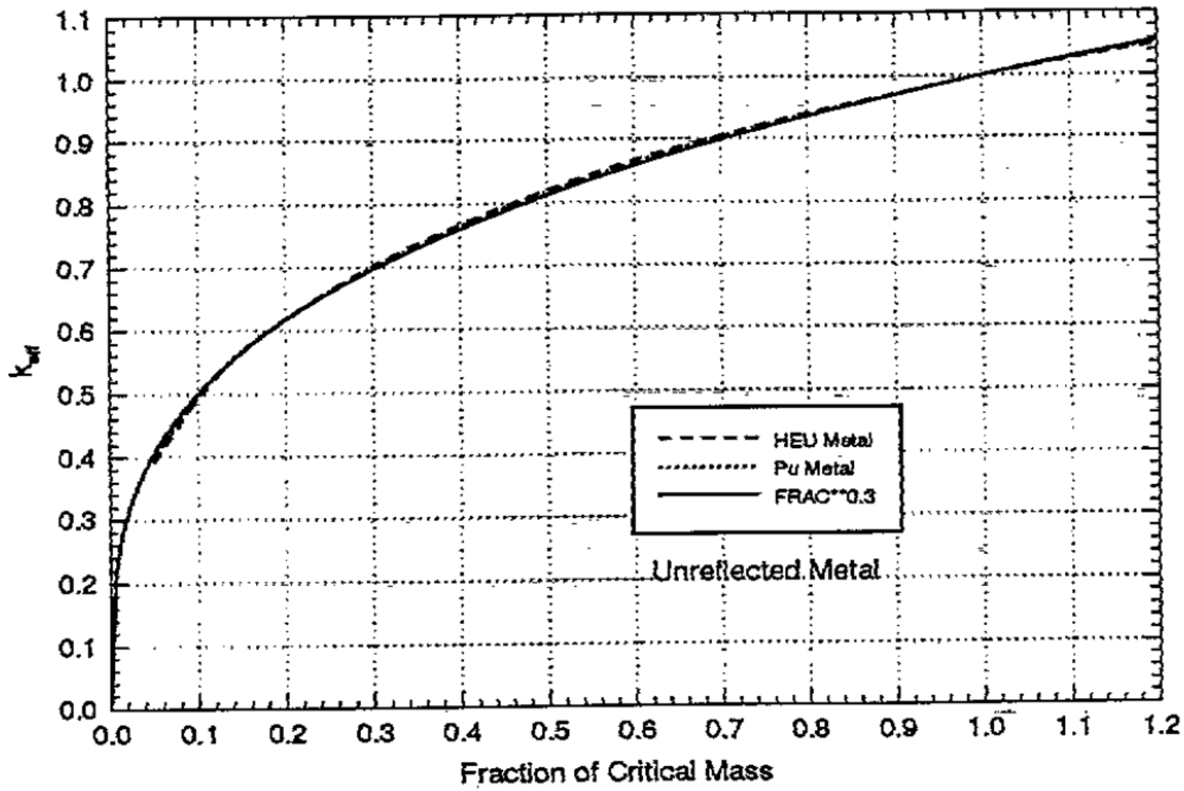


Fig. 1. k_{eff} vs Fraction of Critical Mass: Unreflected Metal

Relation to k_{eff} (continued)

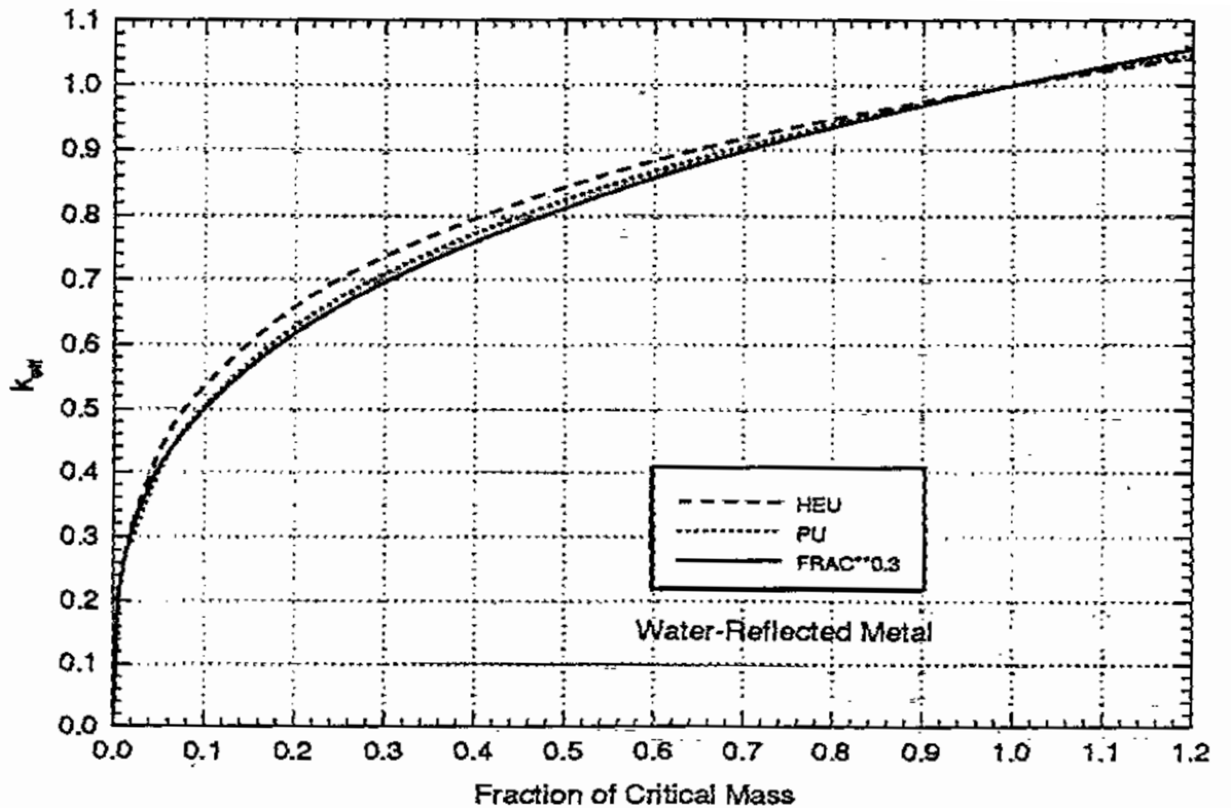


Fig. 2. k_{eff} vs Fraction of Critical Mass: Thick-Water-Reflected Metal

Relation to k_{eff} (continued)

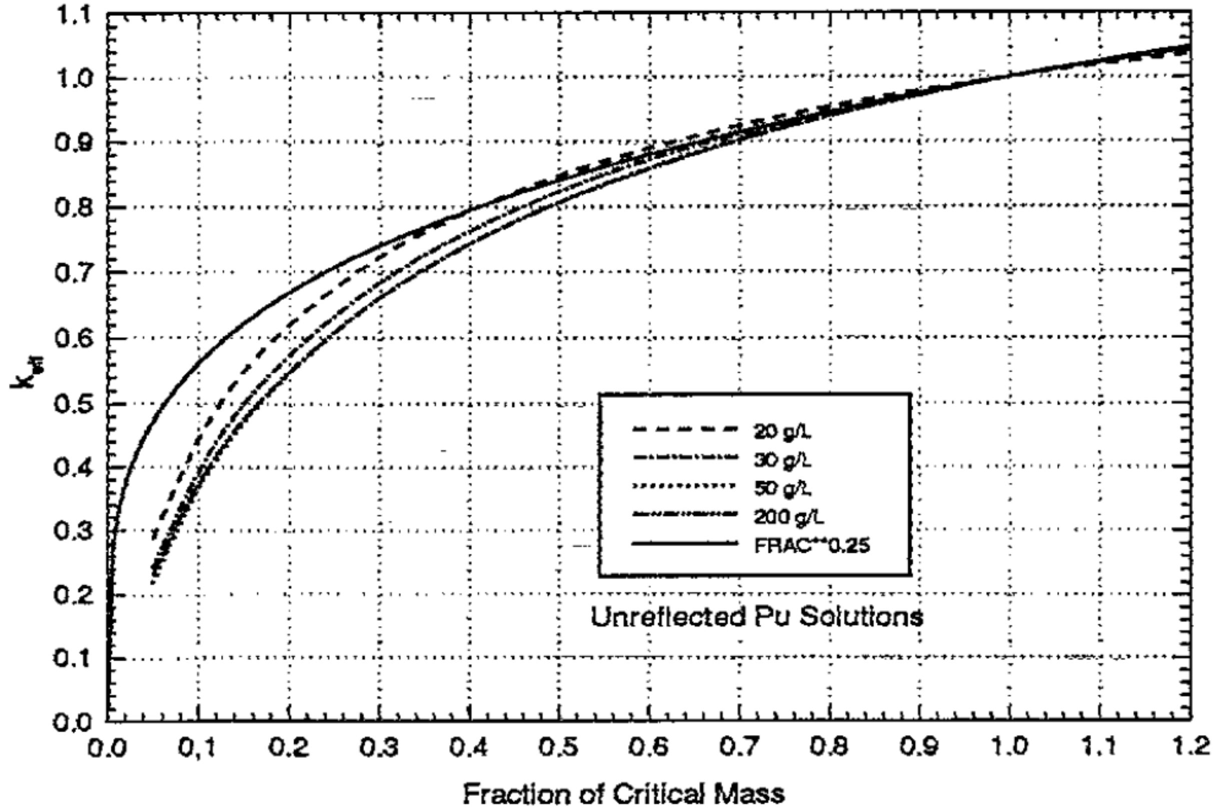


Fig. 4. k_{eff} vs Fraction of Critical Mass: Unreflected Pu Solutions

Relation to k_{eff} (continued)

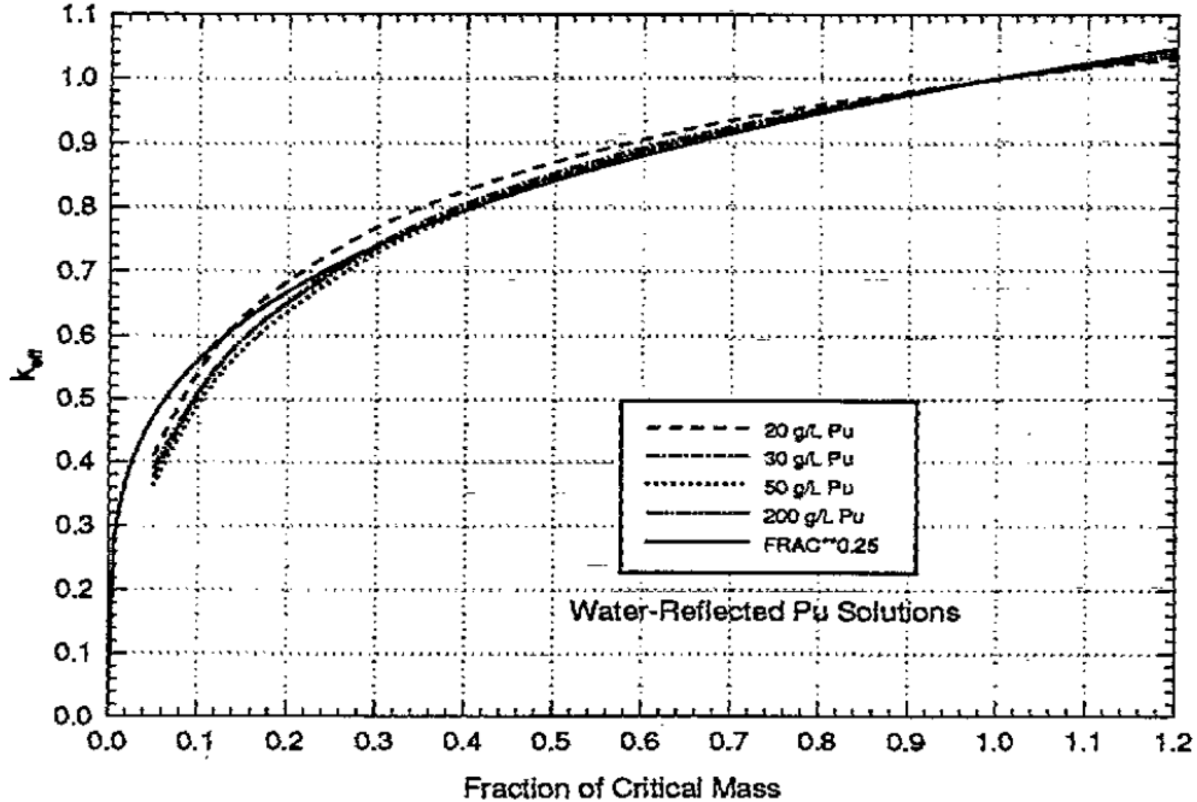
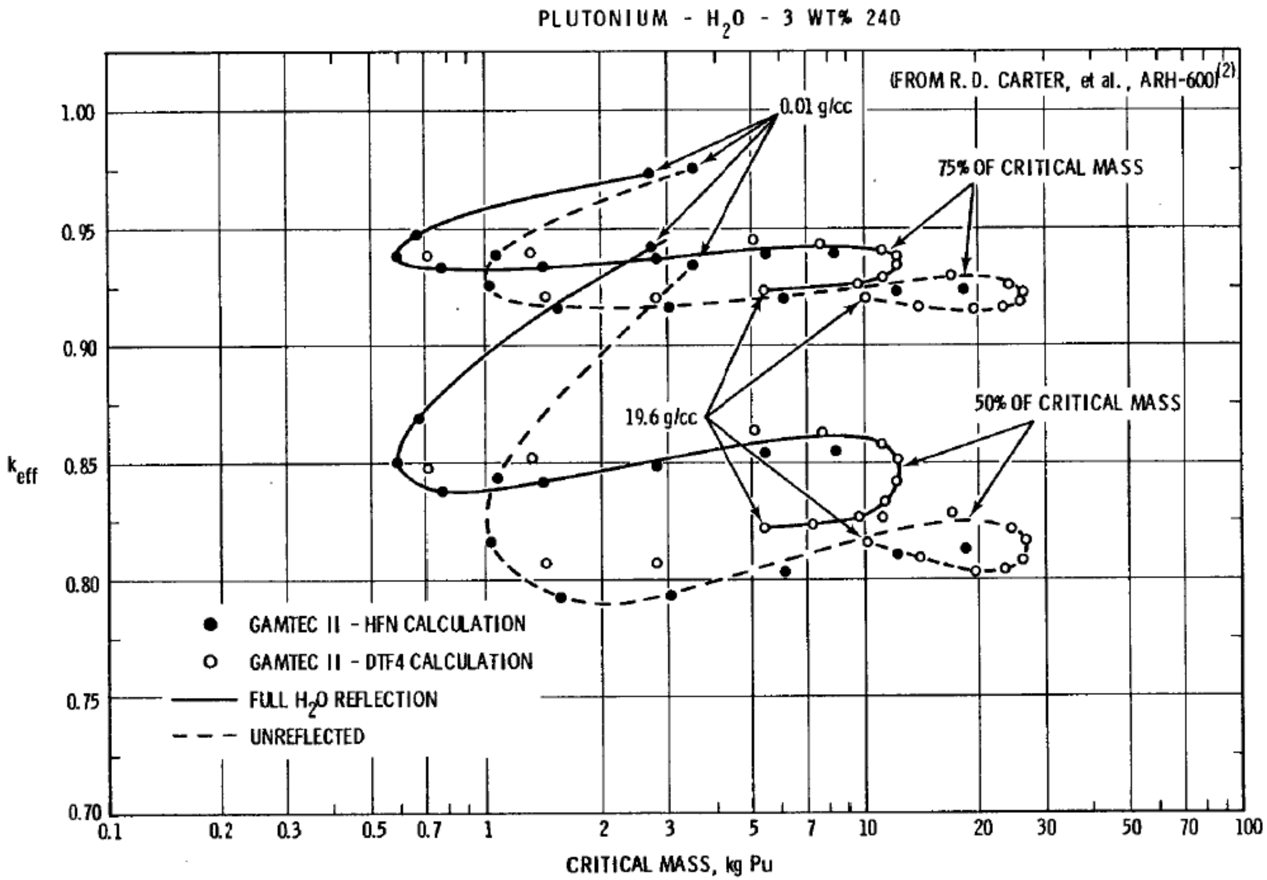


Fig. 6. k_{eff} vs Fraction of Critical Mass: Thick-Water-Reflected Pu Solutions

Relation to k_{eff} (continued)

- Can fraction critical be used to estimate k_{eff}? Not Really.
- This problem is described in PNNL-19176: Anomolies of Nuclear Criticality:
  - *"A problem arises because there is no general consistency between k_{eff} and fraction of critical mass except at the point of criticality (where k_{eff} = unity). Two different systems that have the same fraction of critical mass may have different values of k_{eff}, e.g., for a specified value of k_{eff} on two systems (with different fuel compositions), one system may have a higher fraction of critical mass and be less safe than the other."*
- However, some empirical data does exist which can be used to relate fraction critical to k_{eff} in some cases (i.e. ARH-600 contains calculated k_{eff} vs critical mass curves)

Relation to k_{eff} (continued)



Example Uses of Fraction Critical

- From 2010 file in the Database (File 0148):
  - Fraction critical comparison of a 5288 g rod of delta plutonium metal to the posted 4500 g limit.

Doug,

Regarding the 5288g delta rod:

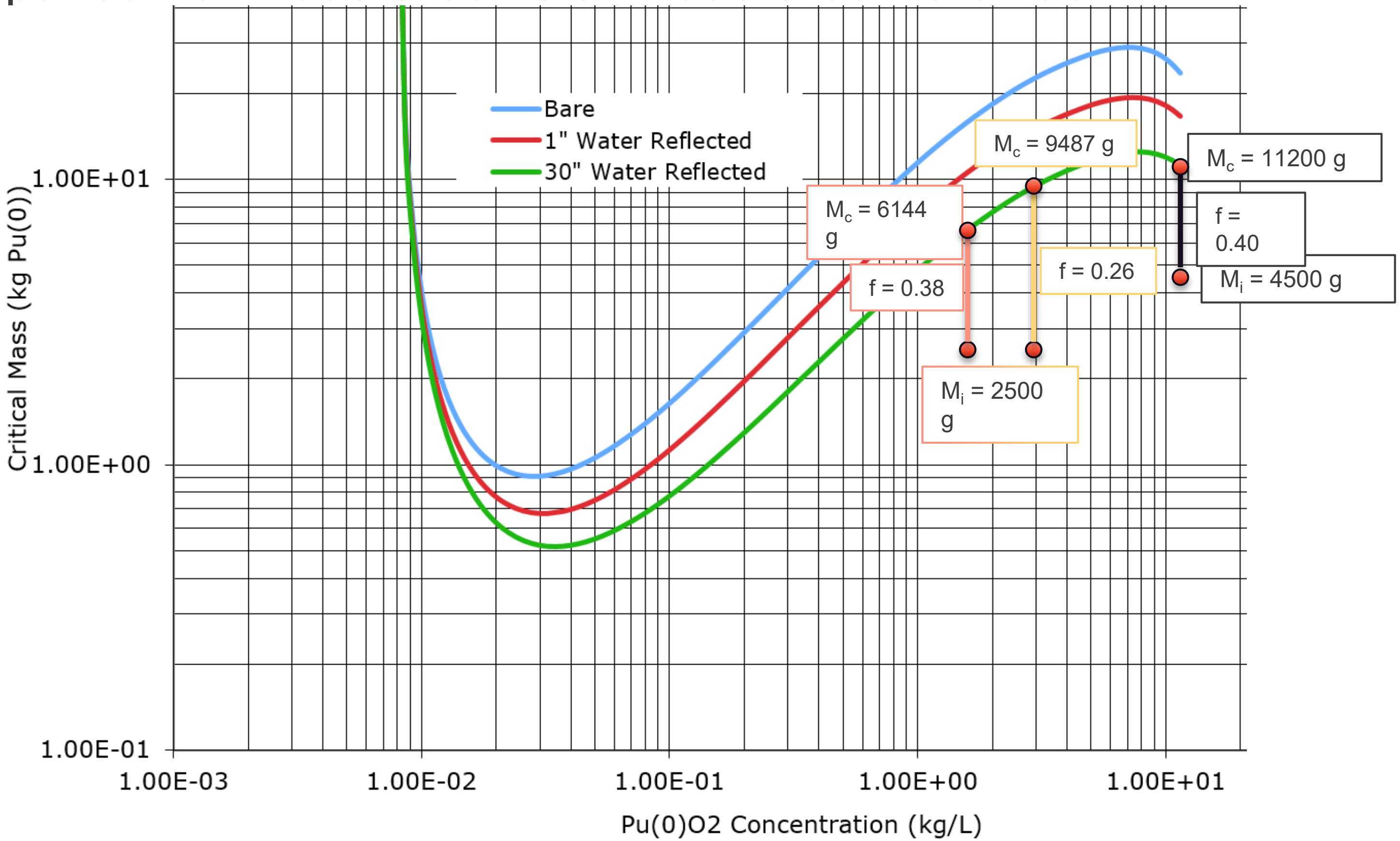
$$\text{Fraction}_{\text{critical}} = \frac{4500\ \text{g}}{5300\ \text{g}} = 0.85\ \{\text{for alpha phase pu metal}\}$$

$$\text{Fraction}_{\text{critical}} = \frac{5288\ \text{g}}{5300\ \text{g}\left(\frac{19.86\ \text{g/cc}}{15.76\ \text{g/cc}}\right)2} = 0.63\ \{\text{for delta phase pu metal}\}$$

So the rod can be justified based on its mass and density.

Example Uses of Fraction Critical

- Comparison of moderated vs unmoderated Pu oxide:



Rule of Fractions

- Related to fraction critical
- Applies to mixtures of isotopes or elements
- Originally appeared in ANSI 8.15-1981
  - Rule is that mixture is subcritical if $\sum_i \boldsymbol{f}_i < \mathbf{1}$
- Removed in ANSI 8.15-2014.
  - Per SRNS-TR-2016-00061, *Technical Justification for NCSEs using ANSI/ANS 8.15-1981*, "This was due to a change in philosophy and not a deficiency identified by the ANS 8.15 working group"
- However, performing calculations for some mixtures may be technically challenging, especially when it comes to validation of some elements in ANSI 8.15

Rule of Fractions (continued)

- Per WSRC-TR-91-569, Validity of the Rule-of-Fractions for Assuring Criticality Safety Margins (U):

"…the Rule-Of-Fractions cannot be relied on to preserve an acceptable margin of safety for any arbitrary combination of fissile and fissionable nuclides. However, for certain specific conditions the Rule-Of-Fractions margin was preserved. The conditions under which it appears valid are:

- *Homogeneous mixtures of fissile-fissile metals*
- *Homogeneous mixtures of fissionable-fissionable solutions*
- *Homogeneous mixtures of fissile-fissionable solutions…"*

- Work by Weber (Precise Margins of the Rule of Fractions for Mixtures of $U^{235/238}$, Pu^{239} and U^{233}) confirms the rule of fractions is conservative for homogenous metal mixtures of U and Pu

Example Use of the Rule of Fractions

- Rule of fractions was used in NCS-CSED-17-009
  - Was used to derive the 150 g U-233 solution mass limit for that evaluation

Table 5. Results for ^{233}U fraction of critical mass

Concentration (kg/L)	1" Water-Reflected ^{233}U Subcritical Mass Limit from TID-7016 (Ref. 17) (kg)	2.2-Liter Container Mass (kg)	^{233}U Fraction of Critical Mass	Sum of Pu and ^{233}U Fractions of Critical Mass
0.03	0.680	0.066	0.098	0.866
0.04	0.620	0.088	0.142	0.911
0.06	0.640	0.132	0.207	0.976
0.07	0.670	0.154	0.230	0.999

Questions?

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