Preliminary Criticality Calculations of Transuranic Fuel Solutions

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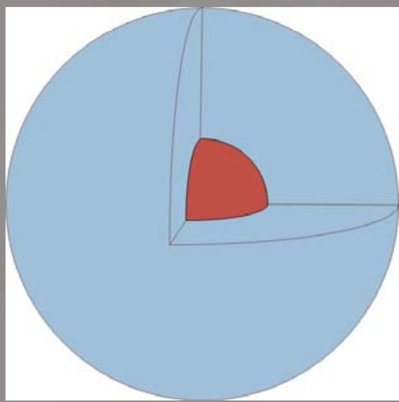
1. Introduction

- The safety of fuel recycling processes depends primarily on the concentration and composition of the solutions at various stages in the process.
- Historically, the safety of solution systems has been maintained by controlling the ***geometry*** and ***concentration*** of the dissolved fissile isotopes, with limited consideration given to the minor actinides in the system.

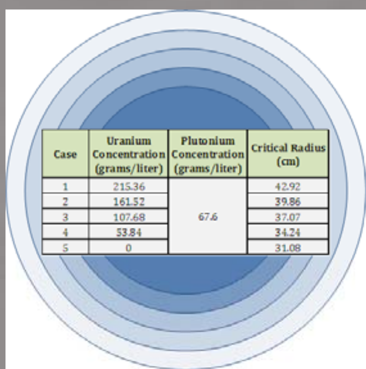
1. Introduction

- This work uses a solution system of used nuclear fuel and involves two processes:
  - Systematic extraction of uranium from the dissolved fuel mixture
  - Addition of actinides in various concentrations and combinations



1.1 Model Description

- The model used in these calculations is a series of critical spheres, composed of water-reflected uranium-plutonium nitrate.
- The concentration of the uranium in the solution was varied over 5 cases, and the radius of the sphere was adjusted to maintain the system in a critical state.



Case	Uranium Concentration (grams/liter)	Plutonium Concentration (grams/liter)	Critical Radius (cm)
1	215.36	67.6	42.92
2	161.52		39.86
3	107.68		37.07
4	53.84		34.24
5	0		31.08

1.1 Model Description

- After determining the effects on the system by changing the uranium concentration, a number of different actinides were added in various concentrations and combinations:
- Curium, Americium, and Neptunium

1.1 Model Description

- The solutions were modeled using MCNP v.1.51 and the ENDF/B-VII.0 cross section libraries.
- Additionally, a hand-calculation prediction was made to provide results for comparison.

1.1 Model Description

$$\text{Predicted } k_{\text{eff}} = \bar{f} \times \bar{\nu} \times \text{EE(everything else)}$$

$$\bar{f} = \frac{\overline{\Sigma_f}}{\overline{\Sigma_a}}, \text{ where } \overline{\Sigma_{rxn}} = N\overline{\sigma_{rxn}}$$

$$\bar{\nu} = \left(\chi^{isotope}\nu^{isotope}\right)_1 + \left(\chi^{isotope}\nu^{isotope}\right)_2 + \cdots$$

$$\overline{\sigma_{rxn}} = \left(\chi^{isotope}\sigma_{rxn}^{isotope}\right)_1 + \left(\chi^{isotope}\sigma_{rxn}^{isotope}\right)_2 + \cdots$$

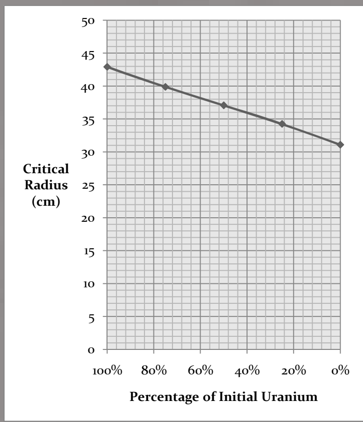
1.1 Model Description

- For the rest of the factors in the 6-factor formula, an approximation is used.
- The “Everything Else” term is calculated using the bare (uranium-plutonium only) cases.

$$\text{EE} = \frac{1}{\bar{f} \times \bar{\nu}}$$

1.2 Results

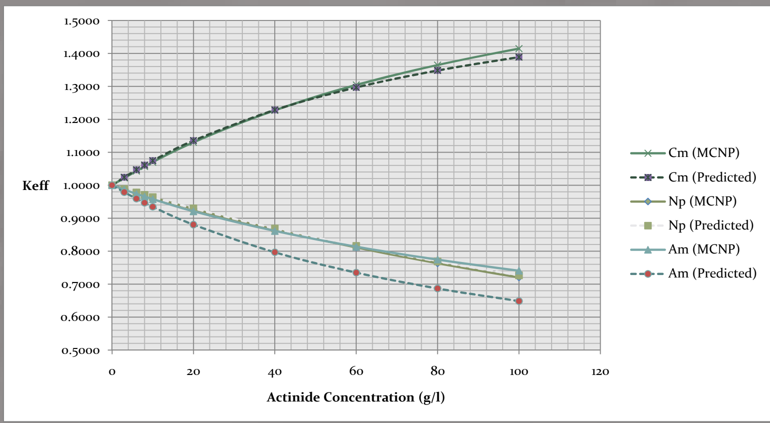
- Removal of the uranium from the system from 215.36 to 0 grams/liter resulted in a 27.6% reduction in the critical radius of the sphere.
- The primary fissile driver in this system is the plutonium present in the fuel solution.



1.2 Results

- Addition of the actinides to the solution created differing effects.
- The addition of curium drove the system supercritical, while americium and neptunium drove the system subcritical.
- The predicted keff was within 2% for both curium and neptunium.
- For americium, the predicted keff was under-predicted by about 14.2%.

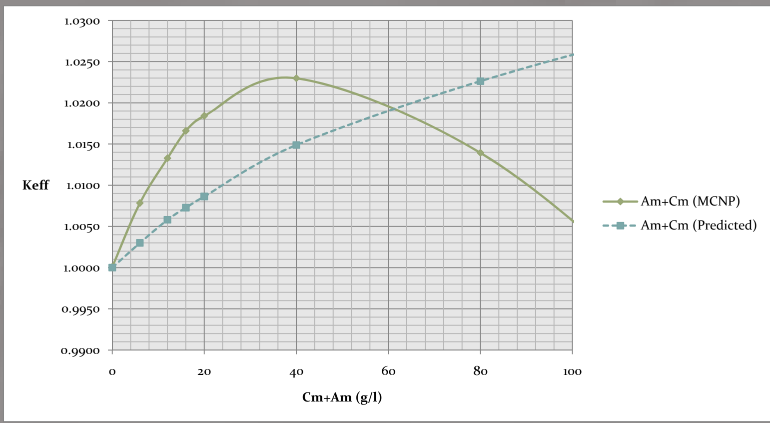
1.2 Results



1.2 Results

- The actinides were also introduced in several combinations.
- The predictive model worked well for low concentrations of actinides (below 20 grams / liter), but did not accurately represent the shape of the curve as concentration was increased.

1.2 Results



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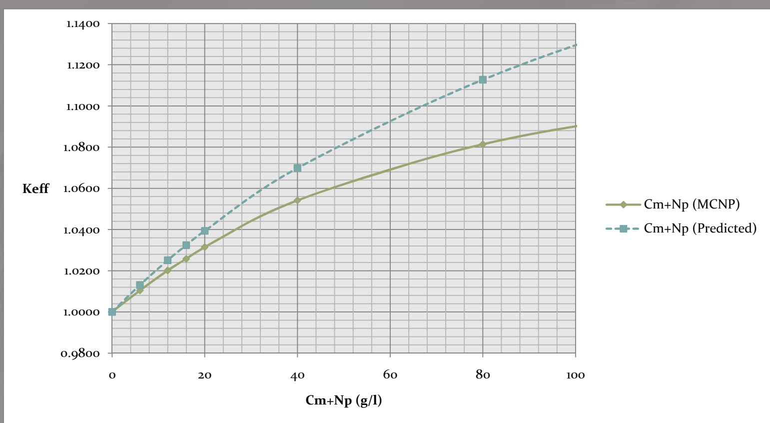
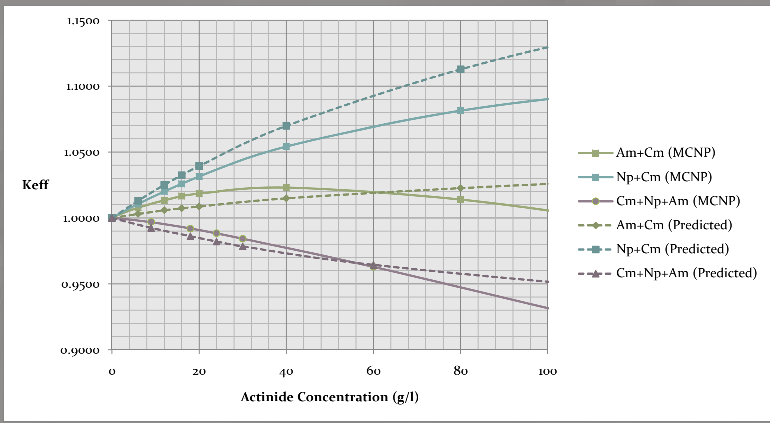


1.2 Results



2. Conclusions

- For determining ***general*** effects of actinides in a plutonium-uranium solution, simplified thermal utilization factor calculations can be performed with some degree of caution.
- The simplified prediction method was effective in determining the effects of addition of a single actinide, with reasonable error for curium and neptunium. The method was less effective for americium.
- A number of potential improvements to this predictive method have been identified and will be explored in future work.

3. References

- M.B. Chadwick, P. Oblozinsky, M. Herman et al.,"ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology", *Nuclear Data Sheets*, **vol. 107**, pp. 2931-3060, (2006).
- A.S. Garcia and L.M. Montierth, “Preliminary Criticality Calculations of Transuranic Fuel Solutions”, *Proceedings of the 2009 Nuclear Criticality Safety Division Topical Meeting on Realism, Robustness and the Nuclear Renaissance*, (2009).