GLE SER—Sensitivity of k_{eff} to Changes in Enrichment

Request was to provide documentation for the following statement:

> *From previous experience and independent calculations, the staff determined that a 1 wt. percent increase in enrichment translates into at least a 3 percent change in $k_{eff.}$*

Previous Experience:

There is ample precedent for considering the reactivity worth of conservative assumptions in evaluating the adequacy of applicants' subcritical margin; this approach is explicitly endorsed in FCSS-ISG-10, "Justification for Minimum Margin of Subcriticality for Safety." The approach is to try to quantify how much conservatism in k_{eff} results from conservative margin in various system parameters, and then consider that margin, along with the administrative k_{eff} margin, as part of the margin of subcriticality for safety mentioned in 10 CFR 70.61(d). Conservative assumptions may include conservatism in enrichment, moderation, reflection, density, burn-up, the neglect of absorbers, etc. Some reviews in which this approach was taken are listed below:

- Mixed Oxide Construction Authorization Request SER (NUREG-1821)
- USEC ACP SER, Appendix C (non-public version) (NUREG-1851)
- LES SER (NUREG-1827)
- Eagle Rock SER (NUREG-1951)
- Westinghouse License Renewal SER, August 2007
- Framatome-Lynchburg k_{eff} Amendment SER, September 2005
- Yucca Mountain High-Level Waste Repository "White Paper," February 2008.

The specific reactivity worth (Δk_{eff}) associated with a change in enrichment varies from system to system; it is different for high-enriched, low-enriched, and mixed oxide systems, and will tend to vary as a function of neutron energy spectrum. Accordingly, only the low-enriched facilities in the above list are truly representative of the neutronics at GLE: USEC ACP, LES, Eagle Rock, Westinghouse, and Framatome-Lynchburg. *Only the Framatome SER specifically quantifies a Δk_{eff} for a 1wt% change in enrichment (Δk_{eff} ~3% for change in enrichment from 4.25 to 5.1wt%).*

I have performed numerous studies with all kinds of neutron systems, and that is the basis for my statement that a 1% change in enrichment gives roughly a 3% change in k_{eff}.

A calculation for a typical system follows:

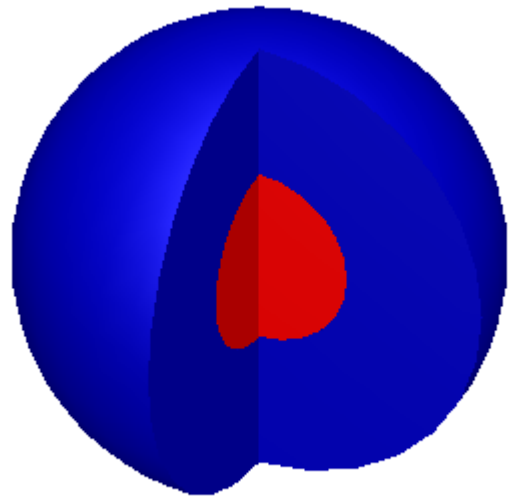
Independent Calculations:

Consider a sphere of optimally moderated UO_2F_2 solution, at 5wt% ^{235}U. According to Table 6 of ANSI/ANS-8.1-1998, the subcritical volume limit for such a system is 30.6 liters. This would be for a sphere with radius 19.4 cm. According to Figure 2.2 of NUREG/CR-0095 (TID-7016), "Nuclear Safety Guide," Rev. 2 (dated June 1978), the minimum critical volume for a UO_2F_2 solution occurs at ~300 gU/l at 100wt% enrichment. Since these curves aren't tabulated for lower enrichments, we'll do an optimal search to find the most reactive concentration.

(NOTE: Eagle Rock SER Table 5.1-1 has a limit of 30.3 liters for UO_2F_2 at 5wt% and 25.3 liters at 6wt%, which is good agreement with the ANS-8.1 numbers.)

Our model is therefore a homogeneous sphere of UO_2F_2 solution, with varying concentrations, 19.4 cm in radius, and surrounded by a 30-cm thick water reflector. The input deck for this is:

```
=csas25 parm=(centrm)
GLE Enrichment Study
238groupndf5
read composition
   uo2f2 1 0.275 300 92235 5 92238 95 end
   h2o    1 0.725 300 end
   h2o    2 1 300 end
end composition
read parameter
  gen=803
  npg=12000
  htm=yes
end parameter
read geometry
  global unit 1
  com='Global Unit'
  sphere 1 1    19.4
  replicate 2 1  30 1
end geometry
end data
end
```

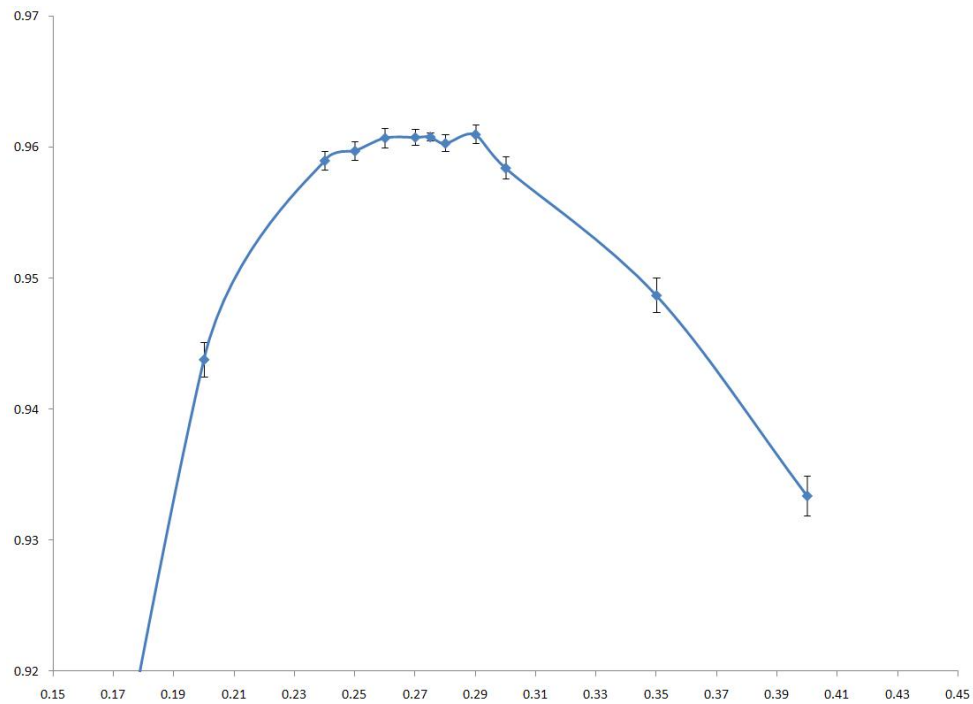


Items that were varied during this study are indicated with highlighting.

The concentration was then varied by varying the UO_2F_2 and H_2O volume fraction, using the standard volume additivity assumption, to determine the optimum value. The results of this sensitivity study were:

Volume fraction UO_2F_2	**Volume Fraction H_2O**	**k_{eff}**
0.1	0.9	0.8202 ± 0.0010
0.2	0.8	0.9438 ± 0.0013
0.24	0.76	0.95898 ± 0.00072
0.25	0.75	0.95972 ± 0.00070
0.26	0.74	0.96071 ± 0.00075
0.27	0.73	0.96076 ± 0.00062
0.275	0.725	0.96079 ± 0.00030
0.28	0.72	0.96030 ± 0.00064
0.29	0.71	0.96098 ± 0.00072
0.3	0.7	0.95842 ± 0.00084
0.35	0.65	0.9487 ± 0.0013
0.4	0.6	0.9334 ± 0.0015

(Cases near the optimum concentration were calculated with higher statistics). A graph of the results are shown below (calculated k_{eff} vs. volume fraction of UO_2F_2):



Based on this study, the staff selected an optimum mixture with volume fraction of UO_2F_2 of 0.275 and volume fraction of water of 0.725. Reactivity is fairly flat over this range.

With 5wt% ^{235}U, $k_{eff} + 2\sigma$ = <u>0.96139</u>.

To now determine the reactivity effect of increasing enrichment, this case is now run with an enrichment of 6wt% ^{235}U. The resulting $k_{eff} = 0.99569 \pm 0.00032$, for $k_{eff} + 2\sigma$ = <u>0.99633</u>.

Therefore, the k_{eff} difference for an increase in enrichment from 5 to 6wt% ^{235}U is ~3.5%.