Management of Criticality in Subcritical Solution Systems

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LA-UR 11-06720

Reactivity Effects in Solution Systems

- Short Term (~ minutes)
  - Fission induced heating causes solution temperature to rise resulting in lower density and increased volume (reactivity drops)
  - Radiolytic gas formation induces void in solution that increases from solution bottom to surface causing drop in average density and solution flow; these effects combined cause rapid reactivity fluctuation around the average value

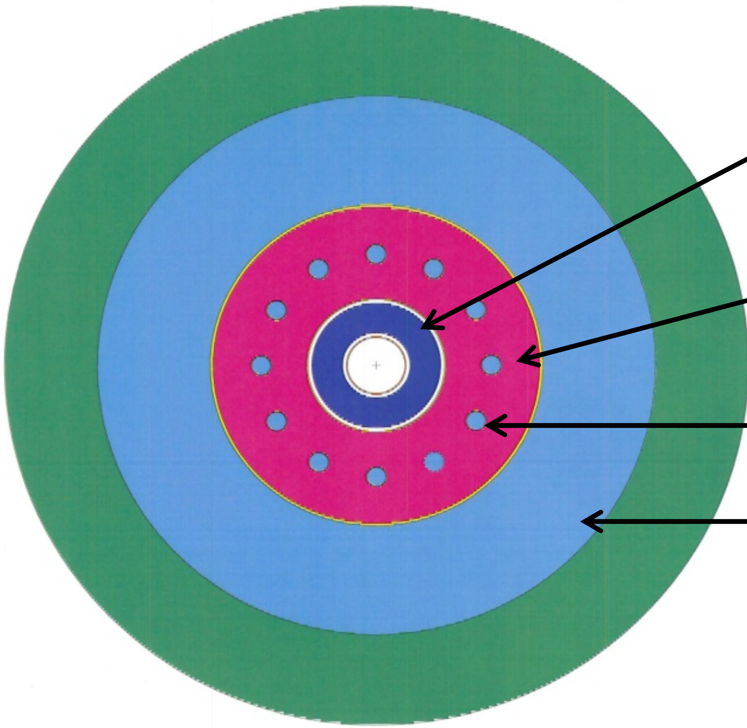
- Mid Term (~ hours to days)
  - Hydrogen loss due to water radiolysis results in reactivity decrease
  - Nitrogen loss in uranyl nitrate systems results in reactivity increase

- Long Term (~ weeks to months)
  - ^{235}U burn-up results in lower reactivity (10 – 20% over one year)
  - Fission product inventory build up results in lower reactivity (10 – 20% over one year)

Subcritical System Design Process

- Object is to maximize fissions per source neutron (direct measure of ^{99}Mo production)
- Select candidate Low Enriched Uranium (LEU) fuel
  - Uranium concentration (gU/liter)
  - Solvent (heavy or light water)
- Select candidate vessel configuration
- Estimate critical fuel volume for candidate fuel and vessel configuration
- Reduce fuel volume by 5%
- Estimate production for reaction vessel at 20° C, 60° C (operating design point) and 80° C
- Estimate production effects of variation of reactivity over time

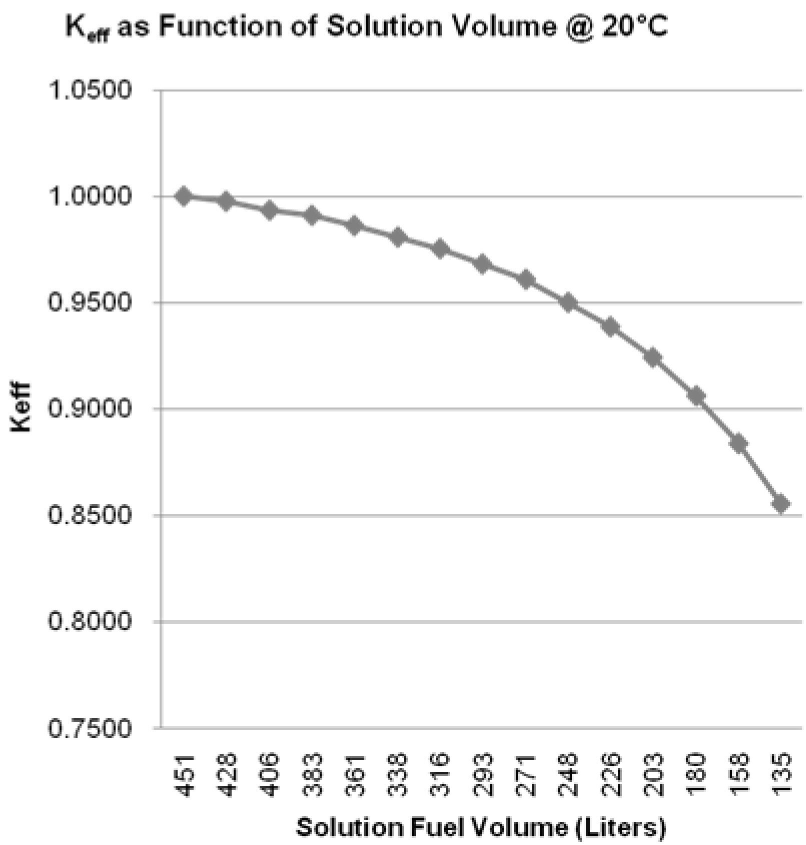
Subcritical Solution Fueled System Configuration



- Central region (could be void; ~ 20 cm o.d.)
- Annular solution fuel (~ 30 cm thick)
- Cooling pipes (~ 3% void)
- Reflector/moderator regions

- 90 gU/liter (19% enriched) LEU
- 451 liters full volume

Keff as Function of Solution Volume

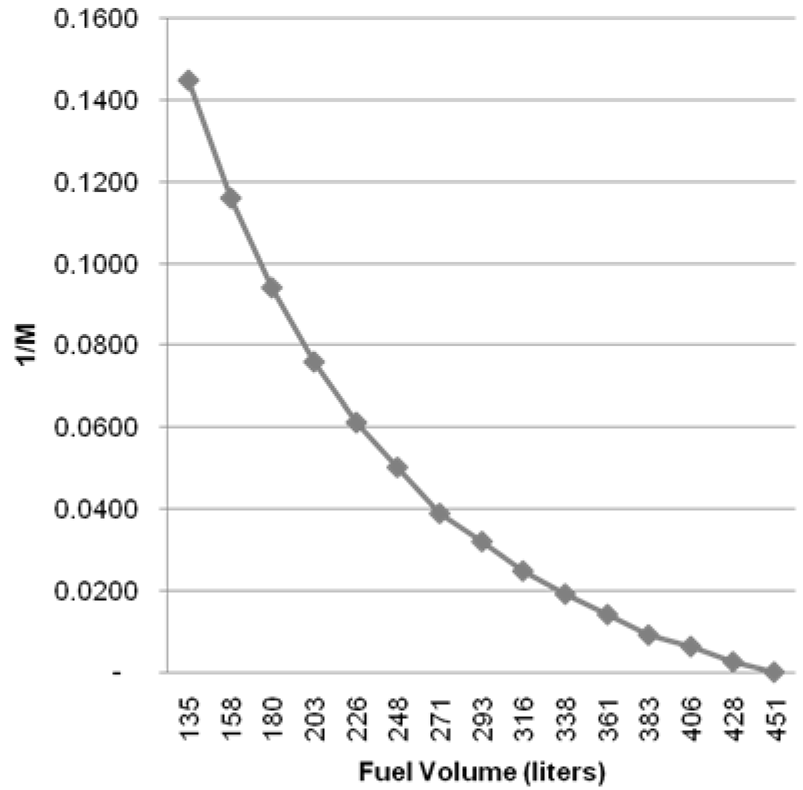


Volume (liters)	Temperature (° C)	Keff
451	20	1.0000
428 (-5%)	20	0.9974
250	20	0.9500
451	60	0.9930

Note that heating fuel at full volume is equivalent in k_{eff} to 50 liter reduction from critical volume

Startup & Operation of Subcritical Solution Systems

1/M Approach to Critical



Comments

- Curve is conservative throughout (always predicts less volume than actual)
- Even when physically far from critical k_{eff} is above 0.95
- Accurate estimate of critical volume not obtained until above 95% of actual value
- Volume control of < 0.5 liter is relatively straightforward.

Conclusions

- For the class of configuration of fissile solution systems typical of that considered for subcritical production operations k_{eff} is not a useful measure of the margin from criticality
- A physical measure such as solution volume is an accurate reference for stand-off from critical
- Nature of fissile solution systems is that once fission heating and radiolytic gas production starts the reactivity drops significantly.
- Fissile solution systems may be operated reliably and safely with k_{eff} approaching delayed critical.