Effects of Natural Uranium Reflection on the Critical Mass of Light Water Moderated Pu and MOX Systems

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AECL – Chalk River Laboratories
International Conference on Nuclear Criticality
2011 Sept 19 – 23, Edinburgh, Scotland

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Purpose

- Investigate the effect of natural uranium reflection on the ^{239}Pu critical mass for light water moderated systems of PuO_2 or MOX [(Pu, natural U)O_2]
- Estimate **"reduction factors"** for the critical mass of ^{239}Pu surrounded by various natural uranium reflectors
  - Reduction factors represent the % by which the critical mass is reduced due to a specific amount of natural uranium reflector

Methodology

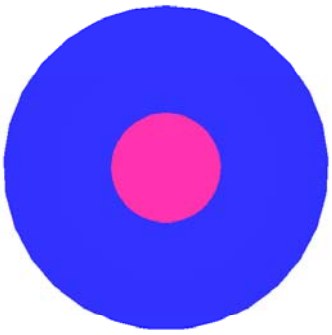
- ^{239}Pu critical masses are estimated at a calculated k_{eff} + 3σ of 0.980, corresponding to criticality based on the code validation against benchmark experiments
- k_{eff} values were calculated with SCALE 5.1/KENO V.a
  - 238-group ENDF/B-V cross-section library
  - 2000 generations, 1500 neutron histories per generation
  - 1.3 mk standard deviation as the stop point

Methodology – cont'd

- The reference cases are represented by light water moderated and reflected PuO_2 and MOX systems
- Parametric studies were performed on homogeneous light water moderated PuO_2 and MOX systems reflected either by a shell of natural uranium or by a thin shell of light water and a shell of natural uranium

Reference Cases - Description

- Model: homogeneous spheres of optimally light water moderated PuO_2 or MOX, reflected by 30 cm of light water
- ^{239}Pu concentrations ranging from 20 g/L to 40 g/L, in PuO_2–water or MOX–water mixtures were used to evaluate the mass of ^{239}Pu



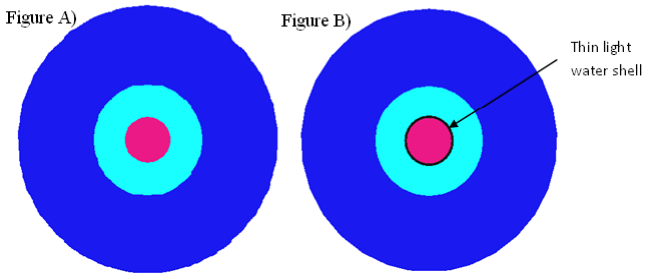
Reference Cases - Results

System	^{239}Pu Concentration (g/L)	Radius* (cm)	^{239}Pu Mass (g)
100 wt% PuO_2	20.0	18.20	505.1
	25.0	16.46	466.7
	30.0	**15.33**	**453.1**
	35.0	14.59	455.7
	40.0	14.10	469.9
30 wt% PuO_2 in MOX	20.0	18.78	554.7
	25.0	16.93	507.7
	30.0	**15.84**	**499.3**
	35.0	15.13	508.1
	40.0	14.65	526.8
15 wt% PuO_2 in MOX	20.0	19.30	602.3
	25.0	17.45	556.6
	30.0	**16.38**	**552.3**
	35.0	15.67	564.4
	40.0	15.16	583.9
8 wt% PuO_2 in MOX	20.0	19.88	657.8
	25.0	18.04	614.7
	30.0	**16.97**	**613.6**
	35.0	16.34	639.0
	40.0	15.85	667.4

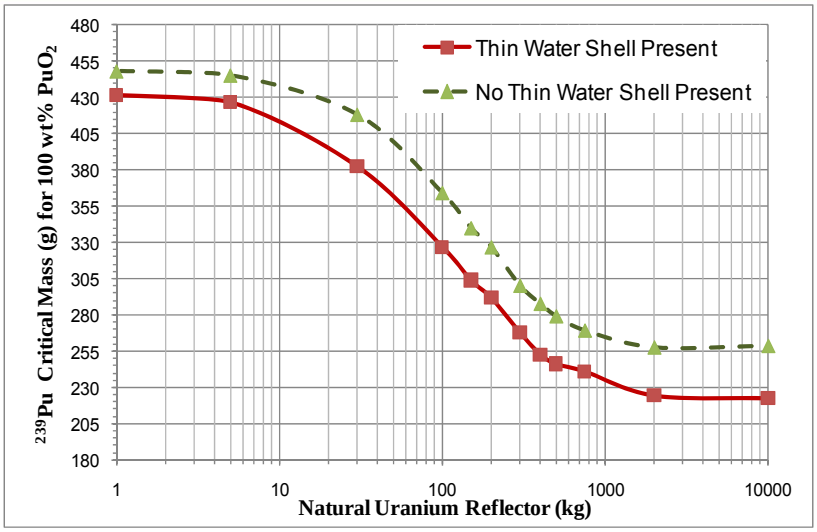
* This represents the radius of the sphere of fissile-light water mixture (i.e., PuO_2 – water or MOX – water mixtures).

Parametric Study 1 - Description

- Model: homogeneous sphere of PuO_2-water mixtures surrounded either by natural uranium and 30 cm light water (Figure A) or by a thin shell of light water, a shell of natural uranium and a 30 cm light water reflector (Figure B)
  - varied concentration of ^{239}Pu in PuO_2-water mixture
  - varied water shell thickness
  - varied the natural uranium reflector mass

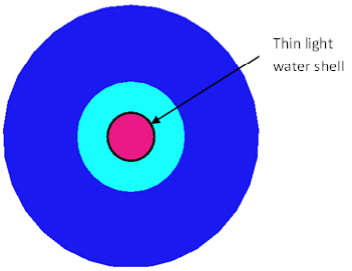


Parametric Study 1 – Results

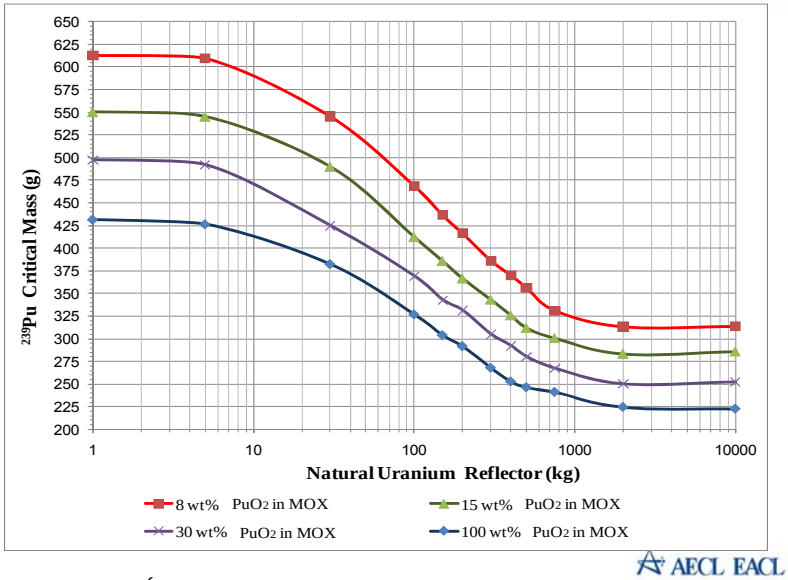


Parametric Study 2 - Description

- Model: homogeneous sphere of MOX-water mixtures surrounded by a thin shell of light water, a shell of natural uranium and a 30 cm light water reflector
  - varied enrichment of PuO_2 in MOX
  - varied concentration of ^{239}Pu in MOX-water mixture
  - varied water shell thickness
  - varied natural uranium reflector mass



Parametric Study 2 - Results



Reduction Factors for PuO_2 and MOX Systems

^{239}Pu critical mass for light water moderated and natural uranium reflected systems (Parametric Study #1 or #2)

^{239}Pu critical mass for light water moderated and reflected systems (Reference Case)

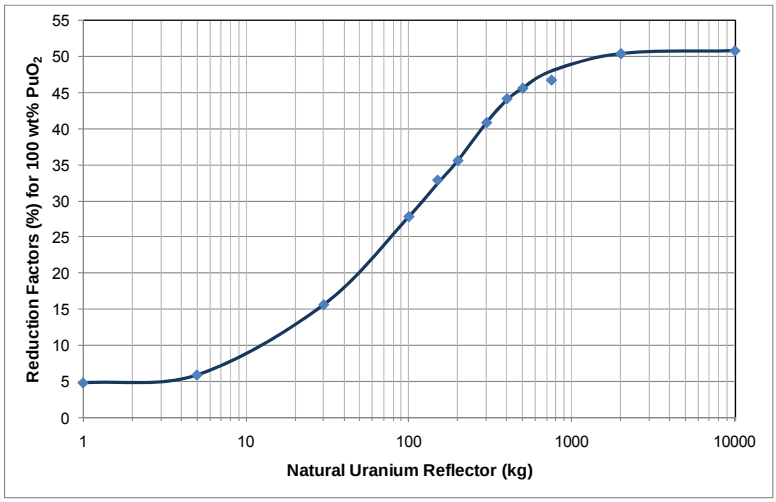
$$\text{reduction factor} = \left| \frac{M_2 - M_1}{M_1} \right| \times 100,$$

- This reduction factor is primarily used to establish the Upper Subcritical Limits (USLs) for optimally light water moderated systems of PuO_2 or MOX reflected by a specific amount of natural uranium. These USLs are then compared to the operating limits to ensure that the process remains subcritical under all normal and credible abnormal conditions.

Reduction Factors for PuO_2 and MOX Systems – cont'd

Natural U reflector (kg)	Reduction factors (%) for moderated PuO_2 and MOX systems			
	100 wt% PuO_2	30 wt% PuO_2 in MOX	15 wt% PuO_2 in MOX	8 wt% PuO_2 in MOX
5	5.9	1.5	1.3	0.6
30	15.6	14.9	11.4	11.1
100	27.8	26.1	25.4	23.6
150	32.9	31.4	30.2	28.9
200	35.6	33.7	33.7	32.2
300	40.9	38.9	37.9	37.1
400	44.2	41.5	41.1	39.7
500	45.6	43.9	43.6	41.9
750	46.8	46.5	45.6	46.0
2000	50.4	49.9	48.8	48.9
10000	50.8	49.5	48.3	48.9

Reduction Factors for PuO_2 and MOX Systems – cont'd



Summary

- Parametric studies were performed to investigate the effects of natural uranium reflectors on light water moderated PuO_2 and MOX systems, to accurately assess the plutonium critical masses in support of criticality safety assessments
- The results can be used to establish safe operating limits and restrictions for processes involving light water moderated PuO_2 and MOX, in an environment where natural or depleted uranium is also permitted
- The data obtained can be used to interpolate and derive ^{239}Pu critical masses for any amount of natural uranium reflector

Summary – cont'd

- For the same natural uranium reflector amount, the critical mass of optimally light water moderated systems of PuO_2 was reduced more than that of the MOX systems studied (i.e., the higher the wt% of PuO_2 in MOX, the higher the reduction in the ^{239}Pu critical mass due to natural uranium reflection)
- The reduction factor values for 100 wt% PuO_2 systems could conservatively be applied to any MOX system
- For all systems, non-significant differences were observed between the reduction factors for the critical mass corresponding to 2 000 kg and to 10 000 kg natural uranium reflectors

Acknowledgments

- The authors gratefully acknowledge the help and assistance provided by fellow staff at AECL, including Fred Adams, Andrew Bergeron, Laura Blomeley, Lloyd Dunn, Christine McNally, Darren Radford, Jeremy Whitlock and Fook Choy Wong.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