Modeling Incidental Reflection Conditions for NRC Licensing

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Protecting People and the Environment

Introduction

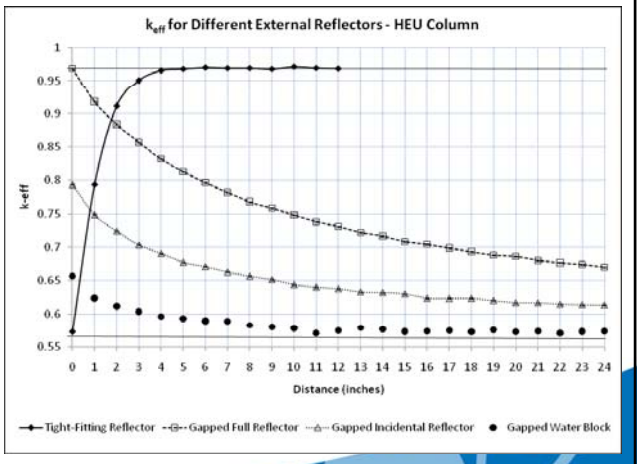
- NRC fuel cycle licensees handling, possessing, or storing fissionable materials are required to ensure that equipment and processes are subcritical under the most reactive credible upset conditions
- NRC licensees make commitments in their licenses regarding how criticality safety analyses will be generated
  - Subcriticality under the most reactive reflection condition physically possible:
    - Typically 30.48 cm (12 inches) of tight-fitting water (full reflection);
    - A bounding credible reflection condition may be employed;
    - Gapped reflectors;
    - Or water blocks

Modeled Cases

- Four different fissile systems were modeled to determine if general conclusions could be drawn or how reflector worth (i.e., the increase in keff resulting from a given reflector) depends on system geometry, enrichment, and neutron energy spectrum.
  - (1) a column containing low-enriched uranyl nitrate solution,
  - (2) a column containing high-enriched uranyl nitrate solution,
  - (3) a glovebox containing sixteen two-liter bottles of low-enriched uranium oxide powder, and
  - (4) a glovebox containing three two-liter bottles of high-enriched uranium oxide powder.
- Calculations were performed using KENO VI.

Tight-Fitting and Gapped Reflectors of Various Thicknesses

- Evaluated:
  - (1) tight-fitting reflectors of various thicknesses, ranging from incidental to full reflection,
  - (2) a 30.48 cm (12 inch) thick (full) reflector gapped at various distances, and
  - (3) a 2.54 cm (1 inch) thick (incidental) reflector gapped at various distances
  - Gapped water block

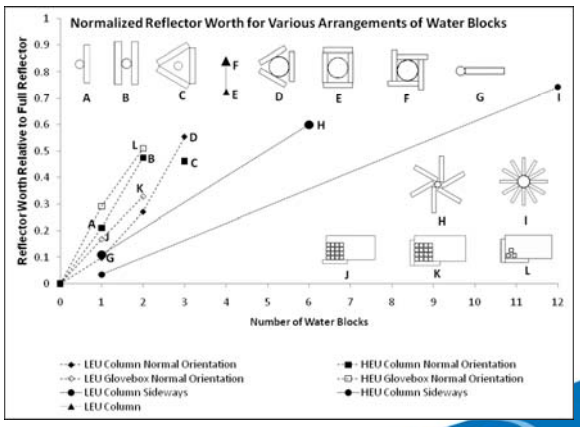


Water Block Relative to a Full Reflector

- The water blocks modeled as10.16 cm (4 inches) thick, 60.96 cm (24 inches) wide, and 182.88 cm (6 feet) tall. The total mass of water in such a block is ~113 kg (249 lb), which is conservative for about 90% of the adult male population in the United States.
  - Tight-fitting water block have a reflector worth ~31% of that for a full reflector around an LEU column and ~43% of that for a full reflector around an HEU column
  - The reflector worth relative to that for a full reflector is 17% for the LEU glovebox and 29% for the HEU glovebox

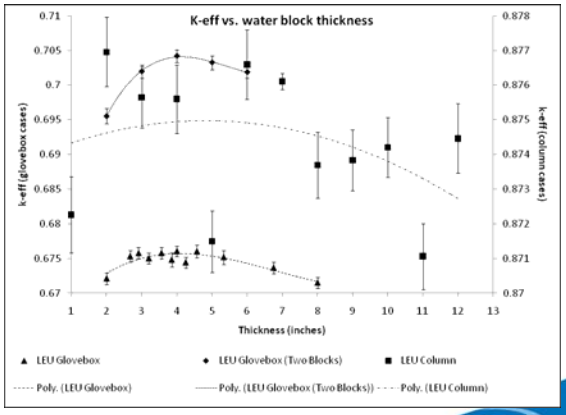
Reactivity Worth of Multiple Water Blocks

- As the number of water blocks increases, reactivity does indeed increase in proportion
- HEU column, the worst case appears to be 12 water blocks turned sideways touching the column.
  - Even with these extreme conditions, it is only possible to achieve ~74% of the Δk_{eff} resulting from a full reflector.
- For the glovebox, the most reactive condition was one in which two water blocks were oriented tangent to the glovebox at right angles to each other, and translated such that there was no gap between them



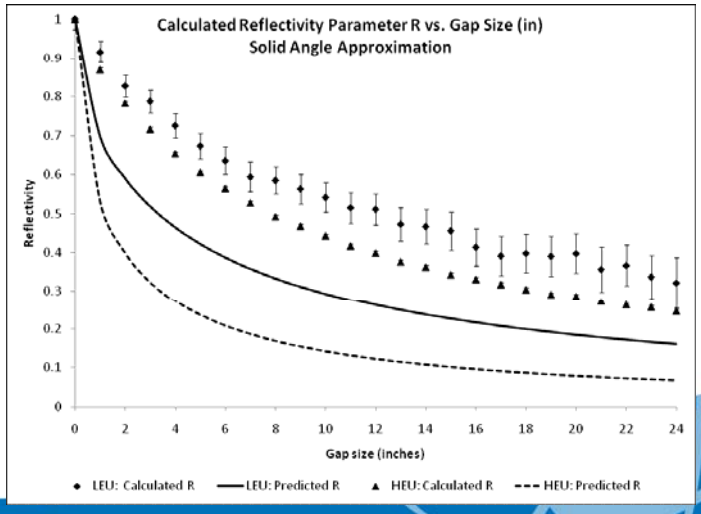
Water Block Dimensional Sensitivity Study

- A study was performed in which the thickness and width of a water block was changed while keeping its total volume (and therefore cross-sectional area) constant.
  - A single water block tangent to:
    - LEU column
    - HEU column
    - LEU glovebox;
  - Two water blocks tangent to an LEU glovebox.

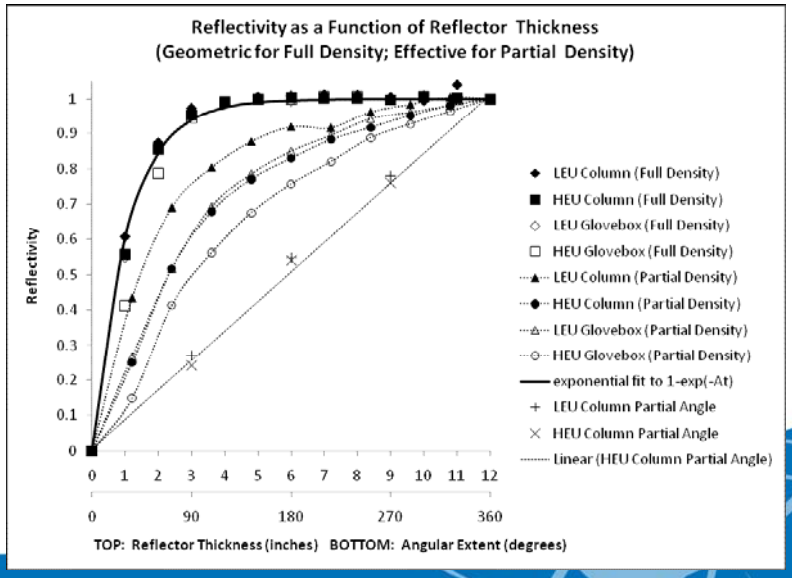


Reflector Worth of Gapped Reflectors

- Reflectivity ≡ $(k_{refl} - k_{BARE})/(k_{FWR} - k_{BARE})$



Tight-Fitting Reflectors of Different Thicknesses, Partial Water Density Reflectors, and Partial Solid Angle Reflectors



Reflection Control

- When a licensee elects to perform explicit modeling with less than full reflection conditions, controls designed to maintain the incidental reflection condition are normally required.
  - Reflection controls seen in NRC licensed facilities generally target the intrusion of human hands or bodies near the fissile system.
  - The classic situation encountered in these facilities is the case where a vessel such as a column cannot be modeled successfully under maximum credible conditions with full reflection.
  - The licensee will then attempt to an incidental reflection condition which is normally one inch of close fitting water.

Conclusion

- This paper has shown that the reflectors considered can have different reflector worth's for different fissile systems
  - Expressing worth relative to the worth of a full water reflector allows more direct comparisons to be made
- Tight-fitting and gapped annular reflectors around a column
  - Can predict the reflector worth with high accuracy
- Incidental reflection
  - Conservatively bound reflection from up to about 3 individuals (represented by 3 water blocks) around a column
- 10.16 cm (4 inch) thick tight-fitting reflector
  - Essentially equivalent to a full reflector
- Additional research into incidental reflection is warranted