HALEU/HBU/ATF Reactor Physics

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HALEU HBU ATF Goals

• Improve fuel cycle economy by enabling fuel to be depleted to higher burnup than the typical current maximum pin burnup limits
  – LEU+ ($8\% > ^{235}\text{U} > 5\%$) refers to a subset of High Assay Low-Enriched Uranium (HALEU) ($20\% > ^{235}\text{U} > 5\%$) and is considered as the near term goal

• Improve fuel system performance under accident conditions
  – Several candidates exists for Accident Tolerant Fuel (ATF)
  – FeCrAl cladding for BWRs
  – Cr$_2$O$_3$+ Al$_2$O$_3$ doped fuel for PWRs
Objectives for HALEU HBU ATF Reactor Physics Study

• Compare LEU and LEU+ cores with respect to
  – Reactivity coefficients
  – Assembly and pin peaking factor
  – Assembly and pin exposures

• Verify that findings of the Phase 1 study (assembly level) is valid at the core level and highlight differences

• Provide recommendations to NRC staff to support future confirmatory analysis

• Provide discharge fuel information as input to criticality safety, decay heat studies
Challenges

• Reactor physics behavior is generally sensitive to core layout and assembly designs
  – Need representative equilibrium cores with contemporary core layouts and fuel assembly designs
    • BWR core design information is publicly available from initial cycles (not representative of current core design strategies)
    • 7x7 and 8x8 assembly designs in publicly available data are low in Gd or do not contain any Gd (not representative of typical BWR fuel assemblies)
    • PWR LEU+ fuel designs for concept cores are proprietary data

• Need to design new lattices and representative cores
  • BWR assembly design is not trivial (enrichments and Gd loadings change axially and radially while geometry also changes axially)
  • PWR assembly designs require new IFBA patterns
Work Plan

• Design a set of candidate modern BWR lattices with different average enrichments

• Design equilibrium 36-month cycle BWR core loading patterns using modern core design strategies
  – Simplified core optimization

• Adopt Southern Nuclear’s LEU+ PWR concept core layout and operating parameters with in-house lattice designs

• Capture transition core physics using color sets of depleted, fresh, LEU, LEU+ fuel lattices
Transition Core

BWR Colorset

PWR Colorset

- 5 max wt % ZIRC-2 cladding
- 10 max wt % FeCrAl cladding
- 10 max wt % FeCrAl cladding
- 8 max wt % FeCrAl cladding

6.5% FA  8.0% FA  6.5% FA
8.0% FA  5.0% FA  8.0% FA
6.5% FA  8.0% FA  6.5% FA
PWR Core Analysis Results

**LEU 4.2% - 4.6%**

- 18-month cycle LEU core assembly burnup distribution (GWd/MTU)

**LEU+ 5.95% - 6.2%**

- 24-month cycle LEU+ core assembly burnup distribution (GWd/MTU)

*Graph showing critical boron concentration (ppm) vs. EFPD (days) for PARCS_LEU+ and PARCS_LEU.*
BWR Lattice Results

- Five LEU+ lattices with maximum pin enrichment values of 6, 7, 8, 9, and 10 are investigated.
- $k_{nf}$ evolution with burnup of these assemblies are used in core design as interpolation points.
• Competing objective functions
  - Need to balance batch sizes
  - Watch for burnup gradients in each batch not to exceed burnup limit for shuffling
  - Fresh fuel extends cycle length
  - Once burned fuels early cycle
  - Twice burned improves economics, lowers leakage
  - Checker board vs ring of fire, high leakage vs flat power
BWR Core Analysis Results

LEU+ 9%/max 7.2%/avg
36-month cycle LEU+ core assembly burnup distribution (GWd/MTU)

LEU 5%/max 4.5%/avg
24-month cycle LEU core assembly burnup distribution (GWd/MTU)