Analysis of Reactivity Insertion Accidents for the NIST Research Reactor Before and After Fuel Conversion

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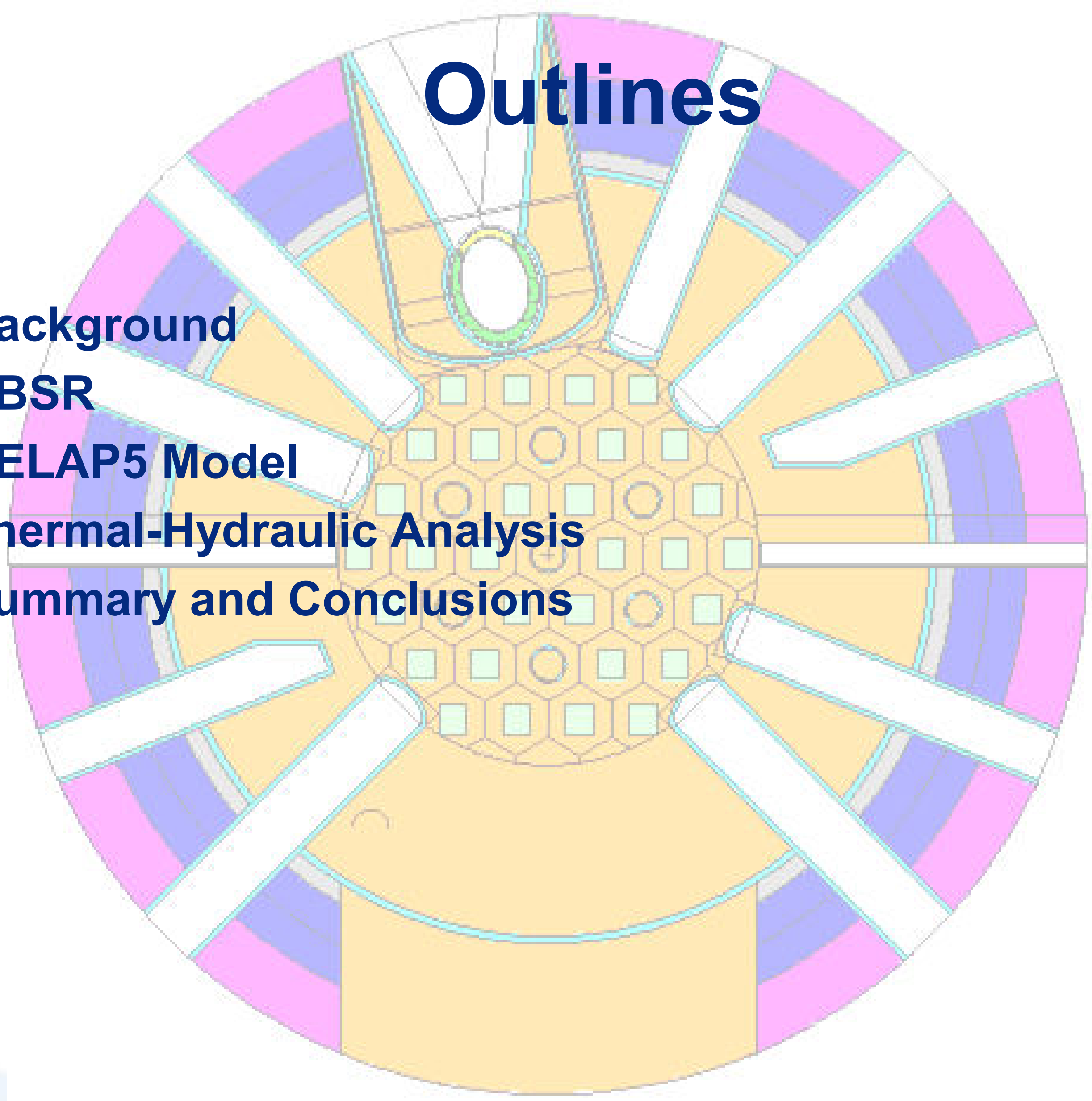
Outlines



- Background
- NBSR
- RELAP5 Model
- Thermal-Hydraulic Analysis
- Summary and Conclusions

Background

- A plan is being developed for the conversion of the NIST (National Institute of Standards and Technology) research reactor (NBSR) from high-enriched uranium (HEU) fuel to low-enriched uranium (LEU) fuel.
  - Fuel conversion
    - HEU (93% ^{235}U): U_3O_8 mixed with aluminum powder
    - LEU (19.75% ^{235}U): A foil of U10Mo (uranium alloy with 10% molybdenum by weight)
- Need of safety analysis works for U.S. NRC conversion license of NBSR
- RELAP5 model has been developed to perform safety analysis for the NBSR.
  - NBSR with LEU fuel and HEU fuel

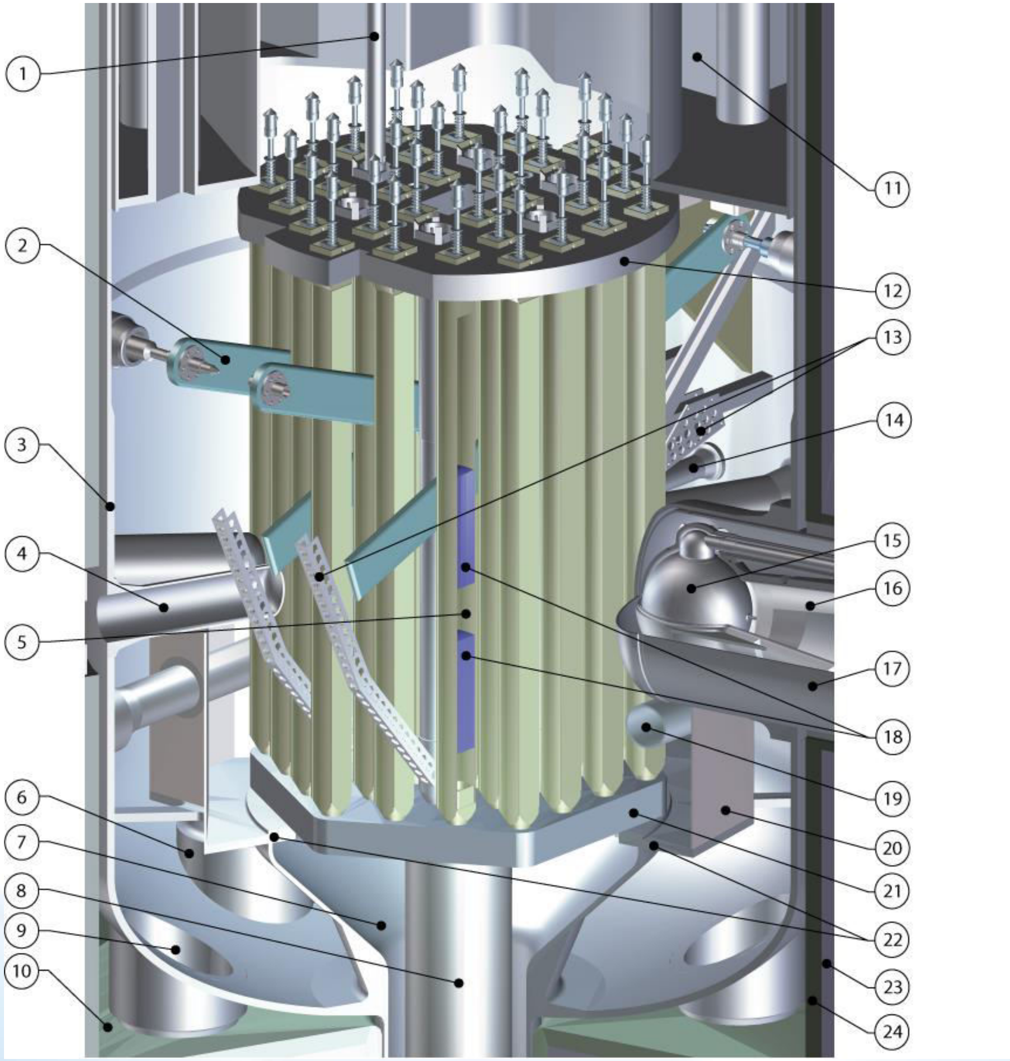
Background (cont.)

- Presenting the results of safety analysis of reactivity insertion accidents
  - Control rod withdrawal startup accident
  - Maximum reactivity insertion accident
- Post-processing of simulation results to evaluate CHFR and OFIR
  - A FORTRAN program was developed.
  - Sudo-Kaminaga correlations for CHFR
  - Saha-Zuber Criteria for OFIR

NBSR

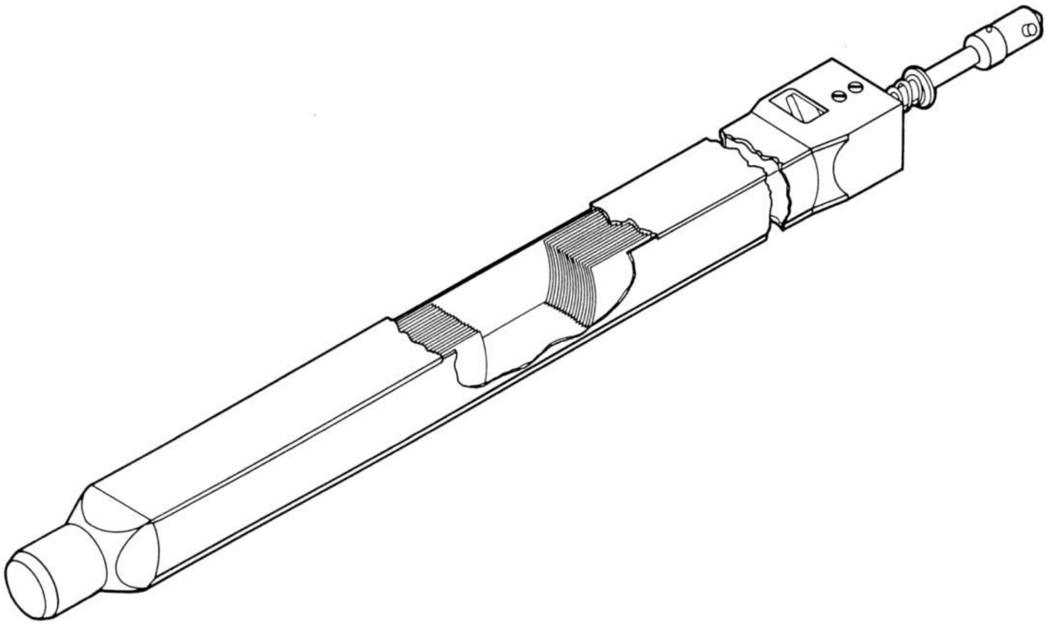
- **NBSR: National Bureau of Standard Reactor**
  - **NBS: Old name of NIST**
  - **Providing world-class capabilities in cold-neutron research**
    - **Materials science, chemistry, biology, neutron standards and dosimetry, nuclear physics, etc.**
  - **20 MW power**
  - **Heavy water (D_2O) moderated and cooled**
  - **Inner and outer plena**
    - **A double plenum to provide optimized cooling to the core**
  - **MTR Plate-type enriched fuel elements**
    - **Two fuel sections with an unfueled gap in the middle to reduce the fast neutron background in the neutron beam, resulting in the thermal neutron reaching a peak in the center of the gap**
    - **17 plates in each section**

NBSR (cont.)



- Cut-away view of NBSR core
- Al reactor vessel (3)
- 18 cm gap (5) between upper and lower fuel sections (18)
- Semaphore-type Cd shim arms (2)
- Cold neutron source (15)

NBSR (cont.)



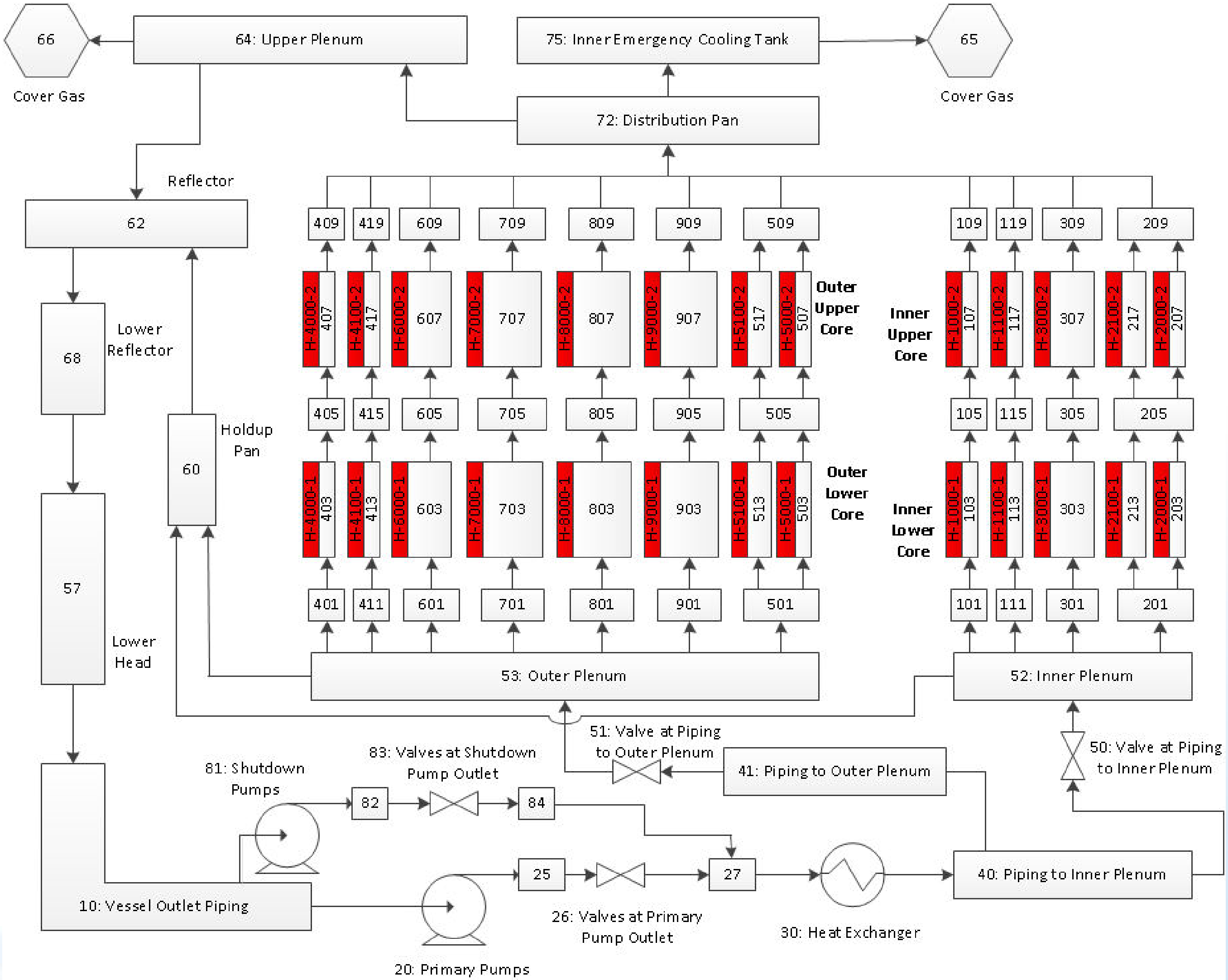
NBSR Fuel Elements

- Two fuel sections
- 17 fuel plates in each section
  - 0.51 mm thickness
  - 6 cm width
  - 28 cm fuel plate length
- 18 cm gap between two fuel sections

RELAP5 NBSR Model

- Detailed NBSR vessel and core
- Primary piping from vessel outlet to inlet
- Primary and shutdown pumps
- Heat exchangers
- Rectangular heat structure to represent the NBSR fuel plates
  - 30 fuel elements
    - 6 in inner plenum
    - 24 in outer plenum
- Point kinetics with 14 precursors
  - 6 for fission product delayed neutrons
  - 8 for photoneutrons
- No reactivity feedback is assumed (conservatively).
  - Only shim arm reactivity is considered.

RELAP5 NBSR Model (cont.)

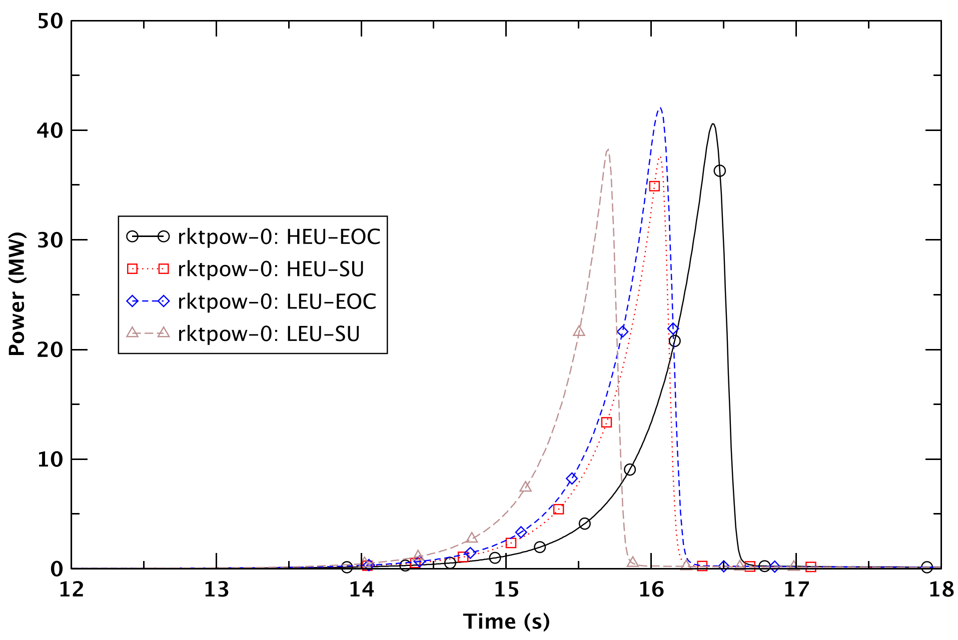


Thermal-Hydraulic Analysis

- **Accidents**
  - **Maximum hypothetical accident (MHA), Insertion of excessive reactivity, Loss of coolant, Loss of coolant flow, Loss of normal electrical power, etc.**
  - **Presenting analysis results of insertion of excessive reactivity**
  - **Control rod withdrawal startup accident**
    - $\mathbf{5 \times 10^{-4}\ \Delta k/k}$ **(50 pcm) per second**
    - **Initial power: 100 W**
  - **Maximum reactivity insertion accident**
    - $\mathbf{0.005\ \Delta k/k}$ **(500 pcm) in 0.5 s**
    - **Initial power: 20 MW**
  - **Two limiting points in a fuel cycle**
    - **Startup (SU) and End-Of-Cycle (EOC) conditions**

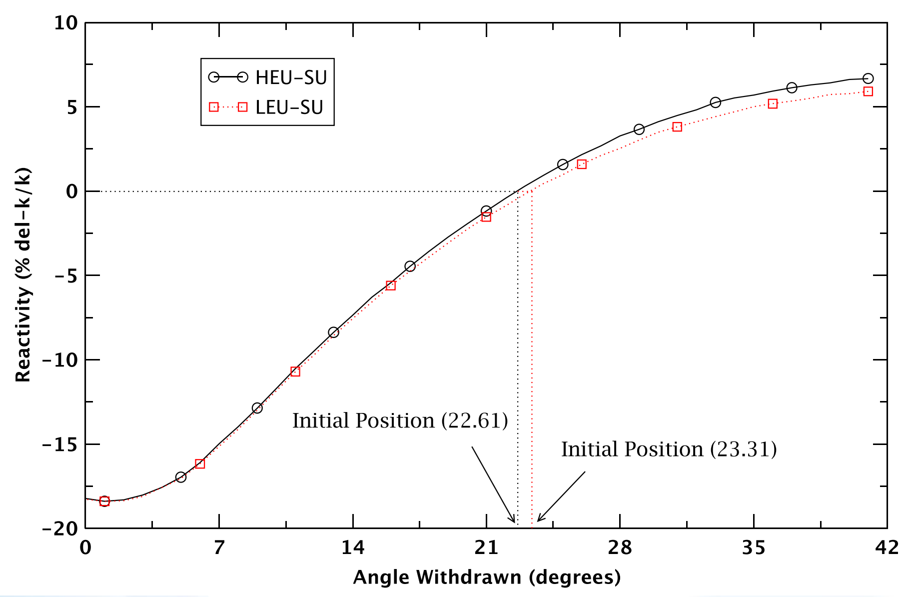
Thermal-Hydraulic Analysis (cont.)

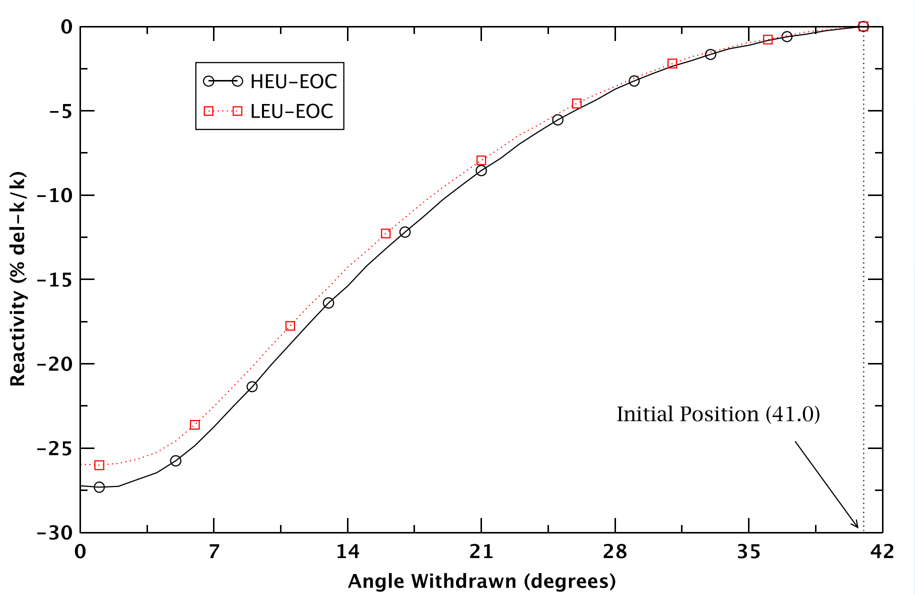
- Control rod withdrawal startup accident
  - Power increases almost exponentially.
  - Reactor trip at 26 MW
  - Peak power
    - 40.2 MW with HEU at EOC
    - 37.6 MW with HEU at SU
    - 42.0 MW with LEU at EOC
    - 38.2 MW with LEU at SU
    - Different negative reactivity insertion rate after reactor trip



Thermal-Hydraulic Analysis (cont.)

- Control rod withdrawal startup accident (cont.)
  - Peak power
    - Shim arms start dropping
      - From 23° at SU
      - From 41° (fully withdrawn) at EOC



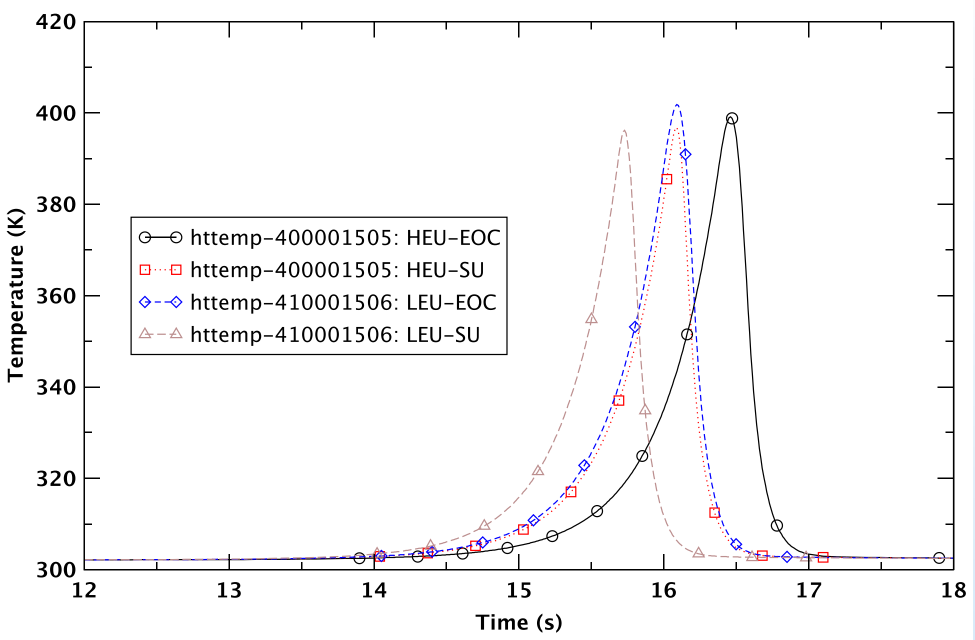


Thermal-Hydraulic Analysis (cont.)

- Control rod withdrawal startup accident (cont.)
  - Power increases more rapidly with LEU fuel
    - Smaller delayed neutron fraction and shorter neutron lifetime
  - Power increases faster at SU
    - Shorter neutron lifetime as a result of shim arm presence

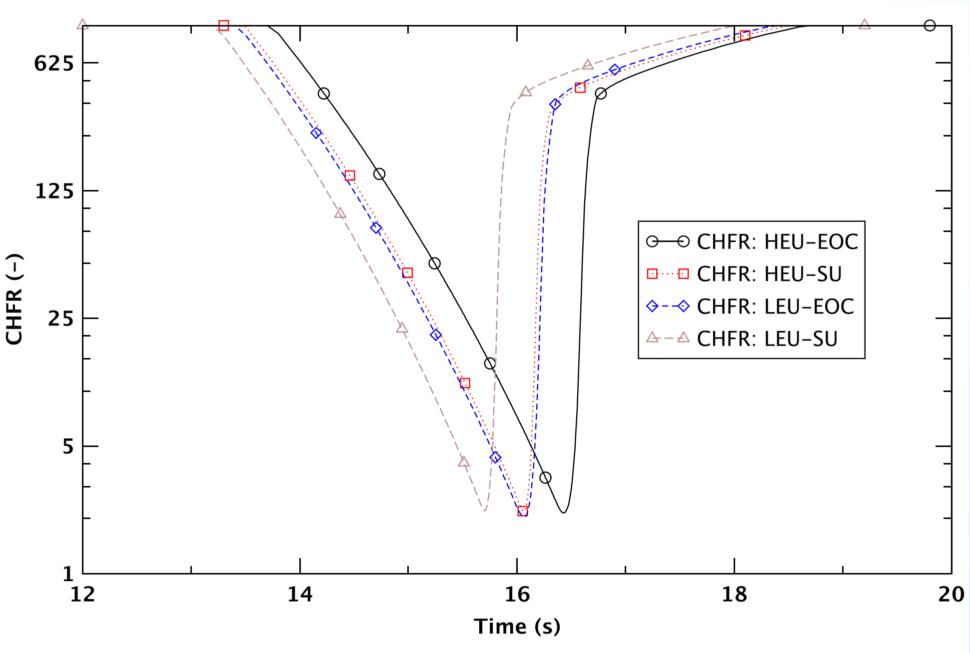
Thermal-Hydraulic Analysis (cont.)

- **Control rod withdrawal startup accident (cont.)**
  - **Cladding temperature**
  - **PCT**
    - **399 K with HEU at EOC**
    - **397 K with HEU at SU**
    - **402 K with LEU at EOC**
    - **396 K with LEU at SU**
  - **Small temperature rise**
    - **100 K with LEU at EOC**



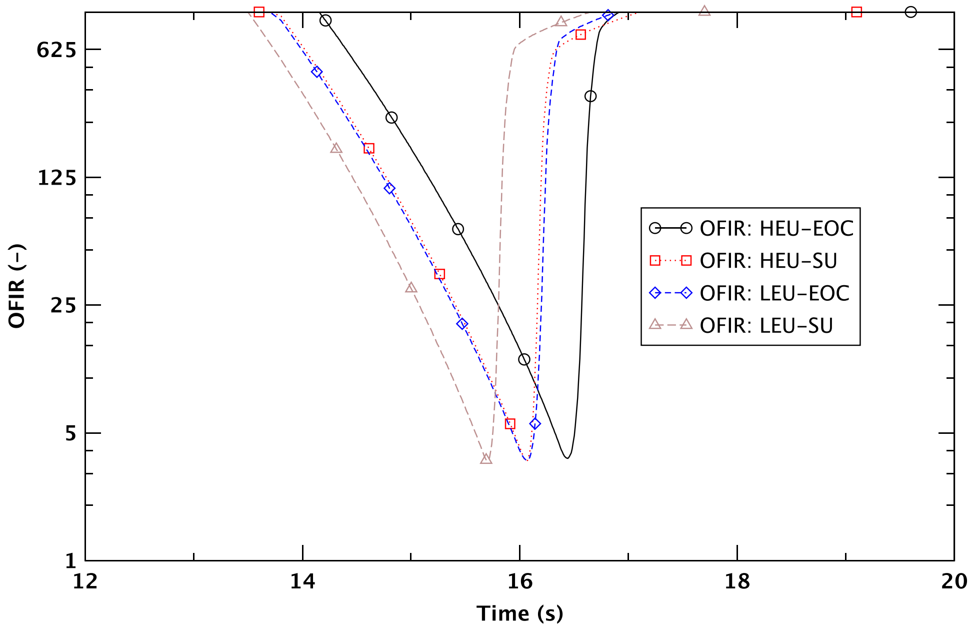
Thermal-Hydraulic Analysis (cont.)

- Control rod withdrawal startup accident (cont.)
  - Critical Heat Flux Ratio (CHFR)
    - A post-processing
  - Minimum CHFR
    - 2.15 with HEU at EOC
    - 2.19 with HEU at SU
    - 2.04 with LEU at EOC
    - 2.21 with LEU at SU
    - Larger than 1.78 and 1.86 (probability greater than 99.9%)
    - BNL performed a statistical analysis with a large size of sampling to quantify uncertainties of key parameters of CHF.



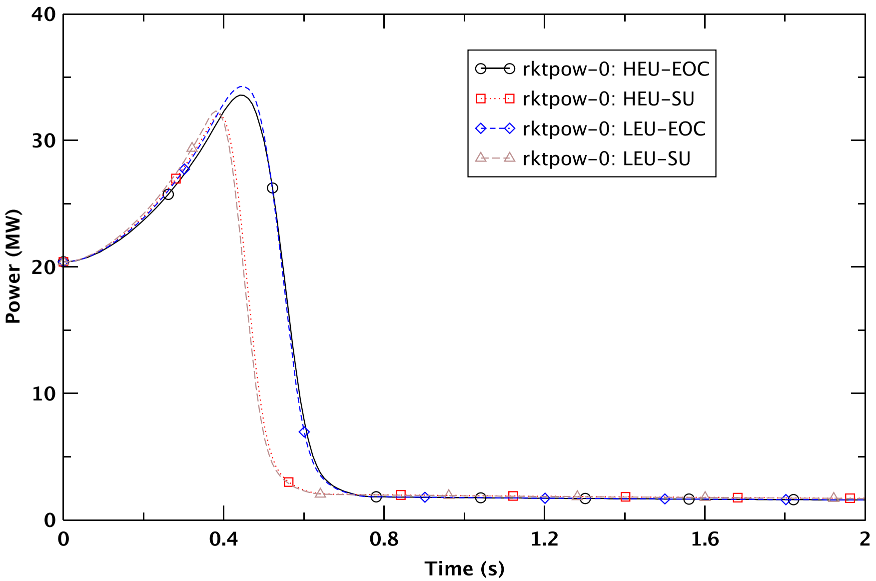
Thermal-Hydraulic Analysis (cont.)

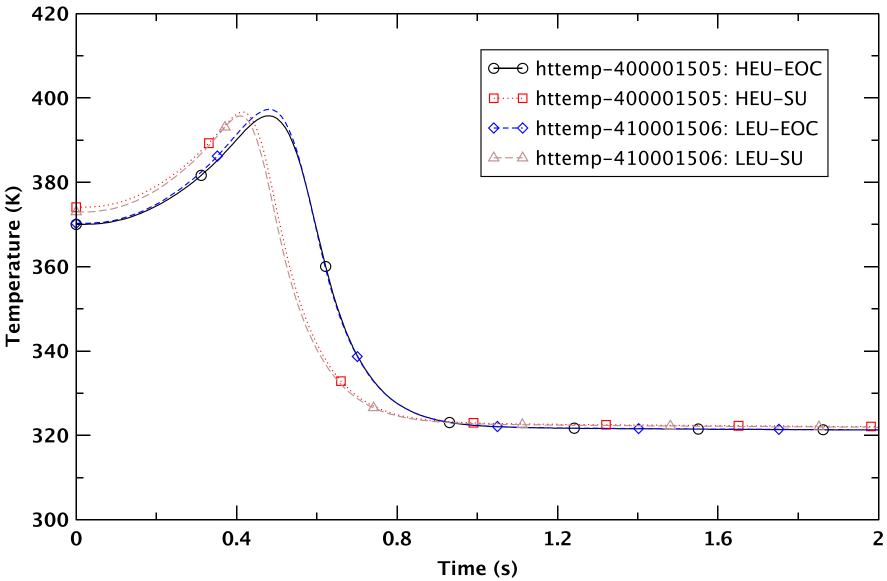
- Control rod withdrawal startup accident (cont.)
  - Onset-of-Flow Instability Ratio (OFIR)
    - A post-processing
  - Minimum OFIR
    - 3.63 with HEU at EOC
    - 3.49 with HEU at SU
    - 3.54 with LEU at EOC
    - 3.50 with LEU at SU
    - Much larger than 1.58 and 1.73 (probability greater than 99.9%)
    - BNL performed a statistical analysis with a large size of sampling to quantify uncertainties of key parameters of OFI.



Thermal-Hydraulic Analysis (cont.)

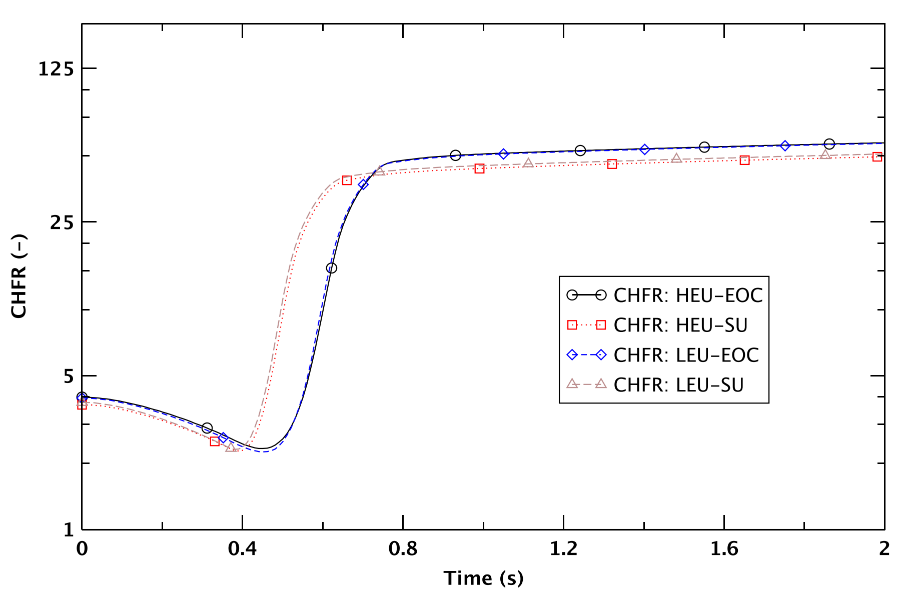
- **Maximum reactivity insertion accident**
  - **Reactor trip at 26 MW**
  - **Peak Power**
    - **Highest peak power of 34 MW with LEU at EOC**
  - **Cladding Temperature**
    - **Highest PCT of 397 K (ΔT = 27 K) with LEU at EOC**

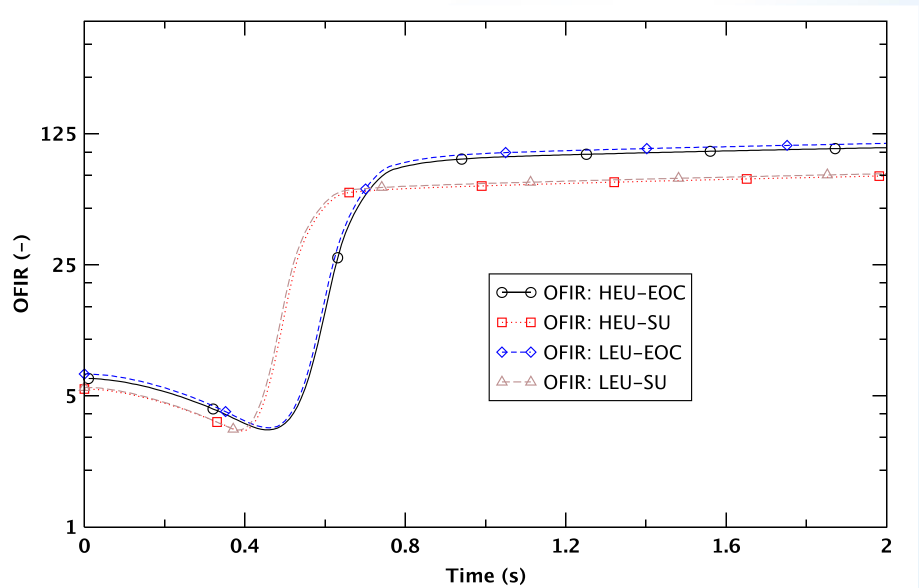




Thermal-Hydraulic Analysis (cont.)

- **Maximum reactivity insertion accident (cont.)**
  - **Minimum CHFR**
    - **Smallest minimum CHFR of 2.25 with LEU at EOC**
  - **Minimum OFIR**
    - **Smallest minimum OFIR of 3.25 with HEU at SU**





Summary and Conclusions

- A detailed RELAP5 model has been developed to analyze the NIST research reactor (NBSR) with fuel conversion from HEU to LEU.
- Insertion of excessive reactivity accidents have been analyzed.
  - Control rod withdrawal startup and maximum reactivity insertion accidents.
- Two limiting points (SU and EOC) in a fuel cycle have been considered.
- A post-processing has been performed to evaluate CHFR and OFIR.
- Reactor power, peak cladding temperature, minimum CHFR, and minimum OFIR have been investigated.
  - All PCTs are lower than blister temperature.
  - All minimum CHFRs and OFIRs are very high.

Summary and Conclusions (cont.)

- **Conclusions**
  - **The integrity of the NBSR fuel elements is preserved in all cases with both LEU and HEU fuels.**
  - **NBSR still has a large safety margin with LEU core.**