A Direct Comparison of High-Order and Low-Order Neutronics Calculations of the 165 MWth Xe-100 Reactor

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Background

AVR reactor
World’s first pebble-bed reactor
Jülich Research Centre, West Germany
46 MWt (15MWe)
Operated from 1967 - 1988

In 2020, Xe-100 reactor was awarded ARDP
World’s first commercial scale advanced nuclear reactor
Washington state, U. S.
200 MWt (82.5MWe)
Delivered by 2027
Objective

Currently, the Xe-100 design has only been modeled with X-Energy’s in-house code VSOP-A [2], which is a lower-order diffusion code. In this study, we are building a high-order Serpent [3] Monte Carlo neutronics model to investigate the neutronics characteristics of the Xe-100 design and to perform a code-to-code verification of the results obtained.
Features
- Helium-cooled;
- graphite-moderated;

TRistructural-ISOtropic (TRISO) fuel
- Microencapsulated coated fuel particles;
- Fuel kernel;
- Four layers of three isotropic materials;
- Vessel for fission product gases;

Advantages
- online refueling scheme;
- low excess reactivity;
- high outlet coolant temperature;
- capability of the load-following mode;
- Etc.

(B. Boer, 2009 [1])
Nominal design [4]

- Technology developer, country of origin: X Energy, LLC, United States of America
- Reactor type: Modular HTGR
- Coolant/moderator: Helium/graphite
- Thermal/electrical capacity, MW(t)/MWe: 200/82.5

At this preliminary stage, only public data were employed.

Design considered in this study [5]
(A design variance corresponding to the requirement of a specific customer)

- 200MWt/82.5MWe (nominal design)
- 165MWt/62.0MWe (this study)
- At this preliminary stage, only public data were employed.
Xe-100 Serpent model (fuel pebble)

- Kernel material: UC_{0.5}O_{1.5}
- $^{235}$U enrichment: 15.5 wt.%
- Kernel diameter: 0.425 mm
- Buffer layer thickness: 100 μm
- IPyC layer thickness: 40 μm
- SiC layer thickness: 35 μm
- OPyC layer thickness: 40 μm

- TRISO particles per pebble: 19,542
- Uranium loading per pebble: 7 g
- TRISO particles randomly distributed
- outer fuel-free zone thickness: 5 mm

- Pebbles in the core: 219,503
- Same TRISO distribution
- Hexagonal Closest Packing (HCP)
- Discrete Element Method (DEM)
Xe-100 Serpent model (core)

- $\text{B}_4\text{C}$ compacts (8 mm thickness)
- Incoloy-800H canisters
- inner radius: 41.5 mm
- inner wall thickness: 0.5 mm
- outer wall thickness: 2.5 mm

- Borings are 10 cm from active core
- Diameters: 13 cm
- Active length: 660 cm
- Reactivity Control System (RCS)
  - CR x 9; max. insertion 660 cm
- Reserve Shutdown System (RSS)
  - CR x 9; max. insertion 860 cm

- ENDF/B-VII.0
- 1,000,000 realizations per cycle
- 500 active cycles
- $\pm k_{\text{eff}} < 10$ pcm
- 13 hours with 40 processor cores
Differences between the models (VSOP-A ↔ Serpent)

**VSOP-A model**
- Deterministic (diffusion)
- XS generation: difficult
- Flux structure: 4 groups
- Fuel: incompressible flow
- BU phases: all (run-in, etc.)
- TH feedbacks: yes
- Status: mature
- Geometric details: complete

**Serpent model**
- Monte Carlo (5 × 10^8 histories)
- XS generation: naturally solved
- Flux structure: continuous
- Fuel: single pebble resolved
- BU phases: fresh core
- TH feedbacks: no (900K/600K)
- Status: preliminary
- Geometric details: in progress
Results comparisons (spectra and flux distributions)

- Neutron spectra
- 165MW Xe-100 ↔ GA’s 350MW MHTGR
- Similar hardness

- Radial neutron flux distributions
- 4-group structure
- Normalized based on max. flux

Graphs showing normalized neutron flux per lethargy and normalized fast neutron flux versus energy and radial width.
Results comparisons (CR worth and RTC)

- Difference w.r.t. the $k_{\text{eff}}$ with all CR withdrawn
- Worth of the RSS was minor in the overlap region
- Similar trend
- Max. discrepancy ~ 3400 pcm

$$RTC(T) = \frac{k_{\text{eff}}(T+50^\circ\text{C}) - k_{\text{eff}}(T-50^\circ\text{C})}{100^\circ\text{C}}$$
- Doppler Coef. (moderator temp. at 600K)
- MTC (fuel temp. at 900K)
Summary and ...

- A preliminary Serpent model of the 165MWth Xe-100 design was built
- Neutronics characteristics were investigated
- Comparative studies demonstrated the Serpent model to be reasonable

Future work

- Extension of the current Serpent model
- Modeling of more geometric details (e.g., coolant channels)
- Implementation of the discrete element method (DEM)
References


