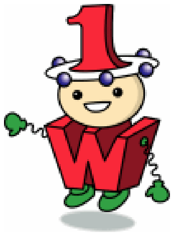
Present Status of UTR-KINKI and Preliminary Feasibility Study on its Future Conversion to Low-Enriched Fuel

C. D. Stratton, J. A. Morman and J. G. Stevens
Nuclear Science and Engineering Division, Argonne National Laboratory
G. Wakabayashi, T. Sano, S. Hohara, and H. Yamanishi
Atomic Energy Research Institute, Kindai University

Background

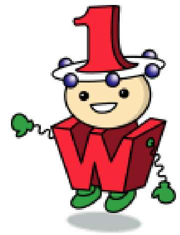


- The Kindai University Reactor (UTR-KINKI) is an educational and training reactor with a thermal power of 1 W.
- The reactor is currently utilized for nuclear education, training and research in Japan.
- The reactor is fueled with HEU, and with the recent progress in the removal of HEU from other facilities in Japan, it is the only reactor left in Japan that is fueled with HEU.
- In order to investigate the feasibility of continuing the operation of the reactor by converting it to low-enriched fuel, a preliminary technical study was conducted.

UTR-KINKI: Overview

- UTR: University Teaching and Research Reactor
- One of many UTRs designed and built in the 1950s and 1960s by U. S. companies, based on the Argonaut-type reactor as a prototype.

UTR-KINKI: History



- 1959: The US Atomic Energy Commission operated a UTR in the Tokyo International Trade Fair as part of its Atoms for Peace exhibit.
- 1960: Atomic Energy Research Institute was established.
- 1961: UTR-KINKI reached its first criticality on November 11 and started operation with a licensed thermal power of 0.1 W.
  - The first private nuclear reactor in Japan.
  - The first university owned nuclear reactor in Japan.
- 1974: the licensed thermal power was increased to 1W.

The reactor was visited by their majesties the Emperor and Empress on May 12, 1959.

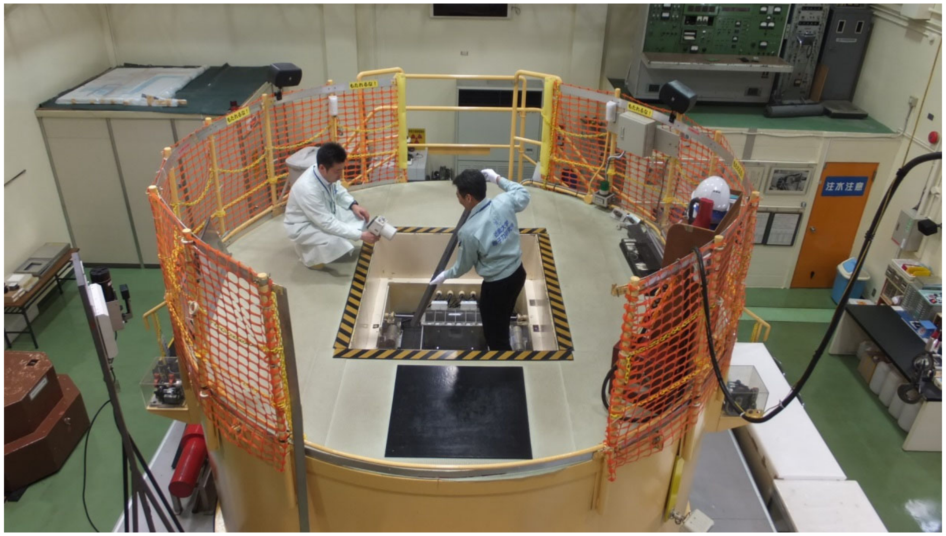
Mr Koichi Seko, the founder of Kindai University decided to purchase the UTR to develop future nuclear engineers at his university.

UTR-KINKI: Education and Training

- Higher Education: UTR-KINKI is jointly used by 14 universities and technical colleges for education and training programs in nuclear science and technology.
- Outreach to Secondary Education:
  - Reactor experiment workshops for science teachers
  - Science workshops for high school students
- International Programs:
  - IAEA Regional Research Reactor School
  - JAEA Instructor Training Program for Asian Countries
- Employee training for nuclear industry.
- Visitor Tours: about 1000 visitors/year

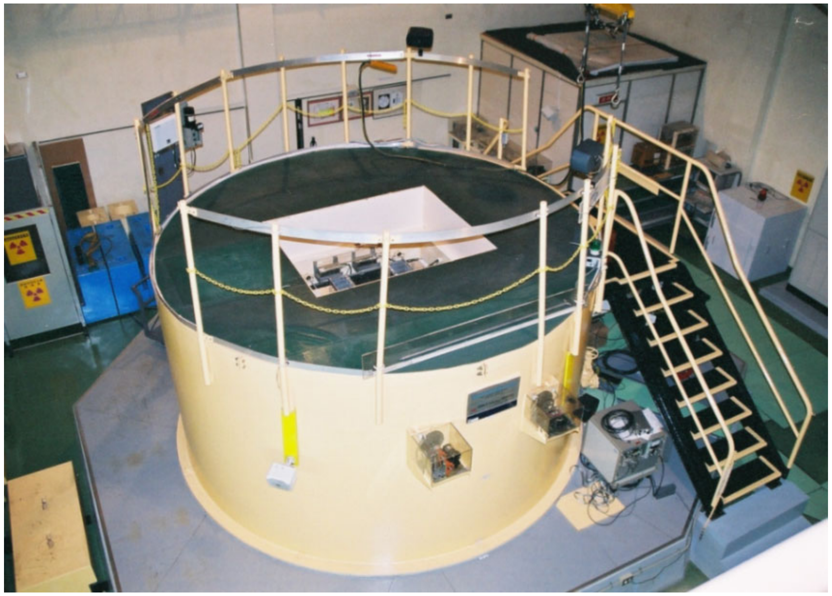
UTR-KINKI: Research

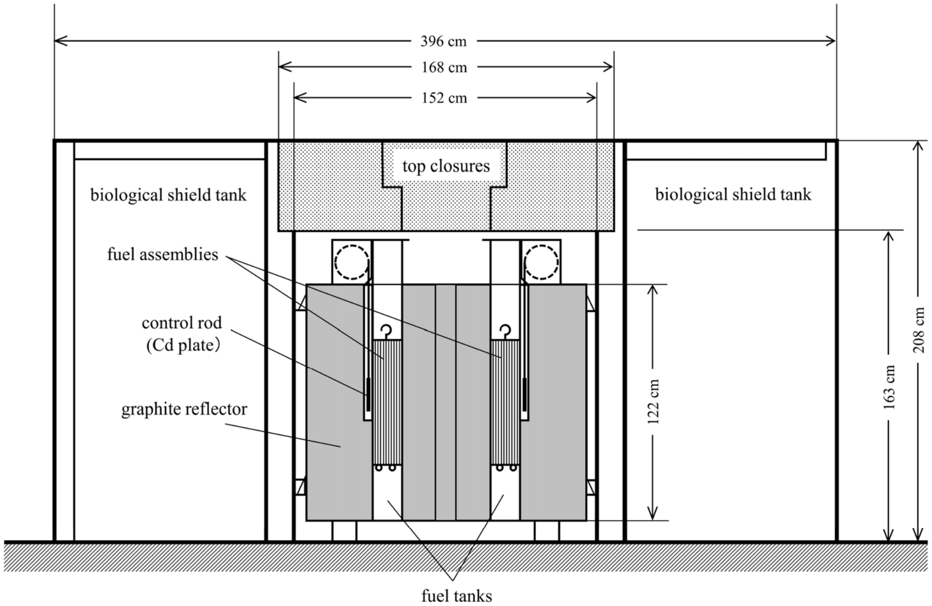
- UTR-KINKI is used by domestic researchers as a joint use facility.
  - detector testing, reactor physics experiments, neutron irradiation to biological samples…
  - 20-25 research projects are selected every year for experiments using the reactor.



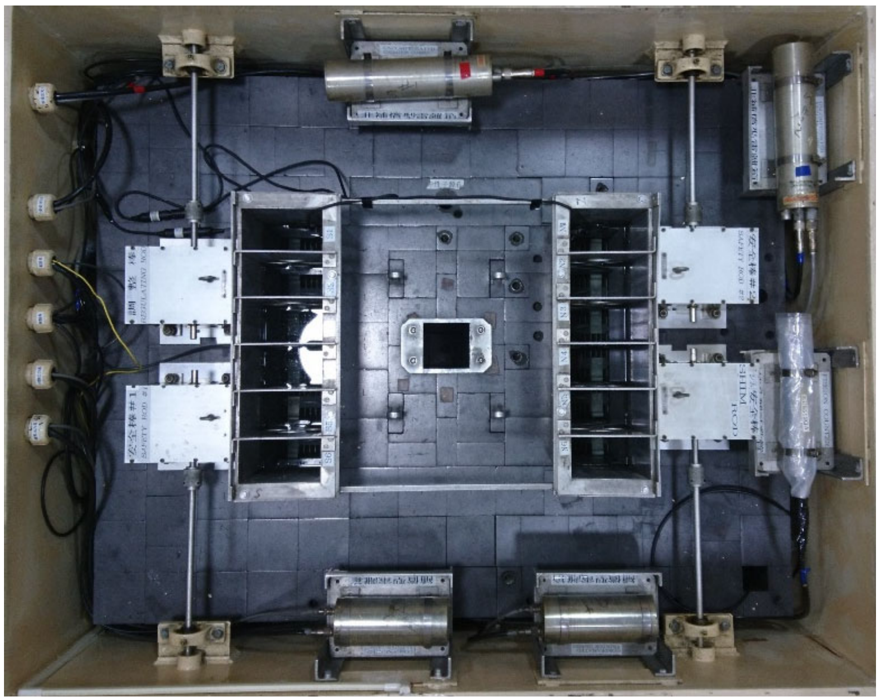
UTR-KINKI: Design and Specification

- The reactor core is located in the centre of the cylindrical biological shield tank filled with water and sand.
- The top of the reactor is closed with thick concrete shield.



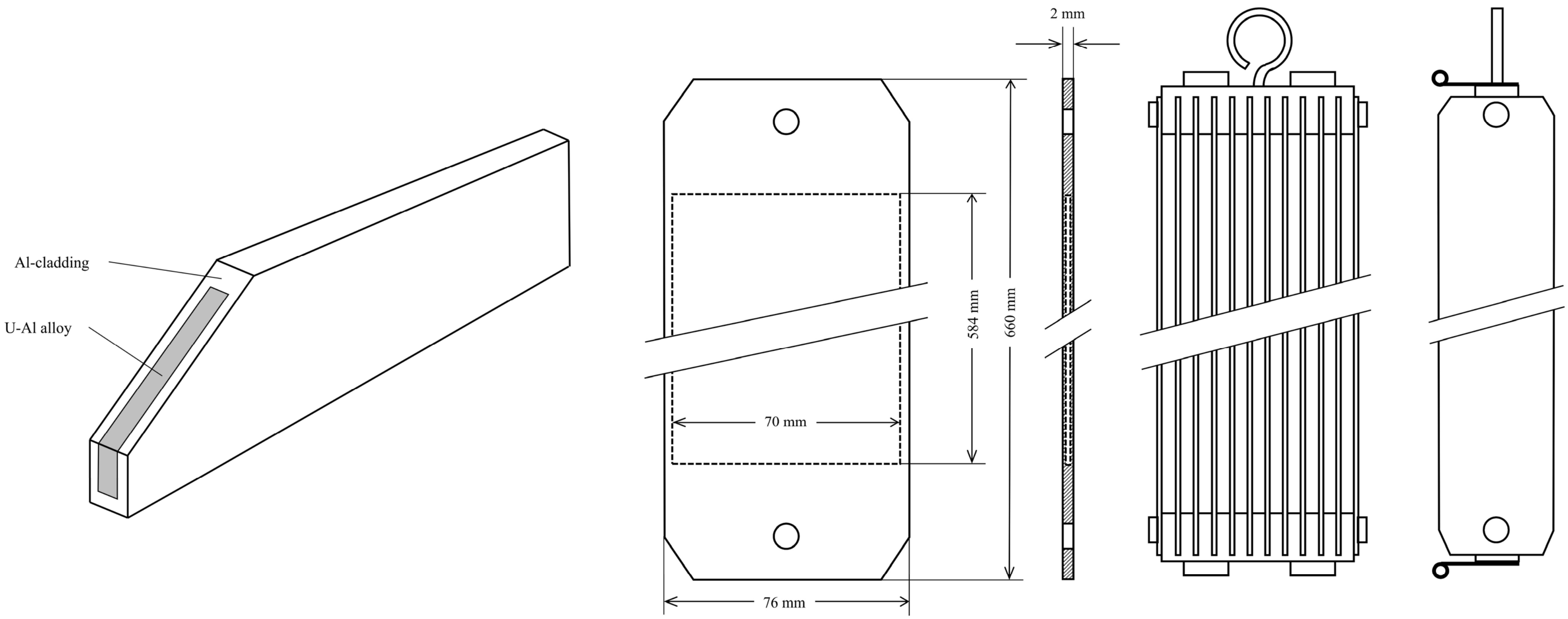


UTR-KINKI: Design and Specification



- Graphite reflected / light-water-moderated reactor.
- Two core tanks are set in a graphite reflector to have a dry and uniform irradiation field in the centre.
- The core tanks are filled with light water as a moderator.
- The reactor is controlled by four control rods (Cd plates).
- Each core tank has 6 fuel assemblies, and each fuel assembly has space for 12 fuel plates.

UTR-KINKI: Design and Specification



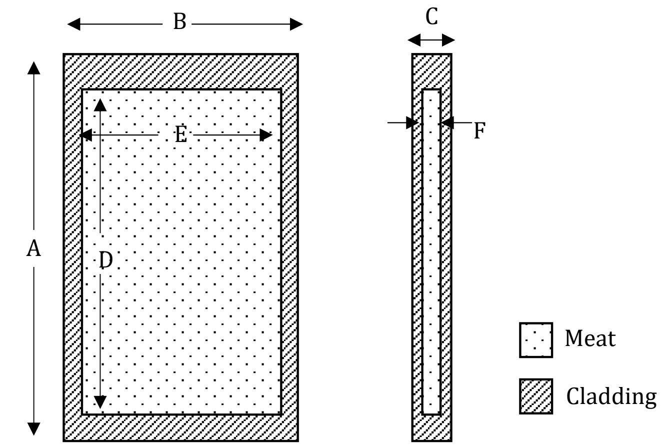
Iowa State University UTR-10, University of Florida Training Reactor Conversions to LEU

- Iowa State University UTR-10 core was the same design as UTR-KINKI but operated at 10 kW.
- University of Florida reactor operates at a power of 100 kW.
- **Two successful conversions** with the same type of fuel plate
  - Iowa State University UTR-10 converted in 1991.
  - UFTR converted in 2006 with the same plate design.

	Iowa State University UTR-10	University of Florida Training Reactor
Power	10 kW	100 kW
Date Converted	1991	2006

LEU Fuel Plate Design Comparison

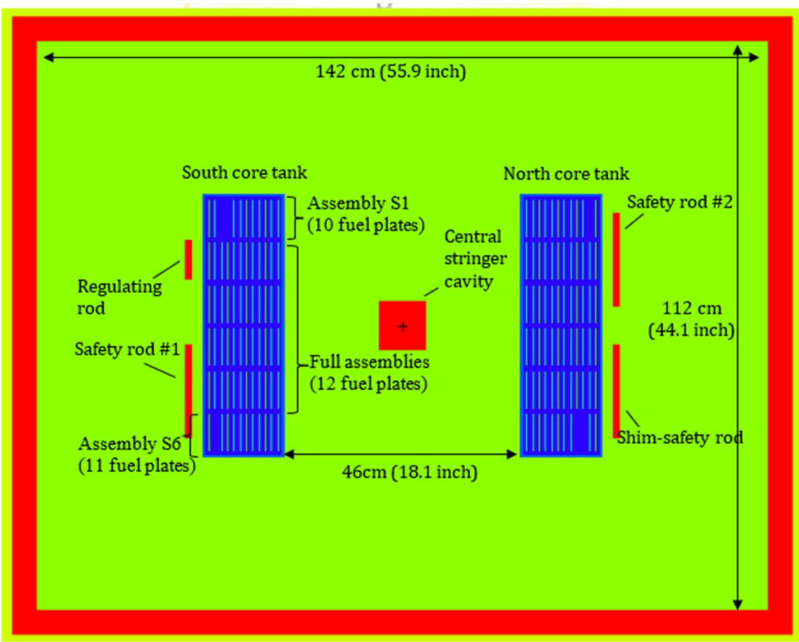
- U_3Si_2 - Al fuel at 19.75% enrichment
- More plates per assembly with thinner fuel meat
  - 24 LEU plates per assembly compared to 12 HEU plates per assembly for UTR-10
  - LEU fuel meat approximately ½ HEU thickness
- Overall fuel plate width and height the same as the HEU design
  - **No changes** necessary to core tank size



Label	Description	HEU Dimensions (mm/in.)	LEU Dimensions (mm/in.)
A	Plate length	660.4 / 26.00	659.6 / 25.97
B	Plate width	76.2 / 3.00	76.2 / 3.00
C	Plate thickness	2.03 / 0.08	1.27 / 0.05
D	Fuel meat length	584.2 / 23.00	609.2 / 23.98
E	Fuel meat width	69.8 / 2.75	62.7 / 2.47
F	Fuel meat thickness	1.02 / 0.04	0.51 / 0.02

Feasibility Study for UTR-KINKI

- Neutronics model of UTR-KINKI reactor simulated with MCNP6.2 using ENDF/B-VII.1 cross sections.
- Rod worths and worth of central stringer graphite compared to experimental results.
- Feasibility study to evaluate the operability and performance of the core with replacement of HEU with LEU in model.
- Two LEU fuel forms studied:
  - 3.25 gU/cc uranium content as in ISU conversion
  - 4.8 gU/cc as a standard loading in current use

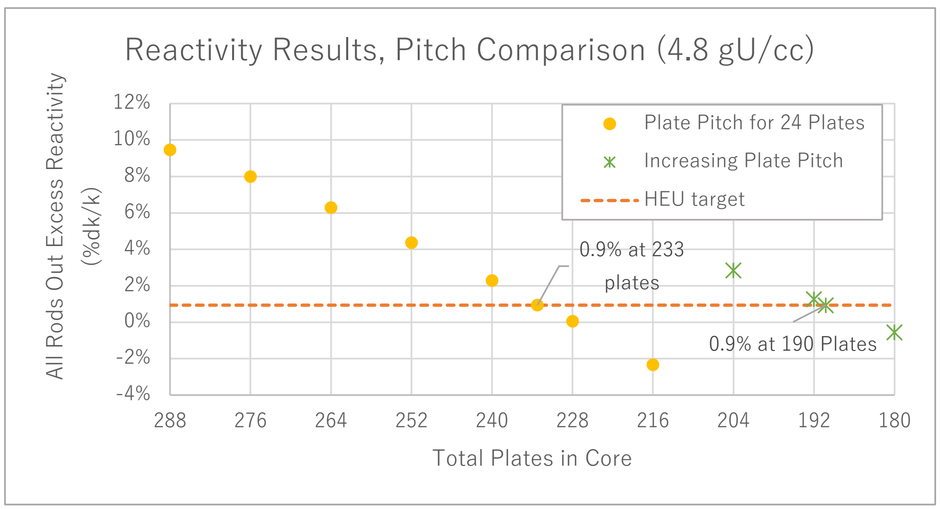


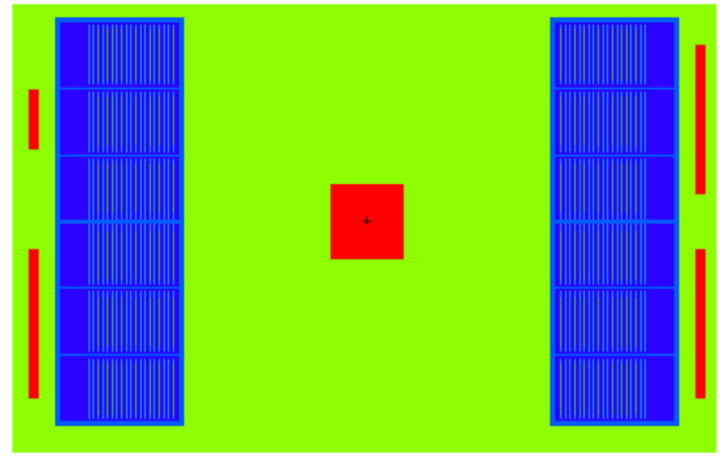
		Experimental Excess Reactivity or Worth (%dk/k)	Model Excess Reactivity or Worth* (%dk/k)
Excess reactivity		0.265	0.938
One rod stuck condition: (SR#2)		1.013	1.244
Rod worth	SR#1	0.578	0.541
	SR#2	0.590	0.480
	SSR	0.549	0.461
	RR	0.135	0.067
Graphite worth	Half C.S.	0.095	0.078
	Empty C.S.	0.15	0.156

*Worth calculated in reference to excess reactivity with all rods out

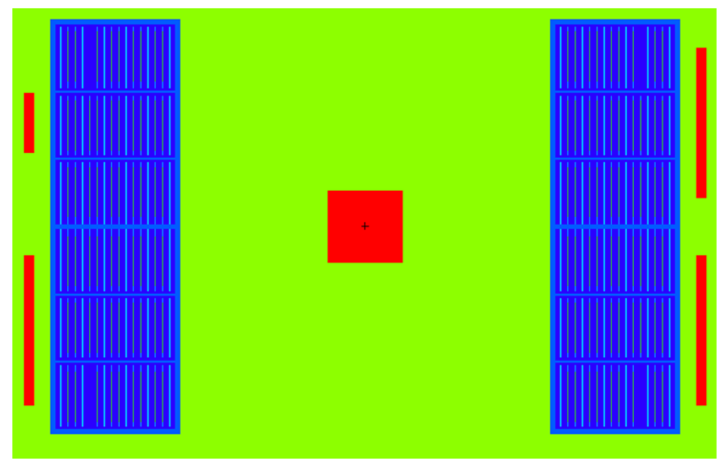
Feasibility with 4.8 gU/cc

- Higher uranium loading at 4.8 gU/cc provides for significantly less plates than ISU design of 24 plates per assembly.
- Increasing plate pitch advantageous compared to maintaining plate pitch of a 24 plate per assembly design
  - ~40 fewer plates required if plate pitch increased





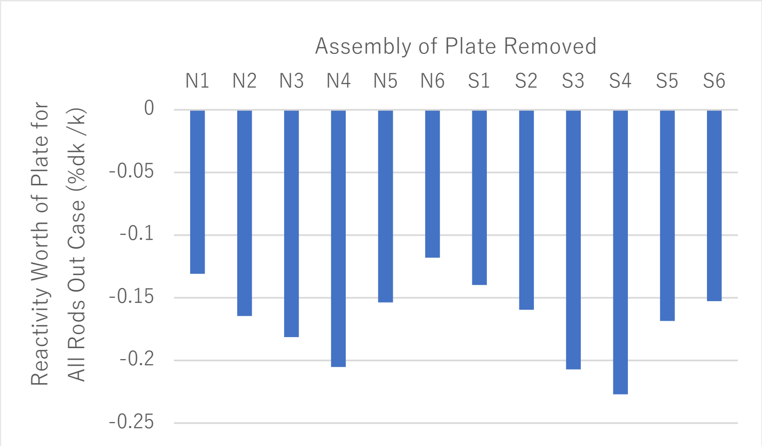
228 plate configuration with plate pitch maintained from 24 plate per assembly design

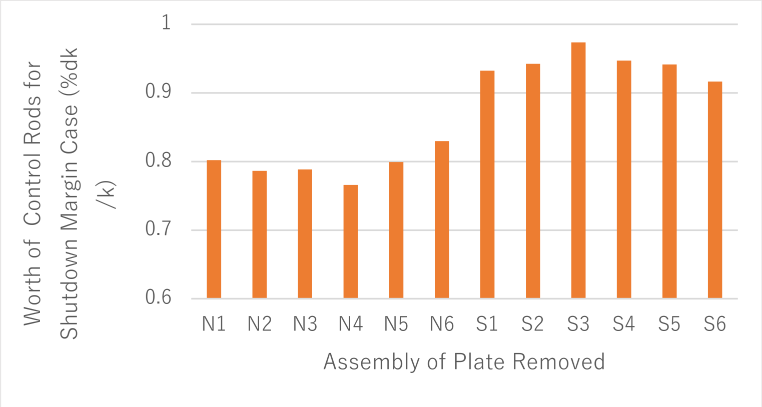


188 plate configuration (16 plates per assembly with 1 plate less in corner assemblies)

Design Optimization of Plate Configuration

- Non-uniform number of plates per assembly (less than full) evaluated for optimized configuration.
  - For maintaining excess reactivity, plate had less worth when removed from corner assemblies than central assemblies.
  - For shutdown margin case of Safety Rod #1 out, control rod worth is enhanced by removal of a plate from an assembly in the South core tank.

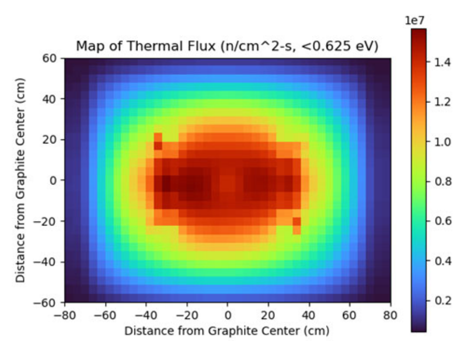


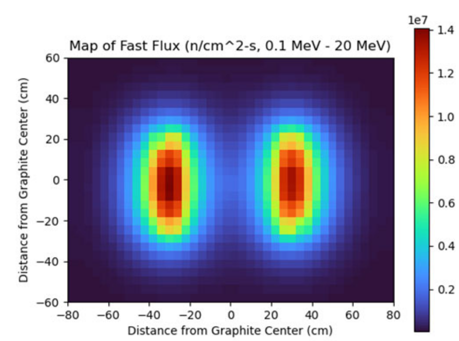


HEU compared to LEU Results

- Increase of ^{235}U required by ~15% for LEU designs compared to HEU to match excess reactivity.
- 4.8 gU/cc can meet reactivity with 94 fewer plates than 3.25 gU/cc loading.
- Similar control rod worth with LEU fuel as evident by shutdown margin case of highest worth rod out (SR#1).
- Similar peak thermal flux in central stringer
  - 2% reduction with LEU design

		HEU (Model Results)	LEU 4.8 gU/cc	LEU 3.25 gU/cc
Number of Plates		138	188	282
Excess reactivity (%dk/k)		0.935	0.852	0.818
Shutdown margin case (one rod stuck condition: SR#1 out) reactivity worth (%dk/k)*		0.910	0.868	0.949
Central stringer peak flux ($x10^7$ n/cm^2-s)	Thermal	1.44	1.37	1.41
	Epi	0.58	0.55	0.57
	Fast	0.19	0.18	0.18
*Worth calculated in reference to excess reactivity with all rods out				





Conclusions

- Feasibility study shows reactor can be converted to LEU while maintaining performance (flux) and operability of HEU core (excess reactivity and control rod worths).
- Two successful conversions using the same LEU plate design: Iowa State University UTR-10 and University of Florida Training Reactor.
- 4.8 gU/cc has benefit of significantly fewer total plates required than the 3.25 gU/cc for the same core parameters.

Acknowledgement

The Argonne work on this project was sponsored by the U.S. Department of Energy, Office of Material Management and Minimization in the U.S. National Nuclear Security Administration Office of Defense Nuclear Nonproliferation under Contract DE-AC02-06CH11357.

Disclaimer