NSE
Nuclear Science and Engineering
science : systems : society

MIT

Preliminary Design Considerations for MITR-III

Sara Hauptman[1]
hauptman@mit.edu

J. Buongiorno[1], A. Craft[2], K. Shirvan[1], L. Hu[1], G. Kohse[1], L. Snead[1], B. Forget[1]

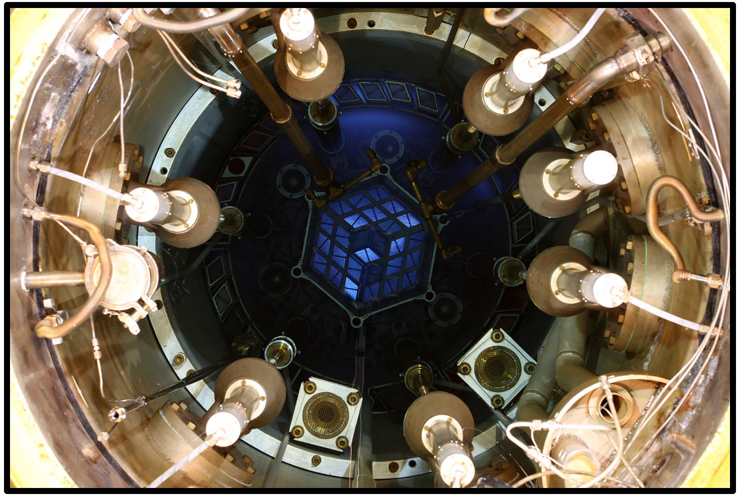
[1] Massachusetts Institute of Technology
[2] Idaho National Laboratory

TR 2024
Albuquerque, NM

October 4th, 2024

Backgrounder on Current MITR-II

- Massachusetts Institute of Technology Research Reactor (MITR-II)
  - 6 MW_{th} light-water, materials testing reactor
  - Operating since 1976



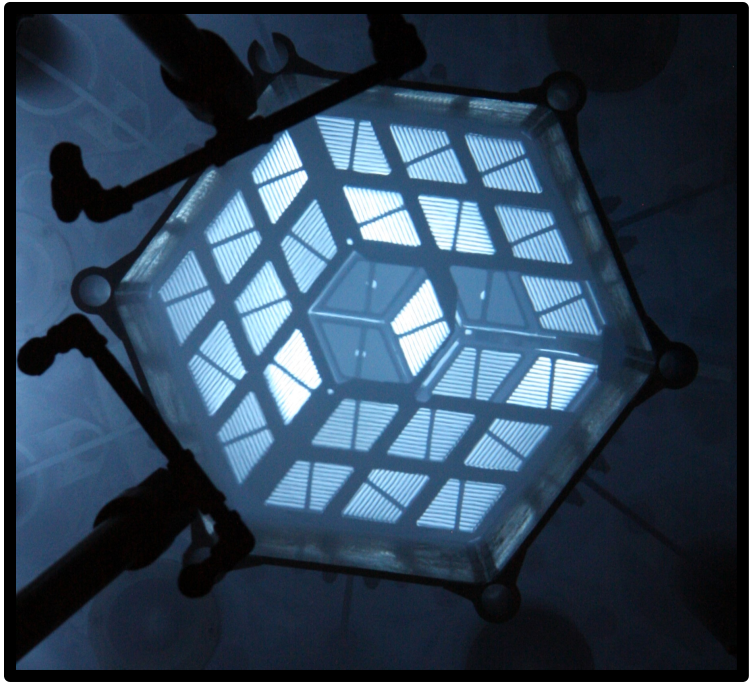
Motivation for Redesign

- Aging systems affecting reactor availability
- Legacy MITR-I design constrains use of space and reactor access
- Advanced reactor market has increased need for irradiation facilities
- Current long term planning includes fuel change (LEU Conversion)

MITR-I (1958-1974) → **MITR-II (1976-Present)** → **MITR-III**

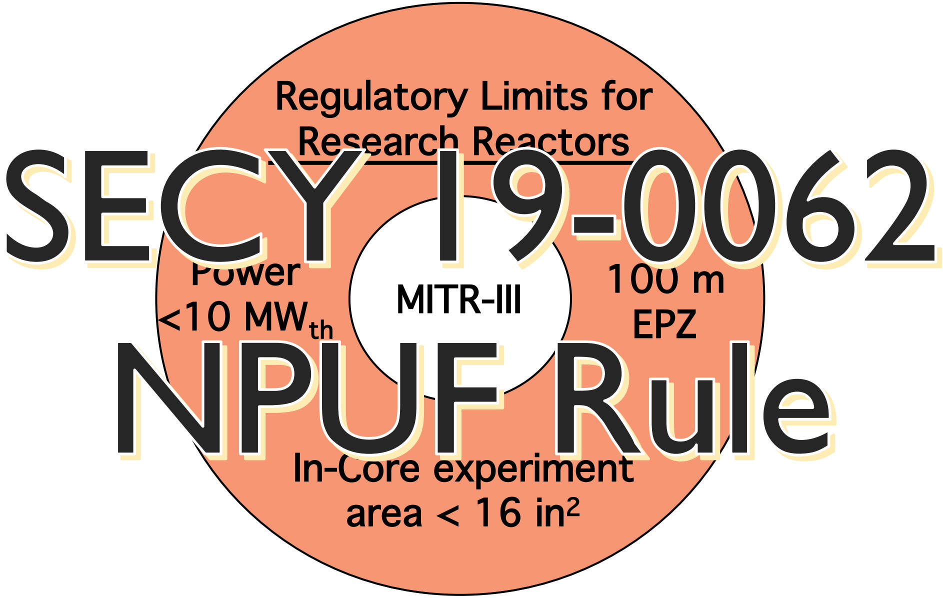
Design Goals

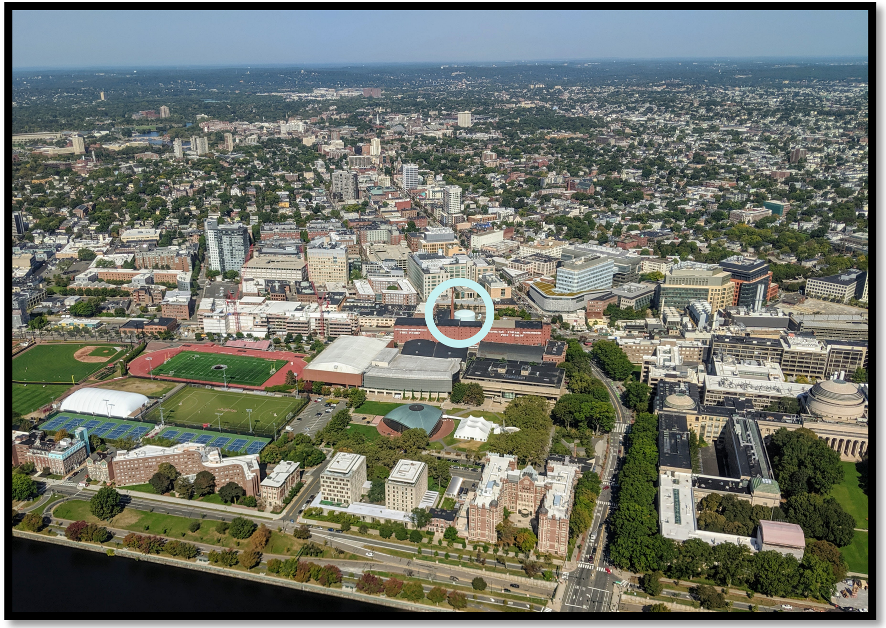
1) Maintain high performance and neutron flux
2) Increase in-core irradiation volume
3) Streamline routine evolutions
4) Boost reactor availability
5) Add versatility to ex-core facilities



Constraints

- Fuel enrichment <19.75 wt% U235
- Fixed site and physical containment





Proposed Design Pathways

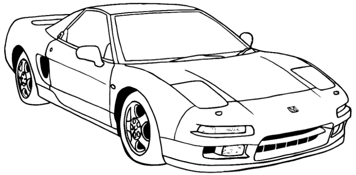
Short upgrade timeline

Al clad U-10Mo

H_2O cooled and moderated

D_2O and graphite reflectors

Leverage USHPRR work



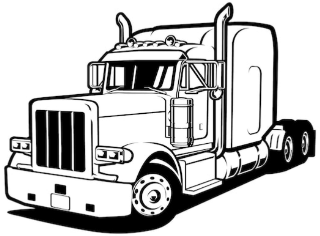
In-core performance

Multiple fuel options

H_2O cooled and moderated

Multiple reflector options

Replacement of legacy systems



Utilize commercial operating experience

Al or Zr clad UO_2 rods

H_2O cooled and moderated

Multiple reflector options

Existing industry support & infrastructure

Fuel Type Screening

$$Power \approx RR_f$$

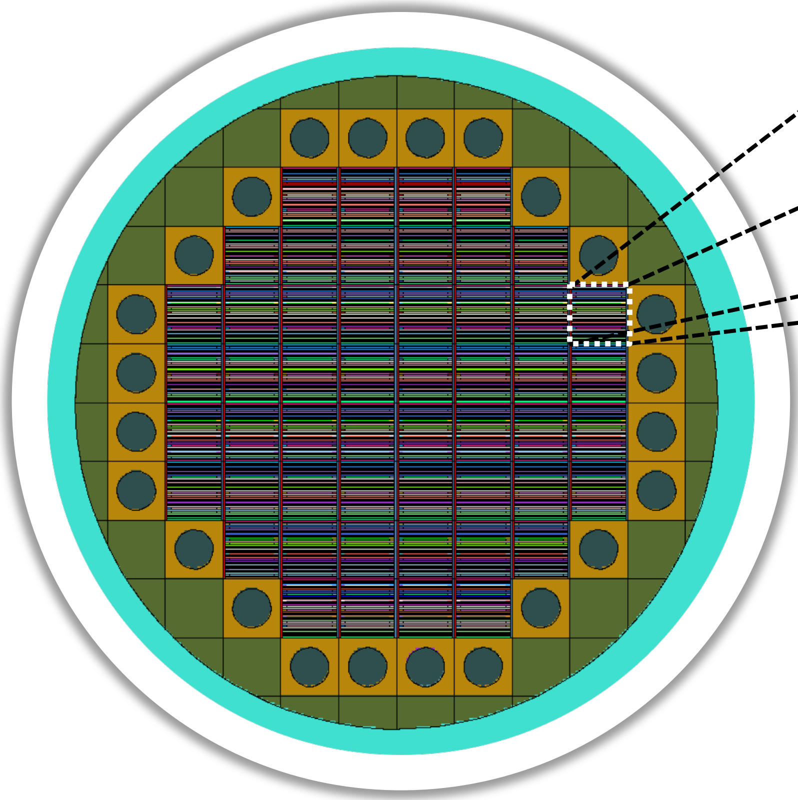
$$RR_f = V \sigma_f N_{235} \varphi$$

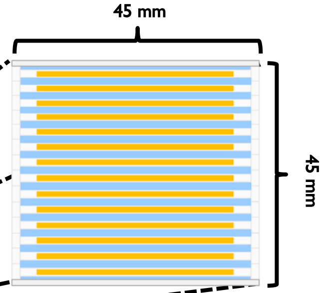
$$V \propto \frac{Power}{\varphi * \rho_{235}}$$

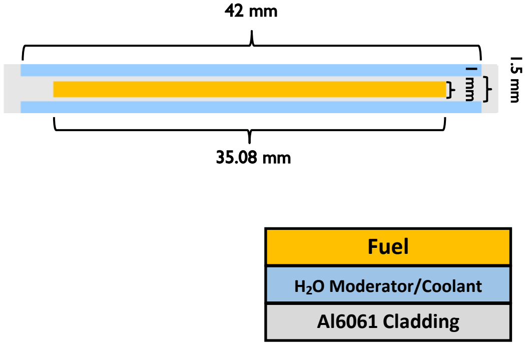
Fuel	U235 Density [g/cc]	Power [MW]	Normalized Volume Est	Fuel Maturity
TRISO	2.11 (kernel) 0.26 (particle)	10	1.18 9.55	Medium (AGR)/ Low (FCM)
$UZrH_x$ (TRIGA 45/20)	<1.04	10	2.39	High
UO_2	1.86	10	1.34	Medium/High
U-10Mo	3.02	10	0.82	Low
*U-7Mo	1.78	10	1.39	Low
*U_3Si_2 (5.3 g/cc)	1.05	10	2.37	Low/Medium
MITR-II (UAl_x)	1.49	6.0	1.0	High

*Dispersion form factor, aluminum matrix

Design Starting Point: Flat Plate Geometry

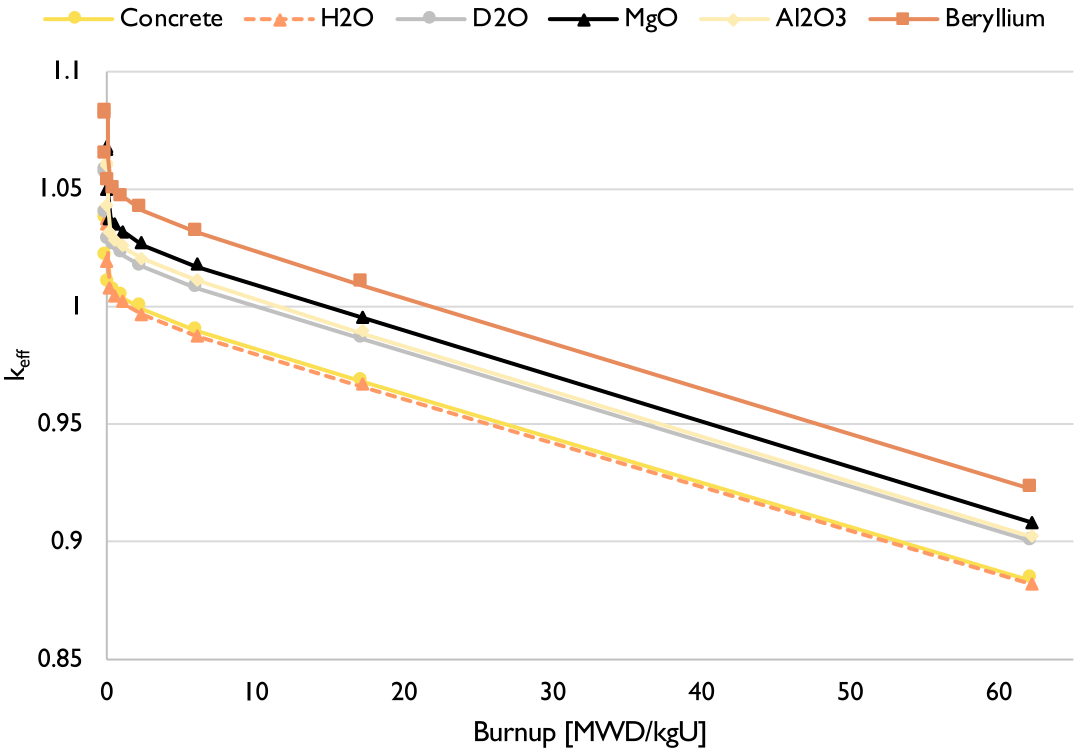






- 52 fuel elements
- 14 plates per element
- 36 cm core diameter, 60 cm height
- 24 peripheral control rods

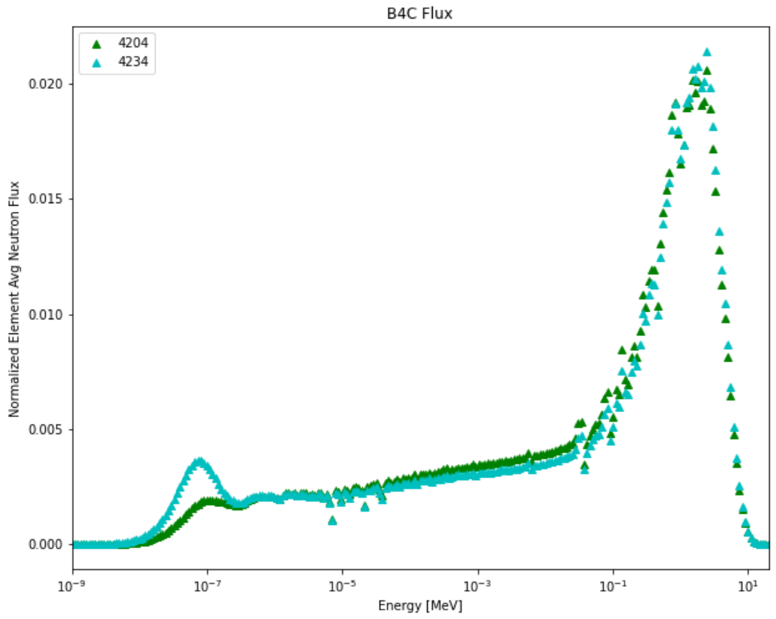
Reflector Screening

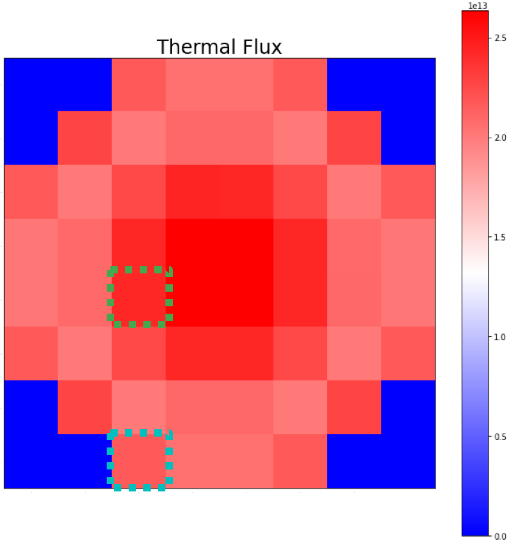


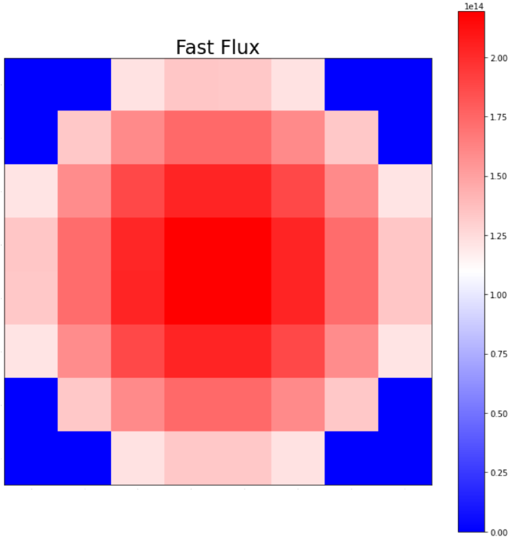
Reflector Material	Burnup Beyond Reference Case [MWD/kgU]
H_2O	0
Concrete	0.6
D_2O	8.5
MgO	13
Al_2O_3	10
Beryllium	20.5

Core Averaged Flux

Thermal (<1 eV)	Fast (>100 keV)
2.2×10^{13} n/cm^2/s	1.6×10^{14} n/cm^2/s







Key Takeaways

- Initial analysis supportive of MITR-III design goals
  - Increased irradiation volume
  - High flux and reactor availability
- Even with site and fuel constraints, performance standards can likely be preserved or exceeded

This work was funded under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

Backup Slides

Design 1: Economical

Priority: Shorten timeline of reactor upgrade

Parameter	Suggested Value	Support	Challenge
Fuel Meat	Al-clad U-10Mo (19.75 wt%)	Fuel qualification process underway Very high uranium density	Fabrication complexity Neutron absorption losses in molybdenum
Element Form	Monolithic, plates	Existing analysis/model support; Mini-fuel testing at ATR	Geometry constraints of existing structures and shielding
Moderator	H_2O	Compact, high MTC	Absorption losses; liquid
Coolant	H_2O	Inexpensive; Suited for low temperature operation	Low boiling temperature for transient analysis
Reflector	D_2O	Existing inventory; Familiarity with hazards and handling precautions	Tritium hazard; Expensive to bleed and feed

Design 2: Performance

Priority: Remove legacy systems to optimize for experiments

Parameter	Suggested Value	Support	Challenge
Fuel Meat	Dispersion or TRISO particle Al or Zr metallic matrix	Great heat transfer and FP retention	Fuels not qualified
Element Form	Plate type, un-finned	High heat transfer, compact	Fabrication feasibility
Moderator	H_2O	Compact, high MTC	Absorption losses; liquid
Coolant	H_2O	Inexpensive; Suited for low temperature operation	Low boiling temperature for transient analysis
Reflector	D_2O	Existing inventory; Familiarity with hazards and handling precautions	Tritium hazard; Expensive to bleed and feed
	Beryllium	High neutron reflection;	Toxicity; Limited lifetime
	MgO	Non-toxic; stable	Limited testing data
	Al_2O_3		

Design 3: Commercial

Priority: Take advantage of power reactor data

Parameter	Suggested Value	Support	Challenge
Fuel Meat	UO_2 (<20% enriched)	Operating data and industry support	Limited form factor
Element Form	Pellet stack, Al/Zr clad	Simple to model; available correlations	Decrease in heat transfer efficiency; no existing fabrication
Moderator	H_2O	Compact, high MTC	Absorption losses; liquid
Coolant	H_2O	Inexpensive; Suited for low temperature operation	Low boiling temperature for transient analysis
Reflector	D_2O	Existing inventory; Familiarity with hazards and handling precautions	Tritium hazard; Expensive to bleed and feed
	Beryllium	High neutron reflection;	Toxicity; Limited lifetime
	MgO	Non-toxic; stable	Limited testing data
	Al_2O_3		

Acknowledgement and References

This work was funded under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

1. P. GRAY, "Twentieth Anniversary Observance of the MIT Research Reactor and the Completion of the MITR-II Modification," [Speaking Notes], Cambridge, MA (July 27, 1978).
2. G. ALLEN, L. CLARK, J. GOSNELL, and D. LANNING, "The Reactor Engineering of the MITR-II Construction and Startup," Massachusetts Institute of Technology Department of Nuclear Science and Engineering, MITNE-186, Jun. 1976.
3. NRL STAFF, "Reactor Systems Manual", *Chapter 8*, SR# 2020-14H, (Mar 6, 2021).
4. "Technical Specifications for the MIT Research Reactor (MITR-II)," Docket No. 50-020, Rev. 6, MIT Nuclear Reactor Laboratory, Cambridge, MA (2010).
5. K. SUN, L. HU, E. WILSON, A. BERGERON, T. HELTEMES, "Low Enriched Uranium (LEU) Conversion Preliminary Safety Analysis Report for the MIT Research Reactor (MITR)", MIT-NRL-18-01, Rev. 2, October 2018.
6. K. SUN, A. DAVE, et. al., "Transitional cores and fuel cycle analyses in support of MIT reactor low enriched uranium fuel conversion," *Progress in Nuclear Energy*, **119**, 103171 (2020).
7. L. HU, K. SUN, A. DAVE, E. BLOCK, and J. FOSTER, "MITR Startup Plan for Initial LEU Fueled Core", MIT-NRL-19-02, Rev. 0, July 2019.
8. J. KIM, Y, TAHK, et. al., "On-going Status of KJRR Fuel (U-7Mo) Qualification", Idaho National Laboratory, INL/CON-17-41243, (March 2017).
9. D. CHANDLER, B. R. BETZLER, J. W. BAE, D. H. COOK, G. ILAS, "CONCEPTUAL FUEL ELEMENT DESIGN CANDIDATES FOR CONVERSION OF HIGH FLUX ISOTOPE REACTOR WITH LOW-ENRICHED URANIUM SILICIDE DISPERSION FUEL*," *EPJ Web Conf.*, vol. 247, p. 08017, 2021, doi: 10.1051/epjconf/202124708017.