A Neutronics Feasibility Study of the TRIGA LEU Fuel in the 20 MWt NIST Research Reactor

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RERTR The Reduced Enrichment for Research and Test Reactor Program

- Established in 1978 under the Global Threat Reduction Initiative (GTRI) The RERTR set the stage for the conversion of research reactors in the united states

NTI
BUILDING A SAFER WORLD

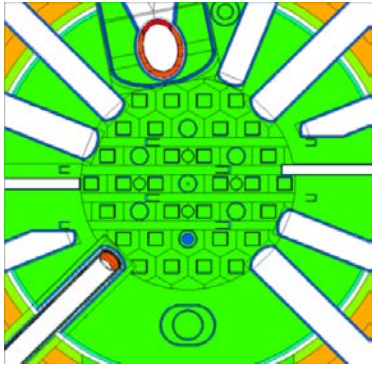
- Development of new LEU fuel (< 20 wt.%)
- Design and Safety analysis for conversion
- Production of Molybdenum-99 with LEU

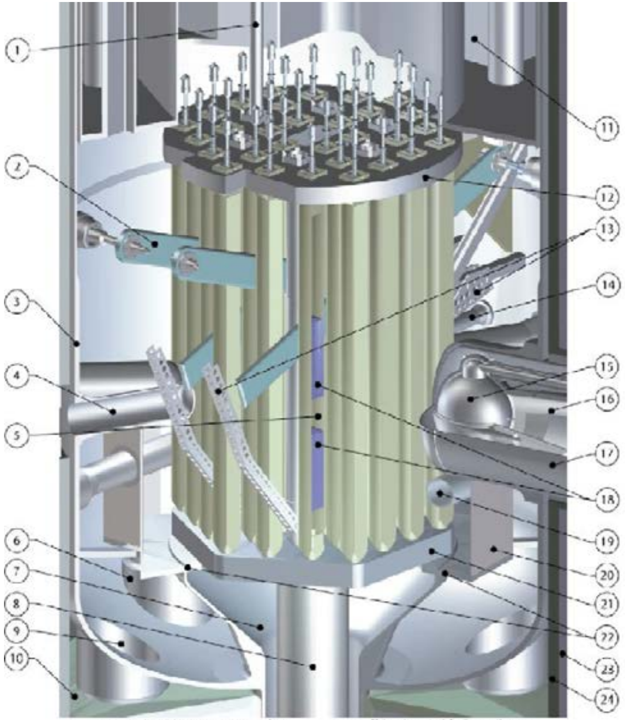
NBSR (National Bureau of Standards Reactor)

- Located at the National Institute of Standards and Technology(NIST) campus in Gaithersburg, Maryland, USA
- Main use is for neutron scattering research
- Hosts 2000 guest researchers annually
- First critical on December 7, 1967

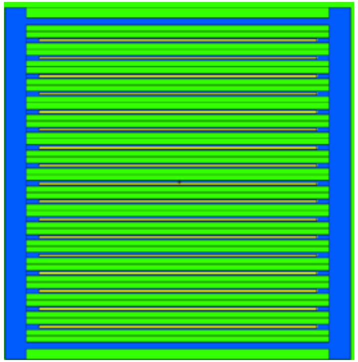
NBSR cont.

- Operates at 20 MW Thermal
- Average thermal flux density of 2.5×10^{14} n/cm^2-s
- 30 fuel elements
- 4 control blades
- D_2O cooled



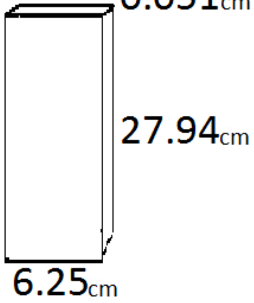


NBSR Current Fuel

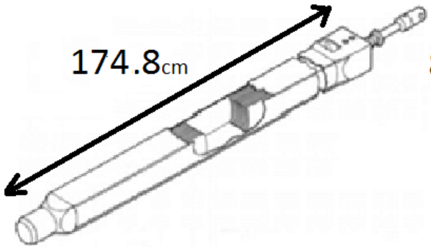


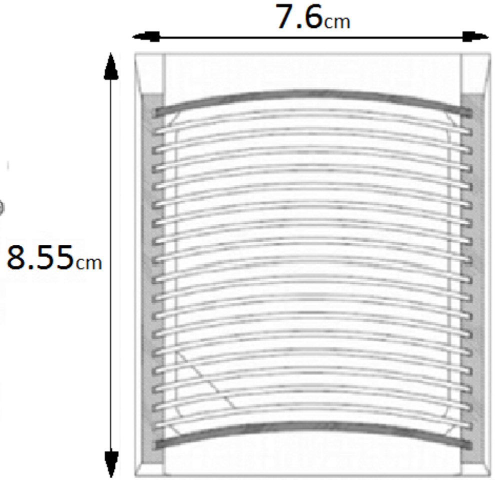
- Utilizes MTR plate type fuel (U_3O_8) 93 wt.% enriched
- Aluminum cladding
- 17 fuel plates, 19 plates total

Fuel plate

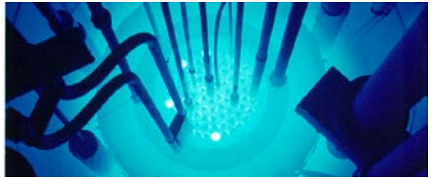


Fuel element





General Atomics LEU Fuel



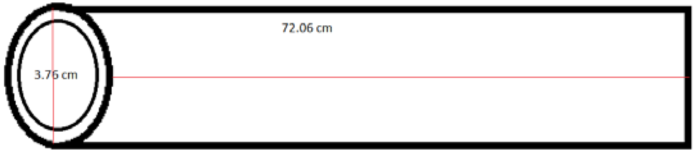
Why TRIGA?

From its conception in the 1980’s TRIGA (Training Research Isotopes General Atomics) fuel was a fuel designed to be “safe enough for a student”, and specifically for use in a research reactor.

*Prompt negative temperature coefficient

*19.7 wt.% enriched

*Aluminum cladding



More Benefits of the TRIGA Fuels

1. Long core life times.

-250kW reactor operating 200 days a year, 8 hours per day the U-235 consumption is approximately 20 grams per year

2. Commercially available

- Cheap to buy and easy to obtain

3. Inherently safe

-The zirconium hydride mix allows for an extremely stable fuel

4. Operationally flexible

-The size of the rods allow them to be easily fit into other fuel loadings

5. Fully qualified under RERTR

-TRIGA fuel is well known and well tested

Research Goals

1. No physical changes to the core

   - Only changes to the fuel elements to maintain the NBSR's integrity

2. Maintain irradiative capabilities

   -The neutron flux cannot vary greatly as this may effect the testing capabilities in the NBSR

3. Safety requirements

   - Appropriate measurements of related safety parameters

TRIGA In Other Research Reactors

- Advanced Test Reactor(ATR)

  - maintained a 56 day cycle with all fresh fuel

  - 13.06%-7.91% variation from flux requirement

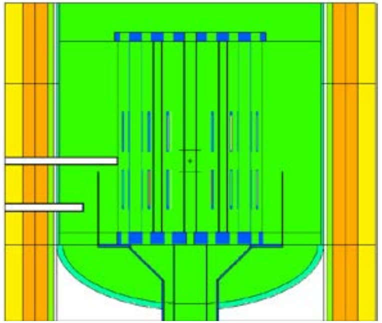
- Massachusetts Institute of Technology Reactor (MITR)

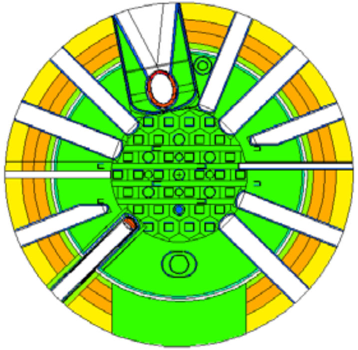
  - Critical heat flux requirement was achieved in beginning of life core evaluation

Modeling Method and Code

- Monte Carlo Neutron Transport Code MCNP6.1.1
- Input deck initially developed by NIST
- 110 cycles with 10 inactive cycles skipped and 10,000 particle histories per cycle to ensure the standard error of the k-eff value is less than 0.0001.

Los Alamos NATIONAL LABORATORY EST.1943





Procedure 1/3 Varying Fuel

- Commercial TRIGA fuel comes 35% , 40%, and 45%wt mixes with 19.7% enriched ^{235}U.
- Below the 35, 40 and 45 stand for the weight percent uranium, while the 20 represents the enrichment

Fuel density = wt.% $ZrH_{1.6}$ *Density of $ZrH_{1.6}$ (5.66g/cc) + wt. % U*Density of U (19.1 g/cc)

Fuel type	HEU	LEU(35/20)	LEU(40/20)	LEU(45/20)
^{235}U (g)	350.00	350.00	350.00	350.00
^{238}U (g)	26.00	1426.65	1426.65	1426.65
O (g)	68.00	0.00	0.00	0.00
Al (g)	625.00	0.00	0.00	0.00
Zr (g)	0.00	3232.00	2619.23	2134.03
H (g)	0.00	67.39	45.75	37.43
Total mass (g)	1069.00	5076.00	4441.62	3948.11
Fuel Density (g/cc)	3.16	10.36	11.04	11.71
Fuel Volume (cc)	296	489.80	402.47	337.22

Procedure 2/3 Varying Cladding

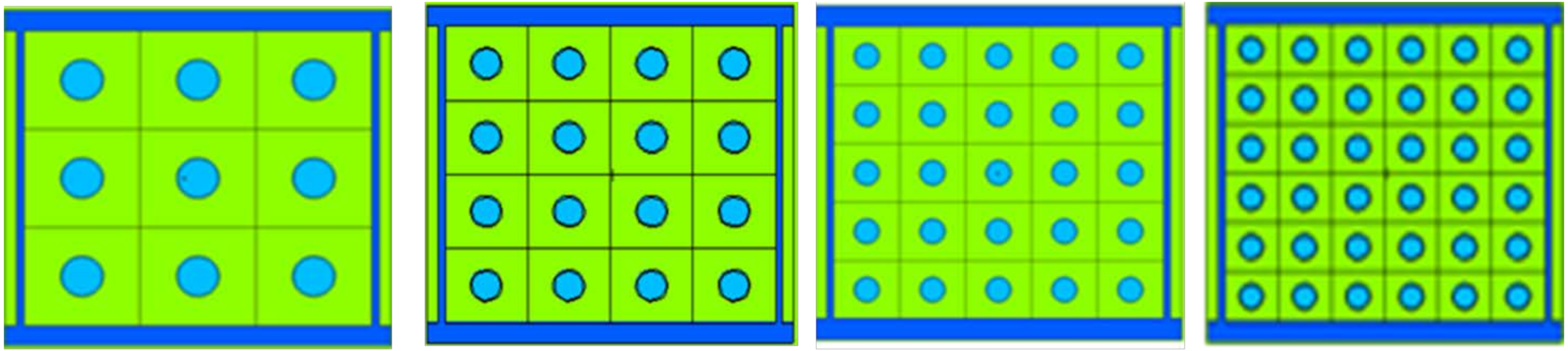
Why not Aluminum?
- Corrosion and blistering make loading difficult

Stainless Steel-304 (SS-304)
- High iron content

Incoloy-800
- High nickel and iron content

Steel, Stainless 304		Incoloy-800	
Density (g/cm3) = 8.00		Density (g/cm3) = 7.94	
Element	Weight Fraction	Element	Weight Fraction
C	0.000400	C	0.000650
Si	0.005000	Al	0.003750
P	0.000230	Si	0.006500
S	0.000150	S	0.000100
Cr	0.190000	Ti	0.003750
Mn	0.010000	Cr	0.210000
Fe	0.701730	Mn	0.009750
Ni	0.092500	Fe	0.435630
		Ni	0.325000
		Cu	0.004880

Procedure 3/3 Varying Configurations



3 x 3 4 x 4 5 x 5 6 x 6

- Varying configurations were tested to determine the effect of rod placement
- Note the amount of fuel per fuel casing is unchanged
- Self shielding and homogeneity of fuel

Results 1/2

Stainless Steel 304

Fuel Type	35/20	35/20	35/20	35/20	35/20	40/20	40/20	40/20	40/20	40/20	45/20	45/20	45/20	45/20	45/20
Rods	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6
keff	1.04015	1.07424	1.08083	1.08322	1.07923	1.02818	1.07036	1.07338	1.08752	1.08301	1.01866	1.06721	1.08508	1.08927	1.08617

Incoloy 800

Fuel Type	35/20	35/20	35/20	35/20	35/20	40/20	40/20	40/20	40/20	40/20	45/20	45/20	45/20	45/20	45/20
Rods	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6	2 x 2	3 x 3	4 x 4	5 x 5	6 x 6
keff	1.03827	1.0672	1.07528	1.07594	1.07241	1.02646	1.06546	1.06985	1.07989	1.07461	1.0152	1.06392	1.08023	1.08157	1.07687

Things to note:

- Cladding has constant thickness
- Uranium 235 consistent with HEU and constant for each fuel holding

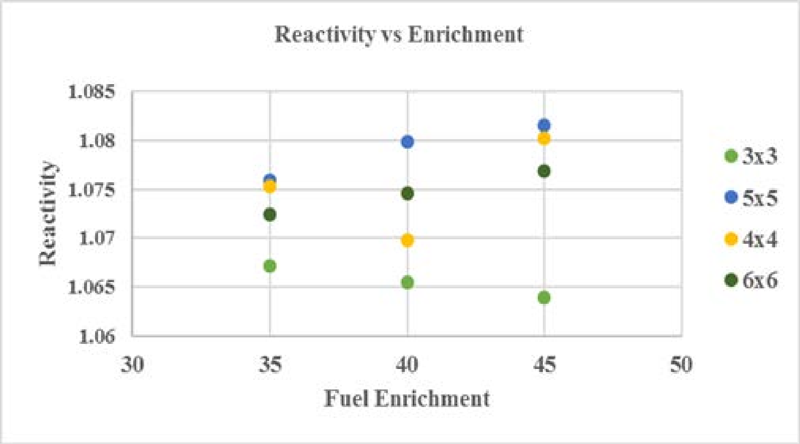
Results 2/2

- **5x5 Configuration**
  Likely due to the reduced self shielding from higher SA/volume ratio in the rods as well as the increased homogeneity of the fuel.

- **45/20 Composition**
  Can be intuitively attributed to the increase in total uranium mass.

- **SS304-Cladding**
  The higher absorption cross section of nickel in the Incoloy-800 likely attributed to the lower reactivity in comparison to stainless steel.

Stainless steel



Conclusions and future work

Fuel Type	45/20
Rod Configuration	5 x 5
Fuel density (g/cc)	11.71
Fuel rod radius (cm)	0.25
Cladding thickness (cm)	0.04
Fuel rod height (cm)	33.20
Total number of rods	50
Total U-235 mass (g)	350
keff	1.08927

- Equilibrium core
  - -Core lifetime with shuffling
- Non-uniform configuration
  - -Purely outer/inner rods
  - -Central focused rods
- Zirconium cladding
- Power and Flux distribution

Acknowledgments

NRC Fellowship Funding Support

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Thanks for Your Time.

Questions?