Conf-911149--3

STATUS REPORT ON CONVERSION OF THE GEORGIA TECH RESEARCH REACTOR TO LOW ENRICHMENT FUEL*

ANL/CP--74818

DE92 004137

DEC 1 3 1991

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To be Presented at the

1991 International Meeting on
Reduced Enrichment for
Research and Test Reactors

4-7 November 1991
Jakarta, Indonesia

*Work supported by the U.S. Department of Energy, Office of International Affairs and Energy Emergencies under Contract No. W-31-109-ENG-38.

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ABSTRACT

The 5 MW Georgia Tech Research Reactor (GTRR) is a heterogeneous, heavy water moderated and cooled reactor, fueled with highly-enriched uranium aluminum alloy fuel plates. The GTRR is required to convert to low enrichment (LEU) fuel in accordance with USNRC policy. The US Department of Energy is funding a program to compare reactor performance with high and low enrichment fuels. The goals of the program are: (1) to amend the SAR and the Technical Specifications of the GTRR so that LEU U_3Si_2-Al dispersion fuel plates can replace the current HEU U-Al alloy fuel, and (2) to optimize the LEU core such that maximum value neutron beams can be extracted for possible neutron capture therapy application. This paper presents a status report on the LEU conversion effort.

INTRODUCTION

The Neely Nuclear Research Center (NNRC) houses the Georgia Tech Research Reactor (GTRR), a Hot Cell Laboratory with 700,000 Curies of Cobalt-60, a Neutron Activation Laboratory with two pneumatic systems for sending and retrieving irradiated samples, a radioactive waste storage and handling facility, a machine shop, and electronic shop, and 26,000 square feet of laboratory and office space.

NNRC provides facilities for physical, chemical, and medical research involving neutrons and ionizing radiations. In particular, it provides access for multiple-discipline users to a five-megawatt research reactor and extensive radiochemical, radioanalytical, and radiobiological facilities. Ongoing work includes trace element analysis, production of radioisotopes for medical and industrial use, medical applications research, neutron radiography, industrial radiation exposure tests, silicon doping, and personnel training programs for industry. An additional program supports reactor use by colleges and universities throughout the southeastern United States.

REACTOR DESCRIPTION AND UTILIZATION

GTRR is a heterogeneous, heavy-water moderated and cooled reactor, fueled with HEU U-Al alloy MTR-type fuel assemblies. It is designed to produce a thermal flux of more than 10^{14} n/cm^2sec at a power of 5 MW. A horizontal section of the reactor is shown in Fig 1.

The reactor core is approximately two feet in diameter, two feet high, and contains provisions for up to 19 fuel assemblies spaced 6 inches apart in a triangular array. Each assembly contains 16 fuel plates with a ^{235}U content of about 188 g. The current core contains 17 assemblies. The fuel is centrally located in a six foot diameter aluminum reactor vessel which provides a two-foot thick D_2O reflector completely surrounding the core.

The reactor is equipped with 22 horizontal and 23 vertical experimental facilities to be used for the extraction of beams of fast and slow neutrons and for the performance of irradiations within the facilities.

A shielded room (approximately 10 feet by 12 feet inside) for biomedical research is located at the side of the reactor. This facility is designed to allow accurate exposures of biological specimens to a wide-angle beam of thermal and/or epithermal neutrons with a relatively low background of fast neutrons and gamma rays. It is fitted with bismuth gamma shield, water tanks for neutron attenuation, a collimator, shutter, and provisions for a converter plate system.

Initial feasibility studies for an epithermal neutron beam for boron neutron capture therapy using the biomedical research facility have been performed at the Idaho National Engineering Laboratory/1/.

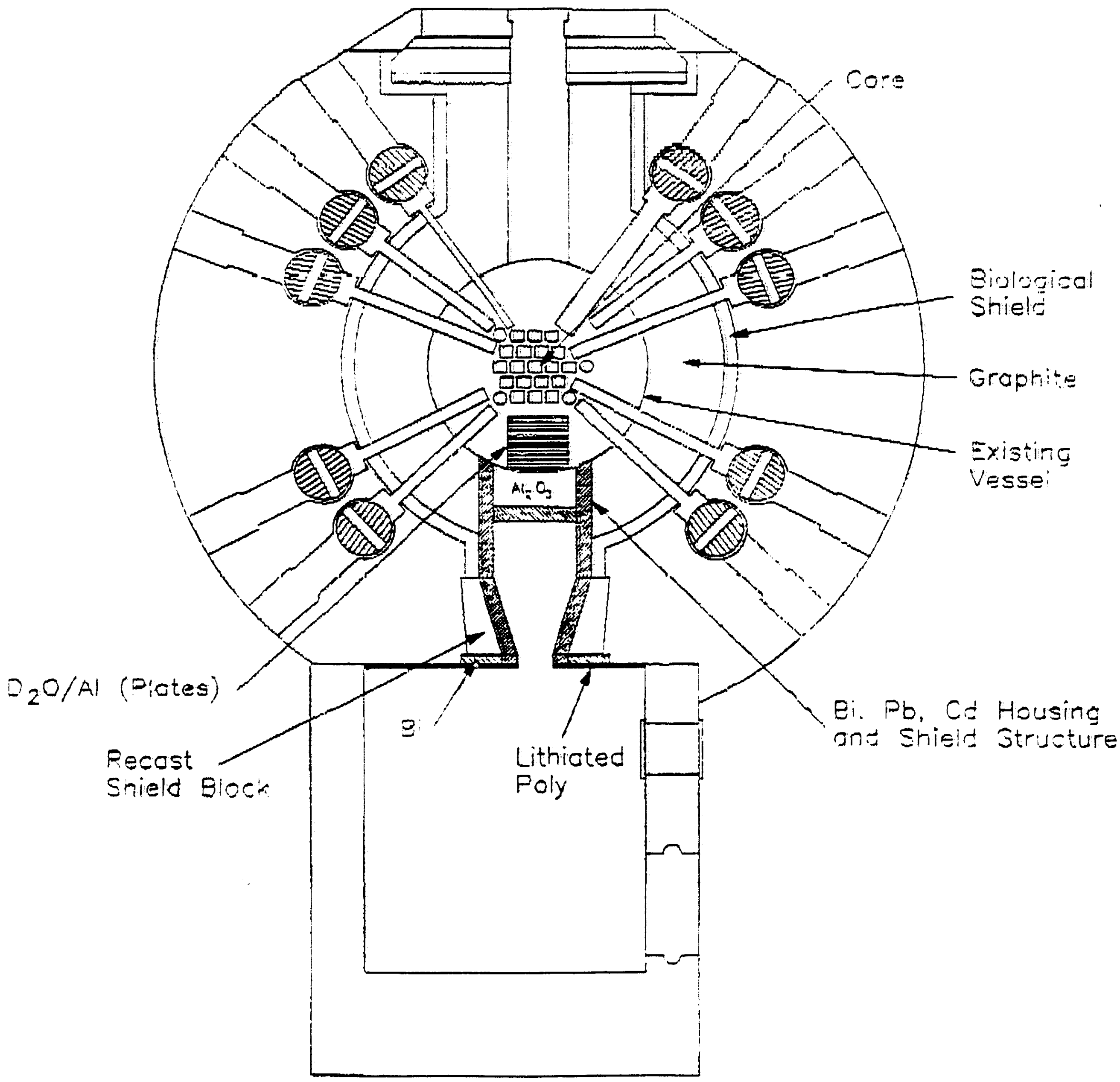


Fig 1. GTRR Horizontal Section Showing Conceptual Epithermal Neutron Facility

LEU CORE CONVERSION ANALYSES

Objectives and Constraints

The key reactor performance objective is that the epithermal neutron flux (0.4 eV - 10 keV) at the bio-medical facility with LEU core should be comparable to or larger than what exists in the present HEU core. The LEU fuel lifetime performance should be comparable to that of the HEU fuel. However, the latter condition is a weaker criterion because HEU fuel consumption since 1974 has been modest. All safety margins must be within acceptable limits. The technical specifications and operating procedures of the present HEU core should be maintained as closely as possible for the LEU core.

The constraints in designing an appropriate LEU fuel assembly were: (1) the outer assembly dimensions and all other hardware except the fuel plates and their spacing must be identical with those of the HEU assembly, (2) the design must utilize the DOE standard fuel plate (for university reactors) containing U_3Si_2-Al fuel with ~3.5 g U/cm^3, 12.5 g ^{235}U, and 0.38 mm cladding, (3) the two outer plates must be unfueled in order to form an enclosed coolant flow volume, (4) the coolant gap thickness should be equal to or larger than the minimum coolant gap thickness in current use in MTR-type fuel assemblies.

Reactor Models

A detailed Monte Carlo model of the reactor was constructed including all beam tubes, experiment penetrations, control rods, and the bio-medical facility in order to obtain absolute excess reactivities and shutdown margins for comparison with limits specified in the Technical Specifications.

Since the reactor is controlled by four shim safety rods (control arms) that swing between the fuel assemblies and since the reactivity worth of the various reactor penetrations is about 5% $\Delta k/k$, a diffusion theory model was constructed without these features. A second Monte Carlo model similar to the diffusion model was constructed to verify that the diffusion theory model was correct and to obtain a reactivity differential for use in the balance table for the diffusion theory burnup calculations. Nuclear cross sections in seven energy groups were calculated using standard methods for use in the diffusion theory calculations.

Critical Experiment

In 1974, a critical experiment was built using 9 fresh HEU fuel assemblies. The measured k_{eff} of the assembly was 1.000 ± 0.005. The k_{eff}'s calculated using the detailed Monte Carlo model for critical cores with two different shim safety rod and regulating rod positions were 0.9910 ± 0.0020 and 0.9879 ± 0.0021. The corresponding reactivity values were -0.91 ± 0.20% $\Delta k/k$ and -1.22 ± 0.22% $\Delta k/k$, respectively. The reactivity bias of about -1.0 ± 0.3% $\Delta k/k$ in the calculations is attributed to uncertainties in the nuclear cross sections and uncertainties in the reactor materials. Calculated reactivity worths of the various reactor penetrations are shown in Table 1.

Table 1. Reactivity Worths of Reactor Penetrations

Penetration	% $\Delta k/k \pm 1\sigma$
Horizontal Beam Tubes	- 1.9 ± 0.2
Inner Vertical Tubes in D_2O Reflector	- 2.3 ± 0.3
Outer Vertical Tubes in Graphite Reflector	- 0.6 ± 0.3
Bio-Medical Facility	- 0.3 ± 0.3
Overflow and Drain Lines Inside Tank	- 0.1 ± 0.3
Lower Graphite Reflector Penetrations	+ 0.2 ± 0.3
Sum	- 5.0 ± 0.6

LEU Fuel Assembly Design Selection

Calculations were run for the current HEU core with 17 fresh fuel assemblies and for several candidate LEU cores satisfying the constraints mentioned above. The number of fueled plates per assembly and number of assemblies in the core are shown in Table 2 along with thermal and epithermal fluxes at the peak thermal flux position in the D_2O reflector. These data provide estimates of the relative fluxes expected at the bio-medical facility.

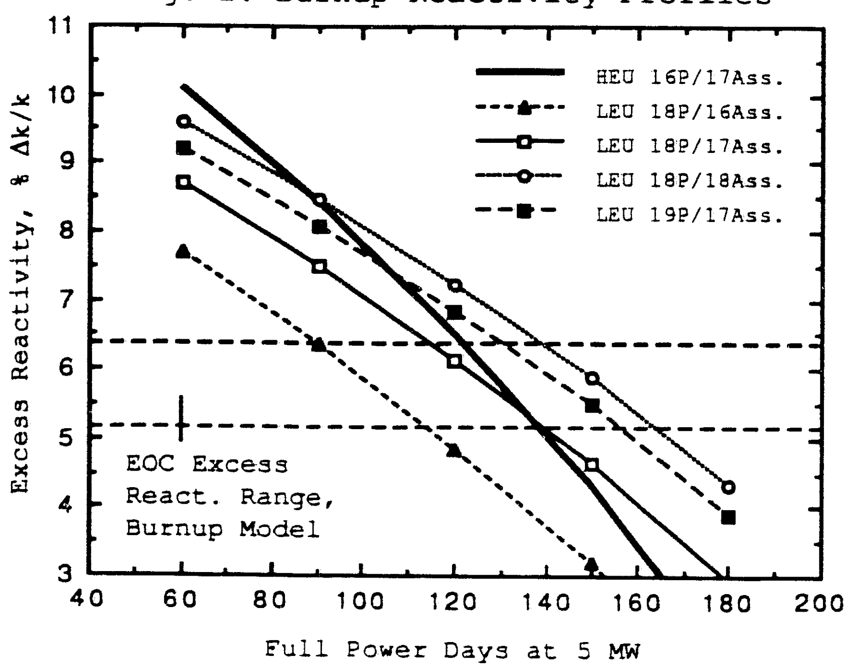
Table 2. Relative Fluxes at Thermal Flux Peak in D_2O Reflector

Fuel	Coolant Gap Thick. mm	Number of Fueled Plates*	Number of Fuel Assem.	Flux Relative to HEU Core ≤0.625 eV	Flux Relative to HEU Core ≥0.625 eV ≤5.53 keV	Flux Relative to HEU Core ≥5.53 keV ≤0.82 MeV
HEU	2.69	16	17	1.00	1.00	1.00
LEU	2.25	18	16	0.96	1.07	1.08
LEU	2.25	18	17	0.92	1.02	1.02
LEU	2.25	18	18	0.88	0.98	0.97
LEU	2.08	19	17	0.89	1.02	1.02

*All fuel assemblies contain 2 unfueled outer plates.

Burnup calculations were also run for the cases shown in Table 2 to estimate fuel lifetimes. Reactivity profiles (including reactivity bias) are shown in Fig. 2 over a limited burnup range. The dashed lines show the EOC excess reactivity range that accounts for reactivity losses due to experiment facilities, cold-to-hot swing, and control provision that are not included in the diffusion theory burnup model. We conclude that the lifetime of an LEU core with 17 fuel assemblies and 18 fuel plates per assembly will be comparable to but probably less than that of the HEU core.

Fig. 2. Burnup Reactivity Profiles



The minimum coolant channel gap thickness in current international experience with MTR-type fuel assemblies is 2.1 mm. An LEU assembly with 19 fueled plates would have a coolant channel width of about this value (Table 2) and would provide a core lifetime that is larger than the present HEU core (Fig. 2). All safety margins are likely to be satisfied with a 19-plate assembly. However, because the reactor's HEU fuel utilization since 1974 has been modest, the more conservative design with 18 fueled plates and a coolant gap of 2.25 mm has been chosen. Actual reactor operation is expected to begin with a 16-assembly core. New fuel assemblies (up to 19) will be added as required.

SAFETY-RELATED ANALYSES

Excess Reactivity

Calculated excess reactivities (including reactivity bias) for fresh HEU and LEU cores with 17 fuel assemblies are shown in Table 3. The Technical Specifications limit the excess reactivity to a maximum of 11.9% $\Delta k/k$. The LEU core is expected to satisfy this requirement.

Table 3. Excess Reactivities of HEU and LEU Reference Cores

	Calculated Excess React.[1], % $\Delta k/k$	
	Fresh HEU Core	Fresh LEU Core
Detailed Monte Carlo Model	11.7 ± 0.4	9.4 ± 0.4
Simplified Monte Carlo Model[2]	16.8 ± 0.4	14.3 ± 0.4
Diffusion Theory Model[2]	16.6	14.6

[1] The reactivity bias of -1.0 ± 0.3% $\Delta k/k$ was added to calculated values.
[2] Without experiment penetrations and control rods.

Temperature Coefficients and Kinetics Parameters

Reactivity changes were computed separately as a function of temperature for the fuel, coolant, heavy water between fuel assemblies, and heavy water reflector for fresh HEU and LEU cores with 14 and 17 fuel assemblies. Key temperature coefficients and kinetics parameters are summarized in Table 4.

Table 4. Temperature Coefficients (% Δk/k/°C at 45°C) and Kinetics Parameters

	HEU 14 Ass.	HEU 17 Ass.	LEU 14 Ass.	LEU 17 Ass.
Coolant	-0.0061	-0.0055	-0.0043	-0.0042
Fuel Doppler	0.0	0.0	TBD	-0.0021
Isothermal[1]	-0.0223	-0.0203	-0.0232	-0.0215
Void Coeff.[2],	-0.0362	-0.0375	-0.0228	-0.0279
l_p[3], μs	780	704	745	695
β_{eff}	0.00755[4]	0.00755[4]	0.0075 - 0.0076[5]	

[1] Includes fuel, coolant, inter-assembly water, and reflector.
[2] % Δk/k/% Void. Uniform voiding of coolant in all fuel assemblies.
[3] Calculated prompt neutron lifetime
[4] Measured effective delayed neutron fraction. [5] Estimated value.

Thermal-Hydraulic Safety Margins

Thermal-hydraulic safety margins were calculated for 14-assembly cores (GTRR minimum core size) with both the current HEU assembly and the LEU assembly with 18 fueled plates. The HEU results shown in Table 5 using ANL methods agree well with limiting values in the Technical Specifications. The LEU assembly has reduced power per plate, a smaller flow area, a higher coolant velocity, and a larger pressure drop due to friction. The peak cladding surface temperature is lower by about 2°C and the margins to DNB and flow instability are similar. We conclude that the LEU core will have adequate thermal-hydraulic safety margins.

Table 5. Thermal-Hydraulic Safety Margins for 14-Assembly Cores.

	HEU	LEU
Coolant Flow, gpm	1625	1625
Coolant Velocity, m/s	2.4	2.6
Friction Pressure Drop[1], kPa	11.0	15.0
Power/Plate[2], kW	21.2	18.8
Outlet Temperature, °C	67.7	68.7
Peak Clad Surface Temperature, °C	109.2	106.7
Minimum DNBR[3]	2.4	2.2
Flow Instability Ratio[4]	2.2	2.1

[1] Pressure drop across active fuel only.
[2] Assuming 95% of power deposited in fuel.
[3] Using modified Weatherhead Correlation for DNB.
[4] Using Whittle-Forgan Correlation with $\eta = 25$.

Shutdown Margins

The Technical Specifications require that the reactor have a shutdown margin of at least 1% $\Delta k/k$ with the most reactive shim safety rod and regulating rod fully withdrawn. Measurements of shim safety rod worths in the present HEU core indicate a shutdown margin of 9 - 10% $\Delta k/k$ under these conditions. Since a fresh LEU core is expected (Table 3) to have a lower excess reactivity than a fresh HEU core of the same size and since the shim safety rod worths in the LEU core are expected to be comparable with those in the HEU core, we anticipate that the shutdown margin requirement will also be satisfied in the LEU core. Specific calculations are in progress.

Transient Analyses

The Technical Specifications have several limitations on experiments. For example: the reactivity worth of each unsecured experiment is limited to 0.4% $\Delta k/k$ and the reactivity worth of each secured removable experiment is limited to 1.5% $\Delta k/k$. Analysis of hypothetical transients related to these reactivity limitations are in progress.

CONCLUSION

Conversion of the GTRR core from HEU to LEU fuel is feasible utilizing an LEU assembly containing 18 DOE standard silicide fuel plates (for university MTR-type reactors) as a replacement for the current HEU assembly with 16 fueled plates. Both HEU and LEU assemblies contain two unfueled outer plates to form an enclosed flow volume. The LEU assemblies would contain 225 g ^{235}U instead of 188 g ^{235}U in the current HEU assemblies.

Calculations indicate that the epithermal flux at the bio-medical facility will be slightly larger than in the present HEU core. The lifetime of the LEU core is expected to be comparable but probably smaller than that of the HEU core. This is acceptable because of the reactor's modest fuel consumption since 1974. A lifetime larger than that of the HEU core could be achieved with 19 fueled plates per LEU assembly, but the thickness of the coolant channel gap would be close to the minimum gap utilized in current international experience with MTR-type fuel assemblies. All safety margins with the 18 plate assembly appear to be satisfied, although work on several key parameters is still in progress.

Reference

/1/ D. Nigg, Private communication, August 1991.

Acknowledgment

The authors wish to acknowledge extensive contributions to this work by K. E. Freese, Argonne National Laboratory, who passed away in June 1991.

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2/03/92