LEU CONVERSION STATUS OF U.S. RESEARCH REACTORS SEPTEMBER 1996*

J. E. Matos

RERTR Program
Argonne National Laboratory
Argonne, Illinois 60439-4841 USA

Presented at the
1996 International Meeting on Reduced Enrichment
for Research and Test Reactors

October 7-10, 1996
Seoul, Korea

*Work supported by the U.S. Department of Energy
Office of Nonproliferation and National Security
under Contract No. W-31-109-38-ENG

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ABSTRACT

This paper summarizes the conversion status of research and test reactors in the United States from the use of fuels containing highly-enriched uranium (HEU, ≥ 20%) to the use of fuels containing low-enriched uranium (LEU, < 20%). Estimates of the uranium densities required for conversion are made for reactors with power levels ≥ 1 MW that are not currently involved in the LEU conversion process.

INTRODUCTION

At the request of the Department of Energy, the RERTR Program has summarized the conversion status of research and test reactors in the United States and has made estimates of the uranium densities that would be needed to convert these reactors to the use of LEU fuels. Detailed conversion studies for each of the reactors need to be completed in order to establish the feasibility of using LEU fuels.

U.S. research and test reactors are regulated by one of three independent regulatory bodies. Research reactors belonging to the Department of Energy are regulated by DOE. Those belonging to the Department of Defense are regulated by DOD. University research reactors, government research reactors other than DOE and DOD reactors, and commercial research reactors are regulated by the Nuclear Regulatory Commission (NRC).

LEU U_3Si_2-Al fuel with uranium densities up to 4.8 g/cm^3 is fully-qualified and has been approved for licensing[1] by the NRC. TRIGA LEU fuel with up to 2.2 g U/cm^3 (30 wt-% U) is also fully-qualified and has been approved for licensing[2] by the NRC. TRIGA LEU fuel with 3.7 g/cm^3 (45 wt-% U) has been thoroughly tested[3] in the Oak Ridge Research Reactor and is available for routine use. The RERTR Program began development[4] of advanced fuels with uranium densities up to 8-9 g/cm^3 in 1996. Testing of the first miniplates containing LEU fuel with high uranium densities is expected to begin in the Advanced Test Reactor at the Idaho National Engineering Laboratory in the Spring of 1997.

U.S. REACTOR CONVERSION STATUS

University Research Reactors

There are nineteen operating university reactors that use or formerly used HEU fuel. Nine of these reactors have completed conversion to LEU fuel and two more conversions are planned in 1997. Six reactors are working on the safety documentation required for LEU conversion. Suitable LEU fuels are currently not available for reactors at the Massachusetts Institute of Technology and the University of Missouri at Columbia.

Studies[5,6] for converting university research reactors from HEU to LEU fuel have been underway in the U.S. since 1985. Prior to this, the University of Michigan demonstrated the LEU conversion process in the Ford Nuclear Reactor (FNR) during 1981-1984 in cooperation with the RERTR Program.

In 1986, the NRC amended[7] its regulations to limit the use of HEU fuel in domestically licensed research and test reactors (non-power reactors). Generally, the amendments require that newly-licensed non-power reactors use LEU fuel and, contingent upon federal government funding for conversion-related costs, that licensees of existing non-power reactors replace HEU fuel with LEU fuel acceptable to the Commission. There is also a “unique purpose” provision. The amendments are intended to reduce the risk of theft or diversion of HEU fuel and to encourage similar action by foreign operators of non-power reactors.

Table 1 shows the conversion status of the nineteen operating U.S. university research reactors that use or formerly used HEU fuel. Nine reactors were converted from HEU to LEU fuels between 1984 and 1994. Safety documentation has been approved by the NRC for conversion of the 5 MW reactor at the Georgia Institute of Technology and the 1 MW reactor at the University of Massachusetts at Lowell. All of the HEU fuel at Georgia Tech was shipped to the Savannah River Site in February 1996. LEU replacement fuels have been manufactured by Babcock & Wilcox for both of these reactors and are currently scheduled for delivery in 1997. Work on the safety documentation for conversion is in progress at two MTR-type and four TRIGA-type university reactors.

Suitable LEU fuels are not currently available for research reactors at the Massachusetts Institute of Technology and at the University of Missouri at Columbia. The MITR-II reactor at MIT is a 5 MW tank-type reactor which has a compact core that is cooled and moderated with light water and reflected with heavy water and graphite. Fuel elements have a rhomboid shape and contain 510 g U-235 in 15 plates which have a fuel meat thickness of 0.76 mm and a HEU (93%) density of about 1.6 g/cm^3. The aluminum cladding has a thickness of 0.38 mm with 0.25 mm high fins that increase heat transfer surface area of the fuel plate. With no changes in the fuel element geometry, the uranium density required for LEU conversion is estimated to be about 9 g/cm^3 and possibly larger if the neutron spectrum in the HEU core is relatively hard in comparison with conventional MTR reactors.

The MURR at the University of Missouri at Columbia is a 10 MW reactor contained in a pressurized water vessel immersed in an open pool of light water. The compact core is composed of 8 fuel assemblies with an active volume of 33 liters. The core is cooled and moderated with light water and reflected with beryllium and graphite. The pie-shaped fuel assemblies each contain 775 g U-235 in 24 plates containing UAl_x-Al fuel meat having a thickness of 0.51 mm and a uranium density of about 1.6 g/cm^3. The cladding thickness is 0.38 mm. If no changes are made in the geometry of the fuel assembly, the uranium density required for LEU conversion is estimated to be about 9 g/cm^3 and possibly larger if the neutron spectrum in the HEU core is relatively hard in comparison with conventional MTR reactors.

Commercial Research Reactors

There are no commercial research reactors with power ≥ 1 MW using HEU fuel in the U.S. The last research reactor of this type was General Atomics' TRIGA Mark F reactor that used 70% enriched uranium fuel and had a power level of 1.5 MW before it was shutdown in 1995. There is one 100 kW commercial training reactor operated by the General Electric Company that has a lifetime core and uses HEU fuel. There are no plans to convert this lifetime core.

Department of Commerce Research Reactor

The NBSR is the only non-DOE government research reactor with a power level ≥ 1 MW that uses HEU fuel. The reactor is operated by the National Institute of Standards and Technology (NIST) for the Department of Commerce and is licensed by the NRC. NIST has applied to the NRC for a "unique purpose" exemption from LEU conversion under the provisions stated in Ref. 7, but the NRC has never ruled on this application.

The NBSR is a heavy-water cooled and moderated reactor using MTR-type fuel elements with a lattice pitch of 17.8 cm (7 in.). The fuel elements have upper and lower sections, each 27.9 cm high, separated by a gap 17.8 cm high to minimize the fast neutron background in the beam tubes. The HEU U_3O_8-Al fuel meat has a uranium density of about 1.1 g/cm^3. Since the neutron spectrum in the core is well-thermalized, the uranium density required for LEU conversion is estimated to be about 6 g/cm^3.

Department of Defense Research Reactors

There are no Department of Defense research reactors in the U.S. that have a steady-state power ≥ 1 MW and use HEU fuel. The Stationary Neutron Radiography System (SNRS), located at the McClellan Air Force Base in California, uses a TRIGA reactor that has a power level of 1.3 MW and uses LEU fuel. The DOD also regulates two bare, fast, prompt burst facilities that use HEU fuel and have lifetime cores. There are no plans to convert these reactors.

DOE Research Reactors

Table 2 shows the conversion status of the five operating DOE research reactors with power ≥ 1 MW that use HEU fuel. It is feasible to convert two of these reactors using the LEU fuels that are currently available. The NBSR reactor in Table 2 belongs to the Department of Commerce and was addressed above. Fuels data and the estimated LEU density required for conversion are shown in Table 3. As previously stated, detailed studies need to be completed for each reactor to establish the feasibility of LEU conversion.

The Advanced Test Reactor (ATR) at the Idaho National Engineering Laboratory is a clover-leaf, multi-flux-trap, light water reactor with a maximum power level of 250 MW. Each of its 40 fuel assemblies has 19 plates containing HEU (93%) aluminide fuel with a uranium density of ~1.7 g/cm^3. An estimated uranium density of about 9 g/cm^3 in the fuel meat would be required for LEU conversion if no changes are made in the fuel element geometry.

The High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory is a light water moderated and cooled, beryllium reflected, annular design with a central flux trap and a maximum power of 100 MW. The reactor core consists of two concentric annuli containing involute shaped fuel plates. The fuel meat consists of a air-foil shaped part made of U_3O_8-Al with a HEU (93%) density of about 1.1 g U/cm^3. A complimentary part of each plate in the inner annulus consists of B_4C in Al as a burnable poison in order to achieve a uniform power distribution. In the outer annulus, the complimentary part consists of pure aluminum. The uranium density required for LEU conversion is estimated to be 7-9 g/cm^3, depending on the hardness of the neutron spectrum in the HEU core, and provided that the LEU fuel plates can safely withstand the rather severe operating conditions of this reactor and be manufactured with the required fuel distribution.

The High Flux Beam Reactor (HFBR) at the Brookhaven National Laboratory (BNL) is cooled, moderated, and reflected with heavy water and is currently operated at a power level of about 40 MW. The MTR-type fuel elements have a square lattice pitch of approximately 7.7 cm (~3 in.), as in conventional light water MTR cores. The HEU (93%) fuel elements contain 351 g U-235 in U_3O_8-Al fuel meat which has a uranium density of about 1.1 g/cm^3. The core configuration of this reactor is particularly important because the tight lattice (for a heavy water reactor) and the high U-235 loading lead to a neutron spectrum that is harder than in most other thermal research reactors. HEU cores with hard neutron spectra require a significantly larger increase in U-235 content with LEU fuel to maintain the same fuel cycle length than do cores with well-thermalized neutron spectra.

Core conversion studies being performed by the RERTR Program indicate that it may not be possible to convert the HFBR to LEU fuel with the current core configuration. Calculations done with LEU loadings of 450 and 650 g U-235 per fuel element produce cycle lengths in the range of 5-6 days, compared with a 22 day cycle length for the HEU core. Increasing the U-235 content with LEU fuel simply hardens the neutron spectrum without providing much additional excess reactivity that can be used for burnup. Alternative core configurations which allow for better neutron thermalization are currently being investigated.

The Brookhaven Medical Research Reactor (BMRR), also located at BNL, is a tank-type reactor that uses two types of MTR fuel elements with HEU. These elements have a uranium densities of about 0.4 g/cm^3 and 0.57 g/cm^3 in the fuel meat. Based on past conversion studies and on LEU conversions of reactors of this type, the LEU density needed to match the cycle length of the reactor if all HEU fuel elements had the higher uranium loading is about 3.0 g/cm^3. Utilization of U.S. university standard LEU silicide plates with a uranium density of 3.5 g/cm^3 would reduce the number of elements that would need to be manufactured and disposed of.

The reactor is used mainly for boron neutron capture therapy (BNCT). Changes in the neutron spectrum at the medical irradiation locations need to be examined carefully because a number of animal studies have been performed using the spectrum generated by the HEU core.

The Annular Core Research Reactor (ACRR) at the Sandia National Laboratory has been selected[8] by DOE to produce medical radioisotopes, principally Mo-99, in the U.S. Historically, the reactor had been operated in a pulsed mode or at steady-state power levels up to 2 MW for limited periods of time to fulfill defense mission requirements. To be able to meet 100% of the U.S. demand for Mo-99, the reactor is being modified for steady-state operation at a power level of 4 MW. The modifications include installation of heat exchangers and cooling towers, removal of a stainless steel tube from the center of the core, and various other hardware upgrades.

ACRR fuel consists of stainless steel clad cylindrical fuel elements with two concentric annuli of fuel pellets which are 78.5 wt% BeO and 21.5 wt% UO_2. The uranium enrichment is 35%. The reactor had used TRIGA UZrH fuel prior to changing over to the unique BeO-UO_2 fuel in 1978. Current plans are to utilize TRIGA LEU fuel or a variant of this LEU fuel in the ACRR when the BeO-UO_2 needs to be replaced.

Lifetime Cores: The ATRC at INEL is a 5 kW HEU-fueled critical facility that is used conjunction with the ATR. The NRAD reactor at Argonne-West in Idaho is a 250 kW reactor that uses 70% enriched TRIGA fuel and is used mainly for neutron radiography. There are no plans to convert either of these lifetime cores.

CONCLUSION

A program for conversion of university research reactors in the United States has been underway since 1986. Seventeen of 19 university reactors that use or formerly used HEU fuel have converted to the use LEU fuel or are involved in some stage of the conversion process. Suitable LEU fuel is not currently available for two university reactors.

Of the six U.S. government reactors that use HEU fuel and have power levels $\geq$ 1 MW, conversion of one reactor appears to be feasible and one is planning to convert to LEU fuel that is currently qualified and has been approved for licensing. Suitable LEU fuels are not currently available for three of these reactors. Initial results of an LEU conversion feasibility study by the RERTR Program indicates that it may not be possible to convert the High Flux Beam Reactor at Brookhaven National Laboratory to LEU fuel with its current core configuration. Alternative core configurations which allow for better neutron thermalization in this tight-lattice heavy water reactor are currently being investigated.

Detailed LEU conversion feasibility studies are in progress or planned for all U.S. thermal research reactors with power ≥ 1 MW that currently utilize HEU fuels.

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TABLE 1

U.S. UNIVERSITY REACTORS USING OR FORMERLY USING HEU FUEL
LEU CONVERSION STATUS AS OF SEPTEMBER 1996

	Reactor Power	LEU Fuel Type	Conversion Date
CONVERTED TO LEU FUEL			
1. University of Michigan Ford Nuclear Reactor	2 MW	UAl_x-Al	1984
2. Rensselaer Polytechnic Institute	100 W	UO_2 Pins	9/87
3. Ohio State University	10 kW	U_3Si_2-Al	12/88
4. Worcester Polytechnic Institute	10 kW	UAl_x-Al	12/88
5. Iowa State University	10 kW	U_3Si_2-Al	8/91
6. Manhattan College	0.1 W	U_3Si_2-Al	3/92
7. University of Missouri at Rolla	200 kW	U_3Si_2-Al	7/92
8. Rhode Island Nuclear Science Center	2 MW	U_3Si_2-Al	8/93
9. University of Virginia	2 MW	U_3Si_2-Al	4/94
SAFETY DOCUMENTATION HAS BEEN APPROVED BY USNRC			
10. Georgia Institute of Technology	5 MW	U_3Si_2-Al	1997 (a)
11. University of Massachusetts at Lowell	1 MW	U_3Si_2-Al	1997 (b)
WORK ON SAFETY DOCUMENTATION IN PROGRESS			
12. Purdue University	1 kW	UAl_x-Al	
13. University of Florida	100 kW	U_3Si_2-Al	
14. University of Wisconsin TRIGA	1 MW	UZrH Rods	
15. Oregon State University TRIGA	1 MW	UZrH Rods	
16. Texas A & M University TRIGA	1 MW	UZrH Rods	
17. Washington State Univ. TRIGA	1 MW	UZrH Rods	
SUITABLE LEU FUEL NOT CURRENTLY AVAILABLE			
18. Massachusetts Institute of Technology	5 MW		
19. University of Missouri at Columbia	10 MW		(c)

(a) LEU fuel elements have been manufactured and are scheduled to be delivered in early 1997.
(b) LEU fuel plates have been manufactured. Assembly into fuel elements and delivery is scheduled during 1997.
(c) The University of Missouri at Columbia has applied to the NRC for "Unique Purpose" exemption from LEU conversion, but the NRC has never ruled on this application.

TABLE 2

U.S. GOVERNMENT REACTORS WITH POWER ≥ 1 MW USING HEU FUEL

LEU CONVERSION STATUS AS OF SEPTEMBER 1996

	Reactor	Power	Operator	Conversion Status
DOE Reactors				
1.	ATR	250 MW	Idaho National Engineering Lab	Suitable LEU fuel not available.
2.	HFIR	100 MW	Oak Ridge National Laboratory	Suitable LEU fuel not available.
3.	HFBR	60 MW	Brookhaven National Laboratory	Conversion may not be feasible.
4.	BMRR	3 MW	Brookhaven National Laboratory	Conversion appears feasible.
5.	ACRR	4 MW	Sandia National Laboratory	Conversion planned.
Department of Commerce Reactor				
6.	NBSR	20 MW	National Inst. of Stds. & Tech (a)	Suitable LEU fuel not available.

(a) The NBSR reactor is operated by the National Institute of Standards and Technology for the Department of Commerce and is licensed by the NRC. NIST has applied to the NRC for "Unique Purpose" exemption from LEU conversion, but the NRC has never ruled on this application.

TABLE 3

FUELS DATA FOR U.S. REACTORS WITH POWER ≥ 1 MW THAT ARE NOT CURRENTLY IN THE LEU CONVERSION PROCESS

Reactor	Fuel Element Type	Coolant/ Moder-ator	Fuel Meat	Uranium Enrich-ment,%	HEU Dens. g/cm^3	Fuel Meat/Clad Thick., mm	Estimated LEU Density g/cm^3
DOE Reactors							
ATR	MTR Sectors	H_2O	UAl_x -Al	93	1.7	0.51/0.38	~ 9
HFIR	Involute Plate	H_2O	U_3O_8-Al	93	1.1	0.76/0.25	7-9
HFBR	MTR	D_2O	U_3O_8-Al	93	1.1	0.58/0.35	(a)
BMRR	MTR	H_2O	UAl_x -Al	90	0.57	0.51/0.38	~ 3
ACRR	Single Rods	H_2O	UO_2-BeO	35	10.1	33.5 OD/0.5	(b)
Department of Commerce Reactor							
NBSR	MTR	D_2O	U_3O_8-Al	93	1.1	0.51/0.38	~ 6
University Reactors							
MURR	MTR Sectors	H_2O	UAl_x-Al	93	1.6	0.51/0.38	~ 9
MITR-II	MTR	H_2O	UAl_x -Al	93	1.6	0.76/0.25	~ 9

(a) Initial studies indicate that it may not be possible to convert the HFBR to LEU fuel with its current core configuration. Alternative core configurations with better neutron thermalization are being investigated.

(b) The ACRR uses stainless steel clad cylindrical fuel elements with two concentric annuli of fuel pellets which are 78.5 wt% BeO and 21.5 wt% UO_2. A variant of TRIGA LEU fuel is planned to be used in this reactor.