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CONVERSION AND STANDARDIZATION OF UNIVERSITY REACTOR FUELS USING LOW-ENRICHMENT URANIUM—OPTIONS AND COSTS*

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ABSTRACT

The highly-enriched uranium (HEU) fuel used in twenty United States university reactors can be viewed as contributing to the risk of theft or diversion of weapons-useable material. The U.S. Nuclear Regulatory Commission has issued a policy statement expressing its concern and has published a proposed rule on limiting the use of HEU in NRC-licensed non-power reactors. The fuel options, functional impacts, licensing, and scheduling of conversion and standardization of these reactor fuels to use of low-enrichment uranium (LEU) have been assessed. The university reactors span a wide range in form and function, from medium-power intense neutron sources where HEU fuel may be required, to low-power training and research facilities where HEU fuel is unnecessary. Conversion provides an opportunity to standardize university reactor fuels and improve reactor utilization in some cases. The entire program is estimated to cost about $10 million and to last about five years. Planning for conversion and standardization is facilitated by the U.S. Department of Energy.

INTRODUCTION

The HEU fuel used in twenty U.S. university reactors can be viewed as contributing to the risk of theft or diversion of weapons-useable material. The U.S. Nuclear Regulatory Commission has issued a policy statement[1] (August 1982) expressing its concern and has published a proposed rule[2] (July 1984) on limiting the use of HEU in NRC-licensed non-power reactors. Remarks on U.S. policy[3] concerning LEU core conversions and a paper on licensing considerations[4] in converting NRC-licensed non-power reactors to LEU fuel are contained in these proceedings.

As part of the extensive national debate[5] on the proposed rule, two studies[6,7] were performed to assess the implications of conversion of the U.S. university reactors to LEU fuel. These reactors span a wide range in form and function, from medium-power intense neutron sources where HEU fuel may be required to low-power training and research facilities where HEU fuel is unnecessary. Conversion provides an opportunity to standardize university reactor fuels and improve reactor utilization in some cases. This paper provides a summary of the current status of LEU fuel options, functional impacts, licensing considerations, and schedule considerations for possible conversions. Planning for conversion and standardization is facilitated by the U.S. Department of Energy.

LEU FUEL OPTIONS

The current status of the RERTR Program is discussed in Ref. 8. Extensive studies[9-13] of the performance, safety, and economic aspects of core conversions have been performed by a number of international organizations for a variety of research reactor designs. A whole-core demonstration[14] in the 2 MW Ford Nuclear Reactor (FNR) at the University of Michigan using LEU UAl_x fuel with about 1.7 g U/cm^3 began in December 1981 and was completed around December 1984. A second whole-core demonstration[15,16] in the 30 MW Oak Ridge Research Reactor (ORR) using LEU U_3Si_2 fuel with about 4.8 g U/cm^3 is scheduled to begin in November 1985 and to be completed in the Spring of 1987.

The whole-core demonstration in the ORR is intended to provide a statistical basis for licensing LEU U_3Si_2 fuel with up to 4.8 g U/cm^3 in research reactors utilizing plate-type fuel. The fuel elements for this demonstration are being manufactured by Babcock & Wilcox, NUKEM, and CERCA.

TRIGA LEU fuel with 20 wt% U has been developed and tested[17] by GA Technologies as a standard replacement for its HEU (70%) FLIP-type fuel. This LEU fuel is fully-qualified, with burnup/

pulsing capabilities and limitations similar to those of FLIP fuel, for routine use in reactors using HEU FLIP fuel without any changes in the current fuel element geometry.

With this background, the twenty U.S. university reactors using HEU fuel can be divided into three groups: (1) fourteen plate-type reactors requiring fuels with medium uranium density (<4.8 g/cm^3), (2) four TRIGA reactors that could use TRIGA LEU fuel with 20 wt% U, and (3) two plate-type reactors that would require fuels with very high uranium density (>7 g/cm^3) without changes in the fuel element geometry. The characteristics of plate-type reactor fuels are shown in Table 1.

Plate-Type Reactors Requiring Medium Uranium Density

Several options have been developed[7] for the fourteen plate-type reactors using HEU fuel because their designs are more varied and there is little standardization. In the 1950's and 1960's the procurement procedures for university reactors resulted in a variety of designs for the same basic type of reactor. Many of the differences in the designs of the fuel elements do not affect the safety, operation, or performance of the reactors, but they do increase the cost of procuring fuel. For this reason, it is desirable to standardize the designs of the fuel plates and, to the extent possible, the design of entire fuel elements.

Options based on minimum changes in the current fuel element designs and on two standard fuel plate designs are discussed below. All of the LEU designs would contain U_3Si_2 fuel with a uranium density less than about 3.8 g/cm^3.

Option 1: Minimum changes in the current fuel element geometry. Reactor operators have expressed a strong preference for this option because they believe it would minimize the effort required to obtain the necessary licensing approvals. However, this option is likely to be the most expensive from a fuel procurement point of view since ten reactors would retain unique fuel plate designs. Also, it is not necessarily the least expensive from a licensing point of view because it may limit the possibilities for adopting generic envelopes of safety limits for use in licensing reviews. The highest uranium density that would be required is about 3.85 g/cm^3 for the reactor at Manhattan College, which has a unique fuel element design consisting of six concentric tubes.

Option 2: Two standard LEU fuel plates (Michigan and Virginia). Michigan plates have 0.76 mm-thick fuel meat, ~1.77 g U/cm^3, and 9.3 g ^{235}U per plate. The proposed Virginia plates have 0.51 mm-thick meat, ~3.75 g U/cm^3, and 12.5 g ^{235}U per plate. The latter plates are very similar to those used in the ORR and the fuel plate specifications can probably be adjusted to conform with those for the ORR. All plates would have a nominal cladding thickness of 0.38 mm.

Detailed data for this option are shown in Table 1. Six reactors requiring about 2650 fuel plates would utilize the Virginia plate and six reactors requiring about 3350 fuel plates would utilize the Michigan plate. Retention of the unique design at Manhattan College would require special tooling. RPI is a special case to be discussed below.

This option would preserve the present fuel element geometries in the higher power reactors with more stringent thermal-hydraulic requirements and provide for large fuel plate production runs that would reduce fuel procurement costs. We estimate that the overall safety of each facility would be about the same or greater than that with the present HEU design, but more detailed evaluations would need to be made.

Option 3: One standard LEU fuel plate (Michigan) with two fissile loadings. This option is similar to Option 2, except that the Virginia plate is replaced with a Michigan plate containing 12.5 g ^{235}U per plate and ~2.4 g U/cm^3. With the Michigan plate geometry alone, two fissile loadings would be required to accommodate the needs of the various reactors.

Fuel procurement costs with this option are estimated to be about the same as with Option 2. However, licensing costs would be larger because the 2 MW reactor at the University of Virginia and the 5 MW heavy-water-moderated reactor at the Georgia Institute of Technology would need to change their fuel element geometry and more detailed thermalhydraulic analyses would need to be performed.

A fourth option with considerable merit is to utilize the stainless steel clad SPERT F pins containing 4.8% enriched UO_2 pellets and similar fuel pins that are being stored at several universities to assemble power-reactor-type fuel elements for use by those reactor operators who consider this option an opportunity to enhance the utilization of their facilities. A significant fuel procurement cost advantage would be realized because the fuel pins have already been manufactured. A disadvantage is that the fuel element design and the licensing costs would be larger. However, we estimate that the overall costs would be significantly less than for a direct conversion to one of the LEU standard-plate options.

The critical facility at the Rensselaer Polytechnic Institute is already committed[18] to this option because it would greatly improve the utilization of the facility. The University of Florida[19,20] and other reactor operators are also considering this possibility.

Table I. A Possible LEU Standardization Option[+] for University Plate-Type Reactors

Reactor		Power, MW	No. Els. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mm	Clad Thick., mm	Fuel Meat (Min.-Max.) Thick., mm	Width mm	Length mm
					Standard Plate: UVAR (Virginia)								
1. GTRR:	HEU	5	17	Alloy	0.66	16[a]	188	11.75	1.27	0.38	0.51	63.5	584-610
	LEU	5	17	U_3Si_2	3.74	16[a]	200	12.5	1.27	0.38	0.51	51.8-61.0	572-610
2. UVAR:	HEU	2	~20	UAl_x	0.69	18	195	10.83	1.27	0.38	0.51	51.8-61.0	572-610
	LEU	2	~20	U_3Si_2	3.74	18	225	12.5	1.27	0.38	0.51	51.8-61.0[b]	572-610
3. UV CAV.:	HEU	10^{-4}	~16	UAl_x	0.68	18	195	10.83	1.27	0.38	0.51	51.8-61.0	572-610
	LEU	10^{-4}	~16	U_3Si_2	3.74	18	225	12.5	1.27	0.38	0.51	51.8-61.0	572-610
4. U. Fla.:	HEU	0.1	21	Alloy	0.43	11	160	14.5	1.78	0.38	1.02	58.4	606
	LEU	0.1	21	U_3Si_2	3.74	14	175	12.5	1.27	0.38	0.51	51.8-61.0	572-610
5. U. Wash.:	HEU	0.1	24	Alloy	0.41	11	146	13.3	1.78	0.38	1.02	57.2	603
	LEU	0.1	24	U_3Si_2	3.74	14	175	12.5	1.27	0.38	0.51	51.8-61.0	572-610
6. Ia. St.:	HEU	10^{-2}	12	Alloy	0.61	12	264	22.0	2.03	0.51	1.02	69.9	584
	LEU	10^{-2}	12	U_3Si_2	3.74	24	300	12.5	1.27	0.38	0.51	51.8-61.0	572-610
					Standard Plate: FNR (Michigan)								
7. RINSC:	HEU	2	30	UAl_x	0.72	18	124	6.9	1.52	0.61	0.30	52.1-61.0	559-597
	LEU	2	30	U_3Si_2	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610
8. ULR:	HEU	1	26	UAl_x	0.72	18	135	6.9	1.52	0.61	0.30	52.1-61.0	559-597
	LEU	1	26	U_3Si_2	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610
9. UM-Rolla:	HEU	0.2	19	U_3O_8	0.94	10	170	17.0	1.52	0.51	0.51	63.0	597
	LEU	0.2	~24	U_3Si_2	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610
10. Purdue:	HEU	10^{-3}	16	Alloy	0.92	8-10	132-165	16.5	1.52	0.51	0.51	62.7	600
	LEU	10^{-3}	16	U_3Si_2	1.77	15-18	140-167	9.3	1.52	0.38	0.76	54.4-63.5	572-610

[a] Element has 16 Fueled and 2 Non-Fueled Plates.
[b] If this dimension could be changed to 54.4 - 63.5, UVAR would have the same fuel meat dimensions as FNR, but with 0.51 mm thick meat instead of 0.76 mm thick meat.
[+] Based on two standard plates (Virginia and Michigan).

Table I. A Possible LEU Standardization Option+ for University Plate-Type Reactors (Cont'd.)

Reactor		Power, MW	No. Els. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mm	Clad Thick., mm	Fuel Meat (Min.-Max.) Thick., mm	Fuel Meat (Min.-Max.) Width mm	Fuel Meat (Min.-Max.) Length mm
Standard Plate: FNR (Michigan)													
11. WPI:	HEU	10^{-2}	24	Alloy	0.38	10	136	13.6	2.51	0.76	0.99	~63.5	610
	LEU	10^{-2}	24	U_3Si_2	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610
12. OSU:	HEU	10^{-2}	24	Alloy	0.44	10	140	14.0	2.74	0.91	0.91	61.9	616
	LEU	10^{-2}	24	U_3Si_2	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610
Special Cases													
13. M.C.:	HEU	10^{-7}	16	Alloy	0.71	18^c	200	Var.	1.27	0.38	0.51	Var.	610
	LEU	10^{-7}	16	U_3Si_2	3.84	18^c	230	Var.	1.27	0.38	0.51	Var.	610
14. RPI:	HEU	$<10^{-4}$	21	UO_2-SS	1.82	4-11	Var.	28.6	0.76	0.13(SS)	0.51	64.5	593
	LEU SPERT Pins, 4.8% Enrichment, SS cladding.												
15. MURR:	HEU	10	8	UAl_x	~1.6	24	780	Var.	1.27	0.38	0.51	Var.	610
	LEU Options Require Feasibility Study.												
16. MIT	HEU	5	~24	UAl_x	~1.6	15	510	34.0	1.52	0.38	0.76	52.8	568
	LEU Options Require Feasibility Study.												
FNR	LEU	2	~30	UAl_x	1.77	18	167	9.3	1.52	0.38	0.76	54.4-63.5	572-610

+Based on two standard plates (Virginia and Michigan).
cCylindrical elements with 6 concentric rings (3 plates each) per element.

TRIGA Reactors

As mentioned previously, TRIGA LEU fuel with 20 wt% U is currently available as a standard replacement for the HEU (70%) FLIP-type fuel currently used in four university reactors. No changes in the fuel element geometry are required. Safety margins with the 20 wt% U TRIGA LEU fuel are likely to increase because this LEU fuel has a fissile content of about 98 g per fuel rod while the HEU FLIP fuel has a fissile content of about 135 g per rod.

An option worth considering is to replace the HEU FLIP fuel in some of these reactors with TRIGA LEU fuel containing 30 wt% U because this fuel would contain approximately 160 g ^{235}U per rod. The development, testing, and post-irradiation-examination of 30 wt% U TRIGA LEU fuel is discussed in Ref. 17.

Plate-Type Reactors Requiring Very High Uranium Density

The reactors at the University of Missouri-Columbia and the Massachusetts Institute of Technology are special cases because they currently utilize HEU UAl_x fuel with a uranium density of about 1.6 g/cm^3 and employ advanced thermalhydraulic designs. Extensive studies are required to determine the feasibility and characteristics of potential enrichment reduction and upgrade options.

FUNCTIONAL IMPACTS

The functional impacts of conversion and standardization can be categorized as direct costs and benefits and societal costs and benefits. The former can be quantified to a considerable extent,[6,7] while the latter are certainly significant but are more difficult to quantify. Among the societal benefits of HEU to LEU conversion is relief from the risk of theft or diversion of weapons-useable material. A direct benefit would be relief from some of the security costs incurred to minimize this risk.

Here we concentrate on direct costs and benefits. It is convenient to treat the direct costs as (a) fuel costs exclusive of fabrication, (b) fuel fabrication costs, (c) fuel shipment costs, (d) costs of reactor engineering analyses and modifications, (e) costs of safety analyses and possible litigation associated with license modifications, (f) costs of startup tests, and (g) costs of lost revenue or function associated with conversion.

Careful consideration of the possibilities of standardization and improvement is particularly important for some university reactors. Standardization of reactor fuel and fuel elements can yield substantial savings in most cost components. Facility improvement in function can result from conversion in some cases as, for example, by use of SPERT fuel in the RPI reactor.

The fuel in U.S. university reactors has been and presumably will continue to be owned by the USDOE which bears the costs of ore, conversion, enrichment, and disposal. LEU fuel requires more uranium than does HEU fuel but the feed-to-product ratio and the separative work requirements are less, so that fuel costs exclusive of fabrication are found to be similar for HEU and LEU.[12] Costs of LEU fuel fabrication are reasonably well defined and are estimated to average about $8,000 per plate-type fuel element and about $7,000 per TRIGA fuel rod.[6,7] Additional fuel procurement costs contribute about a further 10 percent.[7] Costs of fuel shipments are projected to average about $600 per plate-type fuel element or TRIGA fuel rod.

The fabrication cost of the replacement LEU fuel for lifetime cores has been variously estimated[6,7] and is about $2,500,000 for ten plate-type cores and about $3,000,000 for four TRIGA cores. For those university reactors which burn fuel, there may be little incremental cost associated with HEU to LEU conversion if the reactors are permitted to use their HEU fuel inventories to their planned burnup.

The cost of reactor engineering analyses and modifications, the costs of safety analyses for license modifications, and the costs of startup tests with LEU have also been estimated.[6,7]

The provision of adequate federal funds to cover these costs is essential to maintain strong and viable U.S. university reactor programs.

SAFETY ISSUES AND LICENSING

Safety issues have been examined elsewhere.[6,11] The conclusion from a number of analyses is that the physics differences between HEU and LEU cores will result in little change in the consequences of hypothetical reactivity insertion or LOCA transients. Thermalhydraulic safety margins and shutdown margins are also expected to be similar.

The preparation of adequate analyses and documentation can be costly both in time and effort but can be facilitated by standardization and by generic licensing provisions. A significant additional issue is the possibility of costly litigation related to license modifications. This issue could have a decisive effect on university reactor programs.

SCHEDULES

Practical schedules for conversion and standardization of the fuels used in U.S. university reactors would depend on several factors which include availability of federal funding, availability of licensable fuels, availability of shipping and transfer casks, completion of the safety analyses required for licensing reviews, and integration with reactor utilization schedules.

Formulation and actual implementation of these schedules will depend on the actions and requirements of the NRC. Of particular importance is the extent to which reactors with regular refueling cycles will be allowed to utilize their existing HEU fuel inventories. Considerable interactions between the reactor operators, the DOE, the NRC, and the RERTR Program would be desirable to formulate workable schedules.

CONCLUSION

The LEU fuel options and the cost, licensing, and schedule considerations have been assessed for possible conversion to LEU of the fuels used in twenty U.S. university reactors. Conversion provides an opportunity to standardize university reactors fuels and improve reactor utilization in some cases. The entire program is estimated to cost about $10 million (in 1985 dollars) and to last about five years.

Several considerations are especially important in order to maintain strong and viable U.S. university reactor programs. These are: (1) adequate federal funding must be provided to cover conversion-related costs, (2) the time and effort required to prepare adequate analyses and documentation would be reduced by standardization and generic licensing provisions, and (3) litigation related to license modifications could be very costly and have a decisive effect.

Considerable interaction between the reactor operators, the DOE, the NRC, and the RERTR Program would be desirable to facilitate effective planning. If adequate federal funding is provided, conversion and standardization appears to be both feasible and desirable.

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