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# CONVERSION AND STANDARDIZATION OF UNIVERSITY REACTOR FUELS USING LOW-ENRICHMENT URANIUM - PLANS AND SCHEDULES


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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. To minimize this risk, the U.S. Nuclear Regulatory Commission issued its final rule on "Limiting the Use of Highly Enriched Uranium in Domestically Licensed Research and Test Reactors," in February 1986. This paper describes the plans and schedules developed by the U.S. Department of Energy to coordinate an orderly transition from HEU to LEU fuel in most of these reactors. An important element in the planning process has been the desire to standardize the LEU fuels used in U.S. university reactors and to enhance the performance and utilization of a number of these reactors. The program is estimated to cost about $10 million and to last about five years.

## INTRODUCTION

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. To minimize this risk, the U.S. Nuclear Regulatory Commission (NRC) issued its final rule[1] on "Limiting the Use of Highly Enriched Uranium in Domestically Licensed Research and Test Reactors" in February 1986. Implementation of this rule is contingent upon provision of adequate funding by the U.S. Government and the availability of fuels acceptable to the Commission. The rule also contains a provision for "unique purpose" under which a licensee can apply to the NRC for exemption from the rule if a project, program, or commercial activity cannot be reasonably accomplished without the use of HEU (>20) fuel. The Commission itself will make the final decision on any conversion requirement based upon a finding of unique purpose.

The Department of Energy is responsible for planning and coordination of the university reactor conversion program through its Division of University and Industry Programs and in conjunction with its on-going university reactor fuel assistance program. An important element in the planning process has been the desire to standardize the LEU fuels used in most of these reactors in order to minimize fuel fabrication and licensing costs for conversions and to minimize refueling costs in the coming years. Conversion also presents an opportunity to enhance the performance and utilization of a number of these reactors.

## UNIVERSITY REACTOR FACILITIES USING HEU FUEL

The twenty U.S. universities which currently operate test, research, and training reactors using HEU fuel are listed below.

### Plate-Type Fuel

1. University of Missouri at Columbia (10 MW)
2. Massachusetts Institute of Technology (5 MW)
3. Georgia Institute of Technology (5 MW)
4. Rhode Island Nuclear Science Center (2 MW)
5. University of Virginia (2 MW)
6. University of Lowell (1 MW)
7. University of Missouri at Rolla (200 kW)
8. University of Florida (100 kW)
9. University of Washington (100 kW)
10. Ohio State University (10 kW)
11. Worcester Polytechnic Institute (10 kW)
12. Iowa State University (10 kW)
13. Purdue University (1 kW)
14. Rensselaer Polytechnic Institute (100 W)
15. University of Virginia-Cavalier (100 W)
16. Manhattan College (0.1 W)

### TRIGA-Type Fuel

17. Texas A&M University (1 MW)
18. Washington State University (1 MW)
19. Oregon State University (1 MW)
20. University of Wisconsin (1MW)

The University of Missouri at Columbia and the Massachusetts Institute of Technology have applied to the NRC for an exemption under the "unique purpose" provision of the conversion rule. As stated above, the Commission itself will make the final decision on these exemption applications.

## ORGANIZATION AND RESPONSIBILITIES FOR UNIVERSITY REACTOR CONVERSION PROGRAM

The Department of Energy has organized the program into three phases:

- Phase I : Revision of Safety Documentation
- Phase II : NRC Review and Fuel Fabrication
- Phase III: NRC Executive Order and Fuel Transfer

The first phase involves the safety studies that must be performed on each reactor to ensure that the LEU fuel will perform within the appropriate margins of safety. The second phase consists of NRC review of the safety documentation and evaluation of the licensee's request for conversion. This phase will also include ordering of the fuel from the fabricator after NRC approval is assured. The issuance of an NRC executive order for conversion will initiate the third phase of the program which is exchange of the reactor fuel.

Responsibilities for the various tasks that are required to implement the program are outlined below.

<u>Department of Energy</u>

- Develop Implementation Guidelines
- Review University Proposals
- Coordinate Implementation Scheduling
- Administer Implementation Budget

<u>Universities</u>

- Develop Workplan
- Estimate Costs and Develop Budget
- Revise Safety Report, Technical Specifications, and Other Documents (with ANL Assistance, if Needed)
- Implement Conversion Plan
- Ship New and Spent Fuel (with EG&G Assistance)

<u>Nuclear Regulatory Commission</u>

- Develop Regulatory Guidelines
- Review and Approve Use of LEU Fuel
- Review and Approve Safety Documentati
- Issue Executive Order for Conversion

<u>Argonne National Laboratory</u>

- Provide Data and Documentation for Licensing of LEU Fuel
- Coordinate Safety Studies
- Provide Assistance as Needed on Safety Studies

<u>EG&G Idaho</u>

- Develop Fuel Specifications and Procurement Documentation
- Procure Fuel
- Provide for and Coordinate New and Spent Fuel Shipping

## FUEL STANDARDIZATION

Three types of standard plate and pin fuels are planned to be used for conversion of sixteen or seventeen of the twenty U.S. university reactors currently using HEU fuel. The type of fuel to be utilized depends on the type of reactor and choices by the reactor operator. The standard fuels are:

| Fuel Type | Fuel Geometry | Uranium Density, $g/cm^3$ | Enrichment |
|---|---|---|---|
| $U_3Si_2$-Al | Plates | 3.5 | <20% |
| $UZrH_x$ | TRIGA pins | 1.3-2.2 | <20% |
| $UO_2$ | SPERT pins | 8.9 | 4.8% |

### Plate-Type Fuel

For plate-type fuels, it is not possible, in practice, to standardize the entire fuel elements for the various reactors since they were designed by several reactor vendors in the 1950s and 1960s with little regard for standardization. The alternative is to standardize the fuel meat dimensions and all fuel plate materials. The dimensions of the rolled plates can be customized to meet the requirements of a number of fuel element designs. Cost savings can be substantial since manufacture of the fuel plates accounts for approximately 70% of fuel element fabrication costs.

At the 1985 International Meeting in Petten, the Netherlands, several LEU plate-type fuel options[2] were presented. During the past year, a decision was made to standardize the fuel in as many plate-type reactors as possible using a single plate with $U_3Si_2$ fuel and about 3.5 g $U/cm^3$ in order to minimize fuel fabrication and licensing costs for conversions and to minimize future refueling costs. A study[3] was also begun at the University of Michigan to determine the feasibility of changing the fuel in the FNR reactor from LEU $UAl_x$ fuel to the standard LEU $U_3Si_2$ fuel.

Specifications and inspection procedures for the standard LEU fuel plate are being developed by EG&G Idaho using their experience in procuring fuel for the Advanced Test Reactor (ATR) and the recommendations contained in a technical document[4] currently being prepared under the auspices of the IAEA.

Licensing approval for $U_3Si_2$ fuel with up to 4.8 g $U/cm^3$ is being approached on a generic basis utilizing all of the development and testing data[5-9] that has been accumulated to date and the whole-core demonstration[10] in the ORR as evidence that LEU $U_3Si_2$ fuel will behave in a safe and reliable manner under irradiation.

Flexibility in meeting the fissile loading needs of the various reactors is being retained by utilizing fuel elements containing different numbers of the standard fuel plate. A detailed listing of the current element designs with HEU fuel and the options being considered with LEU fuel is shown in the attachment.

## TRIGA-Type Fuel

TRIGA LEU fuel with 20-45 wt% U (1.3-3.7 g $U/cm^3$) is currently licensed for use in GA Technologies' Mark F reactor and is under additional licensing review by the NRC for general use with up to 30 wt% U (2.2 g $U/cm^3$) as a standard replacement for the HEU (70%) FLIP-type fuel used in four university reactors. One of the advantages of TRIGA fuel has always been the standardized designs employed by GA Technologies.

Final results from TRIGA LEU fuel post-irradiation examination and evaluation are provided in Ref. 11. A whole-core demonstration using fuel with 20 wt% U is planned by GA in its Mark F reactor beginning in 1987 as a general operational demonstration. Future LEU replacement fuel for the Mark F is planned to contain 30 wt% U.

## SPERT-Type Fuel

About 6000 of the 9000 stainless-steel-clad SPERT fuel pins containing 4.8% enriched $UO_2$ pellets that were manufactured in the 1960s (for about $28 each) are available for possible use in conversion of university research reactors. A requalification program using a statistical sampling from 600 of these pins for use in licensing reviews began at ANL in September 1986 and is expected to be completed by November 1986.

If NRC approval is obtained, most of these 600 pins will be used for conversion and upgrade of the critical facility[12] at the Rensselaer Polytechnic Institute (RPI) in early 1987. The current HEU core at RPI consists of fuel boxes containing stainless-steel-clad plates with $UO_2$-SS fuel meat. The University of Florida[13-14] and the University of Washington are also considering use of SPERT fuel pins for conversion and upgrade of their 100 kW Argonaut reactors.

## CONVERSION SCHEDULES

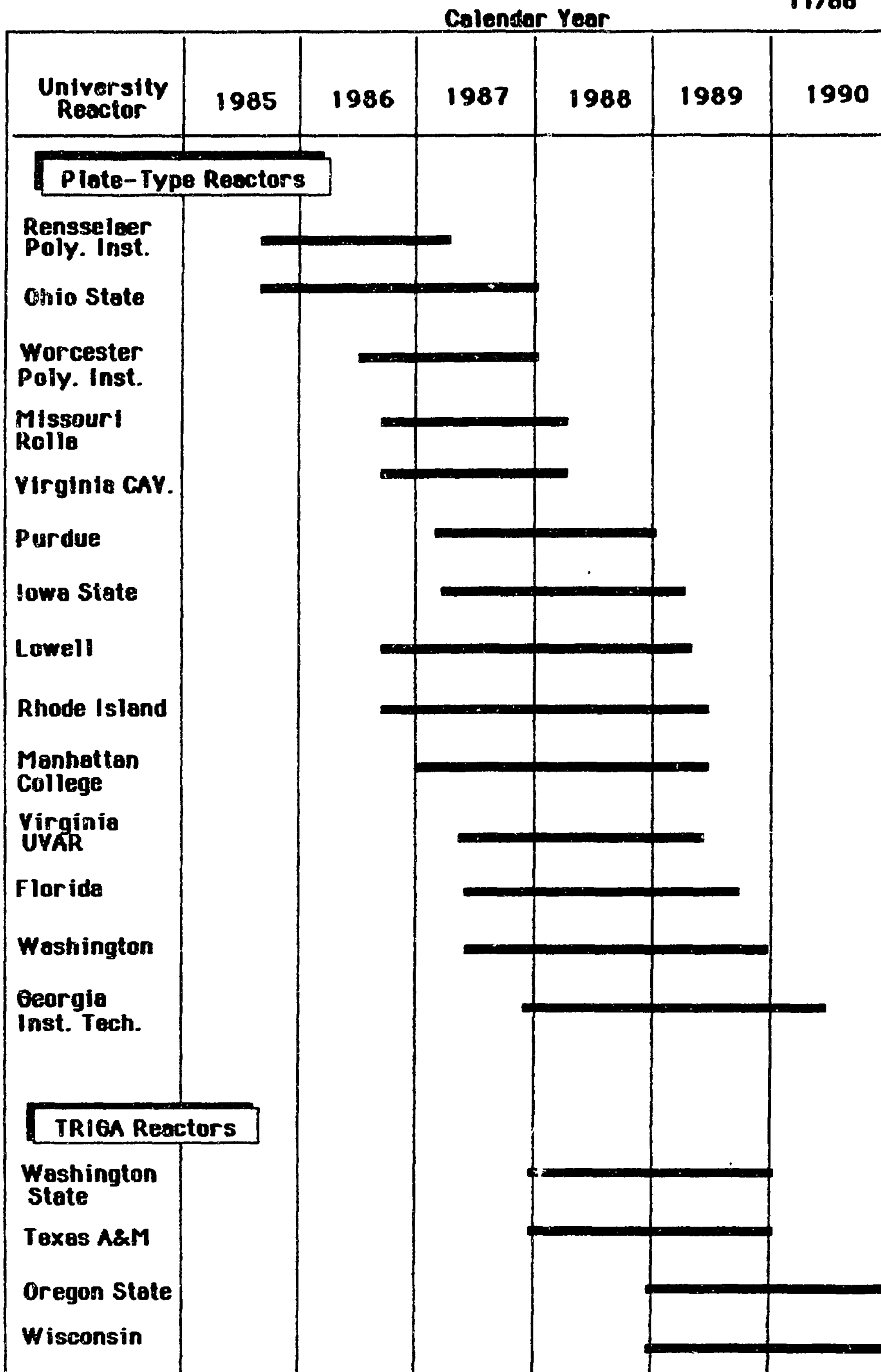
The 20 university reactors using HEU fuel can be divided into three groups:

- 14 plate-type reactors that could use $U_3Si_2$ fuel with <4.8 g $U/cm^3$. One, and possibly three, of these reactors plan to utilize SPERT pins.
- 4 TRIGA reactors that could use TRIGA LEU fuel with 20-30 wt% U, and
- 2 plate-type reactors that require fuel with >7 g $U/cm^3$ without changes in their fuel element geometries. As mentioned above, these two reators (Missouri-Columbia and MIT) have applied for exemption from the NRC conversion rule and will not be addressed further in this paper.

The current conversion schedule for 18 reactors is shown in Fig. 1.

Fig. 1 Conversion Schedule for U.S. University Reactors

11/86



Among the fourteen plate-type reactors, safety studies for three reactors (Rensselaer Polytechnic Institute[12], Ohio State[15-17], and Worcester Polytechnic Institute) are at an advanced stage, with conversions anticipated in 1987. RPI is committed to conversion using SPERT pins.

Safety studies for four other plate-type reactors (Missouri-Rolla, Virginia CAVALIER, Rhode Island, and Lowell) were initiated in 1986. These studies will take varying periods of time depending on the complexity of the facility. Two universities (Missouri-Rolla and Virginia[18]) would like to use the conversion process as thesis projects for some of their graduate students. Conversions of these reactors utilizing standard $U_3Si_2$ plates are anticipated in 1988 and 1989.

Safety studies for the remaining seven plate-type reactors are planned to be initiated during 1987, with conversions taking place in 1989 and 1990. The fuel elements for Manhattan College are unique among the university reactors since they consist of six concentric tubes. It is planned to retain this unique geometry. The University of Florida and the University of Washington plan to use either SPERT pins or standard $U_3Si_2$ plates for conversion.

The four TRIGA reactors (Texas A&M, Washington State, Oregon State, and Wisconsin) are 1 MW facilities using FLIP fuel with 70% enrichment. This fuel has a very long life and these reactors require infrequent refueling. Because of the relatively high cost for entire cores of fresh fuel, the safety studies for these reactors have been scheduled to begin around 1989 with conversions taking place in late-1990.

These schedules assume, of course, that adequate and sustained funding will be provided by the U.S. Government.

## CONCLUSION

The Department of Energy has developed a program with three phases leading to conversion to LEU (<20%) of most of the university reactors which currently utilize HEU (>20%) fuel. Conversion schedules for the various reactors have been staggered over a five year period extending through 1990 in order to maintain an orderly transition from HEU to LEU fuels.

In developing conversion priorities, considerations such as availability of appropriate licensed fuels and shipping containers, fuel procurement planning, safety studies and reviews, and safeguards and security concerns were taken into account to ensure an efficient and economical procedure.

Standardization of the fuels used in university research reactors played an important part in the planning process. Some university reactor operators view the conversion process as an opportunity to enhance the performance and utilization of their facilities.

The entire program is estimated to cost about $10 million (in 1985 dollars). Provision of adequate and sustained funding by the U.S. Government is necessary to meet the goals of this program.

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ATTACHMENT

LEU Fuel Options for U.S. University Plate-Type Reactors as of 11/86.

| University Reactor | | Power, MW | No. Els. In Core | Fuel Type | U Dens., g/cm | Fueled 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 | Plate Width mm | Element Cross Section mm | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard Plate-Type Fuel | | | | | | | | | | | | | | | | |
| 1. Virginia | HEU | 2 | 20 | $UAl_x$ | 0.69 | 18 | 195 | 10.83 | 1.27 | 0.38 | 0.51 | 52.1-61.0 | 572-610 | 70.5 (C) | 74.7 | 82.6 |
| UVAR | LEU | 2 | 20 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 70.5 | 74.7 | 82.6 |
| 2. Virginia | HEU | $10^{-4}$ | 16 | $UAl_x$ | 0.68 | 18 | 195 | 10.83 | 1.27 | 0.38 | 0.51 | 52.1-61.0 | 572-610 | 70.5 (C) | 74.7 | 82.6 |
| CAV | LEU | $10^{-4}$ | 16 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 70.5 | 74.7 | 82.6 |
| 3. Rhode | HEU | 2 | 30 | $UAl_x$ | 0.72 | 18 | 124 | 6.9 | 1.52 | 0.61 | 0.30 | 52.1-61.0 | 559-597 | 71.4 (F) | 77.3 | 77.3 |
| Island | LEU | 2-3 | 21 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 71.4 | 77.3 | 77.3 |
| 4. Lowell | HEU | 1 | 26 | $UAl_x$ | 0.78 | 18 | 135 | 6.9 | 1.52 | 0.61 | 0.30 | 52.1-61.0 | 559-597 | 71.4 (F) | 77.3 | 77.3 |
| | LEU | 1 | 21 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 71.4 | 77.3 | 77.3 |
| 5. Georgia | HEU | 5 | 17 | Alloy | 0.66 | 16[a] | 188 | 11.75 | 1.27 | 0.38 | 0.51 | 63.5 | 584-610 | 72.9 (C) | 75.2 | 70.4 |
| Inst. | LEU 1 | 5 | 17 | $U_3Si_2$ | 3.47 | 16[a] | 200 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 72.9 | 75.2 | 70.4 |
| Tech. | LEU 2 | 5 | 17 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 72.9 | 75.2 | 70.4 |
| 6. Ohio | HEU | $10^{-2}$ | 24 | Alloy | 0.44 | 10 | 140 | 14.0 | 2.74 | 0.91 | 0.91 | 61.9 | 610 | 73.1 (F) | 76.2 | 76.2 |
| State | LEU | $>10^{-2}$ | 24 | $U_3Si_2$ | 3.47 | 16[a] | 200 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 73.1 | 76.2 | 76.2 |
| 7. Missouri | HEU | 0.2 | 19 | $U_3O_8$ | 0.94 | 10 | 170 | 17.0 | 1.52 | 0.51 | 0.51 | 63.0 | 597 | 71.5 (C) | 75.7 | 80.3 |
| Rolla | LEU | 0.2 | 19 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 71.5 | 75.7 | 80.3 |
| 8. Purdue: | HEU | $10^{-3}$ | 16 | Alloy | 0.92 | 8-10 | 132-165 | 16.5 | 1.52 | 0.51 | 0.51 | 62.7 | 600 | 70.2 (F) | 75.2 | 75.2 |
| | LEU | $10^{-3}$ | 16 | $U_3Si_2$ | 3.47 | 12-14 | 150-175 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 70.2 | 75.2 | 75.2 |
| 9. Iowa | HEU | $10^{-2}$ | 12 | Alloy | 0.61 | 12 | 264 | 22.0 | 2.03 | 0.51 | 1.02 | 69.9 | 584 | 76.2 (F) | 76.2 | 140.7 |
| State | LEU | $10^{-2}$ | 12 | $U_3Si_2$ | 3.47 | 24 | 300 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 76.2 | 76.2 | 140.7 |

[a] Element has 16 fueled and 2 non-fueled plates.

ATTACHMENT (Cont.)

LEU Fuel Options for U.S. University Plate-Type Reactors as of 11/86.

| Reactor | | Power, MW | No. Els. in Core | Fuel Type | U Dens., $g/cm^3$ | Fueled 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 | Plate Width mm | Element Cross Section $mm^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Special Cases | | | | | | | |
| 10. Worcester | HEU | $10^{-2}$ | 24 | Alloy | 0.38 | 10 | 136 | 13.6 | 2.51 | 0.76 | 0.99 | ~63.5 | 610 | ~70.9 (F) | 77.4 x 77.4 |
| Poly.Inst. | LEU | $10^{-2}$ | 24 | $UAl_x$ | 1.77 | 18 | 167 | 9.3 | 1.52 | 0.38 | 0.76 | 54.4-63.5 | 572-610 | ~70.9 | 77.4 x 77.4 |
| 11. Manhattan | HEU | $10^{-7}$ | 16 | Alloy | 0.71 | 18 | 200 | Var. | 1.27 | 0.38 | 0.51 | Var. | 610 | Var. (C) | 88.9 mm O.D. |
| College | LEU | $10^{-7}$ | 16 | $U_3Si_2$ | 3.8-4.4 | 18 | 230-260 | Var. | 1.27 | 0.38 | 0.51 | Var. | 610 | Var. | 88.9 mm O.D. |
| 12. Rensselaer | HEU | $< 10^{-4}$ | 25 | $UO_2$-SS | 1.82 | 4-11 | Var. | 28.6 | 0.76 | 0.13(SS) | 0.51 | 64.5 | 552 | 70.4 (F) | 72.6 x 72.6 |
| Poly.Inst. | LEU | $< 10^{-4}$ | | SPERT Pins, 4.8% Enrichment, SS cladding. | | | | | | | | | | | |
| 13. Florida | HEU | 0.1 | 21 | Alloy | 0.43 | 11 | 160 | 14.5 | 1.78 | 0.38 | 1.02 | 58.4 | 606 | 72.3 (F) | 72.1 x 60.7 |
| | LEU 1 | 0.1 | 21 | $U_3Si_2$ | 3.47 | 14 | 175 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 72.3 | 72.1 x 60.7 |
| or | LEU 2 | >0.1 | | SPERT Pins, 4.8% Enrichment, SS Cladding. | | | | | | | | | | | |
| 14. Washington | HEU | 0.1 | 24 | Alloy | 0.41 | 11 | 146 | 13.3 | 1.78 | 0.38 | 1.02 | 57.2 | 603 | 72.3 (F) | 72.3 x 60.7 |
| | LEU 1 | 0.1 | 24 | $U_3Si_2$ | 3.47 | 14 | 175 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 72.3 | 72.3 x 60.7 |
| or | LEU 2 | >0.1 | | SPERT Pins, 4.8% Enrichment, SS Cladding. | | | | | | | | | | | |
| 15. Missouri | HEU | 10 | 8 | $UAl_x$ | ~1.6 | 24 | 780 | Var. | 1.27 | 0.38 | 0.51 | Var. | 610 | Var. (C) | Pie Shaped |
| Columbia | Reduced Enrichment Options Require Feasibility Study. | | | | | | | | | | | | | | |
| 16. Mass. | HEU | 5 | ~24 | $UAl_x$ | ~1.6 | 15 | 510 | 34.0 | 1.52 | 0.38 | 0.76 | 52.8 | 568 | 64.3 (F) | Rhomboid |
| Inst.Tech. | Reduced Enrichment Options Require Feasibility Study. | | | | | | | | | | | | | | |
| Michigan | LEU | 2 | ~30 | $UAl_x$ | 1.77 | 18 | 167 | 9.3 | 1.52 | 0.38 | 0.76 | 54.4-63.5 | 572-610 | 70.5 (C) | 74.7 x 82.6 |
| | LEU | 2 | <30 | $U_3Si_2$ | 3.47 | 18 | 225 | 12.5 | 1.27 | 0.38 | 0.51 | 58.9-62.8 | 572-610 | 70.5 | 74.7 x 82.6 |