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RERTR PROGRAM ACTIVITIES RELATED TO THE DEVELOPMENT AND APPLICATION OF NEW LEU FUELS*

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RERTR PROGRAM ACTIVITIES RELATED TO THE DEVELOPMENT AND APPLICATION OF NEW LEU FUELS*

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ABSTRACT

The status of the U.S. Reduced Enrichment Research and Test Reactor (RERTR) Program is reviewed. After a brief outline of RERTR Program objectives and goals, program accomplishments are discussed with emphasis on the development, demonstration and application of new LEU fuels. Most program activities have proceeded as planned, and a combination of two silicide fuels (U_3Si_2-Al and U_3Si-Al) holds excellent promise for achieving the long-term program goals. Current plans and schedules project the uranium density of qualified RERTR fuels for plate-type reactors to grow by approximately 1 g U/cm^3 each year, from the current 1.7 g U/cm^3 to the 7.0 g U/cm^3 which will be reached in late 1988. The technical needs of research and test reactors for HEU exports are also forecasted to undergo a gradual but dramatic decline in the coming years.

INTRODUCTION

One hundred thirty-seven research and test reactors (92 foreign, 45 U.S.) using High-Enrichment-Uranium (HEU, >20% enrichment) of U.S. or other Western origin are currently in operation in thirty-four countries. The cumulative power of these reactors is 1370 MW, and their annual ^{235}U requirement is about 1025 kg. The average cycle time of a fuel element lasts approximately 4 years, so that about 4100 kg of HEU are in continuous circulation to fuel these reactors. There is concern that some of this material may be diverted to make nuclear weapons, especially when it is in the unirradiated state.

Historically, and as recently as the early 1960's, only Low-Enrichment-Uranium (LEU, <20% enrichment) was meant to be exported by the U.S. for use in research reactors. The research reactors considered in the "Atoms for Peace" program were LEU-fueled, and so was the "Geneva Reactor" (1955). As power and neutron flux were revised in research reactors to satisfy more demanding experimental requirements, greater ^{235}U loadings of the fuel elements began to

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be needed to avoid the financial penalty of a reduced fuel lifetime. The increased loadings could have been achieved either by continuing the development of fuels with higher uranium density or by increasing the uranium enrichment. Of the two choices, the latter prevailed in the 1960's. HEU became freely available and research reactor fuel development was terminated. HEU became of common use in research reactors and was applied even in those reactors where LEU would have been adequate.

Against this background, renewed concerns abour nuclear proliferation emerged in the late 1970's. Both the International Nuclear Fuel Cycle Evaluation (INFCE) Program and the Nuclear Alternative Systems Assessment Program (NASAP) concluded that the risk of international nuclear proliferation depends strongly on the magnitude and accessibility of inventories of weapons-usable fissile materials. Several countries expressed deep concern about this problem. In particular, the U.S. announced a Nuclear Non-Proliferation Act Initiative to significantly reduce U.S.-supplied HEU inventories for fueling research and test reactors, and plans for the RERTR Program to develop safe and viable alternative uranium-based fuels of significantly reduced enrichment. One of the major goals of the RERTR Program is to reverse the trend that prevailed in the 1960's, and to concentrate on renewed fuel development, demonstration and design activities to provide the technical foundation which will allow research and test reactors to achieve their performance/safety/economics goals without reliance on HEU materials.

THE RERTR PROGRAM, ITS OBJECTIVES AND GOALS

The Reduced Enrichment Research and Test Reactor (RERTR) Program was established by the U.S. Department of Energy in 1978 (and is coordinated with the U.S. Department of State, the U.S. Disarmament Agency, and the U.S. Nuclear Regulatory Commission) to provide the technical means needed to utilize LEU instead of HEU fuels in research and test reactors, and to do so without significant penalty in experiment capabilities, operation costs, component modifications, or safety characteristics.

Four main LEU fuel types are being developed with high uranium densities for different reactor types:

Aluminide Fuels (UAl_x-Al). Used in plate-type reactors. Current normal uranium density range with HEU is 0.4-0.8 g U/cm^3, with peak density of 1.7 g U/cm^3. Estimated highest practical density is 2.3 g U/cm^3.

Oxide Fuels (U_3O_8-Al). Used in plate-type reactors. Current normal uranium density with HEU is ~0.8 g U/cm^3, with peak density of 1.3 g U/cm^3. Estimated highest practical density is 3.2 g U/cm^3.

Silicide Fuels (U_3Si_2-Al, U_3Si-Al). Being developed and demonstrated by the RERTR Program for application in plate-type reactors. Estimated highest practical density is 5.5 g U/cm^3 with U_3Si_2-Al, 7.0 g U/cm^3 with U_3Si-Al. A variation of this fuel (U_3SiAl-Al) is under development by the Canadian AECL for application in rod-type reactors.

TRIGA Fuels ($UZrH_x$). Used in rod-type reactors. Current uranium density with HEU is 0.5 g U/cm^3. Developed by GA Technologies and being tested in cooperation with the RERTR Program for densities up to 3.7 g U/cm^3.

Development of each fuel type normally entails several consecutive phases. First, small plates (miniplates) for plate-type fuel or rods for rod-type fuel are fabricated, irradiated and subjected to Post-Irradiation-Examinations (PIEs) to screen the most promising candidates. Second, full-size elements of the types identified by the miniplate tests are fabricated, irradiated, and examined to test their behavior under irradiation. Third, full-core demonstrations are performed for some reactor configurations of general interest, but not for each fuel type, to demonstrate that the new fuels provide the desired experimental capabilities, economics, and safety characteristics when used to fuel an entire reactor core.

The new fuel types are meant to be simple to fabricate, and to require equipment and procedures very similar to those of current fuels. The goal is to have the enrichment change perturb as little as possible every aspect of reactor operation, and minimize potential economic penalties or conflicts. In particular, it is desirable (1) for all current fuel manufacturers to become as soon as possible qualified and active producers of the new fuels, without the enrichment change affecting their competitive position; (2) to avoid extensive modifications of safety analysis reports, by using geometric configurations close to those previously used; (3) to have fuel cycle services for spent LEU fuels available under conditions comparable to those proffered for the spent HEU fuels to be displaced, and (4) to insure that both experimental capabilities and fuel cycle costs are not significantly penalized by the conversion to LEU fuel.

In parallel with the fuel development activities, the RERTR Program develops analytical methods and design options to evaluate and optimize the utilization of the new LEU fuels as they are developed. The performance of reactors of special interest is assessed with the new fuels in a variety of design configurations; safety issues are addressed; and the economics of the fuel cycle are studied to determine the combination of fuel material/design/operation which will optimize the overall reactor performance with LEU fuel. An important vehicle for the validation of the results of these studies, and for their international acceptance, is their inclusion in IAEA guidebooks which are developed by a large group of international consultants coordinated by the IAEA and then published and distributed by the IAEA.[1,2] As part of its analytical activities, the RERTR Program also provides the U.S. Executive Branch with technical and economic evaluations of each HEU Export License Application related to HEU use in research reactors.

ACCOMPLISHMENTS

The goals of the RERTR Program have been aggressively pursued during the past five years, in cooperation with many research reactor organizations and with domestic and foreign fuel fabricators. The main achievements are summarized below. More detailed information about RERTR fuel development and demonstration activities is provided in Ref. 3.

1. UAl_x-Al Fuels. Miniplates with up to 2.3 g U/cm^3 have been fabricated with LEU by EG&G Idaho and irradiated to 88% burnup in the Oak Ridge Research Reactor (ORR). PIE results are excellent. Full-size elements with 1.7, 2.1, and 2.3 g U/cm^3 have been fabricated through the combined efforts of CERCA, NUKEM and TI. ORR irradiation of the less dense elements is complete with good PIE results, while irradiation of the denser elements continues.

2. U_3O_8-Al Fuels. Miniplates with LEU and up to 3.1 g U/cm^3 have been fabricated by ORNL and irradiated to 88% burnup in the ORR. PIE results are good. Full-size elements with 1.7, 2.1, 2.3, and 3.2 g U/cm^3 have been fabricated through the combined efforts of NUKEM, CERCA and TI. ORR irradiation of the less dense elements is complete with good PIE results, while irradiation of the denser elements continues.

3. U_3Si_2-Al Fuels. Miniplates with up to 3.8 g U/cm^3 have been fabricated at ANL and irradiated to 83% burnup in the ORR. PIE results are excellent. Six full-size elements with 4.8 g U/cm^3, fabricated by NUKEM, CERCA and B&W, have been or will soon be irradiated in the ORR. PIEs of the first element to reach ~50% burnup are under way, with excellent preliminary results.

4. U_3Si-Al Fuels. Miniplates with up to 5.7 g U/cm^3 have been fabricated at ANL and irradiated to 83% burnup in the ORR. The PIEs completed to date (up to 4.8 g U/cm^3) show some evidence of swelling, but good promise that this material will perform satisfactorily with LEU at 7.0 g U/cm^3 and for any burnup level. Four full-size fuel plates, two at 5.5 g U/cm^3 and two at 6.0 g U/cm^3, were fabricated by CERCA and irradiated in SILOE under a cooperative agreement with the RERTR Program. The plate with the highest burnup was estimated to have reached over 50% average burnup in July 1983, without significant thickness increase. A full-size SILOE test element with 6.0 g U/cm^3 is planned for fabrication by CERCA[4] in early 1984.

5. <u>U_3SiAl-Al Fuels</u>. This material is no longer pursued for plate-type applications by the RERTR Program, but the results obtained are useful to clarify the behavior of other silicide fuels. Miniplates with up to 7.0 g U/cm^3 were fabricated at ANL and irradiated to 83% burnup in the ORR. Some of these miniplates underwent failures at high (>75%) burnups in 1982, casting doubts on the future of the silicide fuels. The failures were later found to be due to a form of breakaway particle swelling[5] related to the presence of Al in the particles. The phenomenon is totally absent from U_3Si_2 particles and appears only slightly in regions of U_3Si particles where aluminum has diffused from the matrix.

6. <u>$UZrH_x$ Fuels</u>. Full-size pins, with densities of 1.3, 2.2, and 3.7 g U/cm^3, were fabricated by GA Technologies and have been under irradiation in the ORR since 1980. All pins will have reached their burnup goal before the end of 1984. Visual examinations indicate excellent fuel behavior.

7. <u>Low-Power, Whole-Core LEU Fuel Demonstration</u>. A whole-core LEU demonstration with UAl_x-Al fuel (1.7 g U/cm^3) began in 1981 in the Ford Nuclear Reactor at the University of Michigan. The results have confirmed the validity of the calculations, methods and data used to predict performance and safety characteristics of research reactors undergoing conversion.[6]

8. <u>High-Power, Whole-Core LEU Fuel Demonstration</u>. A whole-core LEU demonstration with U_3Si_2-Al fuel (4.8 g U/cm^3) is planned in the ORR, beginning in early 1985. This demonstration is to verify the validity of calculations, methods and data used to predict operational and fuel cycle characteristics of research reactors undergoing conversion.

9. <u>Reprocessing</u>. Savannah River Laboratory tests and studies have concluded that RERTR silicide, oxide and aluminide fuels can be successfully reprocessed at the Savannah River Plant.[7]

10. <u>Generic Conversion Studies</u>. Extensive generic studies have indicated a wide range of applicability of the new fuels to the conversion of both light- and heavy-water moderated research reactors. Much of these studies were included in IAEA guidebooks.[1]

11. <u>Generic Safety Studies</u>. Extensive generic studies have addressed the safety and licensing aspects of research reactor conversions, with favorable results. Much of these studies are being included in an IAEA guidebook.[2]

12. <u>Economic Studies</u>. The new fuels have been shown to offer considerable potential for economic advantages in many research reactors undergoing conversion.[8]

13. <u>Joint Conversion Studies</u>. Joint study programs for the conversion of specific reactors have been in progress with research organizations involving as many as 25 reactors in 17 countries.

PLANS, SCHEDULES, AND IMPLICATIONS FOR FUTURE AVAILABILITY OF LEU FUELS

The fuel development and demonstration activities which normally define the program's critical path fit into the schedule illustrated in Fig. 1. Asterisks mark the dates when all information needed to make some particular fuels qualified and licensable for use in research reactors is expected to have been compiled. The corresponding uranium densities are indicated in parenthesis.

For each fuel the following qualification dates emerge for intermediate and final uranium densities (g U/cm^3):

UAl_x-Al	1982 (1.7)	1984 (2.3)
U_3O_8-Al	1984 (1.7)	1985 (3.2)
U_3Si_2-Al	1985 (4.8)	1987 (5.5)
U_3Si-Al		1988 (7.0)
$UZrH_x$		1984 (3.7)

The cumulative uranium density expected to become qualified for application in plate-type LEU research and test reactor fuels is plotted as a function of time in Fig. 2. The density increases in several discontinuous steps from the current value of 1.7 g U/cm^3 to the 7.0 g U/cm^3 which will become qualified in 1988. The progress in qualified density can also be visualized as a continuous curve bounded by the histogram outline, with a steep and nearly constant rate of increase close to 1 g U/cm^3 per year.

The gradual increase of the qualified uranium density leads to a correspondingly gradual increase in the amount of HEU which will no longer need to be exported for the operation of research reactors. The histogram which provides current estimates for this value as a function of time is shown in Fig. 3.

The near-term fuels (UAl_x-Al, U_3O_8-Al, and $UZrH_x$), U_3Si_2-Al and U_3Si-Al are responsible for nearly equal percentages (~28% each), of the total anticipated HEU export decrease, and are supplemented by the contribution of U_3SiAl-Al fuel rods developed in Canada. The largest numbers of potential reactor conversions are represented by the steps occurring in 1984 and 1986 (31 and 14 reactors with powers no less than 1 MW, respectively) but the few reactors for which the high densities provided by the U_3Si-Al fuel are needed correspond to a large fraction of the HEU exports.

The data shown in Fig. 3 apply to research reactors with power in excess of 1 MW and located in countries other than the U.S. A plot of the corresponding anticipated potential decrease of HEU usage in U.S. research reactors would show a similar pattern.

SUMMARY AND CONCLUSION

The RERTR Program has made significant progress in the development, demonstration and application of new LEU research reactor fuels with high uranium density. Some uncertainties which had emerged in 1982 about silicide fuels have been resolved. Two different forms of silicide fuels (U_3Si_2-Al and U_3Si-Al) are now vigorously pursued: the former will be qualified with 4.8 g U/cm^3 at the end of 1985, and the latter will be qualified with 7.0 g U/cm^3 in 1988. A whole-core demonstration utilizing U_3Si_2-Al fuel is planned for 1985.

According to the program schedule, the qualified uranium density in the fuel meat of RERTR plate-type fuels will increase at a nearly uniform rate from the current 1.7 g U/cm^3 to the 7.0 g U/cm^3 scheduled for 1988. The percentage of 1983 HEU average annual exports which will be technically replaceable with LEU fuels will grow at a nearly uniform rate from its small (1.7%) present value and will reach the 100% mark in 1988.

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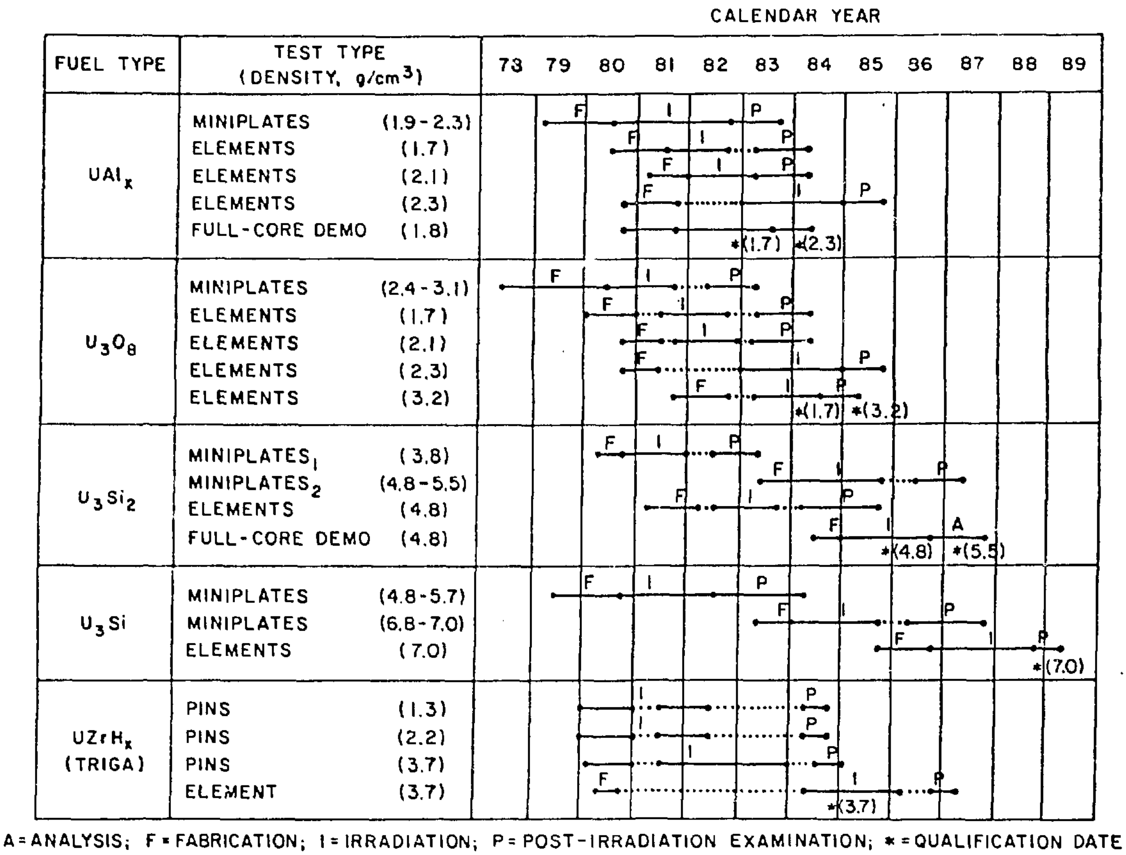

Fig. 1. Schematic Schedule for RERTR Fuel Development and Demonstration Activities.

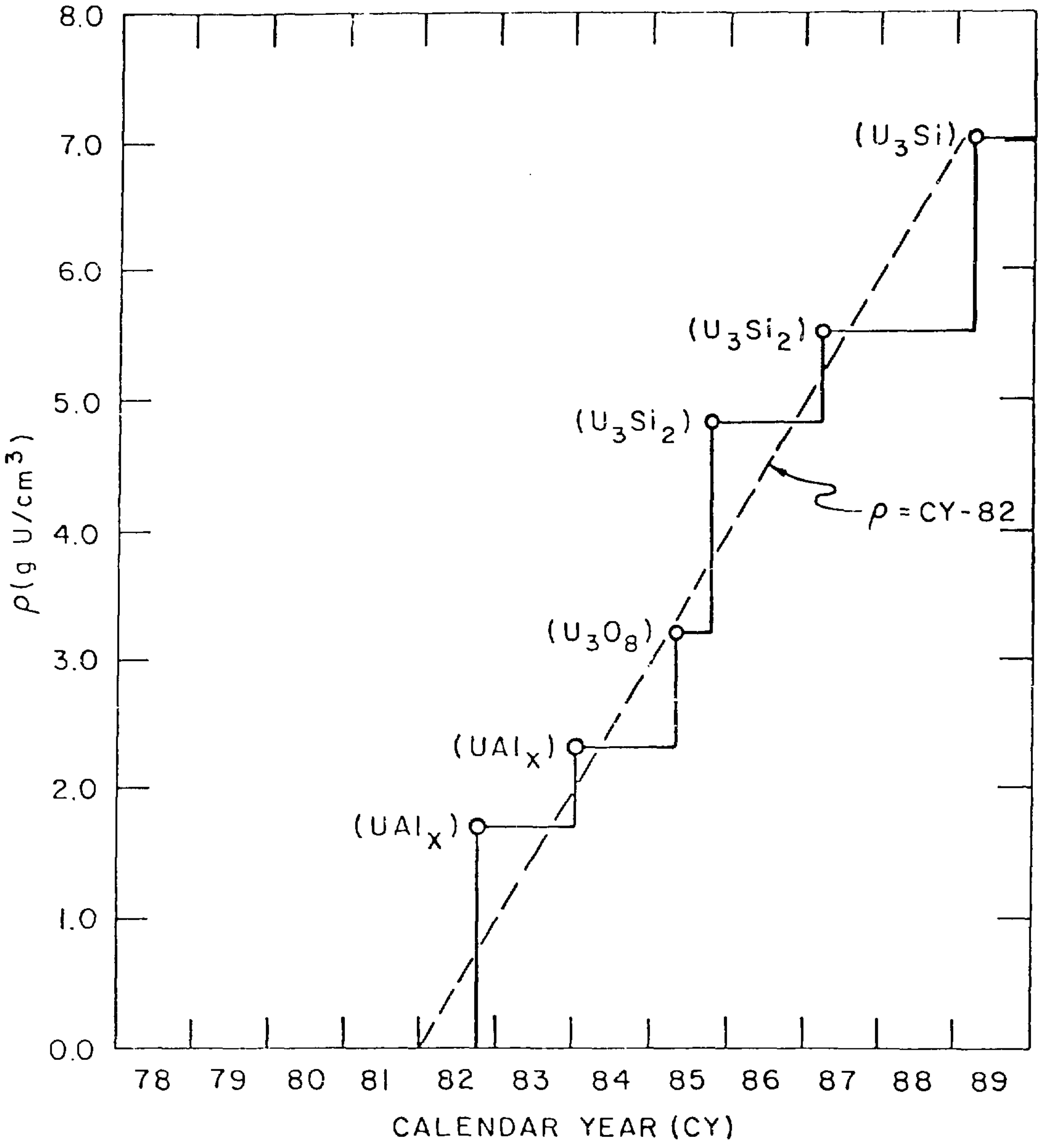

Fig. 2. Projected Uranium-density Progress for Plate-Type Fuel Qualification

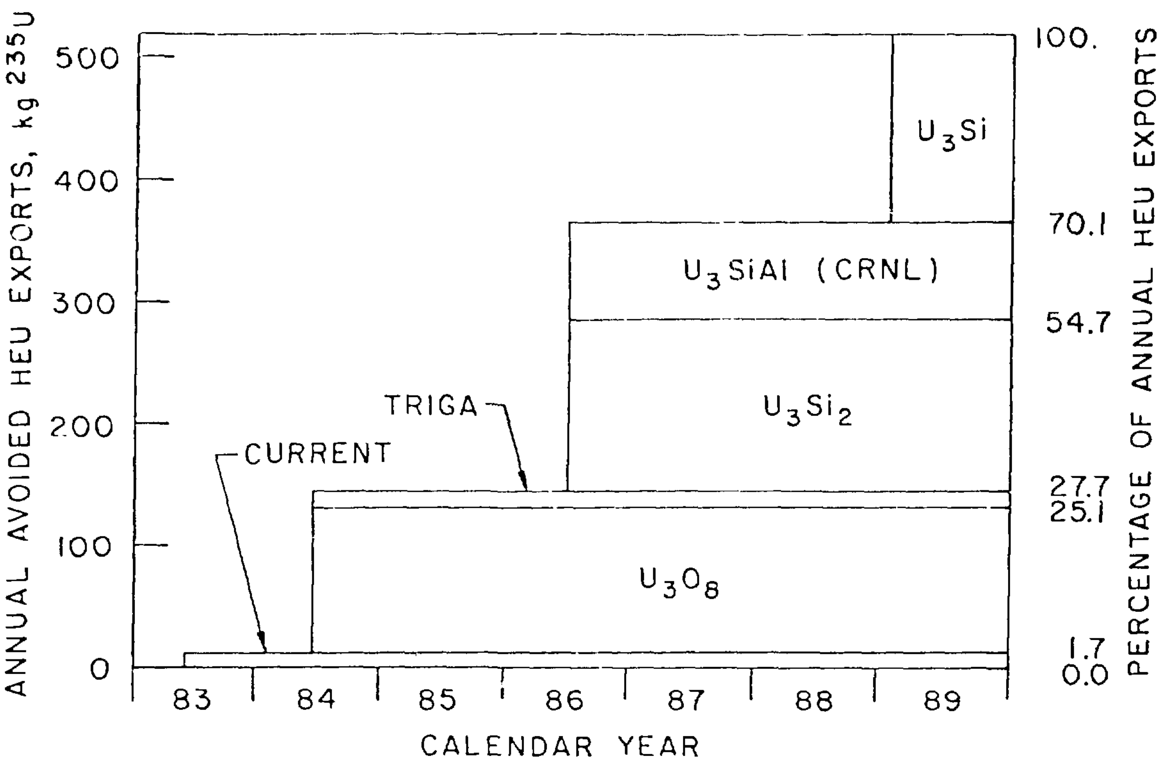

Fig. 3. Potential Avoided U.S. HEU Exports for Research and Test Reactor Fuels.