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# RECENT DEVELOPMENTS OF THE U.S. RERTR PROGRAM*

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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 the RERTR Program objectives, goals and past accomplishments, emphasis is placed on the developments which took place during 1983 and on current program plans and schedules. Most program activities have proceeded as planned and a combination of two silicide fuels ($U_3Si_2$-Al and $U_3Si$-Al) was found to hold excellent promise for achieving the long-term program goals. A modification of the program plan, including the development and demonstration of those fuels, was prepared and is now being implemented. The uranium density of qualified RERTR fuels for plate-type reactors is forecasted 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 1988. The technical needs of research reactors for HEU exports are also forecasted to undergo a gradual and dramatic decline in the coming years.

## 1. INTRODUCTION

The past year has seen some important new developments within the Reduced Enrichment Research and Test Reactor (RERTR) Program. These developments have removed much of the technical uncertainties which were present a year ago, and have made it possible to prepare more definite plans and more precise schedules and projections.

The main objectives of this paper are (1) to provide a brief review of the RERTR Program, of its objectives and previous accomplishments, (2) to summarize the new developments and their implications, (3) to outline current program activities, plans and schedules, and (4) to assess the probable resulting impact on the plans and operations of the research reactor community.

The next sections of this paper are structured to correspond closely to these objectives.

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## 2. THE RERTR PROGRAM, ITS OBJECTIVES, AND PREVIOUS ACCOMPLISHMENTS

The 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. Arms Control and Disarmament Agency, and the U. S. Nuclear Regulatory Commission) to provide the technical means needed to convert research and test reactors to the use of Low-Enrichment-Uranium (LEU <20% enrichment) fuels in lieu of High-Enrichment-Uranium (HEU >20% enrichment) fuels, and to do so without significant penalty in experiment capabilities, operation costs, component modifications, or safety characteristics.

The main problem addressed by the RERTR Program is the existence of 137 research and test reactors (92 foreign, 45 U.S.) in 34 countries using HEU of U.S. or other Western origin. 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. One of the major goals of the RERTR Program is to reverse a trend that prevailed in the 1960's, when HEU fuel development was curtailed in favor of HEU usage, and to develop fuel materials and fuel element designs with much higher uranium density than previously achievable.

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 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 normally entails several consecutive phases. First, small plates (miniplates) for plate-type fuel or rods for rod-type fuel are fabricated, irradiated and examined 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, to demonstrate that the new fuels provide the desired experimental capabilities, economics, and safety characteristics when used to fuel an entire reactor core.

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] 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.

These goals have been aggressively pursued during the past five years, in cooperation with many research reactor organizations and with domestic and foreign fuel fabricators.

By the end of 1982, excellent results about the potential utilization of the new fuels had been obtained by the analytical effort. Miniplates of all three main plate-type fuels (132 plates in all) had been fabricated with up to the highest anticipated densities, and had been irradiated to high burnups in the Oak Ridge Research Reactor (ORR). In addition to the materials already listed, these miniplatees included a third silicide material ($U_3SiAl$-Al) which was considered a good candidate for reaching the highest uranium density goal set for the program.

Irradiations and post-irradiation-examinations (PIEs) of aluminide and oxide miniplates with 20% enrichment nad been successfully completed, and had been followed by irradiations of full-size elements. A whole-core demonstration of LEU aluminide fuel (1.7 g U/cm$^3$) in the Ford Nuclear Reactor (FNR) had provided preliminary confirmation of the accuracy of program calculations and evaluations of LEU conversions.

Close to mid-1982, however, some failures in $U_3SiAl$-Al miniplates cast a shadow of uncertainty on the program's ability to reach one of its most important goals, namely, a qualified fuel with 7.0 g U/cm$^3$. In the absence of additional information, only tentative hypotheses and plans for future program activities could be discussed at the Fifth International RERTR Meeting.[2]

## 3. NEW DEVELOPMENTS

A six-month period dedicated during early 1983 to the acquisition of data related to the definition, explanation, and implications of the failures experienced during the previous year yielded a significant amount of new data on the behavior of silicide fuels under irradiation. These data will be discussed in detail elsewhere at this conference. For the purposes of this presentation, the results which are of greatest interest in assessing future program activities can be summarized as follows.

a. Post-Irradiation-Examinations (PIEs) of $U_3Si_2$-Al miniplates with 3.75 g U/cm$^3$ have shown that this material has exceptionally stable properties under irradiation to burnups in excess of 83%.[3]

b. PIEs of $U_3Si$-Al miniplates with 4.83 g U/cm$^3$ have shown that $U_3Si$ particles swell more than $U_3Si_2$ particles at 83% burnup, but $U_3Si$-Al holds good promise for performing satisfactorily under all conceivable burnup conditions when used in conjunction with LEU.[3]

c. PIEs of $U_3SiAl$-Al miniplates have shown that the failures of this material were due to a form of breakaway particle swelling which is totally absent from $U_3Si_2$-Al fuel.[3]

d. PIEs of a full-size $U_3Si_2$-Al element, fabricated by NUKEM with 4.8 g U/cm$^3$ and irradiated in the ORR to an average burnup close to 50% are in progress. All non-destructive tests have been completed and the results obtained so far are excellent. Another identical element is continuing irradiation and will reach 75% burnup near the end of 1983. No significant swelling of its plates has been detected.[4]

e. Two other $U_3Si_2$-Al elements, fabricated by CERCA with 4.8 g U/cm$^3$, are being irradiated in the ORR and have reached 52% burnup without any apparent change in the thickness of their plates.[4]

f. Four $U_3Si$-Al 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. The plate with the highest burnup was estimated to have reached over 50% average burnup in July 1983, without significant thickness increase.[5]

g. Reprocessing studies at Savannah River Laboratory on LEU silicide, oxide and aluminide fuels were completed with the conclusion that spent RERTR fuels can be successfully reprocessed at the Savannah River Plant.[6]

h. ORR irradiation of two oxide elements fabricated by CERCA with 3.2 g U/cm$^3$ continued successfully. A burnup close to 57% was achieved in September 1983.[4]

i. The LEU demonstration at the Ford Nuclear Reactor has confirmed the validity of the calculations, methods and data used to predict performance and safety characteristics of research reactors undergoing conversion.[7]

j. Analytical studies on the performance, economics, and safety aspects of research reactors operating with LEU fuels continue to indicate a wide range of applicability for these fuels.[8] Significant economic advantages may result for reactors using highly-loaded LEU elements, especially in connection with silicide fuels.

Two direct and important implications can be drawn from these results. First, demonstration of aluminide and oxide fuels is proceeding on schedule and without problems. Second, the silicide fuels are back on the right track with a minor change in emphasis.

Emphasis for the highest-density RERTR fuels is now placed on a combination of $U_3Si_2$-Al/$U_3Si$-Al fuels, replacing the $U_3SiAl$-Al which had been the focus of previous RERTR silicide efforts and which is no longer pursued.

The $U_3Si_2$-Al fuel shows almost ideal properties under irradiation. Current tests have been limited to loadings of 4.8 g U/cm$^3$, but there is high confidence that the loading can be extended to ~5.5 g U/cm$^3$ without negatively affecting its irradiation behavior. Fabrication costs are anticipated to be comparable to those of aluminide fuels of the same volume loading because of the similar comminution properties.

The $U_3Si$-Al fuel shows some incipient swelling at high (~83%) burnups, but there is good probability that LEU fuels with this material will become qualified with uranium loadings as high as 7.0 g U/$cm^3$. Further work on comminution processes is needed to bring the expected fabrication costs close to those expected for $U_3Si_2$-Al fuels.

## 4. CURRENT PROGRAM PLANS AND SCHEDULE

The developments which have taken place during 1983 (Section 3) have been taken into account in formulating a new long-range plan for the RERTR Program. The activities of this plan are based on the following premises:

a) Demonstration activities of aluminide, oxide, and zirconium hydride fuels will proceed as scheduled in previous plans.

b) Development and demonstration of silicide fuels will proceed at the maximum practical speed, and will concentrate on both $U_3Si_2$-Al and $U_3Si$-Al fuels.

c) A new campaign of silicide miniplates will begin irradiation in the ORR at the beginning of 1984. This campaign will include a number of $U_3Si$-Al and $U_3Si_2$-Al miniplates in a variety of parametric variations, for screening and optimization purposes.

d) Irradiation of six $U_3Si_2$-Al elements in the ORR (two elements each from NUKEM, CERCA and B&W) will continue until the elements from each fabricator reach, respectively, 50% and 75% average burnup. (Two elements have already reached ~50% burnup.)

e) A high-power, high-loading Whole-Core-Demonstration will take place with $U_3Si_2$-Al fuel, and with irradiation beginning around January 1985. This demonstration will provide information on performance, safety, and fuel cycle characteristics of highly-loaded LEU elements.

f) Prototype elements with $U_3Si$-Al fuel will be fabricated and irradiated as miniplate irradiations provide adequate data on the optimal conditions and irradiation potential of this fuel.

g) Analysis will concentrate on safety, economics, and performance evaluations with special regard for the high loadings which silicide fuels are expected to make available.

Taking into consideration only the fuel development and demonstration activities which normally define the program's critical path, the major activities described above fit into the schedule illustrated in Fig. 1. The over-all aspects of this schedule have not changed significantly from what was anticipated in November 1982.[1] An important difference is found, however, in the whole core demonstration with high power and high uranium loading which is now being definitely planned to use LEU $U_3Si_2$-Al fuel and to start in early 1985.

Some important dates are marked with asterisks in the schedule. On these dates, all the information needed to make particular fuels qualified and licensable for use in research reactors is expected to have been compiled. The numbers in parenthesis close to the asterisks indicate the uranium density (in g U/cm$^3$) of the fuel in question.

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) |

## 5. IMPLICATIONS FOR FUTURE AVAILABILITY OF LEU FUELS

The dates, materials and uranium densities listed in the RERTR Program schedule (Fig. 1) can be used to infer the timetable with which the uranium density of qualified LEU fuels will progressively increase, and the dates when specific research reactors now using HEU fuels will be technically able to use the new LEU fuels.

The uranium density which is 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. Since collection of relevant data will proceed almost continuously for each fuel type and density, 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 $UZrH_x$), $U_3Si_2Al$-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 (thirty-one and fourteen 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 an almost identical pattern.

## 6. SUMMARY AND CONCLUSION

The RERTR Program has made significant progress during 1983. The 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.

The program schedule indicates that the qualified uranium density in the fuel meat of RERTR 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. It also indicates that 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.

## 7. REFERENCES

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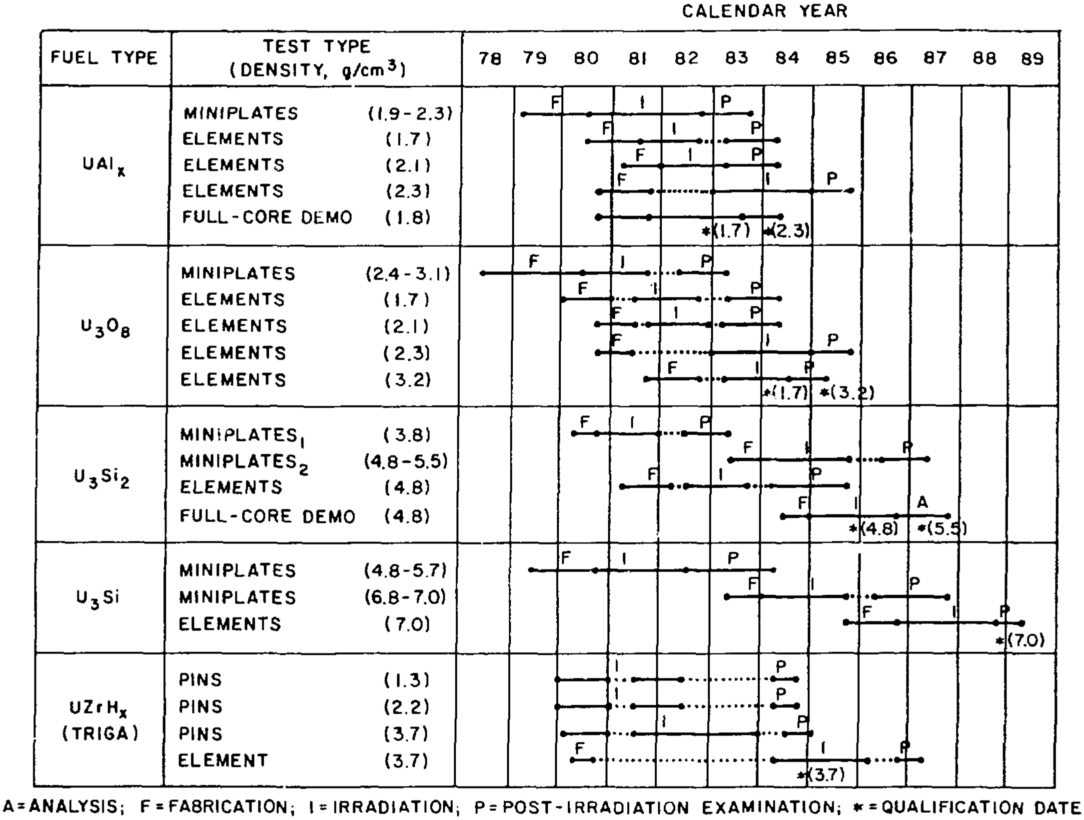

Fig. 1. Schematic Schedule for RERTR Fuel Development and Demonstration Activities.

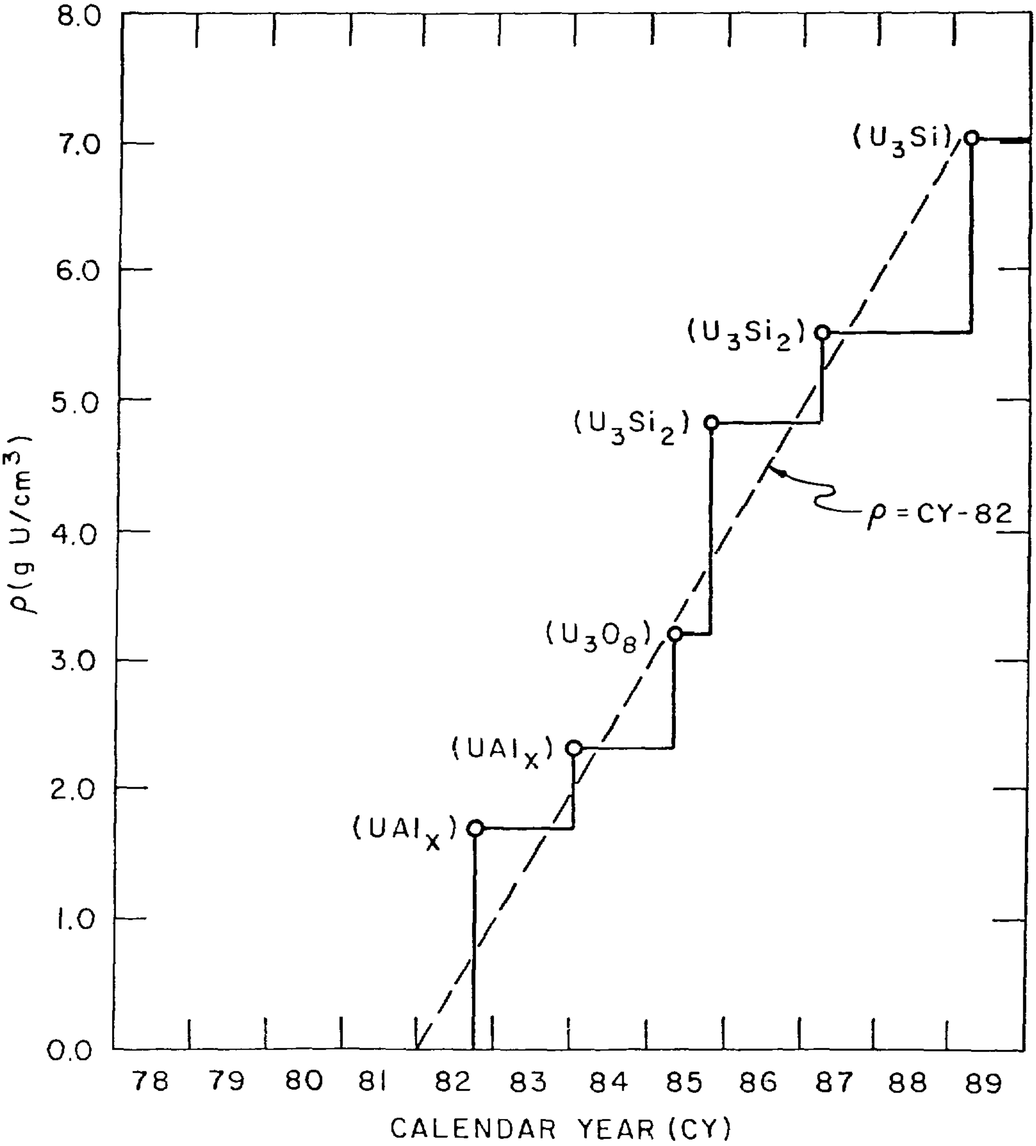

Fig. 2. Projected Uranium-density Progress for Plate-Type Fuel Qualification

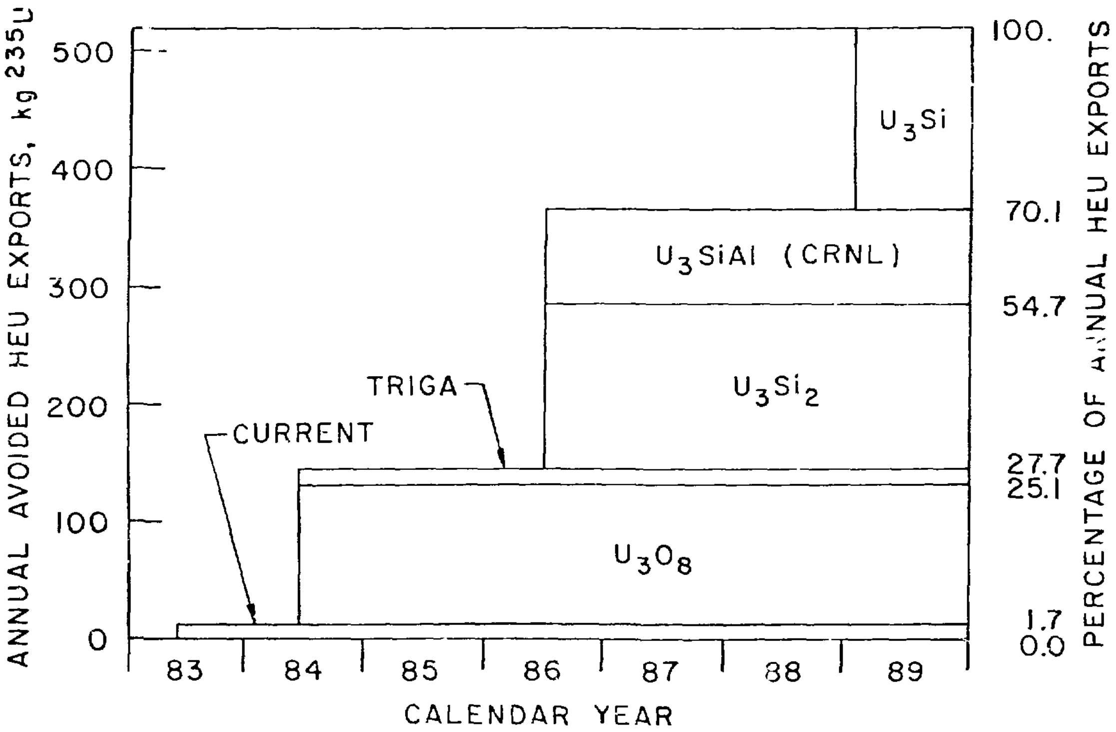

Fig. 3. Potential Avoided U.S. HEU Exports for Research and Test Reactor Fuels.