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THE STATUS OF THE RERTR PROGRAM:  
OVERVIEW, PROGRESS AND PLANS

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ABSTRACT

The status of the U.S. Reduced Enrichment Research and Test Reactor (RERTR) Program is reviewed. After a summary of the accomplishments which the RERTR Program had achieved by the end of 1984 with its many international partners, emphasis is placed on the progress achieved during 1985 and on current plans and schedules. A new miniplate series, concentrating on  $U_3Si_2-Al$  and  $U_3Si-Al$  fuels, was fabricated and is well into irradiation. The whole-core ORR demonstration is scheduled to begin in November 1985, with  $U_3Si_2-Al$  fuel at  $4.8 \text{ g U/cm}^3$ . Altogether, 921 full-size test and prototype elements have been ordered for fabrication with reduced enrichment and the new technologies. Qualification of  $U_3Si-Al$  fuel with  $\sim 7 \text{ g U/cm}^3$  is still projected for 1989. This progress could not have been achieved without the close international cooperation which has existed since the beginning, and whose continuation and intensification will be essential to the achievement of the long-term RERTR goals.

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INTRODUCTION

The Reduced Enrichment Research and Test Reactor (RERTR) Program was established in 1978 by the Department of Energy. Its goal is to develop the technology which will make it feasible to use, without significant penalties, Low-Enrichment Uranium (LEU) fuels instead of High-Enrichment Uranium (HEU) fuels in research reactors.

Great progress towards this goal has been achieved through the close cooperation which, from the beginning, has existed between the Program and the many organizations represented at this meeting. In particular, one of the first cooperation agreements to be reached was with the Petten Establishment, where several cooperative irradiation tests related to the program goals have been conducted. Therefore, it gives me special pleasure to report here on the status of the RERTR Program, on the progress achieved during the past year, and on our plans for the future.

#### OVERVIEW OF THE OCTOBER 1984 PROGRAM STATUS

By October 1984, when the last International RERTR Meeting was held,<sup>1</sup> the three main fuels which were in operation with HEU at the inception of the program ( $UAl_x-Al$  with up to  $1.7 \text{ g U/cm}^3$ ;  $U_3O_8-Al$  with up to  $1.3 \text{ g U/cm}^3$ ; and  $UZrH_x$  with  $0.5 \text{ g U/cm}^3$ ) had been extensively tested with reduced enrichment and with greatly increased uranium densities. The new uranium densities extended up to  $2.3 \text{ g U/cm}^3$  for  $UAl_x-Al$ ,  $3.2 \text{ g U/cm}^3$  for  $U_3O_8-Al$ , and  $3.7 \text{ g U/cm}^3$  for  $UZrH_x$ . Extensive tests had been conducted on each fuel for up to these densities and, in some cases, beyond them. In particular,

(a) for  $UAl_x-Al$ , miniplates with LEU and up to  $2.5 \text{ g U/cm}^3$  had been fabricated by EG&G, NUKEM and the CNEA, and irradiated to 89-96% burnup in the ORR with excellent PIE results. Full-size elements with  $1.7$ ,  $2.1$ ,  $2.2$  and  $2.3 \text{ g U/cm}^3$  had been fabricated by CERCA and NUKEM. Irradiation of two elements with  $2.1$  and  $2.3 \text{ g U/cm}^3$  was still in progress in the ORR, while irradiation of all the other elements had been completed in the ORR, HFR-Petten and SILOE, with good PIE results.

(b) for  $U_3O_8-Al$ , miniplates with LEU and up to  $3.6 \text{ g U/cm}^3$  had been fabricated by ORNL, NUKEM and the CNEA, irradiated to 80-98% burnup in the ORR, and examined with good PIE results. Full-size elements with  $1.7$ ,  $2.1$ ,  $2.3$  and  $3.2 \text{ g U/cm}^3$  had been fabricated by NUKEM, CERCA and TI. Irradiation of two elements with  $2.3 \text{ g U/cm}^3$  was still in progress in the ORR, while irradiation of all the other elements had been completed in the ORR and HFR-Petten. PIE had been completed for all the irradiated elements but one, with good results.

(c) for  $UZrH_x$ , full-size LEU pins with densities of  $1.3$ ,  $2.2$  and  $3.7 \text{ g U/cm}^3$  had been fabricated by GA Technologies and irradiated beyond 50% average burnup in the ORR.

Almost all data needed to qualify these fuels for their use with LEU and the higher uranium densities had been achieved, but some supplementary activities were still in progress. Among these, two  $UAl_x-Al$  elements and two  $U_3O_8-Al$  elements were still

under irradiation in the ORR, and post-irradiation examinations of TRIGA pins were pursued to verify the good performance of the  $UZrH_x$  fuel meat and to determine the effects of long-term irradiation on the Incoloy clad.

Two new fuel types based on silicides ( $U_3Si_2$ -Al and  $U_3Si$ -Al) had been identified as holding great promise for application in LEU research reactor fuels:

(d) for  $U_3Si_2$ -Al, miniplates with up to  $3.8 \text{ g U/cm}^3$  had been fabricated by ANL and irradiated to 90-96% burnup in the ORR with excellent PIE results. Six full-size elements with  $4.8 \text{ g U/cm}^3$  had been fabricated by NUKEM, CERCA and B&W. Irradiation of five of these elements had been completed in the ORR, with irradiation of one element still to be completed. PIE of one element with ~41% average burnup had given excellent results.

(e) for  $U_3Si$ -Al, miniplates with up to  $6.1 \text{ g U/cm}^3$  had been fabricated by ANL and the CNEA, and irradiated to 84-96% burnup in the ORR. PIE of a  $6.1 \text{ g U/cm}^3$  miniplate fabricated by the CNEA had given good results, but had shown that some burnup limits might need to be imposed for the higher densities.

Activities related to the fabrication and irradiation of a second series of miniplates concentrating on silicide fuels had been started.

A whole-core LEU demonstration with  $UAl_x$ -Al fuel ( $1.7 \text{ g U/cm}^3$ ) had been in progress since 1981 in the Ford Nuclear Reactor (FNR) at the University of Michigan, and had confirmed the validity of RERTR evaluations. Another whole-core LEU demonstration, this time with  $U_3Si_2$ -Al fuel ( $4.8 \text{ g U/cm}^3$ ) was planned to begin in the ORR during 1985.

Reprocessing studies at the Savannah River Laboratory had concluded that the RERTR fuels could be successfully reprocessed at the Savannah River Plant. This conclusion was an important prerequisite for an ongoing DOE economic study to define the terms and conditions under which spent LEU research reactor fuels might be accepted for reprocessing.

Extensive studies had been conducted, with favorable results, on the performance, safety and economic characteristics which could be expected to accompany implementation of the new LEU fuel in research reactors under a variety of conditions.

Finally, joint study programs were in progress for 28 reactors from 17 different countries.

PROGRESS OF THE RERTR PROGRAM IN 1985

Miniplates

Both fabrication and irradiation of the second miniplate series have made significant progress.<sup>2</sup> This series concentrates on: (a) defining the density and irradiation limits of  $U_3Si_2$ -Al and  $U_3Si$ -Al fuels, which were identified as the most promising fuels of the first series, (b) testing variations of these fuels which might further improve their applicability, such as  $U_3Si_{1.5}$  and  $U_3Si$  with Cu impurities, and (c) testing other fuels which might offer special advantages, such as  $USi$ ,  $UA1_2$ , and  $U_6Fe$ .

Altogether, 72 miniplates fabricated by ANL and 6 fabricated by NUKEM have been under irradiation in the ORR during the past year. Table I summarizes their distribution among the various fuel types, enrichments, and fuel loadings. The plates differ greatly in the average burnups achieved so far, which range from ~26% to ~90%. Some of the early plates are already being examined, while irradiation of others has just begun. The first preliminary PIE results from these miniplates are reported elsewhere<sup>2</sup> at this meeting.

A major conclusion reached from non-destructive thickness measurements of the irradiated miniplates of this series is that the swelling rate of the  $U_6Fe$  plates is unacceptably high. Therefore, this material is no longer on our list of candidate fuels to be further tested. All the  $U_6Fe$  miniplates have been removed. Exceedingly large swelling was also experienced in  $U_3Si$  plates (6.3 g  $U/cm^3$ ) at high burnups. The results of the thickness measurements performed on all the other fuel types have been consistent with expectations.

Table I. Miniplate Numbers and Uranium Densities (g  $U/cm^3$ ) in the Second Series

Enrichment	$U_3Si_2$	$U_3Si$	$U_3Si_{1.5}$	$U_3SiCu$	$USi$	$UA1_2$	$U_6Fe$
0.2%	2 (4.8)	2 (6.1-6.2)			3 (3.7-3.8)		2 (6.9-7.1)
19.4-19.8%	12 (4.8-5.7)	15 (4.8-7.2)	5 (5.1-6.0)	6 (5.3-7.0)	4 (3.8-3.9)		4 (7.0-8.0)
40.1-44.8%	4 (3.9-5.2)	5 (4.5-6.4)	2 (3.8-3.9)	3 (3.8-4.2)	3 (3.8-3.9)	2 (3.0)	
92.6-93.0%	2 (1.7)	2 (2.0)					
TOTAL	20 (1.7-5.7)	24 (2.0-7.2)	7 (3.8-6.0)	9 (3.8-7.0)	10 (3.7-3.9)	2 (3.0)	6 (6.9-8.0)

## Full-Size Test Elements

Irradiation of all the six ORR elements fabricated in equal numbers by NUKEM, CERCA and B&W with  $U_3Si_2$ -Al at  $4.8 \text{ g U/cm}^3$  was completed by the end of 1984. One of the two elements fabricated by each fuel vendor is estimated to have reached ~50% average burnup and the other ~75% average burnup, as planned. All visual and dimensional tests performed so far indicate excellent behavior of all these elements. PIE of one element with ~41% average burnup are complete with excellent results, and those of the other elements are in progress. Irradiation of all  $UAl_x$ -Al and  $U_3O_8$ -Al has been completed.

Irradiation testing of a full-size  $U_3Si$ -Al ( $6.0 \text{ g U/cm}^3$ ) element has been in progress with good results in the SILOE reactor at the CENG, France,<sup>3</sup> where irradiation of a  $U_3Si_2$ -Al element is also scheduled to start soon. Irradiation of other  $U_3Si_2$ -Al elements with up to  $490 \text{ g }^{235}U$  per element is scheduled to start in November 1985, in the R-2 reactor at Studsvik, Sweden.<sup>4</sup> Further testing of  $U_3Si_2$ ,  $U_3Si_{1.5}$ , and  $U_3Si$  elements are at the planning stage.

## Full-Size Prototype Elements

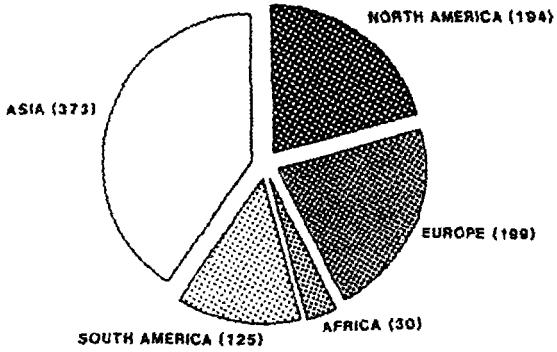
As an adjunct to the irradiation and examination of full-size LEU test elements which is part of the international RERTR demonstration activities, a number of LEU prototype elements have been fabricated for irradiation testing in various reactors.

Prototype elements provide information specific to the reactor in which the irradiation takes place, instead of aiming at the general information which is the goal of test elements. Prototype elements, however, are very valuable also in a general sense because they contribute to the establishment of a wide database concerning the performance, safety, and economy of the fuels.

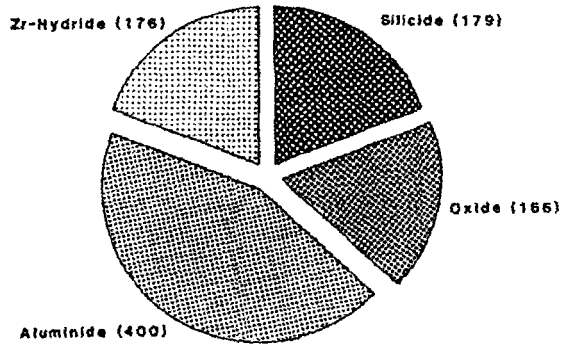
This contribution has gradually become very significant. The RERTR Program has tabulated all the prototype and test elements which are known to have been ordered with reduced enrichment and with the technologies which it has assisted in developing. The results indicate that, altogether, 921 full-size elements have been ordered for fabrication with reduced enrichment and with the new technologies.

Irradiation of these elements will provide an extensive and well diversified database on the performance of these fuels. Figure 1 illustrates the distribution of all the 921 full-size elements according to the geographical location of the reactors in which they are to be tested, their fuel type, and their enrichment.

BY CONTINENT



BY FUEL TYPE



BY ENRICHMENT

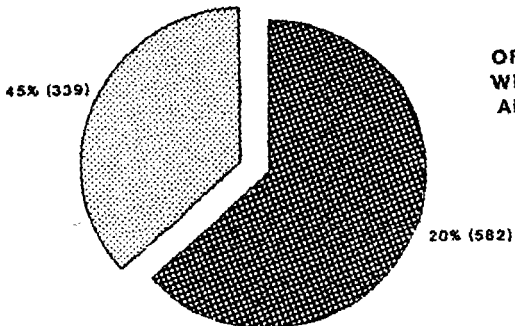


FIG. 1

DISTRIBUTION OF 921  
FULL-SIZE ELEMENTS  
ORDERED FOR FABRICATION  
WITH REDUCED ENRICHMENT  
AND RERTR TECHNOLOGIES

## Full-Core Demonstrations

Tests and calculations of the LEU FNR core have been concluded. The final results confirm that, as reported at previous meetings,<sup>5</sup> the FNR demonstration has proven the validity of RERTR evaluations and provides an important benchmark to test LEU reactor calculations. The University of Michigan has decided that the FNR will continue to be operated with LEU fuel in the future.

Procurement activities for the ORR LEU demonstration<sup>6</sup> fuel are nearing completion. Orders have been placed for 100 standard fuel elements (20 from NUKEM, 20 from CERCA and 60 from B&W), all with  $U_3Si_2-Al$  at 4.8 g U/cm<sup>3</sup>. These elements will be essentially identical to those which have already been irradiated to high burnups in the ORR. In addition, 12 control elements have been ordered from B&W with  $U_3Si_2-Al$  at 3.5 g U/cm<sup>3</sup>. The planned delivery schedule of the elements will allow beginning of the demonstration in mid-November 1985.

The ORR demonstration will provide information on performance, safety, and fuel cycle characteristics of highly-loaded LEU elements. An important goal is to test the process of converting a relatively high-power research reactor by gradual substitution of the current HEU fuel with the new LEU fuel. Thus, the ORR will be taken through the entire transition phase, beginning with an equilibrium HEU core and ending with an approximate equilibrium LEU core. The demonstration will take approximately one and one-half years to complete.

## Methods and Joint Studies

Analytical activities have progressed, with their focus on the calculations characterizing LEU utilization in several reactors with which the RERTR Program has joint study agreements. Joint studies are currently in progress with 30 organizations from 17 countries.

A relatively new computational development is the increasing importance assumed by three-dimensional calculations, which are now used almost routinely in the final evaluations performed within the program. The three-dimensional calculations make it possible to study in detail some neutron flux distributions which are difficult to evaluate in two dimensions, such as those caused by partially inserted control rods, extended fuel burnups and burnable poisons.

Nodal methods may offer a possible solution for reducing the running time of these calculations,<sup>7</sup> but the evidence is not yet conclusive.

Other relatively new activities in the analytical area have been directed to the expansion of computational methods to cover reactors of very low power. One such activity was directed to include natural circulation in the thermalhydraulics treatment of the PARET code. In general, the results obtained for low-power research reactors confirm that the use of LEU fuels in such reactors would have minimal impact on reactor operations.

#### FUTURE PROGRAM TRENDS

The continued good behavior observed in  $U_3Si_2$ -Al and  $U_3Si$ -Al fuels with LEU provides a strong incentive to concentrate most of the Program's fuel development efforts on the testing and refinement of these fuel types.

The major goals will be:

- (a) to increase as much as possible the practically useable uranium density of the silicide fuels, so that their range of applicability is extended;
- (b) to improve the fuel cycle economy of these research reactor fuels in comparison with present HEU fuels; and
- (c) to accumulate a large database on fuel performance which will facilitate licensing.

Consistent with these goals, the major RERTR planned activities can be summarized as follows:

1. Development and demonstration of LEU fuels will continue to be concentrated on  $U_3Si_2$ -Al and  $U_3Si$ -Al fuels.
2. The current miniplate fabrication campaign will be completed, and irradiation of the miniplates will continue.
3. Post-irradiation examination of the miniplates of the second series will continue and expand as more irradiated miniplates become available.
4. Post-irradiation examination of all the six  $U_3Si_2$ -Al ( $4.8 \text{ g U/cm}^3$ ) elements irradiated in the ORR will be completed in early 1986.
5. The whole-core demonstration in the ORR with  $U_3Si_2$ -Al ( $4.8 \text{ g U/cm}^3$ ) fuel will begin around the end of 1985 and continue for about one and one-half years.



6. The behavior of test and prototype elements with silicide fuels will be studied for application beyond  $4.8 \text{ g U/cm}^3$ . Elements with  $\text{U}_3\text{Si-Al}$ ,  $\text{U}_3\text{Si}_2\text{-Al}$  or intermediate compositions will be fabricated and irradiated as miniplate irradiations provide data on the optimal fabrication procedures and burnup potential of these fuels.
7. Analyses will continue to concentrate on safety, economics, and performance evaluations. Efforts will continue to define generic envelopes of safety limits for possible use in licensing reviews.

The current schematic schedule of the RERTR Program is illustrated in Figure 2, using the same format as that used at the 1984 International RERTR meeting.<sup>1</sup> Only a minor slippage in the ORR fuel procurement differentiates the two schedules.

Three important initiatives affecting the program have been under active consideration by U.S. agencies during the past year. These initiatives concern:

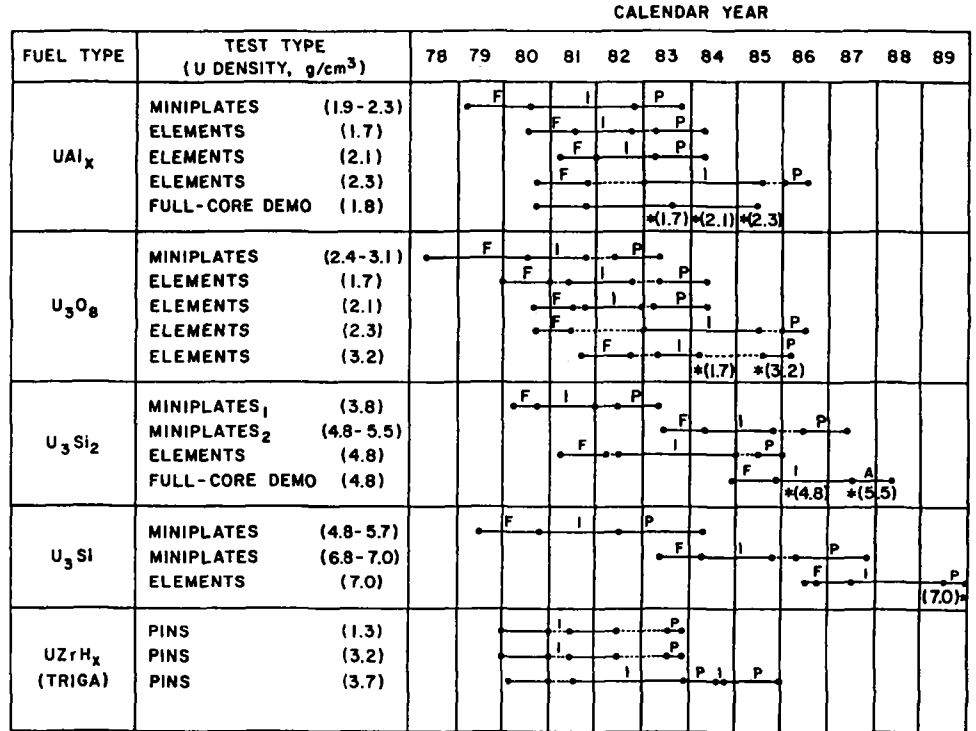
- (a) Reprocessing of spent LEU fuel (DOE),
- (b) Charges for uranium enrichment services (DOE), and
- (c) Rule limiting use of HEU in NRC-licensed non-power reactors (NRC).

The evaluation and concurrence process of these initiatives is not concluded, but it is anticipated that the first two initiatives might reduce the expected fuel cycle costs with LEU operation in comparison with those with HEU operation. The third initiative might bring about direct NRC guidance on licensing issues related to LEU conversions.

#### SUMMARY AND CONCLUSION

The RERTR Program and its many international partners have made significant progress in 1985 towards their common goals.

A new miniplate series, concentrating on  $\text{U}_3\text{Si}_2\text{-Al}$  and  $\text{U}_3\text{Si-Al}$ , has been fabricated and is well into irradiation. Six  $\text{U}_3\text{Si}_2\text{-Al}$  ( $4.8 \text{ g U/cm}^3$ ) ORR elements have been fully irradiated and PIE are in progress with excellent results. The whole-core ORR demonstration with elements of the same type is scheduled to begin in mid-November 1985.



A=ANALYSIS; F=FABRICATION; I=IRRADIATION; P=POST-IRRADIATION EXAMINATION; \*\*=QUALIFICATION DATE

Fig. 2. Schematic Schedule for BERTR Fuel Development and Demonstration Activities.

The significant number (921) of full-size elements which have been ordered to date with reduced enrichment and with the new technologies are expected to provide an extensive and well diversified database on the performance, safety, and economy of these fuels.

The RERTR Program schedule has undergone only minor changes since last year. Qualification of the most advanced LEU fuel currently considered,  $U_3Si-Al$  with  $\sim 7 \text{ g U/cm}^3$ , is still projected for 1989.

The overall progress which has been achieved since program inception, seven years ago, would have not been possible without the active international cooperation which has existed since the beginning among fuel developers, commercial vendors, and reactor operators. Continued and intensified international cooperation will be essential to the achievement of our common long-term goal.

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