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ABSTRACT

The progress of the Reduced Enrichment Research and Test Reactor (RERTR) Program is described. After a brief summary of the results which the RERTR Program, in collaboration with its many international partners, had achieved by the the end of 1986, the activities, results, and new developments which occurred in 1987 are reviewed. Irradiation of the second miniplate series, concentrating on U_3Si_2-Al and U_3Si-Al fuels, was completed and postirradiation examinations were performed on many of its miniplates. The whole-core ORR demonstration with U_3Si_2-Al fuel at 4.8 g U/cm^3 was completed at the end of March with excellent results and with 29 elements estimated to have reached at least 40% average burnup. Good progress was made in the area of LEU usage for the production of fission ^{99}Mo, and in the coordination of safety evaluations related to LEU conversions of [illegible] university reactors. Planned activities include testing and demonstrating advanced fuels intended to allow use of reduced enrichment uranium in very-high-performance reactors. Two candidate fuels are U_3Si-Al with 19.75% enrichment and U_3Si_2-Al with 45% enrichment. Demonstration of these fuels will include irradiation of full-size elements and, possibly, a full-core demonstration. Achievement of the final program goals is still projected for 1990. This progress could not have been possible without the close international cooperation which has existed from the beginning, and which is essential to the ultimate success of the RERTR Program.

INTRODUCTION

The Reduced Enrichment Research and Test Reactor (RERTR) Program was established in 1978 by the Department of Energy (DOE). It was managed and funded by DOE through 1986. Beginning in 1987, management and funding responsibility for the program was assumed by the Arms Control and Disarmament Agency (ACDA). The primary objective of the program is to develop the technology needed to use Low-Enrichment Uranium (LEU) instead of High-Enrichment Uranium (HEU) in research and test reactors, and to do so without significant penalties in experiment performance, economics, or safety aspects.

Excellent progress has been made toward the achievement of this objective through the close cooperation which has existed since the beginning between the program and the many organizations represented at this meeting. In particular, cooperation with the Comision Nacional de Energia Atomica (CNEA) has been active since 1979. As part of this cooperation, miniplates of several fuel types, including the most advanced materials considered by the program, have been fabricated in the laboratories of the CNEA, irradiated in the ORR, and examined after irradiation with excellent results. It is a pleasure to report here, in close proximity to the CNEA laboratories where this work was conducted, on the status of the RERTR Program, on last year's progress, and on our plans.

OVERVIEW OF THE NOVEMBER 1986 PROGRAM STATUS

By November 1986, when the last International RERTR Meeting was held,[1] the main results achieved in the fuel development area were:

(a) The qualified uranium densities of the three main fuels which were in operation with HEU in research reactors when the program began (UAl_x-Al with up to 1.7 g U/cm^3; U_3O_8-Al with up to 1.3 g U/cm^3; and $UZrH_x$ with 0.5 g U/cm^3) had been significantly increased. The new uranium densities extended up to 2.3 g U/cm^3 for UAl_x-Al, 3.2 g U/cm^3 for U_3O_8-Al, and 3.7 g U/cm^3 for $UZrH_x$. Each fuel had been tested extensively for up to these densities and, in some cases, beyond them. All the data needed to qualify these fuel types with LEU and with the higher uranium densities had been collected.

(b) For U_3Si_2-Al, miniplates with up to 3.8 g U/cm^3 had been fabricated by ANL and irradiated to 90-96% burnup in the ORR with excellent PIE results.

A large number of miniplates (35) with densities up to 5.7 g U/cm^3 had been included in a second miniplate series whose irradiation was in progress in the ORR. Four full-size plates, with up to 5.4 g U/cm^3, had been irradiated to an estimated 75% average burnup in the SILOE reactor at CENG, France, with excellent results.

Irradiation of a full-size element, fabricated by CERCA with 5.2 g U/cm^3, had also begun in SILOE. Six full-size elements with 4.8 g U/cm^3 had been fabricated in equal numbers by NUKEM, CERCA, and B&W, and irradiated in the ORR to very high burnups with excellent PIE results.

A whole-core demonstration was in progress in the ORR. Approximately 80% of the core had been gradually converted to LEU using standard elements fabricated by CERCA, NUKEM, and B&W, all with U_3Si_2-Al at 4.8 g U/cm^3. The demonstration core also contained control elements fabricated by B&W with U_3Si_2-Al at 3.5 g U/cm^3. Full conversion was scheduled to occur around the end of the year, and the demonstration was anticipated to last until the end of September 1987.

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

A large number of miniplates (54) had been included in the second miniplate series, with densities up to 7.2 g U/cm^3, enrichments up to 93%, greater than stochiometric Si contents, and other variations. Irradiation of the miniplates was still in progress in the ORR.

Four full-size plates, fabricated by CERCA with up to 6.0 g U/cm^3 had been successfully irradiated to 43-54% burnup in SILOE. A full-size element of $U_3Si_{1.7}$-Al with 4.7 g U/cm^3 had been fabricated by CERCA for irradiation in OSIRIS.

A full-size U_3Si-Al (6.0 g U/cm^3) element, fabricated by CERCA, had been successfully irradiated to ~55% average burnup in SILOE.

In other important program areas, reprocessing studies at the Savannah River Laboratory had concluded that the RERTR fuels could be successfully reprocessed at the Savannah River Plant and DOE had defined the terms and conditions under which these fuels will be accepted for reprocessing.

Extensive studies had been conducted, with favorable results, on the performance, safety, and economic characteristics of LEU conversions. These studies included many joint study programs, which were in progress for 28 reactors from 17 different countries.

A new analytical/experimental program had begun to determine the feasibility of using LEU instead of HEU in fission targets dedicated to the production of ^{99}Mo for medical applications.

Coordination of the safety calculations and evaluations had begun for the U.S. university reactors planning to convert to LEU as required by the recent NRC rule. Calculations for two university reactors were at an advanced stage.

PROGRESS OF THE RERTR PROGRAM IN 1987

1. Fuel Development

In the fuel development area, the efforts of the RERTR Program during 1986 have continued to be concentrated on materials which show promise for utilization in fuels with uranium densities in excess of 4.8 g U/cm^3. Irradiation of the second miniplate series in the ORR was completed in January 1987. The series included:

a) 37 U_3Si_2 miniplates with densities up to 5.7 g U/cm^3 and enrichments up to 93%;

b) 7 $U_3Si_{1.5}$ miniplates with densities up to 6.0 g U/cm^3 and enrichments up to 40%;

c) 34 U_3Si miniplates with densities up to 7.2 g U/cm^3 and enrichments up to 93%;

d) 12 U_3SiCu miniplates with densities up to 7.0 g U/cm^3 and enrichments up to 40%:

e) 24 miniplates containing other materials to provide additional general information on the behavior of dispersion fuels under irradiation.

The miniplates of the second series cover a wide range of densities, thicknesses, and enrichments. In addition, they include some special features to investigate their range of applicability. For instance, several U_3Si_2 and U_3Si miniplates include burnable poisons in their fuel meat.

Postirradiation examinations of the miniplates of the second series have made good progress,[2] but have not yet been completed. Preliminary results appear to confirm expectations based on prior results, and indicate that some improvements in fuel performance can be obtained by adjusting the variables investigated in the second series.

Progress was made also in the development of an effective comminution process for silicides, and in investigating the feasibility of using vapor deposition[3] to coat the silicide compacts with aluminum. However, only intermediate results were achieved in both of these areas.

2. Fuel Demonstration

In the area of fuel demonstration, program efforts have been concentrated on the whole-core demonstration[4] in the Oak Ridge Research Reactor (ORR). The fuel used in the demonstration is U_3Si_2-Al with 4.8 g U/cm^3, which has good potential for wide application because it combines high uranium density with relatively low fabrication cost and excellent irradiation behavior.

The demonstration began in December 1985. After extensive measurements which characterized the HEU core, the first three LEU elements were introduced in the ORR at the beginning of January. Thereafter, the demonstration continued by inserting, at every cycle, three or four additional LEU elements while an equivalent number of HEU elements were discharged. The ORR normal procedure is to operate with two cores which alternate between the reactor and the pool. A full LEU core was attained on December 10, 1986, when the last two control elements containing HEU were replaced with LEU control elements. The reactor continued to operate with an exclusively LEU core after that date, gradually approaching its equilibrium cycle and discharging spent LEU elements as they reached the normal maximum burnup.

On March 26, 1987, a DOE order caused the shutdown of the ORR and of three other ORNL research reactors. The order was caused by concerns about ORNL management procedures, and was in no way related to concerns about the operations or safety of the ORR demonstration. Within a short time, it became apparent that operation of the ORR would be interrupted for at least several months. The demonstration had been planned to continue until the end of September 1987 and to irradiate approximately 20 elements from each vendor. However, after considering carefully the uncertainty surrounding the restart of ORR operations, the large cost of maintaining the facility in operational readiness, and the extensive amount of information already acquired from the demonstration, the RERTR Program concluded that the essential goals of the demonstration had been reached and that the additional data which could have been obtained by further ORR operation would not justify the exhorbitant marginal cost. Therefore, it was decided that no further irradiations of ORR demonstration elements were required and that the demonstration was complete.

As stated last year,[1] the demonstration had two fundamental goals: a) to prove that the properties of the mixed cores corresponding to a gradual conversion can be predicted accurately, and b) to establish a statistically significant database on the irradiation behavior of fuel fabricated under commercial conditions by several international fuel vendors.

The sixteen different mixed-core configurations which were irradiated in the ORR during the transition from a totally-HEU to a totally-LEU reactor have provided a wealth of data for testing and validating our analytical models. The measurements which were performaed include critical rod positions, differential rod worths, flux mapping, isothermal temperature coefficients, gamma heating, β_{eff}, and reactivity worths of various materials.

The results of many measurements performed during the demonstration were compared with preliminary calculations within a very short time after their collection, to assist with the safety evaluations which accompanied the conversion. Agreement between these calculations and measurements was excellent in all cases, and proved beyond doubt that the simple procedure used to implement the transition to a full LEU core - merely treating the LEU elements as if they had been HEU elements - was never cause for valid safety concerns. Extensive analyses of all the experiments performed during the demonstration are now in progress[5] and will be completed during the next year.

The transition cores on which these important measurements were performed were completed in December. Another important series of calibration measurements on a fully-LEU core was performed in February. Therefore, nearly all the planned measurements were successfully completed before the end of the demonstration.

Of the 68 standard elements which were irradiated during the demonstration, 29 have reached at least 40% average burnup. Their distribution is satisfactorily uniform among the vendors (10 from CERCA, 11 from NUKEM, and 8 from B&W). These values are approximately half of those which had been planned, but are considered sufficient to establish the reliability of the commercial process on a statistical basis. All irradiated elements appear to have performed flawlessly, including the 8 control elements fabricated by B&W which have also been irradiated and some of which have reached burnups in excess of 70%. Postirradiation examinations of the elements are planned for next year.

A document summarizing all the available data on the behavior of U_3Si_2 fuel, exclusive of ORR demonstration data, was prepared[6] and submitted to the Nuclear Regulatory Commission (NRC). The document is now under review by the NRC and it is hoped that the NRC will conclude that the fuel can be safely utilized in research reactors.

In a different fuel area, the NRC ruled that TRIGA LEU fuels developed by GA Technologies and tested by the RERTR Program are generically approved for use in research reactors. The NRC also issued a similar generic approval for a number of LEU SPERT fuel pins which were qualified by the RERTR Program during the past year for use in the Rensselaer Polytechnic Institute (RPI) reactor and, possibly, in other research reactors. The RPI reactor has already been converted to use of the SPERT LEU fuel.

3. Generic Analysis and Specific Support

In the analytical area, final volumes of the IAEA Guidebook on Safety and Licensing Aspects of HEU-to-LEU Core Conversions are nearly complete. Analyses of the feasibility to convert the many foreign reactors with which the RERTR Program has joint study agreements have continued. As in previous years, some of these studies concern high-power, high-performance reactors like the HFR-Petten (The Netherlands), the BR-2 (Belgium), and the RHF (France), which require special considerations and methods. The results obtained to date are generally positive, and it is expected that prototype elements with reduced enrichment will soon begin to be tested in several of these reactors.

A significant fraction of the program's analytical efforts was dedicated to the coordination of the safety calculations and evaluations for U.S. university reactors planning to convert to LEU as required by the NRC. The calculations for three reactors (Worcester Polytechnic Institute, University of Missouri at Rolla,[7] and Ohio State University[8]) are nearly complete. Calculations for four other reactors (Manhattan College, Rhode Island Nuclear Science Center[9], University of Lowell, and University of Virginia) are in progress.

As anticipated last year, nearly all of these conversions are based on the systematic utilization of a standard fuel plate (U_3Si_2-Al, ~3.5 g U/cm^3) which minimizes overall refueling costs and simplifies safety evaluations. No significant safety problems have been encountered. Extensive upgrades are planned at several facilities in conjunction with the LEU conversion to enhance the performance and utilization of the facilities. Funding and licensing procedures for the upgrades are separate from the conversion process.

4. LEU Targets

This activity, aimed at determining the feasibility of using LEU instead of HEU in fission targets dedicated to the production of ^{99}Mo for medical applications, has made good progress.[10] Fabrication of targets with much greater uranium content, sufficient for LEU usage, appears to be feasible. Separation of ^{99}Mo from cold solutions was accomplished without major difficulties. Tests on hot solutions are planned to begin soon.

PLANNED ACTIVITIES

The information which has become available from the irradiation and postirradiation examinations of the miniplates of the second series has confirmed the good irradiation behavior, applicability, and limits of the silicide fuels. In general, the activities of the next and final years of the program will concentrate on testing, refining, and applying these fuels.

The major planned activities are:

1. Complete postirradiation examinations of the second miniplate series.

2. Fabricate test/prototype elements with U_3Si-Al using 19.75% enriched uranium and uranium density between 6 g/cm^3 and 7 g/cm^3. Detailed specifications for these elements will be based on the results from the second miniplate series.

3. Fabricate test/prototype elements with U_3Si_2-Al using 45% enriched uranium and uranium density around 4 g/cm^3. This fuel is considered as a backup for the high-density U_3Si-Al LEU fuel.

4. Irradiate both the U_3Si-Al and U_3Si_2-Al test/prototype elements in a research reactor.

5. Conduct postirradiation examinations of the irradiated elements.

6. Select one of the two fuels for fabrication of a full core of a high-performance reactor requiring very high fissile density in its fuel meat.

7. Irradiate the full reduced-enrichment core in the selected high-performance reactor. Evaluate the results.

8. In parallel with these activities, complete documentation of the fuels which have already been qualified, and support their implementation.

9. Perform calculations and evaluations for reactors preparing to undergo conversion, to assist in improving performance and in resolving safety concerns.

10. Develop a viable process, based on LEU, for the production of fission product ^{99}Mo in research reactors.

The schematic schedule for the RERTR fuel development and demonstration activities, which define the Program's critical path, is illustrated in Fig. 1. Only minor details differentiate the current schedule from last year's.

SUMMARY AND CONCLUSION

The RERTR Program and its international partners have made significant progress in 1987 towards their common goals.

Irradiation of the second miniplate series, initiated in previous years and concentrating on U_3Si-Al and U_3Si_2-Al fuels, was completed. Postirradiation examination of many of these miniplates was completed. The results obtained so far have confirmed the anticipated good behavior of these fuels under irradiation, and some of their limits. It also appears that some performance improvements can be obtained by adjusting fabrication parameters which were purposely varied among the miniplates of the series.

The ORR whole-core demonstration was completed. Sixteen mixed-core configurations were irradiated during the transition of the ORR from a fully-HEU core to a fully-LEU core. Extensive measurements were performed in these cores, and in other cores which were not irradiated but assembled for experimental purposes, to characterize in great detail the very sensitive transition period of the conversion. Agreement between the results of these measurements and preliminary calculations performed while the experiments were in progress confirmed at all times the safety of the demonstration and the validity of the computational methods. Of the 68 standard elements irradiated during the demonstration, 29 reached at least 40% burnup. These 29 elements are distributed nearly uniformly among the three international fuel vendors who fabricated the demonstration elements (CERCA, NUKEM, and B&W) and their number is sufficient to establish the reliability of the commercial process on a statistical basis.

A document summarizing all the available data on the behavior of U_3Si_2-Al fuel was prepared and submitted to the NRC. It is currently under review by the NRC for generic approval of their use in research reactors.

With a similar action, the NRC ruled that TRIGA LEU fuels developed by GA Technologies and tested by the RERTR Program are generically approved for operation in research reactors. The NRC also issued generic approval of the use of RERTR-qualified SPERT fuel pins in research reactors, and a research reactor (RPI) has already been converted to LEU fuel using these pins.

Analyses and calculations related to the implementation of LEU fuels in advanced research reactors continued. A few of the reactors under study have very special and demanding features which complicate the analysis, but the results obtained so far are generally positive and some of these reactors are on the verge of testing prototypes.

Good progress was made also in the coordination of the safety evaluations of U.S. university reactors preparing for conversion. One of these reactors has already converted, evaluations for three others have been completed, and evaluation for four more are in progress. Several of these conversion plans and evaluations will be presented at this meeting, including plans for concurrent upgrades. These plans provide good evidence of the competence, resourcefulness and hard work with which the universities are facing the task.

Plans for the future include fabrication, irradiation, and postirradiation examination of test/prototype elements of two fuel types: U_3Si-Al with 6-7 g U/cm^3 and 19.75% enrichment, and U_3Si_2-Al with 4.0 g U/cm^3 and 45% enrichment as a backup. Specifications for these elements will be based on the results of the postirradiation examinations of the second miniplate series. A full-core test in a high-performance reactors is planned for after these tests.

The overall progress which has been achieved in the area of reduced enrichment fuels for research and test reactors would not have been possible without active cooperation among international fuel developers, commercial vendors, and reactor operators. As we approach the conclusion of our work, continued and intensified cooperation will be essential to the achievement of the common goal.

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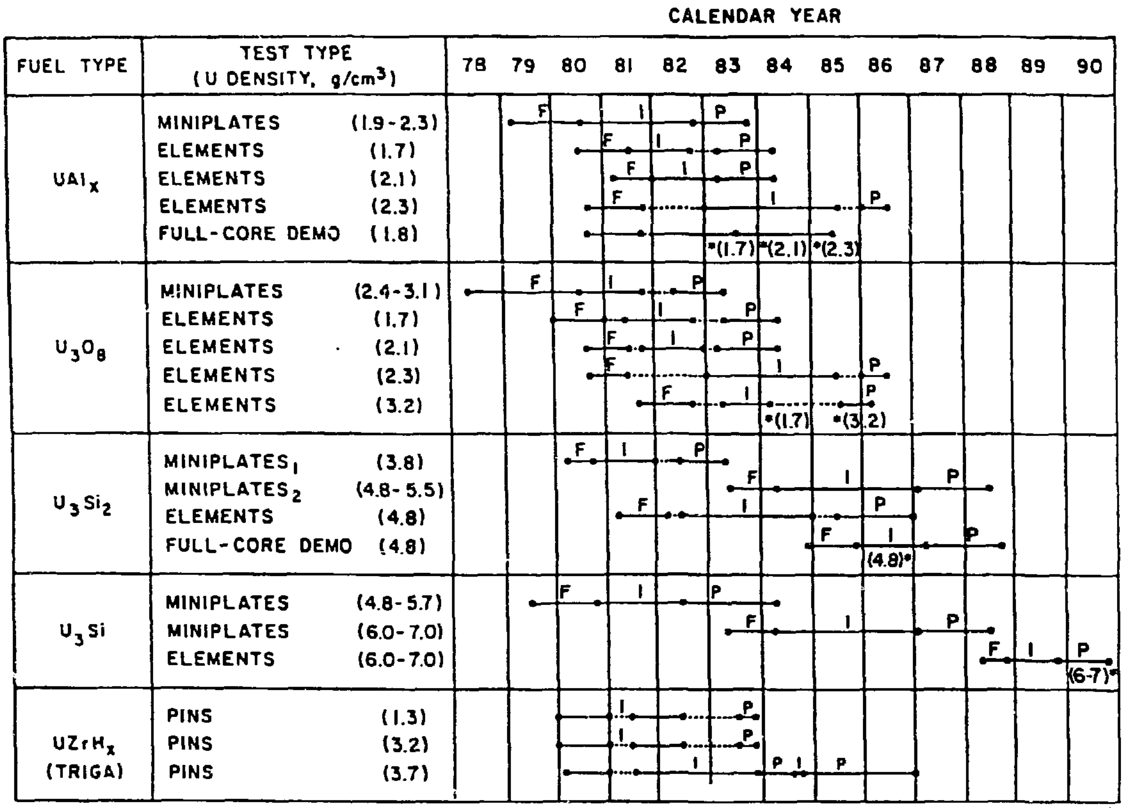
Fig. 1. Schematic Schedule for RERTR Fuel Development and Demonstration Activities.



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

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