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PROGRESS OF THE RERTR PROGRAM IN 1989*

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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 end of 1988, the major events, findings, and activities of 1989 are reviewed.

The scope of the RERTR Program activities was curtailed, in 1989, by an unexpected legislative restriction which limited the ability of the Arms Control and Disarmament Agency to adequately fund the program. Nevertheless, the thrust of the major planned program activities was maintained, and meaningful results were obtained in several areas of great significance for future work.

In particular, postirradiation examination of the U_3Si_2-Al elements irradiated during the ORR whole-core demonstration have confirmed the performance characteristics and licensability of the commercial elements used in the demonstration.

Development of new LEU plate-type fuels with very high uranium loadings was aggressively pursued, and resulted in the production of prototype miniplates for the two major concepts on which the program has concentrated its efforts. In the first concept, LEU $U_{75}Ga_{10}Si_{15}$ wires were imbedded in a solid aluminum plate; in the second concept, a W-Al dispersion compact (surrogate for U_3Si_2-Al) was used with very high W volume fraction. In both cases, hot isostatic pressure was used to bond the plates; and in both cases, the achievable uranium loading would allow LEU usage in all the research reactors studied so far by the program. However, material compatibility and irradiation performance questions remain to be addressed.

The outline of a plan for the development of the new fuels, spanning five years, was developed and is now under review by the Department of Energy, which has reassumed funding responsibility for the program.

Active international cooperation has always been the cornerstone of the RERTR Program, and continues to be essential.

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, funding responsibility for the program was assumed by the Arms Control and Disarmament Agency (ACDA) with management responsibility shared between ACDA and DOE. The primary objective of the program is to develop the technology needed to use Low-Enrichment Uranium (LEU) instead of High-Enrichment Uranium 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 Anreicherungsreduzierung in Forschungsreaktoren (AF) Program has been active since 1979.

It would take too long to list here all the areas in which the AF and RERTR Programs have successfully assisted each other. These areas include fuel development; miniplate fabrication, irradiation and examinations; test element fabrication and testing; prototype and demonstration elements for a variety of fuel types; and reactor performances and safety evaluations. In short, nearly every facet of the program. It is a pleasure to report on the status of the RERTR Program in this city of Berlin, at a meeting organized by the AF Program and by the Hahn-Meitner-Institut, and in close proximity to the BER-II reactor for which the conversion process is planned to begin soon.

OVERVIEW OF THE SEPTEMBER 1988 PROGRAM STATUS

By September 1988, 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, after reviewing the data collected by the program, the U.S. Nuclear Regulatory Commission had issued a formal and generic approval/2/ of the use of U_3Si_2-Al fuel in research and test reactors, with uranium densities up to 4.8 g/cm^3. In addition, a whole-core demonstration using this fuel had been successfully completed in the ORR using a mixed-core approach.

(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. Four full-size plates, fabricated by CERCA with up to 6.0 g U/cm^3 had been successfully irradiated to 53-54% burnup in SILOE, and a full-size U_3Si-Al (6.0 g U/cm^3) element, also fabricated by CERCA, had been successfully irradiated in SILOE with 55% burnup. However, conclusive evidence indicating that U_3Si became amorphous under irradiation had convinced the RERTR Program that this material as then developed could not be safely used beyond the limits established by the SILOE irradiations.

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. One of these reactors had already been converted, four other safety evaluations had been completed, and calculations for five more reactors were in progress.

PROGRESS OF THE RERTR PROGRAM IN 1989

The activities of the RERTR Program during the past year were strongly affected by a new legislative restriction on the funding which the Arms Control and Disarmament Agency (ACDA) can assign to any research program. Since funding responsibility for the RERTR Program resided with ACDA during fiscal year 1989, the new legislative restriction caused a significant reduction of the RERTR budget for that year compared to what had been anticipated a year ago, even though ACDA funded the program to the very limit allowed by law.

The scope of the program activities had to be reduced to conform to the new budgetary situation. Nevertheless, the program was able to maintain unchanged the thrust of the major activities planned during the previous year/1/, and to obtain results which will provide a foundation for the work that will follow in future years.

Fuel Development and Demonstration

Further tests were performed on fuels whose main development and demonstration took place in previous years, and additional documentation of the tests performed on those fuels was compiled. In particular,

1. Postirradiation examinations continued on miniplates from the second (last) miniplate series irradiated in the ORR, providing further insight on the behavior of silicide fuels under irradiation./3/

2. Postirradiation examinations were conducted on selected LEU U_3Si_2-Al elements irradiated in the ORR during the whole-core demonstration. These examinations verified conclusively/4/ that the behavior of the elements used for the demonstration and produced commercially by three international and independent fuel fabricators (Babcock & Wilcox, CERCA, and NUKEM), was consistent with the excellent behavior of the test elements used to qualify the fuel/5/.

3. Detailed analysis of experiments performed at various stages of the whole-core demonstration in the ORR continued, but are still at a preliminary stage/6/. The results obtained thus far suggest that we can calculate accurately the properties of a high-power research reactor undergoing HEU-to-LEU fuel conversion through a complex series of mixed transition core configurations. However, considerable additional work is needed to finally validate the calculational process.

4. A document was issued/7/ listing the characteristics of all miniplates irradiated in the ORR by the RERTR Program since its inception. This activity was part of a continuing effort to document as completely as possible all the fuel data acquired by the program.

The development of new LEU plate-type fuels with fuel meat densities significantly in excess of 4.8 g U/cm^3 was also aggressively pursued, along the lines planned in 1988. In particular,

5. Thin wires of LEU $U_{75}Ga_{10}Si_{15}$ were produced and imbedded and bonded in a solid aluminum plate by Hot Isostatic Pressure (HIP) techniques/8/. The result was a prototypic miniplate which, if current uncertainties about material compatibility and irradiation performance are favorably resolved, could lead to the production of thin fuel plates with extremely high uranium loadings and thin clad. (A normal dispersion-type fuel plate with the same 1.27 mm thickness and normal 0.38 mm clad would require 12.9 g U/cm^3 to achieve the same uranium loading).

6. Dense, uniform compacts were fabricated from W-Al powder dispersion mixtures (a surrogate for U_3Si_2-Al mixtures) with high W volume fractions, and successfully bonded to aluminum frames and clads by HIPping/8/. The result was a prototypic miniplate that demonstrated the fabricability of another fuel concept which could also lead to the production of fuel plates with uniform, thin cladding and very high uranium loadings. (A normal dispersion-type fuel plate with the same 1.27 mm thickness and normal 0.38 mm clad would require 8.3 g U/cm^3 to achieve the same uranium loading.)

7. Ion-bombardment and neutron-irrdiation studies of silicide fuels were continued, in an effort to shed light on the irradiation-induced amorphization process and on how it could be avoided. The results

obtained to date indicate the changes taking place in the crystal. Further experiments are planned to try to modify the crystal to prevent amorphization.

Generic Analysis and Specific Support

Analyses of the feasibility to convert the many research reactors with which the RERTR Program has joint study agreements have continued. In particular, the special problems related to the utilization of LEU in the cores of high-performance reactors reflected and moderated with heavy water have been addressed/9/. The results of these studies offer new implications for the fuels that will be required in some special cases, and will help to better focus our fuel development and analytical activities.

A significant fraction of the analytical effort was again dedicated to the coordination of the safety calculations and evaluations for U.S. university reactors planning to convert to LEU fuel as required by the U.S. Nuclear Regulatory Commission. Two more reactors from this group, at Worcester Polytechnic Institute/10/ and Ohio State University,/11/ were successfully converted during the past year. Safety documentation for three university reactors (The University of Missouri at Rolla/12/, Iowa State University, and Manhattan College) were completed and are being evaluated by the U.S. Nuclear Regulatory Commission. Work on the safety documentation of six other university reactors/13,14/ is at various stages of completion.

^{99}Mo Production

Experimental studies related to the substitution of LEU for HEU in the production of ^{99}Mo have been continued/15/. Tests have been initiated to investigate the applicability of Hot Isostatic Pressing procedures to the bonding of LEU metal foils to a Zircaloy base. These tests are aimed at the production of LEU targets with enhanced uranium content for fission ^{99}Mo generation. A procedure for basic dissolution and processing of LEU silicide targets has been developed and is ready for demonstration on a full-size target with prototypic burnup. Uranium recovery from LEU target processing is likely to be more costly than from HEU target processing since about six times the mass of uranium needs to be recovered.

PLANNED ACTIVITIES

The activities which the RERTR Program proposes to undertake during the coming years are consistent with the plan outlined at last year's international meeting, and are based on the foundation established by the work accomplished during the past year. The schedule, however, reflects the effect of the slower pace at which the reduced budget caused work to be accomplished during 1989. The major elements of this plan are described below.

1. Complete testing and documentation of the fuels which have already been developed, and support their implementation.

2. Transfer LEU fuel fabrication technology to countries and organizations which require such assistance.

3. Perform calculations and evaluations for reactors planning to undergo conversion, to assist in improving performance and in resolving safety issues.

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

5. Continue ion-bombardment and transmission electron microscope examinations, neutron irrdiation, and neutron diffraction to identify possible treatments or modifications of high-density potential fuel compounds (such as U_3Si) that would prevent them from losing their crystalline structure under irradiation.

6. Continue to investigate the application of HIPping procedures to the process of producing miniplates with wires of U_3Si (or similar materials) imbedded in the fuel meat with thin uniform cladding, and produce a full campaign of miniplates of this type for irradiation testing.

7. Continue to investigate the application of HIPping procedures to the process of producing dispersion-type U_3Si_2-Al miniplates with high fuel volume fractions in the fuel meat and thin uniform cladding, and produce a full campaign of miniplates of this type for irradiation testing.

8. Irradiate the miniplates produced in steps 6 and/or 7 in a high-flux test reactor.

9. Select the best candidate fuels on the basis of the irradiation results, and begin fabrication of full-size elements.

10. Perform postirradiation examinations of the irradiated miniplates, to assist in the safety evaluations of the full-size element irradiations.

11. Irradiate the full-size test elements in a high-flux reactor.

12. Perform postirradiation examinations of the elements and prepare a comprehensive report of the results, to be used in the qualification of the elements.

A tentative schedule for the fuel development activities which are part of this plan is illustrated in Figure 1.

Beginning in fiscal year 1990, the Department of Energy (DOE) has requested and reacquired funding responsibility for the RERTR Program. Thus, the legislative restrictions which had such serious impact on program activities in 1989 will no longer apply. The program has submitted cost estimates consistent with the activities and schedule outlined above. Preliminary DOE reviews and congressional funding proposals appear to favor full program funding. Nevertheless, further reviews are in progress in connection with the change in funding responsibility, and no final decision has yet been reached about the future scope of the program. The order in which the planned activities described above have been listed corresponds approximately to the priority with which the RERTR Program would recommend that the activities be retained if less than full funding were to be provided.

SUMMARY AND CONCLUSION

The 1989 scope of RERTR Program activities was curtailed by an unexpected legislative funding restriction. Nevertheless, the thrust of the major planned program activities was maintained, and meaningful results were obtained in several areas of great significance for future work.

Additional information on previously qualified fuels was acquired through the postirradiation examinations of miniplates from the second miniplate series and of full-size U_3Si_2-Al elements irradiated during the whole-core ORR demonstration. These tests confirmed the performance characteristics and licensability of the commercial elements used in the demonstration. In addition, detailed analyses of the experiments performed during the demonstration revealed excellent agreement between measurements and calculations, and a document describing the characteristics of all the RERTR miniplates was issued.

The development of new LEU plate-type fuels with very high uranium loadings was aggressively pursued, and resulted in the production of prototype miniplates for the two major concepts on which the program has concentrated its efforts. In the first concept, LEU $U_{75}Ga_{10}Si_{15}$ wires were imbedded in a solid aluminum plate; in the second concept a W-Al (a surrogate for U_3Si_2-Al) dispersion compact was used with very high W volume fraction. In both cases, hot isostatic pressing bonded the plates; and in both cases, the achievable uranium loading is so high that it would allow LEU usage in all the research reactors studied so far by the program. However, material compatibility and irradiation performance questions remain to be addressed.

Analyses of the feasibility to convert to LEU fuels high-performance research reactors has led to new conclusions, and new implications about the fuel types that will be required in some special cases. Coordination of the safety calculations and evaluations for the conversion of U.S. university reactors has continued. Two of these reactors were converted during the past year, three other safety evaluations were completed, and six more are in progress.

Experimental studies related to the production of fission ^{99}Mo from LEU targets have progressed, and tests were initiated to assess the feasibility of increasing the uranium loading of these targets by HIPping uranium foils on a Zircaloy base.

The outline of a plan for the development of the new fuels, spanning five years, was developed and is now under review.

Active cooperation among international fuel developers, commercial vendors, and reactor operators, has always been the cornerstone on which the success of the overall RERTR effort was based. Now, more than ever, we are looking forward to continued international cooperation as we strive to achieve our common goals.

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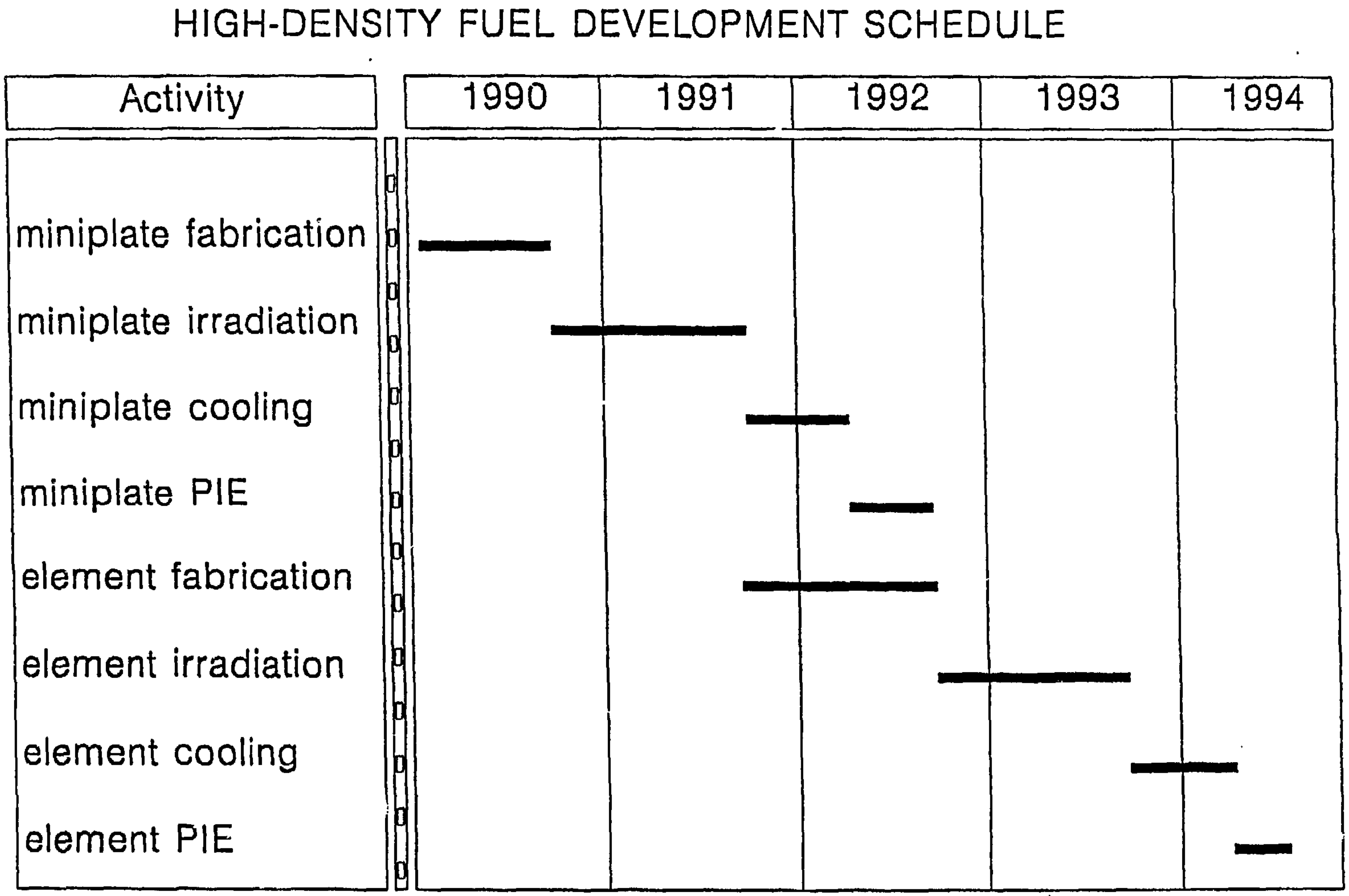
HIGH-DENSITY FUEL DEVELOPMENT SCHEDULE
Activity
1990
1991
1992
1993
1994
miniplate fabrication
miniplate irradiation
miniplate cooling
miniplate PIE
element fabrication
element irradiation
element cooling
element PIE

Figure 1.

A SERIOUS FUNDING PROBLEM DEVELOPED IN 1989

A legislative restriction on the funding which ACDA can assign to any research program came into effect.

ACDA funded the RERTR Program to the very limit allowed by law.

The thrust of the major planned activities was maintained, but their scope had to be curtailed.

FURTHER TESTS AND DOCUMENTATION OF PREVIOUSLY DEVELOPED FUELS

PIEs of the second (last) miniplate series irradiated in the ORR were continued.

PIEs of selected elements used in the ORR whole-core demonstration were conducted.

Detailed analysis of the ORR whole-core demonstration experiments continued.

A document was issued listind the characteristics of all RERTR miniplates.

DEVELOPMENT OF NEW HIGH-DENSITY FUELS

Thin wires of LEU U(75)Ga(10)Si(15) were produced, and were imbedded and bonded by Hot Isostatic Pressure (HIP) in solid aluminum plates.

Dense, uniform compacts of W-Al powder (a surrogate for U(3)Si(2)-Al powder) were fabricated with high W volume fraction and were bonded by HIPping.

Ion bombardment and neutron irradiation studies continued, to study irradiation-induced amorphization.

GENERIC ANALYSIS AND SPECIFIC SUPPORT

Conversion studies of high-performance reactors moderated and reflected by heavy water were conducted.

Two additional U.S. university reactors were successfully converted to the use of LEU fuels.

Safety documentations for the LEU conversion of three U.S. university reactors were completed.

Work on the safety documentation of the conversion of six additional U.S. university reactors is in progress.

PRODUCTION OF FISSION 99Mo FROM LEU TARGETS

Tests have been initiated to assess the feasibility of bonding U foils to a Zircaloy base by Hot Isostatic Pressure.

A procedure for basic dissolution and processing of LEU silicide targets is ready for testing under prototypic conditions.

PLANNED ACTIVITIES

Complete testing and documentation of already developed fuels, and support their implementation.

Transfer LEU fuel fabrication technology to countries and organizations which require it.

Perform calculations and evaluations for reactors planning conversion, to assist in improving performance and resolving safety issues.

Develop a viable process, based on LEU, for the production of fission 99Mo.

PLANNED ACTIVITIES
(continued)

Continue ion-bombardment and TEM examinations, neutron irradiation, and neutron diffraction tests to study and prevent the onset of fuel amorphization.

Continue to investigate the application of HIPping to produce miniplates with wires of U3Si (or similar materials) embedded in Al, and produce a full campaign.

Continue to investigate the application of HIPping to the production of miniplates with dense, uniform U3Si2 dispersions, and produce a full campaign.

PLANNED ACTIVITIES (continued)

Irradiate the miniplates produced in both campaigns in a high-flux test reactor.

Select the best candidate fuels on the basis of miniplate irradiation results, and begin fabrication of full-size elements.

Perform PIEs of the irradiated miniplates, to assist in the safety evaluations of the full-size element irradiations.

PLANNED ACTIVITIES (continued)

Irradiate the full-size elements in a high-flux test reactor.

Perform PIEs of the irradiated full-size elements.

Prepare a comprehensive report on the irradiation performance of the new fuels, to be used for fuel qualification.

HIGH-DENSITY FUEL DEVELOPMENT SCHEDULE