THE RERTR PROGRAM: A STATUS REPORT*

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ABSTRACT

This paper describes the progress achieved by the Reduced Enrichment for Research and Test Reactors (RERTR) Program in collaboration with its many international partners since its inception in 1978. A brief summary of the results that the program had attained by the end of 1997 is followed by a detailed review of the major events, findings, and activities that took place in 1998.

The past year was characterized by exceptionally important accomplishments and events for the RERTR program.

Four additional shipments of spent fuel from foreign research reactors were accepted by the U.S. Altogether, 2,231 spent fuel assemblies from foreign research reactors have been received by the U.S. under the acceptance policy.

Fuel development activities began to yield solid results. Irradiations of the first two batches of microplates were completed. Preliminary postirradiation examinations of these microplates indicate excellent irradiation behavior of some of the fuel materials that were tested. These materials hold the promise of achieving the program goal of developing LEU research reactor fuels with uranium density in the 8-9 g $/cm^3$ range.

Progress was made in the Russian RERTR program, which aims to develop and demonstrate the technical means needed to convert Russian-supplied research reactors to LEU fuels. Feasibility studies for converting to LEU fuel four Russian-designed research reactors (IR-8 in Russia, Budapest research reactor in Hungary, MARIA in Poland, and WWR-SM in Uzbekistan) were completed.

A new program activity began to study the feasibility of converting three Russian plutonium production reactors to the use of low-enriched UO_2-Al dispersion fuel, so that they can continue to produce heat and electricity without producing significant amounts of plutonium.

The study of an alternative LEU core for the FRM-II design has been extended to address, with favorable results, the transient performance of the core under hypothetical accident conditions.

A major milestone was accomplished in the development of a process to produce molybdenum-99 from fission targets utilizing LEU instead of HEU. Targets containing LEU metal foils were irradiated in the RAS-GAS reactor at BATAN, Indonesia, and molybdenum-99 was successfully extracted through the ensuing process.

These are exciting times for the program and for all those involved in it, and last year's successes augur well for the future. However, as in the past, the success of the RERTR program will depend on the international friendship and cooperation that have always been its trademark.

INTRODUCTION

This is the twenty-first time that specialists from all over the world have gathered under the aegis of the Reduced Enrichment for Research and Test Reactors (RERTR) Program to exchange information about their activities, to coordinate their efforts, to make new friendships, and to renew old ones.

The RERTR Program was established in 1978 at the Argonne National Laboratory (ANL) by the Department of Energy (DOE), which continues to fund the program and to manage it in coordination with the Department of State (DOS), the Arms Control and Disarmament Agency (ACDA), and the Nuclear Regulatory Commission (NRC). The primary objective of the program is to develop the technology needed to use low-enriched uranium (LEU) instead of high-enriched uranium (HEU) in research and test reactors, and to do so without significant penalties in experiment performance, economic, or safety aspects of the reactors. Research and test reactors utilize nearly all the HEU that is used today in civil nuclear programs.
Close cooperation with international organizations has been the cornerstone of the RERTR Program since its beginning. This cooperation and the high quality of the technical contributions that many partners have brought to the overall effort are to be credited for much of the progress that the program has achieved.

It is especially appropriate, this year, that the meeting is held in São Paulo, Brazil, close to the IPEN site where the IEA-R1 reactor is located. During the past year, the IAE-R1 reactor was fully converted to the use of low-enriched uranium fuel. The new LEU fuel used in the conversion of the IEA-R1 was qualified and fabricated by IPEN, and IPEN is participating fully in the U.S. spent fuel acceptance program. In addition, the reactor has been upgraded in power along with many other upgrades in combination with the conversion. We have much to learn from the manner in which IPEN has faced these tasks, and I believe that holding our meeting here is a fitting tribute to the IPEN accomplishments.

I am looking forward to listening to the many interesting papers listed in the agenda, and to interacting with the other participants, so that we may learn from each other, as we did in the past, how better to achieve our common goals. I am also looking forward to the opportunity of visiting IPEN, its facilities, and the immense and vibrant metropolis of São Paulo.

OVERVIEW OF THE PROGRAM STATUS

By October 1997, when the last International RERTR Meeting was held[1], many important results had been achieved in the fuel development area:

(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 increased significantly. The new qualified 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 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 (NRC) had issued a formal 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. A whole-core demonstration using this fuel had been successfully completed in the ORR using a mixed-core approach. This type of fuel had become internationally accepted, and was routinely fabricated for nineteen reactors by four fuel fabricators in four countries, with five more fuel fabricators in as many countries preparing to do so. Plates with uranium densities of up to 6.0 g/cm^3 had been fabricated by CERCA with a proprietary process, but had not yet been tested under irradiation.

(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 Oak Ridge Research Reactor (ORR). Postirradiation examinations of these miniplates had given good results, but had shown that burnup limits would 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 to 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 used safely in plates beyond the limits established by the SILOE irradiations.

(d) Limited work had been accomplished to develop methods for producing plates with much higher effective uranium loadings. The effort to develop new advanced LEU fuels had been restarted after a pause of about six years. Two batches of microplates containing a variety of promising fuel materials, including dispersion fuels containing U-Mo and U-Zr-Nb alloys, were being irradiated in the Advanced Test Reactor (ATR) in Idaho.

Important results had been obtained also in other areas. Reprocessing studies at the Savannah River Site (SRS) had concluded that the RERTR fuels could be successfully reprocessed there and DOE had defined the terms and conditions under which these fuels would be accepted for reprocessing. These results had been rendered moot, however, by DOE's decision to phase out reprocessing at SRS and by the expiration of the Off-Site Fuel Policy at the end of 1988. An Environmental Impact Statement and a related Record of Decision had been completed in May 1996 for a new DOE policy allowing, until May 2009, the return of spent research reactor fuel elements of U.S. origin irradiated before 13 May 2006.

An analytical/experimental program was in progress to determine the feasibility of using LEU instead of HEU in fission targets dedicated to the production of ^{99}Mo for medical applications. Procedures had been developed for dissolution and processing of both LEU silicide targets and LEU metal foil targets. These procedures were ready for demonstrations on full-size targets with prototypic burnups. Two series of LEU metal foil targets had been irradiated in the RAS-GAS reactor at BATAN, Indonesia, but difficulties had been encountered in separating the irradiated uranium foils from their enclosures. Methods had been developed to overcome this problem, but remained to be tested.

Extensive studies had been conducted, with positive results, on the performance, safety, and economic characteristics of LEU conversions. These studies included many joint study programs that were in progress for about 32 reactors from 21 countries. A study to assess the feasibility of using LEU in the fuel of a modified version of the FRM-II reactor, which was being designed with HEU at the Technical University of Munich, had stimulated spirited discussions.

Coordination of the safety calculations and evaluations was continuing for the U.S. university reactors planning to convert to LEU as required by the 1986 NRC rule. Nine of these reactors had been converted, safety evaluations had been completed for four other reactors, and calculations for four more reactors were in progress.

The end of the Cold War, which prompted the DOE decision to phase out reprocessing at SRS, also enabled a new cooperation between the RERTR program and several Russian institutes with the goal of converting to LEU many Russian-designed research reactors still operating with HEU. International attention had become increasingly focused on the dangers of nuclear proliferation and had resulted in increased support for the goals of the RERTR program, especially after it became known that in 1990 Iraq had been on the verge of acquiring and using a nuclear weapon built from research reactor fuels containing HEU.

LEU fuels were planned for the new MPR-10 TRIGA reactor in Thailand, the new MAPLE1 and MAPLE2 reactors in Canada, the new Jules Horowitz Reactor in France, and the new China Advanced Research Reactor in China. However, there was increasing pressure for HEU use in some new research reactors pushing the limits of current technology. The Advanced Neutron Source Reactor had been discontinued by the U.S. Congress, but the FRM-II reactor in Germany was still being designed with HEU fuel, and so was the PIK reactor in Russia. New and better LEU fuels were needed to convert the most demanding existing reactors and to encourage the use of LEU fuels in research reactors yet to be built.

PROGRESS OF THE RERTR PROGRAM IN 1998

The main events, findings, and activities of the RERTR Program during the past twelve months are summarized below.

1. The United States Foreign Research Reactor Spent Nuclear Fuel (FRRSNF) Acceptance Program had a very successful year since October 1997. Four research reactor spent fuel shipments containing 858 fuel assemblies were received by the Savannah River Site (SRS), and one shipment containing 299 fuel assemblies was received by the Idaho National Engineering and Environmental Laboratory (INEEL). Including the four previous analogous shipments that occurred in 1996 and 1997 and the two Urgent Relief shipments that occurred in 1994 and 1995, altogether 2,231 FRRSNF assemblies have been accepted by the United States. These shipments, and other similar future shipments which will be conducted in accordance with the Final Environmental Impact Statement[3] and the related Record Of Decision[4], are expected to eliminate the large inventories of spent fuel which currently fill the pools and storage facilities of many research reactors. The process is consistent with U.S. policy[5] and will resolve urgent operational problems of the reactor sites while, at the same time, eliminating a serious proliferation concern.

2. The fuel development effort whose resumption was urged by the attendees of the 1995 International RERTR Meeting in Paris, and which was actually restarted about two and a half years ago, has begun to achieve important results. The first batch of microplates irradiated in the ATR reactor in Idaho to 40% burnup was removed from the core in November 1997. The second batch of microplates was removed from the same core in July

1998 with 70% burnup. After a suitable cooling time, some of these microplates have been examined[6]. At least one of the fuels that have been tested in this process, the U-10Mo fuel, shows excellent behavior under irradiation and substantial promise for achieving the program goal of developing LEU fuel meat with a uranium density of 8-9 g/cm^3.

3. An analytical model was developed to predict the behavior of stabilized uranium alloys under irradiation in dispersion fuels, and to interpret the results of the ATR microplate irradiations[7]. On the basis of the results of the ATR microplate irradiations and of their interpretation, combined with theoretical considerations[8], a fuel development plan has been developed[9] to define the compositions that will be used in the next batch of microplates to be tested through in-core irradiations.

4. Some important aspects of fuel structure and fabrication that are common to all the major fuels under consideration have been investigated. These aspects include the feasibility of using materials less reactive with uranium than aluminum, such as magnesium, in the matrix of the fuel cores[10], and the most efficient available processes for fabricating powders of uranium alloys suitable for use in fuel plate production[11].

5. Cooperation with various components of the Russian RERTR program has continued. The main Russian organizations taking part in this effort include the Research and Development Institute of Power Engineering (RDIPE), the All-Russian Research and Development Institute of Inorganic Materials (VNIINM), the Novosibirsk Chemical Concentrates Plant (NZChK), the Russian Research Center "Kurchatov Institute"(RRCKI), the Research Institute of Atomic Reactors (RIAR), and the Petersburg Nuclear Physics Institute (PNPI). The purpose of the activity is to conduct the studies, analyses, fuel development, and fuel tests needed to establish the technical and economic feasibility of converting Russian-supplied research and test reactors to the use of LEU fuels. Significant results that were obtained during the past year included the continued irradiation of LEU UO_2-Al elements[12] and analytical studies to investigate the feasibility of converting to the use of LEU fuels several Russian-designed research reactors currently operating with HEU fuels. These reactors include the IR-8 reactor in Russia[13], the Budapest research reactor in Hungary[14], the MARIA reactor in Poland[15], and the WWR-SM reactor in Uzbekistan[16].

6. During the past year, the RERTR program has become involved in a new, very important activity which is not part of its primary objective, but which fits well with the program goals and to which the program can make significant contributions because of its unique capabilities. Three powerful nuclear reactors fueled with natural uranium were built in Russia in the 1960s to produce plutonium, heat, and electricity. Two of these reactors are at Tomsk-7, and one is at Krasnoyarsk-26. Thanks to the end of the Cold War the plutonium is no longer needed, but the reactors must continue to operate in order to supply the heat and electricity which are still needed in the harsh Siberian climate. An ongoing program aims at converting these reactors to the use of UO_2-Al dispersion fuel, containing 90% enriched uranium, that would eliminate the production of significant quantities of plutonium. The RERTR program has been tasked by DOE to assess, with the assistance of a Russian LEU Expert Group, the feasibility of achieving the same goal using LEU fuel instead of HEU fuel. The first conclusions of this feasibility study will be presented at this meeting[17].

7. In the area of Reactor Analysis, significant improvements were made to the methods and codes available to study the performance and safety characteristics of research reactors. These improvements include a comprehensive upgrade of the WIMS-ANL code[18] and the development of methods and codes to improve full-core Monte Carlo burnup calculations[19, 20].

8. The study of an alternative LEU core which could provide the same experiment performance and the same fuel lifetime as the HEU core currently planned for the FRM-II has continued in order to address the remaining technical issues raised at previous meetings. In particular, the nuclear transients resulting from power ramps and from hypothetical accident conditions in the two cores were calculated and compared to each other, with favorable results[21]. Separately, the thermal-hydraulics effects of transverse power distribution in involute fuel plates were studied with and without oxide film formation[22].

9. Progress was also achieved during the past year on several aspects of producing ^{99}Mo from fission targets utilizing LEU instead of HEU. The goal is to develop and demonstrate during the next few years one or more viable technologies compatible with the processes currently in use with HEU at various production sites throughout the world. This activity is conducted in cooperation with several other laboratories including Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and the Indonesian National Atomic Energy Agency (BATAN). During the past year, the chemical processes to be used in combination with LEU metal foils have been refined[23]. Most importantly, a third series of LEU metal-foil targets were irradiated in the RSG-GAS research reactor at BATAN and, after separation from their enclosures, were successfully processed to extract from them the ^{99}Mo formed during the irradiation[24].

10. During the past year, conversion of the IEA-R1 reactor in Brazil to LEU U_3O_8 dispersion fuel was completed, the JRR-4 reactor in Japan was fully converted, and the first LEU elements were inserted into the HOR reactor in the Netherlands. With these developments, the research reactors that have been fully converted to LEU fuels outside the United States now include ASTRA, DR-3, FRG-1, IAN-R1, IEA-R1, JMTR, JRR-4, NRCRR, NRU, OSIRIS, PARR, PRR-1, RA-3, R-2, SAPHIR, SL-M, THOR, and TR-2, while those that have been fully converted in the U.S. include FNR, GTRR, ISUR, MCZPR, OSUR, RINSC, RPI, UMR-R, UVAR, and WPIR. Five foreign reactors, BER-II, SSR, HOR, TRIGA II Vienna, and TRIGA II Ljubljana, have been partially converted, and three more, GRR-1, La Reina, and MNR, have fabricated or ordered LEU cores. (SAPHIR, TR-2, GTRR, ISUR, MCZPR, and UVAR were shut down after conversion). Approximately 65% of the work required to eliminate use of HEU in U.S.-supplied research reactors has been accomplished.

PLANNED ACTIVITIES

The major activities that the RERTR Program plans to undertake during the coming year are described below.

1. Complete procurement and installation of fuel fabrication equipment needed to develop advanced fuels.

2. Complete postirradiation examination of the first two batches of microplates irradiated in the ATR.

3. Begin production of a third batch of microplates for irradiation in the ATR, including samples of various materials of interest for advanced fuel development, chosen on the basis of the results from the first two batches.

4. Continue out-of-pile tests on some of the fuel materials, to assess their properties and likely performance.

5. Continue irradiation testing of microplates in the ATR.

6. In collaboration with the Russian RERTR program, continue to implement the studies, analyses, fuel development, and fuel tests needed to establish the technical and economic feasibility of converting Russian-supplied research and test reactors to the use of LEU fuels.

7. Continue to assess the feasibility of converting the Russian plutonium production reactors to the use of LEU dispersion fuels.

8. Continue LEU conversion feasibility studies for U.S. reactors. Continue calculations and evaluations about the technical and economic feasibility of utilizing reduced-enrichment fuels in reactors that require such assistance, and in reactors of special interest.

9. Continue development of one or more viable processes based on LEU, for the production of fission ^{99}Mo in research reactors. Future international collaboration is expected to include CNEA (Argentina), KAERI (Korea), ANSTO (Australia), and NORDION (Canada).

10. Complete the testing, analysis, and documentation of LEU fuels that have already been developed, support their implementation, and transfer their fabrication technology to countries and organizations that require such assistance.

SUMMARY AND CONCLUSION

The past year of the RERTR program has been distinguished by exceptionally important accomplishments and events.

a) In the area of **U.S. acceptance of spent fuel** from foreign research reactors, five additional shipments have taken place, including 1,157 fuel assemblies. This brings to 2,231 the total number of spent fuel assemblies that have been accepted by the U.S. under the FRRSNF Acceptance Policy.

b) In the area of advanced **fuel development**, postirradiation examinations of the first two batches of microplates irradiated in the ATR has revealed excellent irradiation behavior of the U-10Mo dispersion fuel. This fuel material holds the promise of meeting the program goal of developing an LEU fuel with uranium density of 8-9 g/cm^3 in its core.

c) Significant progress has been achieved in the **Russian RERTR program**, which aims to develop and demonstrate the technical means needed to convert Russian-supplied research reactors to LEU fuels.

d) A new program activity addresses the feasibility of converting three **Russian plutonium production reactors** to the use of low-enriched UO_2-Al dispersion fuel, so that they can continue to produce heat and electricity without producing significant amounts of plutonium.

e) **Computational methods** have been developed or upgraded to assess with greater accuracy the performance and safety of research reactors.

f) The study of an alternative LEU core for the **FRM-II design** has been extended to address, with favorable results, the transients that would be caused by hypothetical accident conditions.

g) A major milestone was accomplished in the effort to develop a process to produce **molybdenum-99** from fission targets utilizing LEU instead of HEU. Targets containing LEU metal foils were irradiated in the RAS-GAS reactor at BATAN, Indonesia, and ^{99}Mo was successfully extracted from the ensuing process.

h) New **conversion** activities have brought to 36 the number of reactors that have been converted or are in the process of being converted.

i) These are exciting times for the program and for all those involved in it. In particular, the successes of the fuel development and ^{99}Mo process development efforts, and the new challenges related to the conversion of the Russian plutonium production reactors, are stimulating new ideas and activities. Thanks to the success of the U.S. FRRSNF Acceptance Policy, the problem of many research reactors holding spent fuel of U.S. origin, which loomed so large four years ago, is now under control. Discussions are under way for the resolution of the corresponding problem of research reactors holding spent fuel of Russian origin.

As in the past, success of the RERTR program depends on free exchange of ideas and information. With the international friendship and cooperation that have been a trademark of the RERTR program since its inception, the program goal of eliminating the international traffic of HEU for civilian purposes appears to be within reach.

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