PROGRESS OF THE RERTR PROGRAM IN 1999*

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Presented at the

1999 International Meeting on

Reduced Enrichment for Research and Test Reactors

October 3-8, 1999

Budapest, Hungary

*Work supported by the US Department of Energy
Office of Nonproliferation and National Security
under Contract No. W-31-109-38-ENG.

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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 during 1999 and discusses planned activities for the coming year.

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

- Three additional shipments containing 1,006 spent fuel assemblies from foreign research reactors were accepted by the U.S. Altogether, 3,237 spent fuel assemblies from foreign research reactors have been received by the U.S. under the acceptance policy.
- Postirradiation examinations of the first two batches of microplates revealed good irradiation behavior of U-6Mo, and excellent irradiation behavior of U-Mo alloys with higher Mo content or with small Ru additions. Irradiation of a new batch of microplates to investigate the behavior of these fuels at high temperatures is scheduled to begin in October 1999. These materials hold the promise of achieving the program goal of developing LEU research reactor fuels with uranium densities in the 8-9 g /cm^3 range.
- Progress on irradiation testing and safety analyses 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.
- The U.S. Government has decided to aggressively pursue, in cooperation with the Russian Government, eventual conversion of three Russian plutonium production reactors to the use of low-enriched UO_2-Al dispersion fuel. This effort is now proceeding, with assistance from RERTR personnel.
- At the request of the German government, the RERTR program has addressed the performance of a new alternative LEU FRM-II core design that could be installed in the same building structure erected for the current 20 MW HEU design with the same 50-day fuel life. The results have been favorable.
- Significant improvements were made in the design of an LEU metal-foil target that would allow efficient production of fission ^{99}Mo without reliance on HEU. Targets containing LEU metal foils in the new target design were irradiated in the RAS-GAS reactor at BATAN, Indonesia, the foils were separated from the targets, and ^{99}Mo was successfully extracted.

These are exciting times for the program. The most interesting developments, and the greatest challenges, are in the fuel development area. The RERTR plans to aggressively pursue the goal of achieving 8-9 gU/cm^3 in the fuel meat. In addition, the program plans to qualify as soon as possible, working in conjunction with commercial fuel fabricators, U-Mo fuels with 5-6 gU/cm^3

that can be used as substitutes for silicide fuels. 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-second time that scientists 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) 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 used 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 gives me special pleasure to attend this year the last International RERTR Meeting of the second millennium at KFKI, in Budapest, Hungary. The Budapest Research Reactor (BRR) is different from most of the other research reactors that have been described in the past at our meetings, because it is based on a Russian design. Holding the meeting here this year is especially fitting because of the excellent technical capabilities of KFKI, the efficient and constructive attitude with which KFKI is preparing to convert the BRR to LEU fuel, and the growing importance of Russian-designed research reactors within the RERTR program.

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 the KFKI facilities and the charming sites of historical Budapest.

OVERVIEW OF THE PROGRAM STATUS

By October 1998, 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 Oak Ridge Research Reactor (ORR) using a mixed-core approach. This type of fuel had become internationally accepted, and was routinely fabricated for twenty 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 and full-size elements with 5.8 g/cm^3 had been fabricated by CERCA and had been irradiated to 55% and 74% burnup, respectively, with good preliminary results.

(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. 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) The effort to develop new advanced LEU fuels with much higher effective uranium loadings had been restarted in 1996 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, had been irradiated in the Advanced Test Reactor (ATR) in Idaho. Preliminary examination had indicated very promising behavior of microplates containing U-10Mo alloy dispersion particles in an aluminum matrix

Important results had been obtained also in other areas. Reprocessing studies at the Savannah River Site (SRS) had concluded in 1983 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. Three series of LEU metal foil targets had been irradiated in the RAS-GAS reactor at BATAN, Indonesia. The LEU foil targets from the third series had been successfully separated from their enclosure and the ^{99}Mo had been extracted. The targets and the process still needed to be optimized.

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 HEU from research reactor fuel for use in a nuclear weapons program.

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, the new China Advanced Research Reactor in China, and the new Replacement Reactor in Australia. However, some reactor designs still considered use of HEU in their fuels. 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 use of LEU fuels in research reactors yet to be built.

PROGRESS OF THE RERTR PROGRAM IN 1999

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 18 October 1998. Three additional shipments of spent research reactor fuel containing 560 MTR-type elements were received at the Savannah River Site (SRS), and one additional shipment containing 446 TRIGA elements was received at the Idaho National Engineering and Environmental Laboratory (INEEL). With these additional shipments, 2,492 MTR elements have been received at SRS and 745 TRIGA elements have been received at INEEL under the FRRSNF program, for a total of 3,237 elements. 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 greatly reduce the inventories of spent fuel at many research reactor facilities worldwide. The process is consistent with U.S. policy [5] and will resolve operational problems of the reactor sites while, at the same time, eliminating a serious proliferation concern.

2. The effort to develop new LEU research reactor fuels with a uranium density of 8-9 g/cm^3 in their fuel meat made excellent progress during the past year. Examination of the two batches of microplates that were irradiated in the ATR (RERTR-1, removed in November 1997 with 40% burnup, and RERTR-2, removed in July 1998 with 70% burnup) has provided very important results [6, 7]. Some of the materials tested (e.g., U-Zr-Nb alloys) were found to behave poorly under irradiation and have been removed from the list of candidate fuels. By contrast, many of the U-Mo alloys were found to have excellent behavior under irradiation and are now the focus

of the RERTR fuel development effort. In particular, U-Mo alloys with a 6% weight content of Mo behaved well. U-Mo alloys with higher Mo contents, or with small additions of Ru, behaved very well.

3. A new irradiation experiment to investigate the behavior of the new fuels at high temperatures has been assembled and is planned to begin irradiation testing in October 1999 [8]. Microplates containing all the main U-Mo alloy dispersion fuels of interest, in addition to some microplates containing U_3Si_2, will be irradiated in this experiment under prototypic reactor conditions. All the U-Mo plates have a uranium density of at least 8 g/cm^3 in their fuel meat, and the peak temperature of many of the fuel plates is planned to exceed 200ºC.

4. The analytical model developed to predict the behavior of stabilized uranium alloys under irradiation in dispersion fuels has been modified to take into account the results of the ATR microplate irradiations and data from prior UO_2 and U_3O_8 irradiations [9]. The new model is based on remarkably similar behavior exhibited by U-Mo, UO_2, and U_3O_8 fuel particles under irradiation.

5. Cooperation with various components of the Russian RERTR program has continued [10, 14]. The purpose of the activity is to conduct the conversion studies, safety 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 in the WWR-M reactor at the Petersburg Nuclear Physics Institute in Russia. In addition, analytical studies were conducted 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 Moscow, Russia [11], the Budapest research reactor in Hungary [12], the MARIA reactor in Poland [13], and the WWR-M reactor in St. Petersburg, Russia [14].

6. During the past year, the U.S. Government has reviewed the results of the feasibility study [15] of converting the Russian Plutonium Production Reactors (RPPR) to the use LEU fuels. As a result of this review, the U.S. Government has decided to aggressively pursue, in cooperation with the Russian Government, the option of using LEU fuels in the conversion of the RPPRs. One hundred and two LEU test fuel elements have been fabricated, and their irradiation is planned to begin soon. RERTR program personnel are involved in this effort.

7. The study of alternative LEU cores that could provide the same experiment performance and the same fuel lifetime as the HEU core currently planned for the FRM-II has continued [16]. In January 1999, the German Federal Government established a BMBF Expert Commission to evaluate the feasibility of converting the FRM-II design from HEU to LEU fuel. At the request of the BMBF Expert Commission, the RERTR program has assessed the performance of a new alternative LEU FRM-II core design that could be installed in the same building structure erected for the current 20 MW HEU design with the same 50-day fuel life. The results of this study determined that, with core thermal powers of 20 MW and 22 MW, the thermal neutron fluxes in the cold neutron source of the alternative LEU design would be 85% and 93% of the corresponding value of the 20 MW HEU design. The BMBF Expert Commission issued a report in June 1999, summarizing their findings. A decision on the fuel enrichment that the FRM-II will use is expected by the end of 1999.

8. Significant progress was achieved during the past year on several aspects of producing ^{99}Mo from fission targets utilizing LEU instead of HEU [17]. 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 the Indonesian National Nuclear Energy Agency (BATAN), the Australian Nuclear Science and Technology Organization (ANSTO), and the Argentina Comision Nacional de Energia Atomica (CNEA). Cooperation in this area is also being discussed with MDS Nordion and AECL (Canada), with Mallinckrodt Medical (The Netherlands), with IRE (Belgium), with AEC (South Africa), and with KAERI (Republic of Korea). During the past year, the design of the LEU metal-foil target was optimized and tested [18], the acidic chemical process to be used in combination with this target was demonstrated [19], and the feasibility of using LEU metal foil targets in combination with the basic process was assessed [20].

9. During the past year, the first LEU elements were inserted into the MNR reactor in Canada and in the GRR-1 reactor in Greece. 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 TRIGA II Ljubljana, while those that have been fully converted in the U.S. include FNR, GTRR, ISUR, MCZPR, OSUR, RINSC, RPI, UMR-R, UVAR, and WPIR. Seven foreign reactors, BER-II, SSR, HOR, TRIGA II Vienna, TR-2, MNR, and GRR-1, have been partially converted, and La Reina has fabricated or ordered an LEU core. (SAPHIR, GTRR, ISUR, MCZPR, and UVAR were shut down after conversion).

PLANNED ACTIVITIES

With the tremendous success of the U. S. FRRSNF Acceptance Program, it is expected that most of the fuel of U.S. origin irradiated in research reactors through 12 May 2006 will be returned to the United States and safely disposed there. There is significant uncertainty, however, about what will be done with the research reactor fuel of U.S. origin that will be irradiated after May 2006, and with spent research reactor fuels from other sources.

Almost none of the countries in which the research reactors are located possess the resources and facilities required to dispose of spent research reactor fuel, and the U.S. has repeatedly and firmly stated that the FRRSNF Acceptance Program will not be extended past the established dates. For totally unrelated reasons, AEA Technologies (U.K.) has discontinued acceptance of spent research reactor fuel at Dounray. The French company COGEMA, however, has indicated that it will continue to accept spent research reactor fuel for the foreseeable future, and that it will dispose of it subject to conditions acceptable to many reactors. COGEMA currently accepts U-Al alloy and aluminide fuels, but does not accept silicide fuel. Current indications are that it will accept fuels based on U-Mo alloys.

In pursuit of its fundamental goal, and to assist in the resolution of this very pressing problem affecting almost the entire research reactor community, during the next few years the RERTR fuel development effort will concentrate on the development of fuels based on U-Mo alloys, with two major thrusts:

(1) To develop, demonstrate, and qualify U-Mo fuels with uranium densities in the 8-9 gU/cm^3 range, to enable conversion of reactors that cannot be converted today. This effort is estimated to require 5 or 6 years.

(2) To develop, demonstrate, and qualify U-Mo fuels with uranium densities in the 5-6 gU/cm^3 range, that can replace silicide fuels in current use. This effort is estimated to require 3 or 4 years and, if successful, will ensure that the research reactors that have converted to LEU silicide fuels do not face a crisis at the end of the of the FRRSNF acceptance period.

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

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

2. Begin irradiation in ATR of a third batch of microplates (RERTR-3), including samples of all the materials which appear to be promising on the basis of the results from the first two batches. Perform the irradiation tests under conditions close to prototypical for high-performance reactors.

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

4. In cooperation with fuel manufacturers, begin to fabricate full-size plates or elements containing U-Mo alloy dispersion fuels in the 5-6 gU/cm^3 range for prototypic testing in research reactors.

5. 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.

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 development of one or more viable processes based on LEU for the production of fission ^{99}Mo in research reactors, in cooperation with several current and future ^{99}Mo producers.

SUMMARY AND CONCLUSION

1999 has been a very productive year for the RERTR program. The main events are summarized below.

a) In the area of **U.S. acceptance of spent fuel** from foreign research reactors, three additional shipments have taken place, including 1,006 fuel assemblies. This brings to 3,237 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 good irradiation behavior of the U-6Mo dispersion fuel, and excellent irradiation behavior of U-Mo dispersion fuels with higher Mo content or with small Ru additions. 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. Irradiation of a new experiment to investigate the behavior of these fuels at high temperatures is scheduled to begin in October 1999.

c) **The Russian RERTR program**, which aims to develop and demonstrate the technical means needed to convert Russian-supplied research reactors to LEU fuels, has made good progress**.**

d) The U.S. Government has decided to aggressively pursue eventual conversion of three **Russian plutonium production reactors** to the use of low-enriched UO_2-Al dispersion fuel. This effort is proceeding, with assistance from RERTR personnel.

e) At the request of the German government, the RERTR program has addressed the performance of a new alternative LEU **FRM-II core design** that could be installed in the same building structure erected for the current 20 MW HEU design with the same 50-day fuel life. The results, for cores with 20 MW and 22 MW, have been favorable (85% and 93%, respectively, of the HEU design fluxes).

f) Significant improvements were made in the design of an LEU metal-foil target that would allow efficient production of fission **molybdenum-99** without reliance on HEU. Targets containing LEU metal foils in the new target design were irradiated in the RAS-GAS reactor at BATAN, Indonesia, the foils were separated from the targets, and ^{99}Mo was successfully extracted from the ensuing process.

g) Two new **conversions** began in 1999 when the first LEU elements were inserted in the cores of the MNR reactor in Canada and the GRR-1 reactor in Greece.

These are exciting times for the program and for all those involved in it. New promising LEU fuels are being developed, ^{99}Mo is being produced from LEU targets, new LEU reactors are being designed, more reactors are considering conversion, and unprecedented cooperation is beginning to take place for the conversion of both reactor fuels and reactor targets.

The most exciting developments, and the greatest challenges, are in the fuel development area. Every result that we have obtained so far seems to indicate that U-Mo alloys will behave well in reactor cores, and will make it possible to reach the program goal of achieving a fuel meat density of 8-9 gU/cm^3. However, the constraints posed by the expiration of the FRRSNF Program and by the fact that COGEMA cannot accept spent silicide fuel may result in a serious problem for research reactors that have converted to LEU silicide fuel. The RERTR program plans to accelerate as much as possible, working in conjunction with commercial fuel fabricators, qualification of U-Mo fuels that can be used as substitutes for silicide fuels.

More than ever before, success of the RERTR program depends on free exchange of ideas and information, and on international friendship and cooperation. If we continue to help each other, the challenges of today will become the successes of tomorrow and we shall finally reach our common goal of eliminating the international traffic of highly-enriched uranium for civilian purposes.

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