STATUS AND PROGRESS OF THE RERTR PROGRAM IN THE YEAR 2002*

Armando Travelli

Argonne National Laboratory
Argonne, Illinois 60439-4841 USA

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ABSTRACT

Following the cancellation of the 2001 International RERTR Meeting, which had been planned to occur in Bali, Indonesia, 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 the years 2001 and 2002, and discusses the main activities planned for the year 2003.

The past two years have been characterized by very important achievements of the RERTR program, but these technical achievements have been overshadowed by the terrible events of September 11, 2001. Those events have caused the U.S. Government to reevaluate the importance and urgency of the RERTR program goals. A recommendation made at the highest levels of the government calls for an immediate acceleration of the program activities, with the goal of converting all the world's research reactors to low-enriched fuel at the earliest possible time, and including both Soviet-designed and United States-designed research reactors.

The RERTR program has prepared and submitted to the Department of Energy a plan and a schedule to achieve this goal. The plan makes full use of two very important technical developments that have occurred within the program during the past two years:

- Excellent results have been obtained from the irradiation of miniplates containing monolithic LEU U-Mo fuel with uranium density of 15.6 g/cm^3. If an economically viable manner of fabricating monolithic LEU U-Mo fuel elements is developed, and if the preliminary irradiation tests are confirmed, this fuel holds the promise of enabling LEU operation of all existing and future research reactors in combination with unprecedented performance.
- The progress achieved within the Russian RERTR program, both for the traditional tube-type elements and for the new "universal" LEU U-Mo pin-type elements, promises to enable soon the conversion of most Russian-designed research and test reactors.

The plan is structured to achieve LEU conversion of all HEU research reactors supplied by the United States and Russia during the next ten years, with high priority given to reactors in the United States and Russia. This effort will address, in addition to the fuel development and qualification, the analyses and performance/economic/safety evaluations needed to implement the conversions.

In combination with this over-arching goal, the RERTR program plans to achieve at the earliest possible date two other major goals:

1) Qualification of LEU U-Mo dispersion fuels with uranium densities of 6 g/cm^3 and 7 g/cm^3, so that reactors currently using or planning to use LEU silicide fuel can then rely on a fuel that is acceptable to COGEMA for reprocessing; and
2) Elimination of all obstacles to the utilization of LEU in targets for isotope production, so that this important function can be performed without the need for weapons-grade materials.

To better concentrate on these primary goals, and in consideration of the excellent progress made by the French fuel development program, the RERTR program has decided to forgo parallel qualification of LEU U-Mo dispersion fuel with uranium density of 8-9 g/cm^3.

Only a concerted effort from all of us, working together as we have for many years, will ensure that these goals can be achieved. We intend to promote the efficiency and safety of research reactors while, at the same time, eliminating the traffic in weapons-grade uranium and, with it, the possibility that some of this material might fall in the wrong hands. In today’s environment, few causes can be more deserving of our joint efforts.

INTRODUCTION

This is the twenty-fourth time that scientists from all over the world gather under the aegis of the Reduced Enrichment for Research and Test Reactors (RERTR) Program to exchange information about their activities and to coordinate their efforts. This year’s meeting has special importance because it immediately follows another meeting that had to be canceled, for the first time since the program began. The 2001 International RERTR Meeting was planned to be held in Bali, Indonesia. Its cancellation was forced by the September 11, 2001 attacks and the ensuing international reaction. The 2002 RRFM meeting [1] provided a forum for some of the papers that had been prepared for the Bali meeting, and I wish to thank its organizing committee again for this kindness. I also wish to thank the Indonesian National Nuclear Agency (BATAN) and Dr. Suripto, in particular, for the enthusiasm, diligence and care with which they had prepared to host the 2001 International RERTR Meeting.

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 minimize and eventually eliminate use of high-enriched uranium (HEU) for civilian applications worldwide. Most of the civilian HEU is used in research and test reactors, and the RERTR program concentrates on the use of low-enriched uranium (LEU) in these reactors, instead of HEU, and on making the conversion feasible without significant penalties in experiment performance and in economic or safety aspects.

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.

This is the second time that an International RERTR Meeting is held in Argentina, the first having taken place in Buenos Aires in 1987. Cooperation between the RERTR program and the Comisión Nacional de Energía Atómica (CNEA) began even earlier than that, in 1980, and has included a number of different program activities, including the production and testing of qualification elements of several LEU fuel types, production of Mo-99 from LEU targets, and reactor core conversions.

Because of this long-standing connection, and the significant contributions that the CNEA has made to the RERTR goals through the years, I am especially glad that this meeting is being held in Argentina, in the beautiful city of San Carlos de Bariloche.

OVERVIEW OF THE PROGRAM STATUS IN 2000

By October 2000, when the most recent International RERTR Meeting was held [2], many important results had been achieved in the fuel development area:

1. The qualified uranium densities of the three main fuels which were in operation with HEU in research reactors when the program began had been increased significantly with LEU (UAl_x-Al, from 1.7 g/cm^3 to 2.3 g/cm^3; U_3O_8-Al from 1.3g/cm^3 to 3.2 g/cm^3; and $UZrH_x$, from 0.5 g/cm^3 to 3.7 g/cm^3). A new LEU fuel type, based on U_3Si_2-Al had been developed, qualified, and licensed [3] with uranium densities up to 4.8 g/cm^3. This fuel type had been widely accepted and was fabricated routinely for more than twenty research reactors by several international fuel fabricators.

2. The effort to develop new advanced LEU fuels with higher effective uranium loadings had been restarted in 1996 after a pause of about six years. Three batches of samples (RERTR-1, -2, and -3), each containing 32 microplates formed with a variety of promising fuel materials, had been irradiated between 1997 and 1999 in the Advanced Test Reactor (ATR) in Idaho. Postirradiation examinations of these samples had indicated very promising behavior of U-Mo alloy particles dispersed in an aluminum matrix, with Mo content between 6% and 10% and uranium densities up to 8-9 g/cm^3. Irradiation of two nearly identical batches of plates, RERTR-4 and RERTR-5, containing 32 positions each and planned to reach 75% and 50% burnup, respectively, had begun.

4. The back-end of the research reactor fuel cycle had become a very important issue for research reactor operators. While reprocessing studies at the Savannah River Site (SRS) had concluded in 1983 that the RERTR fuels could be successfully reprocessed there, these results had been rendered moot by the end of reprocessing operations at SRS and by the expiration of the Off-Site Fuel Policy at the end of 1988. A Record of Decision [4] had been issued in 1996 for a new DOE policy allowing, until May 2009, the return of spent research reactor fuel elements of U.S. origin irradiated before May 13, 2006. Implementation of this policy through the U.S. Foreign Research Reactor Spent Nuclear Fuel (FRRSNF) Acceptance Program had been very successful. By October 2000, 2,904 MTR elements had been received at SRS and 835 TRIGA elements had been received at INEEL under that program, for a total of 3,740 elements.

5. Many reactors using or planning to use LEU silicide fuel intended to have their spent fuel reprocessed after termination of the FRRSNF Acceptance Program, but the closure of the UKAEA Technology reprocessing plant at Dounreay, U.K., had created a potential problem. The COGEMA plant in La Hague, France, which was the main remaining site where research reactor fuel could be reprocessed, had indicated that, unlike Dounreay, it could not accept silicide fuel. Thus, development and qualification of LEU U-Mo fuel, which COGEMA had indicated it could accept, had become deeply intertwined with the back-end of the research reactor fuel cycle.

6. Qualification of LEU U-Mo dispersion fuel with uranium densities of up to 6 g/cm^3 was planned to occur through irradiation of test elements fabricated by BWXT using atomized powder produced by KAERI. Irradiation of the elements in the HFR-Petten was scheduled to begin in the spring of 2001 and qualification of this fuel type was projected to occur by

the end of 2003. Qualification of a similar fuel with uranium density of 8-9 g/cm^3 was projected to occur by the end of 2005. These qualification activities for LEU U-Mo dispersion fuels were planned to be conducted in close collaboration with a parallel French fuel development program [5,6] concentrating on the qualification of LEU U-Mo fuel with uranium density of 8 g/cm^3.

7. The feasibility of using LEU instead of HEU in fission targets dedicated to the production of ^{99}Mo for medical applications had been the object of intensive studies for several years. Procedures had been developed for dissolution and processing of both LEU silicide targets and LEU metal foil targets, and for both acidic and basic processes. In particular, four metal foil targets of a new annular design had been irradiated at BATAN, showing that (1) aluminum can be used for target tubes and (2) uranium foils with nickel, zinc, or aluminum fission-recoil barriers can be removed from the target. The acidic chemical process to be used in combination with this target had been demonstrated and was ready for a final test to be conducted at BATAN.

8. 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 for about 35 reactors from 23 countries.

9. The end of the Cold War had 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. Active cooperation with various components of the Russian RERTR program was in progress and included 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. Irradiation of LEU UO_2-Al fuel assemblies in the WWR-M reactor at the Petersburg Nuclear Physics Institute in Russia was in progress and several analytical studies had been conducted to investigate the feasibility of converting to the use of LEU fuels a number of HEU research reactors of Russian design.

10. Thirty-six HEU research reactors had been converted to LEU fuels, or were in the process of converting. In addition, LEU fuels were planned for the new Ongkharak 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 Research Reactor in Australia. However, some reactor designs still considered use of HEU in their fuels. 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 all future research reactors.

PROGRESS OF THE RERTR PROGRAM IN 2001 and 2002

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

1. First and foremost, the events of September 11, 2001, have changed greatly the importance assigned by the U.S. Government to the goals of the RERTR program and the urgency with which those goals are to be pursued. At their May 2002 Summit meeting, President Bush and President Putin established a Joint Expert Group to address the means to reduce inventories of special nuclear materials in their countries -- especially high-enriched uranium. On September 16, 2002, U.S. Secretary Abraham and R.F. MINATOM Minister Rumyantsev issued a joint statement [7] announcing that the Joint Expert Group had concluded its work with several important recommendations. Of great interest to all of us is the explicit recommendation that both countries should commit themselves to the "accelerated development of LEU fuel for both Soviet-designed and United States-designed research reactors." The RERTR program has prepared and submitted to the Department of Energy proposals, plans, and schedules consistent with this recommendation.

2. The two new batches of miniplates whose irradiation had begun in 2000 were removed from the ATR core and examined. In particular, RERTR-5 was removed in January 2001 with ~50% burnup and RERTR-4 was removed in September 2001 with ~75% burnup. Each of these batches contained 32 LEU miniplates with larger dimensions than those used in prior experiments. Most of the plates had dispersion meats with uranium densities of either 6 g/cm^3 or 8 g/cm^3, and were intended to investigate the swelling behavior of U-Mo dispersion fuels under a variety of realistic operating conditions. The results of these tests on LEU U-Mo dispersion fuels [8] are very positive and confirm the applicability of this fuel type for a variety of research reactor fuel applications.

3. Two of the miniplates irradiated in RERTR-4 contained LEU U-Mo fuel in a monolithic form, instead of a dispersion of U-Mo in aluminum. The uranium density of the meat of these fuel plates was 15.6 g/cm^3, and the thickness of the fuel meat was adjusted to maintain the power density of the plates within acceptable limits. The results of this irradiation test are excellent [8]. Even at 75% burnup, the plates show minimal changes due to irradiation and provide convincing evidence that monolithic LEU U-Mo fuel can be used successfully in research reactor fuels. If an economically viable manner of fabricating monolithic LEU U-Mo fuel elements is developed, and if the preliminary irradiation tests are confirmed, monolithic LEU U-Mo fuel holds the promise of enabling LEU operation of all existing and future research reactors in combination with unprecedented performance.

4. The schedule to qualify LEU U-Mo dispersion fuel with uranium densities of up to 6 g/cm^3 has suffered a serious slippage, directly linked to patents obtained by KAERI in 1999-2000 and covering the use of spherical U-Mo particles in research reactor fuels. BWXT could not proceed with production of the test elements because of legal concerns caused by the patent. After initial discussions on the subject by KAERI and ANL personnel, in early August 2001 the DOE General Counsel (DOE/GC) assumed total responsibility for resolving this issue between DOE and KAERI. Responding to a letter by DOE/GC, BWXT has recently agreed to fabricate two fuel elements needed to qualify LEU U-Mo dispersion fuels with uranium density of 6 g/cm^3, but only approximately half of the plates involved will be fabricated using spherical powder. The rest will be fabricated using comminuted powder produced by AECL, in Canada. Similarly, two LEU U-Mo dispersion fuel elements with uranium density of 7 g/cm^3 will be fabricated by the CNEA, in Argentina, using both spherical powder and hydride/dehydride powder produced by the CNEA. Irradiation of these four elements in the HFR-Petten reactor is expected to begin in September 2003 and qualification is expected in

October 2005. The good irradiation behavior of LEU U-Mo fuel samples provides convincing evidence that these tests will be successful.

5. Cooperation with various components of the Russian RERTR program has continued [9]. Irradiation of five LEU UO_2-Al tube-type assemblies, fabricated by the Novosibirsk Chemical Concentrates Plant (NZChK) with uranium density of 2.5 g/cm^3, was successfully concluded [10] in the WWR-M reactor at the Petersburg Nuclear Physics Institute (PNPI), St. Petersburg. A new "universal" LEU U-Mo pin-type fuel [11], which could be used with minor modifications to convert most Russian designed research and test reactors, has been developed by the A. A. Bochvar Institute for Inorganic Materials (VNIINM). Seventy-two mini-pins have been fabricated with uranium densities of 4 g/cm^3 and 6 g/cm^3 for irradiation testing in the MIR reactor at the Russian Institute of Atomic Reactors (RIAR), Dmitrovgrad, and two full-size pin-type assemblies have been fabricated with uranium density close to 6 g/cm^3 for irradiation testing at PNPI. The irradiations are planned to begin before the end of 2002. Preparations are being made to fabricate two pin-type LEU prototype assemblies for irradiation in the WWR-SM reactor in Tashkent, Uzbekistan, as a prelude to a full core conversion. Detailed analytical studies have been conducted to study the performance of LEU fuel in the WWR-SM reactor [12] and in the WWR-M reactor [13] in Kiev, Ukraine. In addition, analytical studies are in progress to investigate the feasibility of converting to the use of reduced enrichment the design of the PIK reactor under construction in Gatchina, Russia [14].

6. Significant progress was achieved on several aspects of producing ^{99}Mo from fission targets utilizing LEU instead of HEU. This activity is conducted in cooperation with several other laboratories including the Indonesian National Nuclear Energy Agency (BATAN), the Argentina Comisión Nacional de Energía Atómica (CNEA), MDSN/AECL/SGN (Canada), and the Australian Nuclear Science and Technology Organization (ANSTO). The final demonstration planned to take place at BATAN is still on hold because of the international situation, but significant progress was achieved in the cooperation with CNEA [15], MDSN/AECL/SGN [16], and ANSTO [17].

7. The methods and codes used to study the design, performance and safety characteristics of research reactors have been improved. These improvements include upgrades of the WIMS-ANL cross section generation code, the REBUS diffusion theory burnup code, and the codes used to determine thermal-hydraulic safety margins.

8. Several joint studies are in progress to facilitate reactor conversions or to improve utilization of LEU fuel in converted reactors. In particular, conversion studies continued for the HFR-Petten reactor [18] in the Netherlands and the SAFARI-1 reactor in South Africa.

9. An analytical model was developed to predict the thermal conductivity of stabilized uranium alloys under irradiation in dispersion fuels, taking into account the results of the ATR microplate irradiations and of the postirradiation examinations performed to date [19].

10. With the recent conversions of the R2-0 reactor in Sweden and of the ULRR in the U.S., 20 research reactors have been fully converted to LEU fuels outside the United States, including ASTRA (Austria), BER-II (Germany), DR-3 (Denmark), FRG-1 (Germany), IAN-R1 (Colombia), IEA-R1 (Brazil), JMTR (Japan), JRR-4 (Japan), NRCRR (Iran), NRU (Canada), OSIRIS (France), PARR (Pakistan), PRR-1 (Philippines), RA-3 (Argentina), R2 (Sweden),

R2-0 (Sweden), SAPHIR (Switzerland), SL-M (Canada), THOR (Taiwan), and TRIGA II Ljubljana (Slovenia). Eleven research reactors have been fully converted in the U.S., including FNR, GTRR, ISUR, MCZPR, OSUR, RINSC, RPI, ULRR, UMR-R, UVAR, and WPIR. Seven foreign reactors, GRR-1 (Greece), HOR (Netherlands), La Reina (Chile), MNR (Canada), SSR (Romania), TR-2 (Turkey), and TRIGA II Vienna (Austria), have been partially converted. (ASTRA, DR-3, GTRR, ISUR, MCZPR, SAPHIR, and UVAR were shut down after conversion).

11. The U.S. FRR SNF Acceptance Program made significant progress since October 2000. Additional shipments of spent research reactor fuel with 1,924 MTR-type elements were received at the SRS, and an additional shipment containing 126 TRIGA elements was received at the Idaho National Engineering and Environmental Laboratory (INEEL). With these additional shipments, 4,576 MTR elements have been received at SRS and 961 TRIGA elements have been received at INEEL under the FRR SNF Acceptance Program, for a total of 5,537 elements. In addition, 252 MTR-type fuel elements were shipped to SRS under an Environmental Assessment. These shipments are consistent with U.S. policy [20] and will resolve operational problems of the reactor sites while eliminating a serious proliferation concern.

PLANNED ACTIVITIES

1. The highest priority of the RERTR program during the next few years, contingent on DOE guidance and funding, will be given to implementing the recommendation reached by the Joint Expert Group and described in the Abraham/Rumyantsev joint statement. In doing so, the RERTR program plans to exploit to the fullest extent the excellent results recently obtained by fuel development activities both in the U.S. and Russia. This will entail aggressive development of LEU U-Mo fuels, in both dispersion and monolithic forms, for conversion of research reactors supplied by the U.S. and Russia.

2. Qualification of LEU U-Mo dispersion fuel with uranium densities of 6 g/cm^3 and 7 g/cm^3 will be pursued in a manner meant to minimize the possibility of additional slippages. Conclusion of this activity is now scheduled to occur in October 2005.

3. Development, testing, and qualification of monolithic LEU U-Mo fuel will be pursued very aggressively, with the goal of achieving qualification of this fuel by the end of 2007 and conversion of all U.S. research reactors by the end of 2012. Without the aggressive approach, achievement of these goals had been planned to occur, respectively, two and five years later.

4. Development, testing, and qualification of both monolithic and dispersion LEU U-Mo fuel for conversion of Russian-designed research reactors will also be pursued very aggressively, in cooperation with the Russian RERTR program, with the goal of achieving conversion of all Russian-designed research reactors also by the end of 2012.

5. As qualification of these fuels proceeds with the strong impetus provided by the Presidential Summit and the joint Abraham/Rumyantsev statement, the fuels will be applied to the conversion of all research reactors worldwide, in close collaboration with the many partners of the RERTR program. The main goal will be to ensure that, by 2012, no HEU will be needed to support operation of research reactors anywhere.

6. In parallel with fuel development and reactor conversion activities, the RERTR program plans to continue its efforts with all the world's isotope producers, medical and otherwise, to ensure that HEU ceases to be needed for this important purpose.

SUMMARY AND CONCLUSION

The past two years have been very productive for the RERTR program. The technical achievements have been overshadowed, however, by the terrible events of September 11, 2001. Those events have caused the U.S. Government to reevaluate the importance and urgency of the RERTR program goals. A recommendation made at the highest levels of the government calls for an immediate acceleration of the program activities, with the goal of converting all the world's research reactors to low-enriched fuel at the earliest possible time, and including both Soviet-designed and United States-designed research reactors.

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