STATUS AND PROGRESS OF THE RERTR PROGRAM IN THE YEAR 2004*

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ABSTRACT

The overall status of the RERTR program at the time of the last RERTR meeting is reviewed and the progress achieved since that meeting is described.

In the fuel area, unexpected failures of LEU U-Mo dispersion plates and tubes under irradiation testing have prompted a revision of the plans to qualify these fuels. While potential solutions to the difficulties with U-Mo dispersion fuels are being explored in collaboration with our international partners, greater emphasis has been placed on accelerating development of monolithic LEU U-Mo fuel. The feasibility of converting several Russian-designed research reactors to LEU fuels has been addressed, and progress has been made in the development of LEU-based ^{99}Mo production processes. The Russian RERTR program has made significant advances.

A very important event of 2004 was the USDOE establishment of the Global Threat Reduction Initiative (GTRI). This new program accelerates and combines under the same USDOE management several programs, including RERTR, which aim to secure, remove, or dispose of, nuclear and other radioactive materials throughout the world that are vulnerable to theft by terrorists.

INTRODUCTION

The International Atomic Energy Agency (IAEA) has always been a strong supporter of the activities of the RERTR program, almost from the program's very beginning. To list just some of the ways in which the IAEA supported the RERTR program, it was at the IAEA Headquarters that representatives of the RERTR program met in 1980, as part of Group 8 of the International Fuel Cycle Evaluation (INFCE), to discuss the feasibility of operating research reactors with LEU fuel. Also beginning in 1980, the IAEA sponsored, coordinated, and published a series of guidebooks [1, 2, 3] identifying and resolving the main problems that can be expected to occur when HEU research reactors are converted to the use of LEU fuels. Many international scientists have received IAEA fellowships to study reactor conversions at Argonne National Laboratory and elsewhere, and the IAEA has sponsored attendance at International RERTR Meetings by many international scientists who otherwise could not have attended. The IAEA actively participates in trilateral arrangements for the return of Russian-supplied research reactor fuels to the country of origin. Last but not least, the IAEA co-sponsored most of the International RERTR Meetings and always assumed an active role in the discussions that took place at those meetings. The RERTR program is grateful to the IAEA for these contributions, and is very appreciative of the IAEA decision to host the 2004 International RERTR Meeting at its headquarters.

OVERVIEW OF THE PROGRAM STATUS IN 2003

By October 2003, when the most recent International RERTR Meeting was held [4], 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 [5] 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. Five batches of samples (RERTR-1, -2, -3, -4, and -5), each containing 32 microplates formed with a variety of promising fuel materials, had been irradiated between 1997 and 2001 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. Two RERTR-4 miniplates, containing monolithic LEU U-Mo fuel with uranium density of 15.6 g/cm^3 and irradiated to up to 75% burnup, had yielded excellent preliminary results.

3. Monolithic LEU U-Mo fuel had become the most promising fuel material to convert several U.S.-designed research reactors and, possibly, Russian-designed research reactors. A large fraction of the 2003 fuel development effort was dedicated to the development of a fuel fabrication process that could be used to produce fuel elements containing monolithic U-Mo. A promising method to produce monolithic U-Mo fuel meat for fuel plates was developed, based on casting of thin ingots followed by cold rolling. Several promising methods to bond an aluminum clad to a monolithic U-Mo meat were also identified. These methods were based on Friction Stir Welding (FSW), Hot Isostatic Pressing (HIP), and Transient Liquid Pressure Bonding (TLPB).

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 [6] 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 Acceptance (FRRSNFA) Program had been very successful. A parallel program, the Russian Research Reactor Fuel Return (RRRFR) program, had been established to facilitate the return of Russian-origin fuel to its country of origin.

5. Many reactors using or planning to use LEU silicide fuel intended to have their spent fuel reprocessed after termination of the FRRSNFA Program, but the closure of the SRS and

UKAEA reprocessing plants 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 declared that it could not accept large quantities of 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 in the HFR-Petten of test elements fabricated by BWXT using atomized powder produced by KAERI. This qualification, originally scheduled to occur in 2004, had been postponed to late 2006 mostly because of problems linked to patents obtained by KAERI in 1999-2000 and covering the use of spherical U-Mo particles in research reactor fuels. To overcome these problems, BWXT was to fabricate two elements with uranium density of 6 g/cm^3, with approximately half of the plates containing spherical powder and the rest containing comminuted powder produced by AECL. Two other LEU U-Mo dispersion fuel elements with uranium density of 7 g/cm^3 were to be fabricated by the CNEA for irradiation in the HFR-Petten using both spherical powder and hydride/dehydride powder produced by the CNEA. A two-element qualification test of LEU U-Mo dispersion fuel with uranium density of 7.0 g/cm^3, jointly sponsored by RERTR, CEA, and ANSTO, was to be performed in the Osiris reactor during 2004. These qualification activities were planned to occur in close cooperation with a parallel French fuel development program concentrating on the qualification of LEU U-Mo fuel with uranium density of 8 g/cm^3. However, shortly before the 2003 RERTR meeting, a failure of the French FUTURE [7] test in BR-2 had raised concerns about the ability of that fuel to withstand high power rates.

7. Cooperation with the Russian RERTR program had resulted in the qualification of WWR-M2 LEU UO_2-Al tube-type fuel with uranium density of 2.5 g/cm^3. This fuel was successfully irradiated in the WWR-M reactor at the Petersburg Nuclear Physics Institute (PNPI), and could be used in several Russian-designed research reactors. Fuels under development for conversion of the other Russian-designed research reactors concentrated on the use of LEU U-Mo dispersion fuel. Seventy-two mini-elements of the “universal” LEU U-Mo pin-type fuel design [8] developed by the A. A. Bochvar Institute for Inorganic Materials (VNIINM) were under irradiation in the MIR-M1 reactor at the Russian Institute of Atomic Reactors (RIAR), Dimitrovgrad, and one full-size assembly of the same fuel type was under irradiation testing at PNPI. A tube-type design, developed by the Novosibirsk Chemical Concentrates Plant (NZChK) had been irradiation-tested in the IVV-2M reactor in Zarechniy and post-irradiation examinations were in progress. Both fuel types were candidates for irradiation testing in the WWR-SM reactor in Uzbekistan.

8. 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, in Indonesia, showing that aluminum can be used for target tubes and that 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 at

BATAN. However, this final demonstration was on hold because of the international situation caused by the September 11, 2001, attacks.

9. 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 41 reactors from 23 countries.

10. Thirty-eight 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.

11. The events of September 11, 2001, had changed greatly the importance assigned by the U.S. Government to the goals of the RERTR program and the urgency with which those goals were to be pursued. On September 16, 2002, following up on the conclusions reached by Presidents Bush and Putin at their May 2002 Summit meeting, U.S. Secretary Abraham and R.F. MINATOM Minister Rumyantsev had issued a joint statement announcing that their Joint Expert Group had recommended that both countries should commit themselves to the "accelerated development of LEU fuel for both Soviet-designed and United States-designed research reactors." The Department of Energy had requested the U.S. Congress to authorize a significant increase of RERTR funding for the "Accelerated RERTR."

PROGRESS OF THE RERTR PROGRAM IN 2004

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

1. On May 26, 2004, U.S. Secretary Abraham announced at the IAEA the establishment of the Global Threat Reduction Initiative (GTRI). The new GTR office accelerates and combines under the same USDOE management several programs aiming to secure, remove, or dispose of, nuclear and other radioactive materials throughout the world that are vulnerable to theft by terrorists. In particular, the RERTR program, the Foreign Research Reactor Spent Nuclear Fuel Acceptance (FRRSNFA) program, and the Russian Research Reactor Fuel Return (RRRFR) program are part of the new GTR office, in addition to radiological sources. This is expected to increase significantly the efficiency with which the programs interact and operate. The Secretary announced that approximately $450 million will be dedicated to GTRI over a span of nine years, during which GTRI is scheduled to accomplish its mission.

2. Several events, in quick succession, dampened the hopes of the RERTR program for a rapid qualification of the U-Mo dispersion fuel. The French IRIS-2 test in Osiris failed in November and was terminated prematurely. The failure mode appears to be similar to that reported for the FUTURE test one month earlier. The power density was lower than in the FUTURE test, but the uranium density was very high (8 g/cm^3) in both tests. In mid-December, preliminary results from the post-irradiation examination of hexagonal fuel tubes irradiated to ~60% burnup in the IVV-2M reactor in Zarechniy, Russia, indicated that the

tubes had also failed through a similar mechanism. In all three cases (BR-2, Osiris, and IVV-2M), the fuel meat contained U-Mo dispersion fuel and had developed large pores at the interface between the U-Mo/Al interaction product and the aluminum matrix. The plates experienced break-away swelling when these pores became interconnected. No pores have been seen in the residual fuel or in the interaction product. Unlike the other two failed tests, the Russian test had been run with moderate uranium density (5.4 g/cm^3).

3. The continued string of negative results for U-Mo dispersion fuel caused concern about the fuel element tests planned in the HFR-Petten and in Osiris. While it appeared possible that the problems experienced in the failed tests would not occur under the more benign conditions planned for the new tests to be performed, the outlook was not favorable. In addition, even if the tests were successful, lack of a clear understanding of what had happened in the failed tests would have made it very difficult to prove to regulatory agencies that the problem would not occur in other future tests or applications. As a result of these considerations, it was decided to postpone the tests until better information was available, and to suspend any activity directly related to the tests.

4. International fuel developers and experts have met several times since these failures occurred, to discuss different interpretations of the failure modes and different ideas about how the failures could be avoided. Two sets of U-Mo dispersion miniplates are to be irradiated in the ATR to test some of these ideas. Miniplates for RERTR-6 are being fabricated and planning is under way for RERTR-7. Irradiation of RERTR-6 is scheduled to begin in February 2005, and irradiation of RERTR-7 is scheduled to begin in May 2005.

5. The effort to produce U-Mo monolithic miniplates and full-size plates has continued, with the miniplates meant for irradiation in RERTR-6 and RERTR-7. A larger and more powerful mill was procured and installed at ANL-West. The ventilation system required to utilize the mill for radiological work is to be installed before the end of 2004. The mill makes it possible to increase greatly the operation rate of Friction Stir Welding (FSW). Scale-up activities with Transient Liquid Phase Bonding (TLPB) and Hot Isostatic Pressing (HIP) processes have also made progress, but so far the bonding obtained with TLPB is less satisfactory than the bonding obtained with FSW, and the bonding obtained with HIP is less satisfactory than the bonding obtained with TLPB.

6. Postirradiation examinations of the miniplates irradiated in RERTR-4 and RERTR-5 have continued, with special emphasis on the clues that they could provide on the causes and remedies of the failures. In general, silicon additions to the aluminum matrix appear to provide a promising cure. Monolithic plates seem not to be affected by the problem, and their interaction layer is limited to 4-8 µm; however, the small size of the monolithic plates may have reduced the effective temperature at which they operated during irradiation.

7. The fuel behavior modeling codes DART and DART-TM were improved, in collaboration with the CNEA, to take into account the products resulting from the interaction between U-Mo particles and the aluminum matrix.

8. As part of the Mo-99 effort, a digester was developed to assist CNEA increase their production capability from LEU targets. A goal was to avoid the formation of a crust of

sodium diuranate and manganese dioxide on the upper part of the digester wall. It was found that stirring and rinsing operations, carefully timed, allowed recovery of 95% of the solids. Tests run with IPNS-irradiated targets gave similar results and excellent (99.5%) Mo-99 yield. Studies on Thermoxid resins, which promise to improve significantly Mo-99 extraction, provided encouraging results. Cooperative tests of the Modified Cintichem process at BATAN are anticipated to resume soon.

9. Cooperation with the Russian RERTR effort continued. At the beginning of December, RERTR personnel met with Dr. Chernyshov, from JSC "TVEL," and other Russian scientists, to discuss plans for joint activities. Preliminary agreement was reached for irradiating full-size assemblies of both LEU U-Mo dispersion pins and tubes in the MIR-M1 reactor, at RIAR, Russia, before they are irradiated abroad to high burnups. Tragically, Dr. Chernyshov was killed in a terrorist attack on a Moscow subway shortly thereafter. However, it is expected that the activities of the Russian RERTR program will proceed in a manner consistent with the preliminary agreement that he had fostered. Irradiation of LEU U-Mo dispersion pins continues at both PNPI and RIAR. In particular, RIAR irradiations are expected to reach 70% burnup in late 2004, and all pins appear to have behaved well to date. PIEs of pins with 20% burnup showed no problems.

10. Analyses have been performed for the conversion of several Russian-designed reactors. In particular, calculations for the WWR-M at KINR, in the Ukraine, were performed and transmitted to KINR, where the safety analysis report of the conversion is proceeding. Preliminary work for the conversion of another HEU facility under design at KIPT, also in the Ukraine, has started. An attractive LEU core design for the IRT-Sofia reactor was developed using IRT-4M assemblies. A feasibility study for the conversion of the 10 MW IRT-1 reactor at the Tajoura Nuclear Research Center in Libya was completed, also using LEU IRT-4M fuel assemblies. A feasibility study for the LEU conversion of the DRR, at Dalat, Vietnam, was completed using LEU WWR-M2 assemblies. The dimensions and ^{235}U loading of a pin-type fuel assembly for possible use in the WWR-SM reactor in Uzbekistan were finalized for fabrication of test assemblies. Finally, an attractive option for the conversion of the 6 MW WWR-K reactor was identified and studied. All of these studies resulted in attractive solutions for the core conversions, both in terms of fuel consumption and of experiment performance.

11. To date, twenty 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).

PLANNED ACTIVITIES

1. The highest priority of the RERTR program during the next few years, contingent on DOE guidance and funding, will be to fulfill the commitments expressed by Secretary Abraham in his IAEA announcement of GTRI. The RERTR program plans to pursue as expeditiously as possible LEU conversion of the reactors that can be converted with currently qualified fuels, and to develop, jointly with its international partners, the fuels that will make it possible to convert the remaining reactors within the time schedule outlined by Secretary Abraham. 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. The unexpected behavior of LEU U-Mo dispersion fuels will be investigated and corrected, with the goal of qualifying this fuel type for application in research reactors. Conclusion of this activity for plate-type fuel is scheduled to occur in 2010.

3. Development, testing, and qualification of monolithic LEU U-Mo fuel will be pursued very aggressively. The current goal is to achieve qualification of this fuel by the end of 2010.

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 qualification of these fuels by 2010.

5. As qualification of these very advanced fuels proceeds with the strong impetus provided by GTRI, the qualified fuels will be used in the conversion of all remaining research reactors worldwide, in cooperation with the many partners of the RERTR program. The overarching goal will be to ensure that by 2013 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 cooperative efforts with all international isotope producers, medical and otherwise, to ensure that HEU ceases to be needed also for this important purpose.

SUMMARY AND CONCLUSION

- One of the most important events affecting the RERTR program during the past year was the decision by the U.S. Secretary of Energy to establish the Global Threat Reduction Initiative (GTRI), and his related announcement at the IAEA. GTRI accelerates and combines under the same USDOE management several programs aiming to secure, remove, or dispose of, nuclear and other radioactive materials throughout the world that are vulnerable to theft by terrorists. The RERTR, FRRSNFA, and RRRFR programs are part of GTRI, which also includes disposal of radiological sources. Approximately $450 million will be dedicated to GTRI over a span of nine years, during which GTRI is scheduled to accomplish its mission.

- Unexpected fuel failures that occurred during irradiation tests of U-Mo dispersion fuels in BR-2, Osiris, and IVV-2M have dampened the hopes for rapid qualification of this fuel type in plate-type or tube-type geometry. All qualification tests have been suspended and an intense fuel development and testing program is in place to solve the problem. Qualification of this fuel type is now scheduled for 2010.

- Excellent progress has been made in the development of a fabrication process for monolithic LEU U-Mo fuel. Most existing and future research reactors could be converted to LEU with this fuel, which has a uranium density close to 16 g/cm^3. Qualification of this fuel type is also scheduled to occur in 2010.

- Irradiation tests of the new "universal" Russian LEU U-Mo pin-type fuel have been in progress for more than one year, and are scheduled to reach 70% burnup before the end of 2004. Irradiation of modified tube-type elements are to begin soon, while development of monolithic fuel is being pursued. Postirradiation examinations of pins at 20% burnup give no indication of problems.

- Studies and planning are in progress for LEU conversion of US-designed research reactors, with the goal that all these reactors will be converted by 2013. Using the results of the fuel development effort of the Russian RERTR program, feasibility studies and preparations are in progress for the LEU conversion of several HEU research reactors supplied by the Russian Federation. The overall goal is to achieve LEU conversion of all HEU research reactors by 2013.

- Continued progress is being made in the effort to eliminate 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.

The goals outlined above are very ambitious, but achievable. We intend to eliminate the inventories and traffic of weapons-grade uranium that research reactors now require while promoting their efficiency and safety. We can achieve this objective by the year 2013, if all of us continue to work in harmony to prevent the possibility that any weapons-grade uranium might fall into the wrong hands.

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