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STATUS AND PROGRESS OF THE RERTR PROGRAM*

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ABSTRACT

The progress of the Reduced Enrichment Research and Test Reactor (RERTR) Program is described. The major events, findings, and activities of 1993 are reviewed after a brief summary of the results which the RERTR Program had achieved by the end of 1992 in collaboration with its many international partners.

The disappearance of the Soviet Union and the end of the Cold War have been followed by more changes. Bill Clinton was elected President of the United States, and his administration has raised the issue of proliferation of weapons of mass destruction to the forefront of its agenda and moved aggressively to deal with it. A new policy on nonproliferation was signed in Washington during the last week of September 1993 and includes the goal "to minimize the use of highly-enriched uranium in civil nuclear programs". For the RERTR Program, this translates into many favorable developments.

DOE drafted an off-site spent nuclear fuel policy that would allow spent research reactor fuel of US origin to be returned to the US for disposal, and an Environmental Assessment addressing the urgent-relief return of approximately 550 elements.

A cooperation agreement was signed between the RERTR Program and RDIPE, in Moscow, to develop and demonstrate within the next five years the technical means needed to convert Russian-supplied research reactors to LEU fuels. Joint studies were begun to assess the technical and economic feasibility of using reduced enrichment fuels in the SAFARI reactor in South Africa and in the ANS reactor under design at ORNL.

Significant progress was achieved on several aspects of producing ^{99}Mo from fission targets utilizing LEU instead of HEU. Existing fuel data were analyzed and interpreted to derive a better understanding of the behavior of dispersion fuels under irradiation. Design and safety analyses were conducted to support LEU conversions of both US and foreign research reactors. Computer codes were modified and upgraded for the analysis of research reactors operating with LEU fuels. Two

very important reactors, R-2 in Sweden and NRU in Canada, with a combined HEU consumption of nearly 100 kg per year, were converted, bringing the total to 11 converted foreign reactors. The RINSC reactor was also converted to LEU fuel, bringing the total to seven converted US reactors. Approximately 59% of the work required to eliminate the need for further HEU exports has been accomplished.

New challenges and new frontiers - both technical and political - are causing a rejuvenation of the RERTR Program. International friendship and cooperation are essential to the achievement of our common goals.

INTRODUCTION

The 1992 RERTR meeting was held in the wake of a momentous and historical event: the end of the Cold War. We were suddenly facing a different world, with new hopes, fears, opportunities, and problems. Most prominent among the problems was the growing potential for nuclear proliferation. In addition, the issue of how to dispose of spent research reactor fuels after the closing of reprocessing plants that are no longer required for military purposes was a special concern for many of us.

While the events of 1993 have not been as tumultuous, the winds of change have continued to blow. In addition to many developments which could be ascribed directly to the changes of 1992, Bill Clinton was elected President of the United States and put his new administration in place.

The Clinton administration has raised the issue of proliferation of weapons of mass destruction to the forefront of its agenda and has moved aggressively to deal with it. A formal declaration of its nonproliferation policy was issued on 25 September 1993. President Clinton announced its major points on 27 September in a speech to the United Nations General Assembly in New York, where he said:

"I have made non-proliferation one of our nation's highest priorities. We intend to weave it more deeply into the fabric of all of our relationships with the world's nations and institutions."

A very important feature of this policy, as far as we are concerned, is the explicit goal *"to minimize the use of highly-enriched uranium in civil nuclear programs"*. This goal has been shared and pursued by our international RERTR program for many years, and the Clinton administration has embraced it with enthusiasm and determination. In particular, the global vision and the degree of national consistency with which nonproliferation issues are being addressed are unprecedented within the life span of the RERTR Program.

The attitude of the Clinton administration toward nuclear proliferation is already having a significant impact on the problems that the RERTR Program is being asked to address.

The RERTR Program was established in 1978 by the Department of Energy (DOE), which continues to fund and manage the program 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-Enrichment Uranium (LEU) instead of High-Enrichment 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 most of the HEU that is used in civil nuclear programs.

Close cooperation with the many international organizations represented at this meeting has been the cornerstone of the RERTR Program since its beginning fifteen years ago. This cooperation and the high quality of the technical contributions which many partners have brought to the overall effort are to be credited for much of the progress which the program has achieved to date.

Cooperation between the RERTR Program and JAERI began in 1980, with the signing of a cooperation agreement meant to address LEU utilization in all the JAERI research reactors which then used HEU. This cooperation agreement was concluded in parallel with the cooperation agreement between the RERTR Program and KURRI, which was signed in 1978. These agreements formed the basis of a long and fruitful collaboration. Several JAERI and KURRI scientists visited ANL, and several ANL personnel returned the visits. JAERI and KURRI personnel studied the results of experiments performed at ANL, and important safety experiments were performed at JAERI on the safety of LEU silicide fuels. Some of the most important milestones achieved by JAERI include conversion of its world-class JMTR reactor to 45% enriched fuel in 1986, conversion of the JRR-2 reactor to 45% enriched fuel in 1987, and startup of a new LEU reactor, JRR-3M, in 1990. JMTR is scheduled to undergo a second conversion to LEU silicide fuel in 1994.

This meeting is held in Oarai, Japan, as a testimony to the importance of the role that JAERI and KURRI have played and continue to play in the RERTR Program. It is a very special testimony because this is the first time that an RERTR meeting has been held more than once in a country other than the US.

I have very fond recollections of the first RERTR meeting in Japan in 1983. The information exchanged during the meeting showed clearly that the program had reached a decisive favorable turning point because its new and densest fuel, U_3Si_2-Al , could stand up well under irradiation and could be reprocessed. I have also very fond recollections of how well the meeting was organized, and of the warm hospitality of JAERI and the Japanese people. Therefore, it gives me great pleasure to take part in this International RERTR Meeting in Oarai, Japan, close to JAERI and its reactors. I

look forward to an excellent program, to interesting technical exchanges, and to touring the JAERI reactors and facilities. I believe that the successful outcome of the meeting of a decade ago provides us with a good omen for the outcome of this meeting.

OVERVIEW OF THE SEPTEMBER 1992 PROGRAM STATUS

By September 1992, when the last International RERTR Meeting was held^[1], the main results achieved in the fuel development area were:

- (a) The qualified uranium densities of the three main fuels which were in operation with HEU in research reactors when the program began ($\text{UAl}_x\text{-Al}$ with up to 1.7 g U/cm^3 ; $\text{U}_3\text{O}_8\text{-Al}$ 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 uranium densities extended up to 2.3 g U/cm^3 for $\text{UAl}_x\text{-Al}$, 3.2 g U/cm^3 for $\text{U}_3\text{O}_8\text{-Al}$, 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 $\text{U}_3\text{Si}_2\text{-Al}$, after reviewing the data collected by the program, the US Nuclear Regulatory Commission (NRC) had issued a formal approval^[2] of the use of $\text{U}_3\text{Si}_2\text{-Al}$ 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.
- (c) For $\text{U}_3\text{Si-Al}$, 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). PIE of these miniplates had given good results, but had shown that some burnup limits might need to be imposed for the higher densities. Four full-size plates fabricated by CERCA with up to 6.0 g U/cm^3 had been successfully irradiated to 53-54% burnup in SILOE, and a full-size $\text{U}_3\text{Si-Al}$ (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) Two concepts based on hot-isostatic pressing (HIP) procedures had been developed for LEU silicide fuels with the potential of holding effective uranium densities much greater than 4.8 g U/cm^3 . One of the concepts was based on a composite structure of U_3Si wires and aluminum (up to 12.9 g U/cm^3), while the other was based on a $\text{U}_3\text{Si}_2\text{-Al}$ dispersion structure (up to 10.2 g U/cm^3). Sample miniplates had been produced for both concepts.

In other important program areas, reprocessing studies at the Savannah River Laboratory had concluded that the RERTR fuels could be successfully reprocessed at the Savannah River Plant and DOE had defined the terms and conditions under which these fuels would be accepted for reprocessing. A new analytical/experimental program had begun to determine the feasibility of using LEU instead of HEU in fission targets dedicated to the production of ^{99}Mo for medical applications. A procedure for basic dissolution and processing of LEU silicide targets had been developed and was ready for demonstration on a full-size target with prototypic burnup. Extensive studies had been conducted, with favorable results, on the performance, safety, and economic characteristics of LEU conversions. These studies included many joint study programs, which were in progress for about 28 reactors from 17 different countries. Coordination of the safety calculations and evaluations was continuing for the US university reactors planning to convert to LEU as required by the 1986 NRC rule. Six of these reactors had already been converted, three other safety evaluations had been completed, and calculations for five more reactors were in progress. DOE guidance received at the beginning of 1990 had redirected the efforts of the US RERTR Program away from the development of new and better fuels, toward the transfer of already developed fuel technologies, and toward providing assistance to reactors undergoing conversion.

PROGRESS OF THE RERTR PROGRAM IN 1993

As mentioned in the introduction, the nonproliferation policy of the Clinton administration has had a significant impact on the environment in which the RERTR Program operates and on the problems that the program has been asked to address.

1. In response to proliferation concerns and to the needs of foreign research reactor operators, DOE has drafted an off-site spent nuclear fuel policy that would allow spent research reactor fuel containing HEU and LEU of US origin to be returned to the US for disposal. A draft Environmental Assessment addressing the return of approximately 550 urgent-relief elements was completed in September 1993, with a goal of completing the National Environmental Policy Act (NEPA) review process for these elements by the end of December 1993. A draft Environmental Impact Statement addressing the return of all US origin spent research reactor fuel is planned to be completed by the end of December 1994, with a goal of completing the entire NEPA review of foreign spent research reactor fuel returns by April 1995.
2. In March 1993, RERTR and DOE personnel visited Moscow to exchange information and discuss possible cooperation on a Russian RERTR Program with representatives of the Research and Development Institute of Power Engineering (RDIPE), the Russian Federation Ministry of Atomic Energy (MINATOM), and other organizations. This cooperative undertaking would expand the goals of the RERTR effort to include research reactors supplied with HEU fuel by the Russian Federation. The results of the visit were very encouraging. Unknown to us, RDIPE had already been involved since 1978 in

a very active program motivated by Soviet concerns about exporting research reactor fuel containing HEU. The program had completed the development and demonstration of fuel with 36% enrichment, but work on fuels with less than 20% enrichment was interrupted in 1988.

An agreement of cooperation between the US RERTR Program and RDIPE was signed in July 1993 with the goal of developing and demonstrating within the next five years the technical means needed to convert Russian-supplied research reactors to LEU fuels. Our Russian colleagues will describe their activities and plans in several papers that will be presented at this meeting. We are very excited at the prospect of working with them, and I urge you to welcome them as full-fledged members of our global program. With their help, the RERTR program will be in condition to address the problems created by use of HEU in civil nuclear programs nearly everywhere in the world.

3. In September 1993, RERTR and DOE personnel visited the Atomic Energy Corporation of South Africa in Pelindaba, South Africa, to discuss the feasibility of converting the 20 MW SAFARI reactor to low-enriched fuels. As a result of these discussions, a joint study by the AEC and the RERTR Program is now in progress to assess the technical and economic feasibility of converting SAFARI to LEU fuel. We are excited about cooperating with our South African colleagues and urge you to welcome them as full-fledged members of the RERTR Program.
4. On 22 September 1993, a joint study began to assess the feasibility of using reduced uranium enrichments in the fuel of the Advanced Neutron Source, which is currently under design at ORNL. The study is conducted by personnel from ORNL, ANL, INEL, and BNL.
5. Significant progress was achieved during the past year on several aspects of producing ^{99}Mo from fission targets utilizing LEU instead of HEU [Refs. 3,4, and 5]. This issue is receiving increased attention by the Clinton administration. The current goal is to develop and demonstrate a viable technology during the next several years.
6. The results of the postirradiation examinations of a test element fabricated by CERCA using $\text{U}_3\text{Si}_{1.6}\text{-Al}$ LEU fuel with a uranium density of 5.5 g/cm^3 and irradiated in the HFR-Petten were studied to derive a better understanding of the irradiation behavior, safety characteristics, and applicability of silicide fuels^[6]. The element performed well for an average ^{235}U burnup of 66% and a peak ^{235}U burnup of 85%. The swelling behavior of the fuel was consistent with that observed in previous U_3Si_x irradiation experiments.
7. The administration is seriously reviewing the desirability of developing LEU fuels with uranium density greater than the 4.8 g/cm^3 which is currently qualified.

8. Design and safety analyses were performed for reactors undergoing or considering LEU conversions within the joint study agreements which are in effect between the RERTR Program and several international research reactor organizations. A contribution of special significance in this area concerns the GRR-1 reactor in Greece^[7].
9. Computer codes have been modified and upgraded to improve our capability to analyze the performance and safety characteristics of research reactors utilizing LEU fuels. In particular, significant progress has been achieved in generating and testing a 69-group cross section library based on ENDF/B-V data for use with the WIMS-D4 code [8, 9, and 10]. A utility code allows updating and editing WIMS library files.

I reported last year^[1] on the overall progress toward LEU conversion which had been achieved by the end of 1992 by all the research reactors which required HEU exports when the program began and were still in operation without imminent plans of being shut down. It is of interest to revisit the situation of these reactors today, and to see how much progress has been accomplished during the past year.

The research reactors of interest for this review are the forty-two research reactors with power of at least one megawatt which utilized HEU of Western origin in 1978, when the program began. Listed below are the two reactors whose conversion to LEU fuel was completed during the past year. I hope that additional progress will be reported at this meeting.

1. The R-2 reactor (50 MW), at Studsvik, Sweden, was completely and successfully converted to LEU silicide fuel (U_3Si_2-Al) during the past year. The R-2 used to require HEU containing approximately 27 kg of ^{235}U during an average year.
2. The NRU reactor (125 MW), at Chalk River Laboratories, in Canada, was completely and successfully converted to LEU silicide fuel (U_3Si-Al) in July 1993. The NRU used to require HEU containing approximately 65 kg of ^{235}U during an average year.

The conversion of these two reactors is especially significant because of their high performance and power, and because they used to consume significant amounts of HEU. Their combined HEU consumption was almost the same as the combined HEU consumption of all the reactors whose conversion is not feasible with current fuels. Eleven reactors from this list have now been fully converted (ASTRA, DR-3, FRG-1, NRCRR, NRU, OSIRIS, PARR, PRR-1, RA-3, R-2, and THOR.)

To assess the overall conversion progress, six important steps which most reactors are expected to take on their way toward conversion have been defined as detailed in Ref. 1:

1. Determine feasibility of conversion.
2. Develop conversion plan.
3. Begin irradiation of prototype elements.
4. Order LEU elements for conversion.
5. Load first LEU elements in the core.
6. Unload last HEU elements from the core.

The forty-two operating reactors which required HEU exports when the RERTR Program began have been subdivided in seven categories according to the most advanced step which they have achieved. The two graphs of Fig. 1 illustrate the distributions of the numbers of the reactors, and of the average number of kilograms of ^{235}U exported yearly for use in their fuels, among the various categories. Both diagrams would be blank if no progress toward reduction of HEU exports had been achieved, and fully shadowed if total success had been achieved and no further HEU exports were to be required. The percentages of accomplished work are now 56.3% for the number of reactors and 61.2% for the yearly ^{235}U exports, while they were 55.6% and 57.7%, respectively, last year.

Comparable progress has been attained also by the US university reactors. The Rhode Island Nuclear Science Center reactor was successfully converted to LEU silicide fuel in August 1993, bringing to seven the total number of US converted reactors. Conversion of the University of Virginia Reactor is expected in November 1993. Safety documentation is either complete or nearly complete for four other reactors. Work is in progress on the four TRIGA reactors which use HEU fuel.

PLANNED ACTIVITIES

The future activities which the RERTR Program plans to undertake are consistent with the recent DOE guidance. The major elements of this plan are described below.

1. In collaboration with RDIPE and other Russian organizations, perform studies, analyses, fuel development, and fuel tests related to establishing the technical and economic feasibility of converting Russian-supplied research and test reactors to the use of LEU fuels. These activities will be conducted pursuant to the agreement for cooperation between the RERTR Program and RDIPE.

2. Perform calculations and evaluations about the technical and economic feasibility of utilizing reduced-enrichment fuels with current technology in reactors of special interest, such as SAFARI and ANS, and provide technical assistance to conversions.
3. Develop a viable process, based on LEU, for the production of fission ⁹⁹Mo in research reactors.
4. Complete testing, analysis, and documentation of the LEU fuels which have already been developed, support their implementation, and transfer their fabrication technology to countries and organizations which require such assistance.
5. Make plans and general preparations to resume high-density fuel development, should DOE decide in its favor.

SUMMARY AND CONCLUSION

The disappearance of the Soviet Union and the end of the Cold War, which changed so drastically last year's geo-political landscape, have been followed by more changes, including a new US administration. Bill Clinton has raised non-proliferation to one of the highest US priorities, and has vowed to minimize the use of highly-enriched uranium in civil nuclear programs.

For the RERTR Program, this translates into many favorable developments: (a) an off-site spent nuclear policy responsive to the needs of foreign research reactor operators; (b) the possibility of resuming high-density LEU fuel development; (c) strong support of LEU utilization for ⁹⁹Mo production; and (d) several new proactive initiatives related to the feasibility of converting reactors which were not addressed in the past. Very important among these initiatives are the joint undertaking with our Russian colleagues to examine the feasibility of using LEU in Russian-supplied research and test reactors, and the joint studies to assess the technical and economic feasibility of using reduced enrichments in the SAFARI and ANS reactors.

The program has continued to make solid technical progress. Two very important reactors, R-2 in Sweden and NRU in Canada, with a combined HEU consumption of nearly 100 kg per year, were fully converted to LEU since our last meeting in September 1992. In the US, the RINSC reactor was also successfully converted.

The fervor and excitement which accompanies these activities reminds us of the early years of the program. New challenges and new frontiers - both technical and political - are causing a rejuvenation of the RERTR Program. Once more, I ask for international friendship and cooperation. I firmly believe that by continuing to work together, as we have for the past fifteen years, we will overcome the inevitable obstacles and achieve our common goals.

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