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DEVELOPMENT AND TRANSFER OF FUEL FABRICATION AND UTILIZATION TECHNOLOGY FOR RESEARCH REACTORS*

by

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INTRODUCTION

Since the discovery of fission, research reactors have played an important role in the development and peaceful application of nuclear energy. Typically, research reactors are utilized for (1) radioisotope production for medicine, industry and agriculture; (2) studies of radiation damage in materials; (3) basic research in nuclear and solid-state physics; and (4) teaching and training. Acquisition and operation of a research reactor is frequently one of the initial steps undertaken by a country contemplating an active nuclear power program. Approximately 300 research reactors supplied with U.S.-enriched uranium are currently in operation in about 40 countries, with a variety of types, sizes, experiment capabilities and applications.

Despite the usefulness and popularity of research reactors, relatively few innovations in their core design have been made in the last fifteen years. The main reason can be better understood by reviewing briefly the history of research reactor fuel technology and enrichment levels.

In the 1950's and early 1960's, only Low-Enriched-Uranium (LEU, <20% enriched) was exported by the U.S. for use in research reactors. As power levels were upgraded to satisfy more demanding experimental requirements, fuel elements with greater ^{235}U loadings became necessary to avoid the financial penalty of reduced fuel lifetime. The increased loadings could have been achieved either by continued development of fuels and core designs with higher uranium density or by increasing the uranium enrichment. Of the two choices, the latter prevailed in the 1960's. Highly-Enriched-Uranium (HEU, ~93% enriched) became available and research reactor fuel development was terminated. HEU became widely used in research reactors, including those reactors where LEU would have sufficed.

Around 1977, with approximately half of the research reactors using HEU, concerns were raised about their nuclear proliferation potential. The 156 research reactors using HEU of U.S. origin had an annual requirement of approximately 1200 kg of ^{235}U and a total inventory of approximately 5000 kg of ^{235}U. Some of this material could conceivably be diverted for non-peaceful purposes while in fabrication, transport or storage, particularly when still unirradiated. Because of these concerns, stringent requirements on the enrichment of the uranium to be used in research reactors were again considered and a program was launched to assist research reactors in continuing their operation with the new requirements and with minimum penalties. The goal of the new program, the Reduced Enrichment Research and Test Reactor (RERTR) Program, is to develop the technical means to utilize LEU instead of HEU in research reactors without significant penalties in experiment performance, operating costs, reactor modifications, and safety characteristics.

The RERTR Program is a national program established in 1978 by the U.S. Department of Energy (DOE) and centered at the Argonne National Laboratory (ANL). Its activities[1] are concentrated on (a) development of new fuels with high uranium density and low enrichment, thus reversing the trend of the last fifteen years, and (b) development of methods, codes and analyses to assist in the implementation of the new fuels. As required by its mission, the program has made its results freely available and sought international cooperation. An effective technology transfer has thus taken place with many countries interested in research reactor operation and/or fuel fabrication, and has stimulated renewed international activity, cooperation and progress in these areas. This paper reviews briefly the RERTR Program activities with special emphasis on the technology transfer aspects of interest to this conference.

RERTR DEVELOPMENT ACTIVITIES

Efforts to develop research reactor fuels with high uranium density have concentrated on four materials which allow fuel element fabrication with only small changes in equipment and procedures. The first three are aluminum-clad plate-type elements, manufactured using powder metallurgy techniques. The fourth is rod-type UZ_rH fuel with Incoloy cladding. The four materials are listed below with the results achieved.

1. Uranium Aluminide (UAl_x-Al). Miniplates with up to 2.3 g U/cm^3 have been fabricated by EG&G-Idaho and irradiated to 88% burnup in the Oak Ridge Research Reactor (ORR). Postirradiation examinations (PIEs) are to begin in 1982. A whole-core LEU demonstration (1.7 g U/cm^3) was begun in 1981 in the Ford Nuclear Reactor (FNR) at the University of Michigan, where experiments with full LEU cores have been completed and experiments with mixed LEU/HEU cores are now in progress.

2. Uranium Oxide (U_3O_8-Al). Miniplates with LEU and up to 3.1 g U/cm^3 have been fabricated by ORNL and irradiated to 88% burnup in the ORR. PIEs on these plates are nearly complete with excellent results. Irradiation in ORR of full-size elements with 1.7 g U/cm^3 fabricated by Texas Instruments is nearly complete.

3. Uranium Silicide (U_3Si-Al; U_3SiAl-Al; and U_3Si_2-Al). Miniplates with up to 7.0 g U/cm fabricated by ANL are being irradiated in ORR. PIEs on plates with intermediate burnup (30%) and loadings were excellent. PIEs for high burnups (83%) are in progress. Full size elements (LEU, 4.8 g U/cm^3) fabricated by Babcock & Wilcox are to begin irradiation in ORR in 1982.

4. Zirconium Hydride ($UZrH_x$). This fuel, developed by the General Atomic Company (GAC) is an extension of the normal TRIGA fuel which has been used for many years in approximately sixty reactors. Fuel pins with up to 3.7 g U/cm^3, fabricated by GAC, have been irradiated in ORR since December 1979. Irradiation to 50% burnup will be completed in 1983.

Analytical studies related to the design of research reactors have also been performed:

a) Computer codes and methods for physics, thermal-hydraulics, and safety calculations of research reactors have been developed and tested against experimental data.

b) Detailed analyses of various reactor types have been performed to determine the conditions and designs which optimize utilization of the new LEU fuels, considering safety, experiment performance, and fuel cycle costs.

c) The major safety issues related to implementation of LEU fuels have been addessed.

INTERNATIONAL TECHNOLOGY TRANSFER AND COOPERATION

The mission of the RERTR Program requires that results be available for use by all research reactor operators. This has created an incentive to transmit information abroad and to seek international cooperation. Reaction from the international research reactor community has been overwhelmingly favorable and many cooperative relationships have been established in all major program areas.

Significant contributions have come to the RERTR Program from these exchanges. The transfer of information has proceeded in both directions in an effective cooperative spirit. The area, scope, and conditions of the cooperation agreements are tailored to individual needs. Some illustrative examples are given below.

Cooperative agreements on Fuel Development and Demonstration, are in effect with several major foreign fuel fabricators:

a) CERCA (France) has fabricated full-size UAl_x-Al elements with 1.7 g U/cm^3 (under irradiation in ORR and FNR), 2.2 g U/cm^3 (irradiated to 50% burnup in SILOE in 1981) and 2.3 g U/cm^3 (to begin irradiation in ORR in 1982). CERCA has also fabricated U_3O_8-Al elements with 3.2 g U/cm^3 (to begin irradiation in ORR in 1982), and will fabricate U_3SiAl-Al plates with 5.5-6.0 g U/cm^3 (for irradiation in SILOE) and U_3Si_2-Al elements with 4.8 g U/cm^3 (for irradiation in ORR).

b) NUKEM (FRG) has fabricated UAl_x-Al (up to 2.2 g U/cm^3) and U_3O_8-Al (up to 3.1 g U/cm^3) miniplates whose irradiation in ORR to 77% burnup was completed in March 1982; full-size UAl_x-Al elements with up to 1.8 g U/cm^3 (under irradiation in ORR, FNR and about six other reactors); and U_3O_8-Al elements with 2.0 g U/cm^3 (for BER-II), 2.1 g U/cm^3 (under irradiation in HFR-Petten), 2.3 g U/cm^3 (to begin irradiation in ORR in 1982), 2.6 g U/cm^3 (for DR-3), and 2.8 g U/cm^3 (under irradiation in ASTRA). U_3Si_2-Al elements fabricated by NUKEM with 4.8 g U/cm^3 have been under irradiation in ORR since May 1982.

c) The CNEA (Argentina) has fabricated two sets of miniplates that are being irradiated in ORR. The first set containing UAl_x-Al (up to 2.5 g U/cm^3) and U_3O_8-Al (up to 3.1 g U/cm^3) miniplates has achieved a burnup of over 80%. The second set containing UAl_2-Al (up to 3.1 g U/cm^3), U_3O_8-Al (up to 3.6 g U/cm^3), and U_3Si-Al (up to 6.1 g U/cm^3) miniplates has achieved a burnup of over 40%.

The RERTR Program has participated in Generic Studies activities coordinated by the International Atomic Energy Agency (IAEA) leading to the publication of IAEA Guidebooks intended to assist research reactor operators in conversions from HEU to LEU fuels. The first guidebook, on H_2O reactor conversions,[2] was published in 1980 and an addendum on D_2O reactor conversions[3] will be published in 1982. A second guidebook on safety/licensing aspects of reactor conversions,[4] is scheduled for publication in 1983. Each guidebook is the result of extensive technical studies by experts from many countries (for example, 31 organizations from 15 countries are participating in the safety/licensing guidebook).

Joint study programs on Specific Reactor Analysis are in effect for twenty-two reactors from thirteen countries. These studies include in-depth analyses of all major aspects of LEU utilization in specific reactors, with realistic assumptions on the uranium densities that are being developed and tested. The studies examine the reactor performance, economics and safety to provide a range of options allowing optimization of core design and operation after completion of pertinent fuel demonstrations.

Meetings and extended visits have been very valuable in exchanging information, especially for specific reactor analyses. The IAEA has provided valuable assistance through fellowships which allow scientists from reactors in various countries to visit laboratories in which RERTR work is in progress.

To date, twenty-five scientists from ten countries have visited the RERTR Program at ANL for periods between two and six months, many with IAEA fellowships. Typically, the visiting scientists work closely with RERTR staff using RERTR computer codes and exchanging information on particular reactor aspects, and conclude with full reports on the options available.

Valuable information exchanges have also taken place at annual international meetings which have been held since 1978 on RERTR activities (ANL, November 1978; Saclay, September 1979; ANL, November 1980; Jülich, September 1981; and ANL, November 1982). Approximately 100 scientists have participated in these annual meetings, with effective exchanges in all program areas.

CONCLUSION

The RERTR Program and the international cooperating programs and organizations are making significant progress in the development, demonstration and utilization of new fuels and fuel designs for research reactors using LEU materials. The atmosphere of open, constructive and friendly cooperation which has been established has resulted in an effective technology transfer which is benefiting all participants.

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