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STATUS OF REDUCED ENRICHMENT PROGRAM FOR RESEARCH REACTORS IN JAPAN

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ABSTRACT

The status of research and test reactors relevant to RERTR program in Japan is described. The reduced enrichment programs for the JRR-3, JRR-4 and JMTR of Japan Atomic Energy Agency (JAEA) were completed by 1999. The core of JRR-3 was converted from aluminide (UAl_X-Al) to silicide (U_3Si_2-Al) in September 1999. The JRR-3 has been well operated with LEU fuel since 1990. JRR-4 was stopped temporarily for replacement of reflector elements in December 2007, and resumed its operation in February 2010. The JMTR is under refurbishment of reactor facilities. JAEA established a committee to discuss new fuel procurement and spent fuel management. Two subcommittees were also established under the above committee to discuss the U-Mo fuel and spent fuel management, respectively. In Kyoto University Research Reactor Institute (KURRI), the Kyoto University Research Reactor (KUR) was successfully converted to LEU fuel in March 2010.

1. Introduction

The objective of the Reduced Enrichment for Research and Test Reactors (RERTR) program is to develop the technology to minimize the use of highly enriched uranium (HEU) in civilian nuclear application worldwide. As the substitute fuels were developed, existing reactors operating with HEU would be converted to the low enriched uranium (LEU) and new reactors would be designed to use the LEU.

The RERTR program in Japan was pursued under the direction of the “Five Agency Committee” on HEU organized by the Ministry of Education, Ministry of Science and Technology, Ministry of Foreign Affairs, Japan Atomic Energy Research Institute and Kyoto University. The committee started in 1978 until 2000. The committee is not opened since 2001, because the LEU conversion activities of the relevant reactors in Japan are considered to be in a closing phase. The history of RERTR program in Japan is shown in Table 1.

In this paper, the following terms are described:

1. Detail of research reactors and critical assemblies in operation in Japan,
2. Current situation of research reactors relevant to the RERTR program in Japan,
3. Spent fuel management in Japan, and
4. Relevant topics in JAEA.

2. Detail of research reactors and critical assemblies in operation in Japan

Eight research reactors and six critical assemblies are operated in Japan. These are shown in Table 2 and Table 3. Four research reactors (the JRR-3, JRR-4 and JMTR of the JAEA and KUR) are relevant to the RERTR program. These research reactors are shown in Table 4.

3. Current situation of research reactors relevant to the RERTR program in Japan

3.1 JAEA

(1) JRR-3

The JRR-3 achieved the first criticality in 1962 as the first research reactor with the homegrown technology and had been utilized in various kinds of researches. Currently, The JRR-3 is used for neutron beam experiments (neutron radiography, neutron scattering experiments, prompt gamma-ray analysis), activation analysis, production of neutron-transmutation-doped silicon semiconductor, and production of radioisotope, etc. In 1990, JRR-3 completed its modification for upgrade and resumed its operation as a high performance and multi purpose research reactor with thermal power of 20MW. The modification plan was made in 1977, and was designed to use 45% enrichment uranium at the outset of the plan. However, the design was later modified to use low enriched uranium fuel, in response to nuclear nonproliferation measures. The core of JRR-3 was converted from aluminide (UAl_X-Al) to silicide (U_3Si_2-Al) in September 1999 in order to reduce the amount of spent fuel. Uranium density of the silicide fuel is about 4.8Ug/cm^3, and cadmium wires are inserted in each both side plate of fuel element as burnable absorber. The silicide fuel core has 1.6 times as much uranium as that of the aluminide fuel core. Therefore, the amount of spent fuel decreased to about half per year. The JRR-3 has been well operated with LEU fuel since 1990 and reached 62,792 MWD in September 2010 at the last operation cycle.

(2) JRR-4

The JRR-4 has 3.5MW of thermal power, and is used for medical irradiation of BNCT (Boron Neutron Capture Therapy), activation analysis, production of neutron-transmutation-doped silicon semiconductor, and education and training of reactor engineers, etc. JRR-4 terminated its operation with HEU on January 1996. The full core conversion of JRR-4 to LEU silicide fuel (U_3Si_2-Al) with density of about 3.8Ug/cm^3, was achieved in July 1998. After conversion to the LEU fuel, JRR-4 continued its stable operation until December 2007 for temporarily shut-down due to a replacement of reflector elements, and resumed its operation in February 2010. The total thermal output of JRR-4 since July 1998 to September 2010 was 843 MWD.

(3) JMTR

The JMTR core was completely converted from HEU to LEU fuel in January 1994. The type of the LEU fuel is silicide fuel (U_3Si_2-Al) with 4.8gU/cm^3, and a cadmium wire is inserted one side in each fuel element plate. The core conversion from HEU (45% enriched) to LEU with high density uranium enabled extension of the cycle length from 12 days to 25 days. After improvement of the core fuel management, the length of operation cycle was finally extended to 32 days. The JMTR is under refurbishment of irradiation facilities.

3.2 Research Reactor Institute, Kyoto University (KURRI)

The Kyoto University Research Reactor (KUR, 5MW) achieved its first criticality in 1964. Conversion to LEU fuel started from 1992 as a partial core conversion, and two LEU silicide fuel elements have been loaded to the core in May, 1992. These were the first LEU silicide fuel elements loaded and used in Japanese research reactor. In 1994, the U.S. Government gave an approval to utilize the HEU fuel material prepared for Kyoto University High Flux Reactor (KUHFR) project[1] to be used in the KUR. Since then, the KUR continued its operation with HEU until February 23, 2006.

The extensive use of KUR in BNCT field, as well as both fundamental and applied use in various fields, was a strong motivation for the continuation of the KUR operation with LEU fuel after 2006. After the Record of Decision (ROD) concerning the ten-year extension of Foreign Research Reactor Spent Nuclear Fuel (FRR SNF) Acceptance Program issued by the U.S. DOE in November 2004, a new contract concerning the FRR SNF Acceptance Program has been concluded between the U.S. DOE and Kyoto University in February 2006, which opened the LEU path for KUR beyond 2006. The safety review for the full core conversion to LEU silicide fuel has completed in February 2008. Following the fuel fabrication and transportation, the full core conversion of KUR to LEU fuel was successfully achieved on March 2010. The first criticality was achieved on April 15, 2010, and the reactor is fully operated for joint use studies since May 2010.

4. Spent Fuel Management in Japan

4.1 Spent Fuel Management in JAEA

Nine shipments for JRR-3, JRR-4, JMTR and Japan Materials Testing Reactor Critical assembly (JMTRC) spent fuel had been successfully carried out since 1997 to 2006. In autumn 2008, JAEA concluded a new contract for ten-year extension of acceptance of spent nuclear fuel with U.S. DOE under the extended FRR SNF Acceptance Program that was issued by the U.S. DOE in 2004. In September 2009, JAEA carried out the first shipment of 180 spent fuel elements by the new contract to U.S. (120 elements for JMTR, 20 for JMTRC and 40 for JRR-3). To date, the total number of spent fuel elements shipped to U.S. by JAEA is 1643 (1087 elements for HEU, 556 for LEU).

The remaining all HEU spent fuel elements from JMTRC are planned to ship to the U.S. by December 2013, which makes JAEA to complete all the planned HEU shipping back to the U.S. The other LEU spent fuel elements from JRR-3, JRR-4 and JMTR, which are also planned to ship to the U.S. under the extended FRR SNF Acceptance Program.

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[1] The KUHFR project has been officially cancelled in 1991.

4.2 Spent Fuel Management in KURRI

The shipment of HEU spent fuel of KUR under the FRR SNF Acceptance Program has commenced at 1999. All (seven) shipments have been successfully terminated as scheduled, so the HEU spent fuel removal from KUR has successfully completed. The LEU spent fuel will be stored at KURRI site until the shipment to U.S. under the current FRR SNF contract between U.S. DOE and Kyoto University.

5. Relevant Activities in JAEA

In July 2008, a new committee, "Committee on Nuclear Fuel for Research and Test Reactors", was established in JAEA in order to discuss new fuel procurement and spent fuel management.

Two subcommittees were also established under the above committee, discussing the U-Mo fuel and investigation of future spent fuel management, respectively. The activities of the subcommittees are just started, and it is important to continue considering the FRR SNF Acceptance Program.

6. References

As described in this paper, the RERTR program in Japan is in a final phase, awaiting for the shipment of remaining HEU fuels of JAEA reactors under the extended FRR SNF program. The four research reactors relevant to RERTR program were successfully converted to LEU fuel and have been well operated.

7. Acknowledgements

The operators of the relevant research reactors, JAEA and Kyoto University, would like to acknowledge the continuing support from RERTR program for the successful achievements of LEU conversions of the Japanese research reactors.

Table 1. History of Reduced Enrichment Program for Research and Test Reactors in Japan

1977. 11	Japanese Committee on INFCE WC-8 was started. Joint Study Program was proposed at the time of the application of export license of HEU for the KUHFR.
1978. 5	ANL-KURRI Joint Study Phase A was started.
1978. 6	Five Agency Committee on Highly Enriched Uranium was organized.
1978. 9	ANL-KURRI Joint Study Phase A was completed.
1979. 5	Project team for RERTR was formed in JAERI.
1979. 7	ANL-KURRI Joint Study Phase B was started.
1980. 1	ANL-JAERI Joint Study Phase A was started.
1980. 8	ANL-JAERI Joint Study Phase A was completed.
1980. 9	ANL-JAERI Joint Study Phase B was started.
1981. 5	MEU UAl_x-AI full core experiment was started in the KUCA.

1983. 3	ANL-KURRI Phase B was completed.
1983. 8	MEU $UA1_x$-Al full core experiment in the JMTRC was started.
1983.11	ANL-KURRI Phase C was started.
1984. 3	ANL-JAERI Phase B was completed.
1984. 4	ANL-JAERI Phase C was started.
1984. 4	MEU-HEU mixed core experiment in the KUCA was started.
1984. 9	Irradiation of 2 MEU and l LEU UAl_x -Al full size elements in the JRR-2 was started.
1984. 10	Irradiation of LEU UAl_x-Al full size elements in the JRR-4 was started.
1984. 11	Thermal-hydraulic calculations for the KUR core conversion from HEU to LEU were performed.
1985. 1	Irradiation of MEU UAl_x-Al full size elements in the JMTR was started.
1985. 3	Irradiation of MEU UAl_x-Al full size elements in the JMTR was completed. Irradiation of LEU U_xSi_y-Al mini-plates in the JMTR was started.
1985. 6	Irradiation of LEU U_xSi_y-Al mini-plates in the JMTR was completed.
1985. 10	Neutronics calculations for the KUR core conversion from HEU to LEU were performed.
1986. 1	Irradiation of MEU UAl_x-Al full size elements in the JRR-2 was started.
1986. 5	Irradiation of MEU UAl_x-Al full size elements in the JRR-2 was completed.
1986. 8	The JMTR was fully converted from HEU to MEU fuels.
1987.11	MEU UAl_x-Al full core in the JRR-2 was started.
1988. 7	PIE of MEU, LEU UAl_x-Al full size elements in the JRR-2 was completed.
1988. 12	Irradiation of LEU UAl_x-Al full size elements in the JRR-4 was completed.
1990. 3	LEU UAl_x-Al full core test in the new JRR-3 (JRR-3M) was started.
1990. 11	Full power operation of 20MW in the JRR-3M was started.
1992.5	Two LEU U_3Si_2-Al elements were inserted into the KUR core.
1993.11	Two LEU U_3Si_2-Al elements were inserted into the JMTR core.
1994.1	The JMTR was fully converted from MEU to LEU with U_3Si_2-Al fuel.
1994.9	ANL-JAERI Phase C was completed.
1995.12	The JMTRC was shutdown.
1996.12	The JRR-2 was shutdown.
1998.7	The JRR-4 was full converted from HEU to LEU with U_3Si_2-Al fuel.
1999.9	The JRR-3M was fully converted from LEU UAl_x-Al fuel to LEU U_3Si_2-Al fuel.
2000.3	The decommissioning plan for the VHTRC was submitted to the Japanese Government.
2002.1	The decommissioning plan for the DCA was submitted to the Japanese Government.
2002.3	The HTTR operation has been started after the Functional Test completed by the Japanese Government.
2004.4	Core Outlet Gas (He) Temperature of HTTR was reached to 950℃.
2006.2	The KUR operation using HEU was terminated.
2006.8	The JMTR was temporarily shut down to modify the irradiation facilities.
2007.12	The JRR-4 was temporarily shut down to replace reflector elements.
2010.2	The JRR-4 was resumed its operation.
2010.3	The KUR was fully converted from HEU to LEU with U_3Si_2-Al fuel.

Table 2. Japanese Research Reactors in Operation

Name	Owner	Site	Type and enrichment			Max. Power	Start-up date
UTR KINKI	Kinki University	Higashi -osaka	H_2O(UTR)	U-Al	HEU	1W	1961.11
JRR-3	JAEA	Tokai	D_2O(tank)	U UO_2	Natural LEU	10MW 10MW	1963.9 1972.1
			H_2O(pool)	UAl_X-Al U_3Si_2-Al	LEU LEU	20MW 20MW	1990.3 1999.9
KUR	KURRI	Kumatori	H_2O(tank)	U_3Si_2-Al	HEU LEU	5MW 5MW	1964.6 2010.3
JRR-4	JAEA	Tokai	H_2O(pool)	U-Al U_3Si_2-Al	HEU LEU	3.5MW 3.5MW	1965.1 1998.7
JMTR	JAEA	Oarai	H_2O(MTR)	U-Al UAl_X-Al U_3Si_2-Al	HEU HEU LEU	50MW 50MW 50MW	1968.3 1986.7 1994.1
YAYOI	Tokyo University	Tokai	Fast(horizontal ly movable)	U	HEU	2kW	1971.4
NSRR	JAEA	Tokai	H_2O(TRIGA)	U-ZrH	LEU	300kW	1975.6
HTTR	JAEA	Oarai	Graphite-He (gas)	UO_2 particle	LEU	30MW	2002.3

Table 3. Japanese Critical Assemblies in Operation

Name	Owner	Site	Type and enrichment			Max. Power	Start-up date
TCA	JAEA	Tokai	H_2O(tank)	UO_2 UO_2-PuO_2	LEU LEU	200W	1962.8
NCA	Toshiba	Kawasaki	H_2O(tank)	UO_2	LEU	200kW	1963.12
FCA	JAEA	Tokai	Fast Horizontally Split	U U Pu	HEU LEU	2kW	1967.4
KUCA	KURRI	Kumatori	Various multi-core	U-Al UAl_X	HEU HEU	100W 1kW(short time)	1974.8 1981.5
STACY	JAEA	Tokai	Homogeneous Heterogeneous Tank type	U Pu*	LEU	200W	1995.2
TRACY	JAEA	Tokai	Homogeneous Tank type	U	LEU	10kW $5x10^9$W (transient)	1995.12

* Not used in actual operation

Table 4. Research Reactors Relevant to RERTR in Japan
(Converted to LEU fuel under the RERTR program)

Name	Power(MW)	First Critical	Current Fuel Enrichment	Conversion
KUR(KURRI)	5	1964	LEU	2010
JRR-3(JAEA)	20	1962	LEU	1990
JRR-4(JAEA)	3.5	1965	LEU	1998
JMTR (JAEA)	50	1968	LEU	1994

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