Present Status and Future Perspective of Research and Test Reactors in JAERI

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Abstract

Since 1957, Japan Atomic Energy Research institute (JAERI) has constructed several research and test reactors to fulfill a major role in the study of nuclear energy and fundamental research. At present, four reactors, the Japan Research Reactor No. 3 and No. 4 (JRR-3M and JRR4 respectively), the Japan Materia s Testing Reactor (JMTR) and the Nuclear Safety Research Reactor (NSRR), are in operation, and a new High Temperature Engineering Test Reactor (HTTR) has reached first criticality and is waiting for the power-up test. This paper introduce these reactors and describes their present operational status. The recent tendency of utilization and future perspectives are also reported.

1. Introduction

In 1957, JAERI was established as a central research organization with a purpose of contributing to atomic energy research, development and utilization, in implementation of the Japanese national program. Four research reactors, JRR-1, JRR-2, JRR-3 and JRR 4, one material testing reactor, JMTR, and one pulse Factor weld successively constructed in Tokai and Oarai Research Establishment. And the HTTR is going to be powered up as the final stage of its construction at Oarai Research Establishment.

At present, the JRR-1 is preserved as the Monumental Hall after the successful achievement of expected objectives. The JRR-2 was shut down permanendy in December, 1996 and then its decommissioning project has been started in August, 1997. The JRR-3, which is the first domestic research reactor, has been upgraded as JRR-3M for high performance and flexible utilization. In July 1998, the JRR-4 reached the criticality with low-enriched Uranium (LEU) fuel elements under the RERTR program after some modification of reactor facilities. The JMTR is being operated regularly serving as an irradiation bed after two times of fuel conversion from high enriched Uranium (HEU) to medium-endched Uranium (MBU) (45% enriched) and from MEU to LEU. The NSRR is also in service for the study of the fuel behavior under reactivity initiated accident condition. The HTTR achieved the first criticality with minimum core in November 1998 and all of the fuel elements have been loaded in the core in December. Major specifications of these reactors am shown in
Table 1.

Table 1 Research and Test Reactors in JAERI

Name	Type	Coolant	Fuel		Max. Power	Max. Neutron Flux Thermal	Max. Neutron Flux Fast	Start-up
JRR-2	CP-5	D_2O	U-Al	(93 %)	10 MW			1960. 10
				(45 %)	10 MW	$2.0*10^{14}$	$6.0*10^{13}$	1987. 11
JRR-3	TANK	D_2O	MNU		10 MW			1962. 09
			UO_2	(1.5 %)	10 MW			
JRR-3M	POOL	H_2O	$U\text{-}Al_x\text{-}Al$	(20 %)	20 MW	$3.0*10^{14}$	$2.0*10^{14}$	1990. 03
JRR-4	POOL	H_2O	U-Al	(93 %)		$3.5*10^{13}$	$8.7*10^{13}$	1965. 01
			U3Si2-Al	(20 %)	3.5 MW	$7.0*10^{13}$	$1.2*10^{13}$	
JMTR	MTR	H_2O	U-Al	(93 %)	50 MW			1968. 03
			$U\text{-}Al_x\text{-}Al$	(45 %)	10 MW			1986. 08
			$U_xSi_y\text{-}Al$	(20 %)	50 MW	$4.0*10^{14}$	$4.0*10^{14}$	1993. 11
NSRR	TRIGA	H_2O	U-ZrH		300 kW	$1.3*10^{12}$	$4.0*10^{12}$	1975. 06
					23,000 MW (pulse)			
HTTR	GCR	He gas	UO_2	(~ 6 %)	30 MW	$\sim 10^{13}$	$\sim 10^{13}$	1998.11

2. FRR-2

The JRR-2 is a heavy water moderated and cooled tank type reactor with maximum thermal power of lOMW and has been operated smce 1960. The main purpose of utilization were neutron scattering experiments, irradiation tests of nuclear fuels and materials, radio-isotope (Rl) production, activation amalysis and others. A facility for the Boron Neutron Capture Therapy (BNCT) was installed in 1990 and to the present 33 patients who suffered by malignant brain tumors have been successfully treated in the facility.

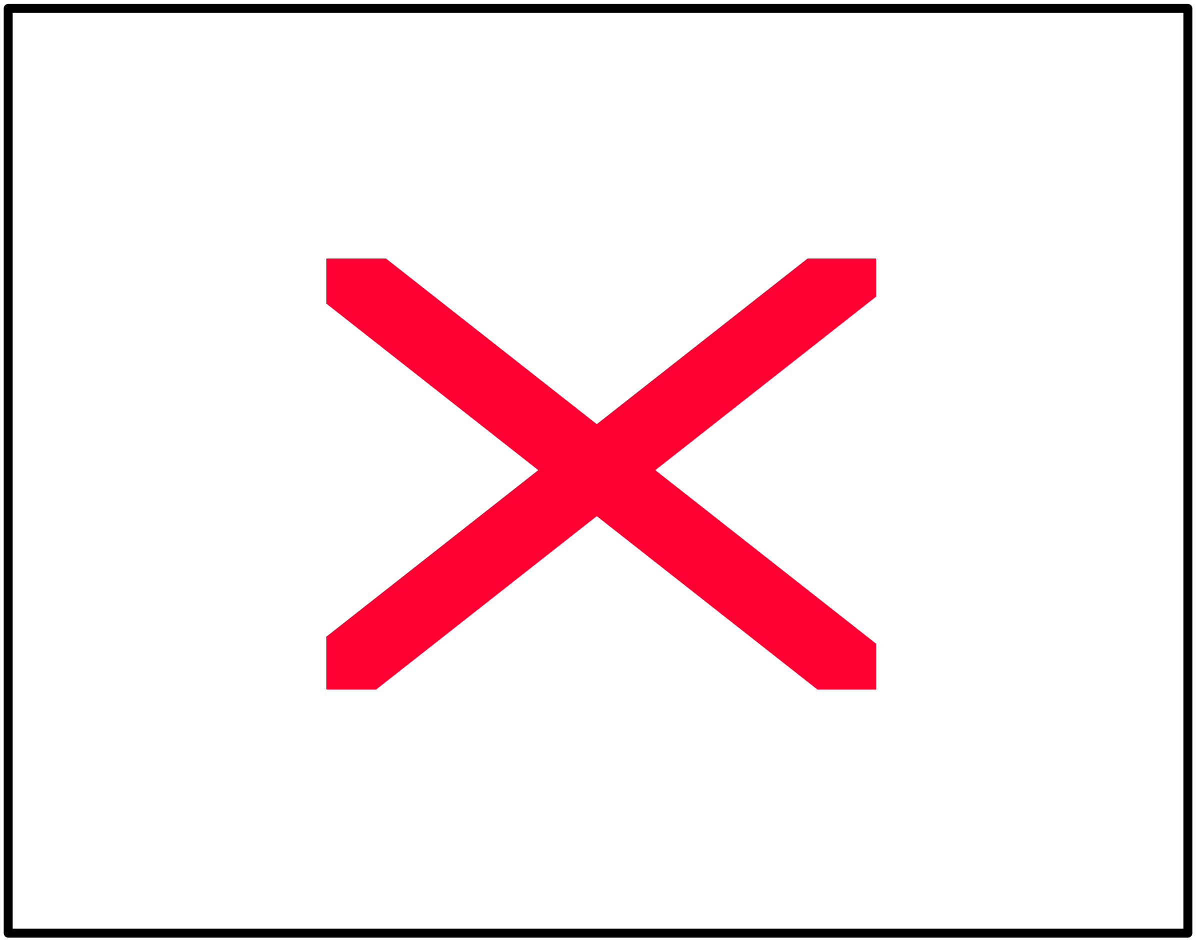
After 35 years operation, the JRR-2 was permanently shut down in December 1996 and the JRR-2 decommissioning project has been started in August 1997. The decommissioning program is devided into 4 major phases, i.e. reactor shut down activities, reactor safe storage, removal of cooling system and removal of reactor body (Fig.1). The program is being carried out in 11 years from 1997 to 2007. The reactor buildmg wig be used for the hot laboratory experiments after completmg all decommissioning activities.

The phase-1 of the decommissioning started on August 25, 1997 and finished in March 1998. Major tasks in phase-1 were removal of control rod drive mechanisms and draining of coolant. The heavy water coolant up to ISm3 dramed from the reactor COD and primary cooling system was safely stomd in the heavy water tanks.

The phase-2 is scheduled from mid 1998 to the end of 1999. Removal of the secondary cooling system and estimation of radioactive inventory win be also carried out in this phase. The primary cooling system will be isolated by Dmoving the expansionjomt between reactor COD tank and cooling system and by closing the opening putts.

The phase-3 is plarmed for 4 years from 2000. The major tasks of this phase are removal of ad facilities in the reactor building such as the primary cooling system, thermal shield cooling system, reactor control system, spent fuel handling and storage facilities, except for the reactor body.

The phased is scheduled for 4 years from 2004. The re actor body win be mmoved by one piece as applied in the Modeling of the JRR-3. The reactor storage facility win be newly constructed in the site of the JRR-2 after the permission of regulatory authority.



3. JRR-3M

In order to meet recent DqoiDmentsfor Factor utilization, the JAERI has decided to modify the JRR-3 and its mmodeling to JRR-3M started m 1985. The JRR-3M attained the first criticality in March 1990 and started fug power operation in November of the same year. The JRR-3M is one of the reactors with the highest flexibility of utilization in the world.

The JRR-3M is a light water moderated and cooled swimming pool type reactor with beryllium and heavy water reflector with the maximum thermal output of 20MW. Fuel elements are U-Alx dispersed MTR type with the enrichment of about 20%.

The JRR-3M is operated with seven or eight operation cycles a year. Its operation cycle is basically consisted of four weeks of rated power operation and one week of shut down for Dfueling, irradiation capsule handling and maintenance works. The JRR-3M has been operated 58 cycles in total, and the integrated thermal power of 26,546MWd was attamed by the end of 1998.

The reactor COD consists of 26 standard fuel elements and 6 control elements. Each control element has a box-shape hafnium neutron absorber and a fuel element follower. The core is divided into five sectors for Dfueling. Five or six standard fuel elements are refueled after each operation cycle. The average and maximum burn-ups are about 32% and about 47%, respectively.

Udlizadon facilities consist of eighteen vertical irradiation holes in fuel and Dflector regions and rime horizontal beam tubes installed tangendaUy to the core.

The irradiation holes are bemg utilized for fuel/material irradiation tests, Rl production, silicon doping, activation analysis and others. One of the vertical irradiation holes in the heavy water reflector tank is used for a cold neutron source (CNS) facility, in which liquid hydrogen of 20K is installed as moderator.

Two horizontal beam tubes lead thermal or cold neutron beams to neutron beam experimental instruments in the beam hall as shown in **Fig.2.** The beam tube for thermal neutron is divided into two tubes and the one for cold neutron is divided into totes tubes to make possible various udlization. The CNS and the neutron grude tubes am providing great advantages to the neutron beam experiments such as neutron scattering experiments, neutron radiography, neutron-induced prompt gamma-ray analysis (PGA) and others.

The PGA facility was constructed as a new experimental equipment in the JRR-3M to analyze special elements that carmot be measured by an ordinary neutron activation analysis.

The CNS facility has been operated without exchanging a moderator cell for seven years since 1990. The moderator cell has a thin wall container of 0.8mm thickness made of austenitUc stainless steel. The fast neutron fluency of the moderator cell is estimated to reach 2 Ox103~ nlcm2 by the latter half in 1998. The cell was replaced by the new one with the same specification in consideration of the neutron radiation damage from January to March 1999.

Use of a super-mirror guide tube instead of a nickel glude tube can increase neutron flux and transmit shorter wavelength neutrons through the gunde. This performance promise to open new possibilities for neutron scattering andlor absorption experiments. The JAERI has developed the super-miTror successfully. At the JRR-3M, a replacing program is prOgDSSmg to obtain higher neutron flux and shorter wavelength neutrons. According to the program, the total length of one thermal neutron guide is 57m including curved section with a length of 36m. the radius of curvature is 3,340m, and its characteristic wavelength is 2A.

The following new instruments am being developed to meet the current requirements for neutron beam experiments.

- · Neutron Laue-Diffractometer for Crystallography in Biology
- · Reflectometer
- · Four- Circle Diffractometer
- · Multiple Extreme Conditions system

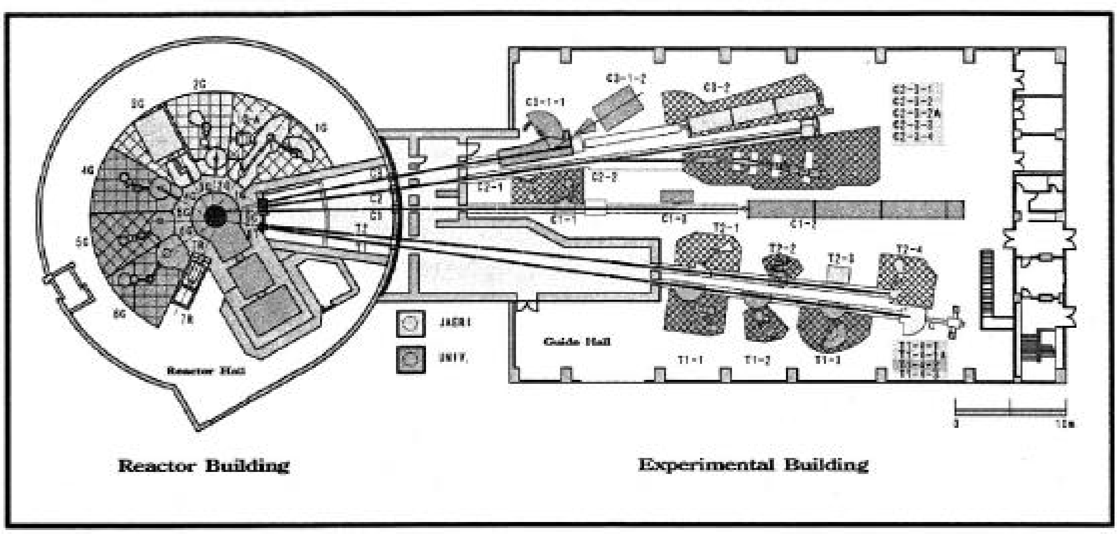


Fig. 2 JRR-3M Beam Experimental Facilities

4. JRR-4

The JRR4 is a light water moderated and cooled swimming-pool type reactor which was constructed originally for the purpose of shielding experiments on nuclear ship and has been operated and utilized smce 1965. The JRR4 was operated at the thermal power of 2.5MW in early stage, and power was increased to 3.5MW since 1976. Until January 1996, the JRR4 has been successfully operated for 31 years with the high-enriched fuel elements. The total operation time and thermal power are 29,378 hours and 2,404MWd respectively.

Due to the U.S. non-proliferadon policy m 1977, the conversion program to the low-enriched fuel COD started in 1996. Key points of the conversion were,

(1) Core configuration should be kept,
(2) Shape and main dimension of the fuel elements should be kept,
(3) Udlizadon facilities are to be upgraded,
(4) Higher safety standards tham original ones are to be applied

According to these key policies, the safety system, reactor cooling system, instrumentation and control system v,ere renewed and the reactor building was reinforced to endure for bigger earthquakes. The following experimental facilities were newly installed amd/or improved (Fig.3)

- · An equipment for "Boron Neutron Capture Therapy (BNCT)" making use of thermal and epithermal neutrons.
- · Acdvadon analyzer for short-lived nuclides
- · Prompt gamma-ray analyzer (PEA) system using the super-mirror neutron gtude tube
- · Large sample irraddadon equipment which enables an irradiation test up to 15cm in sample diameter.

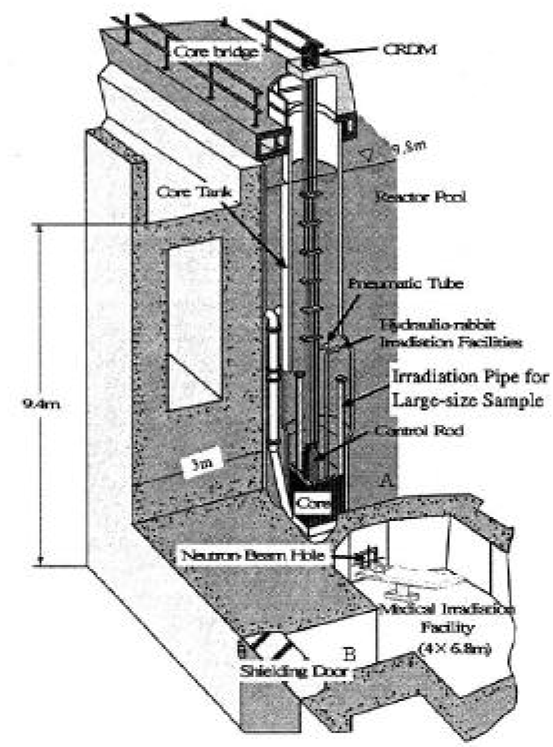


Fig. 3 New experimental facilities in JRR-4

5. JMTR

The JMTR is a light water cooled and moderated tank type material testing Doctor with maximum thermal power of 50MW. Since 1971, it has been operated and utilized as the most flexible irradiadon test bed with the highest thermal fast neutron fluxes in Japan. It has been used for irradiadon tests on fuelslmaterials for LWR, FBR, ATR, HTGR and fusion reactors, fundamental research and Rl production.

The reactor COD which is installed inside of the reactor pressure vessel consists of twenty two standard fuel elements, five control rods and many reflectors of beryllium and aluminum as shown m Fig.4. The control rod consists of box shape hafaium absorber and follower element of fuel. Fuel elements and fuel followers are the MTR type with the emichment of 20% at present which was originally 93% and Educed to 45% im 1986 and reduced again to 20% in 1994 without significant change in irradiadon performance.

The JMTR is operated normally five cycles a year with a continuous full power operation for four weeks in each cycle. It has been operated 126 cycles and the integrated operational power reached about 121,332.5MWd was attained by the end of February 1999.

A lot of irradiation facilities are installed in the JMTR core as follows; about one hundred capsule irradiation holes, one shroud facility (OSF-I), two hydraulic rabbit irradiation facilities. Various kind of irradiadon capsules am provided m meet the requirement of researchers such as,

- · constant temperature control capsule which can keep specimens at desired temperamre not only during nominal power but also power up and power down period.
- · creep capsule which can load and control tensile or compassion load to the specimen at Squired temperature,
- · spectrum controlled capsule which can adjust neutron energy spectrum,
- · gas-sweep capsule in which a carrier gas flows to recover gas element produced by neutron irradiadon, and so on.

Utilizing OSF-I, power ramp tests on high bum-up fuel elements of power mactors have been carried out under rapid power changes in BWR coolant condition. It is expected in the future to make another power ramp experiments on high bum up MOX fuels using the similar facility as OSF-I. A gas-sweep capsule is scheduled to be applied in the irradiadon test on blartket of fusion reactors. A series of irradiation tests on irradiadon-assisted stress corrosion cracking (IASCC) is expected under the high temperature and pressure water condition of LWR. A new technology on the measurement of crack growth under the high temperature and pressure conditions is needed for this experiment.

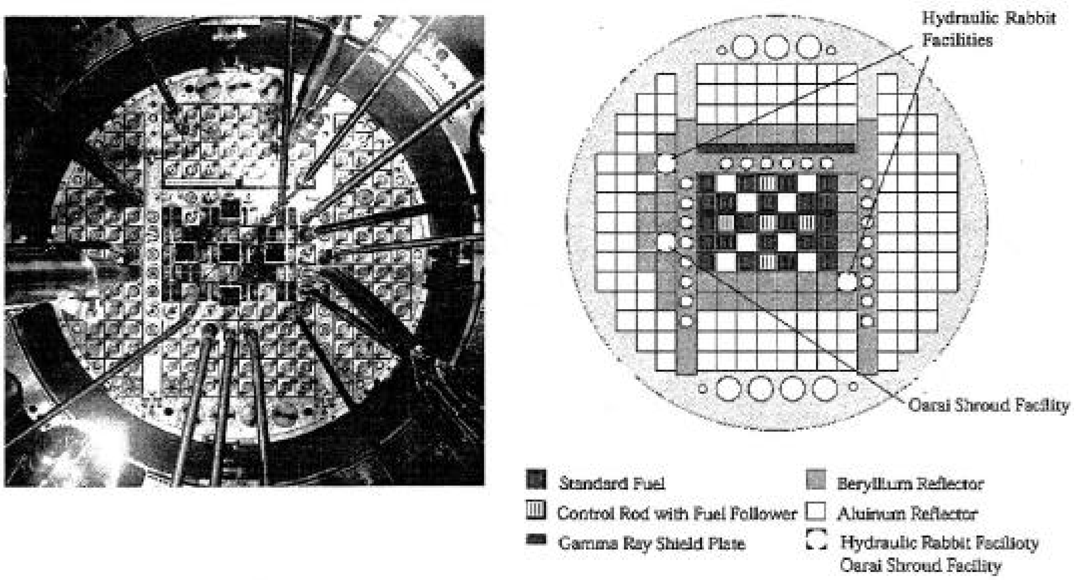


Fig. 4 JMTR Core Arrangement

6. NSRR

The NSRR is a modified TRIGA-ACPR (Annular Core Pulse Reactor) which was built to investigate the reactor fuel behavior under reactivity initiated accident (RIA) conditions. The general view of the reactor COD is shown in Fig5. The core consists of 149 TRIGA-qpe driver fuel rods and 1 lcontrol rods, includmg 3 transient rods which play a main role to make pulse shape operation. These transient rods are instantaneously withdrawn by cornpDssed air, and a large amount of positive reactivity up to 4.7$ cam be imserted into the core within a few milli-second.

The NSRR can be operated in steady power mode up to 300kW as well as in pulse power mode. By the maximum single pulse operation, the peak reactor power of 23000MW and the integrated pulse power of 130MW*sec are able to be attained. Up to now, over 2772 times of pulse operation have been carried out and about 1382 irradiation tests in pulse mode have been done for the light water power reactor (LWR) fuels. The results of these experiments am widely utilized for establishmg the Japanese regulatory guide for LWR's.

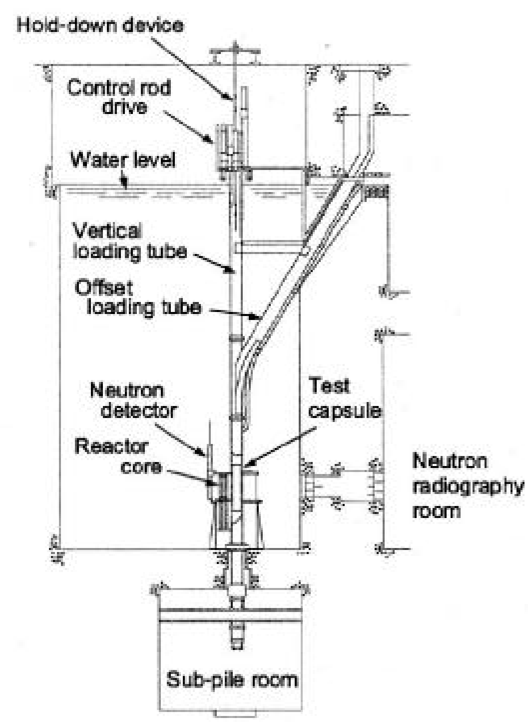


Fig. 5 Cut-view of NSRR

7. HTTR

The HTTR is a graphite moderated gascooled high-temperature test reactor with maximum thermal power of 30MW and outlet coolant temperature of 950°C. After a long period of R&D works over 20 years, construction of the HTTR started in 1991 in order to establish and upgrade HTGR technology and make an innovative basic research in high temperature engineering. The construction works were completed in 1997 and fuel loading started im 1998 after ftmcdonal tests. The first criticality was achieved on 11 November 1998.

The active core of the HTTR 2.9m m height and 2.3m in diameter, consists of thirty fuel columns and seven control-rod-guide columns and is surrounded by replaceable reflector columns and irradiation test columns (Fig.6). A fuel assembly consists of thirtythree fuel rods in trigonal lattice and a hexagonal prismatic graphite block. TRISO coated fuel particles with UOt kemel, about 6wt % in average enricbJnent and 600pm in diameter, are used in fuel rods. Helium gas is used as a coolamt im primary and secondary cooling systems.

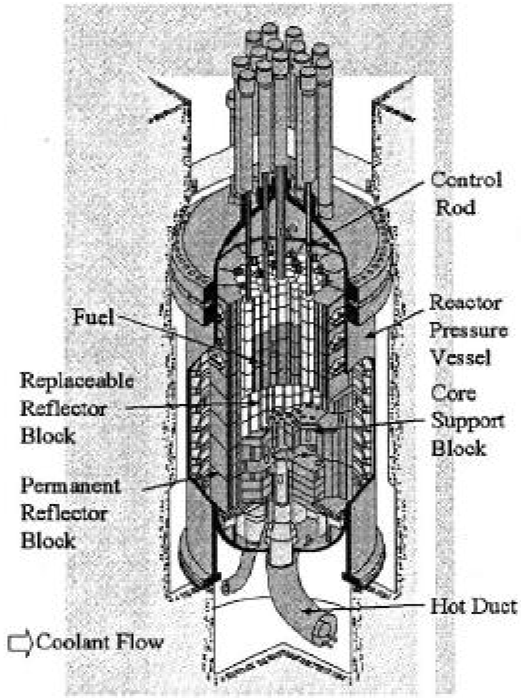


Fig. 6 Cross Sectional View of HTTR Reactor Pressure Vessel

The power-up test will be performed in 1999, and the ftdl power operation is expected to be attained in the year of 2000.

8. Conclusion

At present, the JRR-3,4, JMTR NSRR are m operation, the HTTR has reached first criticality and 1RR-2 is in decommissioning. Research and test reactors of JAERI have been contributing to the basic researches and engineering R&D in nuclear energy. These reactors will play an important role also in the next century as present. The new reactor, HTTR is expected to develop and extend a wide application of nuclear energy in the 21stcenmry.