JAEA-Review
2006-016

JP0650406

Information Exchange Mainly on HTGR Operation and Maintenance Technique between JAEA and INET in 2005

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June 2006

Japan Atomic Energy Agency 日本原子力研究開発機構

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(Received April 4, 2006)

The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. Presently only two HTGR reactors are operational in the world, including the HTTR (High Temperature Engineering Test Reactor) in Japan Atomic Energy Agency (JAEA) and the HTR-10 in the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University in China. JAEA and INET have cooperated since 1986 in the field of HTGR development, particularly on the HTTR and HTR-10 projects. This report describes the cooperation with emphasis on HTGR operation and maintenance techniques between JAEA and INET and outlines cooperation activities during the fiscal year 2005.

Keywords: HTGR, HTTR, HTR-10, International Cooperation

+ Nuclear Science and Engineering Directorate

* Institute of Nuclear and New Energy Technology of Tsinghua University

日本原子力研究開発機構と中国清華大学核能及新能源技術研究院との高温ガス炉運転保守技術等の情報交換に関する報告書（2005 年）

日本原子力研究開発機構大洗研究開発センター高温工学試験研究炉部
橘　幸男、日野　竜太郎[+]、Suyuan YU*

（2006 年 4 月 4 日受理）

高温ガス炉から取り出される高温の熱は、高効率発電のみならず、広範囲なプロセス熱利用、特に、熱化学水素製造に用いることができることから、高温ガス炉への関心が世界的に高まっている。現在、世界で運転されている高温ガス炉は２基のみで、１つが独立行政法人日本原子力研究開発機構の HTTR（高温工学試験研究炉）であり、もう１つが、中国の清華大学核能及新能源技術研究院（INET）の HTR-10 である。原子力機構と INET は、1986 年の覚書締結以来、これまで高温ガス炉分野、特に、HTTR 計画及び HTR-10 計画について研究協力を進めてきた。本報は、2005 年度の原子力機構と INET の高温ガス炉開発に係る主要な研究協力活動について、高温ガス炉運転保守技術に重点を置いてまとめたものである。

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1. Introduction

The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. National projects on HTGRs are ongoing in Japan, China, France, USA, South Africa, Korea, etc., and the VHTR (Very High-Temperature Reactor) is chosen as the most promising Generation IV nuclear reactor system in GIF (Generation IV International Forum). There are presently only two HTGRs operating in the world, HTTR, High Temperature Engineering Test Reactor, in JAEA (see Table 1.1 and Fig. 1.1) and HTR-10 in Institute of Nuclear and New Energy Technology of Tsinghua University (INET) (see Table 1.2 and Fig. 1.2).

Construction of the HTTR was started in 1991 and its first criticality was achieved on November 10, 1998. Then, power-up tests were carried out, and rated thermal power of 30MW at the reactor outlet coolant temperature of 850°C was attained in December 2001. Rated power operation and safety demonstration tests using the HTTR have been conducted since FY2002. After several operational cycles, high temperature test operation of the HTTR to achieve the coolant temperature of 950°C was conducted, and coolant temperature of 950°C at reactor outlet was reached on April 14, 2004.

First criticality of the HTR-10 was achieved at air condition on December 1, 2000, and re-criticality at helium condition was attained in July 2002. Then, power-up tests were conducted, and the first synchronization at 3MWt was achieved in January 2003, followed by full power operation at 10MWt with core outlet He temperature of 700°C in February 2003. Safety demonstration tests including helium circulator trip without scram and reactivity insertion without scram were carried out in 2003 and 2004.

INET is also promoting development of Modular High-Temperature Gas-cooled Reactor (MHTGR) named as High Temperature Gas-Cooled Reactor – Pebble bed Module (HTR-PM) (see Table 1.2 and Fig. 1.2), based on the technology and experiences of the HTR-10. The HTR-PM project is under the standard design phase, and the HTR-PM demonstration plant is planned to finish construction in 2010.

JAEA and INET have cooperated in the area of HTGR development, especially on HTTR and HTR-10 projects, since 1986 when a Memorandum of Understanding was exchanged between the two institutes. This report describes cooperation on HTGR development between JAEA and INET and major cooperation activities in fiscal year 2005 from April 2005 through March 2006.

Table 1.1 Major specifications of HTTR

Thermal power	30MW
Outlet coolant temperature	850°C/950°C
Inlet coolant temperature	395°C
Fuel	Low enriched UO_2
Fuel element type	Prismatic block
Direction of coolant flow	Downward
Pressure vessel	Steel
Number of cooling loop	1
Heat removal	IHX and PPWC (parallel loaded)
Primary coolant pressure	4MPa
Containment type	Steel containment
Plant lifetime	20 years

Table 1.2 Specifications of HTR-10 and HTR-PM

Parameters		HTR-10	HTR-PM
Reactor thermal power	MW	10	458
Net output power	MW	2.5	195
Primary helium pressure	MPa	3.0	7.0
Helium inlet temperature	°C	250	250
Helium outlet temperature	°C	700	750
Helium mass flow rate	kg/s	4.3	176
Main steam pressure	MPa	3.5	14.2
Main steam temperature	°C	435	538
Number of spherical fuel elements	-	27000	520000

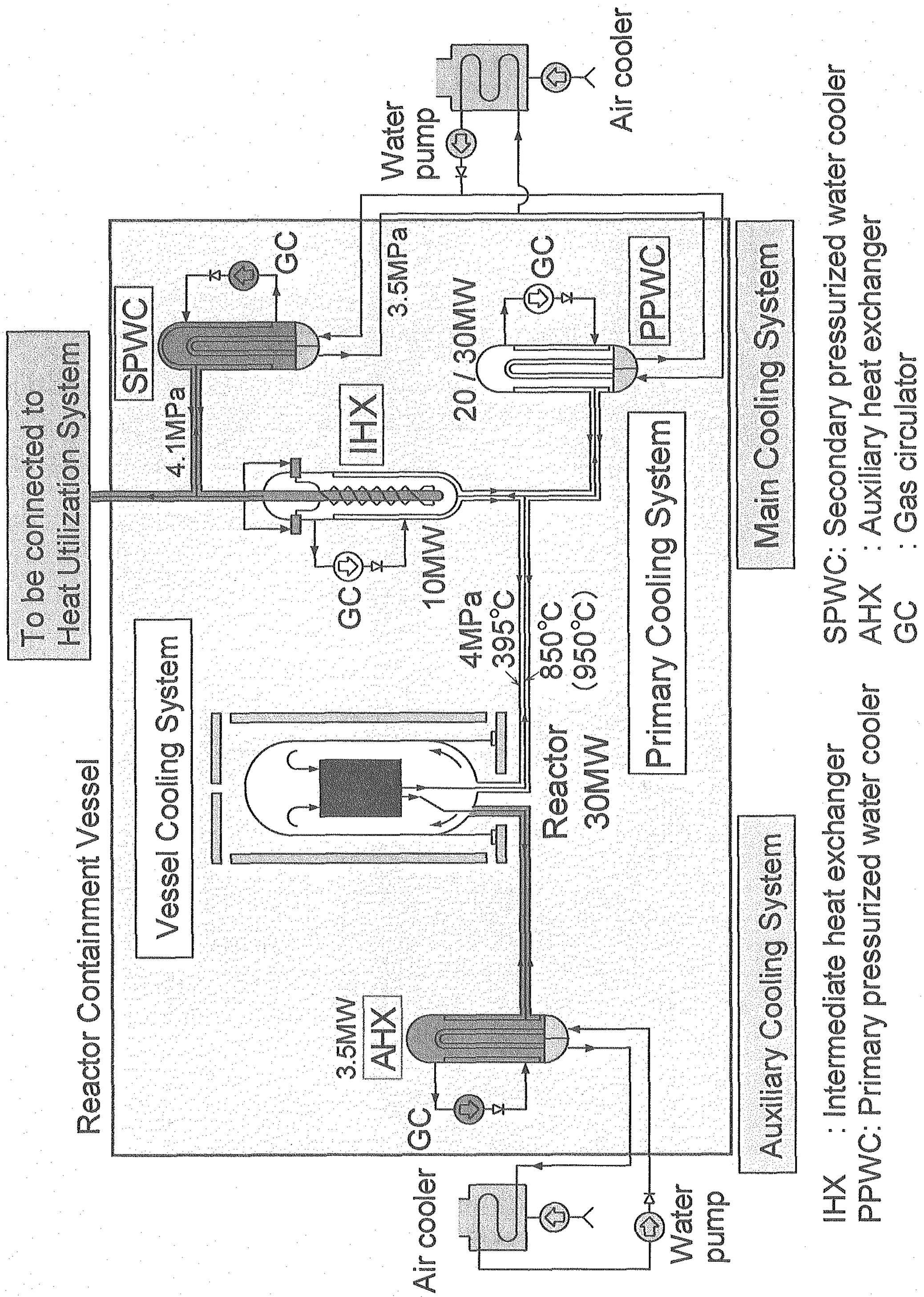
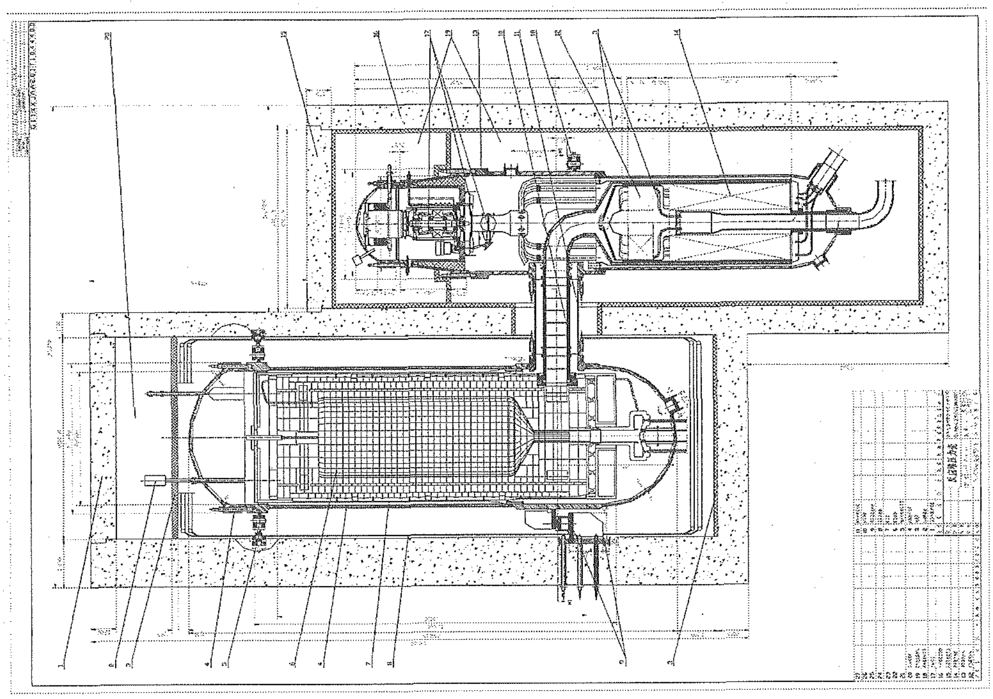


Fig. 1.1 Cooling system of HTTR

HTR-PM



HTR-10

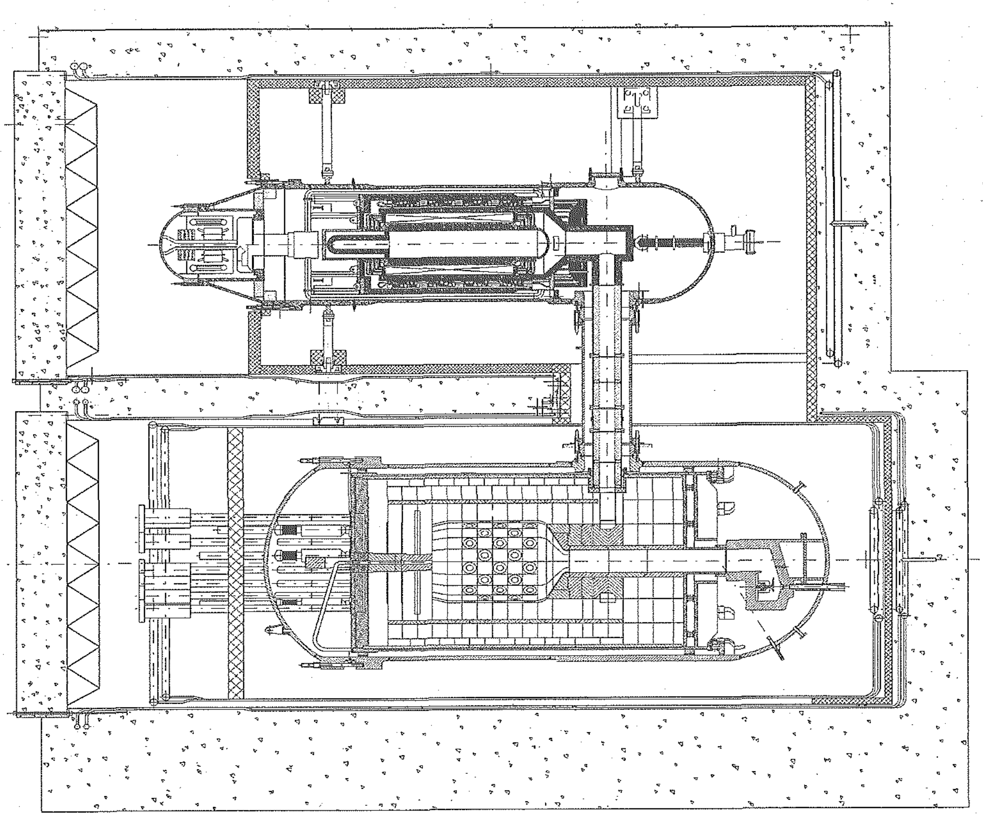


Fig. 1.2 Figures of HTR-10 and HTR-PM

2. Cooperation on HTGR Development between JAEA and INET

2.1 History of Cooperation

Vice chairman of Atomic Energy Commission of Japan, was requested for collaboration between China and Japan in the area of HTGR research and development during his visit to China in June 1985.

In September 1985, Director of Institute of Nuclear Energy Technology of Tsinghua University (INET) visited HTGR research and development facilities in Japan Atomic Energy Research Institute (JAERI), and discussed exchange of a Memorandum of Understanding (MOU) about cooperation on HTGR research and development.

In December 1985, A JAERI delegation visited INET and discussed exchange of a MOU.

In June 1986, JAERI and INET exchanged the initial MOU.

In June 1988, valid duration of the MOU was extended until June 1990.

In June 1990, the MOU was further extended until June 1995. In addition, Personnel Assignment Agreement was added to the memorandum of understanding.

In June 1995, valid duration of the MOU was extended until June 2000.

In June 2000, the MOU was further extended until June 2005.

In September 2003, Institute of Nuclear Energy Technology of Tsinghua University (INET) changed its full official name to Institute of Nuclear and New Energy Technology of Tsinghua University (INET) to further broaden academic disciplines of the institute.

In June 2005, valid duration of the MOU was once again extended until June 2010.

In October 2005, JAERI and Japan Nuclear Cycle Development Institute (JNC) merged to form Japan Atomic Energy Agency (JAEA).

Since June 1986 until today, information exchange meetings have been held almost every year as shown in Table 2.1, and general information exchange on research and development plan on HTTR and HTR-10 as well as on technologies in the area of HTGRs has been made.

Since the HTR-10 is the only pebble bed type HTGR and the HTTR the only prismatic block type HTGR being operated in the world at present, the information exchange has been beneficial for both JAEA and INET.

Since 1990 when the Personnel Assignment Agreement was added, JAEA has accepted researchers from INET in the field of HTGR safety, nuclear heat utilization, etc.

2.2 Area of Cooperation

The original MOU exchanged in 1986 stipulated the area of cooperation as follows. INET and JAEA will provide to each other program status and technical outline information such as is generally available at each of their respective facilities relating to their respective programs for research and development of Gas-cooled Reactors. Each party will review the information provided by the other's programs as a basis for discussions on a future agreement. The subject matter of the information to be exchanged shall include, but not be limited to, the followings:

A) The High-Temperature Gas-cooled Reactor (HTGR), for process heat and cogeneration, including both fuel technology and plant technology.

B) The Very-High Temperature Gas-cooled Reactor (VHTR), for process heat, including both fuel technology and plant technology.

(Note: The Very-High Temperature Gas-cooled Reactor (VHTR) here is similar to but not the same as the VHTR selected as a Generation IV nuclear system.)

In 1990, the MOU was amended by inserting that each party may assign its personnel into the facility of the other in accordance with the Personnel Assignment Agreement, and that for the purpose of carrying out the cooperative activities under the MOU, both parties may exchange samples when agreed by both of them. The MOU in 1990 also added a new paragraph: Each party shall make available, at least once a year to the other party reports written in English which have been published by each party.

2.3 Status of HTTR in 2005

The HTTR was started up on February 14 for periodic inspection (full power operation) and safety demonstration tests, but the reactor scrammed on February 19 at thermal power of 9 MWt by operational error. Then, a failure of reserved shutdown system was encountered on February 21 during routine check. Countermeasures to prevent the operational error were taken, and the failed drive motor for the reserved shutdown system was replaced.

On August 30, the HTTR was restarted for periodic inspection and safety demonstration tests, but the reactor scrammed on September 11 in response to a loss of off-site electric power caused by thunder. On September 14, one wide range monitoring detector out of three failed, and JAEA decided to replace all three wide range monitoring detectors of the nuclear instrumentation system. Also, overhaul of control rod system and reserved shutdown system has been started.

2.4 Status of HTR-10 in 2005

In the year of 2005, INET continued conducting inherent safety test and longtime operation test on HTR-10. After successfully carrying out the experiment of ATWS on accidental control rod withdrawal in 2004, INET completed the experiments of ATWS on helium circulator stopping at thermal power of 3MW and 10MW, respectively. On July 7, 2005, the power of helium circulator was shut off. With the stop of the helium circulator, the reactor power reduced until the reactor automatically shut down as shown in Fig. 2.1. None of the parameters exceeded the operation set limits, despite that all the control rods were locked in the previous positions.

After completion of the scheduled safety tests, HTR-10 was put into a long-term continuous power operation, during which, the functional operating characteristics of its systems and key facilities were tested and verified. HTR-10's running days amounted to 148 days (see Fig. 2.2). Systems and facilities logged with good operating records during the long-term and continuous run. In the process of the operating tests, the performances of some key systems and facilities of HTR-10, such as control rod system, absorption ball system, helium circulator, and steam generator were tested and then inspected following tests in actual operating conditions of high temperature, high pressure, irradiation, etc. All the performances proved consistent with the design specifications.

Examination was conducted on the fuel element charging & discharging system. Knowledge was gained about how the fuel elements and graphite balls flow in the tube at different temperature, pressure and burnup, based on which optimal working mode and control of the charging & discharging system were proposed. Further studies were initiated to find out how the key equipments worked, how the efficiency varied in the helium purification system. Thanks to the improvements on the systems resulting from these studies, the function and performance of the purification system can better meet the design requirements (see Table 2.2).

Achievements have been made in the research and development of the direct cycle helium turbine for electricity generation. The overall design, the integrity arrangement of turbine, gear box and generator, has been adopted. Progresses were made in the design and R&D of key components. The reactor safety analysis has been started.

Table 2.1 Number of people visiting INET from JAEA and JAEA from INET for the purpose of exchanging information

Year	Number of people visiting INET from JAEA	Number of people visiting JAEA from INET
1986	2	0
1987	2	0
1988	1	2
1989	0	1
1990	1	3
1991	3	0
1992	2	2
1993	1	4
1994	3	1
1995	2	2
1996	1	4
1997	2	2
1998	4	2
1999	0	3
2000	3	2
2001	0	2
2002	1	2
2003	1	3
2004	2	5

Table 2.2 Helium quality in different power

(vol ppm)

Time	Power	H_2	O_2	N_2	CH_4	CO	CO_2	H_2O
05-1-3	3.5MW	10.22	0.32	1.13	0.52	6.32	1.91	0.61
05-1-9	10MW	12.56	0.41	1.13	0.81	7.44	2.57	0.70
05-3-7	3.1MW	2.69	0.37	1.91	0.25	1.70	0.61	1.17
05-3-24	7.8MW	8.30	0.29	1.75	0.59	5.93	1.75	0.67
05-4-17	6.6MW	7.50	0.42	1.09	0.52	4.53	1.19	0.49
05-11-10	3.2MW	2.68	0.06	0.39	0.26	1.86	0.72	0.99
05-11-23	6.6MW	3.62	0.27	0.41	0.31	2.67	0.93	0.30
05-12-19	7.0MW	3.49	0.07	0.54	0.33	2.34	0.82	0.07

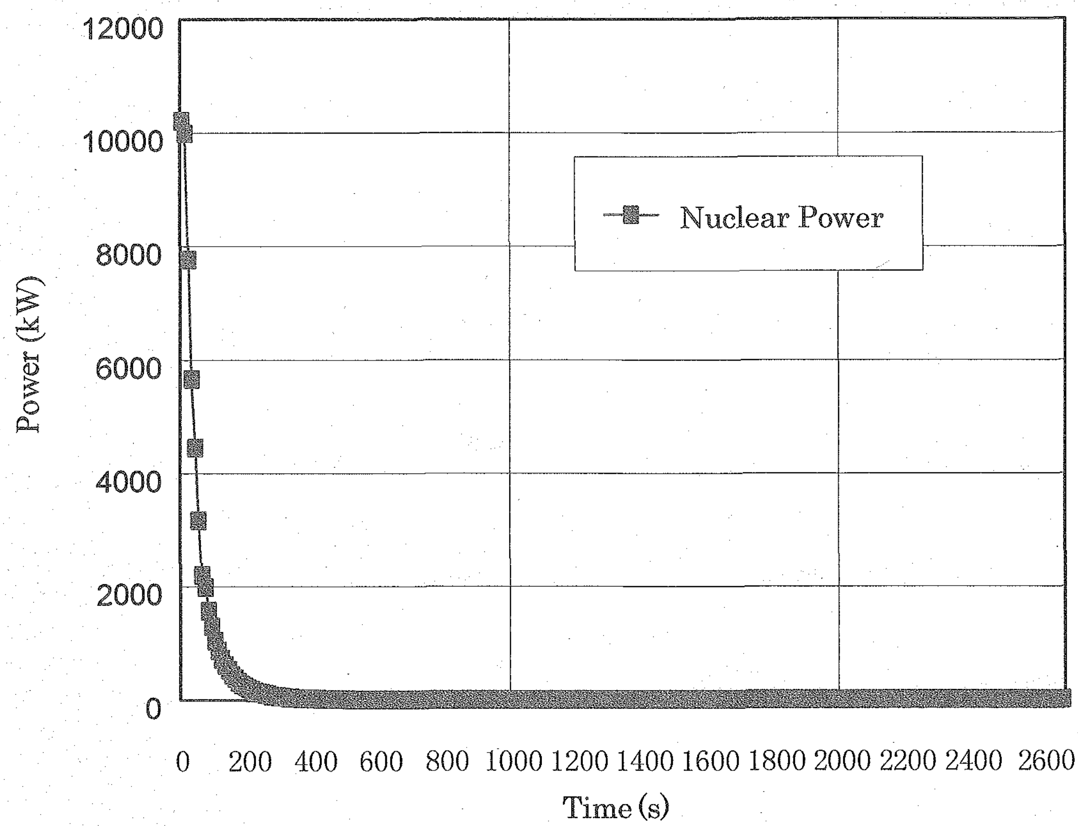
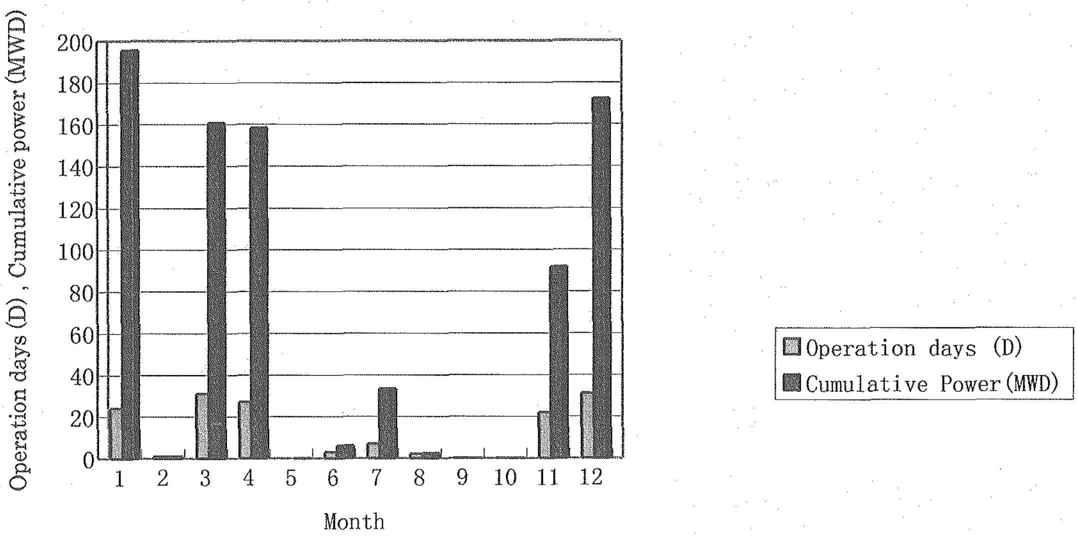


Fig. 2.1 Power fluctuation in ATWS experiment by stopping the helium blower



	1	2	3	4	5	6	7	8	9	10	11	12
Operation days (D)	24	1	31	27		3	7	2	0	0	22	31
Cumulative Power (MWD)	196	1	161	158	0	6	33	2.3	0	0	92	172

Fig. 2.2 Annual statistics on HTR-10 operation

3. Major Cooperation Activities in 2005

3.1 Information Exchange Meeting

An information exchange meeting between JAEA and INET under the MOU was held in INET on August 23 and 24, 2005. An engineer of Department of HTTR, JAEA, and two professors and researchers of INET attended the meeting.

In the meeting, JAEA presented operation and maintenance technology of HTTR such as control of impurities in the primary cooling system, replacement of filters for helium gas circulators, and overhaul of control rod drive mechanism. INET presented status of HTR-10 project, and operational experiences of HTR-10. In addition, JAEA and INET exchanged information on operation and maintenance experiences such as impurities in coolant, helium leak rate of primary cooling system, and filters in cooling system.

Presentation material of JAEA in the meeting is attached in Appendix.

3.2 Mutual Visits between JAEA and INET

On May 16, prior to the occasion of the 13^{th} International Conference on Nuclear Engineering (ICONE 13) held in Beijing, China, a researcher of Department of Advanced Nuclear Heat Technology, visited INET and had discussions with two professors of INET on HTGR and hydrogen production technologies.

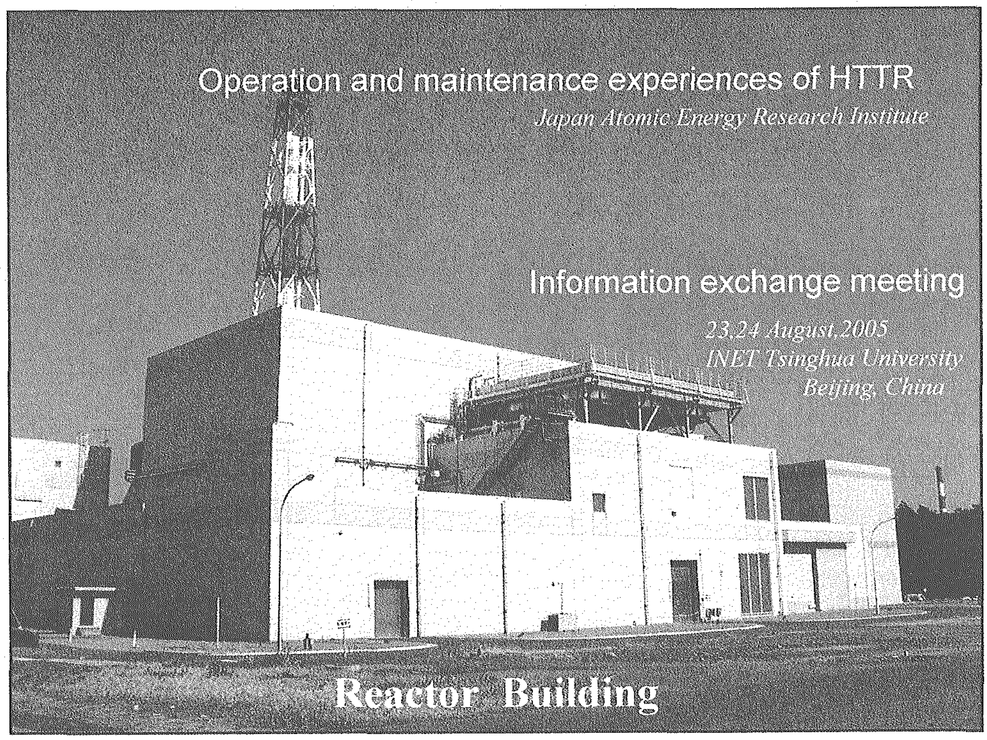
On August 12, after the 18^{th} International Conference on Structural Mechanics in Reactor Technology (SmiRT-18) held in Beijing, China, three researchers of JAEA had discussions with three professors and three researchers of INET on HTGR technologies.

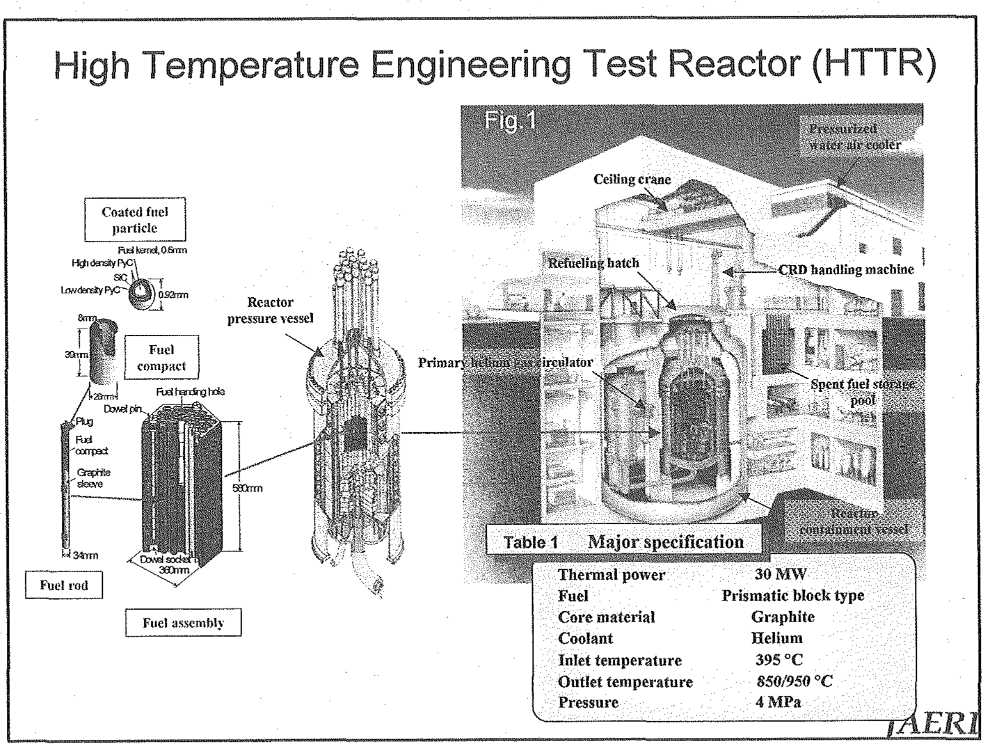
A professor and a researcher visited JAEA on October 5 to 7 during the Third Information Exchange Meeting on the Nuclear Production of Hydrogen including Second HTTR Workshop, and had discussions with Director of Department of HTTR, JAEA on future collaboration between INET and JAEA.

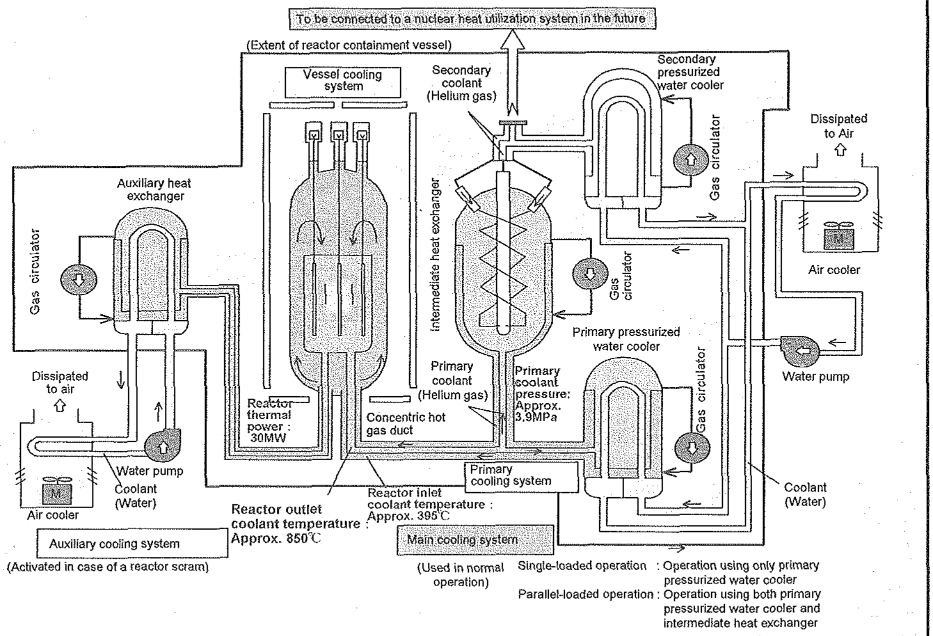
4. Concluding Remarks

This report summarized cooperation on HTGR development between JAEA and INET and major cooperation activities in 2005. An information exchange meeting was held in INET in August, and several mutual visits were made in 2005. Enhancing future collaboration between JAEA and INET is important, and continuous information exchange on HTGR-related technologies proved to be beneficial for the both institutes.

Appendix


Operation and maintenance experiences of HTTR
Japan Atomic Energy Research Institute
Information exchange meeting
23,24 August,2005
INET Tsinghua University
Beijing, China
Reactor Building

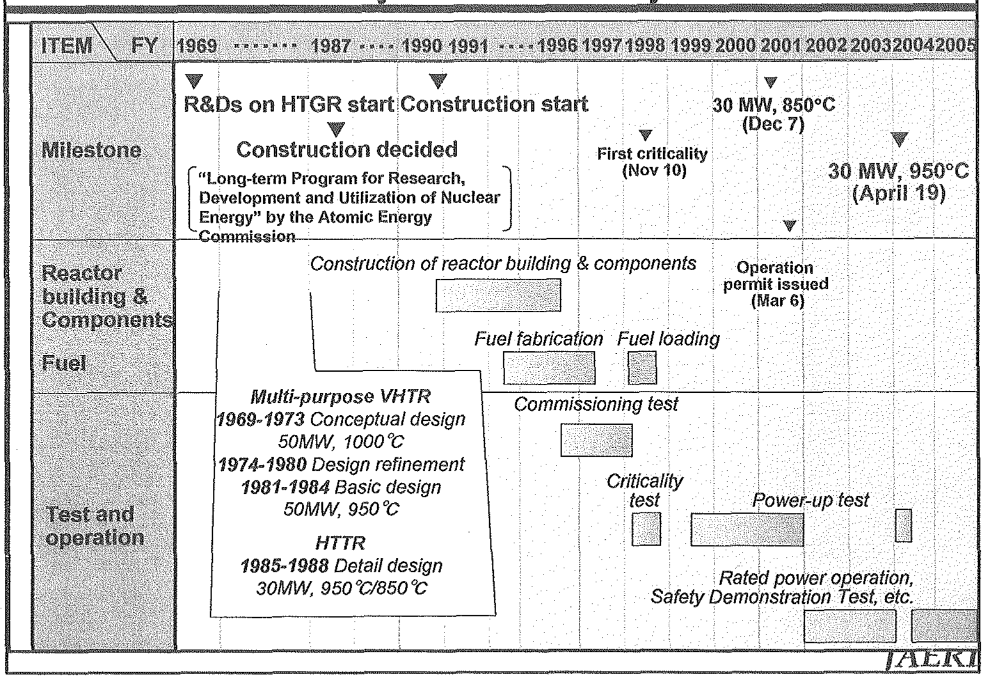

High Temperature Engineering Test Reactor (HTTR)
Fig.1
Pressurized water air cooler
Ceiling crane
Refueling hatch
CRD handling machine
Primary helium gas circulator
Spent fuel storage pool
Reactor containment vessel
Reactor pressure vessel
Coated fuel particle
Fuel kernel, 0.6mm
High density PyC
SiC
Low density PyC
0.92mm
8mm
39mm
26mm
Fuel compact
Fuel handling hole
Dowel pin
Plug
Fuel compact
Graphite sleeve
580mm
34mm
Dowel socket
360mm
Fuel rod
Fuel assembly
Table 1 Major specification
Thermal power 30 MW
Fuel Prismatic block type
Core material Graphite
Coolant Helium
Inlet temperature 395 °C
Outlet temperature 850/950 °C
Pressure 4 MPa
JAERI

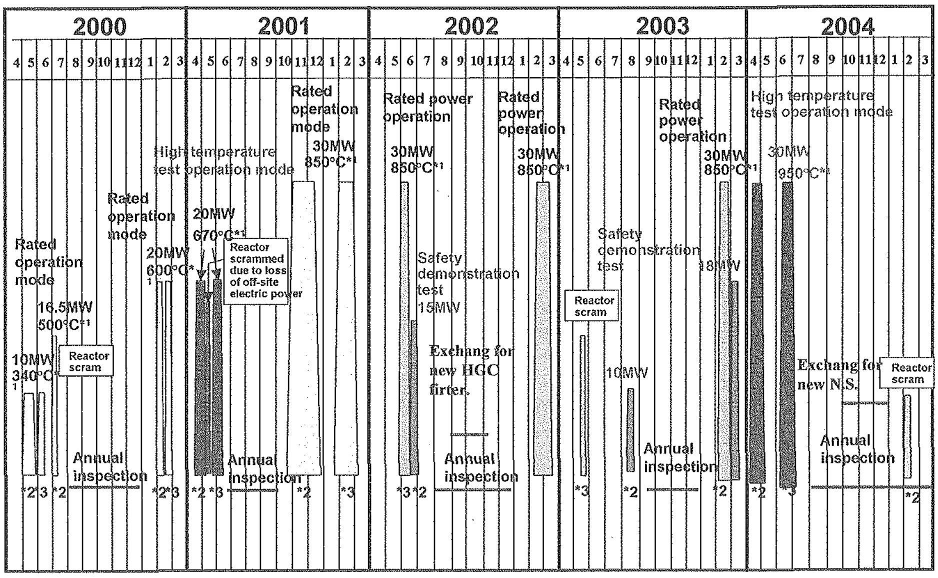


Schematic diagram of cooling system for the HTTR

JAERI

History of HTTR Project





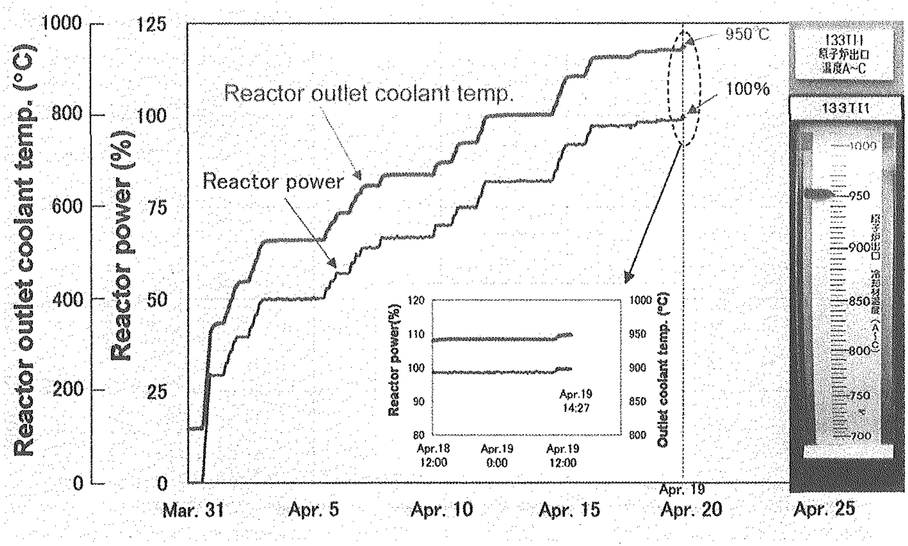
*1: Reactor outlet temperature, *2: Single loaded operation, *3: Parallel loaded operation

6

Power-up test and rated power operation plan of the HTTR

JAERI

Achievement of 950°C at Reactor Outlet



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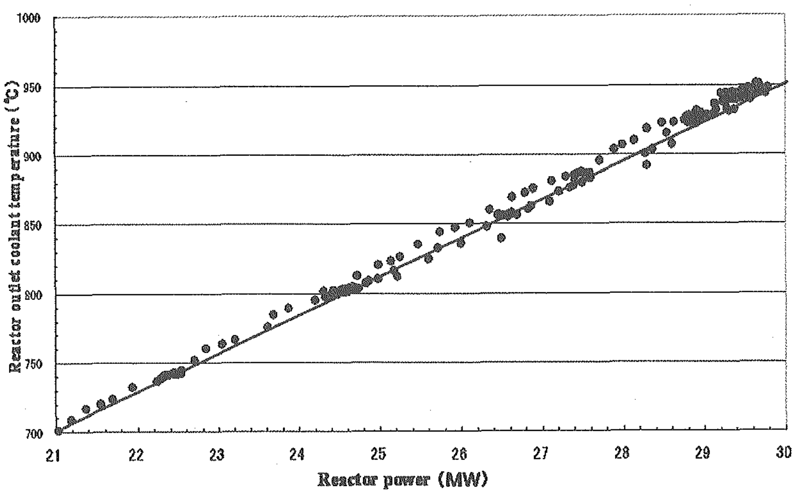


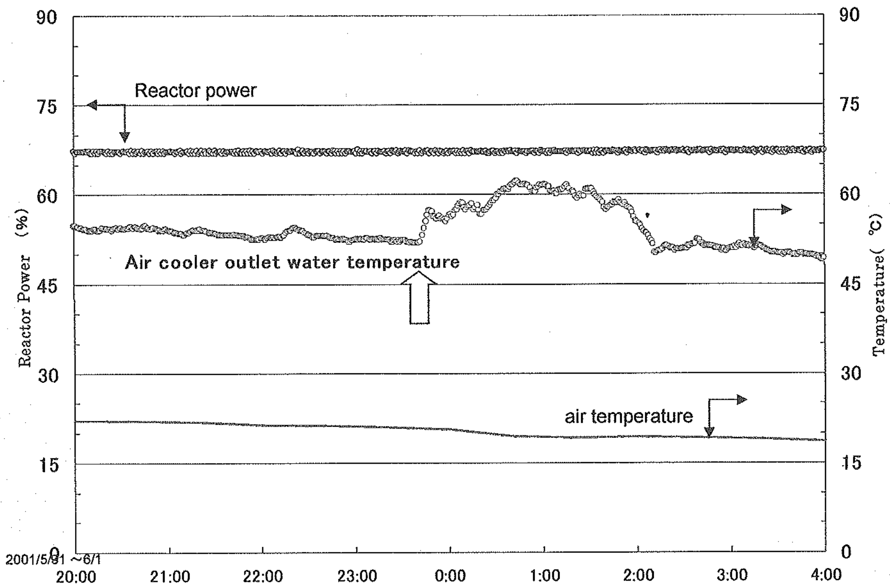
Reactor power and outlet coolant temperature at High temperature test operation / single loaded

JAERI

Topics of Maintenance

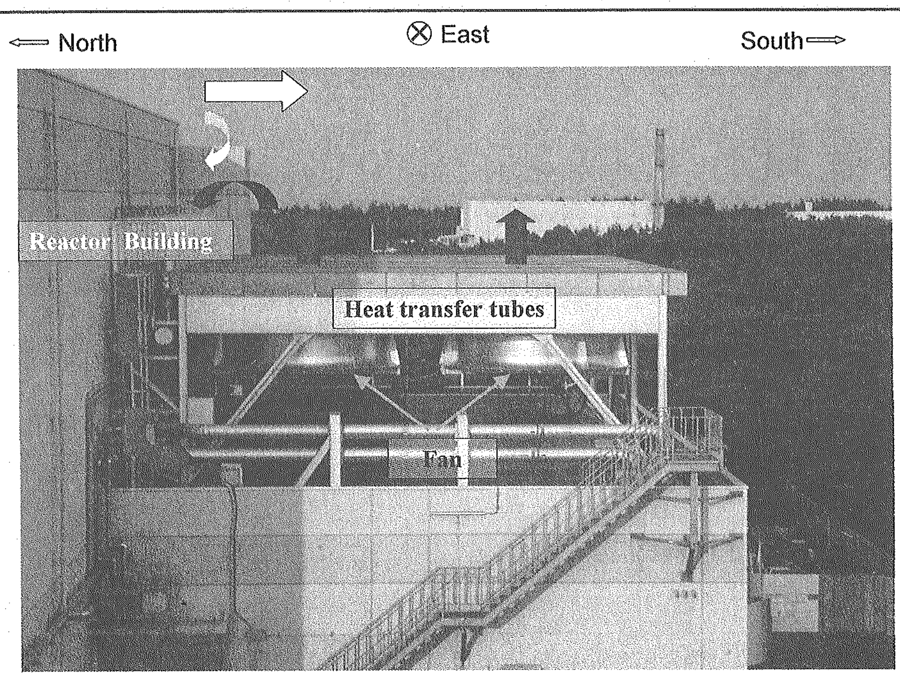
- Behavior of the Pressurized water air-cooler
- Replacement of the filter for the primary helium gas circulator
- Overhaul of the control rod drive mechanism

JAERI



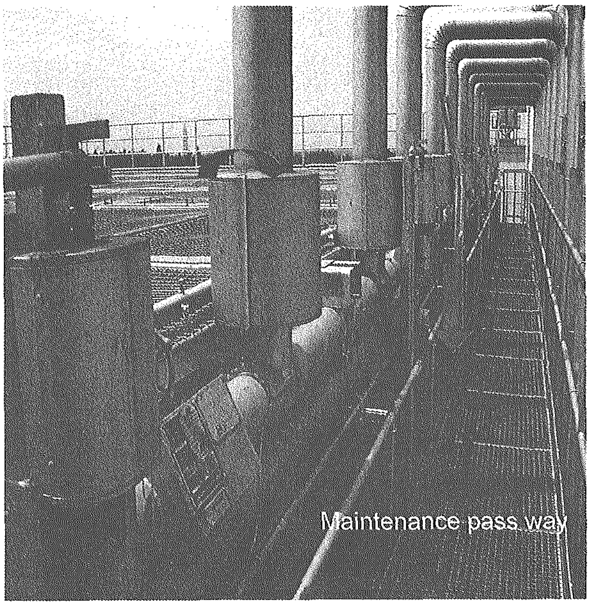
Transients of Air cooler outlet water temperature and air temperature

JAERI



Pressurized water air-cooler

JAERI

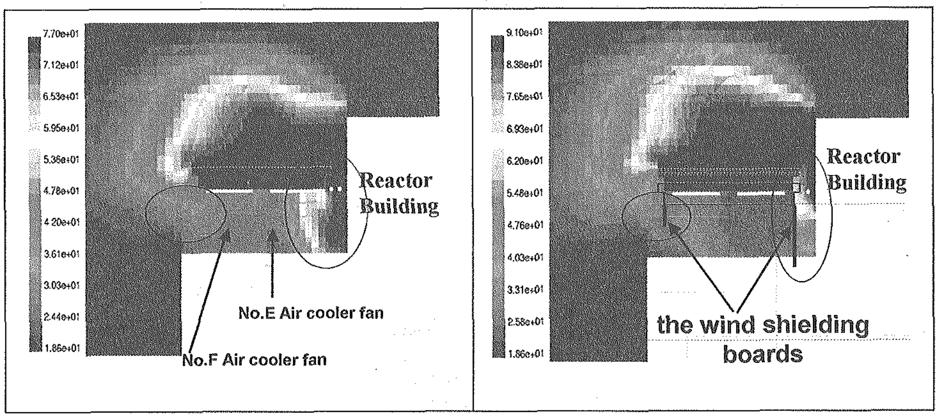


Major specification of the ACL

Type		Forced-draft air-cooled type with fin tube
Heat capacity		30MW
Coolant flow mass rate (maximum)	Pressurized water	640t/h
	Air	2600t/h
Air temperature		(Inlet) 40°C (Outlet) 80°C
Heat transfer tube	O. D.	25.4mm
	Thickness	2.77mm
	Material	Carbon steel
Material	Fin	Aluminum
	Header	Carbon steel
Fan type		Axial-flow variable pitch fan
Number of fan		6

The opening between the reactor building and the air cooler

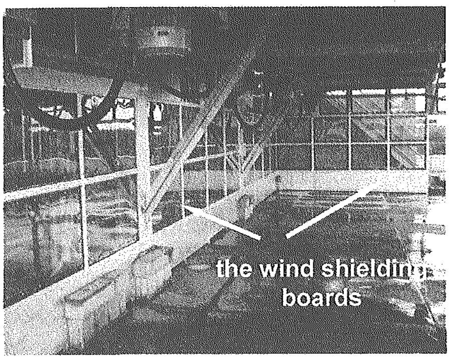
JAERI

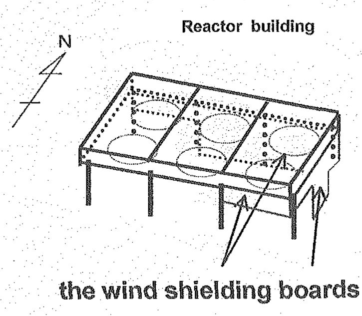


Before improvement after **improvement**

Effects of the wind shielding boards (calculation, 3-D)

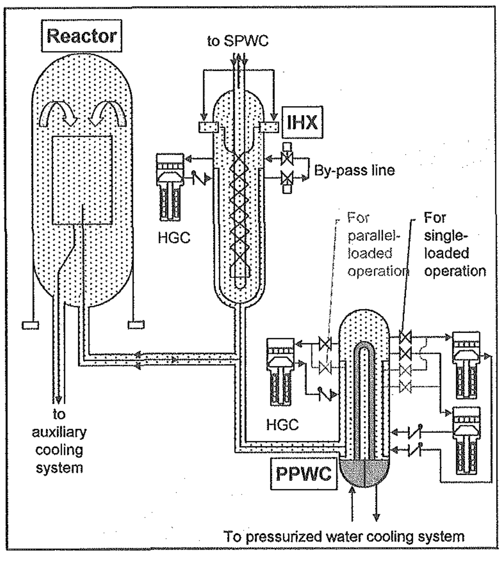
JAERI

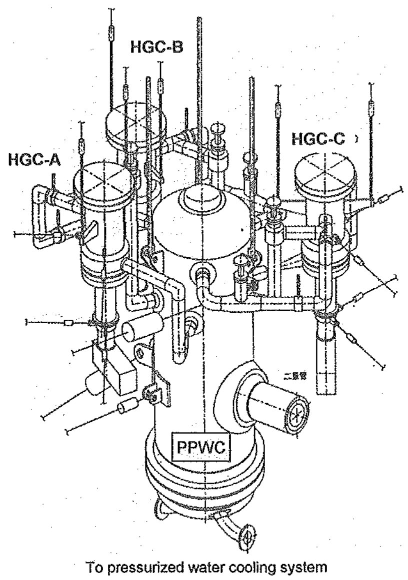




Installation of the wind shielding boards

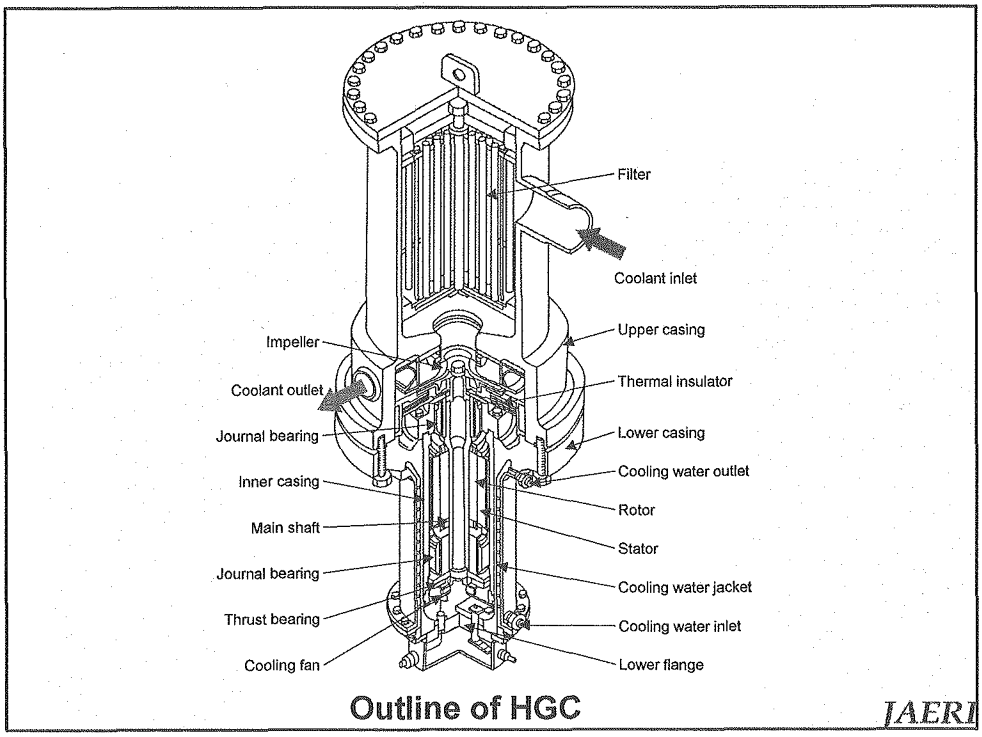
JAERI

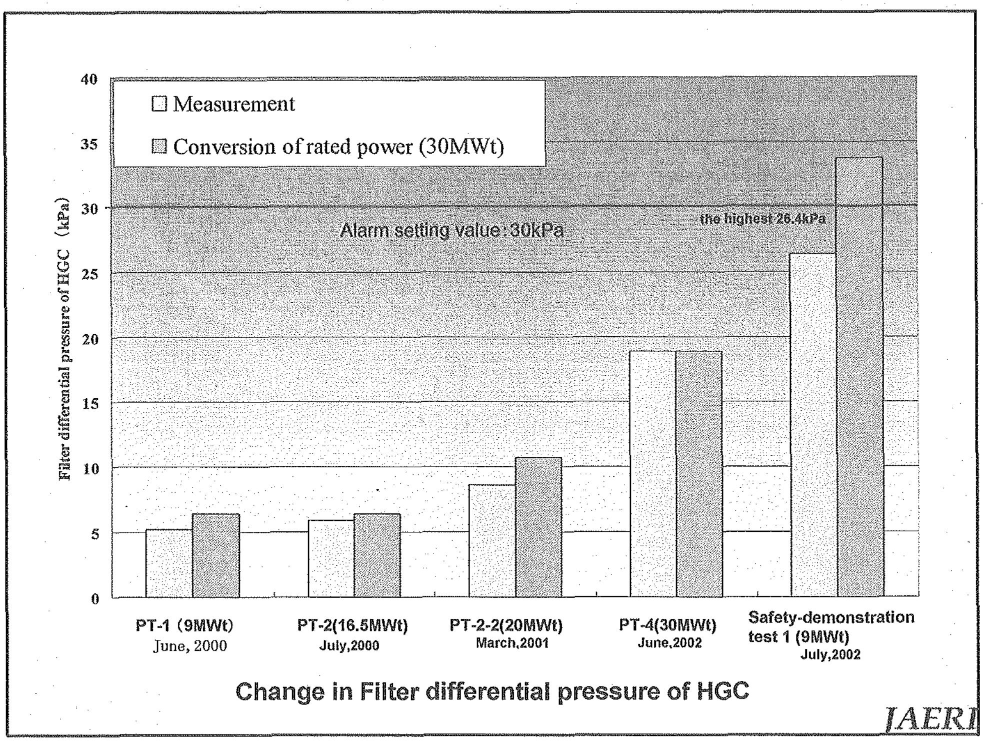


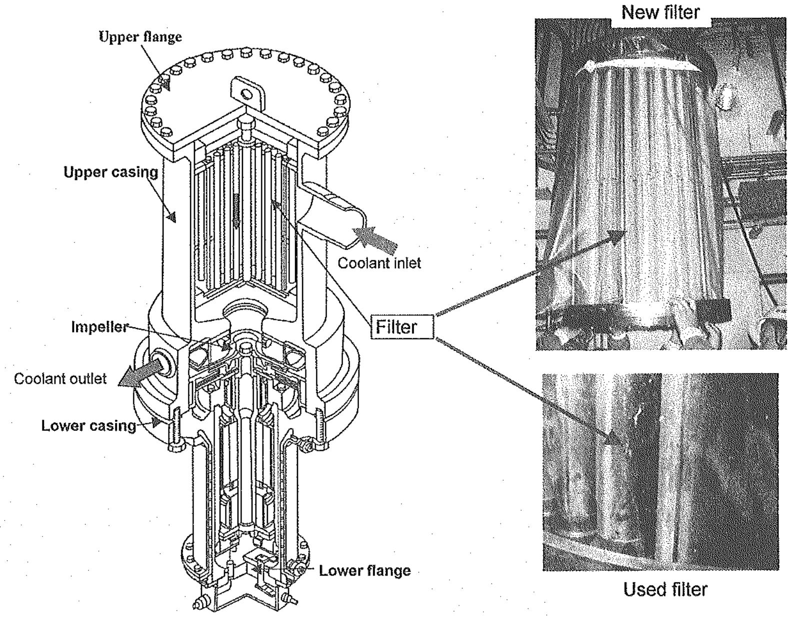


The Arrangement Plan of HGC in primary cooling system

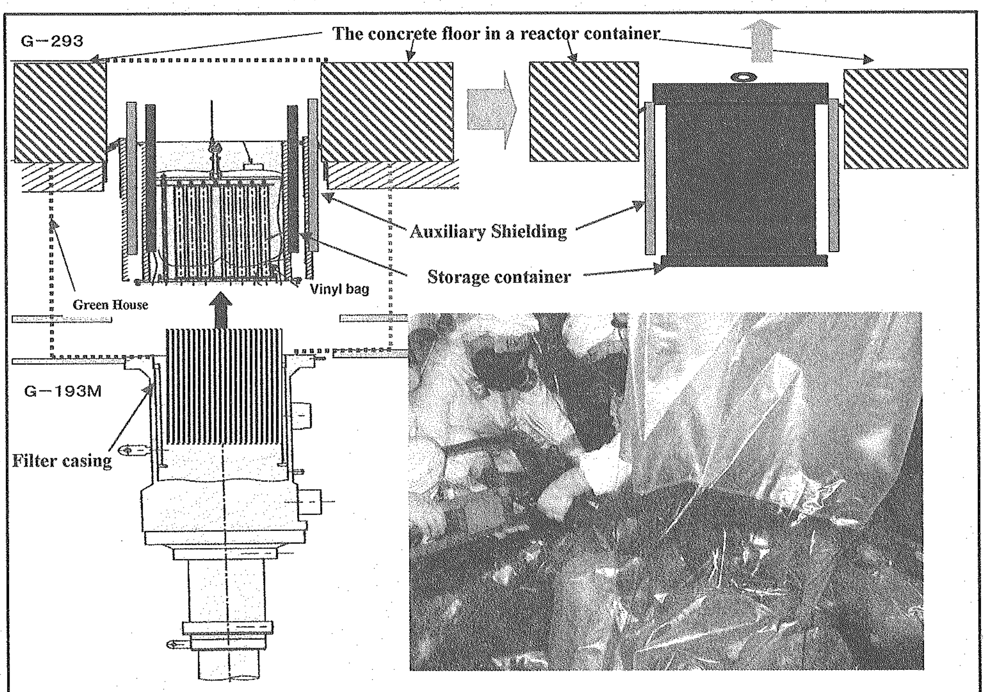
JAERI


Filter
Coolant inlet
Upper casing
Thermal insulator
Lower casing
Cooling water outlet
Rotor
Stator
Cooling water jacket
Cooling water inlet
Lower flange
Impeller
Coolant outlet
Journal bearing
Inner casing
Main shaft
Journal bearing
Thrust bearing
Cooling fan
Outline of HGC
JAERI

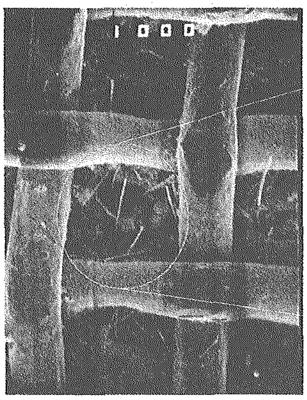

Measurement
Conversion of rated power (30MWt)
Filter differential pressure of HGC (kPa)
40
35
30
25
20
15
10
5
0
Alarm setting value:30kPa
the highest 26.4kPa
PT-1 (9MWt)
June, 2000
PT-2(16.5MWt)
July,2000
PT-2-2(20MWt)
March,2001
PT-4(30MWt)
June,2002
Safety-demonstration test 1 (9MWt)
July,2002
Change in Filter differential pressure of HGC
JAERI



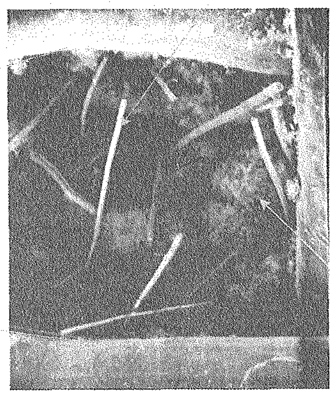
Replacement of the filter for the primary helium gas circulator



Method of filter exchange



SEM-image of filter surface(× 200)



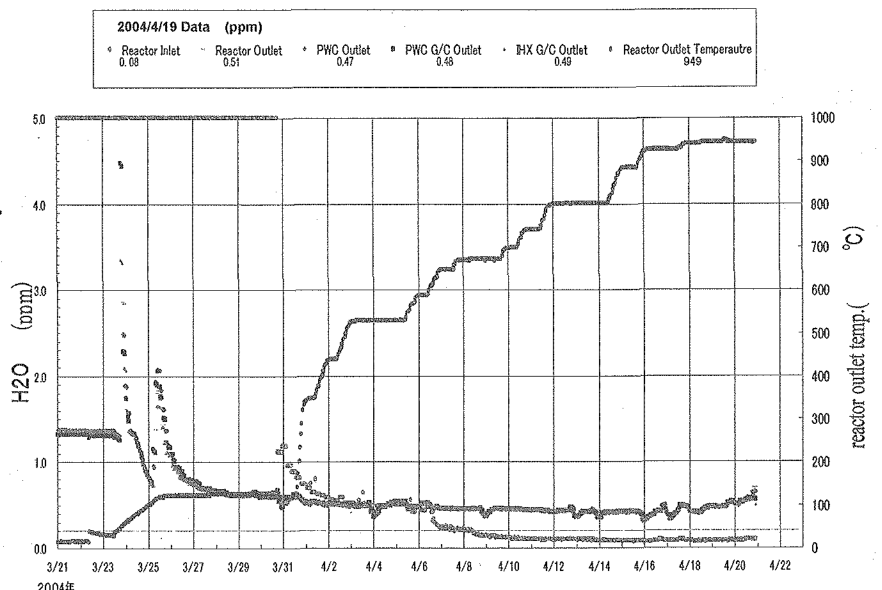
SEM-image of filter surface(× 600)

JAERI

Expected causes of differential pressure increase

- **Graphite powder from the graphite structure of the core**
- **Graphite powder produced by chemical reaction of graphite structure of the core and the moisture in the primary coolant**
- **Abrasion powder of piston ring for the compressor of the helium purification system**

JAERI



Moisture in the primary cooling system

JAERI

Impurity concentration of the primary coolant

Impurity concentration (ppm)

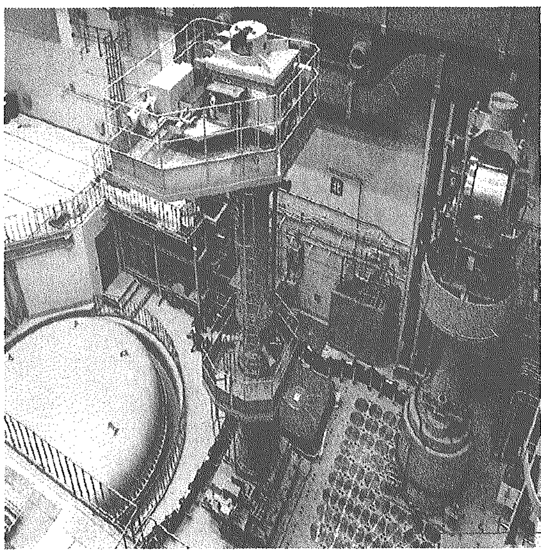
reactor outlet coolant temp. : 950℃

primary coolant pressure : 3.96MPa @ 2004/4/19

H_2	CO	H_2O	CO_2	CH_4	N_2	O_2
0. 21 (3. 0)	1. 32 (3. 0)	0. 08 (0. 2)	0. 19 (0. 6)	0. 01 (0. 5)	0. 15 (0. 2)	0. 03 (0. 04)

( ):Impurity limit **(above 700℃ of outlet coolant temperature)**

JAERI



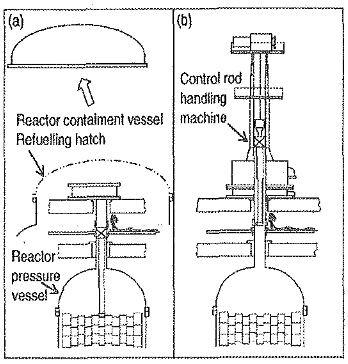
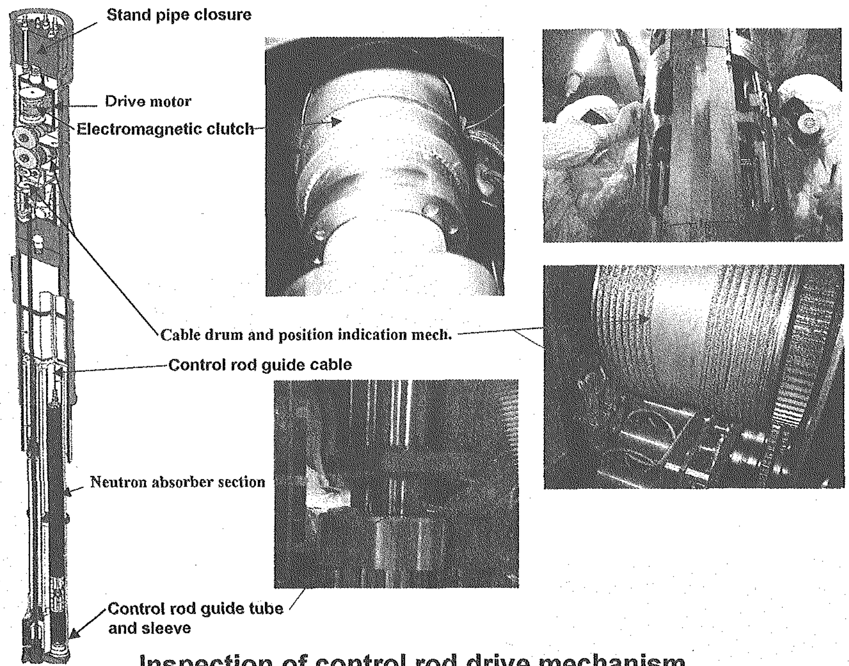


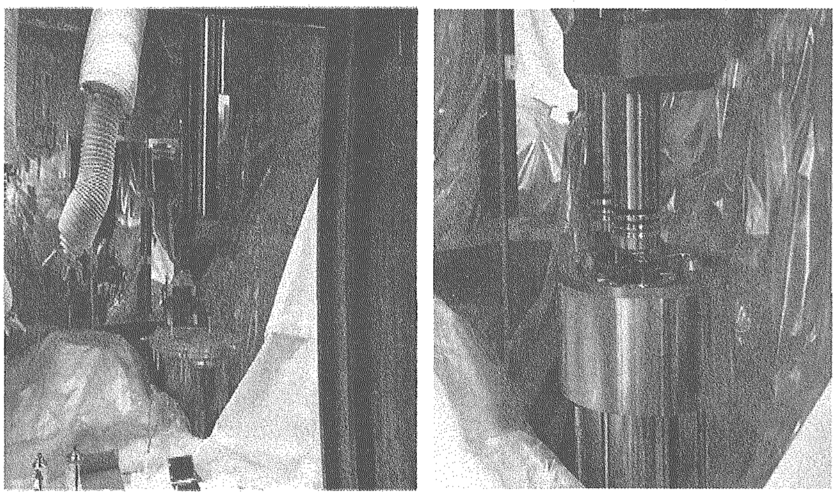
Fig.1

JAERI



Inspection of control rod drive mechanism

JAERI



Inspection of control rod in maintenance pit

END

国際単位系（SI）

表1．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表2．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m-1
密度（質量密度）	キログラム毎立法メートル	kg/m^3
質量体積（比体積）	立法メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
（物質量の）濃度	モル毎立方メートル	mol/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率	（数の）1	1

表5．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表6．国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	1° =(π/180) rad
分	'	1' =(1/60)° =(π/10800) rad
秒	"	1" =(1/60)' =(π/648000) rad
リットル	l、L	$1l=1\ dm^3=10^{-3}m^3$
トン	t	$1t=10^3$ kg
ネーパ	Np	1Np=1
ベル	B	1B=(1/2) ln10 (Np)

表3．固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン[(a)]	rad		$m\cdot m^{-1}=1$[(b)]
立体角	ステラジアン[(a)]	sr[(c)]		$m^2\cdot m^{-2}=1$[(b)]
周波数	ヘルツ	Hz		s^{-1}
力	ニュートン	N		$m\cdot kg\cdot s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\cdot kg\cdot s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N・m	$m^2\cdot kg\cdot s^{-2}$
工率，放射束	ワット	W	J/s	$m^2\cdot kg\cdot s^{-3}$
電荷，電気量	クーロン	C		s・A
電位差（電圧），起電力	ボルト	V	W/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\cdot kg^{-1}\cdot s^4\cdot A^2$
電気抵抗	オーム	Ω	V/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\cdot kg^{-1}\cdot s^3\cdot A^2$
磁束	ウエーバ	Wb	V・s	$m^2\cdot kg\cdot s^{-2}\cdot A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\cdot s^{-2}\cdot A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\cdot kg\cdot s^{-2}\cdot A^{-2}$
セルシウス温度	セルシウス度[(d)]	℃		K
光束	ルーメン	lm	cd・sr[(c)]	$m^2\cdot m^{-2}\cdot cd=cd$
照度	ルクス	lx	lm/m^2	$m^2\cdot m^{-4}\cdot cd=m^{-2}\cdot cd$
（放射性核種の）放射能	ベクレル	Bq		s^{-1}
吸収線量，質量エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2\cdot s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量，組織線量当	シーベルト	Sv	J/kg	$m^2\cdot s^{-2}$

(a) ラジアン及びステラジアンの使用は、同じ次元であっても異なった性質をもった量を区別するときの組立単位の表し方として利点がある。組立単位を形作るときのいくつかの用例は表4に示されている。
(b) 実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号“1”は明示されない。
(c) 測光学では、ステラジアンの名称と記号srを単位の表し方の中にそのまま維持している。
(d) この単位は、例としてミリセルシウス度m℃のようにSI接頭語を伴って用いても良い。

表7．国際単位系と併用されこれに属さない単位でSI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	$1eV=1.60217733(49)\times10^{-19}J$
統一原子質量単位	u	$1u=1.6605402(10)\times10^{-27}kg$
天文単位	ua	$1ua=1.49597870691(30)\times10^{11}m$

表8．国際単位系に属さないが国際単位系と併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里		1海里=1852m
ノット		1ノット=1海里毎時=(1852/3600)m/s
アール	a	$1\ a=1\ dam^2=10^2m^2$
ヘクタール	ha	$1\ ha=1\ hm^2=10^4m^2$
バール	bar	$1\ bar=0.1MPa=100kPa=1000hPa=10^5Pa$
オングストローム	Å	$1\ Å=0.1nm=10^{-10}m$
バーン	b	$1\ b=100fm^2=10^{-28}m^2$

表4．単位の中に固有の名称とその独自の記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa・s	$m^{-1}\cdot kg\cdot s^{-1}$
力のモーメント	ニュートンメートル	N・m	$m^2\cdot kg\cdot s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\cdot s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\cdot m^{-1}\cdot s^{-1}=s^{-1}$
角加速度	ラジアン毎平方秒	rad/s^2	$m\cdot m^{-1}\cdot s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\cdot s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}$
質量熱容量（比熱容量），質量エントロピー	ジュール毎キログラム毎ケルビン	J/(kg・K)	$m^2\cdot s^{-2}\cdot K^{-1}$
質量エネルギー（比エネルギー）	ジュール毎キログラム	J/kg	$m^2\cdot s^{-2}\cdot K^{-1}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m・K)	$m\cdot kg\cdot s^{-3}\cdot K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\cdot kg\cdot s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\cdot kg\cdot s^{-3}\cdot A^{-1}$
体積電荷	クーロン毎立方メートル	C/m^3	$m^{-3}\cdot s\cdot A$
電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\cdot s\cdot A$
誘電率	ファラド毎メートル	F/m	$m^{-3}\cdot kg^{-1}\cdot s^4\cdot A^2$
透磁率	ヘンリー毎メートル	H/m	$m\cdot kg\cdot s^{-2}\cdot A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\cdot kg\cdot s^{-2}\cdot mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	J/(mol・K)	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}\cdot mol^{-1}$
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\cdot s\cdot A$
吸収線量率	グレイ毎秒	Gy/s	$m^2\cdot s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\cdot m^{-2}\cdot kg\cdot s^{-3}=m^2\cdot kg\cdot s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\cdot sr)$	$m^2\cdot m^{-2}\cdot kg\cdot s^{-3}=kg\cdot s^{-3}$

表9．固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\cdot s/cm^2=0.1Pa\cdot s$
ストークス	St	$1\ St=1cm^2/s=10^{-4}m^2/s$
ガウス	G	1 G ^10^{-4}T
エルステッド	Oe	1 Oe ^(1000/4π)A/m
マクスウェル	Mx	1 Mx ^10^{-8}Wb
スチルブ	sb	$1\ sb=1cd/cm^2=10^4cd/m^2$
ホト	ph	$1\ ph=10^4lx$
ガル	Gal	$1\ Gal=1cm/s^2=10^{-2}m/s^2$

表10．国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R=2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
X線単位		$1X\ unit=1.002\times10^{-4}nm$
ガンマ	γ	$1\gamma=1\ nT=10^{-9}T$
ジャンスキー	Jy	$1\ Jy=10^{-26}W\cdot m^{-2}\cdot Hz^{-1}$
フェルミ		$1\ fermi=1\ fm=10^{-15}m$
メートル系カラット		$1\ metric\ carat=200\ mg=2\times10^{-4}kg$
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	
ミクロン	μ	$1\ \mu=1\mu m=10^{-6}m$

（第7版，1998年改訂）