JAEA-Review
2011-042

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February 2012

Japan Atomic Energy Agency

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(Received November 10,2011)

Based on the implementing arrangement between National Nuclear Center of the Republic of Kazakhstan (NNC) and the Japan Atomic Energy Agency (JAEA) for "Nuclear Technology on Testing/Research Reactors" in cooperation in Research and Development in Nuclear Energy and Technology, four specific topics of cooperation (STC) have been carried out from June, 2009. Four STCs are as follows;

(1) STC No.II-1 : International Standard of Instrumentation
(2) STC No.II-2 : Irradiation Technology of RI Production
(3) STC No.II-3 : Lifetime Expansion of Beryllium Reflector
(4) STC No.II-4 : Irradiation Technology for NTD-Si

The information exchange, personal exchange and cooperation experiments are carried out under these STCs. The status in the field of nuclear technology on testing/research reactors in the implementing arrangement is summarized, and future plans of these specific topics of cooperation are described in this report.

Keywords : International Cooperation, Instrumentation, RI Production, Beryllium Reflector, NTD-Si

＊ : National Nuclear Center (NNC), Institute of Nuclear Physics (INP)

JAEA と INP-NNC 間の試験研究炉に関する原子力技術の国際共同研究の現状

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(2011 年 11 月 10 日受理)

カザフスタン共和国の国立原子力センター(NNC)と日本原子力研究開発機構(JAEA)との原子力科学分野における研究開発協力のための実施取決め（試験研究炉に関する原子力技術）に基づき、４項目の特定協力課題を 2009 年 6 月から実施している。4 つの特定協力課題は以下の通りである。

（1）STC No.II-1 ： 中性子照射場における計測機器の国際標準化
（2）STC No.II-2 ：RI 製造に関する照射技術
（3）STC No.II-3 ：試験研究炉で使用するベリリウム製反射体の長寿命化
（4）STC No.II-4 ：シリコン半導体製造に関する技術

これらの特定協力課題の元、情報交換、人員派遣及び共同実験が行われてきた。
本報告書は、実施取決めにおける試験研究炉に関する原子力技術分野の現状をまとめ、今後の計画について記述している。

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1. Introduction

Noting to the memorandum of understanding between the Japan Atomic Energy Agency (JAEA) and the National Nuclear Center of the Republic of Kazakhstan (NNC-RK) for the future cooperation in nuclear energy research and development signed April 30, 2007, the implementing arrangement for cooperation in research and development in nuclear energy and technology was signed on 2, February, 2009. In this arrangement, the following cooperation's concerning nuclear energy and technology have been promoted:

(1) High temperature gas-cooled reactor and its application technology;

(2) Nuclear technology on testing/research reactors;

(3) Other areas as may be mutually agreed by the Parties.

After the agreement, some specific topics of cooperation were discussed in the field of nuclear technology on testing/research reactors between the Neutron Irradiation and Testing Reactor Center (NITRC), JAEA and Institute of Nuclear Physics (INP), NNC-RK from April, 2009. In this discussion, JAEA and NNC-RK own the Japan Materials Testing Reactor (JMTR) and WWR-K, respectively, and basic irradiation techniques had to be standardized to propose common services for the users all over the world. From the results of discussion, it was concluded that three topics: international standard of instrumentation, RI production and lifetime expansion of beryllium reflector, were considered to be important for the testing/research reactors at first. Thus, following specific topics of cooperation (STC) have been carried out from June, 2009.

(1) STC No.II-1 : International Standard of Instrumentation

(2) STC No.II-2 : Irradiation Technology of RI Production

(3) STC No.II-3 : Lifetime Expansion of Beryllium Reflector

Moreover, fabrication of NTD(Neutron Transmutation Doping)-Si with JMTR was considered, and new following topic was proposed on September, 2009.

(4) STC No.II-4 : Irradiation Technology for NTD-Si

The information exchange, personnel exchange and cooperation experiments are carried out under these STCs. Additionally, a part of STC No.II-1 and No.II-3 have been carried out under the partner projects in the International Science and Technology Center (ISTC). R&D schedule in the field of nuclear technology on testing/research reactors is shown in Fig. 1-1.

In this report, the status in the field of nuclear technology on testing/research reactors in the implementing arrangement for cooperation in research and development in nuclear energy and technology is described, and future plans of these specific topics of cooperation are also described.

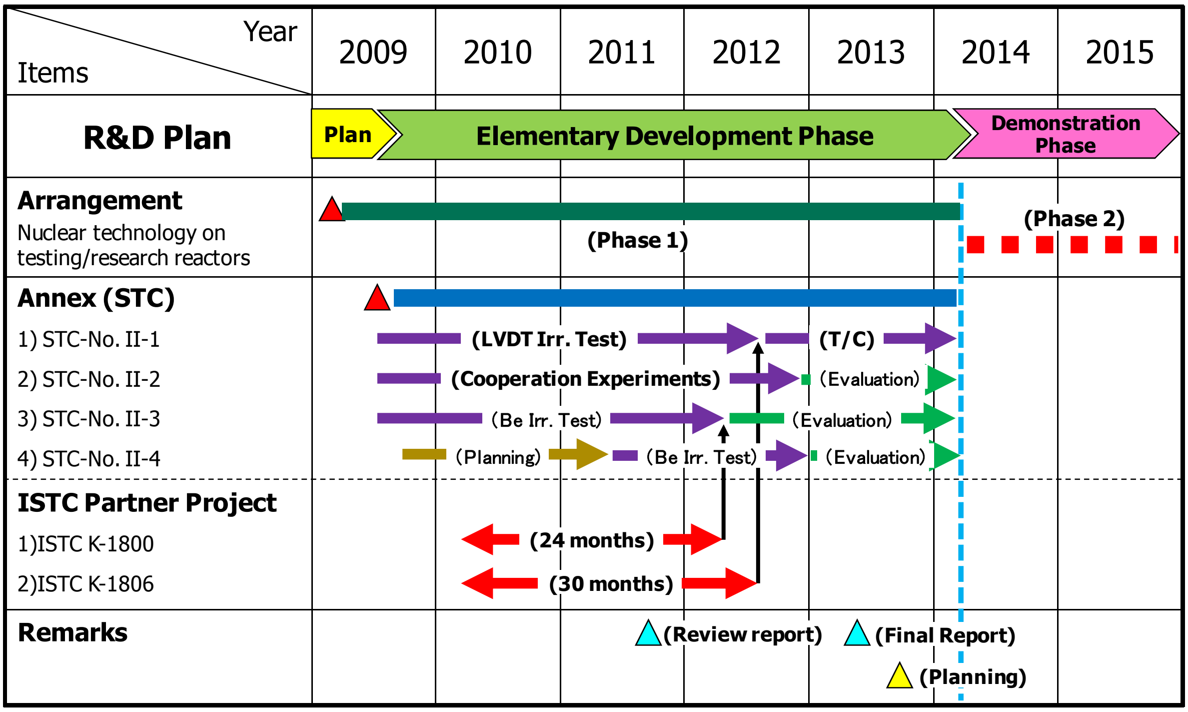


Fig. 1-1 R&D schedule in the field of nuclear technology on testing/research reactors.

2. International Standard of Instrumentation (STC No.II-1)

2.1 Outline

An irradiation test is being conducted at the JMTR with a view to developing instruments that will be carried out for the international standard of the Material Testing Reactors using JMTR and other reactors. A joint research is conducted with INP as a part of the international standard of instrumentation. As information exchange, instruments for neutron irradiation tests with JMTR and WWR-K were summarized on neutron dosimeter, temperature measurement, instrumentation technique such as pressure, displacement and gas concentration [1], and comparison of basic technology for irradiation tests is shown in Table 2-1.

Now, JAEA has developed new measuring instruments with JMTR such as multi-paired thermocouple, Fission Product (FP) gas pressure gauge, Self-Powered Neutron Detector (SPND) and Self-Powered Gamma Detector (SPGD).

Especially, two kinds of the Linear Variable Differential Transformers (LVDT) were designed, and the irradiation capsule which installed these LVDTs was fabricated for the irradiation tests in the WWR-K reactor. The LVDTs have been developed as the FP gas pressure gauge in the fuel rods [2]. Moreover, the activities for new development of these instruments have been discussed through the technical information exchange meetings between INP and JAEA.

2.2. Irradiation Test of Differential Transformers

As the part of STC No.II-1, the irradiation test of the LVDTs was planned under the partner project of the International Science and Technology Center (ISTC), and has been carried out from May 2010 to September 2012. The irradiation test has been carried out to evaluate the durability of two kinds of LVDTs made of the MI-cable and the ceramic-wire under the neutron irradiation conditions. Specifications of MI-cable and the ceramic-wire typed LVDTs is shown in Fig. 2-1. As a part of the project, irradiation capsule installed LVDTs, a temperature controller and a constant-current AC power supplier were supplied for the irradiation test from JAEA to INP. In this irradiation capsule, Type-K thermocouples and fluence monitors were also installed. Nuclear and thermal-hydraulic design of the irradiation capsule was calculated by INP and JAEA. This irradiation capsule was installed in the cell 5-9 in WWR-K (see Fig. 2-2) and irradiation tests were started from 5, April, 2011. The four irradiation cycles were finished up to August, 2011, and the 5th irradiation cycle will be started from September. The constant-current AC power supplier was broken at the 4th irradiation cycle, and this device was repaired after the 4th irradiation cycle by the INP. The detail of the development of irradiation capsule and the results of irradiation tests are as follows.

2.2.1 Development of Irradiation capsule

The irradiation capsule installing LVDTs was designed and fabricated by JAEA. Result of thermal calculation of the irradiation capsule is shown in Fig.2-3. Thermal calculation was carried out by GENGTC Code [3]. N_2 gas was proposed to use as the gap gas from INP side. From the result, the irradiation temperature was high during the neutron irradiation when N_2 gas was used. Thus, He gas is used as the gap gas. LVDTs were fabricated and the irradiation capsule was assembled by Sukegawa Electric Co., Ltd. (Japanese maker). K typed thermocouples (T/Cs) and fluence monitors developed by JMTR were also installed in this capsule. On the other hand, SPNDs were prepared by INP. Outline of the irradiation test is shown in Fig.2-4. After the completion of the irradiation capsule, the insulation and electrical resistance of the LVDTs were measured, and these values were passed in the inspection tests.

2.2.2 Irradiation Test

The irradiation test was started from 5, Apr. 2011 after the irradiation capsule was installed in the cell 5-9 in WWR-K. In the 1st irradiation cycle, the currents of MI cable typed LVDT changed greatly when the heater was turned on. The cooperation experiment was conducted in the 2nd irradiation cycle. Before the irradiation cycle, test plan and experimental procedure were discussed, and evaluation methods of irradiation data were discussed between JAEA and INP. Especially, the stability of LVDTs was evaluated by the following equation;

$$E = \frac{e_1 - e_2}{e_1 + e_2} \quad \cdots\cdots\cdots \quad (1)$$

where e_1 and e_2 are the voltages of the 1st coil and 2nd coil, respectively, E is the supplementary ratio of the voltage.

In the 2nd irradiation cycle, the supplementary ratio of the voltage and electrical resistance of the LVDTs was measured at various temperatures before and after the WWR-K operation. These results are shown in Fig.2-5. From the results before the WWR-K operation, E of the MI cable typed LVDT was almost stable from room temperature to 300˚C. On the other hand, E of the ceramic wire typed LVDT changed greatly at 270˚C. The electrical resistance of MI cable typed LVDT was increased with increasing temperature proportionally, however the electrical resistance of ceramic wire typed LVDT changed at 270˚C. After the WWR-K operation, these phenomena were observed at the reactor powers of 4.8MW and 6MW. These results indicated that the current of ceramic wire typed LVDT failed at high temperature. In the 3rd and 4th irradiation cycles, similar experiment was carried out just like the 2nd irradiation cycle. The 5th irradiation cycle will be started from September, 2011.

2.3 Information Exchange of Thermocouples and Joining Technology

2.3.1 Thermocouples

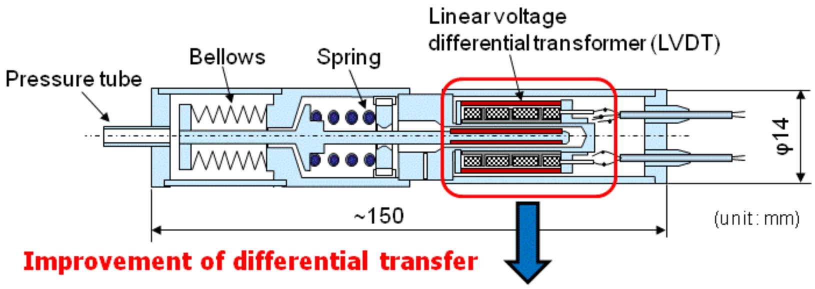
Thermocouples in WWR-K are shown in Table 2-1, and N typed T/Cs are not used. In JMTR, the N typed T/Cs were used for irradiation tests of fuel element, and it is possible to measure stable up to 1100°C for long irradiation time. In the information exchange, confirmation test in WWR-K will be planned with the K and N typed T/Cs made by Japan, and these T/Cs were supplied from JAEA to INP on August, 2011. In addition, these T/Cs were supplied from INP to Kurchatov on August September 22 for the fabrication of irradiation capsule.

2.3.2 Al/SS Friction Weldments

It is necessary for fabrication of the special irradiation capsules to develop the joining technologies between the different materials. In JMTR, the joints of different materials are fabricated by the friction welding method, and there are a lot of fabrication experiments of these joints. Material combinations of friction weldments are shown in Fig.2-6 [4]. From information exchange between JAEA and INP, the characterization will be carried out on the Aluminum/Stainless Steel(Al/SS) friction weldments from JAEA to INP. As the cooperation program, the Al/SS friction weldments will be prepared by JAEA and irradiation tests and PIEs will be carried out. Especially, tensile tests of the irradiated weldments will be considered in the INP.

Table 2-1 Comparison of basic technology for irradiation tests.

Items	JMTR(JA)	WWR-K (KZ)
Thermocouple	-K type (Max. 1000ºC) ø0.5, ø1.0, ø1.6mm -N type (Max. 1200ºC) ø1.0, ø1.5mm -W/Re (1000~1900ºC) ø1.6mm -Multi-paired T/C (K & N type) ø1.8mm (Max. 7 points)	-Allimel-chromel (K type) -W/Re -Cu Const -Allimel-capel
Offline measurement	- Melting wire (In,Sn,Pb,Bi,Ag,Zn) 95~420ºC	- Melt Metals
Thermal calculation	-Capsule temperature design GENTIC(1D) NISA(3D) -Evaluation of specimen temperature NISA(3D)	- Other institute of NNC
Temperature control	- Heater+gas pressure (constant temperature control by reactor power feed-forward control) Ex. 290±3ºC	-Heater -Gas pressure
Evaluation Method	Neutron, gamma calculation by full core 3D modeling -Code : MCNP-4B -Nuclear data library Neutron: FSXLIBJ3R2 (based on JENDL3.2) TMCCS(S(a,b),based on ENDF-B/III) - Gamma:MCPLIB (based on DLC-7E)	-Nuetron calculation by full core 3D Monte-Carlo codes: MCU-REA, MCNP-5
Fluence monitors	- Thermal neutron (<0.683 eV) Al-Co (<500ºC), V-Co,Ti-Co (>500ºC) - Fast neutron (>1MeV) Fe	-Thermal neutron Au, Cu, Dy -Fast Neutron Rh (>0.8MeV), In (>1.15MeV), Ni, S (>3MeV)
Thermal neutron flux (Distribution and transient)	-SPND -Fission chamber	-SPND -Fission chamber -Neutron counters
Displacement	-Differential transformer type	
Pressure	-Differential transformer + bellows type	-Differential transformer type -Resistor type -Mechanical manometer
Gas concentration	-Oxygen, hydrogen sensor (under development)	- Radiometers for radioactive gases
Other	-Crack growth by current potential drop -Optical measurement by light fiber	



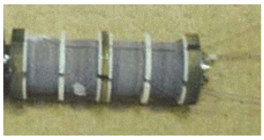
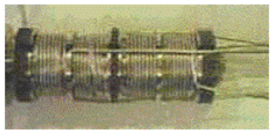
Items \ Type	Conventional Linear Voltage Differential Transformer	Improved Linear Voltage Differential Transformer
Coil materials	Ceramic wire	MI cable
Photograph		
Max. Temperature	<550°C	650°C
Input condition of 1st coil	50mA, 1kHz	50mA, 1kHz
Voltage of 2nd coil (e_1, e_2)	0.9 – 1.1 V	6 – 7 mV

Fig. 2-1 Specifications of MI-cable and the ceramic-wire typed LVDTs.

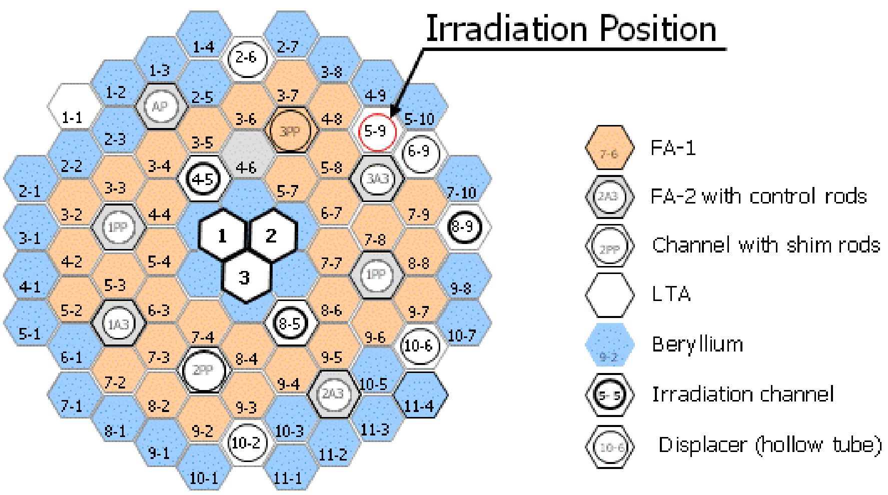
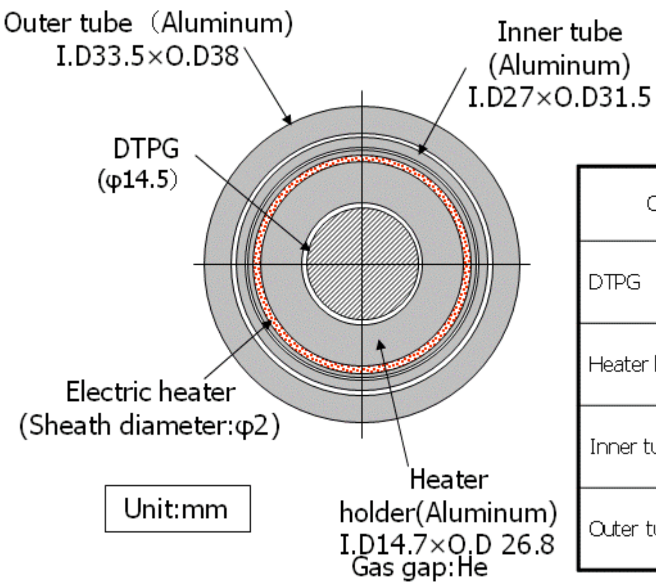


Fig. 2-2 Reactor core map used for differential transformer tests in WWR-K.



- γ heating :1.0W/g (Aluminum)
1.2W/g (Stainless steel)
- Coolant temperture:45°C

Calculation Results by GENGTC Code

Component name		Temp.(°C) He gas	Temp.(°C) N_2 gas*1
DTPG	Centre	251.3	552.8
	Outer surface	213.8	524.0
Heater holder	Centre	200.8	512.4
	Outer surface	200.1	511.9
Inner tube	In surface	187.7	503.1
	Outer surface	187.5	502.9
Outer tube	In surface	46.5	46.5
	Outer surface	46.2	46.2

*1 : N_2 gas between outer tube and inner tube

Fig. 2-3 Result of thermal calculation of irradiation capsule.

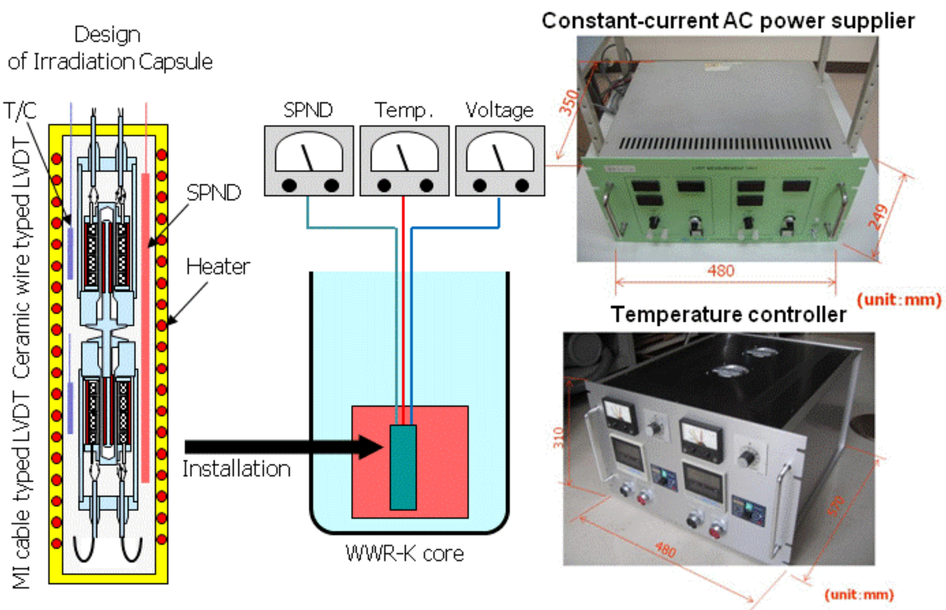


Fig. 2-4 Outline of the irradiation test.

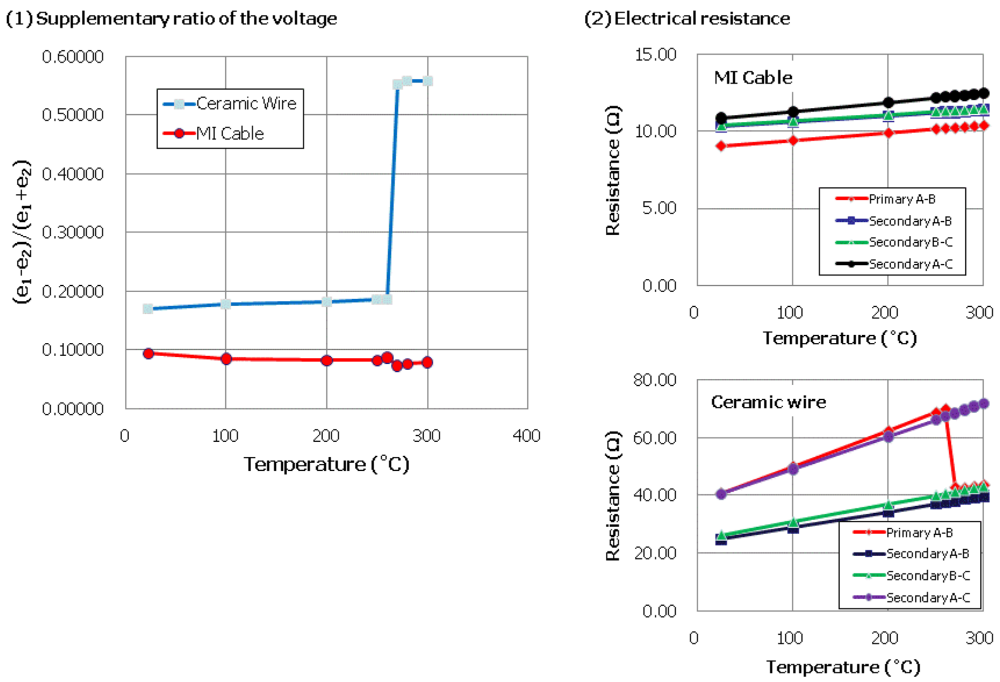


Fig. 2-5 (a) Supplementary ratio of the voltage and electrical resistance of the LVDTs at the 2nd irradiation cycle (before WWR-K operation).

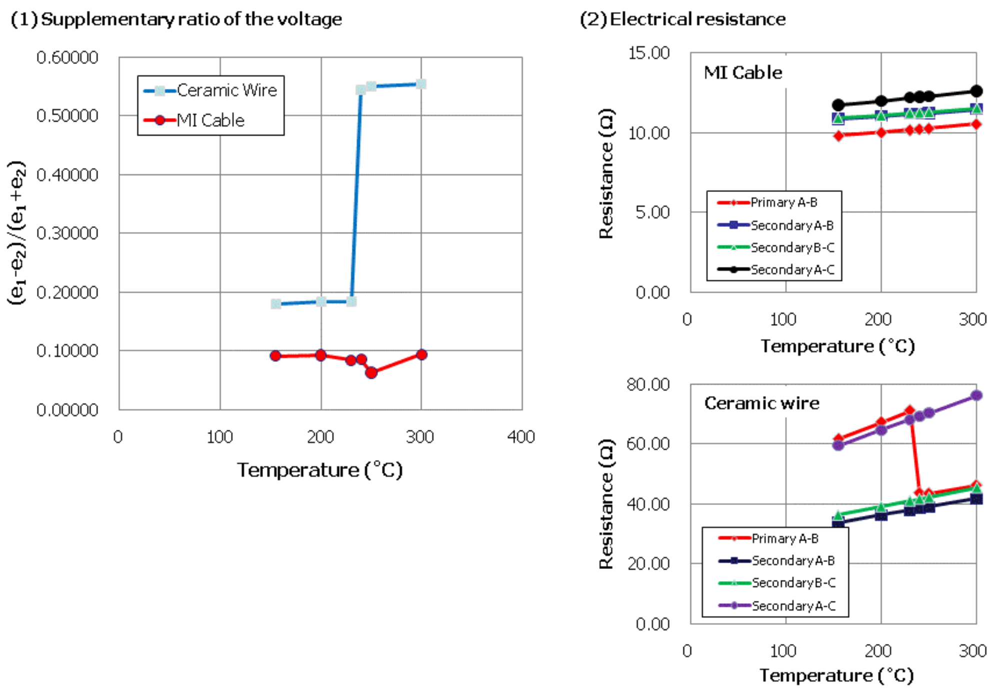


Fig. 2-5 (b) Supplementary ratio of the voltage and electrical resistance of the LVDTs at the 2nd irradiation cycle (WWR-K power at 4.8MW).

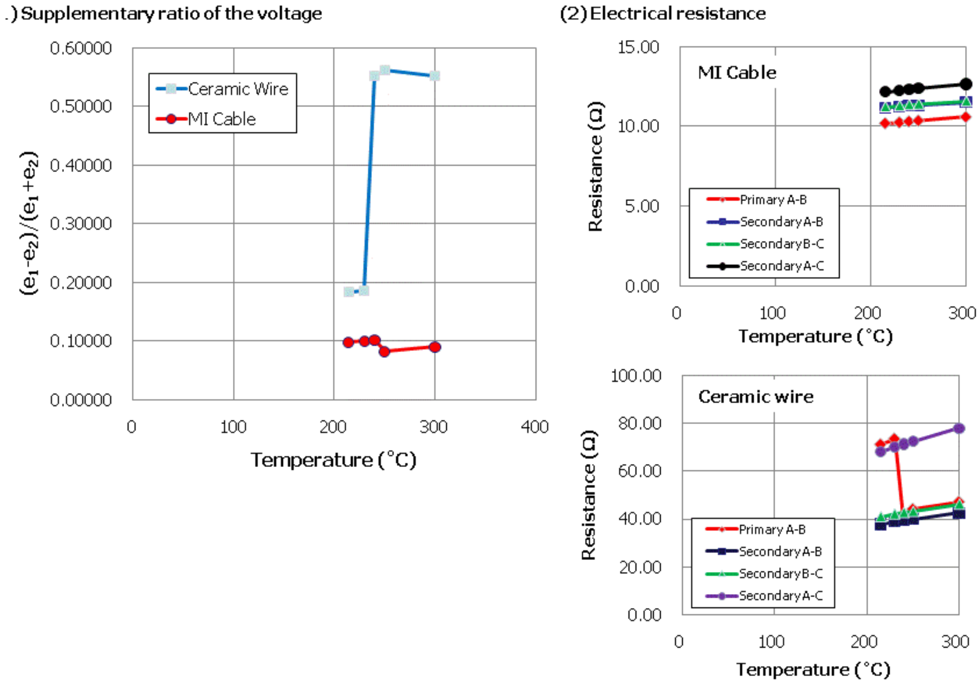


Fig. 2-5 (c) Supplementary ratio of the voltage and electrical resistance of the LVDTs at the 2nd irradiation cycle (WWR-K power at 6MW).

Materials \ Materials	Aluminum	Copper	Nickel alloy	Niobium	Niobium alloy	Stainless Steel	Titanium	Titanium alloy	Zirconium alloy	Vanadium	Vanadium alloy
Aluminum	G	G				G	G		G		
Copper	G	G				G	G				
Nickel alloy			G								
Niobium					N						
Niobium alloy					G	G					
Stainless Steel	G	G		N	G	G	B	G	G	N	
Titanium	G	G				B	G				
Titanium alloy						G					
Zirconium alloy	G					G					
Vanadium						N					
Vanadium alloy											

(Remarks) G : Good weldment B : Brittle weldment N : No welding

Fig. 2-6 Material combinations of friction weldments.

3. Irradiation Technology of RI Production (STC No.II-2)

3.1 Outline

The method of extracting ^{99m}Tc by using the ^{99}Mo-^{99m}Tc generator for adsorbing ^{99}Mo has been developed for the production by ^{98}Mo (n, γ) ^{99}Mo method using testing/research reactors. The Poly zirconium compound (PZC) and the molybdenum acid zirconium gel (Zr gel) were developed as Mo absorbent in Japan and Kazakhstan, respectively. An information exchange on the fabrication methods and characteristics of PZC and the Zr gel was carried out between INP and JAEA at first.

PZC is synthesized from the zirconium tetra-chloride ($ZrCl_4$) and isopropyl alcohol ($(CH_3)_2CH_2OH$) as raw materials by the reactions of hydrolysis and polymerization. PZC is an inorganic polymer that consists of the zirconium, oxygen and chlorine [5]. ^{99}Mo is adsorbed to PZC, and it is packed in column (PZC generator). ^{99m}Tc is eluted by the milking with saline from PZC generator. Zr gel is synthesized by the following processes; (1) resolution of irradiated $^{99}MoO_3$ into ammonia solution, (2) mixture of Mo solution and HNO_3 for synthesizing of sodium poly-molybdate (PMNa), (3) Mixture of PMNa and $ZrOCl_2 \cdot 8H_2O$ for Zirconium molybdate complex [6]. The synthesized Zr gel is dried, crushed and packed in column (Zr gel generator). ^{99m}Tc is eluted by the milking with saline from Zr gel generator.

The flow of ^{99m}Tc milking using the PZC and the Zr gel and characteristics of PZC and Zr gel were summarized and these results are shown in Fig. 3-1 and Table 3-1, respectively. From the result of the information exchange, the common subjects on the ^{99}Mo production by (n, γ) method were selected such as the low radioactivity concentration of the ^{99m}Tc solution, the recycling of ^{98}Mo source and reduction of radioactive wastes.

Next, cooperation experiments were started to obtain specific comparison data of Mo absorbent for the solution of these subjects. In the 1st and 2nd experiments, the basic performance tests of PZC and Zr gel were carried out using the MoO_3 powder irradiated in WWR-K reactor. In the 3rd experiment, the concentration test was carried out using ^{99m}Tc solution obtained from PZC and Zr gel in order to obtain a higher radioactivity concentration product. In the 4th experiment, the recycling tests are started from the viewpoint of effective utilization of ^{98}Mo and reduction of radioactive wastes. In the recycling test, preliminary tests were carried out using PZC and the Zr gel adsorbed un-irradiation Mo. Based on the results of the preliminary tests, the recycling tests using MoO_3 irradiated in WWR-K reactor are planned to be carried out in INP in November, 2011.

3.2 Cooperation Experiments for Mo-99 production by (n, γ) Method

3.2.1 First Experiment (from 26 to 30, Oct., 2009 in INP)

^{99}Mo adsorption and ^{99m}Tc elution tests of PZC and Zr gel were carried out in order to compare the performance of PZC with that of Zr gel[7]. Comparison items were operation time, ^{99}Mo adsorption performance, ^{99m}Tc elution performance, and so on. Test results are shown Table 3-2.

As a result, ^{99}Mo adsorption performance of each adsorbents was the same level as conventional data, namely obtained Mo adsorption amounts of PZC and Zr gel were 215mg/g-PZC and 280mg/g-Zr gel, respectively [8,9]. On the other hand, ^{99m}Tc elution rates of PZC were the range from 37 to 61%, and these values were lower than those of reference data. ^{99m}Tc elution rates of Zr gel were the range from 45 to 82%, and these values were the same level as the reference data. It seems that the shapes of ^{99m}Tc measurement samples for PZC were different from the calibration geometry by the gamma spectrometry. Basic properties of PZC and Zr gel were obtained from this experiment, and the ^{99m}Tc measuring method was improved by gamma spectrometry. The basic properties of PZC and Zr gel were able to be obtained from this experiment. However, it is necessary to improve the shape of measuring samples in the next experiment.

3.2.2 Second Experiment (from 22 to 26, Feb., 2010 in INP)

^{99m}Tc elution performance of PZC was lower than that of reference data in the first experiment. Consequently, ^{99}Mo adsorption and ^{99m}Tc elution tests of PZC and Zr gel were carried out to clarify the cause of low ^{99m}Tc elution rate[10]. Test results are shown in Table 3-3. As a result, ^{99m}Tc elution rates of PZC were the same as those of reference data, and the range from 65 to 98%. Consequently, it was clarified that the cause of low elution rates was disagreement between the sample shape and the calibration geometry.

On the other hand, impurities removal test in ^{99m}Tc solution was carried out using an alumina column. Alumina, made by MP Biomedicals, was packed with polypropylene column. Moreover this alumina column was jointed under the generators. As a result, Mo impurity in ^{99m}Tc solution from PZC generator decreased to 1/100,000 by the attachment of alumina column.

3.2.3 Third Experiment (from 6 to 10, Dec. 2010 in INP)

The production of ^{99}Mo by (n, γ) method is simple, however specific activity of ^{99}Mo obtained is low. Therefore, radioactivity concentration of the ^{99m}Tc solution obtained from this ^{99}Mo is low. Then, concentration test was carried out for improving the radioactivity concentration of ^{99m}Tc solution.

^{99m}Tc was eluted with 0.3% saline from PZC or Zr gel generator. This ^{99m}Tc solution was concentrated with tandem column system. Test results are shown in Table 3-4.

As to the test using ^{99m}Tc solution obtained from PZC generator, the radioactivity concentration of ^{99m}Tc increased more than 20-25 times to the collected solution. On the other hand, as to the test using ^{99m}Tc solution obtained from Zr gel generator, the radioactivity concentration of ^{99m}Tc increased more than 27.5 times. When low concentration saline was used as an eluent of the PZC generator, a falling trend in ^{99m}T elution rate was observed. Therefore, it is difficult for PZC generator to adopt this concentration method.

3.2.4. Preparation for Fourth Test

Used adsorbent was disposed as radioactive waste. Its reduction, recycling and Mo recovery technique are not only necessary to decrease radioactive wastes, but also necessary to reduce cost. JAEA began to develop reduction and recycling technique of used PZC, and recovery technique of Mo from used PZC. The prospect that the Mo can be recovered was obtained by these techniques. Next, JAEA began to develop recovery technique of Mo from used Zr gel. In the cold test, Mo was able to be recovered by more than 98% from Zr gel. Recovery test will be carried out using ^{99}Mo in December, 2011 at INP.

Table 3-1 Basic data of Zr gel and PZC generator.

Production method	Neutron capture method	
	Zr gel	PZC
<Irradiation material> - Chemical type	Natural Mo - MoO_3, Metal Mo	Natural Mo - MoO_3, Metal Mo
<Irradiation> - Facility - Capsule volume - Preparation - Irradiation time - Adsorption of ^{99}Mo	 - Rabbit - About 30 cm^3 - Enclose to capsule - 5-7 days - Batch type (Zr gel)	 - Rabbit - About 30 cm^3 - Enclose to capsule - 5-7 days - Batch type (PZC)
<Treatment as PIE> - Treatment time	Dissolution in cell ~7 h	Dissolution in cell ~ 4 h
<Stability of generator>	Poor	Good
<Process of generator production>	Complicated	Simple
<Characteristics of ^{99}Mo> - Radiation fraction - Activation by-product	 - 37-74 GBq/g(Mo) - ^{92m}Nb	 - 37-74 GBq/g(Mo) - ^{92m}Nb
<Radioactive waste> - Capsule waste - Waste solution	 -By each irradiation - A little γ nuclide	 -By each irradiation - A little γ nuclide

Table 3-2 Comparison with PZC and Zr gel in the 1st cooperation test.

Item		PZC	Zr gel
Grain size of generator (μm)		300-710	<200 65.0%
			200-500 35.7%
			500-700 1.8%
			>700 0.8%
Time from adsorption of Mo to package in the column (h)		4.2	6.0
Adsorption of Mo (mg/1g-generator)		215±7.6	280
pH of Eluted solution	Before	5.5(Saline)	5.5(Saline)
	After	3.2±0.2(Saline)	3.7±0.3(Saline)
Elution of ^{99m}Tc (%)	Saline	37.0-60.7	40.7-81.9
	Pure water	9.2-22.0	45.4-82.2
Impurity (μg/cm^3)	Mo	5.6-6.0 (Column No.2-Run 2)	5-7 (Column No.1-Run 2)
		41-108 (Column No.3-Run 2)	10-15 (Column No.3-Run 3)
	Zr	<0.8 (Column No.2-Run 2)	<5 (Column No.1-Run 2)
		18-18500 (Column No.3-Run 2)	<10 (Column No.3-Run 3)

[Measurement method of impurity] ICP (inductively coupled plasma spectroscopy)

Table 3-3 Comparison between PZC and Zr gel in the 2nd cooperation test.

Item		PZC	Zr gel
Time from adsorption of Mo to package in the column (h)		4.0	6.0
Adsorption of Mo (mg/1g-generator)		227 - 237	250
^{99m}Tc yield (%)		65.0 - 97.6	58.3 - 71.6
Impurity in ^{99m}Tc solution without alumina column (mg/cm^3)	Mo[*1]	8.8 - 16.3	2.1 - 4.7
	Mo[*2]	19.2 - 22.5	-
	Zr[*1]	<0.8	<0.8
	Zr[*2]	0.0002 - 0.004	-
Impurity in ^{99m}Tc solution with alumina column (mg/cm^3)	Mo[*1]	N.D	N.D
	Mo[*2]	0.002 - 0.004	-
	Zr[*1]	<0.8	<0.8
	Zr[*2]	<0.0002	-
	Al[*1]	<0.5	<0.5
	Al[*2]	0.1	-

[Measurement method] *1 : Colorimetry, *2 : ICP (inductively coupled plasma spectroscopy)

Table 3-4 Result of ^{99m}Tc concentration test.

Item		PZC	Zr gel
K (%)		73.5-93.9	94.4
Rate of concentration		20.7-24.5	27.5
Non-radioactive impurities in concentrated solution	Mo (ppm)	0.01	N.D
	Zr (ppm)	N.D	N.D
	Al (ppm)	N.D	N.D

[Measurement method of impurity] ICP (inductively coupled plasma spectroscopy)

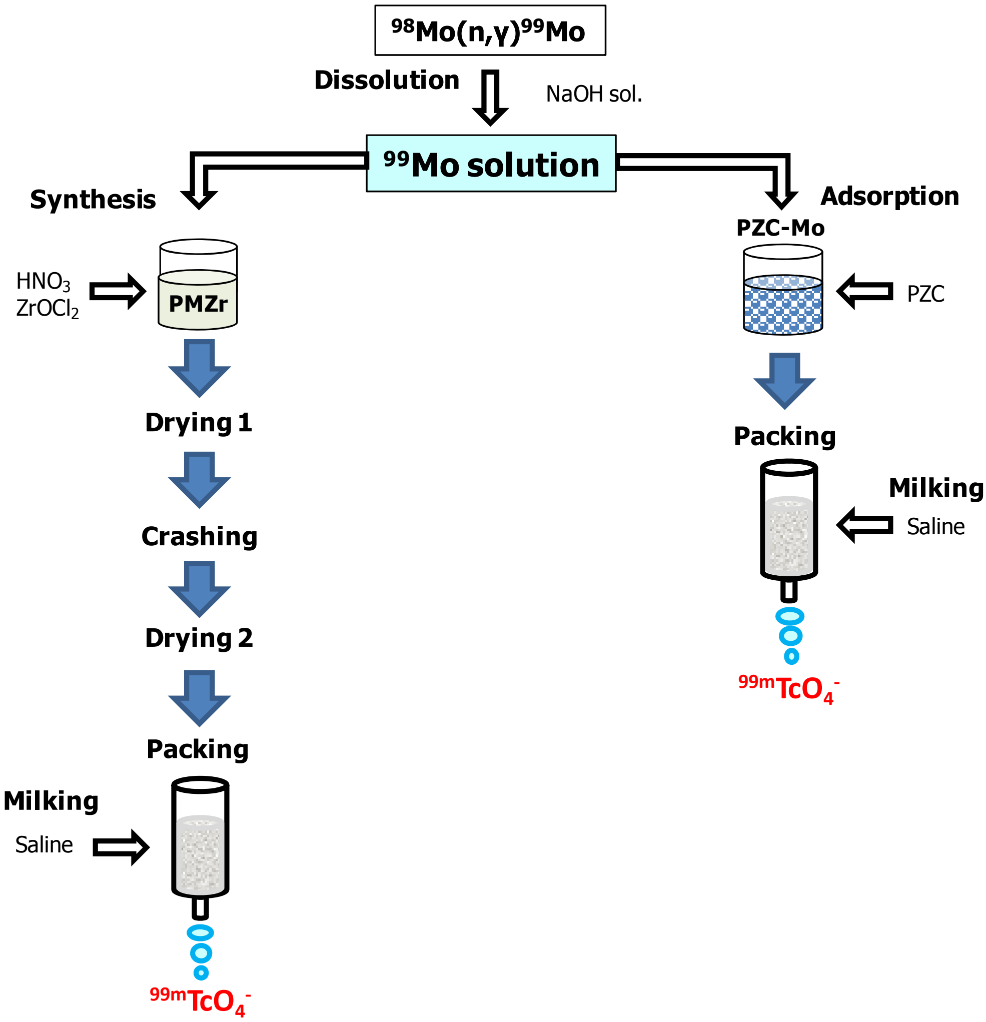


Fig. 3-1　Flow chart of ^{99m}Tc milking using PZC and Zr gel.

4. Lifetime Expansion of Beryllium Reflector (STC No.II-3)

4.1 Outline

Reactors with beryllium exist in many places throughout the world, and a lot of beryllium was used in materials testing reactors (MTRs) from the beginning of atomic energy development. Especially, beryllium has been utilized as a moderator and/or reflector in a number of MTRs. As a structural material, beryllium is a light material which has high tensile strength. Beryllium surface forms a thin oxidation film by interacting with air like aluminum, and beryllium is highly resistant to corrosion in dry gases. Its useful properties, such as thermal conductivity and good elevated-temperature mechanical properties for light element and high melting point, make the attractive metal for nuclear reactors. The nuclear properties of beryllium are its low atomic number, low atomic weight, low parasitic capture cross section for thermal neutrons, readiness to part with one of its own neutrons (n, 2n), and good neutron elastic scattering characteristics [11, 12].

Usage of beryllium in neutron fields causes worse its mechanical properties. Possible durability in this case is determined by the neutron fluence where minimum allowed quality of beryllium is achieved. The activation issues for beryllium in nuclear reactors under neutron irradiation arise mainly via (n, γ) and (n, p) reactions with impurities such as iron, nickel and nitrogen in the beryllium. At the same time, tritium (^3H) is produced in the beryllium by a well-known reaction sequence. Thus, it is difficult to reprocess irradiated beryllium because of high induced radioactivity. Disposal has also been difficult because of toxicity issues and special nuclear material controls.

Two solutions have been proposed for reduction of irradiated beryllium wastes. One is to manage a great amount irradiated beryllium waste accumulated up to now, and recycling development of irradiated beryllium is carried out. The other is to reduce the amount of irradiated beryllium waste generated from now, and the development of beryllium materials is carried out including irradiation test. In this STC, material modification of beryllium reflectors has been discussed for lifetime extension under neutron irradiation, and irradiation test of beryllium samples has been carried out in WWR-K under the ISTC partner project.

4.2 Irradiation Test of Beryllium

In the JMTR, beryllium frames are used as neutron reflector and need to be replaced by new ones every five years, and spent irradiated beryllium is storing in the reactor building. For the lifetime extension, it is, thus, necessary to study irradiation behavior of several beryllium grades under neutron irradiation. The irradiation test of beryllium specimens has been carried out in WWR-K research reactor under ISTC partner project. In the frame of the project, beryllium specimens of three industrial grades are supplied from JAEA. The properties of these specimens are shown in Table 4-1. The traditional grade S-200F is fabricated by the vacuum hot pressing technique (VHP). The grade S-65H with higher purity and the grade I-220H with high mechanical strength are fabricated by the isostatic hot pressing technique (HIP).

The irradiation capsule which installed the beryllium specimens was fabricated. The beryllium specimens have been irradiated up to the fast neutron fluence (E>1MeV) $\sim 1\times 10^{20}$ /cm^2 in the irradiation channels of the WWR-K. Photographs of beryllium specimens and irradiation capsule are shown in Fig. 4-1. Irradiation position in WWR-K is shown in Fig. 4-2. The density of fast neutron flux was measured by Indium detectors screened by Cadmium. The measured values of the flux density comprises 2.0×10^{13} /cm^2/s. It follows from figure 4-3 that at the 55mm axial position, where beryllium samples are irradiated, the flux density of the neutrons having energy higher than 1.0 MeV will be 1×10^{13} /cm^2/s. In order to buildup the fast neutron fluence $\sim 10^{20}$ /cm^2, nearly 115 days of irradiation time is needed. Beryllium samples under irradiation in irradiation device are washed by coolant, which is desalted water. Chemical composition of coolant meets relevant regulatory requirements (see Table 4-2).

Characterization of the irradiated specimens will be carried out by the post-irradiation examinations such as size change and measurements of helium and tritium. Experimental device (VIKA) for the measurement of helium and tritium is shown in Fig. 4-4. The characteristics will be compared with those of the reference specimens.

4.3 Information Exchange of Beryllium Grade

The technical factors on the beryllium element material have been discussed and the database of beryllium will be constructed at the end of this STC. The technical factors in the fabrication of beryllium are as follows [13].

Pure beryllium has a very low mass absorption coefficient, especially in comparison with other metals. Metals having much higher mass absorption coefficients will absorb the radiation at a higher rate. Consequently they incur greater overall swelling, and will swell at faster rates as well. For purposes of this discussion, “purity” will be defined as the chemical composition of the beryllium material. This is indicated primarily by the beryllium assay (i.e. the percentage of beryllium by weight in the material). The remainder of the chemical composition consists of beryllium oxide (BeO) and other trace elements found in the material.

There are two main aspects in the manufacturing of beryllium affecting its isotropy; those are the powder morphology and the consolidation process.

In cast form, the material has very large grains, and it has a hexagonal close-pack (HCP) crystal structure. The HCP structure is inherently anisotropic, giving way to preferential cleavage in the basal plane of the crystal. This means that beryllium with a large grain structure will be mechanically very non-uniform (anisotropic). Powder metallurgy permits the material to be produced in a fine-grained form, which overcomes the crystal structure problem. The use of impact-ground powder versus attrition-milled powder is also an added improvement to isotropy.

The process used for consolidating the beryllium powder is also a factor in the isotropy of the final product. Traditionally, most powder-derived grades of beryllium have been consolidated by the VHP process.

The alternative methods of consolidating beryllium powder are enhanced its isotropy. The best process is hot isostatic pressing (HIPing). In order to prepare beryllium powder for HIPing, it must be sealed in a sheet metal container (can), any residual gases must be evacuated from the can. This loaded can is then placed in the HIP furnace. The HIPing process simultaneously consolidates and sinters the powder by using elevated temperature and pressurized argon gas. The gas exerts pressure uniformly in all directions on the can containing the beryllium powder.

Once exposed to radiation in the test reactor, the beryllium reflector elements will eventually swell, bend, and ultimately even crack. The material's ability to resist this progression will be dependent on its tensile properties, particularly yield strength (YS) and ultimate tensile strength (UTS). Tensile strength in powder-derived beryllium is affected by the material's chemical composition, consolidation method, and its thermal history. Higher BeO content will result in higher YS and UTS, but lower elongation. Just as the HIP process results in more isotropic properties, it also gives higher tensile properties in general, due to the greater pressure and lower temperature during consolidation compared with the VHP process.

Table 4-1 Properties of three kinds of beryllium specimens.

Mechanical Properties

Factor	Grade	YS		UTS		El		GS
		min	SP	min	SP	min	SP	SP
		(MPa)		(MPa)		(%)		(μm)
Reference	S-200F	241	268.9	324	364.7	2.0	3.4	10.3
Isotropy	S-65H	206	271.1	345	448.2	2.0	5.7	6.9
	I-220H	345	459.9	448	564.7	2.0	3.7	5.6

Chemical Properties

Factor	Grade	Elements (%)							
		Be	BeO	Al	Fe	Si	Ni	Ti	C
Reference	S-200F	99.0	1.0	0.05	0.12	0.03	0.01	0.01	0.06
Isotropy	S-65H	99.4	0.7	0.04	0.08	0.02	0.02	0.02	0.007
	I-220H	98.6	1.9	0.01	0.06	0.02	0.02	0.02	0.03

Table 4-2 Chemical compositions of coolant in WWR-K.

Index Name	Index magnitude
pH at 25 °C	5.0 to 6.5
Specific Electric Conduction at 25 °C (mOhm/cm)	4.0
Hardness (mg·equiv./kg)	< 3.0
Ion Chloride Mass Concentration (mg/kg)	< 50
Aluminum Mass Concentration (mg/kg)	< 50
Iron Mass Concentration (mg/kg)	< 50
Copper Mass Concentration (mg/kg)	< 10
Fission Product Total Activity (Bq/kg)	$< 2.5\times10^{7}$

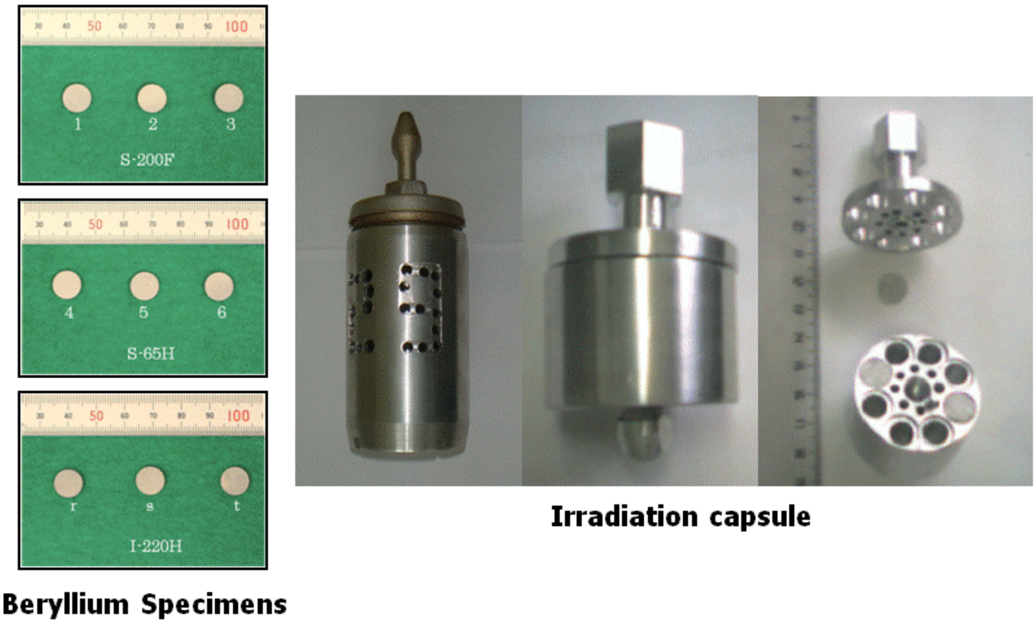


Fig. 4-1 Photographs of beryllium specimens and irradiation capsule.

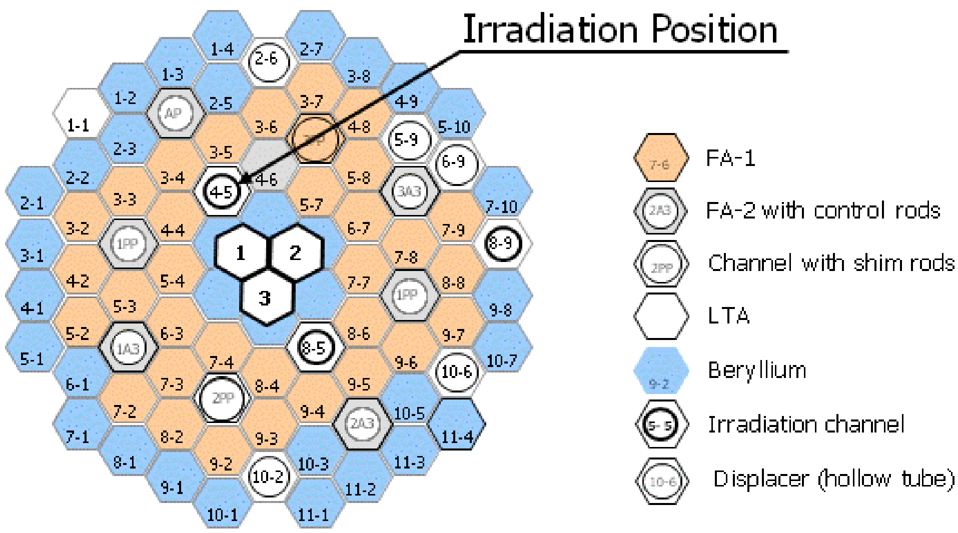


Fig. 4-2 WWR-K core and irradiation position of beryllium specimens.

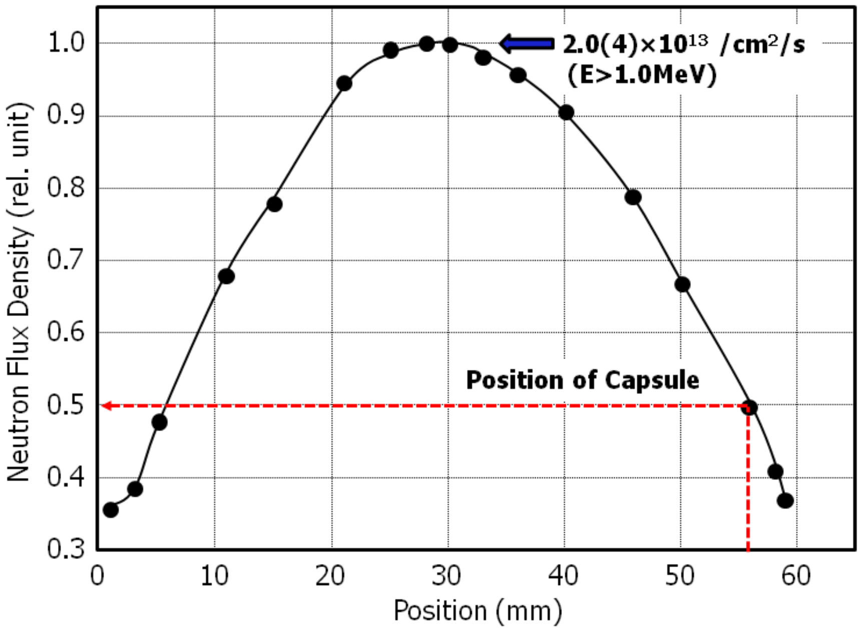


Fig.4-3 Axial distribution of the fast neutron flux density in the channel 4-5.

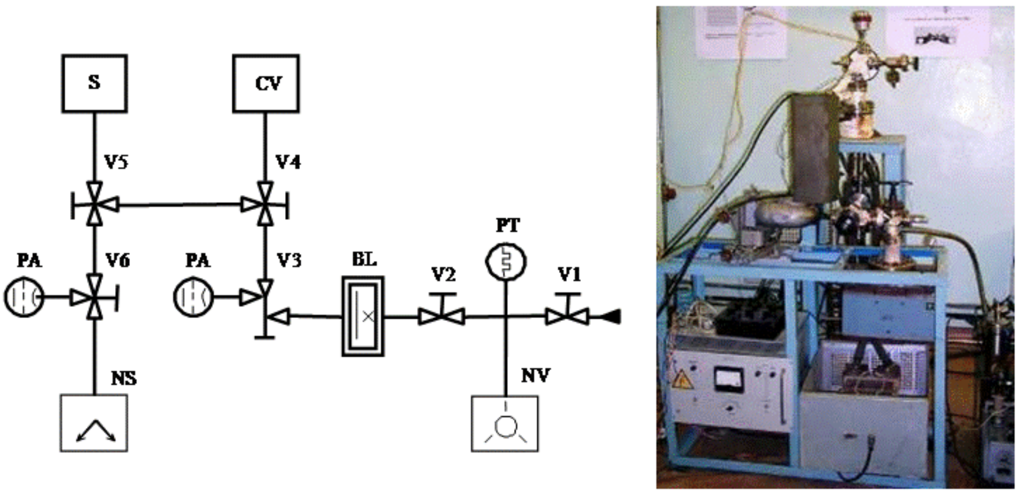


Fig. 4-4 Experimental device (VIKA) for the measurement of helium and tritium.

5. Irradiation Technology for NTD-Si (STC No.II-4)

5.1 Outline

Silicon (Si) semiconductor which made by Neutron Transmutation Doping (NTD) method has good properties such as high blocking voltage and stability under high current as the high performance power device. In recent years, the Si semiconductors with large diameter are required for low cost production [14]. Thus, feasibility study of Si semiconductor production facility on JMTR has been carried out in JAEA in order to produce large size diameter (8-inch) Si semiconductors by NTD method (NTD-Si) [15]. In WWR-K of NNC-INP, which is the light water tank-type research reactor same as the JMTR, several irradiation positions have been evaluated in respect to NTD of Si ingot [16], and it was found to be possible to irradiate the silicon ingot of 8 inch in diameter by the modification of the facility partly.

As a part of STC No.II-4, irradiation tests of Si ingots were planned with WWR-K in order to realize the production of the large size diameter NTD-Si in the JMTR and the WWR-K. Contents of the irradiation test are as follows.

(1) Development of Si rotating device

Si rotating device is designed and fabricated by JAEA in order to carry out the irradiation test of Si ingot in WWR-K. The fabricated Si rotating device is transported from JAEA to INP, and installed on the top of the WWR-K.

(2) Nuclear evaluation of the irradiation channel

For evaluation of the irradiation channel in WWR-K, trial irradiation tests are carried out using aluminum (Al) ingots before irradiation tests of Si ingots. Fluence monitors [17] are installed in these Al ingots in order to measure both fast and thermal neutron fluxes. Nuclear calculations in the irradiation channel are also conducted in INP with the Monte Carlo technique.

(3) Irradiation test of Si ingots

Two single crystal Si ingots with different length are irradiated in the irradiation channel of K-23 in WWR-K. The Si ingots are transported from INP to JAEA after irradiation tests, and the characteristics of NTD-Si are evaluated.

Present status and future plans are described in 5.2.

5.2 Irradiation Test for NTD-Si

5.2.1 Development of Si Rotating Device for Irradiation Test

As the result of information exchange in the technical meetings between JAEA and INP, irradiation tests of Si ingots with 6 inch in diameter were planned because of no drastic modification of irradiation facilities, and the irradiation channel of K-23 in WWR-K was selected for irradiation tests of Si ingots. Photographs and dimensions of Si ingots are shown in Fig. 5-1. Si rotating device was developed in JAEA in order to install in the K-23 channel and to conduct irradiation tests of Si ingots. As the development of the device, main requirements for the structure of the device were as follows;

(1) Loading and position confirmation of Si ingot under reactor operation,
(2) Uniform neutron irradiation in axial and radial directions.

As for (1), up-and-down motor was set to move the Si ingot between the irradiation position and cooling position in the irradiation tube, because the top of the WWR-K is covered with a protective cover and because it is impossible to be accessed from outside the reactor during reactor operation. The position detector was also attached at the device.

As for (2), Si rotating motor was set in order to irradiate Si ingot with axial rotating for the uniform axial neutron flux distribution. Moreover, the center position of the Si ingot axially will be arranged in the position which has the maximum thermal neutron flux in the irradiation channel by the up-and-down motor.

As the result, design condition for Si rotating device was decided and shown in Table 5-1. The Si rotating device consists of up-and-down-motor, rotating motor, holder of Si ingot, control panel, remote controller, etc. Photographs of Si rotating device are shown in Fig. 5-2.

After fabrication of Si rotating device, material inspection, visual inspection, dimensional inspection and performance test were carried out, and confirmed to satisfy design conditions.

The Si rotating device was transported in August, 2011 from JAEA to INP and installed in the WWR-K from September 20 to 23, 2011. As for the installation, to begin with, the performance test of the device was carried out outside the reactor, and next, installed on the top of the WWR-K by anchor bolts. As a result of performance test in WWR-K, it was also confirmed to satisfy design conditions.

5.2.2 Evaluation of Irradiation Field

Distribution of the thermal neutrons flux density over Si ingot was calculated in INP when the Si ingot was located in the K-23 channel of WWR-K. Calculations were performed with the code MCNP, which is based on the Monte Carlo technique. Layout of the calculation nodes is shown in Fig. 5-3, and the distribution of the thermal neutron flux density (E<0.465 eV) over height of the Si ingot is shown in Fig. 5-4. The average height irregularity factor is at about 1.05. From the evaluation, it is possible to conduct uniform irradiation of Si ingots in the K-23 channel in WWR-K.

The preliminary irradiation tests are planned to evaluate the actual irradiation field of Si ingots in the K-23 channel in WWR-K. In the tests, Al ingots, which are the same dimension of Si ingots, will be irradiated with the Si rotating device. Fig. 5-5 shows the photographs and specifications of Al ingots. Four Al ingots made of A1070 were prepared by JAEA. Five holes of 3 mm diameter were drilled in the Al ingots. Four holes are the positions at the circuit of ϕ130 mm and one hole is the center position of the Al ingots. The fast and thermal fluence monitors are installed in these holes and these monitors are placed at the top, middle and bottom positions, respectively. After the fluence monitors are installed in the Al ingots and the Al ingot is set at the Si rotating device, the preliminary irradiation tests are carried out. After the irradiation tests, the fluence monitors are measured for the calculation of fast and thermal neutron flux. From the calculated results, vertical and horizontal flux distributions will be evaluated in the actual irradiation tests of Si ingot.

5.2.3 Irradiation Tests of Si Ingots

The irradiation tests of Si ingots are carried out after the preliminary tests. Two kinds of single crystal Si ingots with different dimensions are used in the irradiation tests. The irradiation condition is shown in Table 5-2. After the irradiation tests, Si ingots are transported from INP to JAEA. Properties of resistivity and stacking defects are evaluated using the Si ingots.

Table 5-1 Design condition for Si rotating device for irradiation test.

Item		Design condition
Irradiation tube (K-23)	Atmosphere	Reactor coolant
	Water temperature	about 45˚C
	Water Flow	No
	Height of the irradiation tube	4.900m
Device for irradiation test of Si	Height from the top of the irradiation tube to core center	4.185m
	Rotating Speed of Si	2rpm
	Height from the top of the core for cooling of Si	> 1.000 m
	Power supply (inside core) (outside core)	48V (AC50Hz or DC) 220V (AC50Hz or DC)

Table 5-2 Irradiation condition of Si ingot.

Item	Condition
Specimen	Si ingot (see Fig.5-1)
Reactor power	6 MW
Irradiation tube	K-23
Rotating Speed	2rpm


Si ingot No. 1


Si ingot No. 2

FZ (Float Zoning) method grade Si ingot

	Diameter [mm]	Length [mm]	Weight [g]
No.1	151.13	202	8,443
No.2	151.14	278	11,621

Fig. 5-1 Photographs and dimensions of Si ingots.

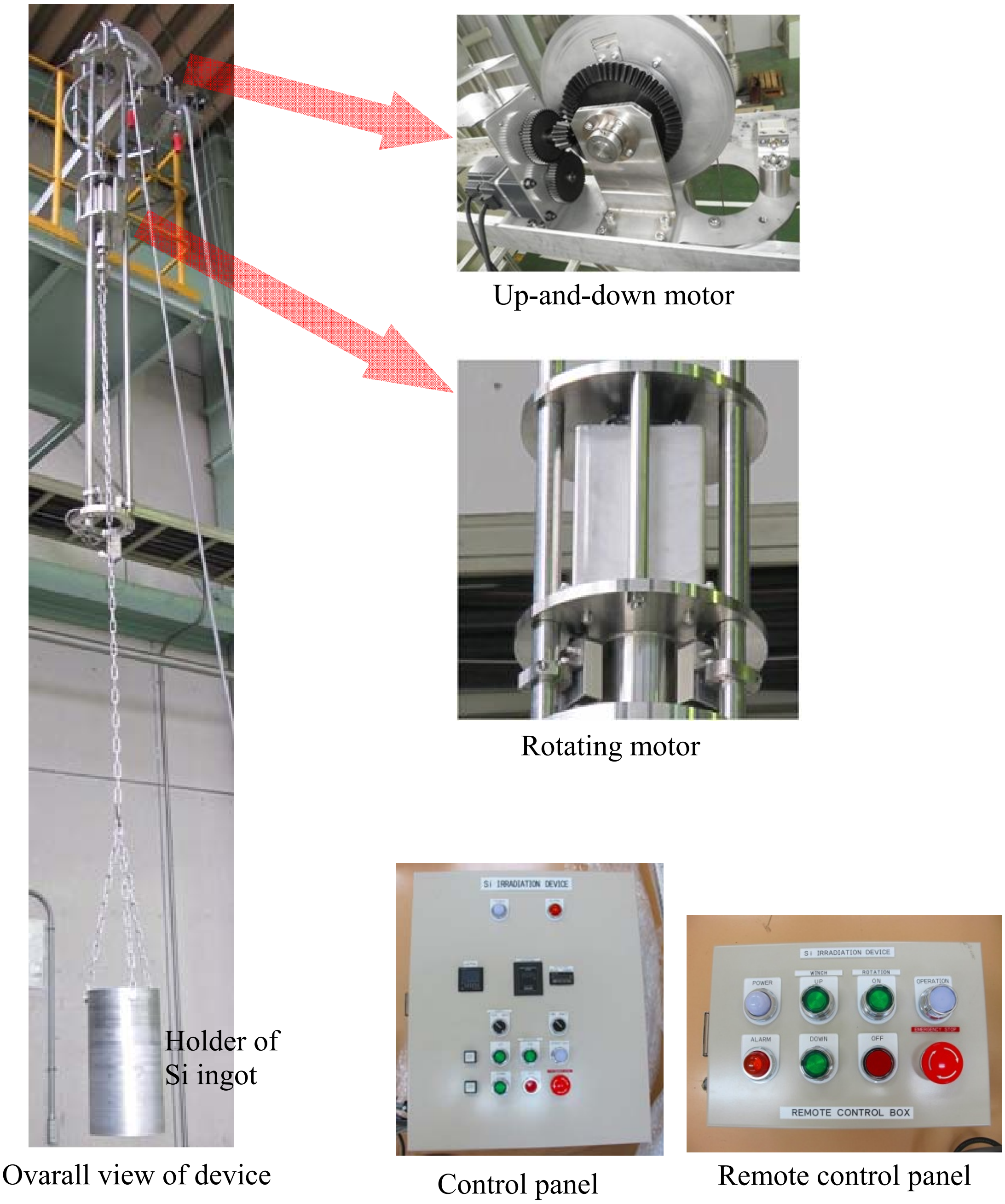


Fig. 5-2 Photograph of Si rotating device.

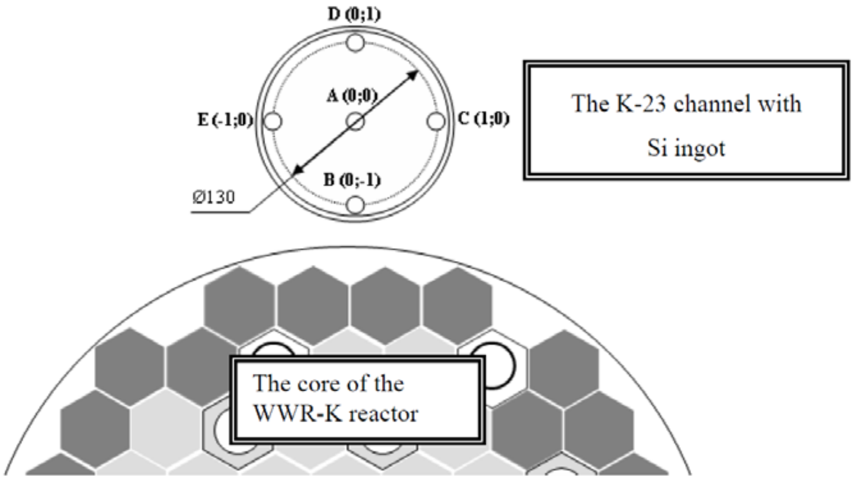


Fig. 5-3 Layout of the calculation nodes.

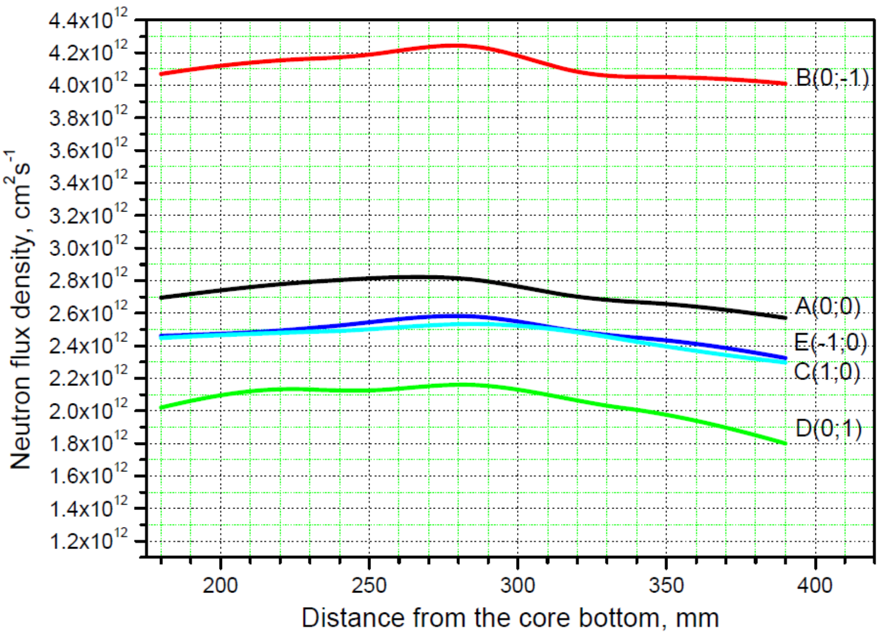
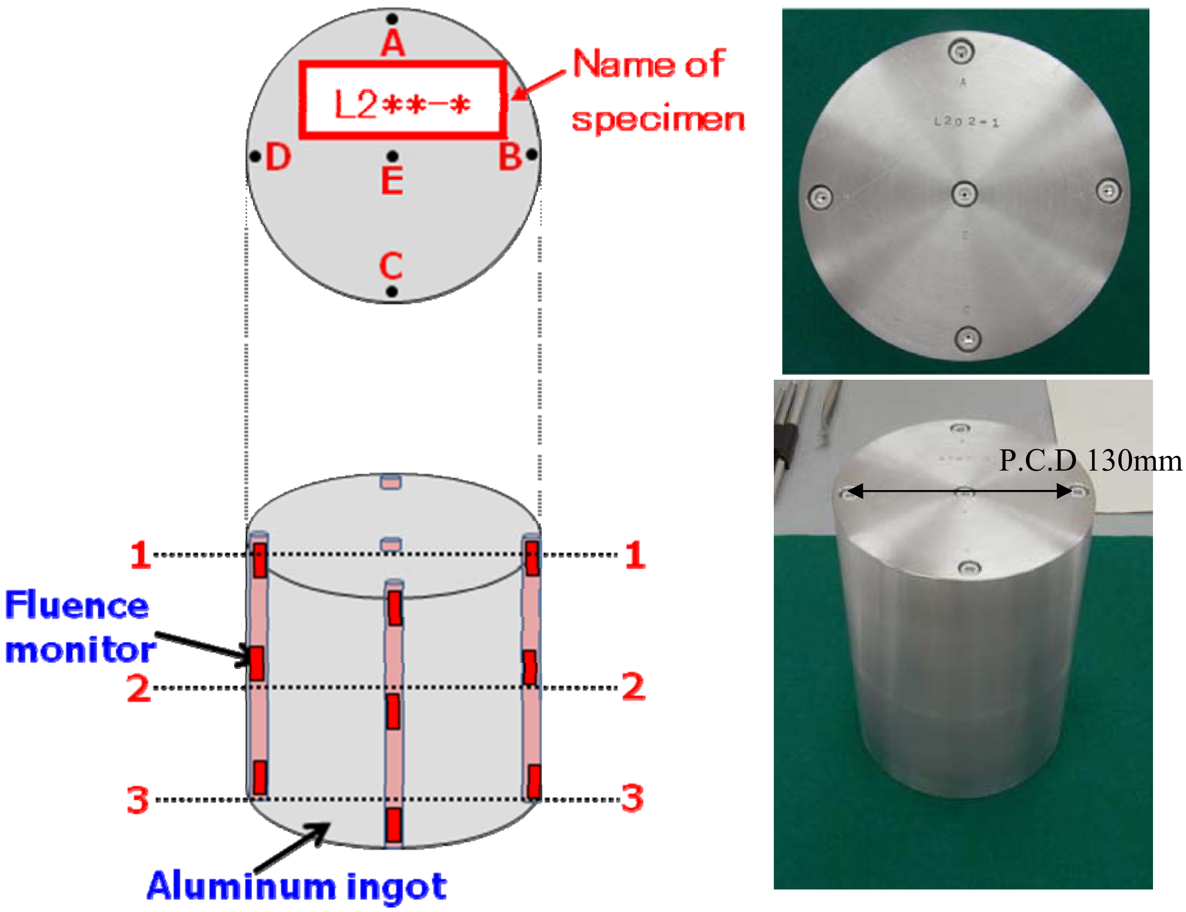


Fig. 5-4 Distribution of the thermal neutron flux density (E <0.465 eV) over height of the Si ingot.



Name of specimen	Diameter [mm]	Length [mm]	Number of F/M	Monitor materials in F/M
L202-1	150	202	15	Fe, Al-Co
L202-2	150	202	15	Fe, Al-Co
L278-1	150	278	15	Fe, Al-Co
L278-2	150	278	15	Fe, Al-Co

Fig. 5-5 Photographs and specifications of specimens [Al ingots].

6. Conclusion and Future Plan

Based on the implementing arrangement between National Nuclear Center of the Republic of Kazakhstan (NNC) and the Japan Atomic Energy Agency (JAEA) for "Nuclear Technology on Testing/Research Reactors" in cooperation in Research and Development in Nuclear Energy and Technology, four specific topics of cooperation (STC) have been carried out from June, 2009. The status and future plans of these STCs are summarized as follows;

(1) STC No.II-1 : International Standard of Instrumentation

As the development of international standard of instruments, the instruments in the testing/research reactors have been discussed, and the irradiation test with two kinds of the Linear Variable Differential Transformers (LVDT) was started in WWR-K. Moreover, information exchange has been carried out on the thermocouples and different material joints, and new activities for nuclear technology are planned between INP and JAEA.

(2) STC No.II-2 : Irradiation Technology of RI Production

As the development of RI production, the ^{99}Mo-^{99m}Tc generators for adsorbing ^{99}Mo have been developed for the production by ^{98}Mo (n,γ) ^{99}Mo method using testing/research reactors. The common subjects on the ^{99}Mo production by (n, γ) method were selected, and cooperation experiments are carried out on the comparison and recycling tests of PZC and Zr gel.

(3) STC No.II-3 : Lifetime Expansion of Beryllium Reflector

As the development of beryllium reflector, the irradiation test with three kinds of beryllium grades was started in WWR-K. Moreover, information exchange has been carried out on the production and characteristics of beryllium, and new activities for nuclear technology are planned between INP and JAEA.

(4) STC No.II-4 : Irradiation Technology for NTD-Si

As the development of NTD-Si, irradiation device was developed in JAEA, and the irradiation tests were started in WWR-K. In the irradiation tests, the neutron calculations in the irradiation hole in WWR-K were conducted using MCNP, and the thermal and fast neutron fluences will be evaluated by the measurement of the fluence monitors after the irradiation tests. After the evaluation, the irradiation tests with two monocrystal Si ingots will be carried out, and the characteristics of NTD-Si will be evaluated.

The information exchange, personnel exchange and cooperation experiments are carried out under these STCs, and new subjects will be discussed for the demonstration phase in the field of nuclear technology on testing/research reactors under the arrangement.

Acknowledgment

Authors greatly appreciate the helpful comments on this paper by Dr. M. Suzuki (Director, NITRC-JAEA), Dr. E. Batyrbekov (Director, INP-NNC-RK), Mr. Y. Komori (Director, JMTR-JAEA), Mr. D. Nakipov (Chief engineer, WWR-K, INP-NNC-RK), Dr. M. Ishihara (Deputy Director, NITRC-JAEA), Dr. T. Nakatsuka (Assistant Principal Researcher, NHHARC-JAEA) and Dr. M. Kaminaga (Deputy Director, NITRC-JAEA). Additionally, valuable discussion with information exchanges and cooperation experiments from JAEA and INP staffs are highly appreciated.

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Appendix I

IMPLEMENTING ARRANGEMENT
BETWEEN
THE JAPAN ATOMIC ENERGY AGENCY
AND
THE NATIONAL NUCLEAR CENTER OF THE REPUBLIC OF KAZAKHSTAN
FOR COOPERATION IN RESEARCH AND DEVELOPMENT
IN NUCLEAR ENERGY AND TECHNOLOGY

The Japan Atomic Energy Agency (JAEA) and National Nuclear Center of the Republic of Kazakhstan (NNC), hereinafter collectively called the “Parties”,

Noting the Memorandum of Understanding between the JAEA and NNC for the Future cooperation in Nuclear Energy Research and Development signed April 30, 2007, and

Wishing to continue the long-term and productive cooperation among the JAEA and the NNC’s predecessors in nuclear energy and technology areas,

Hereby agree as follows:

Article 1
Purpose

The purpose of this Arrangement is to strengthen the research cooperation between the Parties in the field of nuclear energy and technology. Such cooperation shall be on the basis of mutual benefit, equality and reciprocity.

Article 2
Areas of cooperation

The Parties will promote cooperation concerning nuclear energy and technology in the following areas:

(1) High temperature gas-cooled reactor and its application technology;
(2) Nuclear technology on testing/research reactors;
(3) Other areas as may be mutually agreed upon by the Parties.

Article 3
Scope of cooperation

The cooperative activities under this Arrangement may include:

(1) Exchange of scientific and technological information;
(2) Exchange of scientists, engineers and other experts, which includes their short-term visits to the facilities of the Parties;
(3) Joint research; and
(4) Other activities as may be mutually agreed by the Parties.

Article 4
Project Annexes

Cooperative activities under this Arrangement may be undertaken by the Parties or as appropriate, laboratories of the Parties. Each cooperative activity that may involve the sharing of costs or that may give rise to intellectual property shall be described in writing in a Project Annex, which shall be subject to approval by each coordinator (as provided for in Article 5). Such Project Annexes shall include detailed provisions for carrying out the specified forms of cooperation, including such matters as technical scope, exchange of business-confidential information, management, total costs, cost sharing and schedule. Each Project Annexes shall be subject to and shall refer to this Arrangement.

Article 5
Coordination

Each Party shall designate a coordinator for the coordination, preparation, and implementation of the cooperation within the scope of this Arrangement. All administrative contacts between the Parties shall be effected through the coordinators.

Article 6
Finance

6.1 Unless otherwise mutually agreed in writing by the Parties, each Party shall bear all costs of its activities under this Arrangement.

6.2 The implementation of the cooperative activities under this Arrangement shall be subject to the availability of appropriated funds.

Article 7
Exchange of Personnel

With respect to exchange of personnel under this Arrangement:

7.1 Whenever an exchange of personnel is contemplated, each Party shall ensure that qualified personnel are selected for assignment to the other Party.

7.2 The Parties shall enter into a separate Personnel Assignment Arrangement as set forth in Appendix A for the purpose of putting this article into effect.

7.3 Each Party shall be responsible for the salaries, insurance and allowances to be paid to its personnel.

7.4 The assigning Party shall be responsible for bearing the travel and living expenses of its personnel while on assignment to the receiving Party unless otherwise agreed upon in writing.

7.5 The receiving Party shall arrange for adequate accommodations for the assigned personnel and their families.

7.6 The receiving Party shall provide all necessary assistance to the assigned personnel and their families regarding administrative formalities (travel arrangement, etc.).

7.7 The assigned personnel of each Party shall conform to the general and special rules of work and safety regulations in force at the receiving Party.

Article 8
Information

8.1 (1) The Parties shall support the widest possible dissemination of information provided or exchanged under this Arrangement subject to the need to protect proprietary information, to copyright restrictions, and to provisions of this Article.

(2) Upon publication of such information, it shall be mentioned clearly that the information was obtained under this Arrangement.

8.2 Use of proprietary information

(1) Definitions as used for this Arrangement

(i) The term “information” means scientific or technical data, results or methods of research and development, and any other information intended to be provided or exchanged under this Arrangement.

(ii) The term “proprietary information” means information which contains trade secrets or commercial or financial information or know-how (for example, computer programs, design procedures and techniques, or manufacturing methods) which is privileged or confidential, and may only include such information which:

a. has been held in confidence by its owner;
b. is of a type which is customarily held in confidence by its owner;
c. has not been provided by the transmitting Party to other entities (including the receiving Party) except on the basis that it be held in confidence;
d. is not otherwise available to the receiving Party from another source without restriction on its further dissemination.

(2) Procedures

(i) A Party receiving proprietary information pursuant to this Arrangement shall respect the privileged nature thereof. Any document which contains proprietary information shall be clearly marked with the following (or substantially similar) restrictive legend:

"This document contains proprietary information furnished in confidence under the Implementing Arrangement between the JAEA and NNC for Cooperation in Research and Development in Nuclear Energy and Technology on January 19, 2009 and shall not be disseminated outside these organizations, the concerned departments and agencies of Government of Japan and the Government of the Republic of Kazakhstan without the prior approval of ...."

This notice shall be marked on any reproduction hereof, in whole or in part. These limitations shall automatically terminate when this information is disclosed by the owner without restriction.

(ii) With the prior written consent of the Party providing proprietary information under this Arrangement, the receiving Party may disseminate such proprietary information more widely than otherwise permitted in the foregoing paragraph 8.2. (2) (i) above. The Parties shall cooperate with each other in developing procedures for requesting and obtaining prior written consent for such wider dissemination, and each Party will grant such approval to the extent permitted by its national policies, laws and regulations.

(3) If either of the Parties becomes aware that it will be, or it may reasonably be expected to become unable to meet the non-dissemination provisions of this Article, it shall immediately inform the other Party. The Parties shall thereafter consult to define an appropriate course of action.

(4) Information resulting from seminars, workshops and other meetings arranged under this Arrangement, resulting from the assignments of personnel and use of facilities shall be treated by the Parties according to the principles specified in this Article with the provision that no proprietary information orally communicated shall be subject to the non-dissemination provisions of this Arrangement unless the individual communicating such information gives notice to the recipient as to the proprietary information communicated.

(5) The transmitting Party in its relation with the receiving Party does not warrant the suitability of any information transmitted for any particular use or application. The transmitting Party will use its best efforts to furnish such information which will meet the requirements associated with cooperative activities under this Arrangement.

8.3 Right of use of information

Related technology information on the trigger list items of the Nuclear Suppliers Group shall not be exchanged between the Parties under this Arrangement.

Article 9
Patents

The parties shall take necessary steps under the applicable laws and regulations of the relevant country or countries to achieve the equitable distribution of industrial property resulting from the cooperative activities under this Arrangement and licenses thereof, as follows:

9.1 With respect to any invention or discovery made or conceived in the course of or under the cooperative activities under this Arrangement:

(1) If made by personnel of one Party (the assigning Party) while assigned to the other Party (the receiving Party) in connection with exchanges of scientists, engineers and other experts:

(i) The receiving Party shall acquire all rights, titles and interests and to any such invention or discovery in its own country and in third countries.

(ii) The assigning Party shall acquire all rights, titles and interests in and to any such invention or discovery in its own country.

(2) If made or conceived by a Party as a direct result of employing information which has been communicated to it under the cooperative activities under this Arrangement by the other Party, or communicated during seminars or other joint meetings, the Party making the invention or discovery shall acquire all rights, titles and interests in and to such invention or discovery in all countries.

(3) The Party which owns rights, titles and interests referred to in paragraphs 9.1 (1) and 9.1 (2) above shall grant upon request of the other Party, a non-exclusive, irrevocable license of such rights, titles and interests, to the other Party, its Government and nationals of its country designated by it. This license shall be free of charge for research, safety, regulatory and developmental activities, but for all other purposes it shall be subject to just compensation.

9.2 The provisions of the preceding paragraph 9.1 of this Article shall apply mutatis mutandis to the protection of utility model and design.

9.3 Each Party shall assume the responsibility to pay awards or compensation required to be paid to its own nationals according to its own laws. Each Party shall, without prejudice to any rights of inventors under its national law, take all necessary steps to provide the cooperation from its inventors required to carry out the provisions of this Article.

Article 10
Copyright

Copyrights of the Parties shall be accorded due treatment consistent with internationally recognized standards of protection. As to copyrights on materials within the scope of paragraph 8.l, owned or controlled by a Party, that Party shall make efforts to grant to the other Party a license to reproduce or translate copyrighted material.

Article 11
Liability

11.1 Each Party shall alone be responsible for accidents to its staff or damages to its property, regardless of where the damages have been incurred during the term of this Arrangement and shall not bring suit or lodge any other claims against the other Party for damages to its property or accidents to its staff, unless the claim is based on gross negligence or intentional misconduct of the other Party or its employees.

11.2 The foregoing provisions of this Article shall not apply to damages caused by a nuclear incident, as defined by the laws of the countries of Parties. Damages caused by such a nuclear incident shall be compensated in accordance with the laws of the countries of the Parties.

Article 12
Warranty

The Parties warrant that any information obtained and exchanged under this Arrangement shall not contain sensitive technology with respect to nuclear proliferation and nuclear reactor design, and that it is utilized exclusively for the peaceful use of nuclear energy.

Article 13
Dispute

The cooperative activities under this Arrangement shall be implemented in accordance with the laws of the respective countries and the regulations of the respective Parties. Any dispute arising out of the interpretation or implementation of this Arrangement and any question relating to the cooperative activities under this Arrangement shall be settled by amicable efforts of the Parties.

Article 14
Additional Provisions

14.1 This Arrangement shall enter into force upon signature of the Parties and shall remain in force for a period of five (5) years.

14.2 This Arrangement may be terminated at any time at the discretion of either Party upon six (6) months advance notification in writing by the Party seeking to terminate the Arrangement. Such termination shall be without prejudice to the rights which may have accrued under the Agreement to either Party up to the date of such termination.

14.3 This Arrangement may be amended or extended through mutual written agreement of the Parties.

Done in duplicate at Tokai, this 2nd day of February, 2009.

FOR THE JAPAN ATOMIC ENERGY AGENCY	FOR THE NATIONAL NUCLEAR CENTER OF THE REPUBLIC OF KAZAKHSTAN
Toshio Okazaki President, Japan Atomic Energy Agency	Kairat K. Kadyrzhanov Director General, National Nuclear Center of the Republic of Kazakhstan

ANNEX

<table>
<tr><td colspan="3" align="center">NNC-RK
JAEA

COOPERATION IN RESEARCH AND DEVELOPMENT
IN NUCLEAR ENERGY AND TECHNOLOGY
NUCLEAR TECHNOLOGY ON TESTING/RESEARCH REACTORS</td></tr>
<tr><td colspan="2" rowspan="2" align="center">SPECIFIC TOPIC OF COOPERATION
STC SHEET No. II-1</td><td>REF:</td></tr>
<tr><td>Date: June 8, 2009</td></tr>
<tr><td colspan="3">TITLE OF THE SPECIFIC TOPIC OF COOPERATION:

Nuclear Technology on Testing/Research Reactors</td></tr>
<tr><td colspan="3">AREAS OF COOPERATION:

International Standard of Instrumentation under Neutron-irradiation Field</td></tr>
<tr><td colspan="3">CONTENT OF THE SPECIFIC TOPIC OF COOPERATION

1- Purpose: This Specific Topic of Cooperation covers mainly the following items:
Information exchange between JAEA and NNC-RK
Personnel exchange of scientists, engineers and other experts
Experiments for standard instruments and other concerning areas

2 - Specific Conditions:
Specialist meetings will be organized for the information exchange.
Attendees and the place for each meeting will be mutually agreed.

3 - Duration/Schedule:
The cooperation in this area will enter into force from June 8, 2009 until February 1, 2014.</td></tr>
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		Contact Person	Field Coordinator
NNC-RK	Name		
	Signature		
JAEA	Name		
	Signature		

ANNEX

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NUCLEAR TECHNOLOGY ON TESTING/RESEARCH REACTORS</td></tr>
<tr><td colspan="3" rowspan="2">SPECIFIC TOPIC OF COOPERATION
STC SHEET No. II-2</td><td>REF:</td></tr>
<tr><td>Date: June 8, 2009</td></tr>
<tr><td colspan="4">TITLE OF THE SPECIFIC TOPIC OF COOPERATION:

Nuclear Technology on Testing/Research Reactors</td></tr>
<tr><td colspan="4">AREAS OF COOPERATION:

Irradiation Technology of RI Production</td></tr>
<tr><td colspan="4">CONTENT OF THE SPECIFIC TOPIC OF COOPERATION

1- Purpose: This Specific Topic of Cooperation cover mainly the following items:
Information exchange between JAEA and NNC-RK
Personnel exchange of scientists, engineers and other experts
Experiments on RI production

2 - Specific Conditions:
Specialist meetings will be organized for the information exchange.
Attendees and the place for each meeting will be mutually agreed.

3 - Duration/Schedule:
The cooperation in this area will enter into force from June 8, 2009 until February 1, 2014.</td></tr>
<tr><td colspan="2"></td><td>Contact Person</td><td>Field Coordinator</td></tr>
<tr><td rowspan="2">NNC-RK</td><td>Name</td><td></td><td></td></tr>
<tr><td>Signature</td><td></td><td></td></tr>
<tr><td rowspan="2">JAEA</td><td>Name</td><td></td><td></td></tr>
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NUCLEAR TECHNOLOGY ON TESTING/RESEARCH REACTORS</td></tr>
<tr><td colspan="3" rowspan="2">SPECIFIC TOPIC OF COOPERATION
STC SHEET No. II-3</td><td>REF:</td></tr>
<tr><td>Date: June 12, 2009</td></tr>
<tr><td colspan="4">TITLE OF THE SPECIFIC TOPIC OF COOPERATION:

Nuclear Technology on Testing/Research Reactors</td></tr>
<tr><td colspan="4">AREAS OF COOPERATION:

Lifetime Expansion of Beryllium Reflector in the Materials Testing Reactors</td></tr>
<tr><td colspan="4">CONTENT OF THE SPECIFIC TOPIC OF COOPERATION

1- Purpose: This Specific Topic of Cooperation covers mainly the following items:
Information exchange between JAEA and NNC-RK
Personnel exchange of scientists, engineers and other experts
Experiments on Beryllium Reflector Materials

2 - Specific Conditions:
Specialist meetings will be organized for the information exchange.
Attendees and the place for each meeting will be mutually agreed.

3 - Duration/Schedule:
The cooperation in this area will enter into force from June 12, 2009 until February 1, 2014.</td></tr>
<tr><td colspan="2"></td><td>Contact Person</td><td>Field Coordinator</td></tr>
<tr><td rowspan="2">NNC-RK</td><td>Name</td><td></td><td></td></tr>
<tr><td>Signature</td><td></td><td></td></tr>
<tr><td rowspan="2">JAEA</td><td>Name</td><td></td><td></td></tr>
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NUCLEAR TECHNOLOGY ON TESTING/RESEARCH REACTORS</td></tr>
<tr><td colspan="3" rowspan="2">SPECIFIC TOPIC OF COOPERATION
STC SHEET No. II-4</td><td>REF:</td></tr>
<tr><td>Date: September 7, 2009</td></tr>
<tr><td colspan="4">TITLE OF THE SPECIFIC TOPIC OF COOPERATION:

Nuclear Technology on Testing/Research Reactors</td></tr>
<tr><td colspan="4">AREAS OF COOPERATION:

Irradiation Technology for NTD-Si</td></tr>
<tr><td colspan="4">CONTENT OF THE SPECIFIC TOPIC OF COOPERATION

1- Purpose: This Specific Topic of Cooperation cover mainly the following items:
1) Information exchange between JAEA and NNC-RK
2) Personnel exchange of scientists, engineers and other experts
3) Evaluation of neutron irradiation field
4) Planning and experiments for irradiation of silicon ingot
5) Characterization of silicon irradiated in WWR-K

2 - Specific Conditions:
Specialist meetings will be organized for the information exchange.
Attendees and the place for each meeting will be mutually agreed.

3 - Duration/Schedule:
The cooperation in this area will enter into force from September 7, 2009 until February 1, 2014.</td></tr>
<tr><td colspan="2"></td><td>Contact Person</td><td>Field Coordinator</td></tr>
<tr><td rowspan="2">NNC-RK</td><td>Name</td><td></td><td></td></tr>
<tr><td>Signature</td><td></td><td></td></tr>
<tr><td rowspan="2">JAEA</td><td>Name</td><td></td><td></td></tr>
<tr><td>Signature</td><td></td><td></td></tr>
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Appendix II

Activities between the Neutron Irradiation and Testing Reactor Center (NITRC), JAEA and Institute of Nuclear Physics (INP), NNC-RK

No.	Period	Object	Place	Name	
				JA side	KZ side
1	From 13 to 19, April, 2008	- Information Exchange and Discussion on Specific Topics of Cooperation between NITRC-JAEA and INP-NNC-RK	INP-NNC-RK, Almaty, Republic of Kazakhstan	H. Kawamura K. Tsuchiya	P. Chakrov Sh. Gizatulin
2	From 10 to 15, August, 2009	- Technical Meeting on Cooperation in the Field of Irradiation Technology for Testing Reactor	INP-NNC-RK, Almaty, Republic of Kazakhstan	K. Tsuchiya N. Takemoto	P. Chakrov Sh. Gizatulin
3	From 25 to 31, October, 2009	- 1st Joint Experiment on Irradiation Technology of RI Production (STC No.2-II)	INP-NNC-RK, Almaty, Republic of Kazakhstan	A. Kimura	Y. Chakrova V.Bannykh N. Gluschenko
4	From 21 to 27, February, 2010	- 2nd Joint Experiment on Irradiation Technology of RI Production (STC No.2-II)	INP-NNC-RK, Almaty, Republic of Kazakhstan	A. Kimura	Y. Chakrova V.Bannykh N. Gluschenko
5	From 21 to 24, June, 2010	- 3rd International Symposium on Material Testing Reactors (ISMTR) - 5th Specialist Meeting on Recycling of Irradiated Beryllium	The Nuclear Research Institute (NRI), Czech Republic	M. Ishihara K. Tsuchiya	P. Chakrov Sh. Gizatulin

No.	Period	Object	Place	Name	
				JA side	KZ side
6	From 5 to 12, December, 2010	- 3rd Joint Experiment on Irradiation Technology of RI Production (STC No.2-II)	The Nuclear Research Institute (NRI), Czech Republic	A. Kimura	Y. Chakrova V.Bannykh N. Gluschenko
7	From 6 to 10, Dec. 2010	- Irradiation test of Differential Transformers - Technical meeting on Cooperation in the Field of Irradiation Technology for Testing Reactor	INP-NNC-RK, Almaty, Republic of Kazakhstan	M. Tanimoto N. Takemoto T. Saito	Sh. Gizatulin L. Checushine D.Nakipov
8	From 3 to 10, May, 2011	- Irradiation test of Differential Transformers - Technical meeting on Cooperation in the Field of Irradiation Technology for Testing Reactor	INP-NNC-RK, Almaty, Republic of Kazakhstan	K. Tsuchiya T. Saito	P. Chakrov Sh. Gizatulin A. Shaimerdenov
9	From 19 to 27 Sep, 2011	- Irradiation test of Differential Transformers - Technical meeting on Cooperation in the Field of Irradiation Technology for Testing Reactor	INP-NNC-RK, Almaty, Republic of Kazakhstan	M. Tanimoto N. Takemoto	P. Chakrov Sh. Gizatulin

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	$\mathrm{m^2}$
体積	立法メートル	$\mathrm{m^3}$
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	$\mathrm{m/s^2}$
波数	毎メートル	$\mathrm{m^{-1}}$
密度，質量密度	キログラム毎立方メートル	$\mathrm{kg/m^3}$
面積密度	キログラム毎平方メートル	$\mathrm{kg/m^2}$
比体積	立方メートル毎キログラム	$\mathrm{m^3/kg}$
電流密度	アンペア毎平方メートル	$\mathrm{A/m^2}$
磁界の強さ	アンペア毎メートル	A/m
量濃度 (a)，濃度	モル毎立方メートル	$\mathrm{mol/m^3}$
質量濃度	キログラム毎立法メートル	$\mathrm{kg/m^3}$
輝度	カンデラ毎平方メートル	$\mathrm{cd/m^2}$
屈折率 (b)	（数字の） 1	1
比透磁率 (b)	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表される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(b)	rad	1 (b)	m/m
立体角	ステラジアン(b)	sr(c)	1 (b)	$\mathrm{m^2/m^2}$
周波数	ヘルツ (d)	Hz		$\mathrm{s^{-1}}$
力	ニュートン	N		$\mathrm{m\,kg\,s^{-2}}$
圧力，応力	パスカル	Pa	$\mathrm{N/m^2}$	$\mathrm{m^{-1}\,kg\,s^{-2}}$
エネルギー，仕事，熱量	ジュール	J	N m	$\mathrm{m^2\,kg\,s^{-2}}$
仕事率，工率，放射束	ワット	W	J/s	$\mathrm{m^2\,kg\,s^{-3}}$
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	$\mathrm{m^2\,kg\,s^{-3}\,A^{-1}}$
静電容量	ファラド	F	C/V	$\mathrm{m^{-2}\,kg^{-1}\,s^4\,A^2}$
電気抵抗	オーム	Ω	V/A	$\mathrm{m^2\,kg\,s^{-3}\,A^{-2}}$
コンダクタンス	ジーメンス	S	A/V	$\mathrm{m^{-2}\,kg^{-1}\,s^3\,A^2}$
磁束	ウエーバ	Wb	Vs	$\mathrm{m^2\,kg\,s^{-2}\,A^{-1}}$
磁束密度	テスラ	T	$\mathrm{Wb/m^2}$	$\mathrm{kg\,s^{-2}\,A^{-1}}$
インダクタンス	ヘンリー	H	Wb/A	$\mathrm{m^2\,kg\,s^{-2}\,A^{-2}}$
セルシウス温度	セルシウス度(e)	℃		K
光束	ルーメン	lm	cd sr(c)	cd
照度	ルクス	lx	$\mathrm{lm/m^2}$	$\mathrm{m^{-2}\,cd}$
放射性核種の放射能 (f)	ベクレル (d)	Bq		$\mathrm{s^{-1}}$
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	$\mathrm{m^2\,s^{-2}}$
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト (g)	Sv	J/kg	$\mathrm{m^2\,s^{-2}}$
酸素活性	カタール	kat		$\mathrm{s^{-1}\,mol}$

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。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である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含む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	$\mathrm{m^{-1}\,kg\,s^{-1}}$
力のモーメント	ニュートンメートル	N m	$\mathrm{m^2\,kg\,s^{-2}}$
表面張力	ニュートン毎メートル	N/m	$\mathrm{kg\,s^{-2}}$
角速度	ラジアン毎秒	rad/s	$\mathrm{m\,m^{-1}\,s^{-1}=s^{-1}}$
角加速度	ラジアン毎秒毎秒	$\mathrm{rad/s^2}$	$\mathrm{m\,m^{-1}\,s^{-2}=s^{-2}}$
熱流密度，放射照度	ワット毎平方メートル	$\mathrm{W/m^2}$	$\mathrm{kg\,s^{-3}}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$\mathrm{m^2\,kg\,s^{-2}\,K^{-1}}$
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	$\mathrm{m^2\,s^{-2}\,K^{-1}}$
比エネルギー	ジュール毎キログラム	J/kg	$\mathrm{m^2\,s^{-2}}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	$\mathrm{m\,kg\,s^{-3}\,K^{-1}}$
体積エネルギー	ジュール毎立方メートル	$\mathrm{J/m^3}$	$\mathrm{m^{-1}\,kg\,s^{-2}}$
電界の強さ	ボルト毎メートル	V/m	$\mathrm{m\,kg\,s^{-3}\,A^{-1}}$
電荷密度	クーロン毎立方メートル	$\mathrm{C/m^3}$	$\mathrm{m^{-3}\,sA}$
表面電荷	クーロン毎平方メートル	$\mathrm{C/m^2}$	$\mathrm{m^{-2}\,sA}$
電束密度，電気変位	クーロン毎平方メートル	$\mathrm{C/m^2}$	$\mathrm{m^{-2}\,sA}$
誘電率	ファラド毎メートル	F/m	$\mathrm{m^{-3}\,kg^{-1}\,s^4\,A^2}$
透磁率	ヘンリー毎メートル	H/m	$\mathrm{m\,kg\,s^{-2}\,A^{-2}}$
モルエネルギー	ジュール毎モル	J/mol	$\mathrm{m^2\,kg\,s^{-2}\,mol^{-1}}$
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)	$\mathrm{m^2\,kg\,s^{-2}\,K^{-1}\,mol^{-1}}$
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	$\mathrm{kg^{-1}\,sA}$
吸収線量率	グレイ毎秒	Gy/s	$\mathrm{m^2\,s^{-3}}$
放射強度	ワット毎ステラジアン	W/sr	$\mathrm{m^4\,m^{-2}\,kg\,s^{-3}=m^2\,kg\,s^{-3}}$
放射輝度	ワット毎平方メートル毎ステラジアン	$\mathrm{W/(m^2\,sr)}$	$\mathrm{m^2\,m^{-2}\,kg\,s^{-3}=kg\,s^{-3}}$
酵素活性濃度	カタール毎立方メートル	$\mathrm{kat/m^3}$	$\mathrm{m^{-3}\,s^{-1}\,mol}$

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．SIに属さないが、SIと併用される単位

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=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$\mathrm{1ha=1hm^2=10^4m^2}$
リットル	L，l	$\mathrm{1L=1l=1dm^3=10^3cm^3=10^{-3}m^3}$
トン	t	$\mathrm{1t=10^3\,kg}$

表７．SIに属さないが、SIと併用される単位で、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 単位で表される数値
電子ボルト	eV	$\mathrm{1eV=1.602\,176\,53(14)\times10^{-19}J}$
ダルトン	Da	$\mathrm{1Da=1.660\,538\,86(28)\times10^{-27}kg}$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$\mathrm{1ua=1.495\,978\,706\,91(6)\times10^{11}m}$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	$\mathrm{1\,bar=0.1MPa=100kPa=10^5Pa}$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$\mathrm{1\,Å=0.1nm=100pm=10^{-10}m}$
海里	M	1 M=1852m
バーン	b	$\mathrm{1\,b=100fm^2=(10^{-12}cm)2=10^{-28}m^2}$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$\mathrm{1\,erg=10^{-7}\,J}$
ダイン	dyn	$\mathrm{1\,dyn=10^{-5}N}$
ポアズ	P	$\mathrm{1\,P=1\,dyn\,s\,cm^{-2}=0.1Pa\,s}$
ストークス	St	$\mathrm{1\,St=1cm^2\,s^{-1}=10^{-4}m^2\,s^{-1}}$
スチルブ	sb	$\mathrm{1\,sb=1cd\,cm^{-2}=10^4cd\,m^{-2}}$
フォト	ph	$\mathrm{1\,ph=1cd\,sr\,cm^{-2}\ 10^4lx}$
ガル	Gal	$\mathrm{1\,Gal=1cm\,s^{-2}=10^{-2}ms^{-2}}$
マクスウェル	Mx	$\mathrm{1\,Mx=1G\,cm^2=10^{-8}Wb}$
ガウス	G	$\mathrm{1\,G=1Mx\,cm^{-2}=10^{-4}T}$
エルステッド (c)	Oe	$\mathrm{1\,Oe} \triangleq (10^3/4\pi)\mathrm{A\,m^{-1}}$

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$\mathrm{1\,Ci=3.7\times10^{10}Bq}$
レントゲン	R	$\mathrm{1\,R=2.58\times10^{-4}C/kg}$
ラド	rad	$\mathrm{1\,rad=1cGy=10^{-2}Gy}$
レム	rem	$\mathrm{1\,rem=1\,cSv=10^{-2}Sv}$
ガンマ	γ	1γ=1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
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	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	µ	$\mathrm{1\,\mu=1\mu m=10^{-6}m}$

（第8版，2006年改訂）