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Current Status of JMTR Refurbishment Project

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日本原子力研究開発機構

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The JMTR is a light water moderated and cooled, beryllium reflected tank- type reactor using LUE silicide plate-type fuels. Its thermal power is 50 MW, maximum thermal and fast neutron flux is 4 x 10^{18} $m^{-2}s^{-1}$. First criticality was achieved in March 1968, and its operation was stopped from August, 2006 for the refurbishment. The refurbishment is scheduled from the beginning of FY2007 to the end of FY2010. The renewed and upgraded JMTR will be re-started from FY2011. An investigation on aged components (aged-investigation) was carried out for concrete structures of the JMTR reactor building, exhaust stack, etc., and for tanks in the primary cooling system, heat exchangers, pipes in the secondary cooling system, cooling tower, emergency generators and so on, in order to identify their integrity. The aged-investigation was carried out at the beginning of FY2007. As a result, some components were decided to replace from viewpoints of future maintenance and improvement of reliability, and some components or structures were decided to repair. A visual inspection of inner side of the pressure vessel was carried out using an underwater camera in FY2008, and no serious damage was observed. Up to now, refurbishment works are in progress according to the planned schedule. In FY2009, motors of primary cooling pumps, secondary cooling pumps, motors of drain pumps, pump in the primary water transfer line to the water purification system, beryllium reflector frame, low-voltage motor control centers are to be replaced. A nuclear instrumentation system, process control system, safety protection system and so on are to be replaced in FY2010. In this paper, current status of JMTR refurbishment project is presented.

Keywords : JMTR, Testing Reactor, Refurbishment, Aged-Investigation, Replacement

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＋1 Neutron Irradiation and Testing Reactor Center

JMTR 更新プロジェクトの現状

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(2009 年 12 月 16 日　受理)

JMTR は、軽水減速・冷却、ベリリウム反射体付きタンク型炉で、その熱出力は 50MW である。最大高速中性子束及び熱中性子束は、ともに 4 x 10^{18} $m^{-2}s^{-1}$ である。1968 年 3 月に初臨界を達成した後、2006 年 8 月まで利用運転を継続して設備更新のために停止した。更新は 2007 年度初頭から 2010 年にかけて実施し、2011 年度に運転再開予定である。2007 年度当初に、JMTR 原子炉建家、排気筒等のコンクリート構造物、1 次冷却系タンク類、熱交換器、2 次冷却系配管等の健全性を確認するための経年劣化調査を実施した。その結果、今後の信頼性向上の観点から更新すべき機器、修理すべき機器や構造物を決定した。2008 年度は、水中カメラを用いた原子炉圧力容器の目視検査を実施し、有害な損傷の無いことを確認した。現在まで、機器等の更新は、計画したスケジュールに従って順調に進んでいる。2009 年度には 1 次冷却系ポンプ電動機、2 次冷却系ポンプ、ベリリウム反射体枠の更新等が予定されている。核計装設備、プロセス計装設備等は、2010 年度に更新する予定である。本稿では、JMTR 更新計画の現状について示す。

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1. Introduction

The Japan Materials Testing Reactor (JMTR) is a light water moderated and cooled, beryllium reflected tank- type reactor using LUE silicide plate-type fuels. Its thermal power is 50 MW, maximum thermal and fast neutron flux is 4 x 10^{18} $m^{-2}s^{-1}$, and its averaged heat flux is 1.2 MW/m^2. First criticality was achieved in March 1968, and its operation was stopped from August, 2006 for the refurbishment. The refurbishment is scheduled from the beginning of FY2007 to the end of FY2010. The renewed and upgraded JMTR will be re-started from FY2011.

An investigation on aged components (aged-investigation) was carried out for concrete structures of the JMTR reactor building, exhaust stack, etc., and for tanks in the primary cooling system, heat exchangers, pipes in the secondary cooling system, cooling tower, emergency generators and so on, in order to identify their integrity[1,2]. The aged-investigation was carried out at the beginning of FY2007. As a result, some components were decided to replace from viewpoints of future maintenance and improvement of reliability, and some components or structures were decided to repair. A visual inspection of inner side of the pressure vessel was carried out using an underwater camera in FY2008, and no serious damage was observed. Up to now, refurbishment works are in progress according to the planned schedule. Cracks of concrete structures such as the exhaust stack, a foundation of the UCL (Utility Cooling Loop) elevated water tank were repaired. Circulation pumps and water supply pumps of UCL system, a purified water supply system, boilers for the reactor building air conditioning system, blowers and ducts of the emergency exhaust system, high-voltage switchgears and transformers of electric power supply system, secondary cooling tower fan drive systems and pipe linings of secondary cooling system were replaced from viewpoints of future maintenance and improvement of reliability. In FY2009, motors of primary cooling pumps, secondary cooling pumps, motors of drain pumps, pump in the primary water transfer line to the water purification system, beryllium reflector frame, low-voltage motor control centers are to be replaced. A nuclear instrumentation system, process control system, safety protection system (including the control rod drive mechanism) and so on are to be replaced in FY2010.

Discussion on the JMTR re-operation schedule and commissioning tests has just been started. The JMTR re-operation schedule in FY2011 will be fixed before long. In this paper, current status of JMTR refurbishment project is presented.

2. Outline of JMTR

The JMTR was constructed to perform irradiation tests, materials and produce radioisotopes in order to establish domestic technology for developing nuclear power plants.

Its specification is summarized in Table 1. The reactor pressure vessel, 9.5 m high with 3 m in inner diameter, is made of low carbon stainless steel (SUS304L) and is located in the reactor pool. The control rod drive mechanisms are placed under the pressure vessel to make an easy handling of the irradiation facilities and fuels from the top of the core as shown in Fig.1. The core of the JMTR has a cylindrical shape with 1.56 m in diameter and 0.75 m in height. The core consists of 24 standard fuel elements, five control rods with fuel followers, reflectors and H-shaped beryllium frame.

Cooling water in a primary cooling system is pressurized at about 1.5 MPa to avoid local boiling in the core during rated power operation of 50 MW. The heat generated in the core is removed by the cooling water in the primary cooling system. The cooling water flows downwards in the core to transfer the heat from the core to the secondary cooling system through 3 units of heat exchangers. Finally, the heat transferred to the secondary cooling system is removed away into the atmosphere by cooling towers. Fig.2 shows layout of the JMTR with its ancillary facilities and hot laboratory.

For the irradiation, the JMTR provides excellent irradiation performance as shown in Fig.3. About 60 capsules are possible to irradiate simultaneously under various irradiation conditions with maximum neutron flux 4×10^{18} n/m^2/s (for thermal and fast neutrons) at temperatures from 50 to 2000 degree Celsius[3]. The JMTR provides various irradiation facilities to users, such as many types of irradiation capsules, shroud irradiation facility and hydraulic rabbit irradiation facility. Using these capsules/facilities, various irradiation conditions such as controlled temperature, controlled neutron fluence, controlled surrounding environment, are possible to achieve with specially developed irradiation technologies[3].

After irradiation, irradiated capsules are transferred to the hot laboratory, which is connected to the reactor building through a water canal as shown in Fig.2, to conduct PIEs. Many kinds of PIEs are possible to carry out by the user's requests, e.g. eddy current test, X-ray microscopic analysis, gamma scanning and so on for fuel PIEs, crack propagation test, creep test, fatigue test and so on for material PIEs.

Table 1 Major Specifications of JMTR

Reactor Thermal Power	50	(MW)
Fast Neutron Flux (Max.)	4×10^{18}	(n/m^{2}s)
Thermal Neutron Flux (Max.)	4×10^{18}	(n/m^{2}s)
Primary Coolant Flow Rate	6000	(m^3/h)
Coolant Temperature	49 / 56	(°C)
Active Core Length	750	(mm)
Feul	Plate type, 19.75% ^{235}U	
Irradiation Capability (Max.)	60 (20*) capsules	
dpa of Stainless Steel (Max.)	4	(dpa)
Diameter of Capsule	30 – 65	(mm)
Temperature Control (Max.)	2000	(°C)

* Capsule with in-situ measurement

3. Current Status of JMTR Refurbishment Project

The refurbishment project of the JMTR is categorized into three phases; the first is the aged-investigation, the second is the replacement of reactor components, and the third is the installation of new irradiation facilities. Simultaneously, the usability improvement is under discussion to make a user friendly environment as well as a user oriented management.

3.1 Aged-Investigation

An investigation of aged components (aged-investigation) was performed in order to identify integrity of facilities and components to be used for re-operation of the JMTR. The aged-investigation was carried out for concrete structures of the JMTR reactor building, exhaust stack, trench, canal, filter banks and for aged components of tanks in the primary cooling system, heat exchangers, pipes in the secondary cooling system, cooling tower, emergency generators and so on, in order to identify their integrity[4]. Major components and concrete structures investigated are shown in Fig.4. The aged-investigation was carried out from the beginning of FY2007. As a result, cracks of concrete structures such as the exhaust stack, a foundation of the UCL (Utility Cooling Line) elevated water tank were repaired and pipe linings of secondary cooling system were replaced. Motors of primary cooling pumps, pumps in the secondary cooling system and in other systems were decided to replace from viewpoints of future maintenance and improvement of reliability. Other components and the reactor building were decided to use continuously for a long-term by appropriate maintenance activities based on the long-term maintenance plan[4].

3.2 Replacement of Reactor Components

At the beginning of the project, integrity of the components was evaluated and concluded that the integrity of the components was maintained properly, based on the JMTR annual maintenance results obtained in February 2005. The JMTR annual maintenance is still continued, therefore, the integrity of the components still maintained properly even for the components which are not replaced.

Before the refurbishment of the JMTR, Selection of "Components to be continuously used" and "Components to be replaced" had been carried out.

JMTR utilization advisory committee suggested that "JMTR should be operated for more 20 years after refurbishment". Based on this suggestion, following items were considered for selection of "Components to be continuously used" and "Components to be replaced".

(1) Safety

Ageing of components, importance of safety feature, maintenance experience, etc. were considered.

(2) Improvement of availability

Affordability of spare parts for maintenance was considered.

Taking also account of a continuous operation with safety, reactor facilities/equipments to be replaced were decided. As a result, aged or old-designed components of the control rod drive mechanism, primary cooling system, secondary cooling system, electric power supply system and so on, are to be replaced by present-designed ones. For example, circuits of reactor control system, which consist of a huge amount of relays and soldered wirings, will be replaced by present-designed integrated circuits. Reactor components to be replaced and current status of replacement are shown in Fig.5.

Replacement of components has been finished for the ancillary facilities, such as UCL system circulation pumps, high voltage transformer, Power supply units, emergency exhaust blowers, boiler units, secondary cooling tower etc.

Main primary pump motors, secondary cooling system pumps, control rod drive mechanism, reactor operation console, process control system, neutron instruments and beryllium reflector frame will be replaced in this fiscal year or next fiscal year. The replacement schedule is shown in Fig.6.

For components or facilities which are not replaced, e.g. heat exchangers, pressure vessel, secondary cooling towers and so on, their integrity was evaluated from a view point of aging as mentioned in Section 3.1. The long-term operation in future will be possible by maintaining the present condition in accordance with the periodic safety review of the JMTR. After restart of the JMTR, the maintenance activity will be carried out by the maintenance program based on the periodic safety review of the JMTR.

3.3 Installation of New Irradiation Facilities

Corresponding to the user's irradiation request, new irradiation facilities, such as irradiation test facilities for materials/fuels, production facilities for silicon semiconductor and medical radioisotopes, will be planned to install in the JMTR. Preparation schedule for installation of new irradiation facilities is shown in Fig.7.

(1) New Material and Fuel Irradiation Tests

New irradiation facilities for materials/ and fuels tests are being developed and will be installed in the JMTR during four years refurbishment period. The project started from April 2007 by requirements from the regulatory and development uses of LWRs with a purpose of long-term and up-graded operations. Requirements are based on a higher performance utilization of LWRs. For example, irradiation tests for power up rating, longer operation cycles and modified water chemistries for lifetime extension of the power plants are planned to obtain the evaluation data for fuel and materials.

To meet one of these requirements, an irradiation capsule with a larger test section for a large sized specimen of reactor materials is under development in order to investigate the scale effect on the IASCC behavior. Moreover, a new type of a power ramp test facility is also under development to provide the constant surface temperature on test fuel rod during a boiling transient. It is planned to realize the linear power of the test fuel by controlling the pressure of surrounding ^{3}He gas screen, absorber of neutrons.

(2) New Irradiation Facility for Industrial Purpose

One of irradiation facilities for industrial utilization is intended for a production of silicon semiconductor. Here, the irradiation facility will be developed to irradiate a large sized silicon ingot with 8 inches in diameter, which meets the trend requirement in the field of hybrid cars and so on.

Another irradiation facility is intended to provide the ^{99m}Tc for medical use. A hydraulic rabbit irradiation facility, which is well developed and already used for irradiation in the JMTR, can be applied to the production. Now, investigation on production performance and costs are carried out[4)], and detail facilities to be installed in the JMTR are under discussion.

4. Role of New JMTR

After finishing the refurbishment works, the JMTR will be operated for a period of about 20 years until around FY2030.

The new JMTR will be utilized for the following irradiation needs.

(1) Lifetime extension of LWRs, which includes “Aging management of LWRs for utilization” and “Development of LWR fuels and materials for aiming at the highest availability of LWRs”.

(2) Production of fundamental and basic research, which includes “Materials and components development for fusion reactor, such as ITER and demonstration fusion reactors”, “Development of fuels and materials for high temperature gas cooled reactors (HTGR) which improves thermal stability” and “Fundamental research for nuclear energy, such as the determination irradiation damage mechanism”.

(3) New demand from industry, which includes “Production of silicon semiconductor with large diameter for industrial use, such as hybrid car” and “Domestic production of ^{99}Mo for medical diagnosis medicine ^{99m}Tc”.

(4) Human resource development for nuclear energy, which includes “Education and training of nuclear scientists and engineers for the next generation nuclear energy development”.

The new JMTR is planned to contribute the research/development utilization as well as the industrial utilization by offering excellent irradiation fields.

Re-operation schedule is currently discussing in order to increase availability of the

JMTR to the users. A preliminary operation plan for after refurbishment is shown in Fig.8 with a previous typical operation schedule. The JMTR previous typical operation schedule was 6 cycle operation per year, that means 180 days per year. On the other hand, operation plan for after refurbishment is 7 cycle operation per year, that means total 210 days per year by reducing periodical inspection and preparation periods for irradiation samples and so on.

5. Conclusions

The JAEA placed that the JMTR is a testing reactor which supports the basic technology of the nuclear energy, and decided the refurbishment of reactor facilities during four years from FY 2007. The refurbishment works are ongoing as scheduled from FY 2007. By the replacement of reactor components, the failure possibility of each component will decrease, and this leads the improvement of the higher reactor availability in future. Replacement of components has been finished for the ancillary facilities, such as power supply, air conditioning system, UCL system, secondary cooling tower etc. Replacement of the reactor and process control system, beryllium reflector frame, motors of the main primary cooling pumps will be completed until FY2010.

At the same time, irradiation facilities corresponding to user's needs, such as Nuclear and Industrial Safety Agency, will be installed to contribute the lifetime extension of LWRs by the user's fund. Additionally, the contribution to the development of the ITER and the industrial use etc., are being discussed.

After re-operation from FY 2011, the JMTR will be utilized fully by wide fields of users from national institutes, universities, industries as well as research group in JAEA. Moreover, the JMTR will also contribute the promotion on research and development of the nuclear energy from basic to applied fields as an internationally utilized facility under international/Asian network collaborations.

Annual operation schedule of the JMTR is under discussion in order to increase availability of the reactor.

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3) Department of JMTR, "JMTR Japan Material Testing Reactor", booklet, (2005)

4) Koichi IIMURA et al., "Conceptual Study of ^{99}Mo production Facility in JMTR", JAEA-Technology 2008-035(2008)

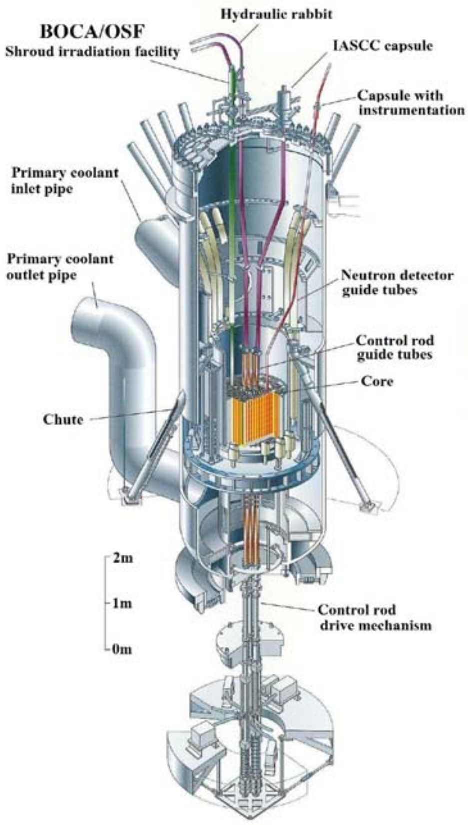

Fig.1 Cutaway View of Reactor Core with Pressure Vessel

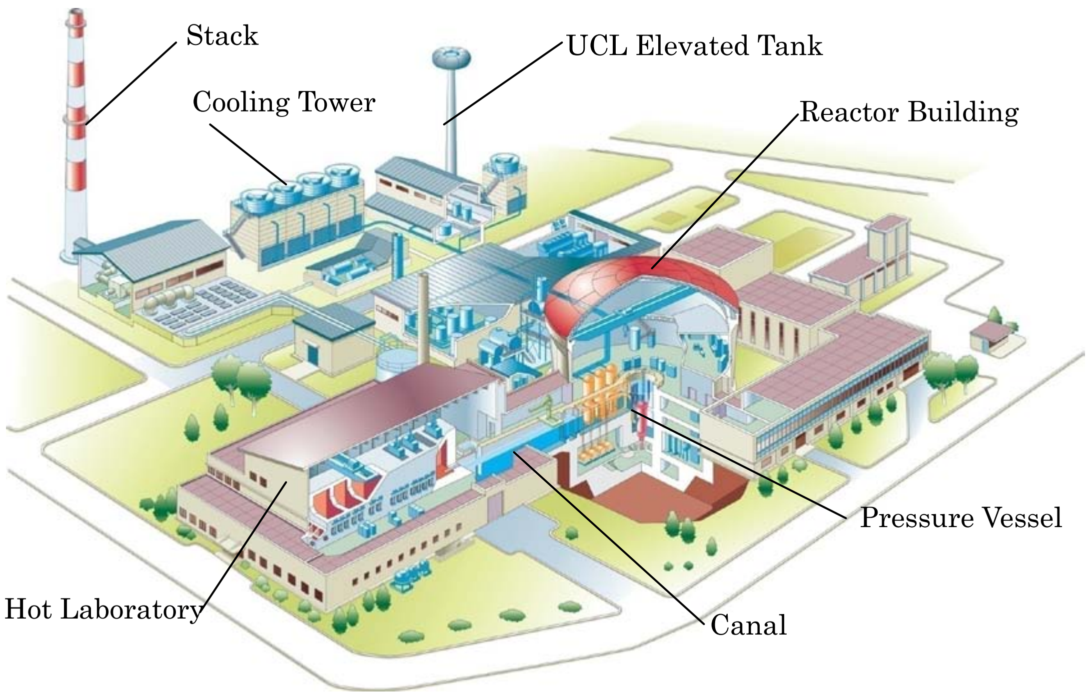

Fig.2 Layout of JMTR with its ancillary facilities and hot laboratory

Irradiation performance

1. Irradiation area of core
   - Simultaneous irradiation positions : about 60
   - Low gamma irradiation area
2. Neutron flux
   - Fast : max 4×10^{18} (n/m²/s)
   - Thermal : max 4×10^{18} (n/m²/s)
3. Neutron fluence /y (at 180 days operation*)
   - Fast and thermal : max. 3×10^{25} (n/m²)
   - dpa (for SUS) : max. 4 (dpa)
4. Dimensions of irradiation capsule
   -φ40mm × 750mm (outer diameter : max 65mm)
5. Irradiation temperature
   - Controlled from 50 to 2000°C

* : Achievement in Oct.2003~Spt.2005

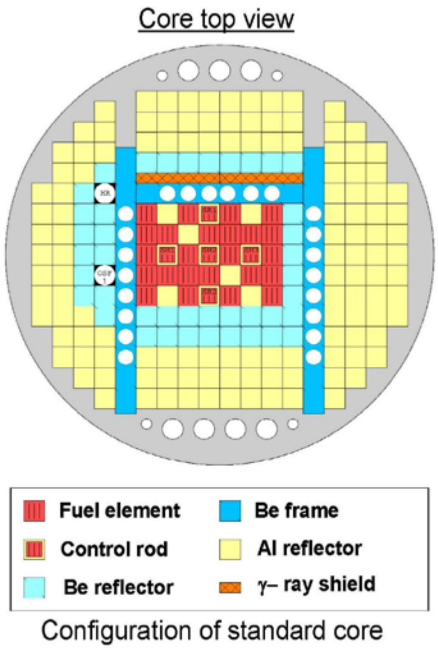

Fig.3 Irradiation performance of JMTR

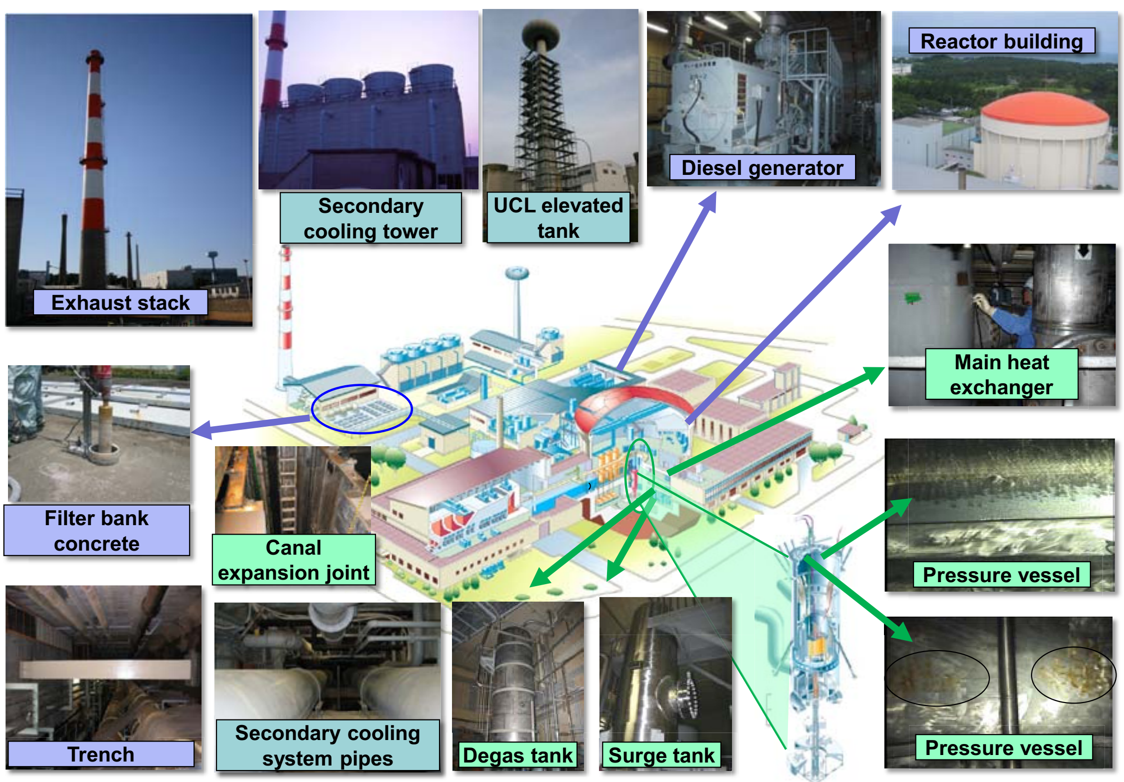

Fig.4 Major components and concrete structures investigated

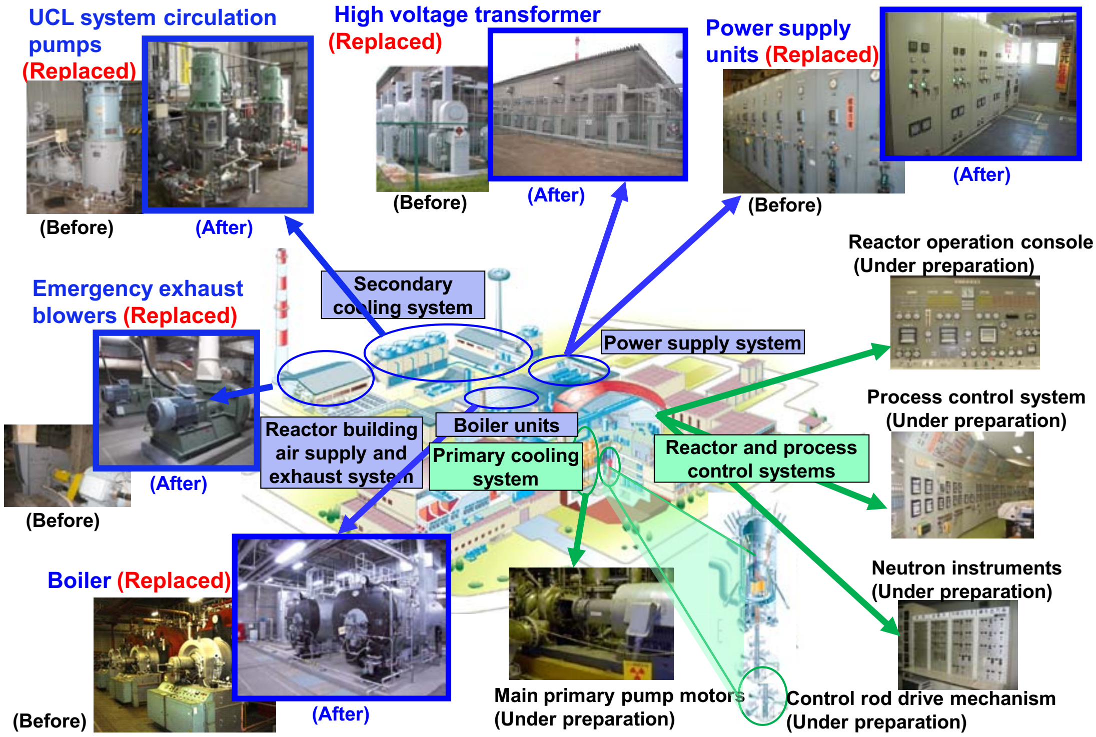

Fig.5 Reactor components to be replaced and current status of replacement

Work schedule for the refurbishment

No.	Item	Year	2007	2008	2009	2010	2011 Re-operation	Status at the end of August 2009
1	JMTR reactor core internals	Beryllium frame Gamma shielding plate						Under fabrication
2	Process and reactor control system	Process, neutron instruments, Safety protection system etc.						Under designning
3	Rector cooling systems	Primary cooling system, Secondary cooling system						Under designning
4	Radioactive waste disposal facility	Reactor room air feed and exhaust system, Drain system						Replacemet of "Reactor room air supply and exhaust system" has been completed.
5	Power supply	High votage power supply unit, Transformer, Cables						Replacemet has been completed.
6	Boiler, refregirator for air conditionning	Boiler, refrigerator for air conditioning system						Replacemet has been completed.
7	Purified water production system	Degassed demineralizer Regular demineralizer						Replacemet has been completed.

Fig.6 Components replacement schedule

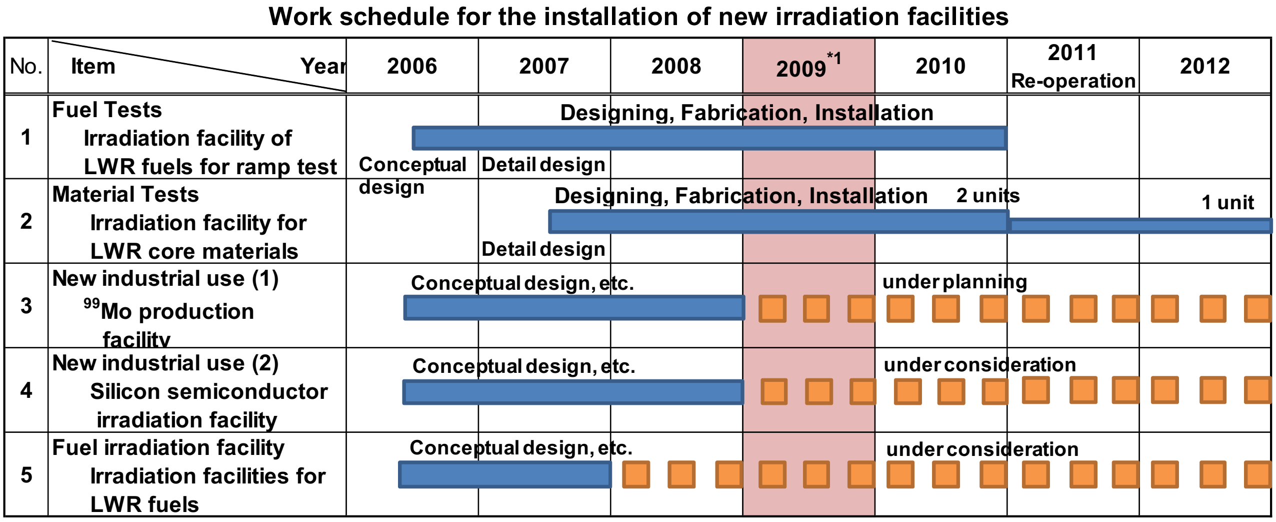

Fig.7 Preparation schedule for installation of new irradiation facilities

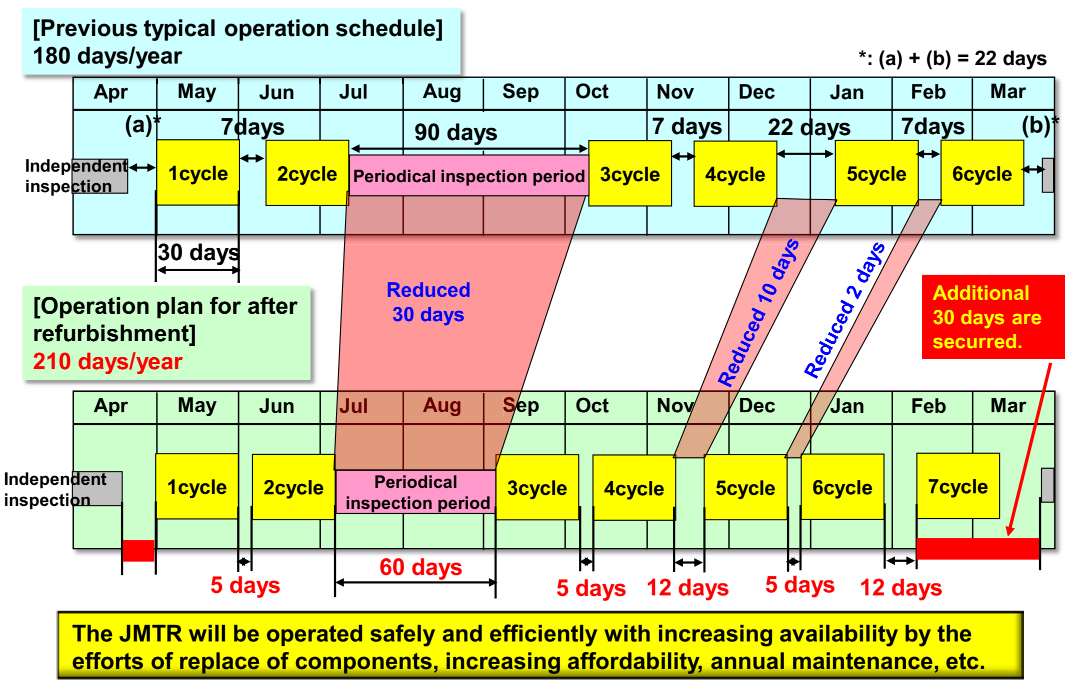

Fig.8 Preliminary operation plan for after refurbishment

Appendix Presentation materials at 2nd International Symposium on Material Test Reactor

The 2nd International Symposium on Material Test Reactors was held September 28 – October 1, 2009 at the Hilton Garden Inn hotel in Idaho Falls, Idaho, US. The objective of the meeting was to provide an opportunity for technical and operational information exchange among international test reactor facilities.

The presentation materials related in “Current Status of JMTR Refurbishment Project” are attached as an appendix.

Current Status of JMTR Refurbishment Project

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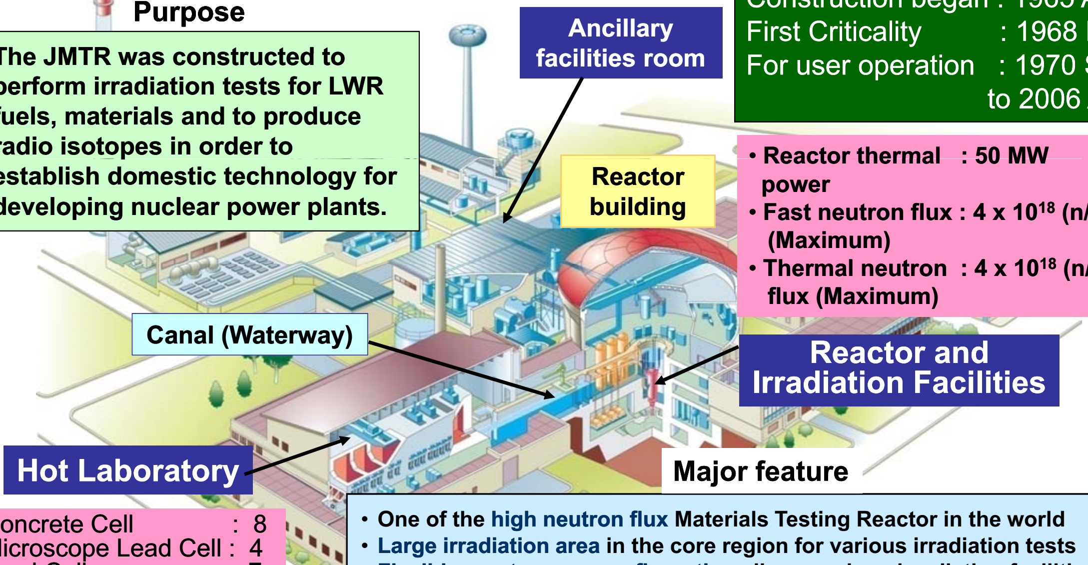
1. Outline of JMTR

Purpose

The JMTR was constructed to perform irradiation tests for LWR fuels, materials and to produce radio isotopes in order to establish domestic technology for developing nuclear power plants.

Construction began : 1965 Apr.
First Criticality : 1968 Mar.
For user operation : 1970 Sep. to 2006 Aug.

- **Reactor thermal power : 50 MW**
- **Fast neutron flux : 4 x 10^{18} (n/m²/s) (Maximum)**
- **Thermal neutron flux : 4 x 10^{18} (n/m²/s) (Maximum)**



Concrete Cell	: 8
Microscope Lead Cell	: 4
Lead Cell	: 7
Steel Cell	: 5
X-ray Microscopic analyzer	: 1

Major feature

- **One of the high neutron flux Materials Testing Reactor in the world**
- **Large irradiation area in the core region for various irradiation tests**
- **Flexible reactor core configuration allows various irradiation facilities installation to the reactor core**
- **The reactor building is connected to the hot laboratory by a canal for PIEs for fuels and materials.**

1

2. JMTR Refurbishment Project

JMTR operation was stopped after completion of the 165th cycle in August 2006, and repairing and replacement work for the re-operation from FY2011, was started in FY2007.

Aged-Investigation

- An investigation of aged components (aged-investigation) was performed in order to identify integrity of facilities and components to be used for re-operation of JMTR.

Replacement of rector related components

- Replacement is carried out within the range of licensing permission of the JMTR
- At present, boiler system, refrigerator for air conditioning system, power supply system, air supply and exhaust system for reactor building have been replaced.

Installation of new irradiation facilities

- Corresponding to the user's requests, new irradiation facilities, such as irradiation test facilities for materials/fuels, production facility for medical isotopes etc. will be planned to install.

2

3.(1) Components replacement policy

At the beginning of the project, integrity of the components was evaluated and concluded that the integrity of the components was maintained properly, based on the JMTR annual maintenance results obtained in February 2005. JMTR annual maintenance is still continued, therefore, the integrity of the components still maintained properly even for the components which are not replaced.

Selection of "Components to be continuously used" and "Components to be replaced"

JMTR utilization advisory committee suggested that "JMTR should be operated for more 20 years after refurbishment". Based on this suggestion, following items were considered for selection of "Components to be continuously used" and "Components to be replaced".

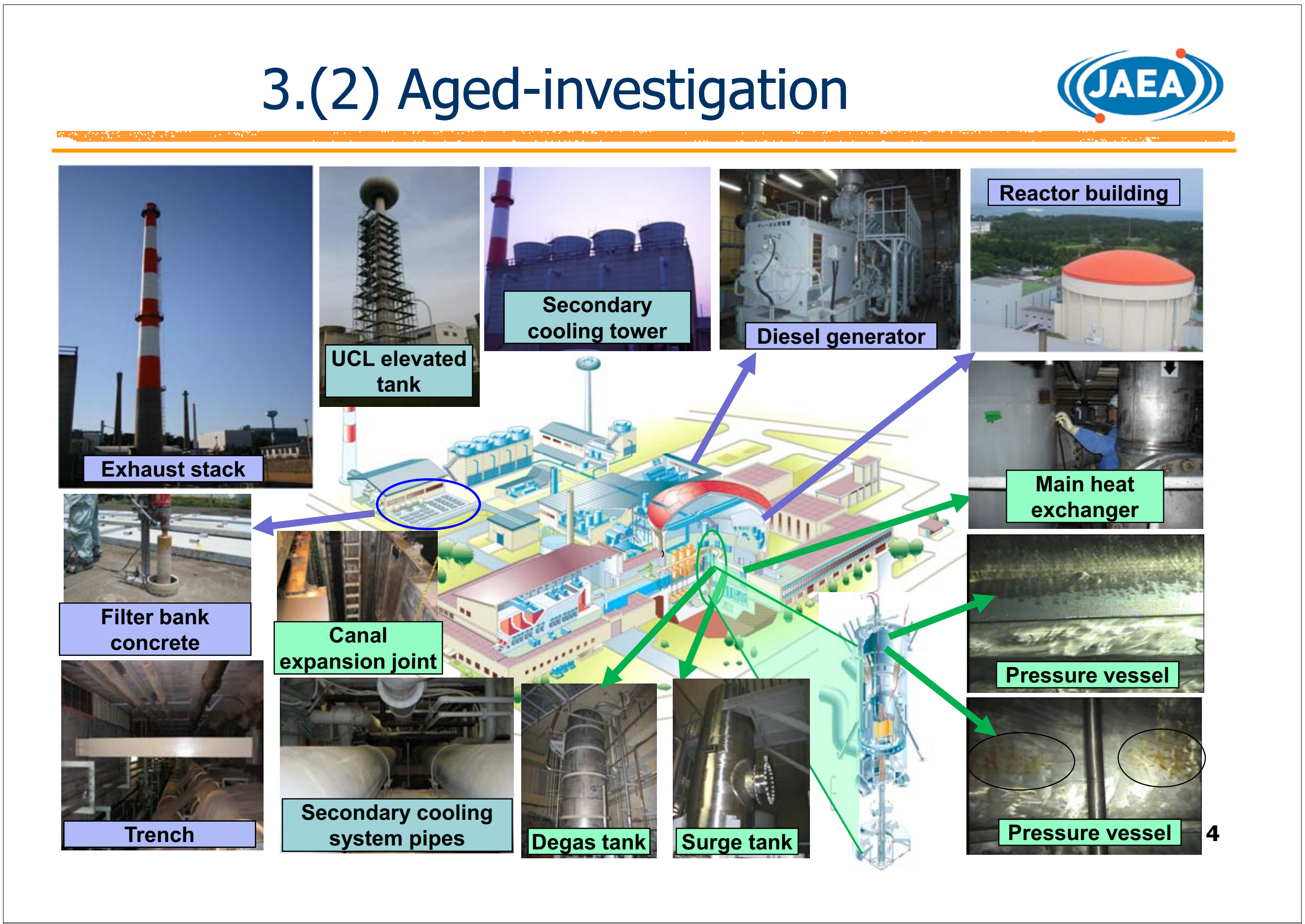
(1) Safety

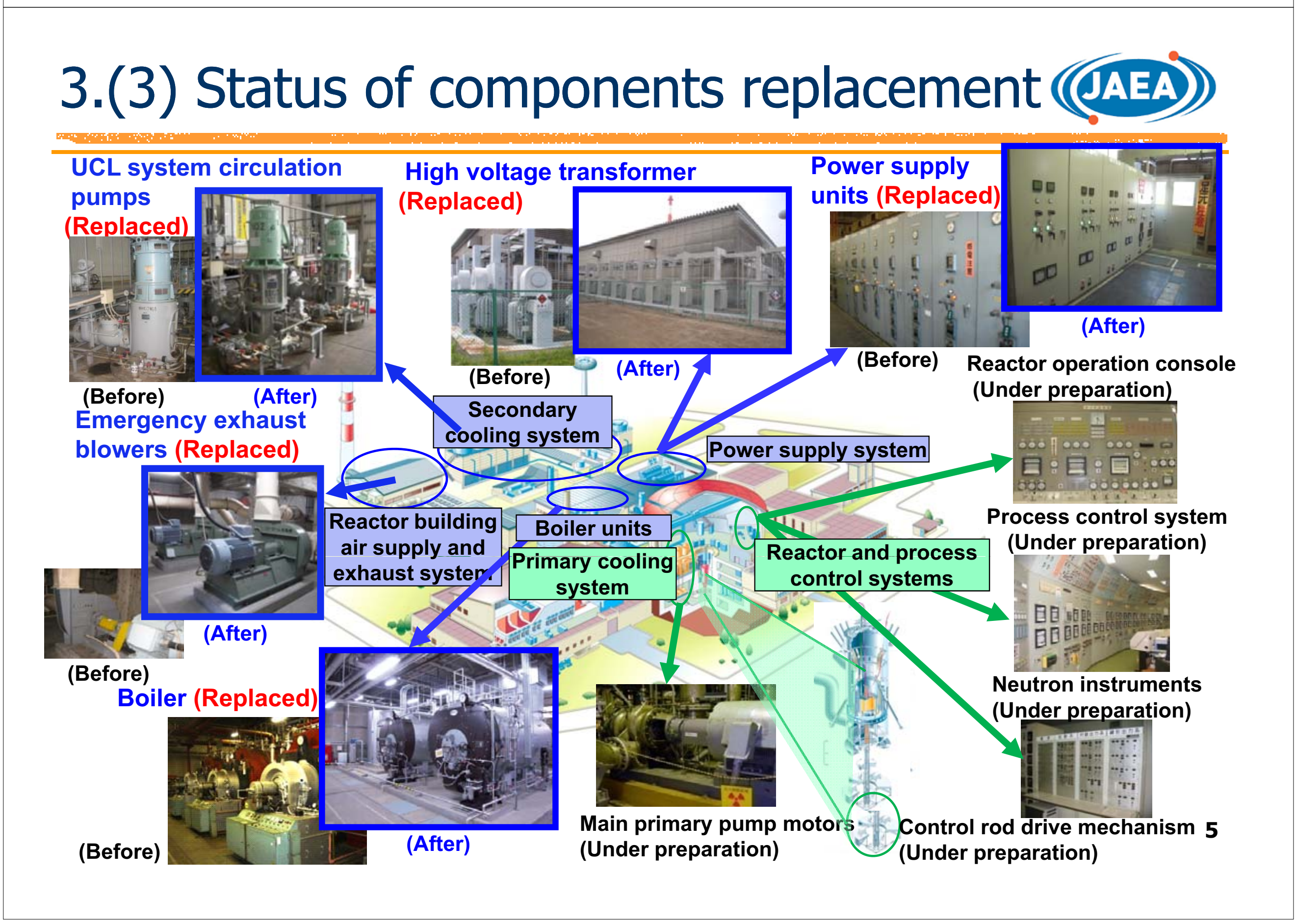
➔ Ageing of components, importance of safety feature, maintenance experience, etc.

(2) Improvement of availability

➔ Affordability of spare parts for maintenance

3


3.(2) Aged-investigation
JAEA
Exhaust stack
UCL elevated tank
Secondary cooling tower
Diesel generator
Reactor building
Main heat exchanger
Filter bank concrete
Canal expansion joint
Pressure vessel
Trench
Secondary cooling system pipes
Degas tank
Surge tank
Pressure vessel
4


3.(3) Status of components replacement
JAEA
UCL system circulation pumps (Replaced)
(Before)
(After)
High voltage transformer (Replaced)
(Before)
(After)
Power supply units (Replaced)
(Before)
(After)
Reactor operation console (Under preparation)
Emergency exhaust blowers (Replaced)
Secondary cooling system
Power supply system
Process control system (Under preparation)
Reactor building air supply and exhaust system
Boiler units
Primary cooling system
Reactor and process control systems
(After)
(Before)
Neutron instruments (Under preparation)
Boiler (Replaced)
(Before)
(After)
Main primary pump motors (Under preparation)
Control rod drive mechanism (Under preparation)
5

3.(4) Components replacement schedule

Work schedule for the refurbishment

No.	Item		2007	2008	2009	2010	2011 Re-operation	Status at the end of August 2009
1	JMTR reactor core internals	Beryllium frame Gamma shielding plate						Under fabrication
2	Process and reactor control system	Process, neutron instruments, Safety protection system etc.						Under designning
3	Rector cooling systems	Primary cooling system, Secondary cooling system						Under designning
4	Radioactive waste disposal facility	Reactor room air feed and exhaust system, Drain system						Replacemet of "Reactor room air supply and exhaust system" has been completed.
5	Power supply	High votage power supply unit, Transformer, Cables						Replacemet has been completed.
6	Boiler, refregirator for air conditionning	Boiler, refrigerator for air conditioning system						Replacemet has been completed.
7	Purified water production system	Degassed demineralizer Regular demineralizer						Replacemet has been completed.

- Replacement of the components is carried out on schedule based on the refurbishment work schedule.
- Components which are required to obtain "Approval of design and construction method"*, have been applied to the MEXT for approvals by March 2009.
  - * Primary cooling system, secondary cooling system, UCL system, Process and control system, Reactor room air supply and exhaust system, Beryllium frame, Gamma ray shielding plate

6

4. Installation of new irradiation facilities

New Irradiation Facilities

[New irradiation facilities will be installed by the external budget from the industrial users etc.]

Work schedule for the installation of new irradiation facilities

No.	Item	2006	2007	2008	2009*1	2010	2011 Re-operation	2012
1	Fuel Tests Irradiation facility of LWR fuels for ramp test	Conceptual design	Detail design	Designing, Fabrication, Installation				
2	Material Tests Irradiation facility for LWR core materials		Detail design	Designing, Fabrication, Installation		2 units		1 unit
3	New industrial use (1) ^{99}Mo production facility	Conceptual design, etc.				under planning		
4	New industrial use (2) Silicon semiconductor irradiation facility	Conceptual design, etc.				under consideration		
5	Fuel irradiation facility Irradiation facilities for LWR fuels	Conceptual design, etc.				under consideration		

*1 : In order to prepar necessary space for new material irradiation facilities installation, existing facilities are to be removed.

Post Irradiation Examination Facilities

Corresponding to new irradiation facilities installed in the JMTR, necessary facilities for PIE are being installed in the hot laboratory.

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5. Role of new JMTR

Irradiation needs	Purpose
Lifetime extension of LWRs	• Aging management of LWRs for long term utilization. • Development of LWR fuels and materials for aiming at the highest availability of LWRs.
Promotion of fundamental and basic research	• Materials and components development for fusion reactor, such as ITER and demonstration fusion reactors. • Development of fuels and materials for high temperature gas cooled reactors (HTGR) which improves thermal stability. • Fundamental research for nuclear energy, such as the determination irradiation damage mechanism.
New demand from industry	• Production of silicon semiconductor with large diameter for industrial use, such as hybrid car. • Domestic production of ^{99}Mo for medical diagnosis medicine ^{99m}Tc.
Human resource development for nuclear energy	• Education and training of nuclear scientists and engineers for the next generation nuclear energy development.

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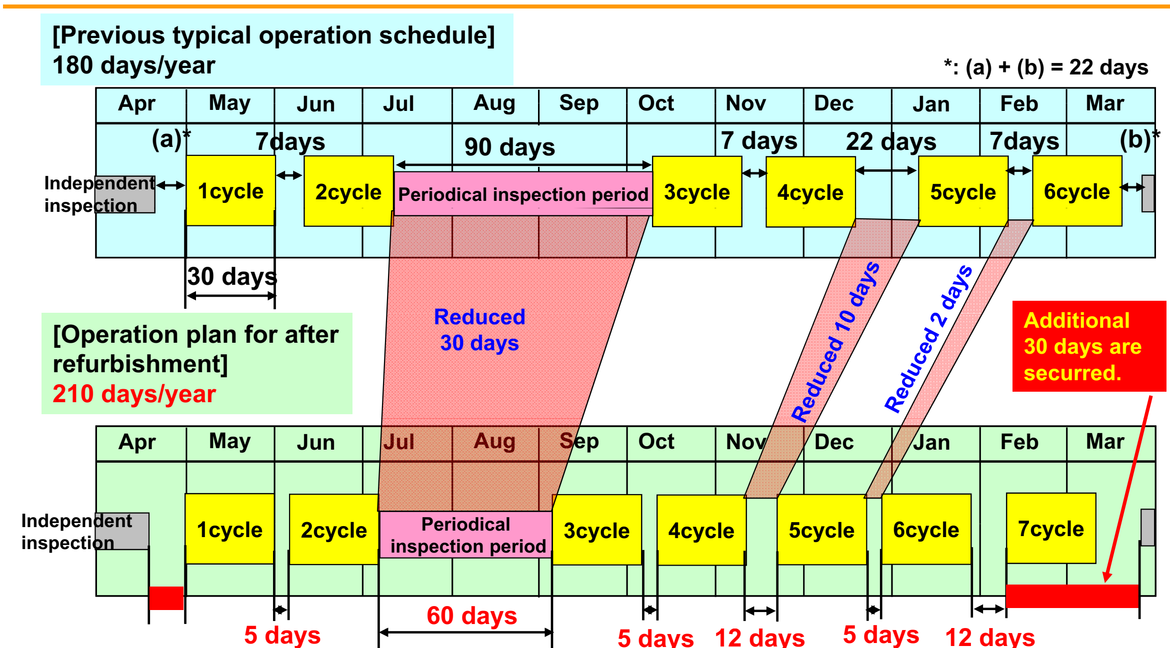
6. Consideration for re-operation schedule



The JMTR will be operated safely and efficiently with increasing availability by the efforts of replace of components, increasing affordability, annual maintenance, etc.

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8. Conclusion

- The JMTR refurbishment project is in progress according to its schedule aiming at re-operation of the reactor from FY2011.
- Replacement of components has been finished for the ancillary facilities, such as power supply, air conditioning system, UCL system, secondary cooling tower etc.
- Replacement of the reactor and process control system, beryllium reflector frame, motors of the main primary cooling pumps will be completed until FY2010.
- Annual operation schedule of the JMTR is under discussion in order to increase availability of the reactor.

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Appendix

Appendix 1. Replacement of reactor components

Selection of components to be replaced

Criteria for selecting components to be replaced

1.Safety point of view
- (1) Aging of components
- (2) Importance of safety feature
- (3) Mantenance experience

2. Improvement of availability
- (4) Affordability of spare parts

Facility, system	Components	Criteria				
		(1)	(2)	(3)	(4)	
Rector and process control system	Reactor control panel	O		O	O	Rep.
	Process control panel	O	O	O	O	Rep.
	Neutron instruments	O	O	O	O	Rep.
	CRDM	O	O	O	O	Rep.
Rector cooling system	Main pump motors	O	O	O	O	Rep.
	Main heat exchangers		O			Cont.
	UCL circulation pump	O	O		O	Rep.
	Secondary cooling system main pipes					Cont.
Radiological waste disposal system	Emergency blowers	O	O		O	Rep.
	Regular blowers					Cont.
Power supply system	Power supply units	O			O	Rep.
	High voltage transformer	O		O	O	Rep.
Other system	Water demineralizer	O			O	Rep.
	Boiler units	O			O	Rep.

Rep. : to be replaced
Cont. : to be continuously used

Appendix 2. Aged-investigation of components to be used for re-operation

Investigation items for aged-investigation

1. Maintenance situation for aging such as corrosion, thinning, fatigue, irradiation effect
2. Possibility of appropriate status supervision after re-operation
3. Validity of current maintenance method

Investigated major components

Tanks in the primary cooling system
Inner wall surface was visually observed from the view points of corrosion, color change etc.

Main heat exchangers
Thinning of the heat exchanger tubes was measured by the eddy current testing. Visual observation was also carried out by using an endoscope.

Secondary cooling system pipes
Visual observation was carried out for the inner surface of the tubes which was covered with lining, from the view points of corrosion and thinning.

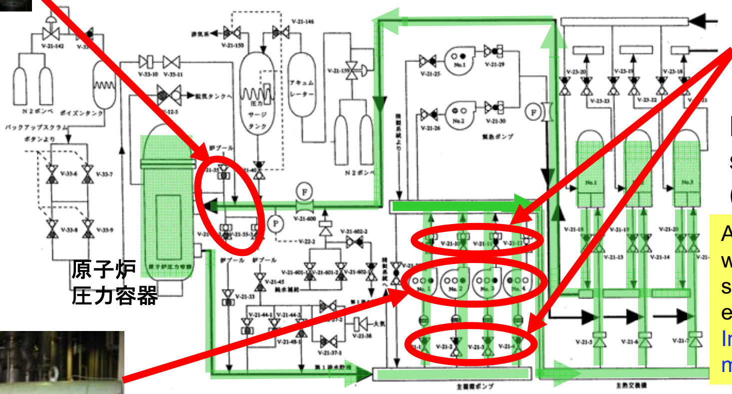
Secondary cooling tower
Main body and major parts were investigated visually from the view points of corrosion, rusting etc.

Power supply system
The insulation diagnosis examination of dynamo stator coil was carried out from the view point of reduction of insulation resistance.

Appendix 3. Replacement plan for the primary cooling system

Rector pool connecting valve (Electromagnetic coil)

Electromagnetic coil is to be replaced with a new one which has same specification of existing one. ➔ Improvement of maintainability



Main pump outlet side Valve (Actuator)

Actuator is to be replaced with a new one which has same specification of existing one. ➔ Improvement of maintainability

Main pumps (Motors)

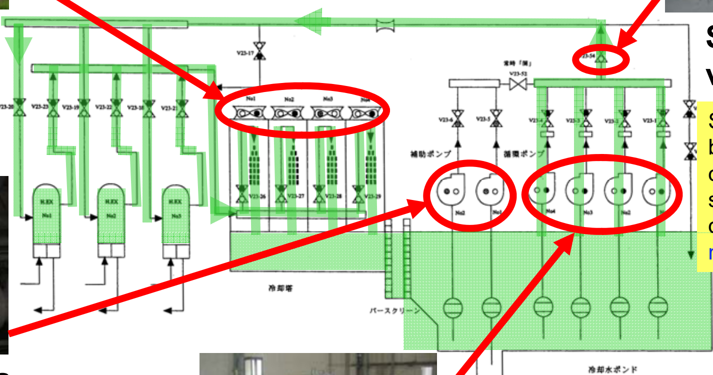
Pump motors are to be replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability

Special consideration is required for pump cast down characteristics.

Appendix 4. Replacement plan for the secondary cooling system

Cooling tower fan (Motor and reduction gear)

Motors and reduction gears of the cooling tower fans have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability



Squeezing valve

Squeezing valve is to be replaced with a new one which has same specification of existing one. ➔ Improvement of maintainability

Auxiliary pumps

Auxiliary pumps have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability and maintainability

Circulation pumps

Circulation pumps have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability and maintainability

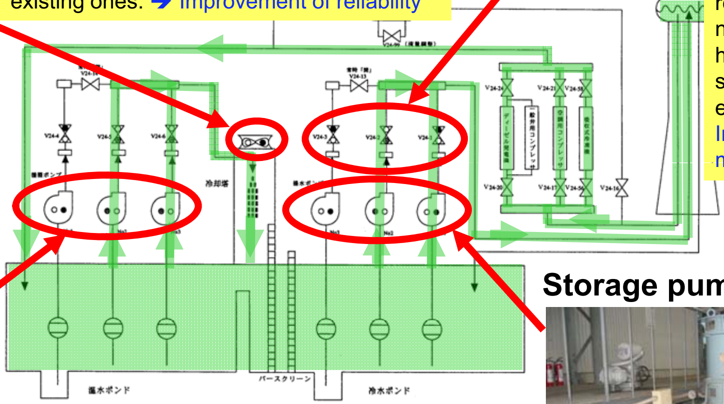
Appendix 5. Replacement plan for the UCL (Utility Cooling Loop) system

Cooling tower fan (Motor and reduction gear)

Motors and reduction gears of the cooling tower fans have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability

Storage pump outlet valves

Storage pump outlet valves have been replaced with new ones which have same specification of existing ones. ➔ Improvement of maintainability



Circulation pumps

Circulation pumps have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability and maintainability

Storage pumps

Storage pumps have been replaced with new ones which have same specification of existing ones. ➔ Improvement of reliability and maintainability

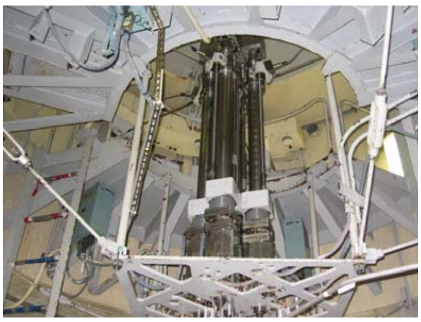
Appendix 6. Replacement plan for the reactor and process control systems

Reactor control panel

Neutron instruments

All of these systems are to be replaced. ➔ Improvement of maintainability, reliability

Process control system



Control rod drive mechanism (CRDM)

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	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方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
量濃度[(a)]，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	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)]	m^2/m^2
周波数	ヘルツ[(d)]	Hz		s^{-1}
力	ニュートン	N		$m\ kg\ s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N m	$m^2\ kg\ s^{-2}$
仕事率，工率，放射束	ワット	W	J/s	$m^2\ kg\ s^{-3}$
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	$m^2\ kg\ s^{-3}\ A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
電気抵抗	オーム	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
磁束	ウエーバ	Wb	Vs	$m^2\ kg\ s^{-2}\ A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
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	lm/m^2	$m^{-2}\ cd$
放射性核種の放射能[(f)]	ベクレル[(d)]	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	$m^2\ s^{-2}$
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	$m^2\ s^{-2}$
酸素活性	カタール	kat		$s^{-1}\ mol$

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

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	$1ha=1hm^2=10^4m^2$
リットル	L，l	$1L=1l=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3\ kg$

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	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

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	$1\ bar=0.1MPa=100kPa=10^5Pa$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$1\ Å=0.1nm=100pm=10^{-10}m$
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
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	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\ s\ cm^{-2}=0.1Pa\ s$
ストークス	St	$1\ St=1cm^2\ s^{-1}=10^{-4}m^2\ s^{-1}$
スチルブ	sb	$1\ sb=1cd\ cm^{-2}=10^4cd\ m^{-2}$
フォト	ph	$1\ ph=1cd\ sr\ cm^{-2}\ 10^4lx$
ガル	Gal	$1\ Gal=1cm\ s^{-2}=10^{-2}ms^{-2}$
マクスウェル	Mx	$1\ Mx=1G\ cm^2=10^{-8}Wb$
ガウス	G	$1\ G=1Mx\ cm^{-2}=10^{-4}T$
エルステッド[(c)]	Oe	$1\ Oe \triangleq (10^3/4\pi)A\ m^{-1}$

(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	$1\ Ci=3.7\times10^{10}Bq$
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	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1 γ=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	$1\ \mu=1\mu m=10^{-6}m$

（第8版，2006年改訂）