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Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities

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Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities

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(Received December 16, 2009)

The condition of facilities and components to be used for re-operation of the Japan Materials Testing Reactor (JMTR) from FY2011, was investigated before the refurbishment work. An investigation of aged components (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. 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. In this paper, the aged-investigation for the JMTR reactor building, heat exchangers and emergency generators is presented.

Keywords : JMTR, Testing Reactor, Refurbishment, Aged-Investigation, Concrete Structure, Cooling System

JMTR コンクリート構造物、冷却系設備及び ユーティリティ設備の健全性調査

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(2009 年 12 月 16 日　受理)

2011 年から再稼働する JMTR で継続して使用する機器や設備の健全性を、機器の更新に先立ち調査した。2007 年度当初に、JMTR 原子炉建家、排気筒、トレンチ、カナル、フィルターバンクのコンクリート構造物、1 次冷却系のタンク類、熱交換器、2 次冷却系配管、非常用発電機等の健全性を確認するための経年劣化調査を実施した。その結果に基づき、排気筒や UCL 高架水槽基礎部等のひび割れは補修し、2 次冷却系配管のライニングは更新した。その他の機器や原子炉建家は、長期保全計画に従った適切な保守により継続的に使用することが確認された。本稿では、JMTR 原子炉建家、熱交換器及び非常用発電機の健全性調査結果について示す。

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1. Introduction

The Japan Materials Testing Reactor (JMTR) located at Oarai Research &Development Center of Japan Atomic Energy Agency (JAEA) is a light water moderated and cooled, beryllium reflected tank- type reactor using LUE silicide plate-type fuels. Its thermal power is 50 MW. The construction of JMTR was began at 1965 in order to establish domestic technology for developing nuclear power plants and the first criticality was achieved in March 1968. Its operation for users was started from 1970 and was stopped August, 2006 for the refurbishment. During this period, the JMTR was operated 165 cycles. The refurbishment was started from the beginning of FY2007 and it will finish the end of FY2010. The renewed and upgraded JMTR will be re-started from FY2011.

The condition of facilities and components to be used for re-operation of the Japan Materials Testing Reactor (JMTR) from FY2011, was investigated before the refurbishment work. An investigation of aged components (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[1]. 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[1].

In this paper, the aged-investigation for the JMTR reactor building, heat exchangers and emergency generators is described.

2. JMTR Reactor Building

Concrete structure of the JMTR reactor building was constructed from 1965 to 1967. After 17 years of the construction i.e., in 1983, strength, carbonation etc. of the JMTR reactor building concrete were investigated and the soundness of the JMTR reactor building was confirmed.

At present, the JMTR reactor building has been used for more than 40 years after completion of the building and is used more than 20 years after the previous soundness investigation. The JMTR reactor building is to be used more than 20 years from now.

Therefore, concrete cracks, carbonation depth etc. were investigated in order to clarify the soundness of the JMTR reactor building concrete before refurbishment for re-operation of the JMTR from 2011.

2.1 Investigation Items

The investigation items and method of investigations for each investigation item are summarized as follows.

(1) Visual inspection

Crack, rust fluid, efflorescence, float and falling of masonry were visually observed. Crack scale was used for measuring cracks which have a width more than 0.3 mm.

Visual inspection and evaluation are carried out base on "Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures"[2). After the visual inspection, cracks of concrete were repaired and the outer wall was painted.

(2) Compression strength of concrete (Destructive tests)

Destructive tests (Core method using 10 cm drilled core samples) were carried out based on "Method of sampling and testing for compressive strength of drilled cores of concrete (JIS A 1107(2002))". Core boring was carried out by using a reinforced bar explorer in order to avoid cutting reinforced bar during drilling.

(3) Visual observation of reinforced bar corrosion

Visual observation of reinforced bar corrosion was carried out based on "Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures" [2)].

(4) Chloride ion content in concrete

Chloride ion content in concrete was measured based on "Methods of test for chloride ion content in hardened concrete (JIS A 1154)".

(5) Carbonation depth of concrete

Carbonation depth of concrete was measured based on "Method for measuring carbonation depth of concrete (JIS A 1152)".

2.2 Investigation Results

(1) Visual inspection

No damage was observed for the outer wall. On the other hand, small cracks (maximum gap size is 0.4 mm), float of paint and falling of masonry were observed for a part of the inner wall.

(2) Compression strength of concrete (Destructive tests)

As results of compression strength tests for 16 samples, average strength of 367.4 kgf/cm^2 and minimum strength of 311 kgf/cm^2 were obtained. There value meat the design basis strength of 210 kgf/cm^2.

(3) Visual observation of reinforced bar corrosion

The point rust was caused on the surface of 7 samples of 16 samples. The point rust caused on the samples were estimated as "Corrosion grade I", which do not affect concrete strength.

(4) Chloride ion content in concrete

Fig. 2.1 shows a chloride ion content measurement result as a function of depth. The chloride ion content in concrete was kept below 0.2 kg/m^3 which is the criterion value of JASS 5N[3)], at the position of the reinforced bar, even that of near the surface was greater than 0.2kg/m^3. Chloride ion content near the surface has been increased by accumulating the coming flying salinity.

(5) Carbonation depth of concrete

Fig. 2.2 shows carbonation depth of inner wall and Fig. 2.3 shows carbonation depth of outer wall. Carbonation of the inner wall didn't become significant because of protection effect by wall paint. On the other hand, carbonation of the outer wall became significant gradually, but the maximum carbonation depth of 23mm was small enough against measured protection thickness of reinforced concrete (57 mm). Therefore, the concrete structure of the JMTR reactor building will keep its integrity more than 60 years according to the prediction by Kishitani correlation as shown in Fig. 2.3.

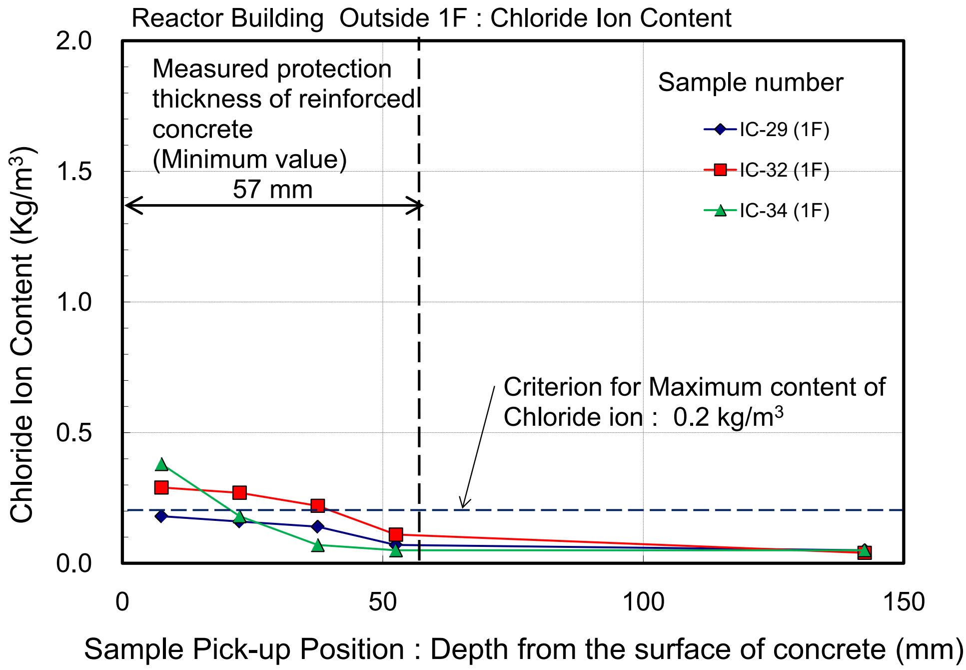

Fig. 2.1 Chloride ion content as a function of depth

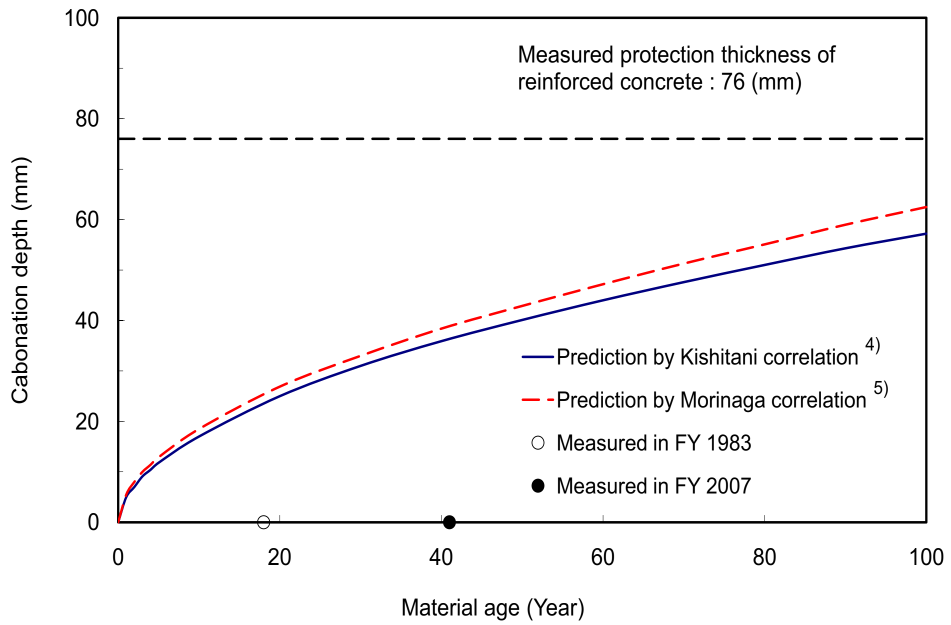

Fig. 2.2 Carbonation depth of inner wall

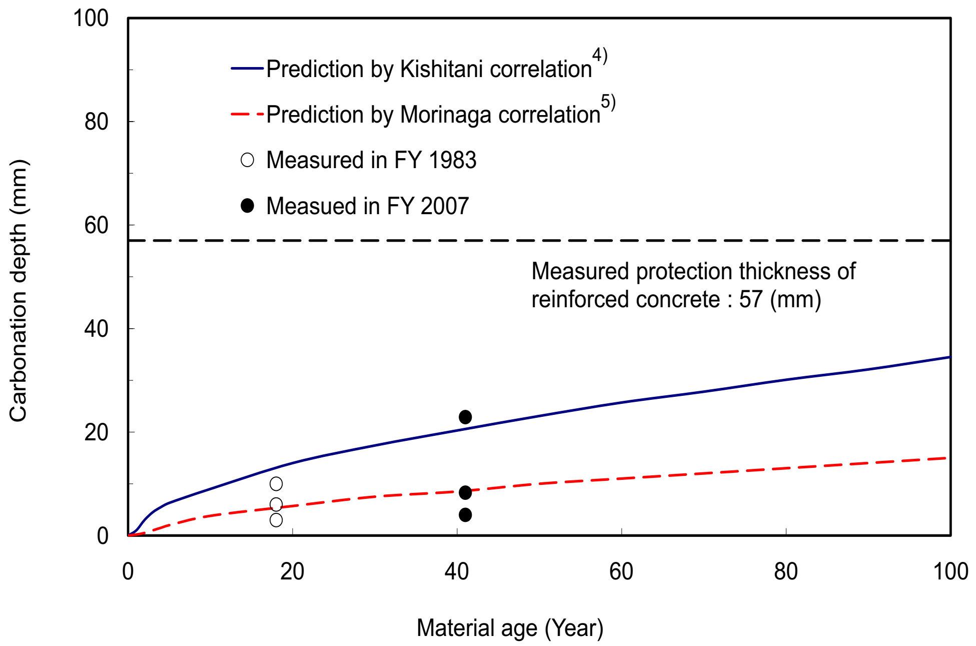

Fig. 2.3 Carbonation depth of outer wall

3. Main Heat Exchangers

Primary cooling system consists of a main circulation loop and a purification loop. The main circulation loop removes heat generated in the core (50MW) and transfers it to the secondary cooling system. The primary cooling system has three main heat exchangers. A detailed investigation was carried out for the main heat exchangers of the primary cooling system. Table 3.1 shows major specifications of the main heat exchangers.

Table 3.1 Major specifications of the main heat exchangers

Dimension	:	11,390 mm H x 1,650 mmϕ
Tube material	:	SUS27TB
		(SUS304,18%Cr, 8%Ni)
Thickness of tube	:	1.2 mm
Number of tubes	:	1,152

3.1 Investigation Items

The investigation items were listed as follows.

(1) Eddy current testing for heat exchanger tubes

Thinning of the heat exchanger tube was measured by the eddy current testing.

(2) Thickness measurement of the main body

Wall thickness of the heat exchanger main body was measured by an ultrasonic thickness gauge.

(3) Visual observation using an endoscope

According to the eddy current testing, visual observation was carried out with an endoscope for the heat exchanger tube that had been evaluated as the thinning of the thinning rate 20% or more. Surface condition and color change of the tube were checked.

3.2 Investigation Results

(1) Eddy current testing for heat exchanger tubes

10 tubes in Unit No.1, 6 tubes in Unit No.2 and 7 tubes in Unit No.3 were evaluated to have the thinning rate 20% or more. All of these thinning was observed at the inner surface of the tube wall.

(2) Thickness measurement of the main body

All measured thickness were greater than required minimum thickness of 6 mm.

(3) Visual observation using an endoscope

Surface condition and color change of the tubes which had been evaluated as the thinning of the thinning rate 20% or more, were checked. No evidence of abnormal condition was observed.

4. Diesel Generators

Electric power supply system of the JMTR consists of a commercial power supply system and an emergency power supply system. The emergency power supply system consists of diesel generators (2 units) and batteries. To confirm the integrity of the diesel generators, the insulation diagnosis examination of the dynamo stator coil (high voltage) was carried out.

Table 4.1 Major specifications of the diesel generators

Type	:	3-phase brushless alternator
Rated output	:	1,750 KVA
Voltage	:	6,600 V
Load current	:	153A
Frequency	:	50Hz

4.1 Investigation Items

The investigation items were listed as follows.

(1) Insulation resistance test

The insulation resistance was measured by adding direct voltage between ground the alternator.

(2) Dielectric dissipation factor test

The voltage and the phase of leakage current were measured by adding alternating voltage between ground the alternator.

(3) Alternating current test

The voltage and the linearity of the leakage current were measured by adding alternating voltage between ground and the alternator.

(4) Partial discharge test

The amount of the partial electrical discharge generated at the coil was measured by adding alternating voltage between ground and the alternator.

4.2 Investigation Results

(1) Insulation resistance test

There was no surface leakage of current was measured as shown in Figs. 4.1 and 4.2. There is no deterioration of insulation resistance caused by moisture uptake.

(2) Dielectric dissipation factor test

There was no evidence of the moisture uptake of the stator coil, the stain, changing in quality, flaking off. No void was generated.

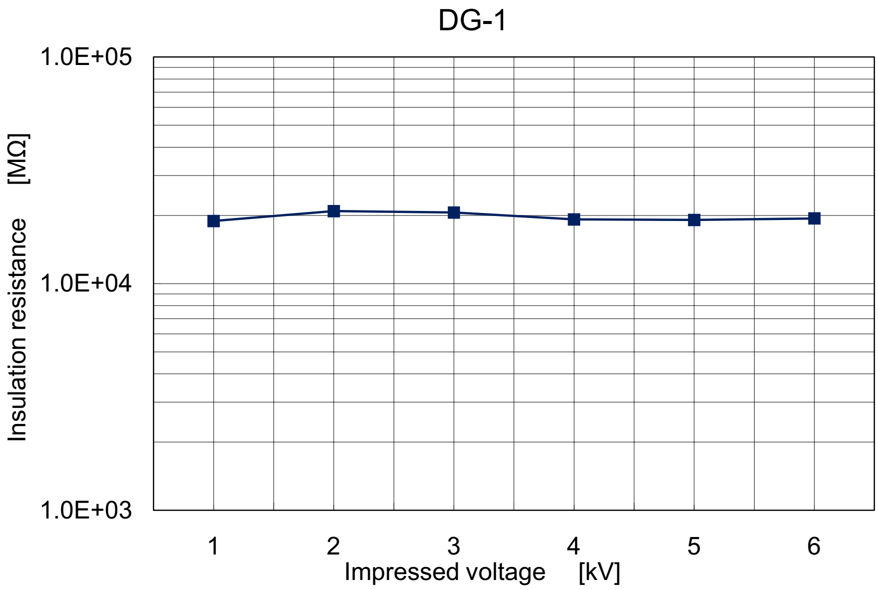

Fig. 4.1 Insulation resistance for DG-1

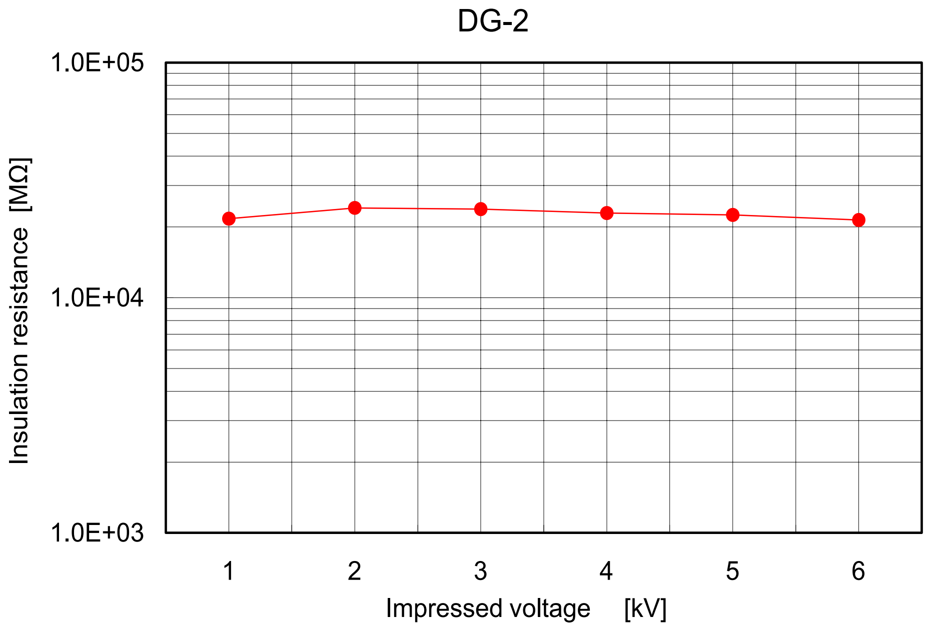

Fig. 4.2 Insulation resistance for DG-2

(3) Alternating current test

There was no void caused by flaking off and the breakdown voltage was measured to be 6.6KV or more.

(4) Partial discharge test

There was no harmful partial discharge, and was no evidence of existing void.

5. Conclusions

An aged-investigation was carried out for concrete structures, cooling systems and the utility facilities that will be continuously used in the future operation of the JMTR, at the beginning of a long-term shut-down period for the repairing or replacement work of the JMTR related facilities.

As a result, it was confirmed that it was possible to use most of those facilities or components continuously. A small aged effect was found in a part of the concrete structure of the JMTR reactor building.

Therefore, cracks of concrete were repaired and the outer wall was painted. Thus the long-term integrity of the concrete structures and the JMTR related facilities was established.

“Facilities and components “ which are identified as having aged effects by the aged-investigation, will be maintained by the periodical maintenance activities based on the "Long-term maintenance plan" in the future.

References

1) H.Ebisawa et al., “The Outline of Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities”, JAEA-Technology 2009-030(2009).

2) Architectural Institute of Japan, “Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures”, (1997).

3) Architectural Institute of Japan, “Japanese Architectural Standard Specification JASS 5N Reinforced Concrete Work at Nuclear Power Plants”, (1999).

4) Architectural Institute of Japan, “Recommendations for Design and Construction Practice of High Durable Concrete”,(1991).

5) S. Morinaga, “Research on life prediction of reinforced concrete building based on corrosion rating of reinforced concrete”, Thesis, University of Tokyo, (1986).

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 "Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities" are attached as an appendix.

Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities

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JMTR Refurbishment Project

- The JMTR was constructed in order to perform irradiation tests for LWR fuels, materials and to produce radio isotopes. The construction of the JMTR was began 1965.

↓

Operation was stopped August 2006.

(*The JMTR was used for about 40 years.*)

↓

Future utilization of the JMTR was investigated.

↓

Re-operation from FY2011 was decided.

(*The JMTR will be utilized more than 20 years.*)

↓

Refurbishment of the JMTR was started from FY2007.

1

Purpose of the Aged-Investigation

- An investigation of aged components (aged-investigation) was performed at the beginning of 2007 as a part of the **JMTR refurbishment project**.

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

↓

- Based on the aged-investigation results, future **maintenance program** for each facility or component is to be **reconsidered**. If necessary, **repairing** or **replacement** of facilities or components is to be carried out.

2

Aged-Investigation

- **Following concrete structures and components were investigated in order to identify their integrity.**
  1. **JMTR reactor building**, Exhaust stack : Concrete
  2. Trench, canal, filter banks : Concrete
  3. Pressure vessel
  4. Diaphragm of the reactor pool
  5. UCL (Utility Cooling Loop) elevated water tank
  6. **Main heat exchangers of the primary cooling system**
  7. Surge tank, Purify water tank, Degas tank
  8. Secondary cooling system pipes, Cooling tower
  9. Canal expansion joint
  10. **Diesel generators (Emergency generators)**
- **In this presentation, the aged-investigation results of the JMTR reactor building, main heat exchangers and emergency generators are presented.**

3

Schedule for Aged-Investigation

Work schedule for the aged-investigation

No.	Item	FY 2006			FY 2007											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	JMTR reactor building					■	■	■	■							
2	Exhaust stack, Trench, canal, filter banks					■	■	■	■							
3	Pressure vessel						■									
4	Diaphragm of the reactor pool															■
5	Elevated water tank of UCL					■										
6	Main heat exchangers				■	■	■	■	■							
7	Surge tank, Purify water tank, Degas tank			■	■	■										
8	Secondary cooling system pipes					■	■	■								
8'	Cooling tower			■												
9	Canal expansion joint					■	■									
10	Diesel generator (Emergency generator)	■	■													

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JMTR Reactor Building (1/3)

➢ Outline of the investigation

Concrete structure of the JMTR reactor building was constructed from 1965 to 1967. At present, the JMTR reactor building has been used for more than **40 years** after completion of the building construction. The JMTR reactor building is to be used **more than 20 years** from now. Therefore, following items were investigated in order to clarify the integrity of the JMTR reactor building concrete.

➢ Investigated items

1. Visual inspection of concrete
   Crack, Rust fluid, Efflorescence, Float and Falling of masonry
2. Compression strength of concrete
3. Visual observation of reinforced bar corrosion
4. Chloride ion content in concrete
5. Carbonation depth of concrete

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JMTR Reactor Building (2/3)

➢ **Investigation results**

1. Visual Inspection

   No damage was observed for the **outer wall**. On the other hand, small cracks (maximum gap size is 0.4 mm) , float of paint and falling of masonry were observed for a part of the **inner wall**.

2. Compression strength of concrete

   Compression strength of concrete was investigated for 16 samples. All the measured results of compression strength were greater than the design basis strength of 210 kgf/cm^2.

3. Visual observation of reinforced bar corrosion

   The point rust was caused on the surface of 7 samples of 16 samples. (Corrosion grade I) ➔ No problem

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JMTR Reactor Building (3/3)

➢ **Investigation results (Continue)**

4. Chloride ion content in concrete

   Chloride ion content in concrete was kept below 0.2 kg/m^3 which is the criterion value of JASS 5N*, at the position of the reinforced bar.

   * Japanese Architectural Standard Specification JASS 5N Reinforced Concrete Work at Nuclear Power Plants .

5. Carbonation depth of concrete

   Carbonation of **the inner wall** didn't become worth because of protection effect by wall paint. On the other hand, carbonation of the outer wall became worth gradually, but the maximum measured carbonation depth was small enough against measured protection thickness of reinforced concrete (57 mm).

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Main Heat Exchanger (1/2)

➢ Outline of the investigation

A detailed investigation was carried out for the main heat exchangers of the primary cooling system.

➢ Major specifications (3 Units)

Dimension : 11,390 mm H x 1,650 mmϕ
Tube material : SUS27TB (SUS304,18%Cr, 8%Ni)
Thickness of tube : 1.2 mm
Number of tubes : 1,152

➢ Investigated items

1. **Eddy current testing** for heat exchanger tubes
   Thinning of the heat exchanger tube was measured by the eddy current testing.
2. Thickness measurement of the main body
   Wall thickness of the heat exchanger main body was measured by an **ultrasonic thickness gauge**.
3. Visual observation using an endoscope
   According to the eddy current testing, visual observation was carried out with an **endoscope** for the heat exchanger tube that had been evaluated as the thinning of the thinning rate 20% or more. Surface condition and color change of the tube were checked.

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Main Heat Exchanger (2/2)

➢ Investigation results

1. **Eddy current testing** for heat exchanger tubes
   10 tubes in Unit No.1, 6 tubes in Unit No.2 and 7 tubes in Unit No.3 were evaluated to have the thinning rate 20% or more.
   Thinning was observed at the inner surface of the tube wall.
2. Thickness measurement of the main body
   All measured thickness were greater than required minimum thickness of 6 mm.
3. Visual observation using an endoscope
   Surface condition and color change of the tubes which had been evaluated as the thinning of the thinning rate 20% or more, were checked.
   No evidence of abnormal condition was observed. ➔ No problem

Eddy current testing for heat exchanger tubes

Thickness measurement by the ultrasonic thickness gauge

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Diesel Generator (1/2)

- **Outline of the investigation**

To confirm the integrity of the diesel generator, the insulation diagnosis examination of the dynamo stator coil (high voltage) was carried out.

- **Major specifications**

Type: 3-phase brushless alternator,
Rated output 1,750 KVA, Voltage : 6,600 V,
Load current : 153A, Frequency: 50Hz

Diesel Generator No.2 (DG-2)

- **Investigated items**

1. The insulation resistance test
   The insulation resistance was measured by adding direct voltage between ground the alternator.
2. The dissipation factor test
   The voltage and the phase of leakage current were measured by adding alternating voltage between ground the alternator.
3. The alternating current test
   The voltage and the linearity of the leakage current were measured by adding alternating voltage between ground and the alternator.
4. The partial discharge test
   The amount of the partial electrical discharge generated at the coil was measured by adding alternating voltage between ground and the alternator.

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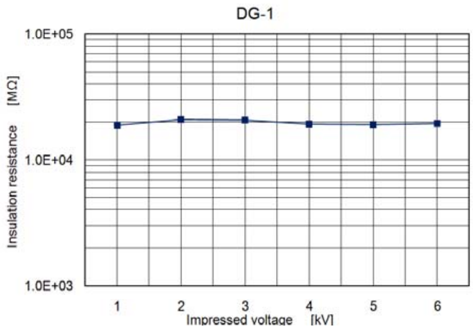
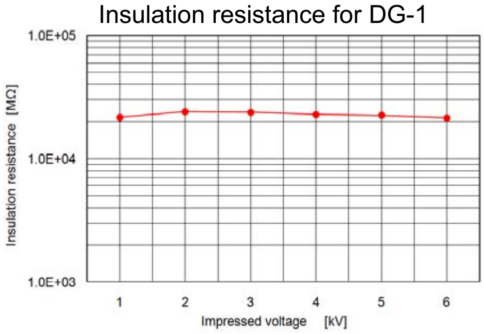
Diesel Generator (2/2)

- **Investigation results**

1. The insulation resistance test
   There was no surface leakage of current was measured(see figures). There is no deterioration of insulation resistance caused by moisture uptake.
2. The dissipation factor test
   There was no evidence of the moisture uptake of the stator coil, the stain, changing in quality, flaking off. No void was generated.
3. The alternating current test
   There was no void caused by flaking off and the breakdown voltage was measured to be 6.6KV or more.
4. The partial discharge test
   There was no harmful partial discharge, and was no evidence of existing void.



Insulation resistance for DG-1



Insulation resistance for DG-2

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Conclusion

- An aged-investigation was carried out for concrete structures, cooling systems and the utility facilities that will be continuously used in the future operation of the JMTR, at the beginning of a long-term shut-down period for the repairing or replacement work of the JMTR related facilities.
- As a result, it was confirmed that it was possible to use most of those facilities or components continuously. A small aged effect was found in a part of the equipment such as the secondary cooling system pipes linings, the secondary cooling towers, etc.
- Therefore, cracks of concrete and a part of the secondary cooling tower, etc., were repaired. The linings of the secondary cooling system pipes were replaced. Thus the long-term integrity of the concrete structures and the JMTR related facilities was established.
- "Facilities and components " which are identified as having aged effects by the aged-investigation, will be maintained by the periodical maintenance activities based on the "Long-term maintenance plan" in the future.

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Appendix

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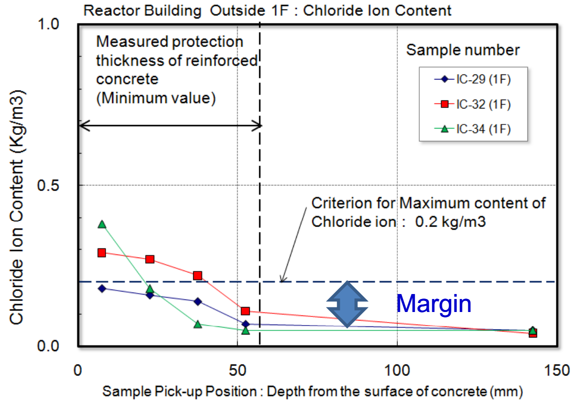
Appendix. 1 JMTR Reactor Building - Chloride ion content in concrete

➢ Investigation results

➢ Chloride ion content in concrete

Chloride ion content in concrete was kept below 0.2 kg/m^3 which is the criterion value of JASS 5N*, at the position of the reinforced bar, even that of near the surface was greater than 0.2kg/m^3. Chloride ion content near the surface has been increased by accumulating the coming flying salinity.



Chloride ion content distribution as a function of depth from the surface

* Japanese Architectural Standard Specification JASS 5N Reinforced Concrete Work at Nuclear Power Plants .

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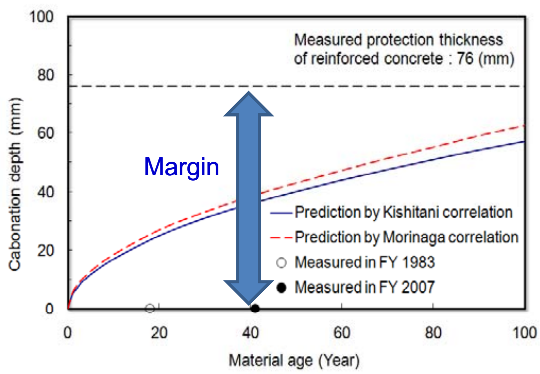
Appendix. 1 JMTR Reactor Building - Carbonation depth of concrete

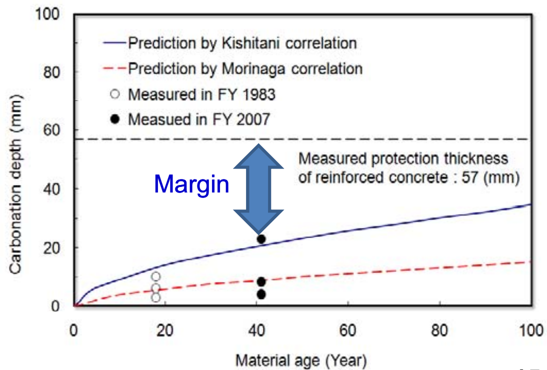
➢ Investigation results

➢ Carbonation depth of concrete

Carbonation of **the inner wall** didn't become worth because of protection effect by wall paint. On the other hand, carbonation of the outer wall became worth gradually, but the maximum carbonation depth of 23mm was small enough against measured protection thickness of reinforced concrete (57 mm).



Carbonation depth of the inner wall



Carbonation depth of the outer wall

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Appendix. 2 Reactor Vessel (1/2)

➢ **Outline of the investigation**

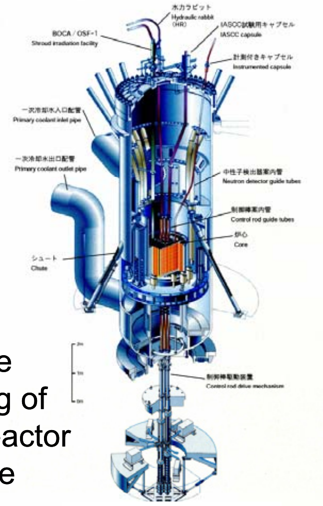
In order to use the reactor pressure vessel for long-term during the JMTR re-operation period, a visual investigation was carried out for the pressure vessel.

➢ **Major specifications**

Dimension : 95,000 mm H x 3,000 mmϕ
Material : SUS304L
Thickness : 34 mm

➢ **Investigated items**

- Visual observation using an underwater camera
  Presence of rust, harmful wound on surface of the pressure vessel inner wall, presence of loosening of the screws and bolts were investigated with a reactor pressure vessel external checking device with the underwater camera.



Pressure vessel

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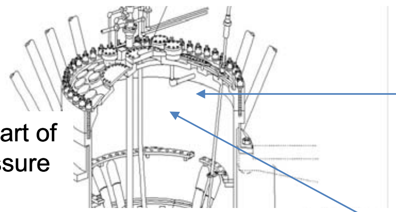
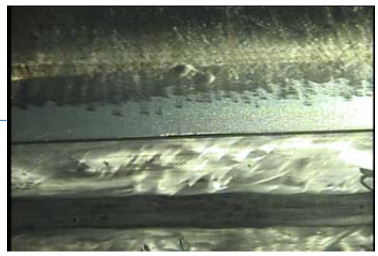
Appendix. 2 Reactor Vessel (2/2)

➢ **Investigation results**

- As a result of the visual observation, the harmful wound was not confirmed. Moreover, there was no loosening of the bolts and the screws. Negligible rust was observed near the upper part of the reactor pressure vessel.



Upper part of the Pressure vessel



- It is thought that the rust observed near the upper part of the reactor pressure vessel comes from the adhering iron etc. Because the upper part of the reactor pressure vessel will be exposed to the air during the reactor shut-down period in order to carry out necessary work for irradiation samples.

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Appendix. 3 Diaphragm of Reactor Pool

- **Outline of the investigation**
  A diaphragm seal of the reactor pool was visually investigated in order to confirm its integrity by the inspection equipment with underwater camera. The diaphragm was located in the reactor pool bottom of about 10 m in depth and it was impossible to observe from the water surface.
- **Investigated items**
  - Visual observation using an underwater camera
    Presence of rust, harmful wound on surface of the diaphragm seal were investigated by the inspection equipment with underwater camera.
- **Investigated results**
  As a result of the visual observation, the harmful wound and rusts was not confirmed.

Surface of the diaphragm seal

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Appendix. 4 Elevated water tank of UCL (1/2)

- **Outline of the investigation**
  To confirm the integrity of the UCL(Utility Cooling Loop) elevated tank, UCL elevated water tank base bolts, the surrounding plate, and the base plate were investigated.

- **Investigated items**
  1. Base bolts
     (1) Visual inspection
     Paints, surface condition after rust flakes off
     (2) Size measurement
     Confirmation of corrosion thinning ratio
  2. Surrounding plate, Base plate
     (1) Visual inspection
     Paints, surface condition after rust flakes off
     (2) Magnetic particle testing
     Confirmation of welding joint
     (3) Size measurement
     Confirmation of corrosion thinning ratio

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Appendix. 4 Elevated water tank of UCL (2/2)

➢Investigated results

1. Base bolts
   (1) Visual inspection
   There were flaking off and floating of the paints.
   (2) Size measurement
   There was one bolt that had the maximum thinning rate of 7.34mm (44.45mm→37.11mm) as a result of measuring 4 thinning bolts in 48 all bolts.

2. Surrounding plate, Base plate
   (1) Visual inspection
   There were flaking off and floating of the paints.
   (2) Magnetic particle testing
   There is no evidence of crack and false indication in the welding region.
   (3) Size measurement
   There was no remarkable thinning in other parts though there was thinning of 4.1mm (22.0mm→17.9mm) on a part of the base plate in the spot at maximum.

Removing paints and rusts from the investigation part

After repairing and paints

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Appendix. 5 Surge tank, Purify water tank, Degas tank (1/2)

➢ Outline of the investigation

In the primary cooling system, there are a surge tank, a purify water tank and a degas tank. All these tanks will be used for during reoperation period. Therefore, an investigation was carried out for these tanks in order to identify their integrity.

➢ Investigated items

1. Visual inspection (Including inside structures)
2. Penetrant testing (PT) for welding region

Surge tank
3950 mm H x 1028 mm ϕ

Purify water tank
3160 mm H x 1486 mm ϕ

Degas tank
6200 mm H x 1566 mm ϕ

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Appendix. 5 Surge tank, Purify water tank, Degas tank (2/2)

➢ Investigation results

1. Visual inspection (Including inside structures)
   There was no abnormal condition in the inside of all three tanks of the surge tank, the purify water tank and the degas tank.

2. Penetrant testing (PT) for welding region
   No false indication was found in the surge tank.

   False indications were observed in the welding lines of the purified water tank and the degas tank. But after grinding, no false indication was found in the re-inspection. Therefore, it was confirmed that they were not progressive defect. ➔ No problem

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Appendix. 6 Secondary Cooling system - Main pipes (1/2)

➢ Outline of the investigation

The main pipes of the secondary cooling system are made of the ordinary steel, and inside of the pipes are covered by resin linings for protecting against rusts. Therefore, the lining check in the pipes was carried out in order to check the lining condition.

Secondary cooling system pipes 450A

➢ Investigated items

□ Visual observation

(1) Observation objects
Linings of the secondary cooling pipes of 450A and 750A.

(2) Observation method
As for 750A pipes, the investigator entered in pipe and the lining was visually inspected by watching . As for 450A pipes, the fiberscope was used for the watching device.

Secondary cooling system pipes 750A

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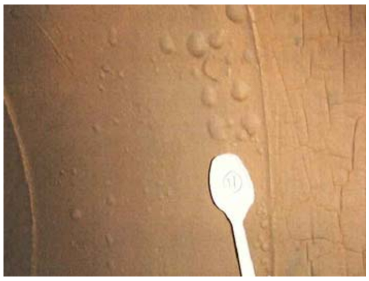
Appendix. 6 Secondary Cooling system - Main pipes (2/2)

➢ Investigation results

- ◻ As a result of the visual observation, the lining of the secondary cooling system pipes had swelling and cracks overall and the aged deterioration of the lining progressed.
  - ➔ Repair of the lining has been carried out.
- ◻ There was no corrosion or thinning of the pipes.


Remarkable clacks


Swelling of lining

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Appendix. 7 Secondary Cooling system - Cooling Tower (1/2)

➢ Outline of the investigation

Wooden structures of the cooling tower were investigated among the second cooling systems, and the integrity of the cooling tower was confirmed.

➢ Investigated items

◻ Visual observation

(1) Observation objects
- Tower exterior for 4 cells in the cooling tower (upper part, middle part, and lower part)

(2) Observation method
- Presence of damage, transformation, adhesion thing, and iron corrosion were observed visually.
- Presence of loosening of bolts, wood inside cracks were checked by wooden hammer.


JMTR secondary cooling system cooling tower (4 cells)

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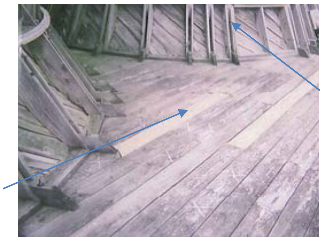
Appendix. 7 Secondary Cooling system - Cooling Tower (2/2)

➢ Investigation results

- As a result of the visual observation, partial internal decay and cracks caused by dryness were confirmed at the top deck, fan stacks, and deck joists, etc. It was confirmed that there were no remarkable corrosion or rust of bolts.



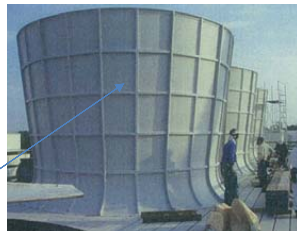
Fun stack

Top deck

Materials for the top deck, fan stacks, and deck joists were changed from wooden to FRP (reinforced plastic), and the repairing of these were carried out.

Deck joist

Fan stack made of FRP



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Appendix. 8 Canal Expansion Joint (1/2)

➢ Outline of the investigation

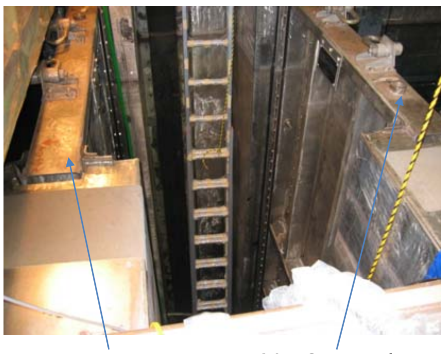
The following checks and examinations were carried out in order to confirm integrity of the canal expansion joint which was located between No.2 and No.3 canal watertight gates.

➢ Investigated items

1. Visual observation
   The canal expansion joint was observed visually from out side.

2. Hardness examination
   The sample was extracted from a part of the canal expansion joint for the deterioration degree investigation of neoprene rubber, and the surface observation and the hardness examination were carried out.

Canal expansion joint



No.3 Canal watertight gate

No.2 canal watertight gate

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Appendix. 8 Canal Expansion Joint (2/2)

➢ Investigated results

1. Visual observation

   Near the part of the waterline and underwater part, small swelling and cracks were observed in both east and west sides of the canal expansion joint. On the other hand, no abnormal condition was observed above the water surface part.

2. Hardness examination

   As a result of hardness examination, a hardness of the specimen was measured to be 77.6 (HAD). A normal hard rubber has a hardness of 60 to 90, therefore, it was confirmed that the measured value was in the range of normal condition.

The hardness of the canal expansion joint will be checked periodically and based on the deterioration situation of the hard rubber, a replacement of the canal expansion joint will be considered.

Canal expansion joint

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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	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	$1\ \mu=1\mu m=10^{-6}m$

（第8版，2006年改訂）