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The refurbishment of JMTR is scheduled from the beginning of FY 2007 to the end of FY 2010. An integrity investigation for concrete structures of the JMTR buildings was carried out in early phase of the refurbishment. This paper describes investigated results and repair work of the vent stack, trenches, canal building and the filter bank. Investigated items were the concrete surface deterioration, rebound number (nondestructive estimation of strength), comprehensive strength using drilled concrete core test piece, carbonation depth, reinforced bar corrosion and chloride ion content. The integrity of these concrete structures was confirmed by these investigations.　Based on the investigation results, repair works such as re-painting were carried out from the viewpoint of preventive maintenance for the vent stack, trenches and canal building.

The data obtained from this investigation will be used to make a periodical maintenance program in future. In order to use the JMTR concrete structure continuously for long-term, it is important to maintain the integrity of a concrete structure by the periodical maintenance and repairing work including the building outer-wall surface painting.

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

JMTR 原子炉施設建家の健全性調査

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JMTR の改修は 2007 年度初頭から 2010 年度にかけて実施する予定である。JMTR 原子炉建家等のコンクリート構造物の健全性調査を改修期間の初期に実施した。本報告は、排気筒、トレンチ、カナル室、フィルターバンクの調査結果及び補修に関するものである。調査項目は、コンクリートの表面劣化、反発度（非破壊強度推定）、コア供試体による圧縮強度、中性化深さ、鉄筋腐食、塩分含有量とした。調査の結果、これらコンクリート構造物の健全性が十分に維持されていることが明らかとなった。予防保全の観点から、調査結果に基づき、排気筒、トレンチ、カナル室について、再塗装等の補修を実施した。

ここで得られた調査結果は、今後の定期的な点検・補修計画において考慮する。JMTR のコンクリート構造物の今後の長期的な継続使用にあたっては、建家外表面の塗装を含む定期的な点検及び補修作業を定期的に実施することが重要である。

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1. Introduction

The JMTR is a light water moderated and cooled, beryllium reflected tank- type reactor using LEU silicide plate-type fuels. It was constructed to perform irradiation tests of fuels materials to establish domestic technology for developing nuclear power plants and also produce radioisotopes. Its specification is summarized in Table 1. First criticality was achieved in March 1968. The refurbishment of JMTR is scheduled from the beginning of FY 2007 to the end of FY 2010. An integrity investigation for concrete structures of the JMTR buildings was carried out in early phase of the refurbishment[1), 2)]. This paper describes the investigated results and repair work of the vent stack, trenches, canal building and filter bank. These concrete structures have been used for more than 40 years after completion of the construction, and are expected to be used more than 20 year from restart of the JMTR. Figure 1 shows layout of these constructions.

2. Investigation Items

The investigation items and method are summarized as follows.

(1) Concrete surface deterioration

Crack, rust fluid, efflorescence, float and falling of masonry are visually observed. Visual inspection and evaluation are carried out base on “Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures”[3)].

(2) Rebound number (nondestructive estimation of strength)

Rebound number is measured with measurement range of 15~70N/mm^2 based on “Method of measurement for rebound number on surface of concrete (JIS A 1155 (2003))”.

(3) Comprehensive strength using drilled concrete core test piece

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

(4) Carbonation depth

Carbonation depth of concrete is measured based on “Method for measuring carbonation depth of concrete (JIS A 1152)”.

(5) Reinforced bar corrosion

Core boring is carried out to expose a reinforced bar by using a reinforced bar explorer. Corrosion condition is observed after removing concrete materials around a reinforced bar. The observation is carried out near the core boring position for the destructive tests. The reinforced bar corrosion is evaluated based on “Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures” [3)].

(6) Chloride ion content

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

Table 2 shows the investigated items and the number of samples.

The vent stack is a self-standing concrete structure with 80m height. An inner-diameter is 2.5 m with thickness of 150 mm at the top part, and 5.2 m with thickness of 500 mm at the lowest part. The investigated positions are shown in Figure 2.

The trenches are concrete structures under the ground, in which there are pipes and cables to carry such as cooling water, compressed air and so on from a machinery house to the reactor facilities. The JMTR has three trenches, A trench, B trench and C trench. The investigated positions of each trench are shown in Figure 3.

The canal is a waterway to transport spent fuels and irradiated capsules, which connects a hot laboratory and a reactor building. The canal building is a concrete structure includes the canal. The investigated positions of the canal building are shown in Figure 4.

The air in the reactor building is purified at the filter bank, in which various types of filters are installed before discharge from the vent stack. The investigated positions of the filter bank are shown in Figure 5.

3. Investigation Results

(1) Concrete surface deterioration

As the result of observation of the concrete surface deterioration, many small cracks (maximum gap size was 0.3mm), float of concrete and exposure of reinforced bar were observed for the vent stack. The exposures of reinforced bar were observed also for the trenches. Though float of paint was observed for an outer wall of the canal building, concrete deterioration was not observed. Falling of paint and cracks were observed for an inner wall. The cracks were small, and the maximum gap size was about 0.25 mm. The cracks of the filter bank were small (less than 0.1mm).

(2) Rebound number (nondestructive estimation of strength)

Rebound number is used to estimate a comprehensive strength. The estimated comprehensive strength was obtained by using an estimation equation[4)] and a material age factor. The average of estimated comprehensive strength of the stack is 29.5±2.0 N/mm^2, and the design basis strength of the stack is 17.7 N/mm^2. The average of estimated comprehensive strength of the trench is 30.3±3.5 N/mm^2, and the design basis strength of the trench is 20.6 N/mm^2. The average of estimated comprehensive strength of the canal is 32.9±2.6 N/mm^2, and the design basis strength of the stack is 20.6 N/mm^2. All the estimated results of comprehensive strength based on the rebound number were greater than the design basis strength.

(3) Comprehensive strength using drilled concrete core test piece

The comprehensive strength test using drilled concrete core test piece was carried out for the stack. All the measured results of comprehensive strength were greater than the design basis strength of 17.7 N/mm^2.

(4) Carbonation depth

Figure 6 shows carbonation depth of the vent stack (first step) and Figure 7 shows carbonation depth of the vent stack (second step), The carbonation of the vent stack increased worth gradually, however measured carbonation depth was small enough to measured protection thickness of reinforced concrete 53 mm and 71 mm in each height. The estimated results of carbonation according to the prediction by Kishitani[5)] or Morinaga[6)] were small than those for planned JMTR operation period as shown in Figure 6 and 7. Carbonation of the filter bank floor face hardly change because of protection effect by cement plastering with 60～65 mm thick.

(5) Reinforced bar corrosion

The observed corrosion of reinforced bar corrosion was grade 1, which do not affect concrete strength.

(6) Chloride ion content

The measured ion content decreased with depth as shown in Figure 8. Concrete materials chloride ion content in depth around 150 mm was mere 0.04～0.05 kg/m^3. It means that the used concrete material did not include salinity significantly. The chloride ion content was estimated to keep below 0.2 kg/m^3, which is the criterion by JASS 5N[7)] to inside the minimum covered depth. Chloride ion content near the surface was increased by accumulating the coming flying salinity.

4. Repair Works

The following repair works for the vent stack were carried out as a preventive maintenance in 2008.

(1) Repair work of concrete (cleanup of surface, sealing of cracks, repair of paint float)

(2) Repair work for ancillary facilities (renewal of landing floor, renewal of conductor rod fixing bracket)

(3) Painter's work for concrete (basecoat, middle coat, final coat)

(4)Painter's work for metallic part (removal of paint film, basecoat (corrosion-resistant primer), final coat (weather-resistant coating))

The repair works for trenches were as follows.

(1) Leakage control work

(2) Repair work for ancillary facilities (Repair of expansion joint, joint-sealing)

(3) Painter's work for concrete

(4) Painter's work for reinforced bar (basecoat (corrosion-resistant primer), middle coat, final coat (resin paint))

The canal building was also repainted in 2009, since many small crack (maximum gap size is 0.25 mm) were observed.

(1) Repair work of concrete outer wall (High-pressure washing, sealing of cracks, repair of paint float, basecoat (filler paint), final coat (acrylic rubber paint))

(2) Repair work of concrete inner wall (cleanup of surface, sealing of cracks, basecoat (filler paint), final coat (polyurethane paint))

(3) Painter's work for metallic part (hand rail painting (polyurethane paint), floor painting (epoxy resin paint))

5. Conclusions

The result of inspections, significant degradation was not observed on the vent stack, trenches, canal buildings and filter bank. The integrity of all the concrete structures was confirmed. However, the repair works for the vent stack and the canal building were carried out as a preventive maintenance in 2008, because many small cracks float of concrete and exposure of reinforced bar were observed. The repair works for the trenches were carried out in 2008, because the exposures of reinforced bar were observed. The repair works for the canal building were carried out in 2009, because the float of paint was observed for an outer wall and falling of paint and cracks were observed for an inner wall. The cracks of the filter bank were small and carbonation of the filter bank floor face hardly change. The data obtained from this investigation will be used to make a plan for the future periodical maintenance. In order to use the JMTR concrete structure continuously for long-term, it is important to maintain the integrity of a concrete structure by the periodical maintenance and the repairing work including the building outer-wall surface painting.

References

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2) H.Ebisawa et al., "Investigation on Integrity of JMTR Concrete Structures, Cooling System and Utility Facilities", JAEA-Review 2009-055(2010).

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

4) Architectural Institute of Japan, "Nondestructive testing method manual for concrete strength estimation" (1983)

5) Architectural Institute of Japan, "Recommendations for Design and Construction Practice of High Durable Concrete", (1991).

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

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

Table 1 Major Specifications of JMTR

Reactor Thermal Power	50	(MW)
Fast Neutron Flux (Max.)	4×10^{18}	(n/m^2s)
Thermal Neutron Flux (Max.)	4×10^{18}	(n/m^2s)
Primary Coolant Flow Rate	6000	(m^3/h)
Coolant Temperature (In/Out)	49 / 56	(℃)
Active Core Length	750	(mm)
Fuel	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	(℃)

* Capsule with in-situ measurement

Table 2 Investigation items and the number of samples

Structures	Position	Investigation Items					
		Visual inspection	Rebound number	Compressive strength	Carbonation depth	Reinforced bar corrosion	Chloride ion content
Vent stack	First step	6	6	3	3	3	3
	Second step	4	4	3	3	3	-
	Landing 1	1	1	-	-	-	-
	Landing 2	1	1	-	-	-	-
	Landing 3	4	4	-	-	-	-
	Landing 4	1	1	-	-	-	-
	Landing 5	4	4	-	-	-	-
Trench	Trench A	6	6	-	-	-	-
	Trench B	6	6	-	-	-	-
	Trench C	6	6	-	-	-	-
Canal	Outer - wall	3	3	-	-	-	-
	Inner - wall	3	3	-	-	-	-
Filter bank	Outer - wall	3	-	-	3	-	-
Total		48	45	6	9	6	3

Table 3 Secular variation of Reinforced bar corrosion (Vent stack)

Structures	Investigation position	Investigation position number	Outer or Inner	Type of reinforcing bars	Depth of concrete cover (mm)	Reinforced bar corrosion Grade (Jun 2007)
Vent stack	First step	S-1	Outer	Reinforcing bar	71	I
			Outer	Reinforcing bar	71	I
			Outer	distribution bar	59	I
		S-2	Outer	Reinforcing bar	73	I
		S-4	Outer	Reinforcing bar	79	I
			Outer	Reinforcing bar	80	I
	Second step	S-7	Outer	Reinforcing bar	53	I
		S-8	Outer	Reinforcing bar	59	I
		S-10	Outer	Reinforcing bar	86	I

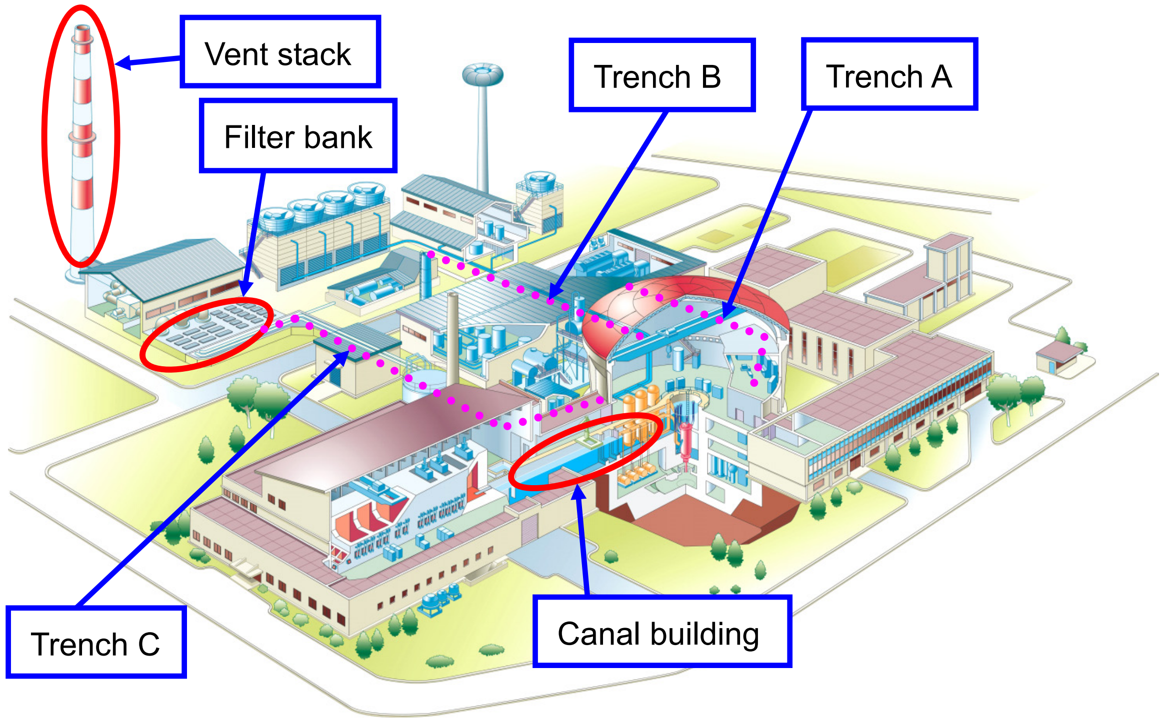
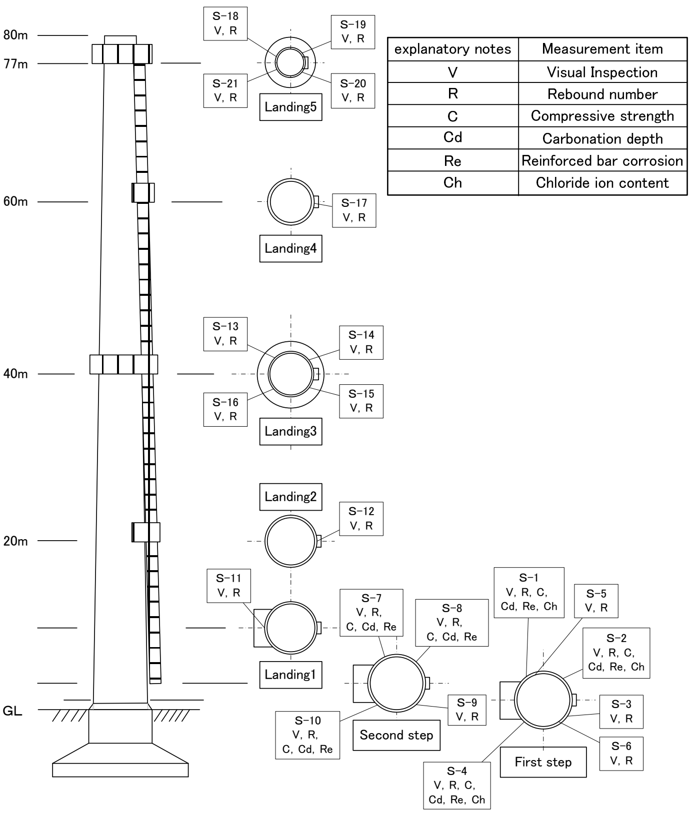


Figure 1 Arrangement of buildings (Vent stack, Trenches, Canal, Filter bank)



explanatory notes	Measurement item
V	Visual Inspection
R	Rebound number
C	Compressive strength
Cd	Carbonation depth
Re	Reinforced bar corrosion
Ch	Chloride ion content

Figure 2 Investigated position of Vent stack.

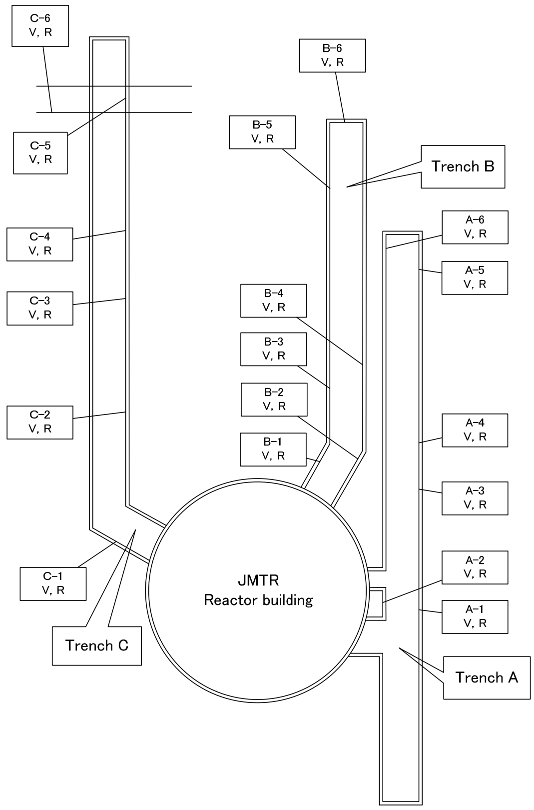
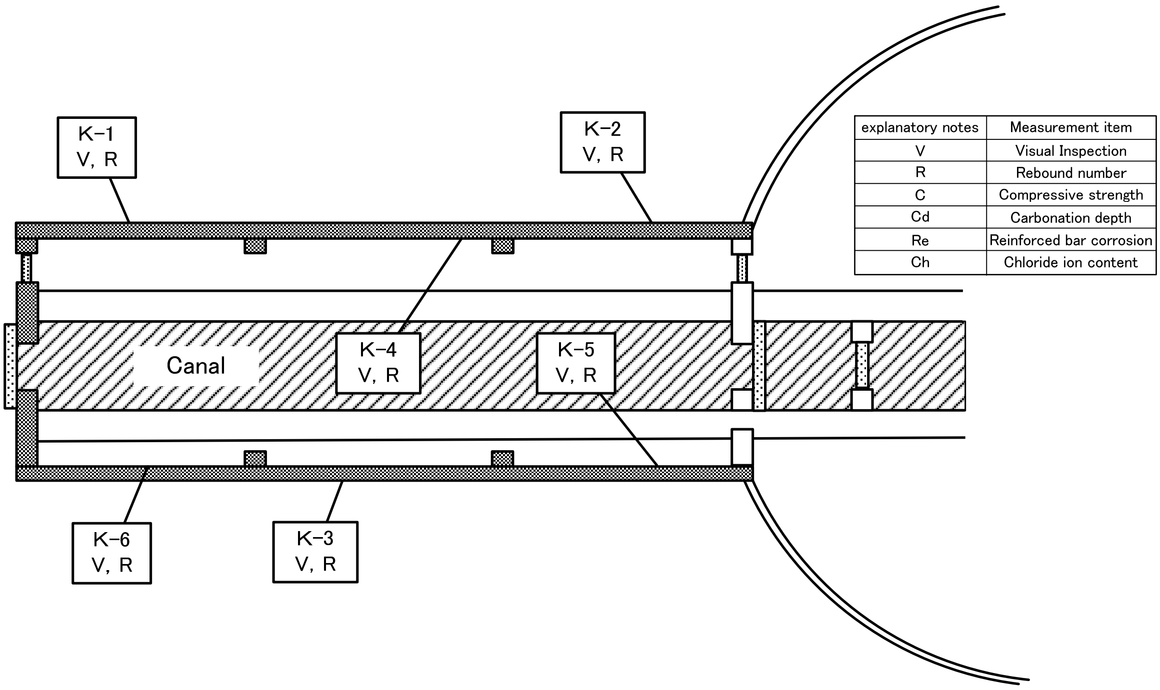
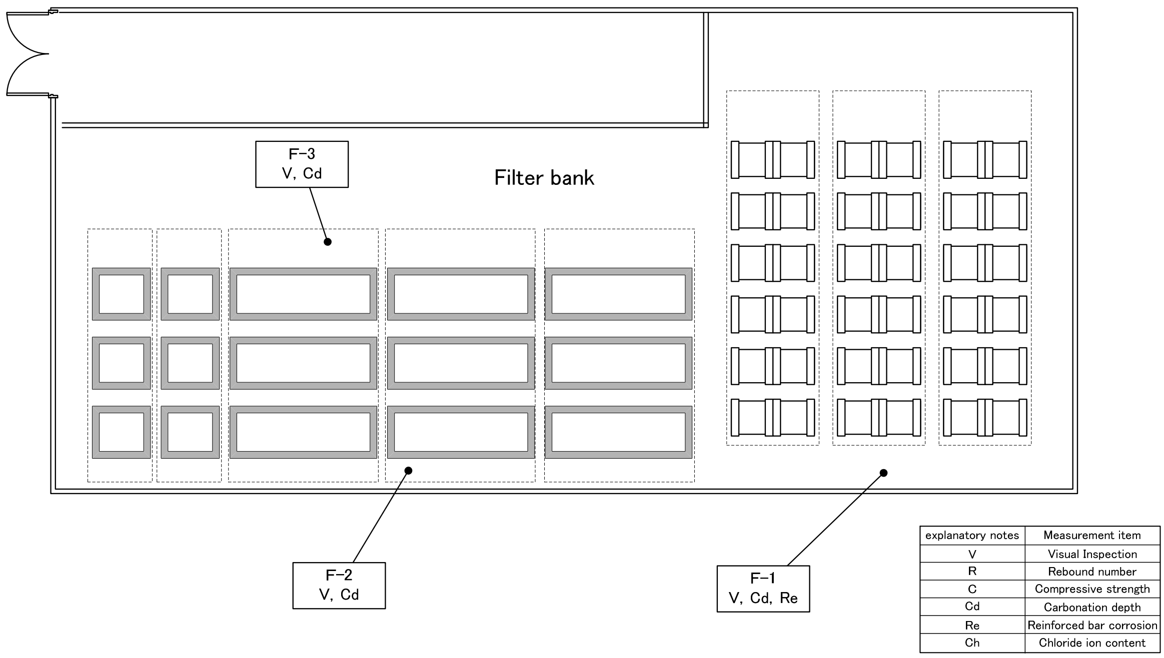


Figure 3 Investigated position of Trench A,B,C.



explanatory notes	Measurement item
V	Visual Inspection
R	Rebound number
C	Compressive strength
Cd	Carbonation depth
Re	Reinforced bar corrosion
Ch	Chloride ion content

Figure 4　Investigated position of Canal building.



explanatory notes	Measurement item
V	Visual Inspection
R	Rebound number
C	Compressive strength
Cd	Carbonation depth
Re	Reinforced bar corrosion
Ch	Chloride ion content

Figure 5　Investigated position of Filter bank.

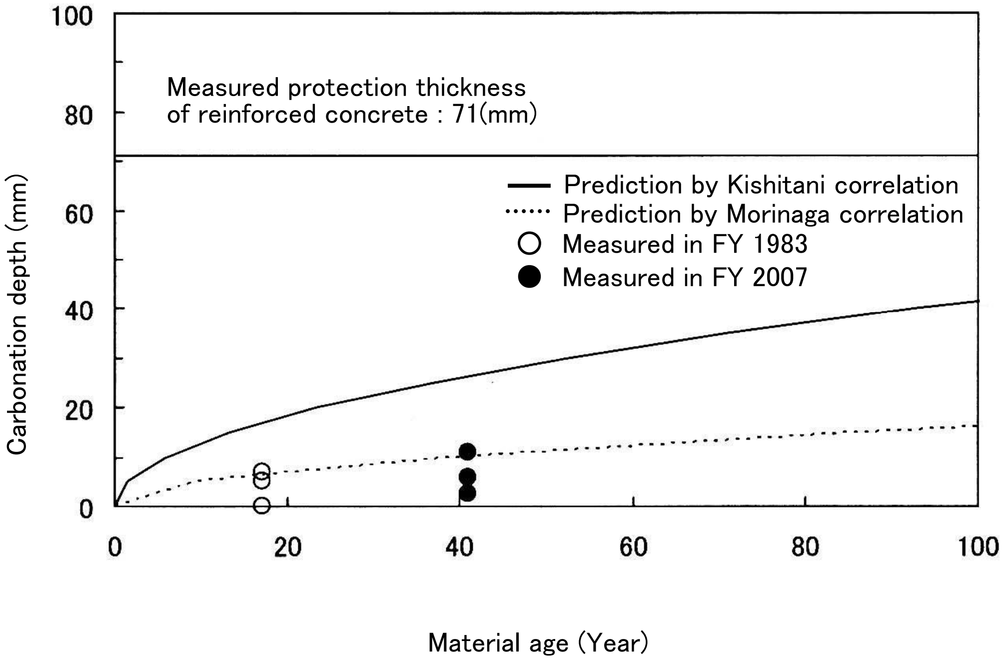


Figure 6 Carbonation depth of the Vent stack (first step).

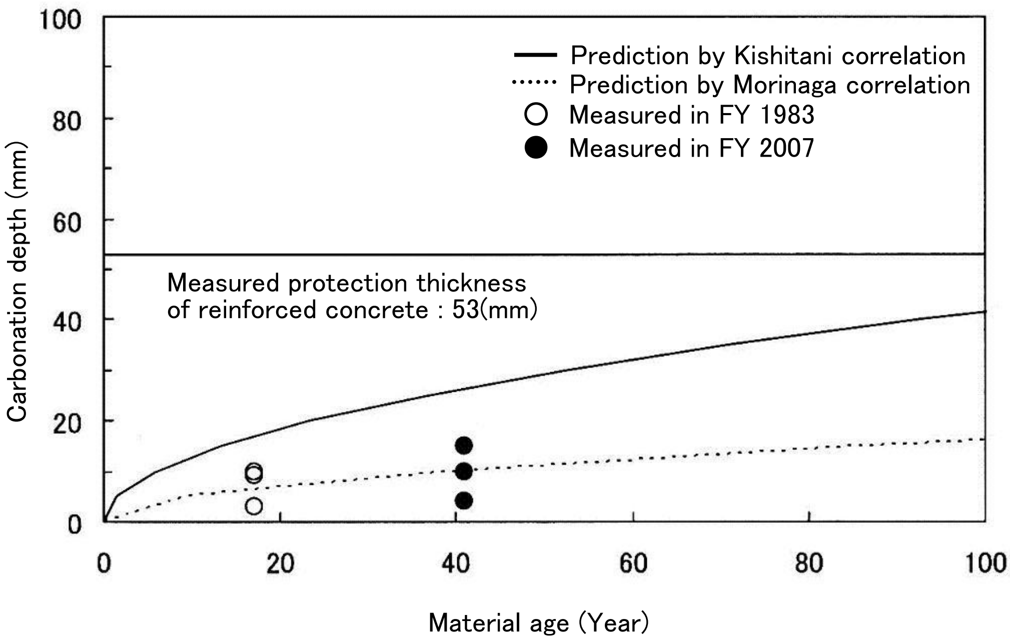


Figure 7 Carbonation depth of the Vent stack (second step).

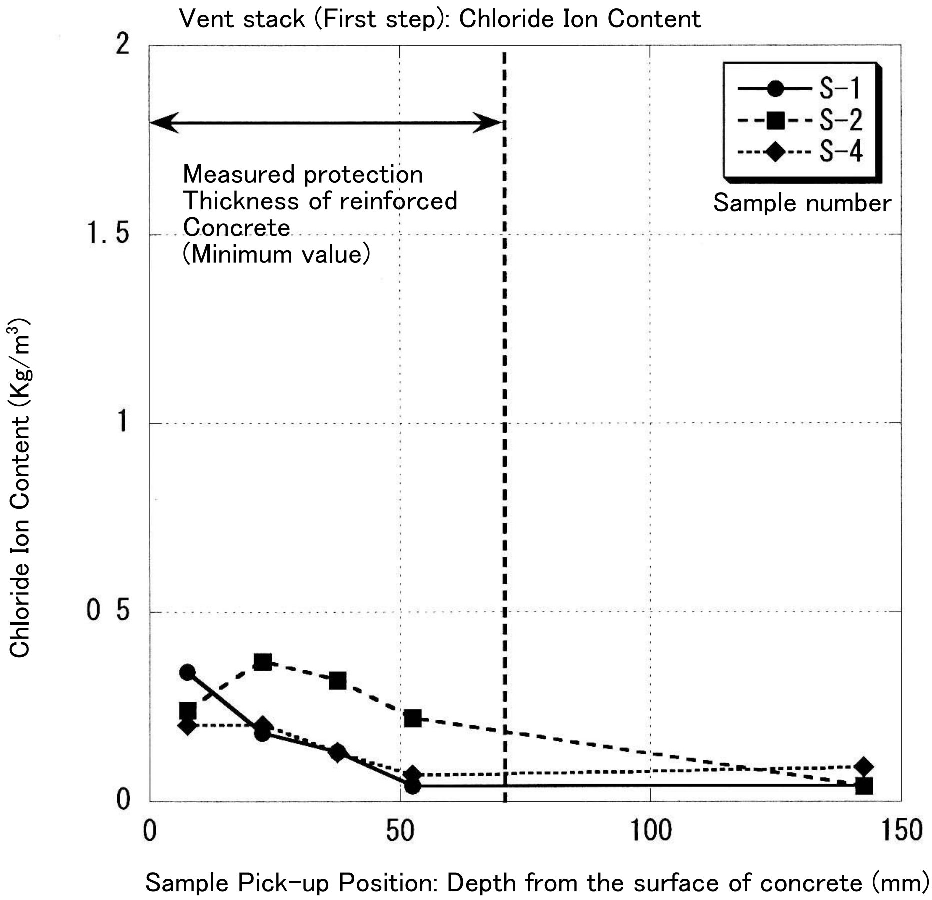


Figure 8 Chloride ion content distributions as a function of depth from the surface.

Appendix Presentation materials at 3rd International Symposium on Material Test Reactor

The 3rd International Symposium on Material Test Reactor was held June 21-23, 2010 at the Nuclear research Institute Rez plc. and Research centre Rez Ltd., Czech Republic. 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 reactor building" are attached as an appendix.

Investigation on Integrity of JMTR Reactor Building

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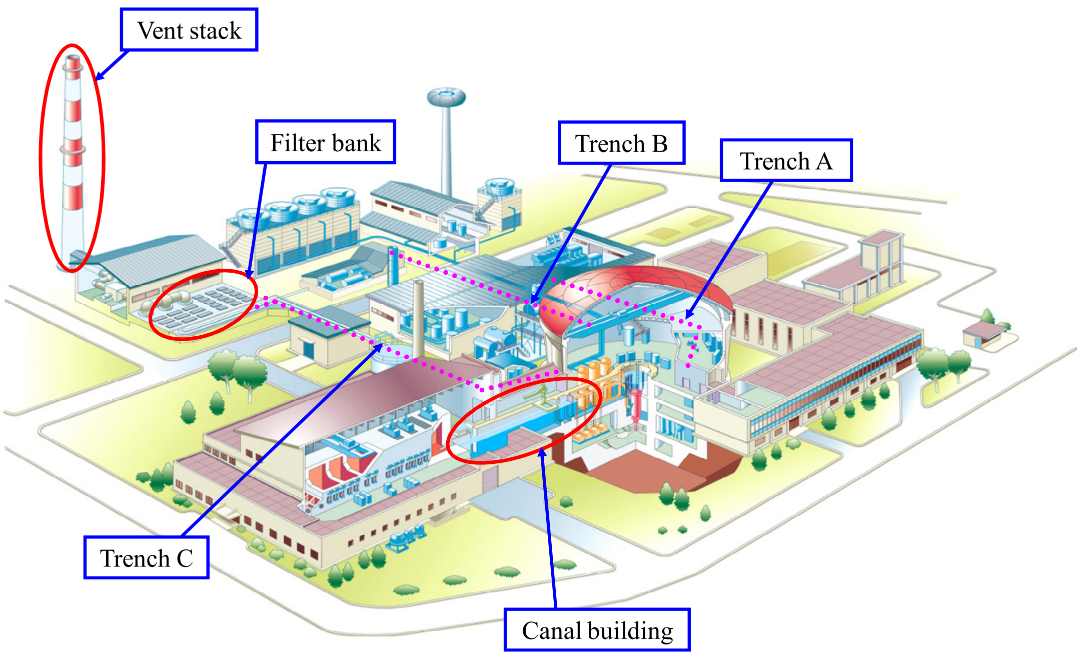
1. Outline of Refurbishment Project

- First criticality of JMTR was achieved in March 1968
- 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 was carried out for concrete structures of the JMTR building and for aged components of tanks in the primary cooling system, heat exchangers and so on, in order to identify their integrity.
- The aged-investigations for JMTR reactor buildings, such as a vent stack, trenches, canal building and filter bank here.

2. Outline of Integrity Investigation

- **An integrity investigation for concrete structures of the JMTR buildings was carried at the beginning of 2007.**
- **The aged-investigation was performed in order to identify integrity of concrete structures.**
- **Based on the aged-investigation results,**
  - **repairing of the concrete structures were carried.**
  - **Future maintenance program is to be considered.**

3. Arrangement of buildings



4. Investigation Items(1/2)

- Concrete surface deterioration
  - We observed Crack, rust fluid, efflorescence, float and falling of masonry.
  - Visual inspection and evaluation
  - base on "Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures"(Architectural Institute of Japan).

- Rebound number (nondestructive strength test)
  - Rebound number was measured based on "Method of measurement for rebound number on surface of concrete (JIS A 1155 (2003))".
  - A rebound hammer with measurement range of 15~70N/mm^2 was used in the test.

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

5. Investigation Items(2/2)

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

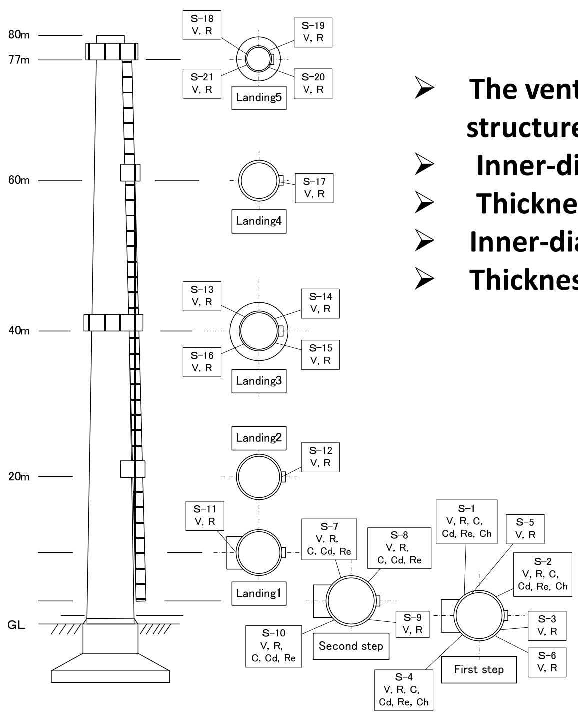
- Reinforced bar corrosion
  - Core boring was carried out to expose a reinforced bar by using a reinforced bar explorer.
  - Evaluated the reinforced bar corrosion
  - based on "Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures" (Architectural Institute of Japan).

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

6. Investigated items, positions

Structures	Position	Investigation Items					
		Visual inspection	Rebound number	Compressive strength	Carbonation depth	Reinforced bar corrosion	Chloride ion content
Vent stack	First step	6	6	3	3	3	3
	Second step	4	4	3	3	3	–
	Landing 1	1	1	–	–	–	–
	Landing 2	1	1	–	–	–	–
	Landing 3	4	4	–	–	–	–
	Landing 4	1	1	–	–	–	–
	Landing 5	4	4	–	–	–	–
Trench	Trench A	6	6	–	–	–	–
	Trench B	6	6	–	–	–	–
	Trench C	6	6	–	–	–	–
Canal	Outer – wall	3	3	–	–	–	–
	Inner – wall	3	3	–	–	–	–
Filter bank	Outer – wall	3	–	–	3	–	–
Total		48	45	6	9	6	3

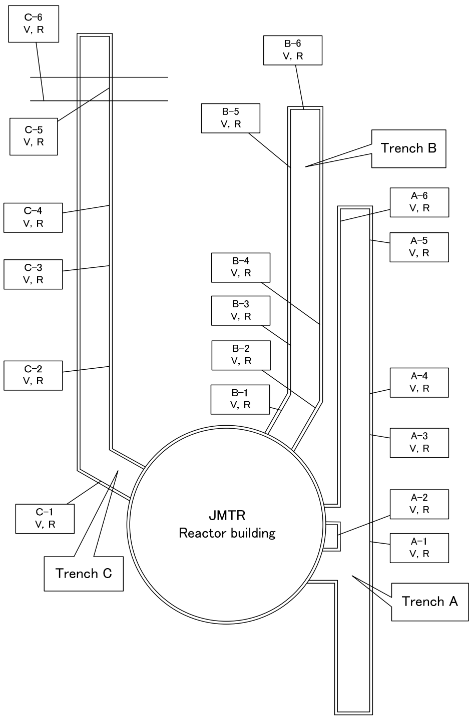
7. Vent stack investigation position



- **The vent stack : a self-standing concrete structure with 80m height.**
- **Inner-diameter at the top part : 2.5 m**
- **Thickness at the top part : 150 mm**
- **Inner-diameter at the lowest part : 5.2 m**
- **Thickness at the lowest part : 500 mm**

Explanatory note	Measurement item
V	Visual inspection
R	Rebound number
C	Compressive strength
Cd	Carbonation depth
Re	Reinforced bar corrosion
Ch	Chloride ion content

8. Trench A,B,C investigation position

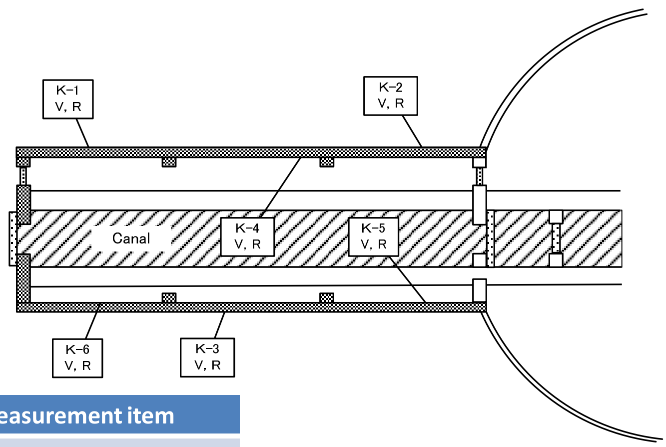


- **The trenches are concrete structures in the ground.**
- **The trenches include pipes and cables to carry utilities from a machinery house to the reactor facilities**
  - **such as cooling water, compressed air and so on**

Explanatory note	Measurement item
V	Visual inspection
R	Rebound number

9. Canal building investigation position

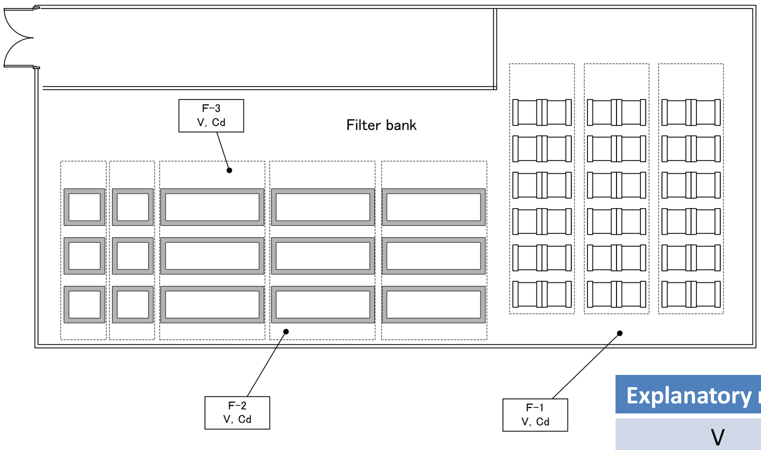
- **Canal is a waterway to transport spent fuels and irradiated capsules.**
- **Canal connects a hot laboratory to a reactor building.**
- **Canal building : a concrete structure includes the canal.**



Explanatory note	Measurement item
V	Visual inspection
R	Rebound number

10.Filter bank investigation position

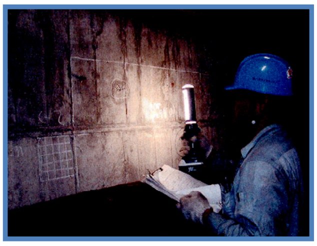
- The air in the reactor building is purified at the filter bank before discharge from the vent stack.
- Filter bank : concrete structure includes various types of filters internally.



Explanatory note	Measurement item
V	Visual inspection
Cd	Carbonation depth

11. Result(Concrete surface deterioration)

- As the result of observation of the concrete surface deterioration for the vent stack,
  - Many small cracks (maximum gap size : 0.3mm),
  - float of concrete,
  - exposure of reinforced bar were observed.



- Observation for the trenches,
  - Exposures of reinforced bar were observed.
- Observation for the canal building,
  - Though float of paint was observed for an outer wall, concrete deterioration was not observed.
  - Falling of paint and cracks were observed for an inner wall.
  - The cracks were small(maximum gap size : about 0.25 mm)
- Observation for the filter bank,
  - The cracks were minor (less than 0.1mm)

12. Result(Rebound number)

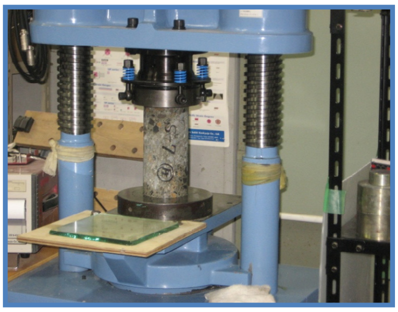
- Rebound number is used to estimate a comprehensive strength.
  - The estimated comprehensive strength was obtained by using an estimation equation (Architectural Institute of Japan) and a material age factor.
- The average value of the stack : 29.5±2.0N/mm^2
  - Design basis strength of the stack:17.7 N/mm^2
- The average of value of the trench : 30.3±3.5N/mm^2
  - Design basis strength of the trench : 20.6N/mm^2
- The average value of the canal building : 32.9±2.6N/mm^2
  - Design basis strength of the canal building : 20.6 N/mm^2

- All the estimated results of comprehensive strength based on the rebound number were greater than the design basis strength.

13. Result(Comprehensive strength)

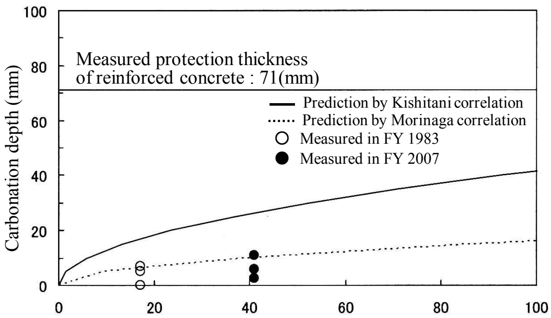
- The comprehensive strength test using drilled concrete core test piece was carried out for the stack.

- All the measured results of comprehensive strength were greater than the design basis strength of 17.7 N/mm^2.

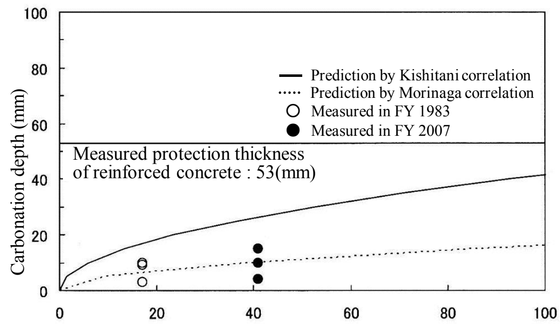


14. Result(Carbonation depth)

- The carbonation of the vent stack became worth gradually.
- These were small enough against measured protection thickness of reinforced concrete 53mm and 71 mm in each height.
- The estimated results of carbonation according to the prediction by Kishitani or Morinaga were small enough during planned JMTR operation period.
- Carbonation of the filter bank floor face hardly become significantly because of protection effect by cement plastering 60~65mm thick.



Carbonation depth of the Vent stack (first step)



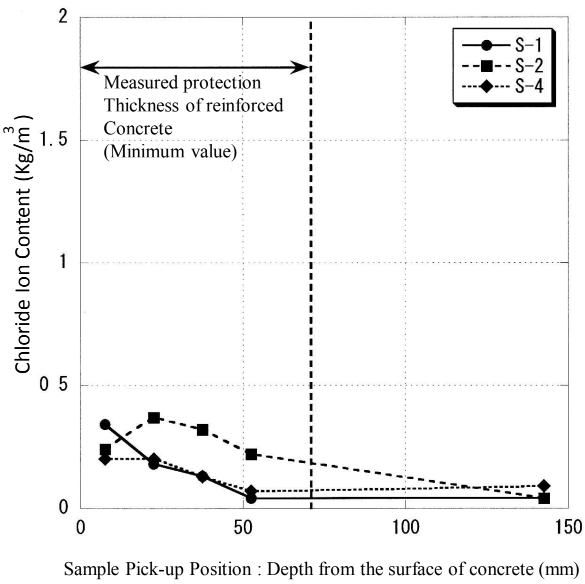
Carbonation depth of the Vent stack (second step)

15. Result (Reinforced bar corrosion)

Structures	Investigation position	Investigation position number	Outer or Inner	Type of reinforcing bars	Depth of concrete cover (mm)	Reinforced bar corrosion Grade (Jun 2007)
Vent stack	First step	S-1	Outer	Reinforcing bar	71	I
			Outer	Reinforcing bar	71	I
			Outer	distribution bar	59	I
		S-2	Outer	Reinforcing bar	73	I
		S-4	Outer	Reinforcing bar	79	I
			Outer	Reinforcing bar	80	I
	Second step	S-7	Outer	Reinforcing bar	53	I
		S-8	Outer	Reinforcing bar	59	I
		S-10	Outer	Reinforcing bar	86	I

- **The observed corrosion of reinforced bar corrosion was grade 1.**
- **Which do not affect concrete strength.**

16. Result(Chloride ion content)



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

- **The measured chloride ion content decreases with depth.**
- **Concrete materials Chloride ion content in depth 150mm was mere 0.04～0.05kg/m^3.**
- **The used concrete material didn't include salinity significantly.**
- **The chloride ion content was estimated to keep below 0.2kg/m^3 inside the minimum covered depth.**
- **0.2kg/m^3 : Criterion value of JASS 5N.**
- **Chloride ion content near the surface has been increased by accumulating the coming flying salinity.**

17. Repair work for vent stack

Before

Repair work of concrete
Repair work for ancillary facilities
Painter's work for concrete and metallic part

After

18. repair works for trenches

Before

After

Leakage control work

Repair work for ancillary facilities

Painter's work for concrete and reinforced bar

19. Repair work for canal building

Before

After

Repair work of concrete outer wall and inner wall

Painter's work for concrete and metallic part

20.Conclusion

- **The result of inspections;**
  - **Significant degradation was not observed on the vent stack, the trenches, the canal buildings and the filter bank**
  - **Integrity of all the concrete structures was confirmed.**
- **The repair works ;**
  - **for the vent stack and the canal building were carried out as a preventive maintenance in 2008.**
  - **for the trenches were carried out a in 2008.**
  - **for the canal building were carried out in 2009.**

- **The data obtained from this investigation will be considered to plan the future periodical maintenance.**
- **In order to use the JMTR concrete structure continuously for long-term, it is important for maintaining the integrity of a concrete structure by the periodical maintenance and the repairing work including the building outer-wall surface painting.**

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	$1L=11=1dm^3=10^3cm^3=10^{-3}m^3$
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	$1\ \mu =1\mu m=10^{-6}m$

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