Committee for monitoring and evaluating the specified nuclear facilities (provisional translation) (9th meeting)
Reference 1-1

Background of underground reservoir plan, current actions (cause analysis etc.), and future direction

April 19, 2013

Tokyo Electric Power Company

1. Background of underground reservoir plan

- Immediately after the 3/11 earthquake, study on large-scale contaminated water storage commenced around April 2011. One of the ideas was the underground reservoir plan.
- At that time, amount of contaminated water continued to increase, and place to install heavy load steel tanks (areas where large cranes can be used) was running out on site.
- Underground reservoir became more specific as a way to overcome the issue and to use the land under transmission lines where large cranes cannot be used.
- Underground reservoir is technology to store rainwater; but by combining with the use of impermeable sheets which are used in numerous final waste disposal sites, further study was conducted to ensure performance for it to become a “facility to store contaminated water for its use period”
- Note that before installing the underground reservoir, construction test were conducted to verify the conditions of the impermeable sheet after installation and on workability of it.

2. Design considerations ~ comparison with specifications of similar structures

Comparison case	Underground reservoir (representative ones)	Final waste disposal sites (representative ones)	1F underground reservoir
Impermeable sheet	Impenetrable sheet (chloroethylene sheet) one layer, others	Two sheets, or impermeable sheet one layer + bentonite (clay) or water tight asphalt concrete, others	Impenetrable sheet with high strength and allows for easy damage detection* two layers + bentonite sheet one layer was selected
Finishing of excavated surface	Form excavated surface, others		Excavation, excavation form, smooth finishing by ground improvement
Monitored items	Water level monitoring, others	Drain water monitoring, others	(1) Water level in reservoir (2) Leak detection hole water level (3) Chloride concentration monitoring

*High-density polyethylene sheet with conductivity: Specialized sheet that allows damages and pinholes caused due to production deficiency or during transport can be detected with spark inspection. High density polyethylene is verified as having no problems in terms of radiation resistance performance and salt water resistance performance based on past research results and test results.

3. Design considerations ~ Seismic design

- For impermeable sheet for underground reservoir, the integrity of the sheet was assessed by calculating the soil deformation (strain) during normal times and earthquakes to compare maximum tensile strain of the sheet (assessed at design horizontal earthquake intensity Kh=0.3, Kh=0.6)

(Assessment flow)

Normal analysis
2D static finite element method analysis

↓

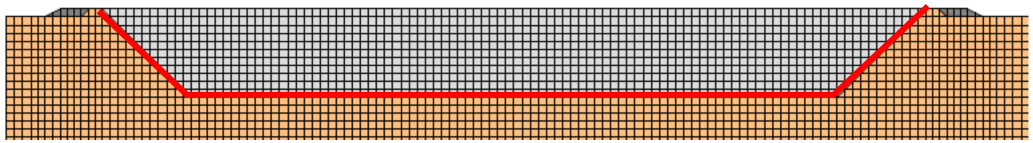
Earthquake analysis
2D static finite element method analysis

↓

Seismic safety assessment
・Reviewed based on tensile strain of impermeable sheet

← Assessment standard value
・Maximum tensile strain of impermeable sheet

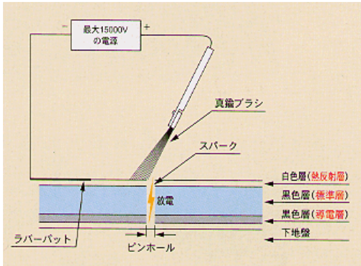
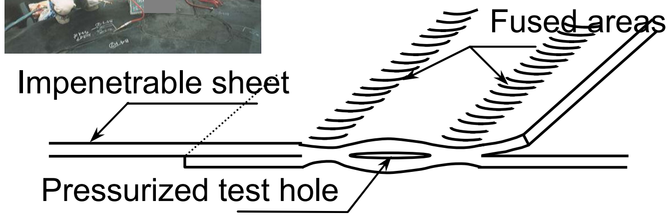
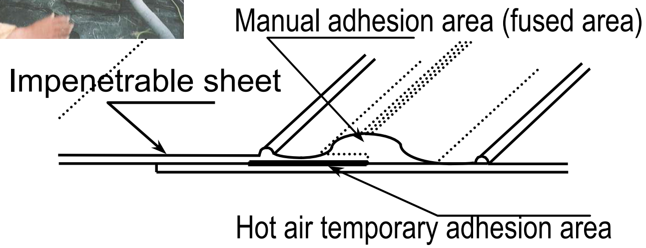
(Analysis model)



Assessment results

	Max. tensile strain εd (%)	Assessment standard value εu (%)	$\varepsilon d / \varepsilon u$
If Kh=0.3	0.148	560	0.00026
If Kh=0.6	0.206	560	0.00037

4. Consideration of work/ quality control

Part	Tests	Test standard/ subject	TEPCO monitoring
Impenetrable sheet pinholes	**Spark test**  	No sparks generated (voltage 15,000V or more) **All surface test**	**Witness all work**
Adhesion area defects (self adhesion)	 **Pressurized test**  	No air leak, pressure loss rate is 20% or less (Pressure 150kPa Maintained time 30s) **Test all**	**Witness all**
Adhesion area defects (manual adhesion)	 **Negative pressure test**  	No air bubbles (Gage pressure-about 6.7kPa Maintained time 10s) **Test all**	**Witness all**

5. Approach to defects anticipated in advance

Anticipated defect	Category	Approach
Damage to impermeable sheet	Design	・ Use of high density polyethylene sheet with sufficient strength, stretch performance, and easy damage detection (consideration given to prevent foreign materials from coming into contact directly with the impermeable sheet by inserting non-woven fabric) ・ Reduce risk of leakage by having two layers of high density polyethylene sheet and bentonite sheet ・ Check that there was no problem with radiation and salt water resistance performance based on external research and test results
	Work	・Check installation surface before installing sheets (TEPCO to witness all work) ・Conduct spark test for all surfaces (TEPCO to witness all work)
Adhesion area defects (self adhesion)	Design	・Enhance reliability of self adhesion area by having double adhesion lines
	Work	・Conduct pressurized test for all lines (TEPCO to witness all) (Complies with "Final waste disposal site planning, design, management procedure 2010 revised version" (Japan Waste Management Association))
Adhesion area defects (manual)	Design	・Strength of manual adhesion area was checked with external test results as not being less than self adhesion areas to ensure reliability
	Work	・Conduct negative pressure test on all lines (TEPCO to witness all) (Complies with "Final waste disposal site planning, design, management procedure 2010 revised version" (Japan Waste Management Association))
Other defects	Water-filling test	・For defects that are not anticipated as above, water filling test is conducted after work is conducted to check whether there is any decline in stored water level

6. Insights from past observation results

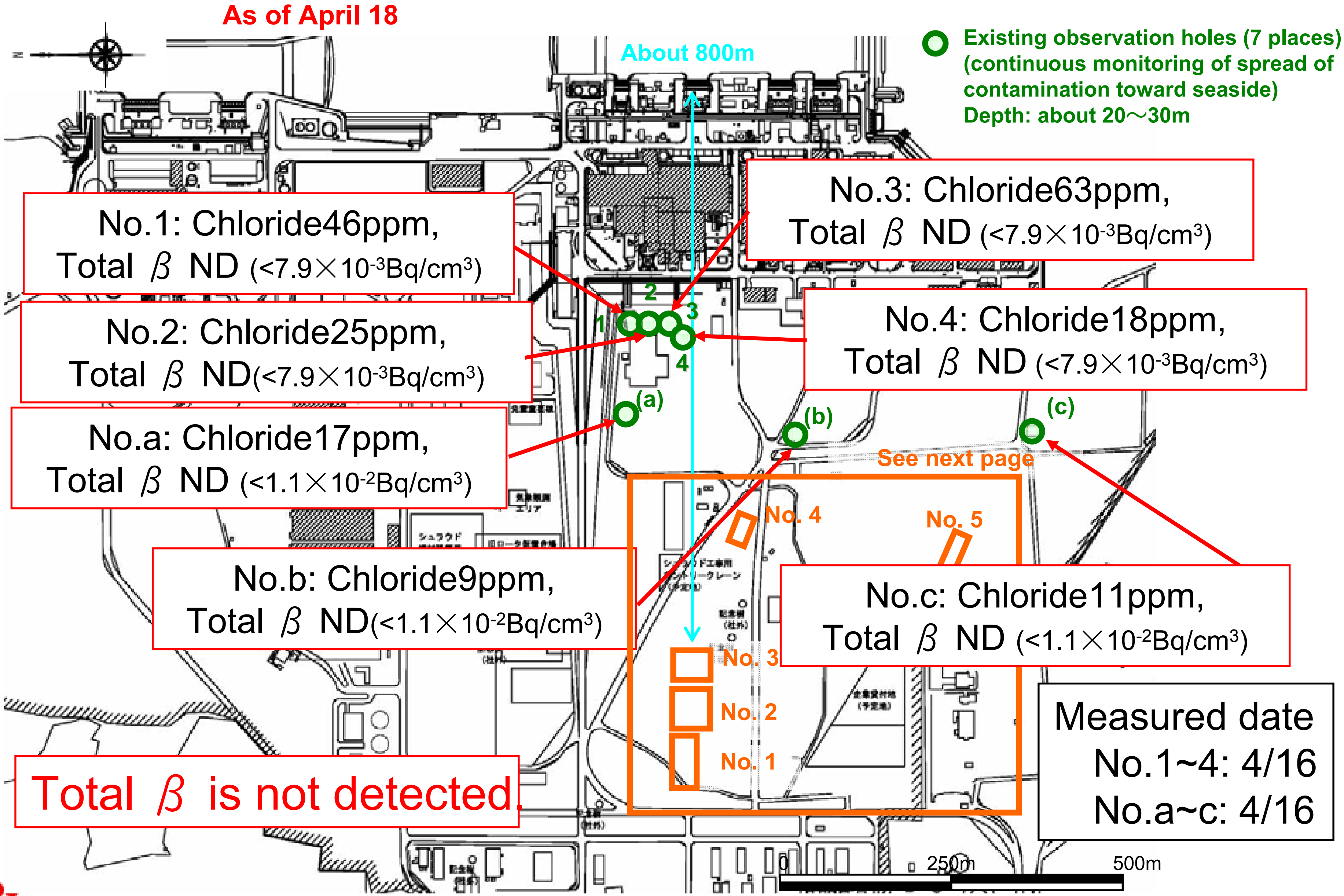
Underground reservoir	No1	No2	No3
Water level in reservoir	2013.4.6：Start transport from No2 2013.4.8：Reached 57% 2013.4.16：Restart transfer to H2 tank	2013.3.12：Water level drops (drops below 95%) 2013.4.6：Start transfer to No1 (current storage rate about 8%)	2013.2.8：No change after reaching water level of 95% 2013.4.13～14：Transfer to No.6 (current storage rate about 80%)
Water level in leak detection hole	—	2013.3.17：Slight increase trend from this day forward	No notable abnormality
Sampling results (total beta)	2013.4.9：Value of northeast side detection hole increased to $1.0 \times 10^4 Bq/cm^3$	2013.4.5：Value of northeast side detection hole at $5.8 \times 10^3 Bq/cm^3$ (first water sample) 2013.4.7：Value of southwest side detection hole increased to about $10 Bq/cm^3$	2013.4.6：Value of southwest side detection hole was $1.8 \times 10^3 Bq/cm^3$ (first water sample) With decrease of water level due to transfer, total beta and chloride concentration showed decrease trend
Relationship between leak event and water level	Leak occurring with water level maintained at 57% (depth 3m), location is somewhere below 3m of depth	Contaminated water is leaking into leak detection hole at current storage rate of 8% (depth about 0.5m), suggesting possibility that there is minor leak very near to the bottom	After decrease in water level due to transfer, total beta and chloride concentration decreased, but there is little data and details are unknown

Note) Refer to Reference 1-1~1-3 for detailed observation data

7. Assumption of causes and future direction based on leakage

- For defects anticipated in advance, certain consideration was given to design, work, and quality control, but cause analysis was re-conducted since the actual cause of leakage (see attachment)
- Among this, it is understood that concern of localized damage to the sheet after start of service cannot be denied in locations where there is water pressure stress concentration or creeping. Therefore, specific leakage mechanisms were considered (see Reference 2-1~2-4)
- In the future, due to the significant difficulty of removing contaminated plastic framework and crushed stones and possible extreme difficulty of finding the damage location when the sheet is directly checked, consideration will be given to conduct studies experiments and estimate leak location from outside perimeter of the underground reservoir for further cause investigation.

8. Current response (1) ~ Existing boring hole monitoring

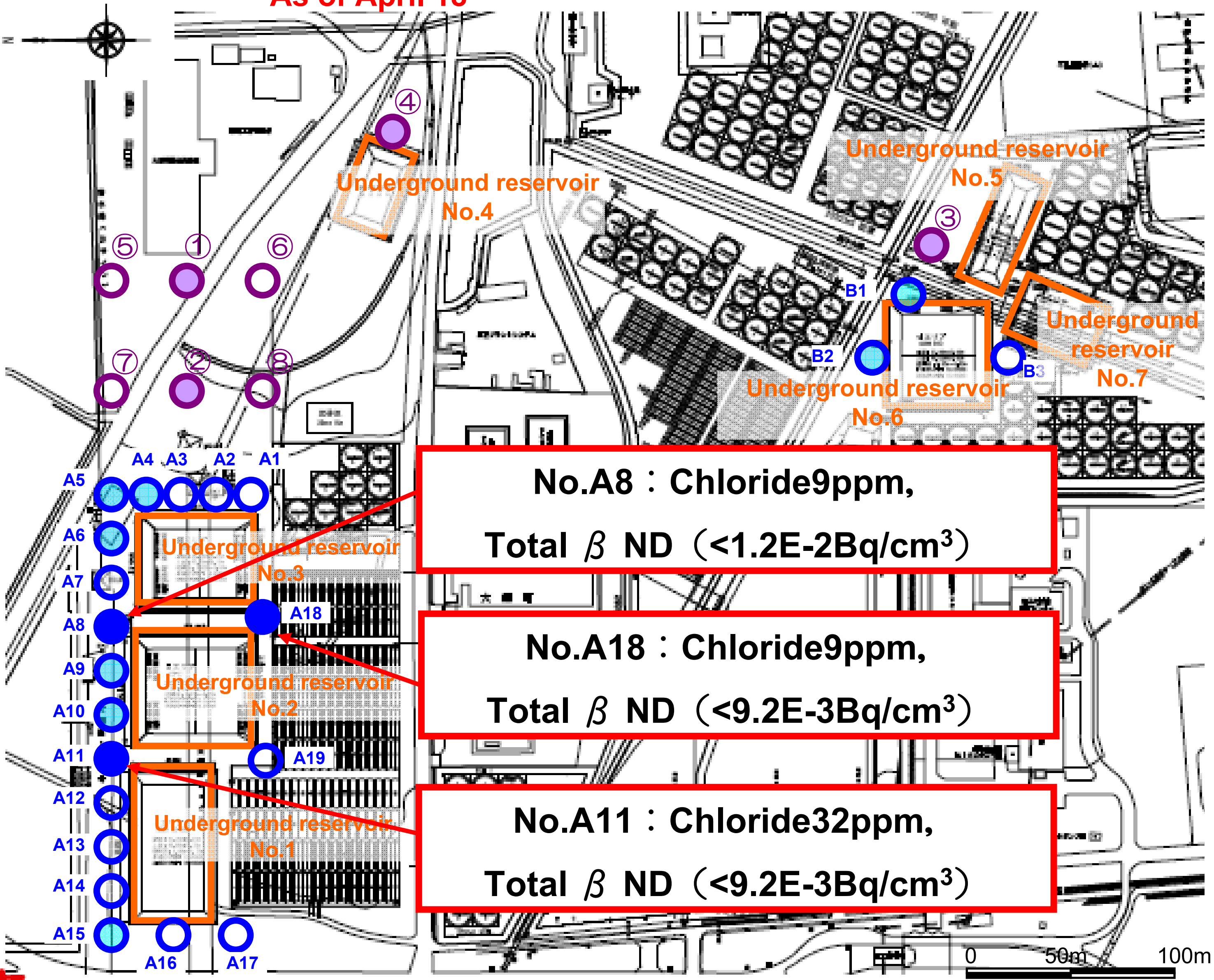


東京電力 TEPCO

ND：Below detectable limits

8. Current response (2) ~ New boring excavation and monitoring

As of April 18



New observation hole (22 places) (Understand contamination around underground reservoir) Depth: about 7～15m

- Drilling complete/ water sampled
- Drilling
- Preparing

New observation hole (8 places) (continuous monitoring of spread of contamination toward seaside) Depth: about 20～30m

- Drilling complete/ water sampled
- Drilling
- Preparing

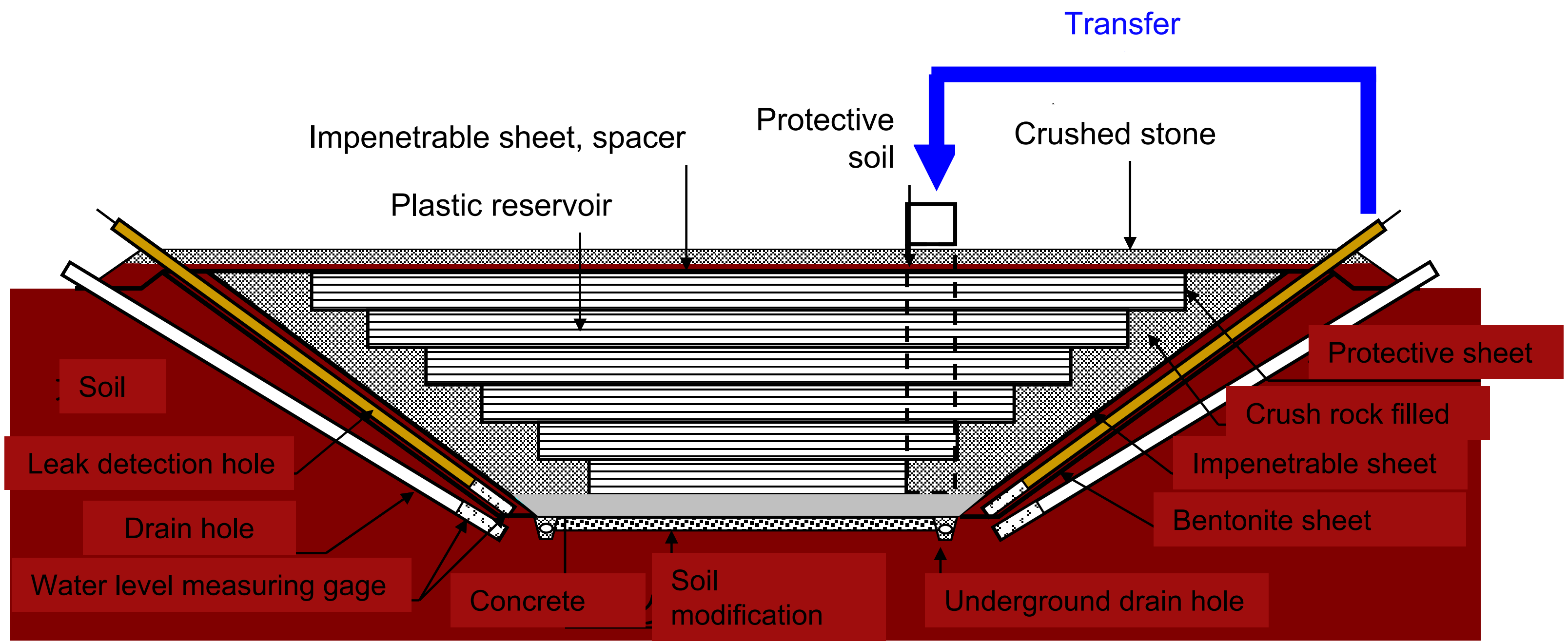
Measured date: 4/17

ND: Below detectable limits

8. Current response (3) ~ Conduct draining & circulation of leak detection hole

■As of April 18

- ●No1Underground reservoir：Started on 4/10, conducted 22 times by 4/18 (pumped amount: about 1～17 liters/time)
- ●No2Underground reservoir：Started on 4/11, conducted 17 times by 4/18 (pumped amount: about 3～19 liters/ time)
- ●No3Underground reservoir：Stared on 4/13, conducted 20 times by 4/18 (pumped amount: about 2～35 liters/ time)



9. Estimated spread of radioactive materials <outline>

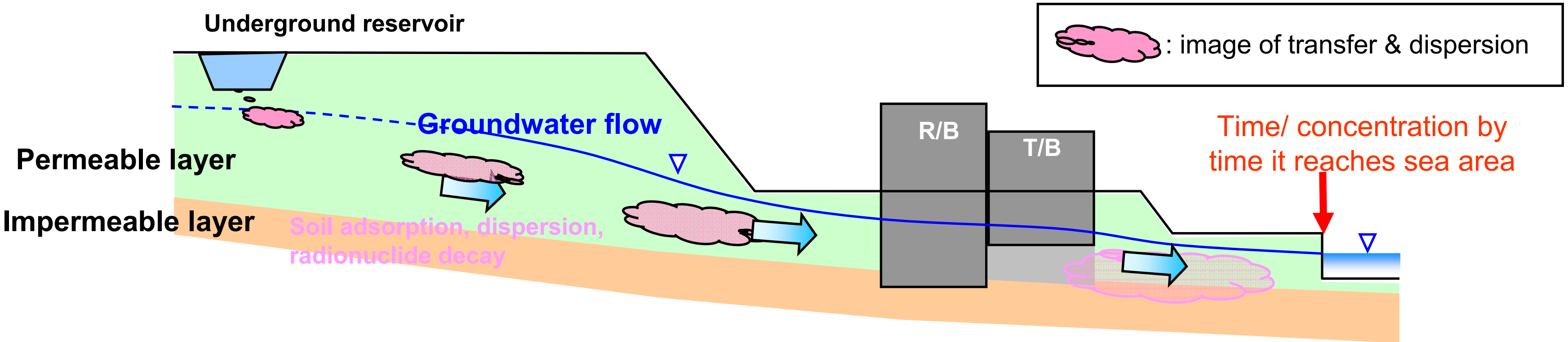
■Leak is monitored with boring holes. Leaked water dispersion condition (from underground reservoir to sea) is estimated to analyze dispersion of radioactive materials.

■Flow of dispersion analysis until the ocean

(1) Assess flow of underground water from leak location
・Estimate water particle flow pathway, flow time using one dimensional saturated flow analysis*

*Assessed that flow only in sandstone bed with gradient from mountain to seaside is dominant

(2) Assess radionuclide transport/ dispersion (CRIEPI)
・ Estimate transfer time and concentration change of radionuclides in groundwater using one dimensional radionuclide transfer dispersion analysis



・Consider soil adsorption and half life of radionuclides that have flowed out from the leak location to estimate dispersion range into surrounding soil, time, and radioactive material concentration where it flows out to.

■Three dimensional analysis used for consideration for area around underground reservoir as supplementary material for leak monitoring.

9. Estimate of dispersion of radioactive material <Results>

- Two cases with different water levels were considered for groundwater level at the underground reservoir location.
- Analysis results of representative radionuclides in leaked water is as in the following table (strontium-90, tritium)

Case (1) Calculate with hypothetical groundwater level around the underground reservoir at around bottom of reservoir (O.P.+30m)	Years until transported to sea area		10 ~ 10^{2} year levels (water ~ Strontium-90)
	Maximum concentration when it reaches the ocean	Strontium-90	About 10^{-7} times
		Tritium	About 10^{-3} times
Case (2) Calculated with hypothetical groundwater level around underground reservoir at bottom of permeable layer (O.P.+20m)	Years until transported to sea area		20 ~ 10^{2} year levels (Water ~ strontium-90)
	Maximum concentration when it reaches the ocean	Strontium-90	About 10^{-8} times
		Tritium	About 10^{-4} times

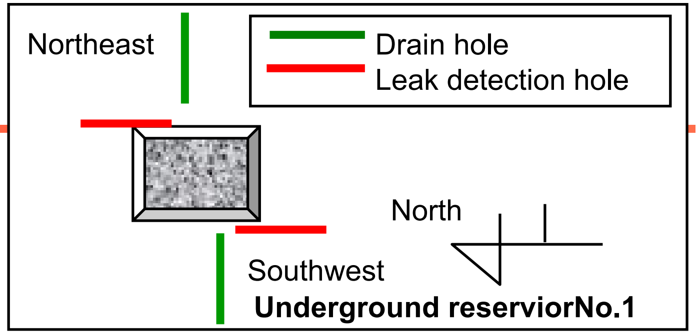
9. Estimate of dispersion of radioactive material <physical property values used in analysis>

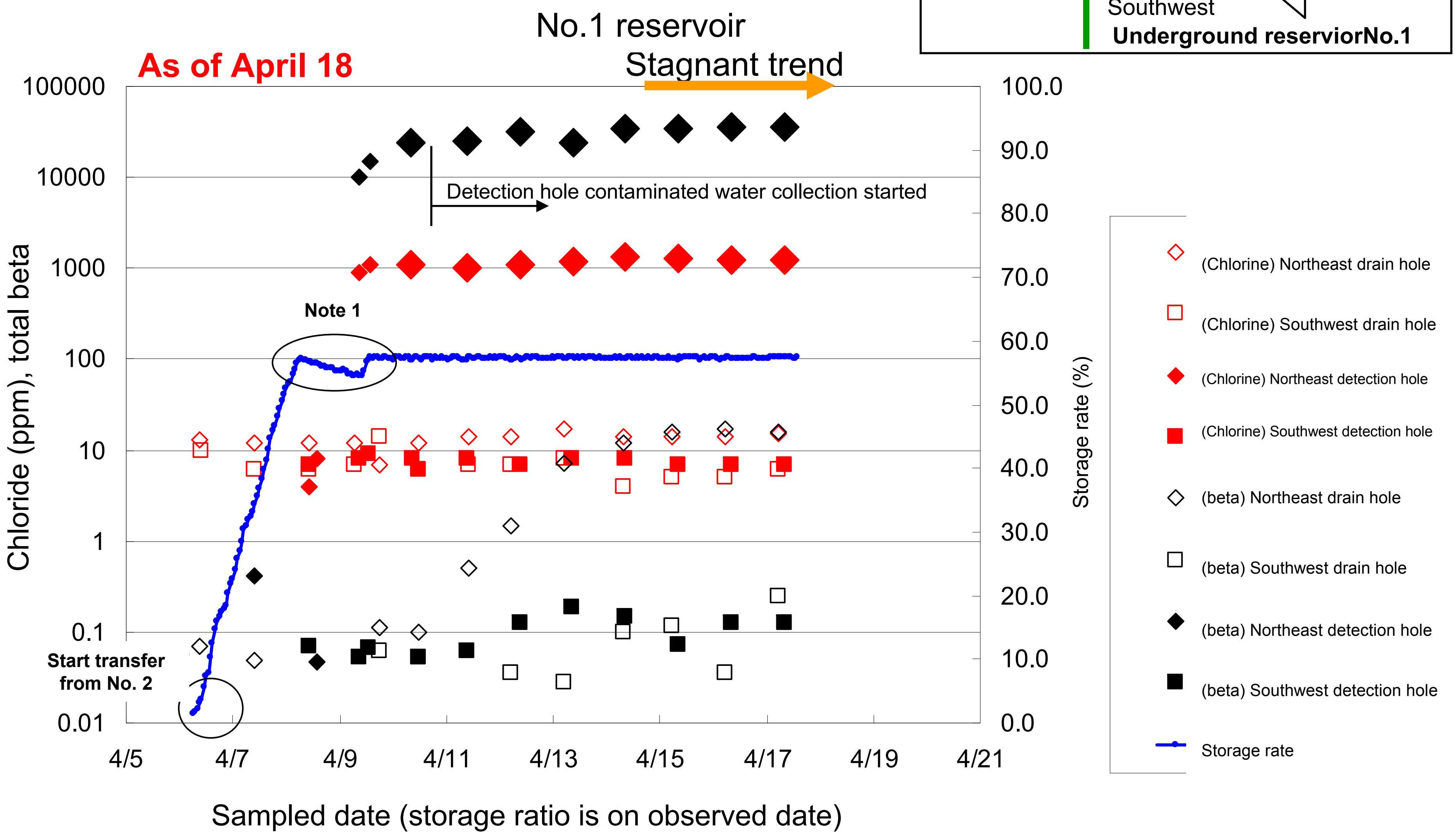
- Conditions for calculation defined based on currently available information and assumptions.

Items	Value	Comments
Permeation distance	880m	Distance from underground reservoir to ocean
Coefficient of water permeability	3.0×10^{-3} cm/sec	Calculate from permeability test results with local sandstone
Void ratio	0.70	"Fukushima Dai-ichi NPS Application for permit for changes to reactor establishment" April 1993 (particle correction in July 1993)
Specific gravity	2.65	"Fukushima Dai-ichi NPS Application for permit for changes to reactor establishment" April 1993 (particle correction in July 1993)
Distribution coefficient (strontium-90)	1.0×10^{-2} m^3/kg	From JAEA adsorption database SBD (sandstone)
Half life – Tritium	12.3 years	—
Half life – Strontium-90	28.9 years	—
Dispersivity	1/10 of transport distance	Gelhar et al.,1992. A critical review of date on field-scale dispersion in Water Resources Research, Vol.28(7) ,pp.1955-1974.

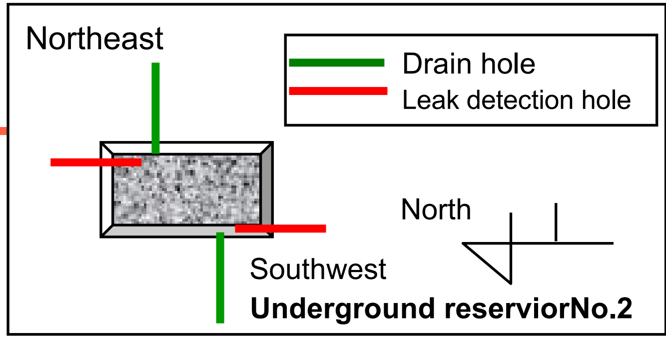
[Reference 1-1] No1 monitoring data

Note1: After shutdown of transfer pump from underground reservoir No2 to No1, some water returned to No2 due to siphon effect is water level decreased, Resumed transfer on 4/9.

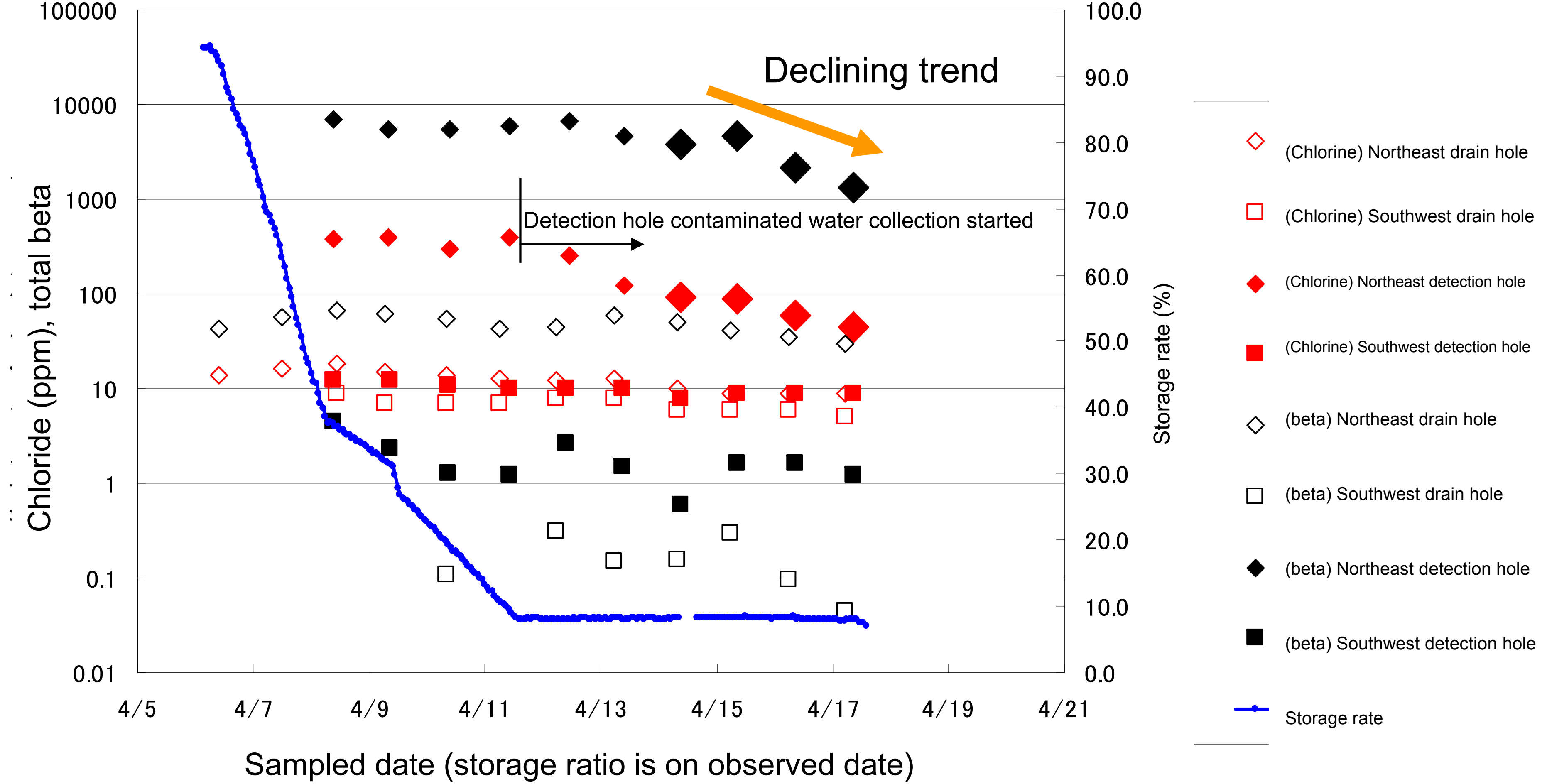




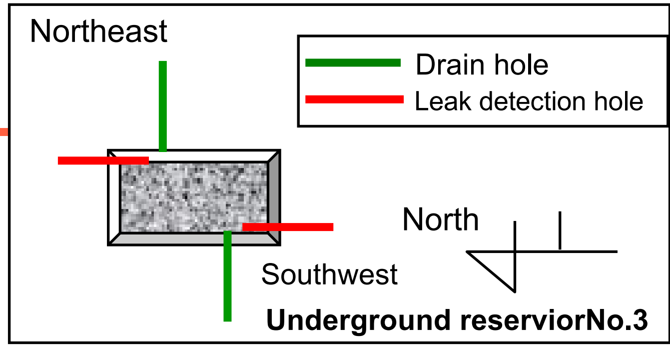
[Reference 1-2] No2 monitoring data

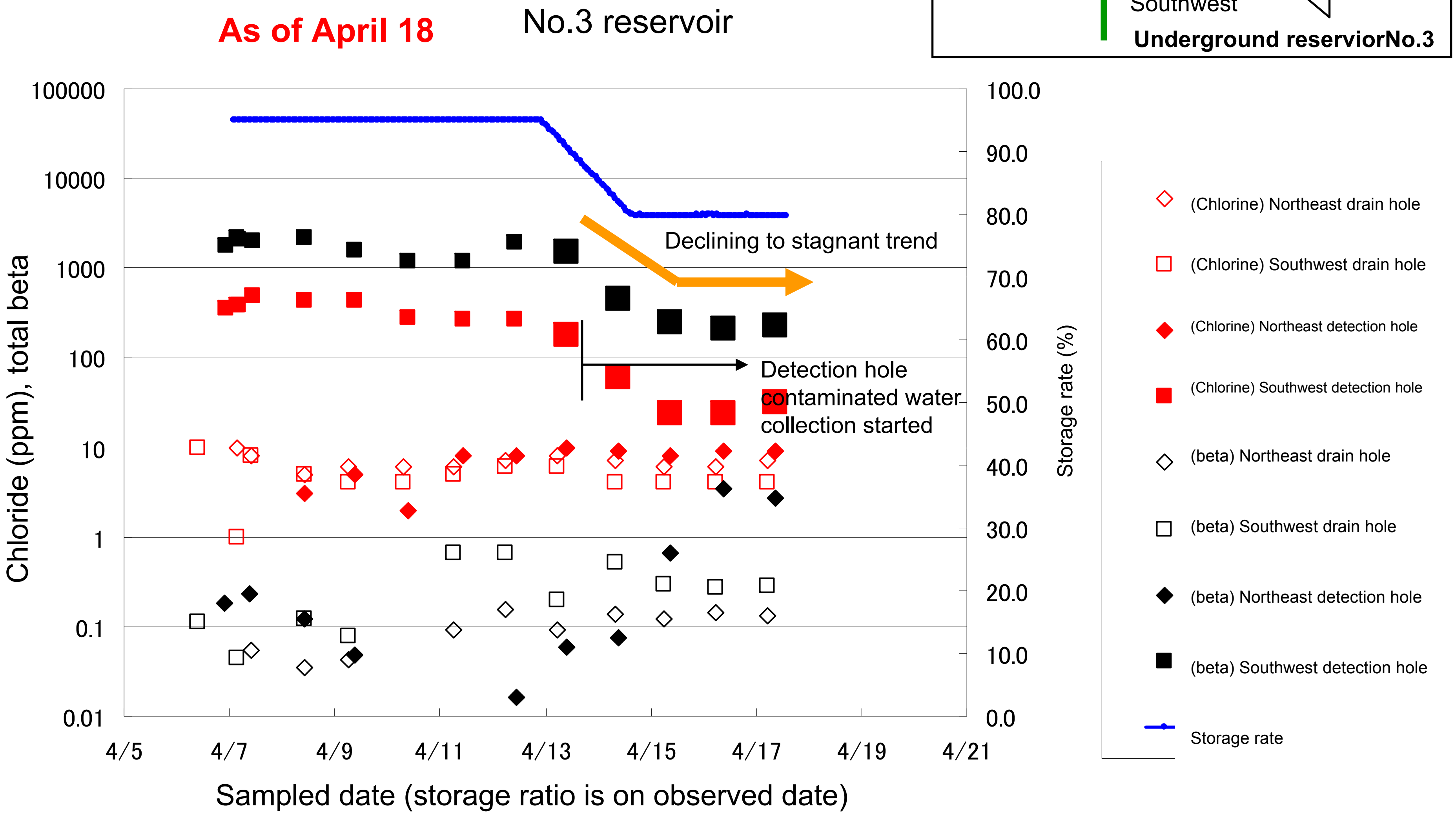


As of April 18 No.2 reservoir



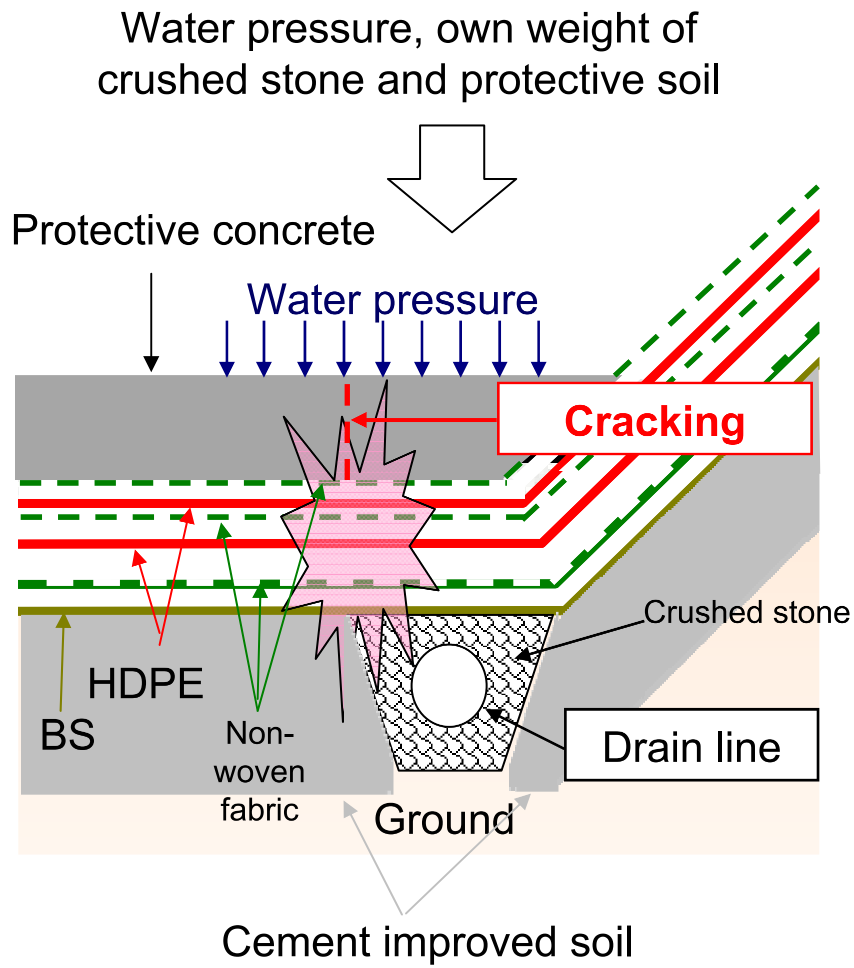
[Reference 1-3] No3 monitoring data





[Reference 2-1]
Damage to bottom slam/ drain pipe underground area (assumed causes)

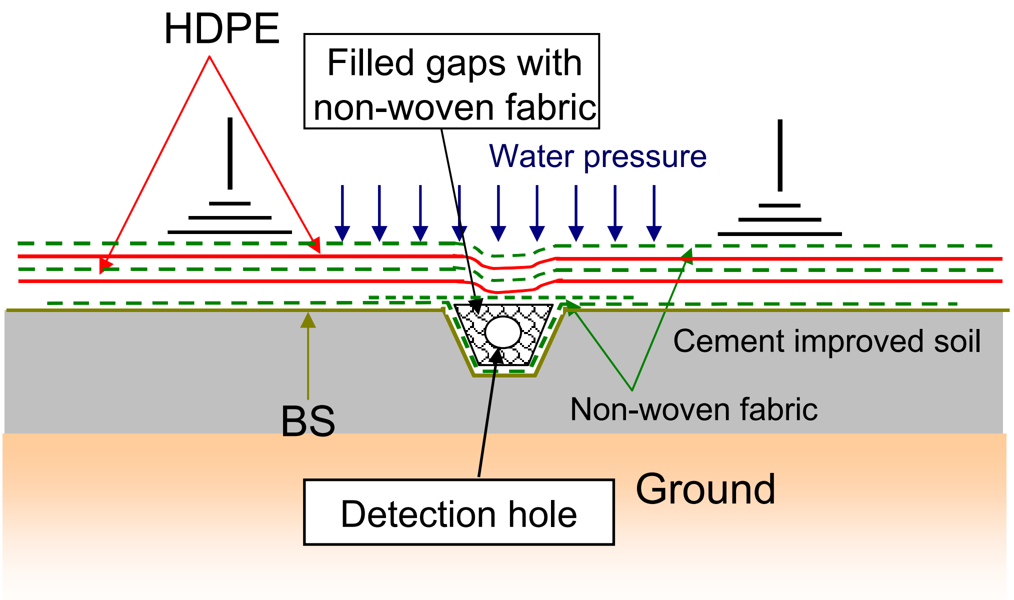
- Bottom slab drain pipe was installed by excavating the ground and laying cement-modified soil on the bottom and laying the drain pipe by excavating into the modified soil in a concave shape. Top, bottom, sides gaps around it were filled with crushed stones. It was covered with a mat and impermeable sheet was installed.
- It has been identified that there may be cracking and damage to the protective concrete directly above the filled crushed stone due to lack of compacting it and effects of consolidation settlement and water pressure. This may have caused local shear stress in the impermeable sheet and led to damage.



Conceptual drawing of installation of drain line at bottom/ damage

[Reference 2-2] Sloped area/ leak detection pipe Damage to installed area (assumed causes)

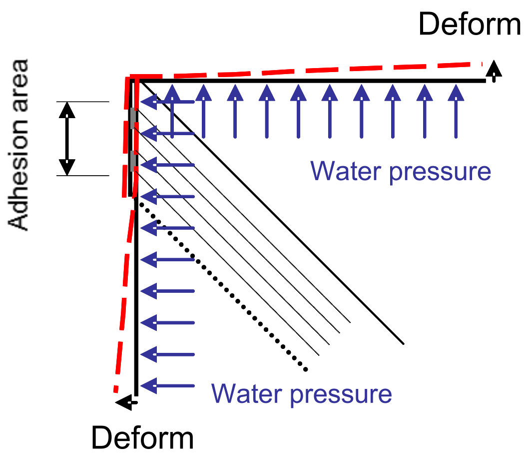
- Leak detection hole is installed by attaching cement improved soil on excavated slope of the ground, and the improved soil was excavated in a concave shape. The space on top and sides were filled with non-woven fabric, non-woven fabric and impermeable sheet was installed on top.
- Due to deficiency in filling the gap with non-woven fabric, there were bumps on the sheet bottom surface, causing deformation of the sheet due to water pressure. This causing localized stress concentration, causing concern for damage.

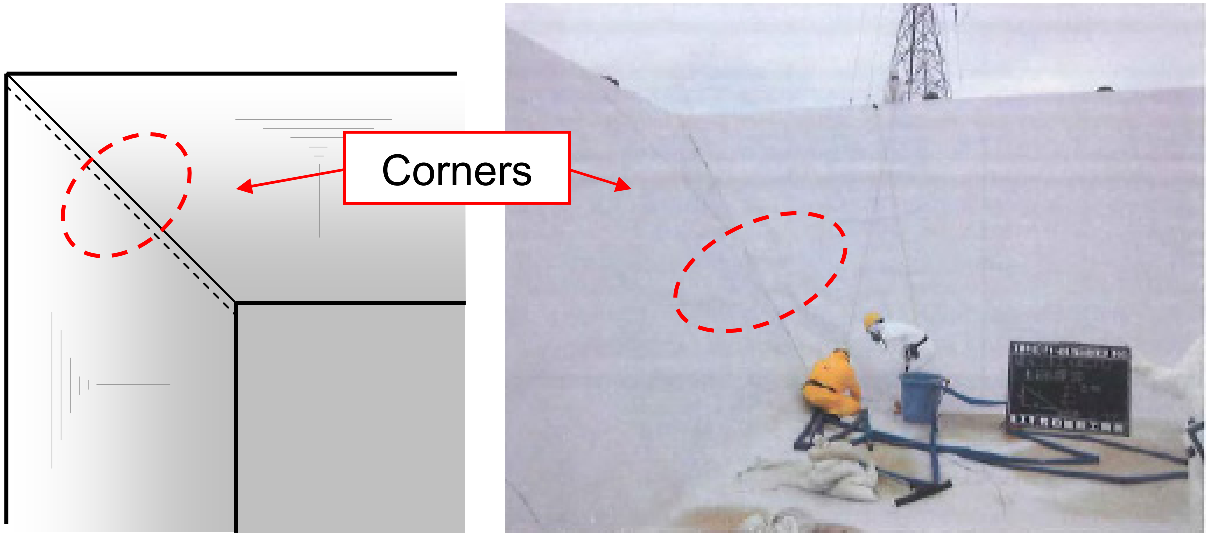


Conceptual drawing of installation of detection hole/ deformation and damage, photo of installation

[Reference 2-3]
Damage to sloped corner/ self adhesion area (assumed causes)

- In the sloped corners, due to problems with work, impermeable sheets were joined together with self-adhesion.
- Gaps are easily formed between the impermeable sheet and ground in sloped corners.
- Due to water pressure from stored water, stress concentrated in corners, causing large deformation, and may have caused damage.

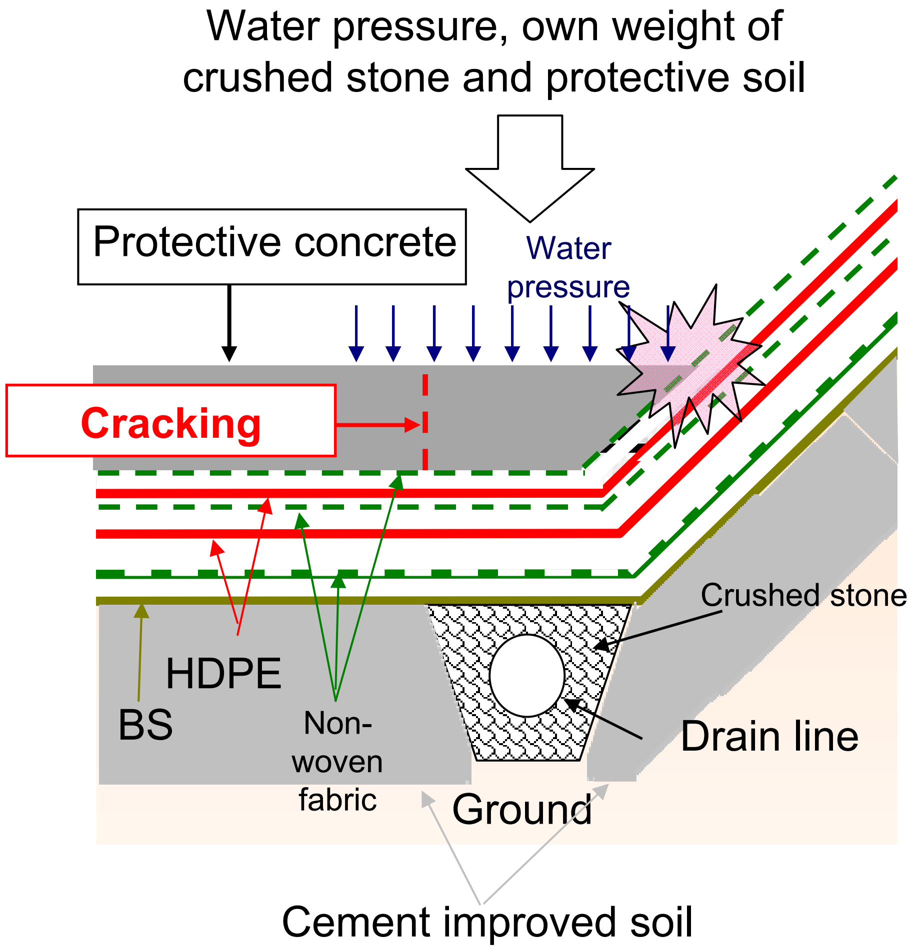




Conceptual image of deformation of sloped corner adhesion area, photo of work conditions

[Reference 2-4] Damage to bottom slab protective concrete contact area (assumed causes)

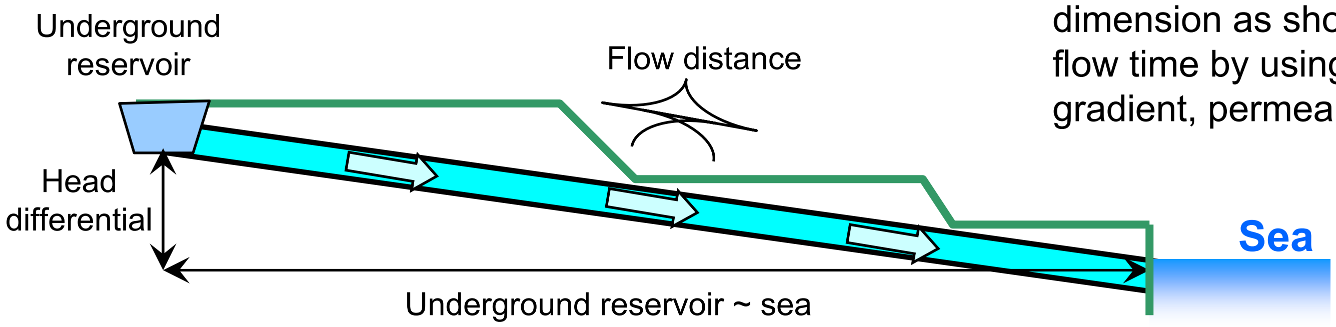
- There may be cracking/ damaging of bottom slab protective concrete caused by deficiency in compacting the drain pipe filled crushed stone, and effects of consolidation settlement and water pressure.
- With this, the edge (sharp corner) of protective concrete contacted impermeable sheet an may have damaged the impermeable sheet.



Conceptual drawing of installation of protective concrete/ damage

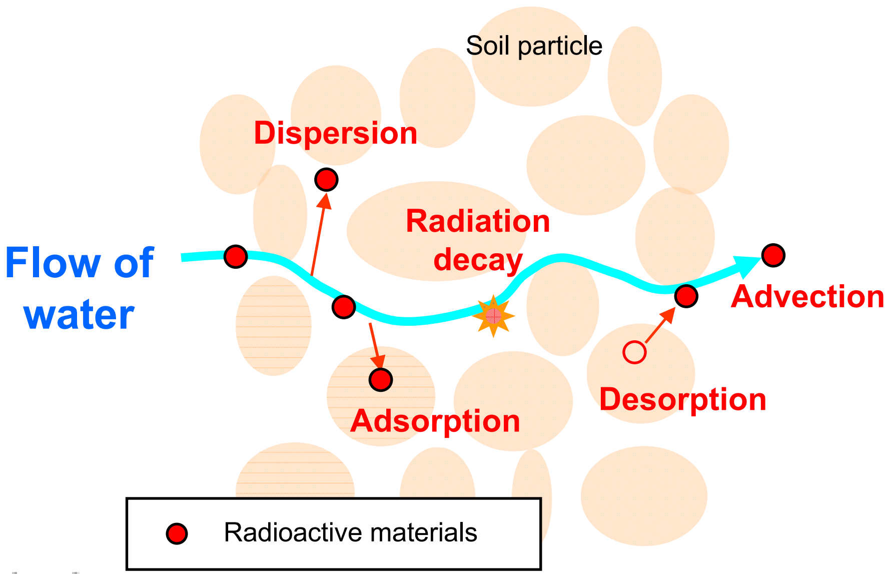
[Reference 3] Conceptual image of one dimensional dispersion analysis of radioactive materials

(1) Assessment of flow from leak point to groundwater



Flow of groundwater is modeled in one dimension as shown in the figure to calculate flow time by using flow distance, hydraulic gradient, permeability coefficient and others.

(2) Assessment of radionuclide advection/ dispersion



Change in concentration of radioactive material at endpoint is estimated based on groundwater flow distance and flow time and considering radioactive material advection, dispersion, radiation decay, adsorption, desorption.

平成25年4月19日
東京電力株式会社

Attachment

Cause Analysis Table for Underground Reservoir Leak

Timing of deficiency	Location of deficiency			Mechanism of deficiency	Verified: Design	Verified: Completion	Verified: Filling	Cautions/ verification points for design and work (description)
1) Product production- delivery	① Sheet material			・Corrosion/ rupture due to radiation, radioactive material	○			・During design: Durable material was selected through literature survey. ・During work: Cement modified soil was used to homogenize the soil under the impermeable sheet 50cm thick, non-woven fabric was installed and impermeable sheet was installed in two layers to enhance reliability (same hereafter and omitted)
				・Corrosion/ rupture due to sodium and other chemical substances	○			・Same as above
				・Leak due to pinholes during transportation	○	○	○	・During work: Visual inspection and spark inspection for the entire surface after installing the sheet was performed to check for damages, and water-filling test was conducted which verified that there were no problems.
2) During construction of underground reservoir	① General areas	a. Bottom slab		・Rupture due to crush stone filling underground drain pipe area	○	○	○	・During design: Cover mat installed on crushed stone to protect the impermeable sheet to enhance reliability ・During work: Spark inspection for the entire surface after installing the sheet was performed to check for damages and water filling test was conducted which verified there were no problems.
				・Damage to sheet due to flying or dropping foreign material	○	○	○	・During work: Spark inspection for the entire surface after installing the sheet was performed to check for damages and water filling test was conducted which verified there were no problems.
				・Rupture due to concrete pouring	○	○	○	・During design: Non-woven fabric was installed under the concrete and impermeable sheet was used for protection to enhance reliability. During work: Verified through monitoring pouring of protective concrete, and water-filling test was conducted which verified that there were no problems.
		b. Sloped area		・Damage to sheet due to ladders (rope ladders and others)	○	○	○	・During work: Spark inspection for the entire surface after installing the sheet was performed to check for damages and water filling test was conducted which verified there were no problems.
				・Rupture due to pouring crushed stones filling between water storage blocks and impermeable sheets	○	○	○	・During design: Non-woven fabric installed on top of impermeable sheet to protect the impermeable sheet to enhance reliability ・During design: Conducted installed test before installation and checked that there were no problems ・During work: Checked that there were no problems with water filling test
		c. Corners		・Rupture due to contact with welded metal mesh of protective concrete	○	○	○	・During work: Conducted pre-pouring inspection before pouring protective concrete and monitored pouring (checked that welded metal mesh does not come in contact with impermeable sheet), as well as water filling test verified that there were no problems
	②-1 Adhesion area (self-adhesion areas)	a. Bottom slab		・Leak from poor adhesion area	○	○	○	・During work: Conducted pressurized test on all lines of adhesion areas and conducted field strength test, as well as water-filling test which verified that there were not problems.
		b. Slope area		・Leak from poor adhesion area	○	○	○	・Same as above
		c. Corners		・Leak from poor adhesion area	○	○	○	・Same as above
	②-2 Adhesion area (manual adhesion area)	a. Bottom/ corners		・Leak from poor adhesion area	○	○	○	・During work: Conducted negative pressure test on all lines of adhesion areas and water filling test which verified that there were no problems
	③ Leak detection holes Area around penetrations	a. Manual adhesion areas	・Leak detection hole penetration	・Damage/ deformation of adhesion area due to lead-in settlement	○			・During design: To prevent having easy welding defects due to adhesion of different materials, material with sufficient stretch capability has been adopted (Note, checked that there was no abnormality as a result of excavation study of No. 2 underground reservoir)
			・Patch ～Sheet	・Damage/ deformation of adhesion area due to lead-in settlement	○	○	○	During work: Because manual adhesion is difficult, conducted negative pressure test on all lines of adhesion areas, and conducted water filling tests which verified there were no problems (Note, checked that there was no abnormality as a result of excavation study of No. 2 underground reservoir)
	④ Protective concrete	a. Bottom		・Damage to impermeable sheet during work for welded metal mesh	○	○	○	・During work: Conducted pre-inspection before pouring protective concrete, pouring monitoring, and water filling test which verified that there were no problems
3) After starting the use of underground reservoir	① General areas	a. Bottom slab	・General areas	・Leak from general area of bottom slab	○	○	○	・During work: Spark inspection for the entire surface after installing the sheet was performed to check for damages and water filling test was conducted which verified there were problems.
				・Damage to sheet due to water pressure effect on areas where flying/dropped foreign material remained	○	○	○	・During work: Checked entire surface (visually) before installing sheet and conducted water filling test which verified that there were no problems
			・Drain pipe underground areas	・Rupture due to stress concentration on drain pipe underground area	○	○	○	・During design: Cover mat was installed on crushed stones to protect the impermeable sheet to enhance reliability ・During work: In order to prevent damage to the sheet due to cracking of the bottom slab concrete due to water pressure, non-woven fabric was installed and water filling test was conducted which verified that there were no problems ・However, because there is concern of sheet damage due to stress concentration and creep for said location, specific damage mechanisms will be considered [Reference 2-1]
		b. Sloped areas	・General areas	・Leak from sloped general area	○	○	○	・During work: Conducted spark inspection on entire surface after installing sheet to check for damages and conducted water filling test which verified that there were no problems
			・Leak detection pipe installed area	・Rupture due to stress concentration on leak detection pipe installed area (sheet deformed and damaged due to space under surface of sheet)	○	○	○	・During design: Enhanced reliability by installing non-woven fabric on upper area of detection hole ・During work: To prevent gradual deformation and damage of the sheet after operation due to gaps remaining between the leak detection pipe installation area and sheet, the space is filled with non-woven fabric and water-filling test was conducted which verified that there were no problems ・However, because there is concern of sheet damage due to stress concentration and creep for said location, specific damage mechanisms will be considered [Reference 2-2]
	② Adhesion area	a. Self-adhesion areas	・General areas	・Leak from poor adhesion area	○	○	○	・During work: Pressurized test of adhesion area was conducted for all lines and field strength test was conducted, as well as water-filling test which verified that there were no problems
			・Corners	・Rupture due to poor adhesion area + corner stress concentration	○	○	○	・During design: Due to stress concentration of automatic adhesion area of sloped corners, in order to prevent gradual deformation of damage of the adhesion area, materials with enough stretch were adopted ・During work: Conducted pressurized test of adhesion area for all lines and water-filling tests which verified that there were no problems ・However, because there is concern of sheet damage due to stress concentration and creep for said location, specific damage mechanisms will be considered [Reference 2-3]
		b. Manual adhesion areas		・Leak from poor adhesion area	○	○	○	・During work: To prevent gradual deformation and damage of adhesion area because defects easily occurs due to difficulty of manual adhesion, negative pressure test of adhesion areas were conducted for all lines and water filling test conducted which verified that there were no problems
	③ Leak detection hole Area around penetrations	a. Manual adhesion area	・Leak detection hole penetration	・Damage/ deformation of adhesion area due to lead-in settlement	○			・During design: Due to adhesion of different material, it is easy to have welding defects, therefore materials with sufficient stretch was used (note that it was confirmed that there was no abnormality based on the results of excavation study of No.2 underground reservoir)
			・Patch ～Sheet	・Damage/ deformation of adhesion area due to lead-in settlement	○	○	○	・During work: To prevent gradual deformation and damage of adhesion area because defects easily occurs due to difficulty of manual adhesion, negative pressure test of adhesion areas were conducted for all lines and water filling test conducted which verified that there were no problems (note that it was confirmed that there was no abnormality based on the results of excavation study of No.2 underground reservoir)
	④ Protective concrete contact area	a. Sloped area		・Cracking of protective concrete due to water pressure, edge contacted with sheet and caused sheet damage	○	○	○	・During design: To prevent cracking of bottom slab occurring due to water pressure and the edge coming into contact with the sheet causing damage to the sheet of the sloped area, non-woven fabric was installed on the upper surface of the impermeable sheet to protect it. ・During work: Verified that there were no problems with water filling test ・However, because there is concern of sheet damage due to stress concentration and creep for said location, specific damage mechanisms will be considered [Reference 2-4]

Items for which possible sheet damage due to stress concentration or creep cannot be completely discredited.