Welded Tank Internal Surface Inspection Results and Future Tank Plan in light of the Detection of Hydrogen Sulfide

April 25, 2019

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Tokyo Electric Power Company Holdings, Inc.

1. Overview and chronological history

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- Turbidity and a foul odor was noticed during periodic sampling of strontium (Sr)-treated water at the multi-nuclide removal equipment intake. In light of this, Sr-treated water from inside welded tanks was sampled and it was found that the concentration of suspended solids (including insoluble iron) was high, and hydrogen sulfide was detected from inside the tank.

<Chronological history>

・August 27, 2018:	Turbidity and a foul odor noticed during periodic sampling at the multi-nuclide equipment intake. Analysis plan to examine the turbidity and foul odor deliberated during September and October.
・October 30, 2018:	It is found that hydrogen sulfide has accumulated to more than 50ppm in the G3-E1 tank. Power station and contracting personnel notified that the aforementioned tank area should not be left open for unnecessary reasons. ※Concentrations in the work area on top of tanks confirmed to be less than 10ppm.
・November 1, 5, 2018:	In accordance with the analysis plan deliberated after turbidity and foul odor were noticed, Sr-treated water from the aforementioned tank was sampled at the beginning of November and a water analysis was conducted thereby revealing a high concentration of suspended solids.

2. Inspection plan

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- Since the concentration of suspended solids was high in the aforementioned tank the environment under the precipitate is anaerobic and conducive to the formation of hydrogen sulfide.
- Thickness measurements of the sides and top of the tank revealed that surface corrosion stemming from hydrogen sulfide is not problematic, however, just to be sure, one of the tanks will be drained in order to inspect the internal surface of the tank and investigate the cause of the generation of hydrogen sulfide.

Action		Details	Period
①	Additional inspection and location where hydrogen sulfide has been generated	A reference tank will be selected from each tank group and hydrogen sulfide concentration measurements taken in order to investigate Sr-treated water that is generating hydrogen sulfide	December 2018 → Completed
②	Inspection of conditions inside tanks	In light of ①, one tank shall be selected for inspection and drained in order to check for corrosion on internal surfaces. The bottom of the tanks will also be checked to confirm that an anaerobic environment conducive to the formation of hydrogen sulfide has not been created as a result of the large amount of suspended solids.	Commenced in January 2019 → This report
③	Deliberation of suspended solid disposal	Methods for disposing of the suspended solids shall be deliberated.	Middle of March 2019 → This report

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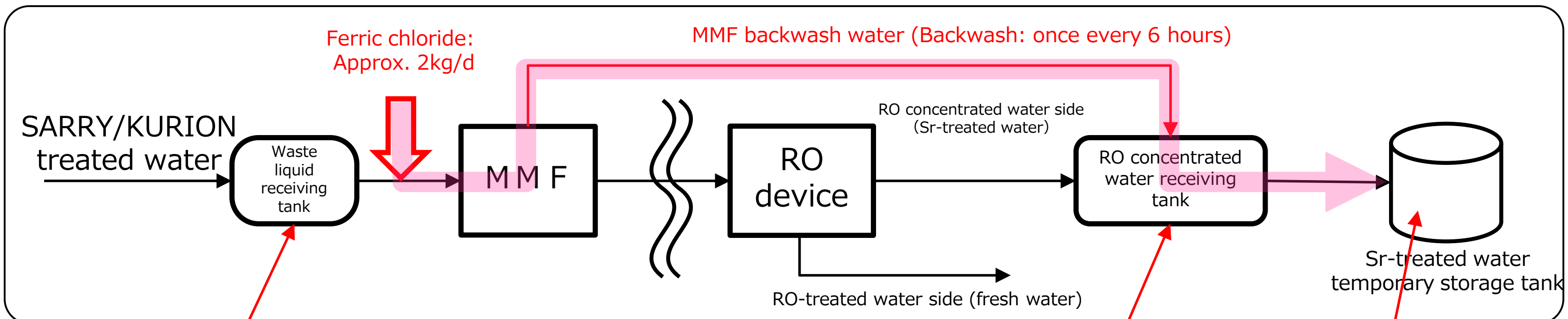
The cause of the generation of hydrogen sulfide

① Ferric chloride injected into existing RO treatment equipment and removed by the multimedia filter (hereinafter referred to as, "MMF"), has coagulated and settled to form crud, and some of this crud was transferred to the Sr-treated water tanks via the RO condensed water side during backwashing to eliminate MMF clogs.

② Since Sr-treated water temporary storage tanks are repeatedly filled with and drained of Sr-water, ferric chloride coagulant (crud) has gradually accumulated at the bottom of the tanks thereby creating an anaerobic environment.

③ Sulfate-reducing bacteria (SRB) promotes organic decomposition during which sulfate is reduced to sulfide ions thereby generating hydrogen sulfide.



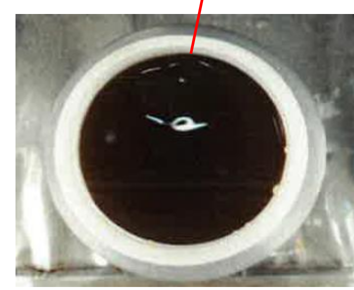
Ferric chloride infiltration route

External appearance of water at the bottom of the waste liquid receiving tank on February 19, 2019

Turbidity at the bottom of the waste liquid receiving tank has not been found

Crud and turbidity found at the bottom

External appearance of water at the bottom of the RO concentrated water receiving tank sampled on February 19, 2019



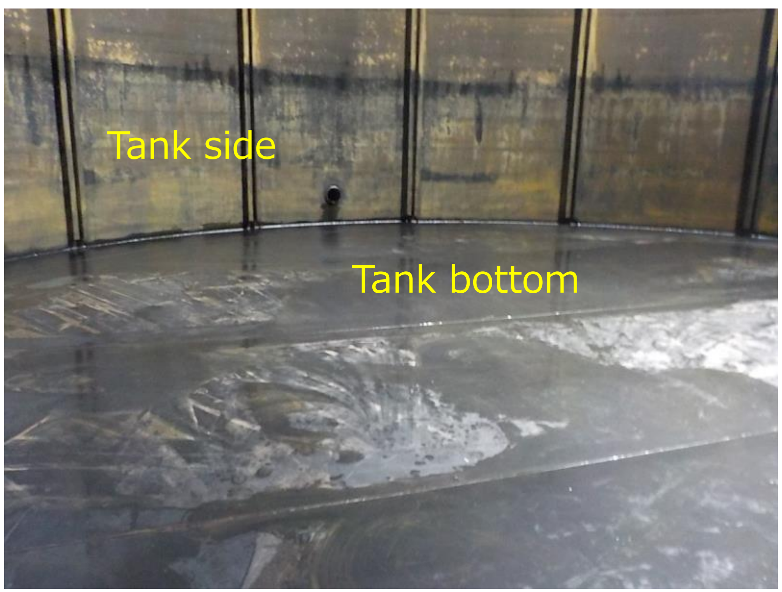
External appearance of water at the bottom of the D-C1 tank sampled on February 12, 2019

Determined to be ferric chloride that has coagulated and settled (crud) inside the RO device

3-2. Results of internal surface inspection of reference tank performed in conjunction with tank internal condition survey

- G3-E5 tank selected as reference tank for internal inspection due to high concentrations of suspended solids and relatively large amounts of sulfate-reducing bacteria found to exist from water analysis tests done on G3 area tanks.
- Sludge recovered from the bottom of the G3-E5 tank and a visual inspection of the inner surface conducted
  - Scratches/gouges (maximum depth: 1.7 mm) and paint chipping assumedly caused during construction found on the bottom. No paint chipping, etc., was found on the side surfaces.
  - No large discrepancies with inspection results from neighboring tanks (G3-F4) in which hydrogen sulfide was not found.
  - Inspection of areas where paint is chipping (locations of corrosion) found that there was no black iron sulfide film, so it was determined that the paint chipping was not caused by sulfate-reducing bacteria. Furthermore, the rate of corrosion of locations of paint chipping assumedly caused during construction is 0.26 mm/year, which is approximately the same as the normal speed of corrosion of carbon steel (less than 0.3 mm/year).

In light of the above inspection results we will continue to use other welded tanks in which Sr-treated water is being stored after draining them to perform internal surface inspections and repair/paint scratches.



Internal surface conditions

Scratches, etc., found at the bottom of the tank

4. Suspended solid disposal (countermeasures to prevent generation of hydrogen sulfide)

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- The following shall be implemented in order to prevent generation of hydrogen sulfide and ensure safety.

- It is easy for ferric chloride to coagulate and settle (crud) inside the temporary storage tank (used tank) in which Sr-treated water is repeatedly filled and drained and it is assumed that sludge inside the tank contains this crud, so sludge will be recovered from all tanks in use.

Tank areas subject to above countermeasure: G3, J1, K1, K2, H8, D areas

- Furthermore, ferric chloride coagulate (crud) does not accumulate in large amounts on the bottoms of welded tanks used to store ALPS-treated water because the tanks are not repeatedly filled and drained, and because particulate matter is captured by crossflow filters and mesh filters, thereby preventing the creation of an anaerobic environment conducive to the generation of hydrogen sulfide. Crossflow filters were damaged in the past. However, the time period during which the filters were not functioning properly was not long enough to allow a large amount of crud to accumulate or to create an anaerobic environment.

【Reference】Impact on welded tanks in other areas by reference tank internal inspection results (scratch countermeasures) (reprinted from materials distributed during team/secretariat meeting on April 25, 2019)

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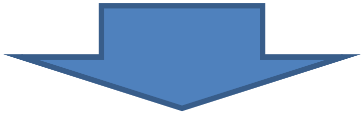
- Scratches with a depth of 1.7mm on the bottom that were found during internal surface inspections of the G3-E5 tank are not problematic because the plate thickness allowance is 9mm (nominal plate thickness: 12mm-required plate thickness: 3mm), but they will be repaired and painted just to be safe.
- The plate thickness allowance of the bottom plate of other welded tanks (stored water: Sr-treated water, ALPS-treated water) is:

  9 mm → G3, G1 south, H1~H6, H8, B, J1~J9, K1 area
  19mm → G1 south, H4 south area
  22mm → D, G7, H4 south, K2~K4 area

  The smallest plate thickness allowance is 9 mm, which is the same as the G3-E5 tank, so there is no problem if there are similar scratches



・At current time there are no leaks from scratches
・Welded tanks in which Sr-treated water is being stored will be drained and the internal surface inspected in conjunction with future ALPS treatment plans
・Welded tanks in which ALPS-treated water is being stored will be subject to internal surface inspections after being drained, or will be inspected using submersible cameras, as part of future long-term inspection plans

6. Hydrogen sulfide countermeasures and tank internal surface repair schedule

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- The work schedule considered when revising the water balance simulation is as follows.
  - Hydrogen sulfide countermeasures/tank internal surface repair schedule
    - Residual water disposed of in order to inspect/repair tank bottoms
    - Hydrogen sulfide-generating crud removed from the bottom of tanks

    } Four tanks/week planned※

    - Repair of chipped paint, blisters, and scratches, etc.

    } Four tanks/week planned※

  - In light of the above plan, the work is expected to take approximately one year since 105 of the tanks in operation will be repurposed as ALPS-treated water tanks.

※May be revised depending upon the inspection results for each tank and repair work progress

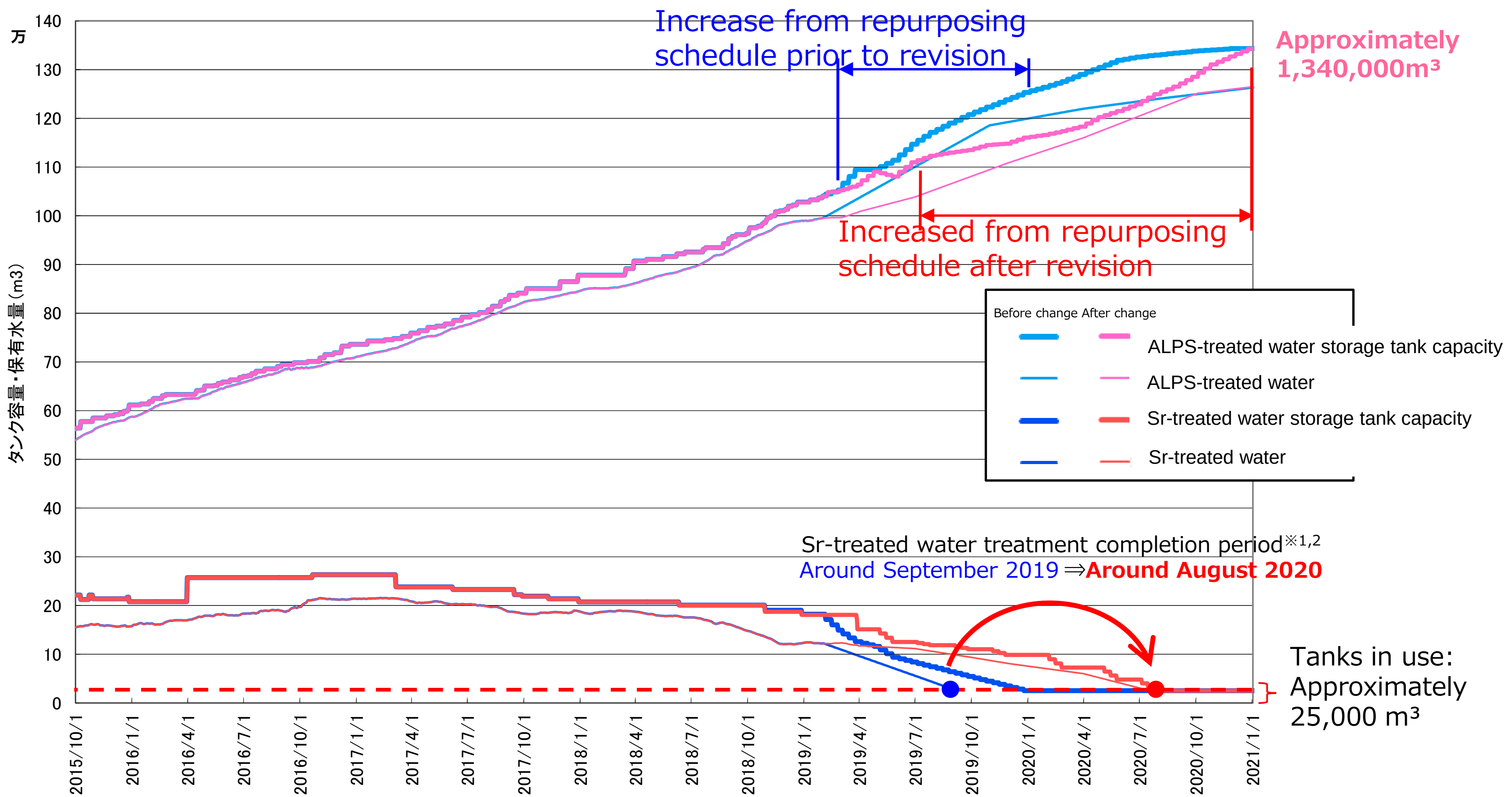
Residual water disposal	
Details	**Number of days**
Opening up side manholes	One day
Water sprayed inside tanks to clean them	Two days
Crud removal	Two days
Side manholes closed	One day

Repair and painting	
Details	**Number of days**
Surface prep	Two days
Repair/painting	Two days
Drying	Two days
Membrane thickness/plate thickness measurements	One day

- Furthermore, since residual radioactive substances are adhered to the inner surface of repurposed welded tanks, the radiation concentration of ALPS-treated water injected into these tanks may increase.

7. Future tank plan in light of hydrogen sulfide countermeasures

- The following is our future tank plan that takes into consideration hydrogen sulfide countermeasures and tank internal surface inspections/repair schedules
- As of the end of December 2020, ALPS-treated water storage tank capacity may be approximately 1,340,000m³ (no change)
- Treating of the Sr-treated water ※1 from inside repurposed welded tanks is expected to be completed around August 2020※2



※1 : Excluding Sr-treated water in tanks in use
※2 : Excluding residual water at the bottom of tanks

8. Status of use of flanged tanks/welded tanks

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- In regards to the future use of tanks, approximately 25,000m³ worth of tanks will be retained for water treated on a daily basis, and the remaining approximate 97,000m³ of tank space will be repurposed for ALPS-treated water storage. The expected completion of treatment of Sr-treated water remaining in the welded tanks to be repurposed is around August 2020.
- Welded tanks currently being used to store Sr-treated water will also be repurposed to store fresh water in flanged tanks. When repurposing these tanks, the transfer of water to welded tanks will begin around August 2019 with expected completion around September 2019 in accordance with hydrogen sulfide countermeasures and tank internal surface inspection/repair schedules.

＜ Tank water list ＞

As of April 4, 2019

Targets			Equipment capacity	Status	Treatment completion date	
Flanged tanks	Sr-treated water		Remaining water (approximately 2000m³)	Completed (some residual water being treated)	November 17, 2018	
	ALPS-treated water		Remaining water (approximately 2000m³)	Completed (some residual water being treated)	March 27, 2019	
	Fresh water (Temporary storage tank)		Approximately 12,000m³ [12 tanks]	To be transferred to welded tanks around August 2019※	Around September 2019	Date revised
Welded tanks	Sr-treated water	Tanks in use (temporary storage tanks)	Approximately 25,000m³ [24 tanks]	In use	—	
		Tanks in use other than those mentioned above (repurposed tanks) ⇒To be repurposed as ALPS-treated water tanks	Approximately 97,000m³ [105 tanks]	Draining commenced in December 2018	Around August 2020※	Date revised
	ALPS-treated water		Approximately 1,031,000m³ [763 tanks]	Water being stored	—	

※As of the 64th meeting of the decommissioning/contaminated water countermeasures team/secretariat (March 20, 2019)
Freshwater in flanged tanks "to be transferred from around May 2019," Sr-treated water in repurposed welded tanks, "to be completed around September 2019"

8. Conclusion

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- Results from tank internal condition inspections do NOT point to a "phenomenon where the speed of corrosion has been accelerated due to the presence of sulfate-reducing bacteria"

- Countermeasures to prevent the generation of hydrogen sulfide will be gradually implemented because work safety intake areas needs to be secured.
    - Sludge (including ferric chloride coagulates/deposits) in repurposed tanks (ALPS-treated water stored after Sr-treated water treated with ALPS) to be removed
    - Safety shall be guaranteed prior to draining Sr-treated water by, for example, continuing to restrict access other than at necessary times around the aforementioned tanks.

- As of the end of December 2020, ALPS-treated water storage tank capacity may be approximately 1,340,000m^3 (no change)

- Treating of the Sr-treated water ※1 from inside repurposed welded tanks is expected to be completed around August 2020

- The transfer of fresh water in flanged tanks to welded tanks will begin around August 2019 with expected completion around September 2019

【Reference】Analysis results of strontium-treated water in welded tanks
(reprinted from materials distributed during team/secretariat meeting on December 27, 2018)

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- As of October 30 the concentration of hydrogen sulfide in the G3-E1 tank was over 50ppm, however on December 13, when measurements were taken again in the same tank, no hydrogen sulfide was detected. (It is assumed that the hydrogen sulfide dissolved in the tank water and was gradually dispersed through the vent line)

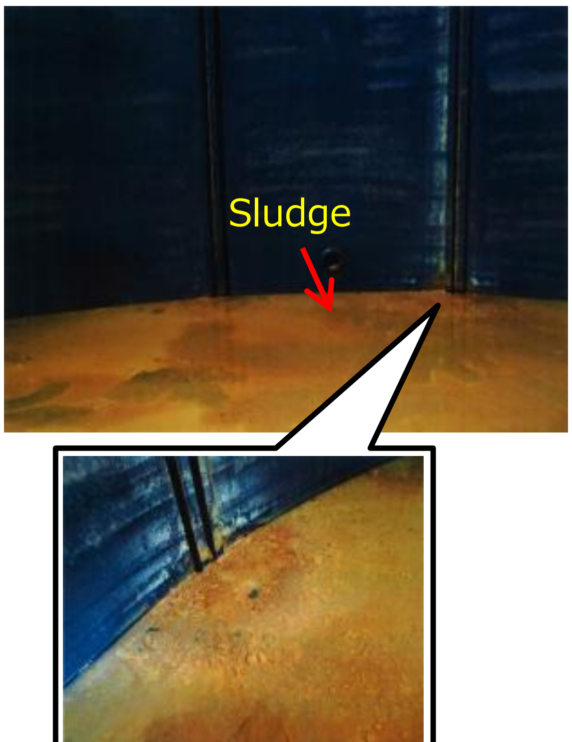
Sample Name	Sampling date	pH	CI		SS		COD		SO4		NA		Fe		TOC		Sulfate-reducing bacteria	
Sr-treated water tank-K2-B1 Middle layer	2018/10/22	7.9	560	mg/L	<1	mg/L	<1	mg/L	260	mg/L	370	mg/L	0.04	mg/L	1.7	mg/L	0	CFU/mL
Sr-treated water tank-K1-D1 Middle layer	2018/10/22	7.8	700	mg/L	<1	mg/L	<1	mg/L	320	mg/L	450	mg/L	0.006	mg/L	2.2	mg/L	0	CFU/mL
Sr-treated water tank--J1-B1 Middle layer	2018/10/26	8.4	950	mg/L	<1	mg/L	<1	mg/L	240	mg/L	570	mg/L	0.3	mg/L	1.1	mg/L	0	CFU/mL
Sr-treated water tank-H8-A1 Middle layer	2018/10/25	7.6	700	mg/L	<1	mg/L	<1	mg/L	150	mg/L	390	mg/L	0.4	mg/L	1.3	mg/L	0	CFU/mL
Sr-treated water tank-H8-B1 Middle layer	2018/10/25	7.8	850	mg/L	<1	mg/L	<1	mg/L	200	mg/L	480	mg/L	1.5	mg/L	2	mg/L	0	CFU/mL
Sr-treated water tank-D-B1 Middle layer	2018/10/26	8	1000	mg/L	<1	mg/L	<1	mg/L	240	mg/L	630	mg/L	0.003	mg/L	1.6	mg/L	0	CFU/mL
Sr-treated water tank-G3-E1 Upper layer	2018/11/1	7.1	1000	mg/L	3	mg/L	4	mg/L	360	mg/L	730	mg/L	0.25	mg/L	17	mg/L	0	CFU/mL
Sr-treated water tank-G3-E1 Lower layer	2018/11/1	7.1	1000	mg/L	110	mg/L	3	mg/L	370	mg/L	730	mg/L	26	mg/L	17	mg/L	0	CFU/mL
Sr-treated water tank-G3-F1 Middle layer	2018/11/2	7.4	1100	mg/L	<1	mg/L	<1	mg/L	360	mg/L	660	mg/L	1.6	mg/L	2	mg/L	0	CFU/mL
Sr-treated water tank-G3-G1 Upper layer	2018/11/5	7.1	950	mg/L	1	mg/L	2	mg/L	340	mg/L	570	mg/L	0.88	mg/L	6	mg/L	0	CFU/mL
Sr-treated water tank-G3-G1 Lower layer	2018/11/5	7.1	900	mg/L	580	mg/L	<1	mg/L	340	mg/L	570	mg/L	120	mg/L	4.9	mg/L	0	CFU/mL
Sr-treated water tank-G3-H1 Middle layer	2018/11/1	7.9	110	mg/L	<1	mg/L	<1	mg/L	54	mg/L	81	mg/L	0.14	mg/L	0.7	mg/L	0	CFU/mL

※ Organic decomposition by bacteria is promoted in environments where there is sulfate but not enough oxygen (anaerobic environment). Through decomposition the sulfate is reduced to sulfide ions thereby generating hydrogen sulfide.
※ Another investigation of bacteria (sulfate-reducing bacteria) will be conducted after revising measurement methods.

【Reference】 Results of internal surface inspection of tanks in which hydrogen sulfide was not generated and sulfate-reducing bacteria was not detected (G3-F4)

(Reprinted from materials distributed during team/secretariat meeting on February 28, 2019)

- In December of last year hydrogen sulfide was found inside welded tanks (G3 area-E1 tank) (announced to the press on December 12)
- Handling status
  - Based on the water analysis results of G-3 area tanks, tank G3-E5 was chosen as a reference tank because of its high concentration of suspended solids and relatively large amount of sulfate-reducing bacteria (refer to the next page)
  - In order to secure a transfer destination for water in the G3-E5 tank, neighboring tank G3-F4 was drained (no hydrogen sulfide was found in this tank).
  - After sludge at the bottom of the G3-F4 tank was removed, a visual inspection of the inside was conducted and it was found that the paint was intact throughout. However, scratches, blisters and paint chipping on welded surfaces was found. Going forward the aforementioned locations will be repaired and repainted.
  - In March, the G3-E5 tank will be drained and an inspection of the internal surface implemented



Prior to sludge removal

After sludge removal

【Reference】Selecting a reference tank for internal surface inspection (reprinted from materials distributed during team/secretariat meeting on February 28, 2019)

- Water from the bottom of the G3 area tanks was sampled in order to check the concentration of suspended solids (SS) and the amount of sulfate-reducing bacteria

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- The concentration of suspended solids was high and the number of sulfate-reducing bacteria was relatively large in the water at the bottom of the G3-E5 tank

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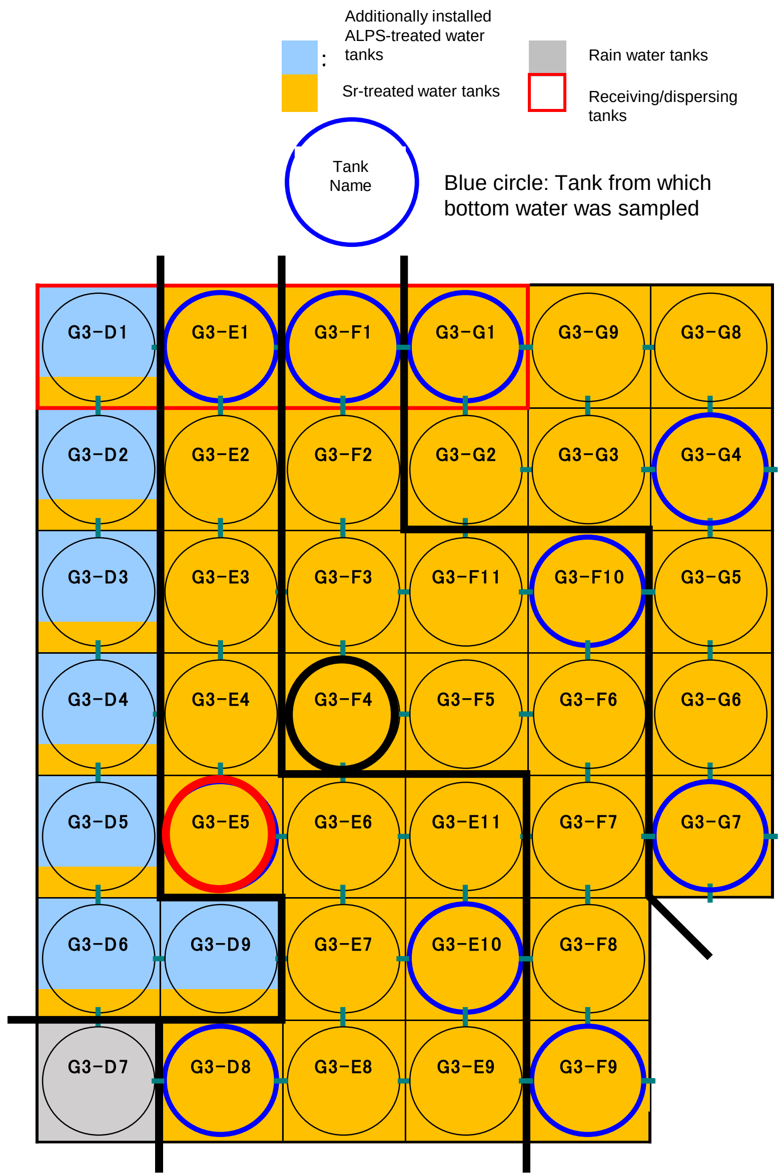
- An internal surface inspection was planned for the G3-E5 tank

Sample Name	pH	Cl [mg/L]	SS [mg/L]	SO4 [mg/L]	Fe crud [mg/L]	S [%]	TOC [mg/L]	Number of sulfate-reducing bacteria
G3-E1	7.5	1000	41	330	7.5	77	16	Low
G3-G1	7	1100	90	360	27	3.8	4.3	None
G3-F1	7.4	1400	53	390	16	3.8	1.8	None
G3-E5	7.4	1200	110	330	32	32	2.6	High
G3-D8	8	1400	2	190	1.2	6.9	0.8	None
G3-E10	7.4	1000	38	350	11	8.2	3.8	None
G3-F10	7.6	1400	72	450	22	3.8	7	None
G3-F9	7.7	1700	67	450	19	2.6	1.9	None
G3-G7	7.8	1000	30	290	13	4	2.4	Low
G3-G4	7.4	1000	73	290	25	5.1	2.7	Middle



【Reference】Usage status of other flanged tanks in use at Fukushima Daiichi

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Type of water being stored	Tank type	Number of tanks	Nominal capacity [m^3]	Date when put into use	Plan to use going forward
Treated accumulated water from Units 5, 6	Unit 5, 6 F area (H, I, J tanks)	21	299×3 508×18	May 2011	To be patrolled and continually used The number of tanks and the amount of water being stored to be decreased in FY2020 The bottom plates and side plate flanges of tanks that will continue to be used after this reduction have been subjected to preventive maintenance
	Unit 5, 6 F area (B tanks※2)	4	110×4	May 2011	To be patrolled and used continuously until the end of use in FY2019
	Unit 5, 6 F area (C tanks)	7	160×5 200×2	May 2011	To be patrolled and continually used Preventative maintenance has been performed on the bottom plates and side plate flanges
RO-treated water (fresh water)	Treated water buffer tanks (the for reactor injection)	1	1,000	2011/6	To be patrolled and continually used until replacement with welded tanks in FY2019
Rain water	Rainwater recovery tanks	9	600×9	2014/3	To be patrolled and continually used Preventative maintenance performed on the side plate flange of the first section Nine rain water recovery tanks and the five tanks before and after the RO unit will be taken out of service, and welded tanks will be used The five tanks before and after the freshwater making RO unit will be replaced with welded tanks or removed
	Mobile RO unit ・Rain water receiving tanks ・Treated water tanks	2 3	600×5	May 2014	
	Fresh water making RO unit ・Rain water receiving tanks ・Treated water tanks	2 3	600×5	May 2014	
ALPS-treated water	Existing ALPS sampling tanks	4	1,100	2013/4	To be patrolled and continually used Preventative maintenance performed on the side plate flange of the first section
Groundwater bypass	Groundwater bypass sampling tanks	9	1,000	2012/12	To be patrolled and continually used Preventative maintenance performed on the side plate flange of the first section