

About the completion of the countermeasure work to address the downward flow of strontium present in the soil in relation to the leak in H4 area tank

<Reference material>
Sept.11, 2014
TEPCO

- As a **preventive and multi-layered measure** to address the leaked water in H4 area, we have performed soil improvement on the downstream side (seaward side) of the leakage area using improvement additives (apatite, zeolite) since June 30 in order to control the downward flow of strontium as much as possible.
- It is scheduled that the soil improvement work using improvement additives will be completed by tonight.
- In the future, we will monitor the site through the existing observation holes.

【Situation of the work site】

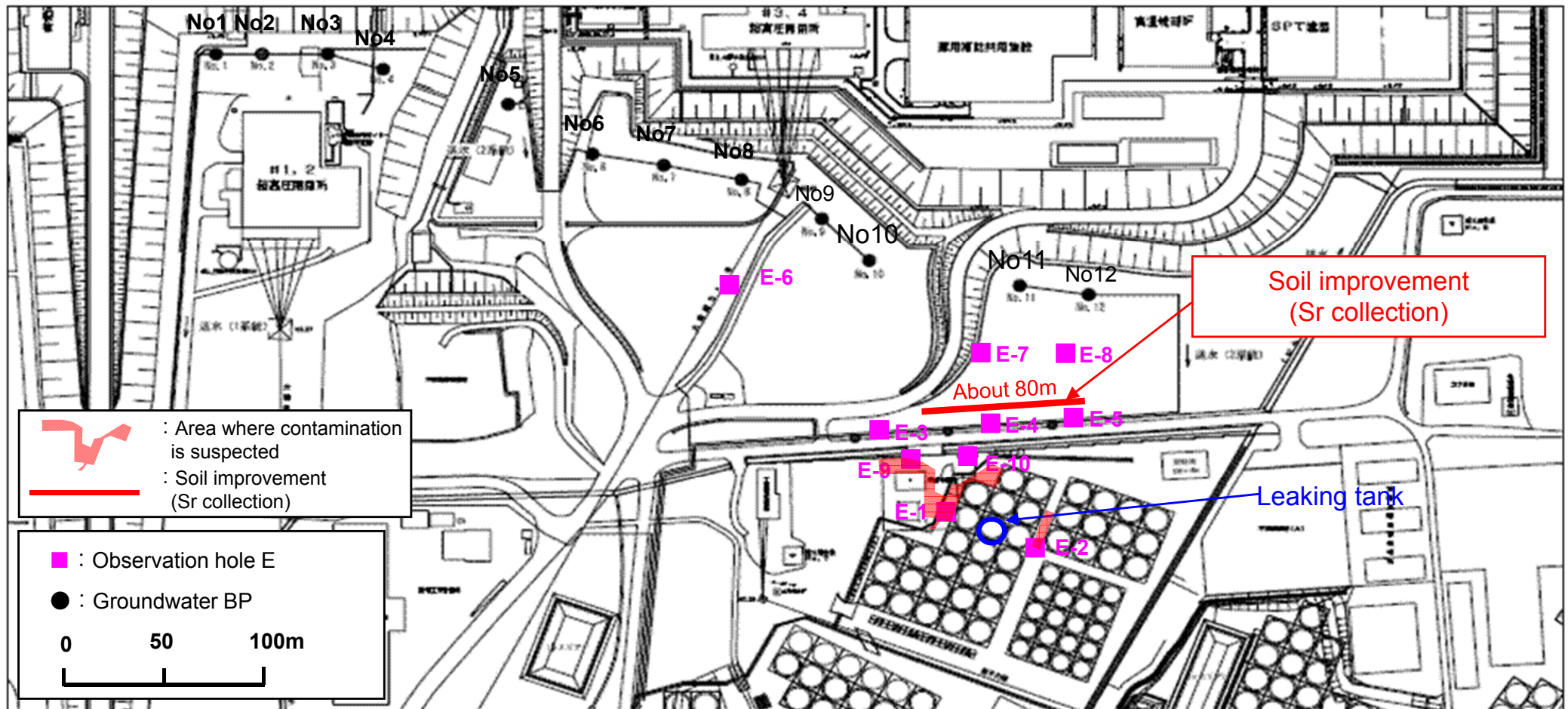


Filming date: September 10, 2014

Provided by: Tokyo Electric Power Company

Layout of the countermeasure

- Perform soil improvement on the eastern side of H4 area using improvement additives (apatite + zeolite + crushed stones), and aim to immobilize and control the downward flow of strontium.
- Locations for the countermeasure shall be determined in consideration of the downward flow range of leaked water etc.

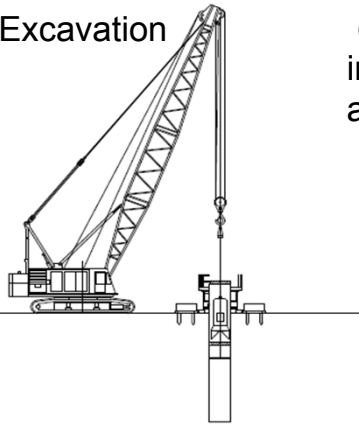


【Locations for the countermeasure】

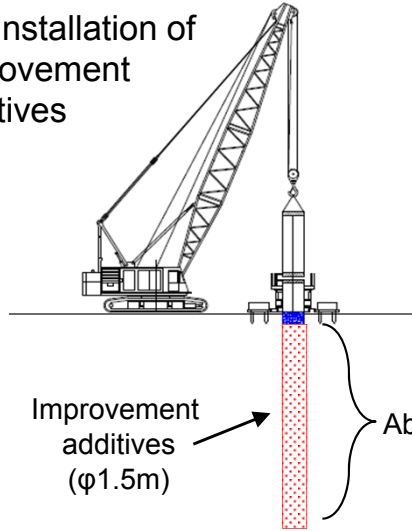
Outline of the work

- Soil improving method: After excavation using a entire perimeter excavator, improvement additives (apatite + zeolite + crushed stones)* are installed.
- Size of improvement additives: 1.5m in diameter, about 20m in depth, in staggered arrangement (considering workability and groundwater flow)
- Range of the measure: About 80m

(1) Excavation



(2) Installation of improvement additives

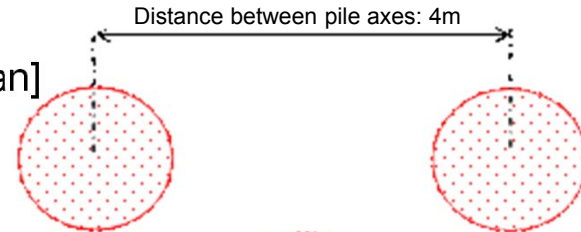


Improvement additives (φ1.5m)

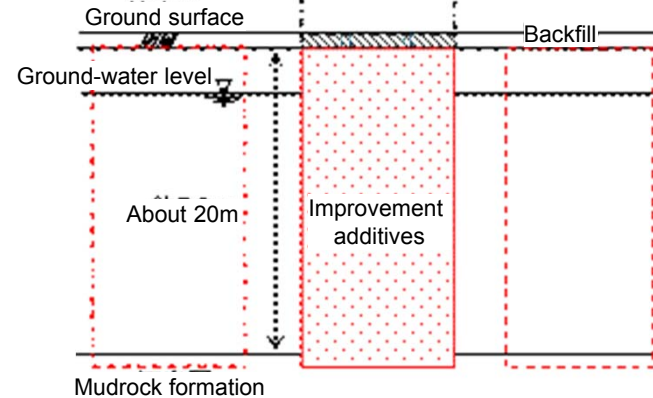
About 20m

*(Weight ratio) Crushed stones: apatite: zeolite = 100 : 5 : 30

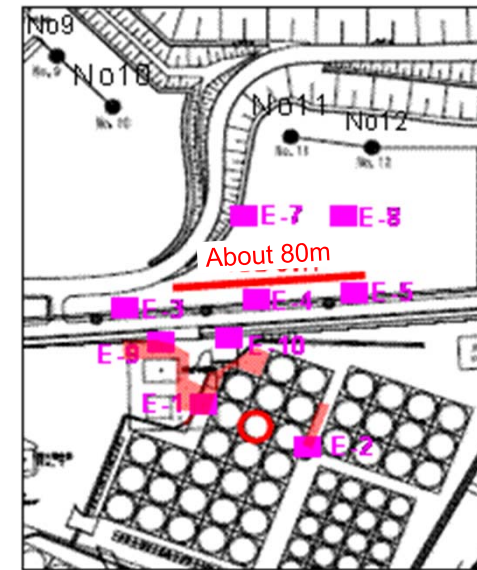
[Ground plan]



1.5m in diameter



[Cross section]



[Range of the measure]



Excavated status



Improvement additives

[Work method (Entire perimeter excavation)]

Immobilization of strontium in the ground at the Fukushima Daiichi Nuclear Power Station --Contaminated soil and groundwater remediation technology using apatite and zeolite --



Tokyo Electric Power Company: Yasuhiro Aikyo, Satoshi Shimura, Yasuyuki Mizunashi, and Motoi Kawanishi
Central Research Institute of Electric Power Industry: Takatoshi Hijikata, Shingo Yokoyama, and Tadafumi Koyama
Taisei Corporation: Kouji, Suami, Masanori Shimomura, Yasunobu Tsukahara, Makoto Ono, and Yuji Ijiri
CH2MHILL
Scott McKinley, Nathan Bowles (now, belongs to PBS Engineering and Environmental)

Objective

Since contaminated water leaked from tank in H4 area to its surrounding ground in August, 2013, TEPCO is recovering contaminated soil in the area and pumping groundwater to prevent the expansion of the soil pollution. This measure is added as multilayered measure to prevent the expansion of the soil contamination to downstream area by constructing the permeable reactive barrier (PRB) in the ground in the water-leaked area to capture radioactive strontium (Sr-90) in flow of contaminated water.

Basic concept

The PRB consists of the material capturing strontium and that has high permeability to let groundwater go through positively.

■ Selecting strontium adsorbent

As strontium adsorbent, apatite is adopted in the Hanford Site, and zeolite (clinoptilolite) in West Valley City, USA.

After having adsorbed strontium, apatite is known to have a characteristic to be gradually taking strontium into structure with progress of the time, and to adhere (not detached). As for zeolite, it is said that adsorption performance is high, but adherence performance is lower than that of apatite.

Then we are going to use the mixture of apatite and zeolite. This method expects apatite of adherence performance.

And for safety factor improvement, it also expects reduction of concentration of strontium in front and rear sides of PRB by adsorption of zeolite and adherence promotion effect of apatite with transportation delay in the piles.

■ Method selection

For soil improvement methods using apatite, there are two types, the solution and powder. In the Hanford Site, in the solution method, they injected solutions of sodium phosphate and citric acid calcium to the soil and precipitated apatite compound in the ground. And in the powder method, they mixed bone powder of cow or fish mechanically and stirred them in the ground.

In the measure, we adopt purification pile method (powder model), as waiting method in downstream containing strontium, mixing zeolite, and well-known for its reliability due to its many actual instances in contaminated soil purification in Japan.

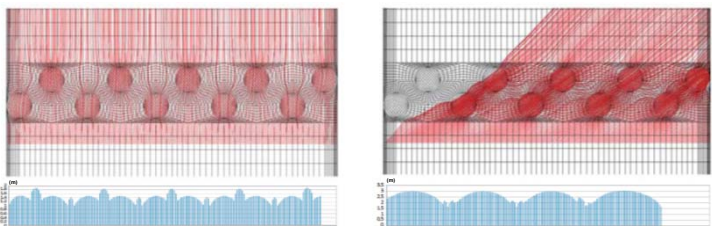
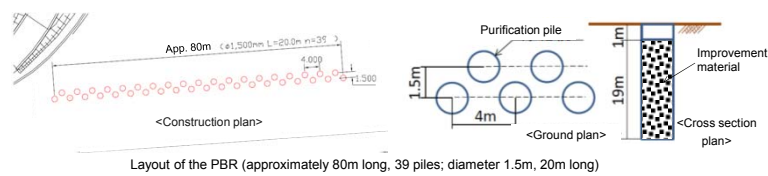
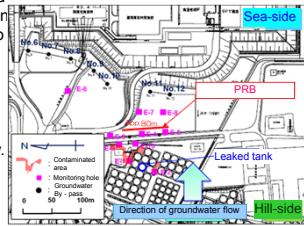
Design of the PRB

■ The place of the PRB

Due to survey of groundwater level and groundwater flow direction, it is known that groundwater flows from hill-side to sea-side. Therefore the PRB is laid for 80m long at the downstream of contaminated area in a direction perpendicular to the direction of groundwater flow.

■ Specifications of the PRB

For the PRB, 39 piles (1.5m across) were designed in a staggered in two lines. Based on groundwater analysis, the interval between piles in the same row is 4m, and between rows is 1.5m related to permeability coefficient of ground and piles so that all groundwater which flows from upper stream flows into piles. According to the analysis, inflow of groundwater will run in the pile over 1m at least. And the PRB targets the middle grain sandstone layer permeability of which is high. Pile is 20m deep, so that it reaches the mudstone layer permeability of which is low.



Groundwater path line and extension distance in piles based on groundwater analysis (angle of the PRB to the groundwater flow direction : left: 90 degree, right: 45 degree)
Permeability coefficients are set as below conservatively based on an actual value.
Ground : 3.0×10^{-5} m/s (medium-grained sandstone), Pile : 1.0×10^{-3} m/s.

Process and schedule

As for July, 2014, the PRB is under construction. And it will be completed at the end of September in the same year. After that, monitoring will be carried out on the upper and lower stream side of the PRB and the collection effect of PRB will be verified.



Material design

■ Material selection (screening)

Size 7 crushed stone (diameter: 2.5 - 5mm) was adopted for base material to raise the permeability of the pile.

As for apatite, based on the batch test targeting several kinds of natural and synthetic materials, pig bone powder (steamed at 180 degrees Celsius) was adopted, because of its adsorptive capacity (large distribution coefficient), availability and inexpensiveness.

As for zeolite, based on the batch test targeting several kinds of natural and synthetic materials, domestic nature clinoptilolite was adopted because of its large distribution coefficient and availability. And the size of clinoptilolite was determined from 1 to 3mm in diameter to enter the gap of the crushed stone.

Measured distribution coefficient [unit: mL/g]
The solute for distilled water and apatite was calcium ion water (0.001M), and the initial concentration of strontium was 10mg/L.

kind of apatite	measurement condition		availability	kind of material	measurement condition	availability	
	distilled water	Ca = 0.001M					distilled water
natural	cow bone (fine grain)	10	○	crushed stone	size 7 crushed stone	35	
	cow bone (rough grain)	4,700	1,100 x	soil	medium-grained sandstone (generated at the site)	25	
	pig bone (powder)	1,500	300 ○		clinoptilolite (Shimane)	26,000	△
synthetic	hydroxyapatite	890	72 x	natural zeolite	clinoptilolite (Futatsui product)	240,000	○
	hydroxyapatite slurry	1,480	140 x		artificial zeolite	83,000	△
	tricalcium phosphate	710	120 △	synthetic zeolite	type-X zeolite	1,100,000	x
	tricalcium phosphate	620	110 △				
	solution	316	490 x				

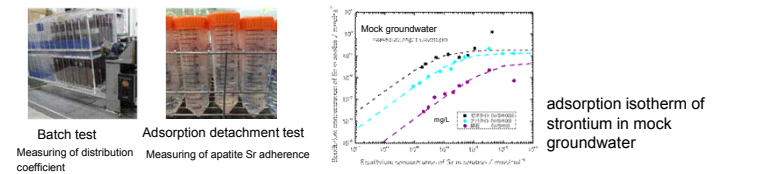
■ Composition of material

● Apatite $[Ca_{10}(PO_4)_6(OH)_2]$; molecular weight: 1004.62

From a result of desorption test after strontium adsorption, the quantity of strontium incorporated into the structure of apatite is 8.5mg/g (corresponding to approximately 0.1mol (strontium) to 1mol (apatite)). In the leaked 300t of contaminated water, radioactive Sr and seawater originated stable Sr were contained about 6g and about 600g at the respectively. Groundwater* also contains 0.3mg/L of stable strontium.

*main components of groundwater; Na+=41, Ca2+=14, Mg2+=13, Sr2+=0.3 (unit: mg/L)

Assuming that apatite has the incorporation ability described above, a weight composition rate of apatite to crushed stone is determined as 5% so as to adsorb all Sr flowing into the PRB at the true velocity of 0.1m/day for a long period.



● Zeolite

Since adsorption property of zeolite is affected by sodium ion contained in groundwater, the batch test is conducted using synthetic groundwater having same chemical components as the real site (Na+=48, K+=22, Mg2+=21, Ca2+=28[mg/L]) and the adsorption isotherm with variable Sr concentration is acquired. If groundwater is continuously flowing into the PRB (Equivalent PRB-thickness = 0.883 m) and the condition of strontium concentration is 0.3mg/L, 30% compound by zeolite achieves adsorption performance of more than ten years. And zeolite itself has enough delay effects that can decrease the concentration rate by 90% after the permeation. Therefore the compounding ratio was determined to be 30%.

● Final composition of each material

From the above consideration, composition ratio in a moss is determined as follows. Crushed stone: Apatite:Zeolite = 100:5:30. Besides the materials injection test under water is carried out in order to confirm the quality of material composition under the condition of real site. From the result, the final composition rate of Crushed stone:Apatite:Zeolite is determined as 100:10:35 by considering the variation in composition ratio of adsorption materials in a pile. The list of distribution coefficient measured using synthetic groundwater is shown below (initial strontium concentration: 0.3mg/L). And we are measuring the adsorption properties of improvement material in column test.



Measured distribution coefficient [unit : mL/g]

	Local soil	size 7 crushed stone	apatite	zeolite	Improved materials
Distilled water	25	750	1,200	62,000	13,000
Synthetic groundwater*	24	9	150	1,400	370

*Component of synthetic ground water: Na+=40, Ca2+=15, Mg2+=15 [mg/L]

Prediction analysis

Assuming that the volume of subsurface contaminated water plume is 732m³ (=volume of leaked water 300m³ / porosity 0.41), initial Sr concentration of leaked water is 10⁸Bq/L, the groundwater true velocity is 0.1m/day and the distance between contaminated region and the PRB is 20 meter and the distribution coefficient of improvement material is 370mL/g, an advection-dispersion transport analysis is conducted for radionuclide Sr.

From the result, it is found that the Sr concentration of downstream side is lower than 1.0Bq/L even after 10 years and thus the retardation effect of PRB is quite significant. It is planned to evaluate the adsorption rate and incorporation rate of improvement material by column test for enhancing the accuracy of analysis.

