Workshop on Radiation Exposure Control
at TEPCO's Fukushima Daiichi Nuclear Power Plant, etc.

Efforts for Reducing Radiation Exposure during Facing Construction of Slope Areas (Unit 1 to Unit 4)

10 November 2015

Shimizu Corporation

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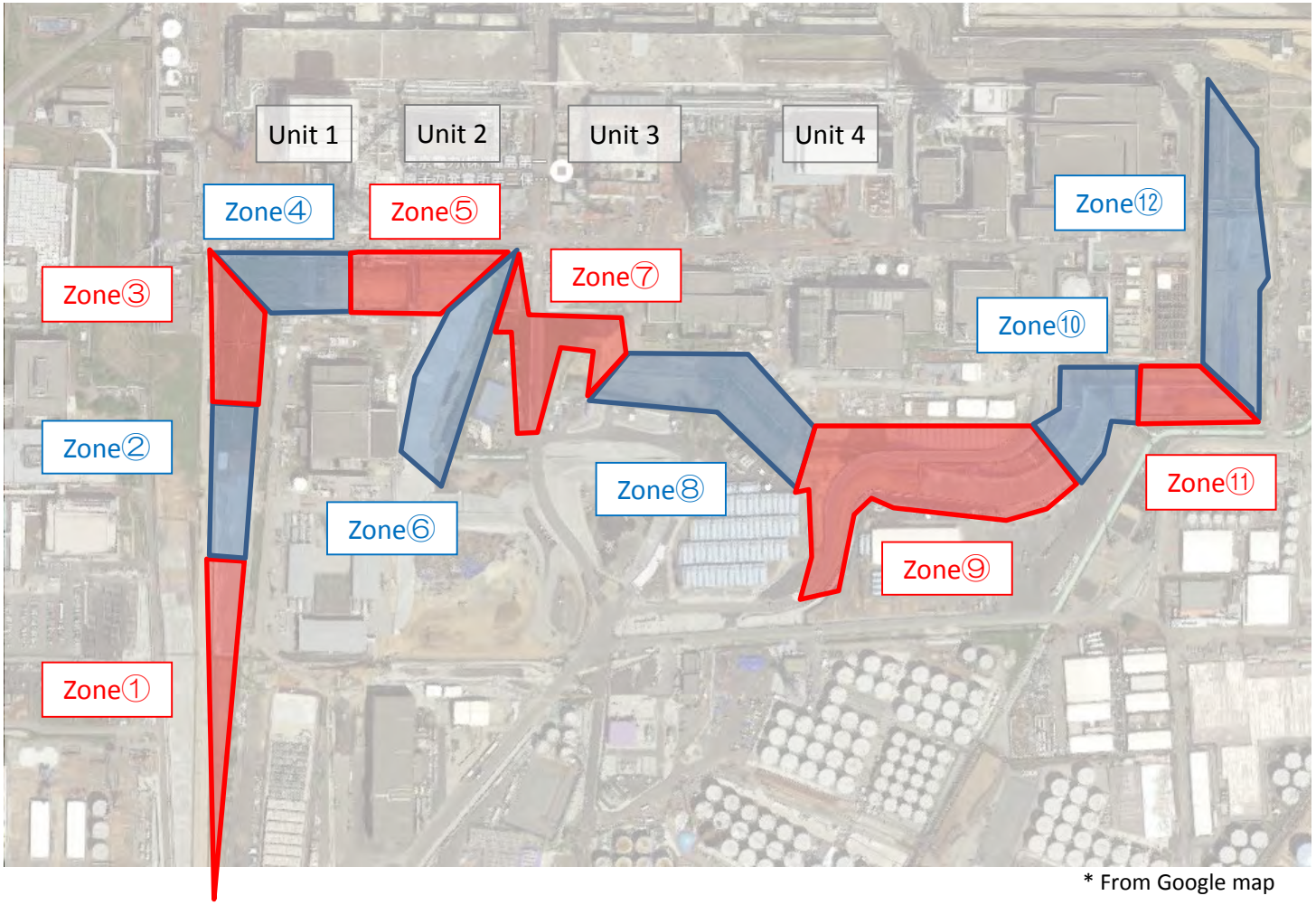
1. Outline of the work

- Name: Fukushima Daiichi NPP Facing Construction
- (slope areas from the buildings at Units 1–4)
- Period: April 2014 to December 2015 (21 months)
- Area covered in the work: 45,550 m^2



* From Google map

Zone Number	Area (m^2)
①	4,695
②	3,367
③	3,215
④	1,573
⑤	1,303
⑥	2,799
⑦	1,057
⑧	5,664
⑨	5,497
⑩	4,181
⑪	3,213
⑫	8,985
Total	**45,549**

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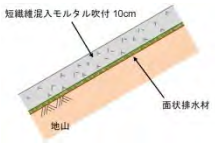
1. Outline of the work

Work flow diagram

Investigation/design ▶ **Removal of debris** ▶ **Weeding/felling trees**

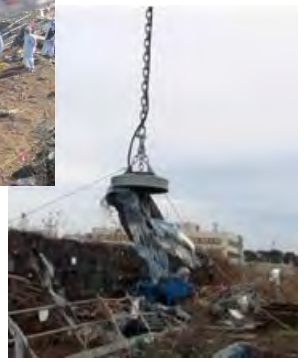


吹付け前線量（mSv/h）	吹付け厚（cm）低減率					
	5	10	15	20	25	30
	57%	79%	89%	92.3%	95.7%	99%
0.3	129	63	33	23	13	3
0.2	86	42	22	15.3	8.7	2
0.1	43	21	11	7.7	4.3	1
0.05	21.5	10.5	5.5	3.8	2.2	0.5
0.03	12.9	6.3	3.3	2.3	1.3	0.3
0.02	8.6	4.2	2.2	1.5	0.9	0.2
0.015	6.45	3.15	1.65	1.2	0.7	0.15
0.01	4.3	2.1	1.1	0.8	0.4	0.1

※20cmと30cmは安全側に内挿して算出

吹付け重量（kg/m²）	105	210	315	420	525	630

※吹付モルタルの単位体積重量＝2,100kgf/m³



Removal of top soil /leveling ▶ **Construction of a drainage system** ▶ **Shotcrete**

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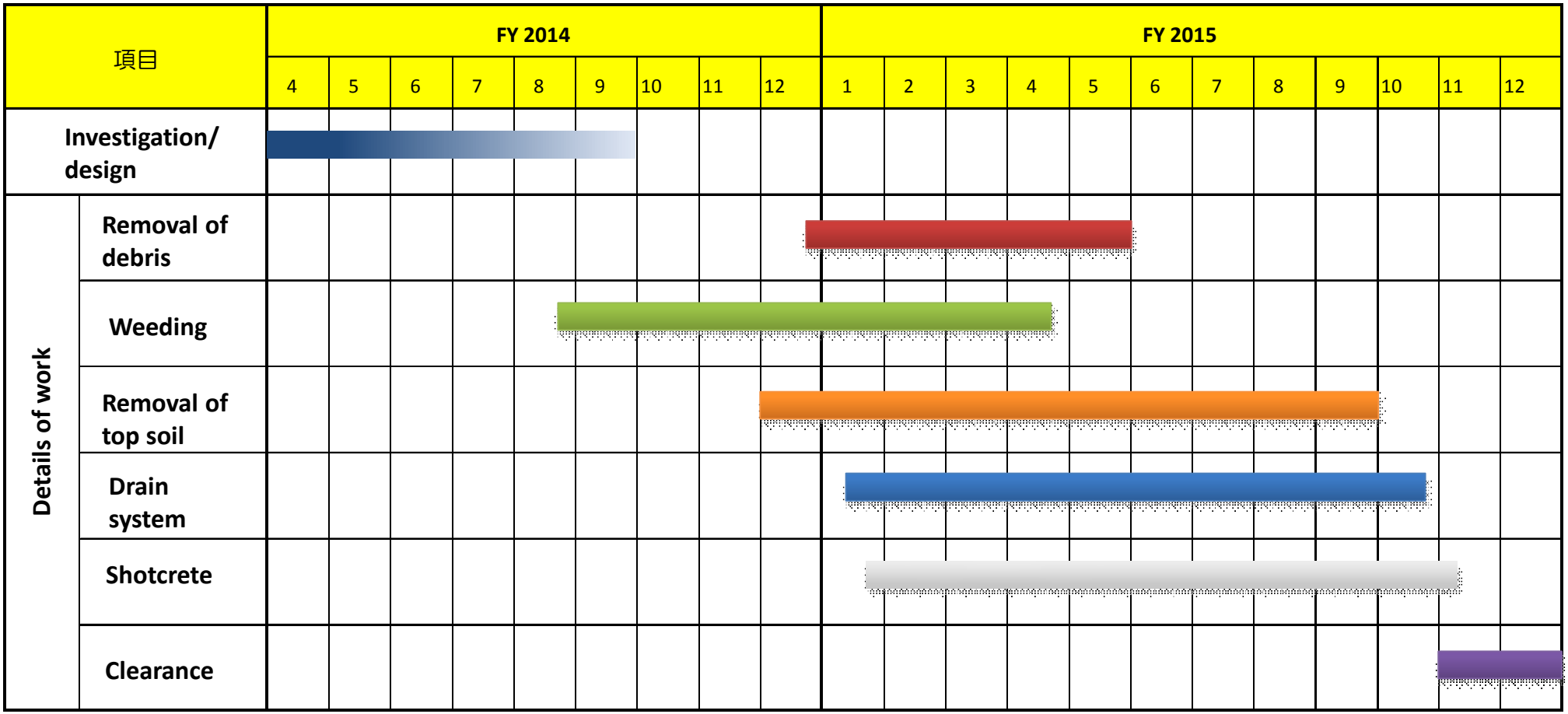
1. Outline of the work

Schedule



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2. Issues and goals of this work

【Issue 1】 High radiation dose at work areas

- There is an area where the radiation dose on the ground surface (1 cm from the ground surface) is 3 mSv/h or higher (part of Zone④, as of April 2014).
- A large quantity of debris with high radiation, distributed after the earthquake, still remain. (Zone③ to Zone⑧）。
- Work hours are restricted due to the works conducted in the high radiation areas.

【Issue 2】 Handling of interfering materials in, top and bottom of the slope, as well as the coordination with other construction works

- There are many transport pipes, piping, and lines in use installed after the earthquake on the slope, which require switching, relocation, and/or protection when implementing the construction
- Detailed coordination is necessary with other works.

【Goal 1】 Surface radiation ≤ 5 μSv/h after the construction

- Setting the amount of the topsoil stripping and shotcrete thickness in accordance with the target surface radiation of 5 μSv/h or lower after shotcrete.

【Goal 2】 Reduction of radiation exposure of workers

- Select and take measures to reduce radiation exposure of workers during the construction work.

Engineering measures

- **Decontamination** Reduction of surface radiation dose by removing debris and topsoil
- **Improving efficiency** Shielding and reduction of surface radiation dose by shotcrete
- **Improving efficiency** Removal of debris using a lifting magnet
- **Automation** Removal of top soil by remote operation of the RCM (Rock Climbing Machine)
- **Improving efficiency** Shotcrete using a spray robot

Decontamination

Shielding

Improving efficiency

Automation

Improving efficiency

Administrative measures

- **Shielding** Wear a shielding vest

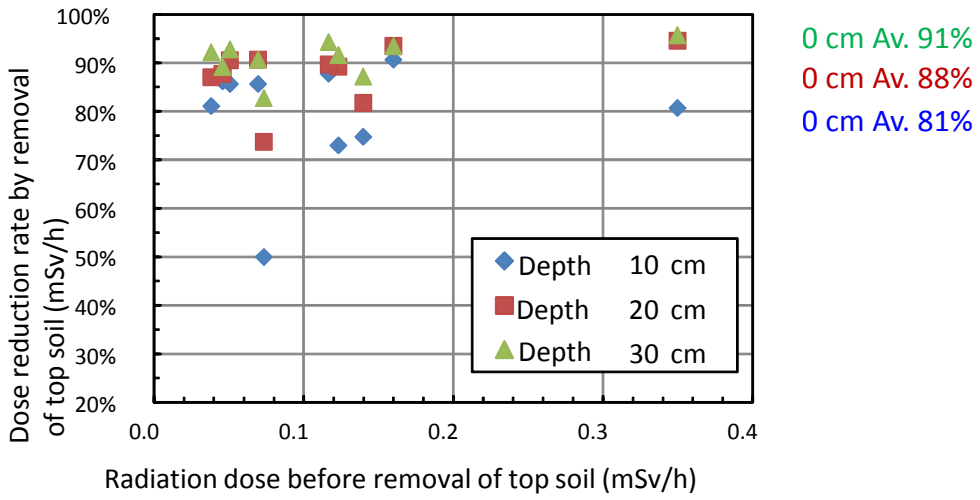
Shielding

Engineering measures ① Decontamination

■ Dose reduction effects of the removal of the top soil

Results of radiation dose measured before and after the removal of the top soil at each zone

Measured zone	Dose before the removal (mSv/h)	Dose after the removal			Dose reduction of the removal		
		10 cm (mSv/h)	20 cm (mSv/h)	30 cm (mSv/h)	10 cm	20 cm	30 cm
Zone①	0.038	0.007	0.005	0.003	81%	87%	92%
Zone②	0.123	0.033	0.013	0.010	73%	89%	92%
Zone③	0.350	0.068	0.019	0.015	81%	95%	96%
Zone⑥	0.073	0.037	0.019	0.013	50%	74%	83%
Zone⑦	0.140	0.035	0.026	0.018	75%	82%	87%
Zone⑧	0.160	0.015	0.011	0.011	91%	93%	93%
Zone⑨	0.117	0.014	0.012	0.007	88%	90%	94%
Zone⑩	0.070	0.010	0.007	0.007	86%	91%	91%
Zone⑪	0.046	0.006	0.006	0.005	86%	88%	89%
Zone⑫	0.046	0.006	0.006	0.005	86%	88%	89%
Zone⑬	0.051	0.007	0.005	0.004	86%	91%	93%
				average	80%	88%	91%



$$\text{Dose reduction rate (\%)} = \frac{Dose\ before\ removal - Dose\ after\ removal}{Dose\ before\ removal}$$

Significant reduction of radiation dose by removal of the top soil

Engineering measures ②Shielding

■ Shielding by shotcrete

Shotcrete thickness : 10 cm (thickness found in general)

Relationship between thickness of the shielding material and the shielding effects

Thickness of soil	Shielding effect	Thickness of concrete	Shielding effect
5 cm	51% Reduction	5 cm	57% Reduction
10 cm	74% Reduction	10cm	79% Reduction
15 cm	86% Reduction	15cm	89% Reduction
30 cm	98% Reduction	30cm	99% Reduction

【From Guideline of contamination conducted by municipalities (Nuclear Emergency Response Headquarters, 26 August 2011)】

Reduction of radiation dose by 79% with shotcrete thickness of 10 cm. (considering mortar ≒ concrete)

Before shotcrete (mSv/h)	Shotcrete thickness(cm) Reduction rate					
	5	10	15	20	25	30
	57%	79%	89%	92.3%	95.7%	99%
0.3	129	63	33	23	13	3
0.2	86	42	22	15.3	8.7	2
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0.015	6.45	3.15	1.65	1.2	0.7	0.15
0.01	4.3	2.1	1.1	0.8	0.4	0.1
Weight of shotcrete (kg/m^2)	105	210	315	420	525	630

* The values in the table for 20 cm and 30 cm are those calculated by conservative interpolation.

* Unit weight of shotcrete ＝ 2,100 kgf/m^3

Calculate the values of radiation dose (after topsoil stripping) which would realize the target surface radiation dose of 5 μSv/h or lower after shotcrete.

Then,

Decided to check if the surface radiation dose after topsoil stripping (before shotcrete) is 0.02 mSv/h or lower.

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Engineering measures ③Improving efficiency

■ Removal of debris using lifting magnets

Efficient removal of high radiation debris left on the slope using lifting magnets

Debris
- Consist of many steel outer walls of buildings including those highly contaminated
- Distributed widely on the slope near the buildings of Unit 1 to Unit 2 (Zone③–⑤)

Attempted to increase efficiency in the collection of the widely distributed debris using a magnet lifted by a crane. Moreover, remote recovery contributed to radiation exposure reduction.

* The lifting magnets are used in general for transporting iron scrap at iron-making factories, etc.

Large electromagnet

Removal of debris

Exporting debris

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Engineering measures ④Automation

Topsoil stripping by remotely operated RCM (Rock Climbing Machine)

Topsoil stripping was conducted by remotely operated RCM in the high radiation areas.
(west side from the buildings Unit 1 to Unit 2).

Radiation exposure dose of the RCM operator is high in the high radiation areas.

Remote operation of the RCM. The operator handles the RCM remotely from a low radiation area with the assistance of a screen view from a camera installed at the driving seat of the RCM, which contributes to radiation exposure reduction.

RCM operating unattended

Operation of RCM from a remote room

Appearance of the operation room

Engineering measures ⑤Improving efficiency

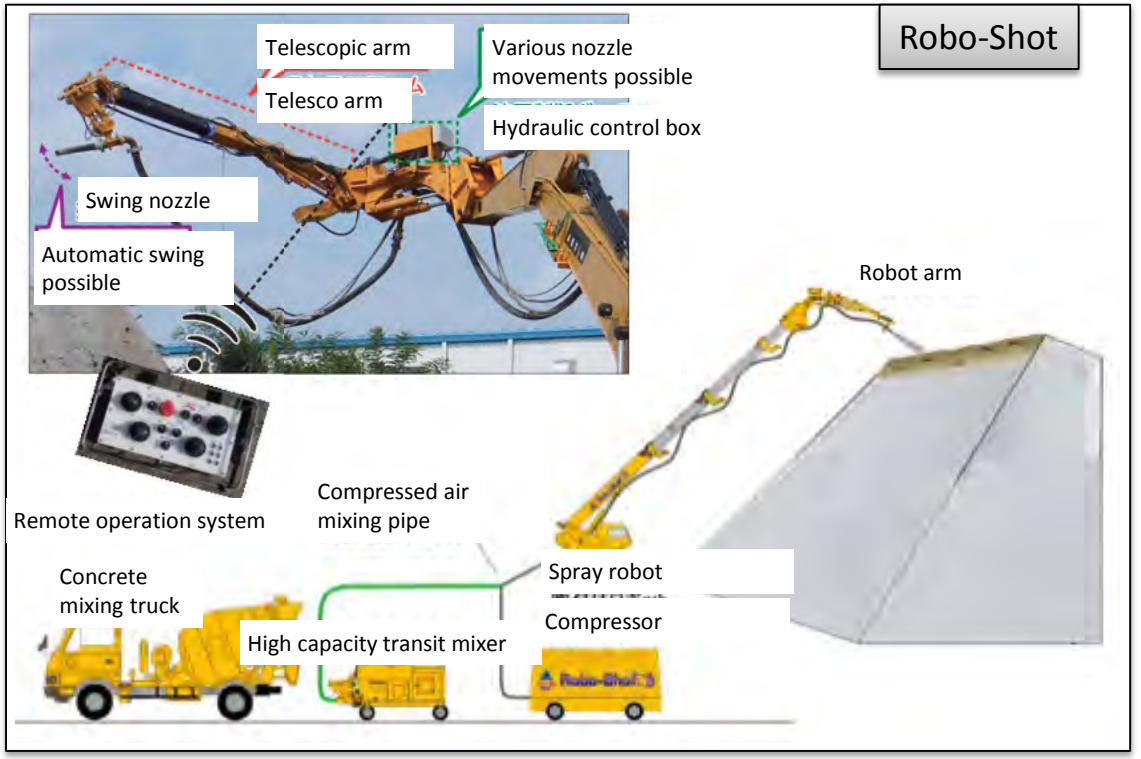
■ Improvement of efficiency of shotcrete with a spray robot

Improvement of efficiency of shotcrete with a spray robot (Robo-Shot)

Mechanization of shotcrete for areas where a spray robot can be placed on the slope (3–5 times as efficient as work conducted by humans).

→ Significant improvement in efficiency. Contribution to radiation exposure reduction of workers by the adoption of remote operation.

Shotcrete with a Robo-Shot



Administrative measures ①Shielding

■ Wearing a shielding vest

Workers wear a shielding vest in the high radiation areas.

Workers wear a shielding vest in the high radiation areas.

→ Contributed to radiation exposure reduction of workers by shielding from gamma rays.

Shielding vest worn by a worker (biorubber RSM)

Shielding mainly for the upper half of the body.

BIORUBBER RSM
E-400 Type 11

Features of the BIORUBBER RSM

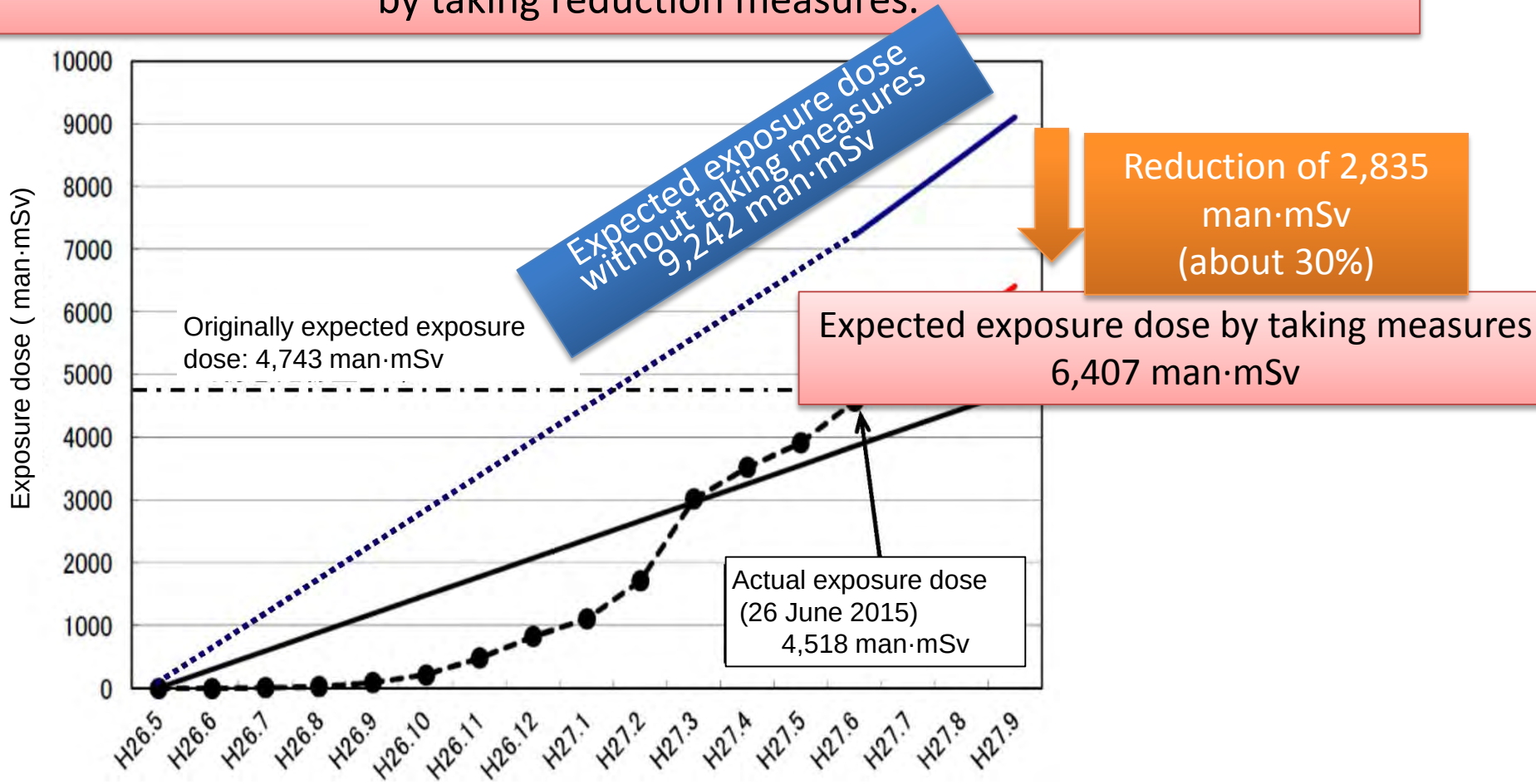
Structure	Rubber, fiber complex + heavy metal
Strength	Stronger than rubber, fiber complex
Durability	No change for 10 years or more
Processability	Possible to cut with scissors or cutters
Functionality	Possible to fold and easy to carry
Flexibility	Possible to install at uneven places
Washability	Possible by surface processing
Use	Floor, ceiling, wall, vehicle

Example of structure

* The gamma-rays shielding factor is 4.4% as the catalog information (measurement of gamma-rays from cesium 137)

4. Summary: Effects of measures for radiation exposure reduction

The exposure dose of workers was reduced by about 30%
by taking reduction measures.



* Extracted with some modifications from “Actions for Reducing Exposure Dose during the Facing Construction (Slope Areas at Unit 1 to Unit 4)” (16 July 2015)

The END

Thank you for your attention