About Reducing Radiation Exposure Dose Rates on the Refueling Floor of the Reactor Building for Unit 3

14 November 2016

Fukushima Daiichi Architectural Work Office,
Kajima Corporation

Contents

1. Introduction

[Objective]

As preliminary work to remove the fuel from the spent fuel pool for Unit 3, reduction of dose is inevitable for the manned work to be possible on the operation floor of Unit 3, which collapsed as a result of the hydrogen explosion.

[Flowchart of the work to be completed before the commencement of the fuel removal] The work marked with * is to be carried out by other companies.

Construction of the temporary lower platform for demolishing the upper debris

↓

Removal of the upper debris and the fuel exchanger in the pool*

↓

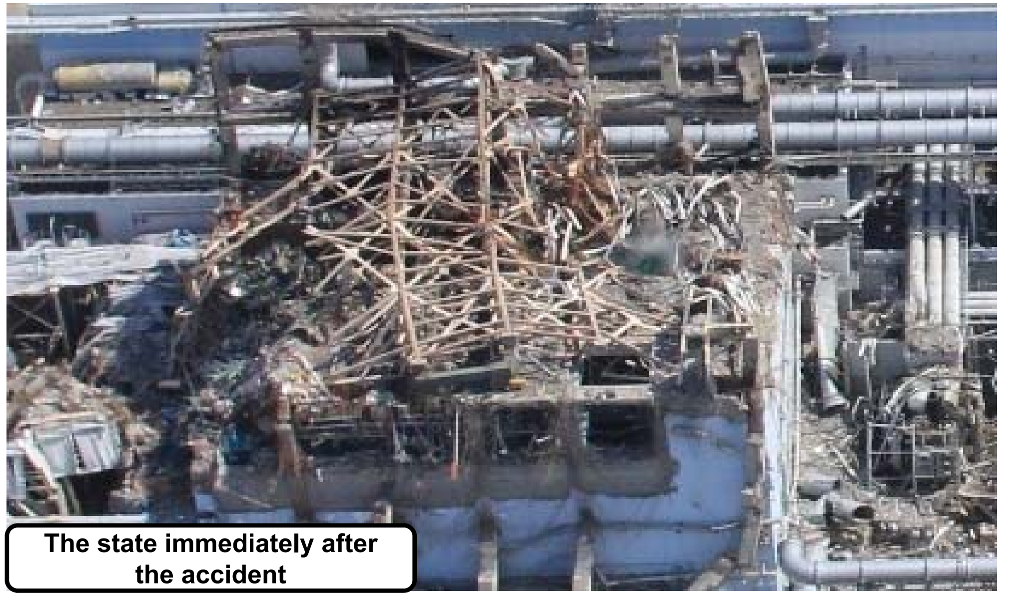
Dose rate reduction (decontamination and shielding)

↓

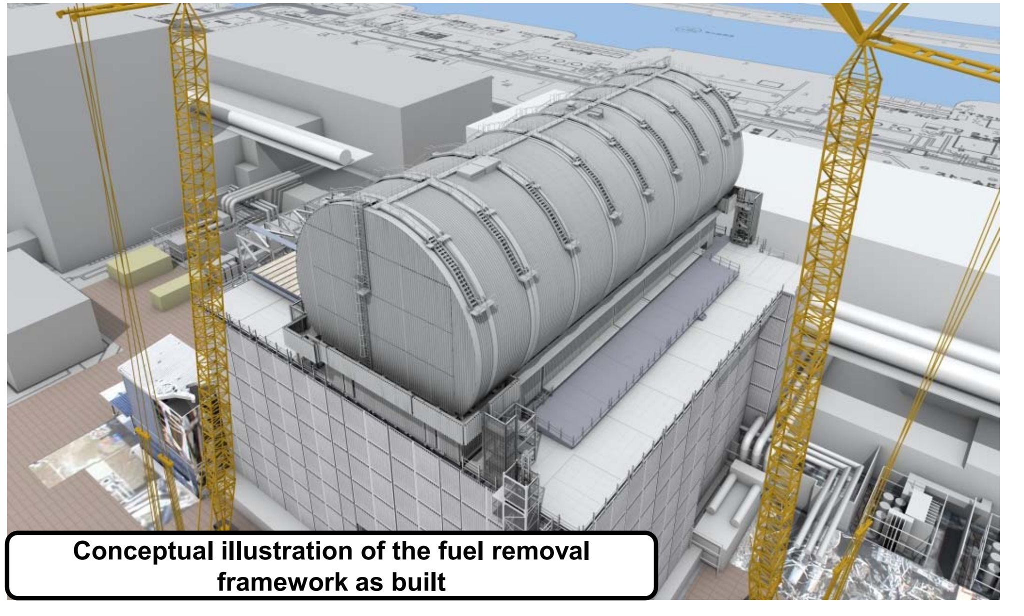
Installation of the fuel extraction cover and the fuel handling equipment*

↓

Commencement of fuel removal*



The state immediately after the accident

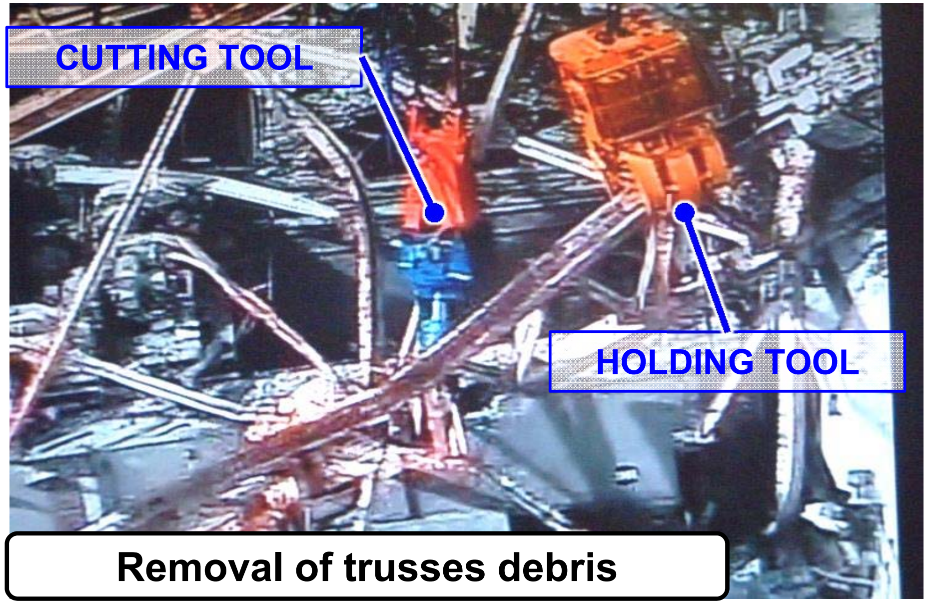


Conceptual illustration of the fuel removal framework as built

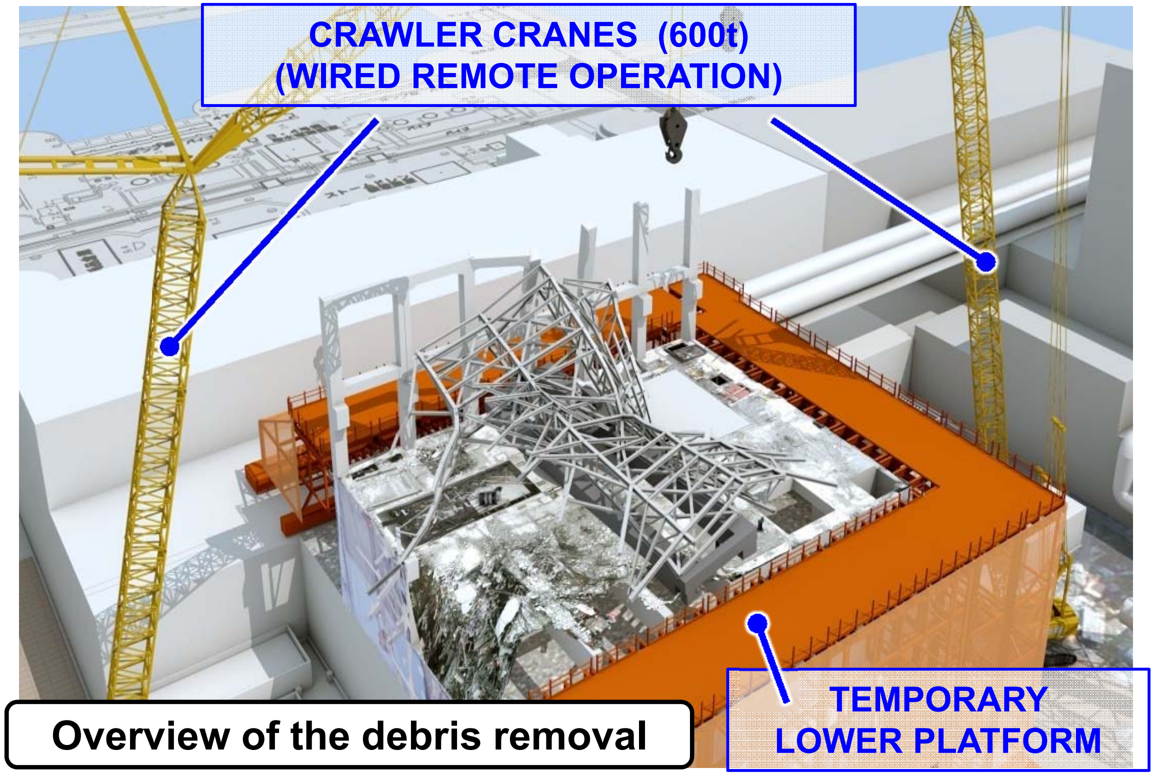
1. Introduction

[Overview of the debris removal (1)]

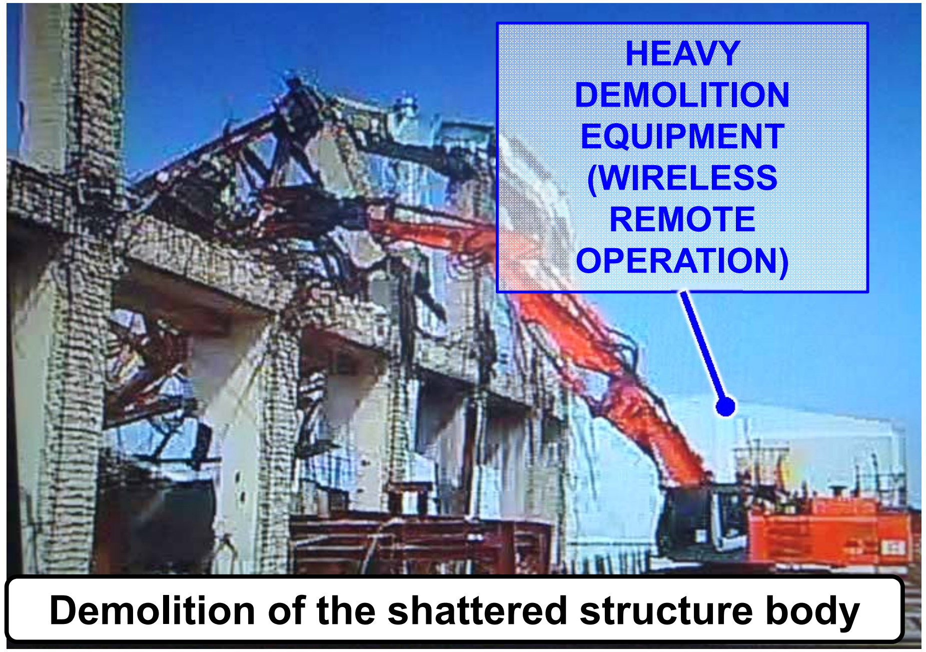
The trusses were demolished and their debris was removed using 2 large crawler cranes and heavy demolition equipment deployed on a temporary lower platform. Both the cranes and the heavy demolition equipment were remotely operated.



Removal of trusses debris



Overview of the debris removal

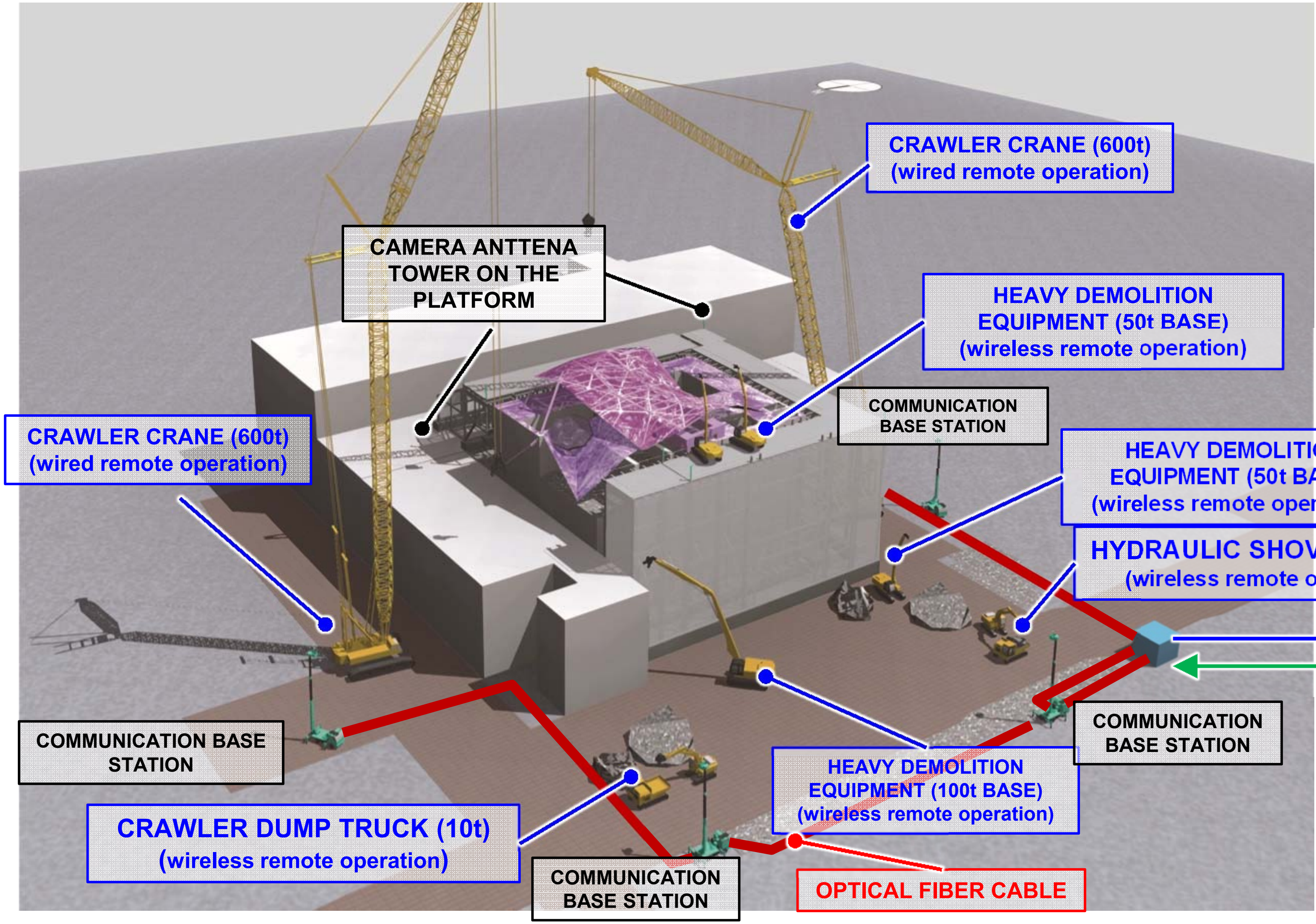


Demolition of the shattered structure body

1. Introduction

[Overview of the debris removal (2)]

Overview of the remote operation system



REMOTE OPERATION ROOM (SEISMICALLY ISOLATED KEY BUILDING)

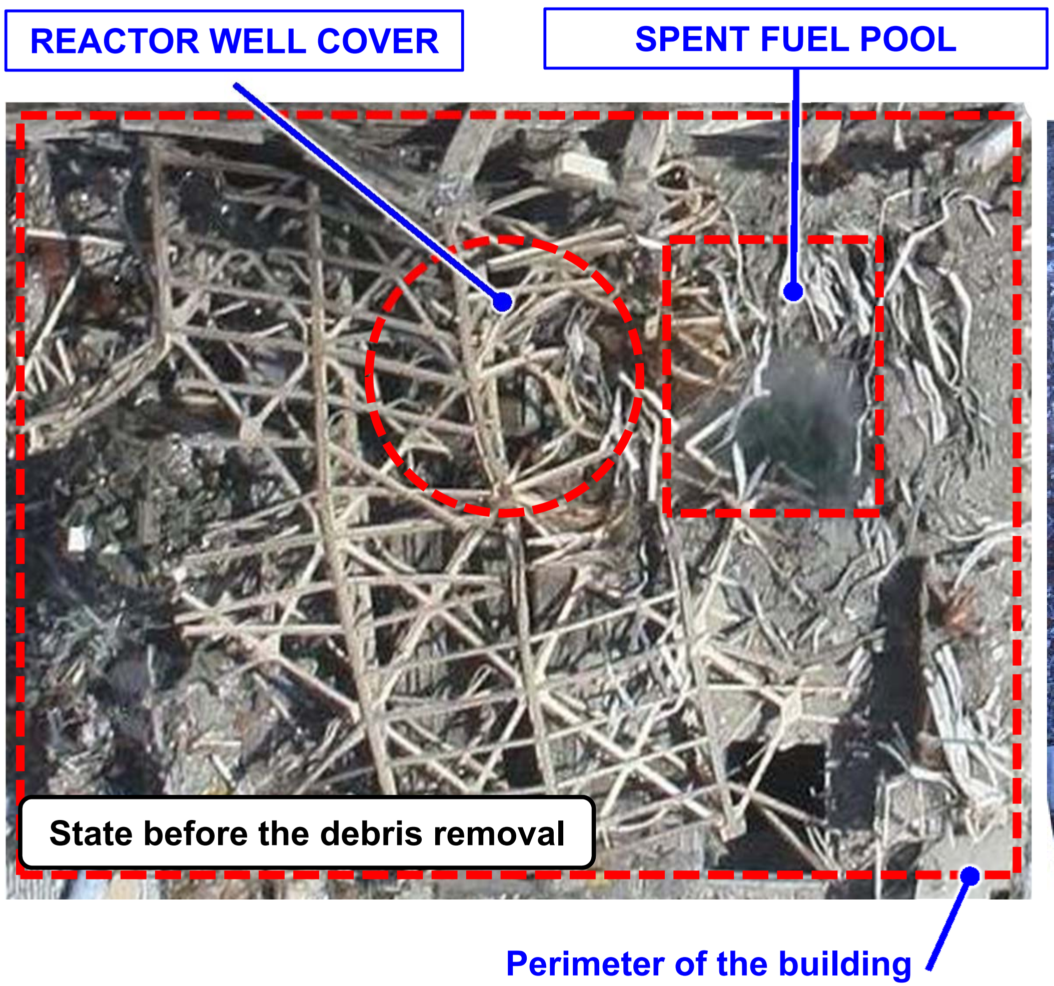
* Dose rates in the operation room are 10μSv/h or less.

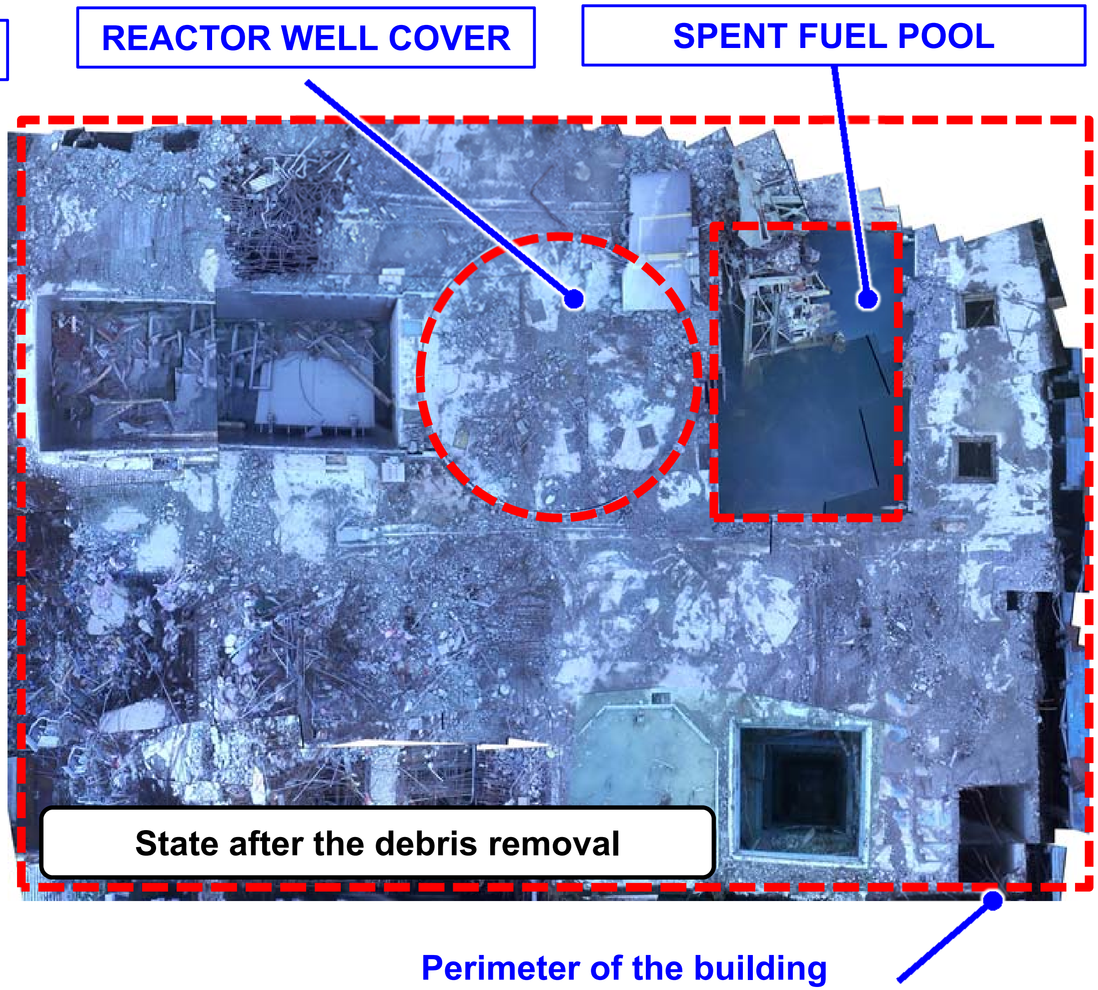
OPTICAL FIBER CABLE-BASED COMMUNICATION

1. Introduction

[Overview of the debris removal (3)]

Removal of the large debris in the upper part was completed in October 2013.
The photographs show the states before and after the debris removal.



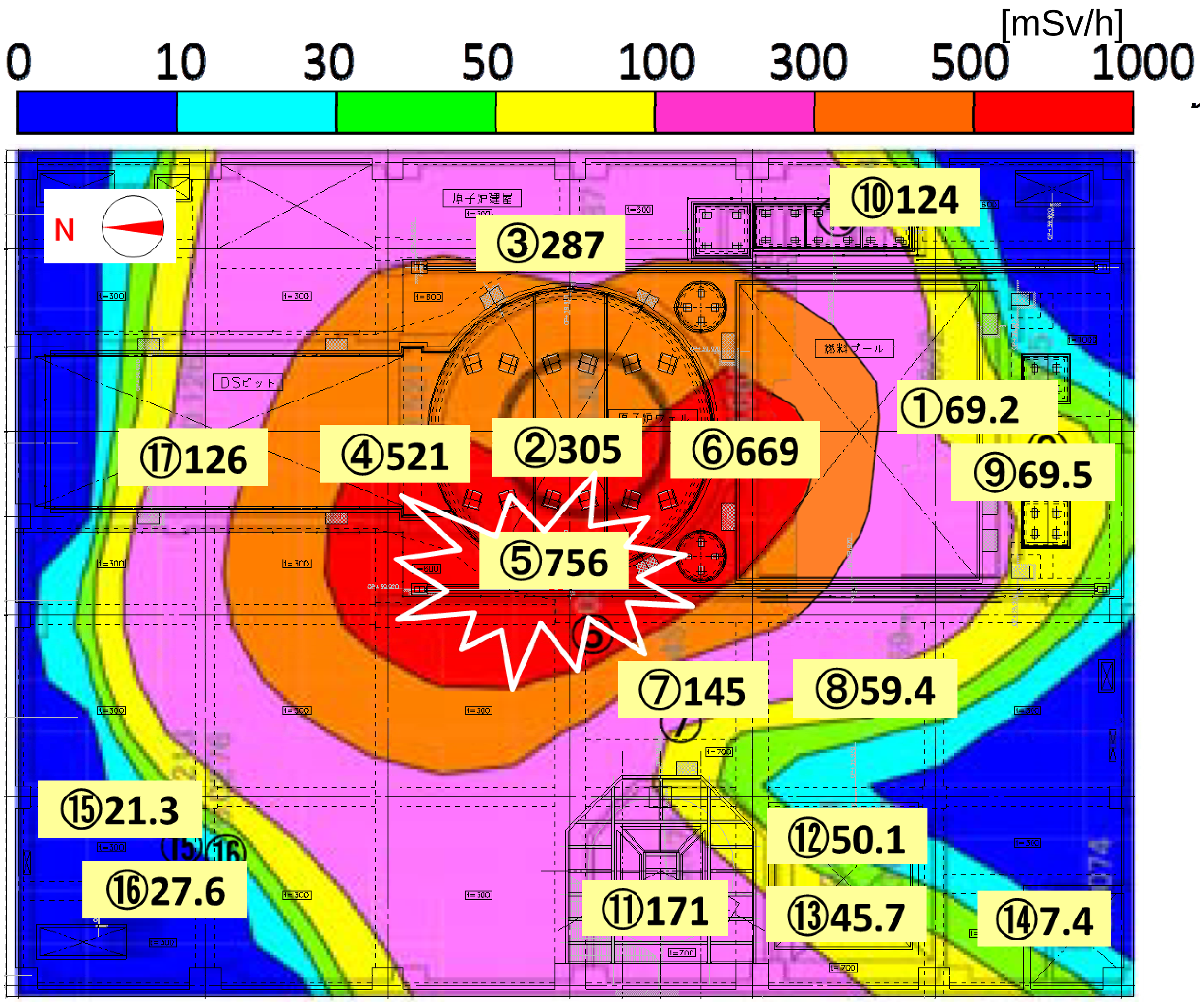


2. Designing the Dose Rate Reduction Method

[Air dose rates on the refueling floor]

- An air dose rate survey was conducted with the upper debris remaining in situ.
- The air dose rates above the reactor well were high (above **700mSv/h**).
- Manned work on and around the refueling floor is unavoidable in view of the future spent fuel removal work.

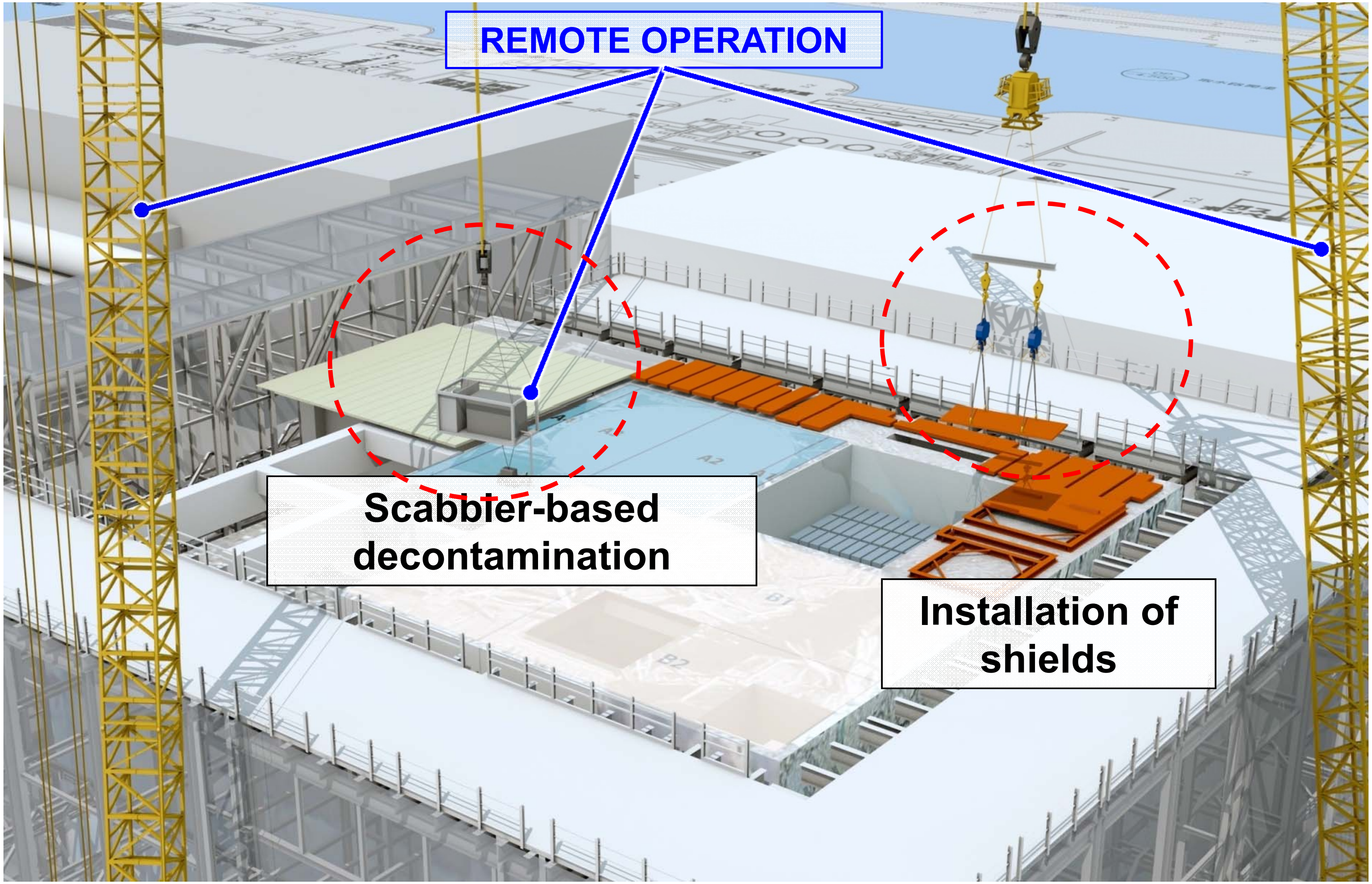
- It was decided to design and implement a dose rate reduction method that combines decontamination and shielding.



Date of measurement: 15 May 2012
*** The measurement height varied between measurement points because of the presence of residual debris.**

2. Designing the Dose Rate Reduction Method

[Overview of the dose rate reduction method]



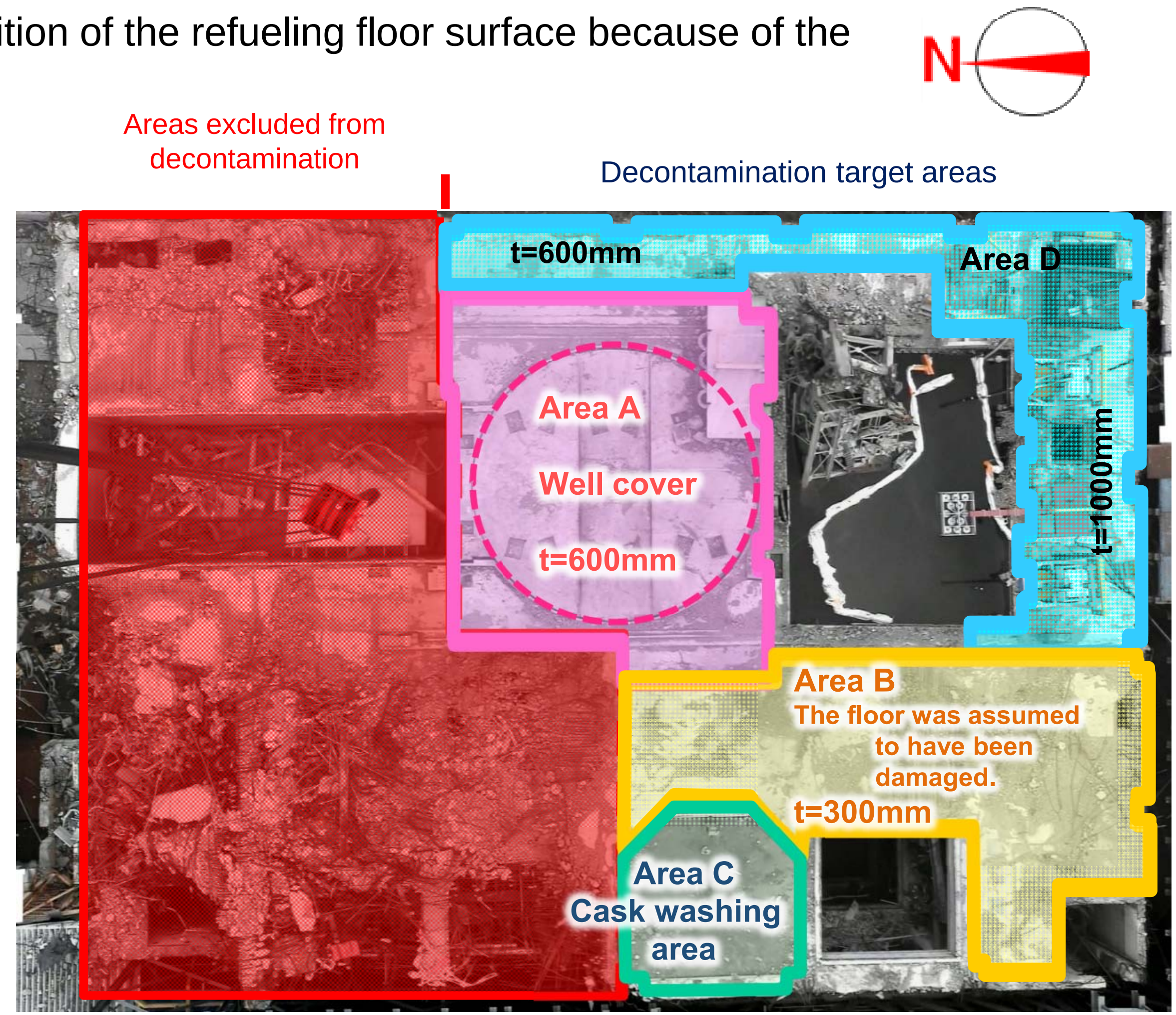
2. Designing the Dose Rate Reduction Method

[Designing of the dose rate reduction method]

- After the dose rate survey, a suspended camera-based investigation of the structure body was conducted.
  However, it was not possible to confirm the condition of the refueling floor surface because of the presence of debris.

- Because the Unit 4 reactor building was similar to the Unit 3 reactor building in structure and the state of damage, an investigation of the inside of the Unit 4 reactor building was conducted to estimate the damage of the Unit 3 floor surface.

- From the result of the investigation of the Unit 4 reactor building, it was deduced that the areas with a slab thickness of 600 mm or more were sound.
  The areas for decontamination were divided based on this deduction as shown in the figure in the right.
  The decontamination and the shielding for each target area were planned.



3. Decontamination Work

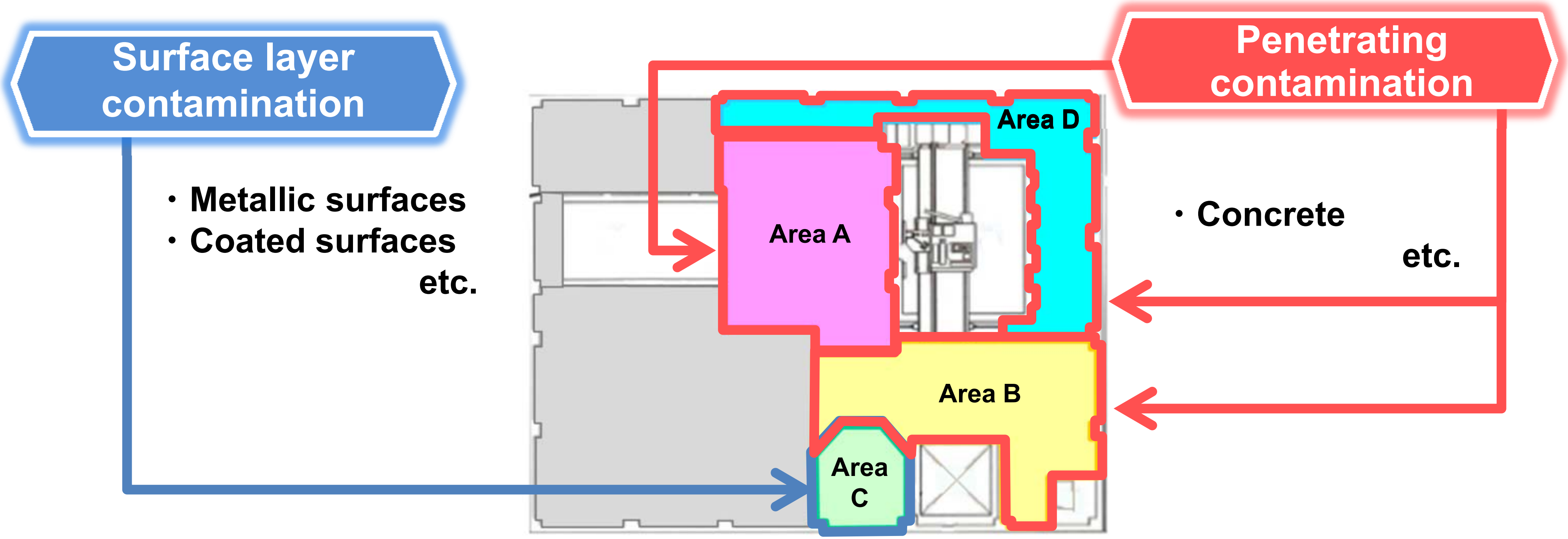
[Classification of contamination types]

(1) Surface layer contamination

This type of contamination is typically seen on metallic surfaces and surfaces of epoxy resin coating on sound concrete and can be decontaminated by washing or wiping.

(2) Penetrating contamination

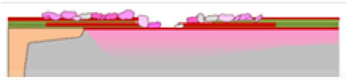
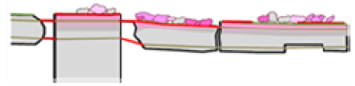
This type of contamination is typically seen in soil and uncoated concrete. An effective decontamination method is to chip off the parts into which the contaminants have penetrated. According to the literature, the depth of penetrated contamination in concrete is in many cases roughly 10 mm or less and the radioactivity level of such contamination at a depth of about 5 mm from the surface is in many cases 1/100 of the level at the surface.



3. Decontamination Work

[Decontamination equipment selected for each area]

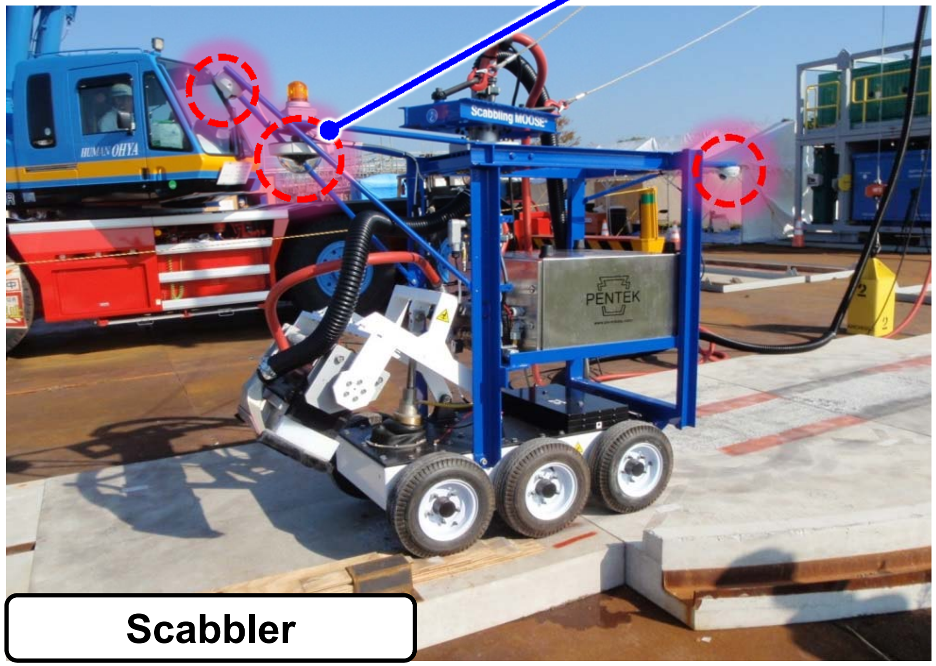
* We planned to use a scabbler. The water jet and chemical decontamination were to be used by other companies.

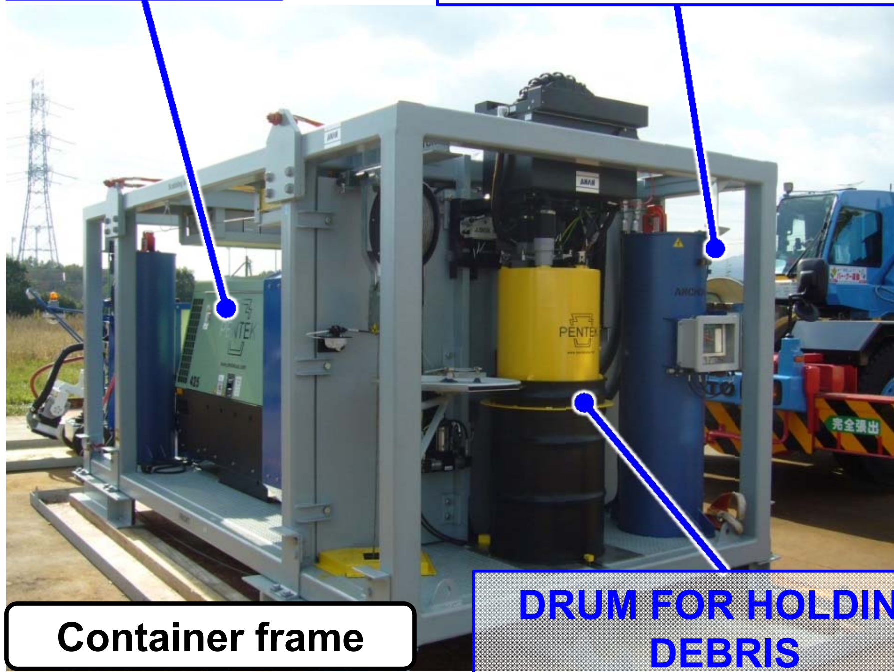
	(1) Slabs with a thickness (t) of 600 mm or more	(2) Slabs with a thickness (t) of 300 mm	(3) Cask washing area
Assumed state			
Contamination type	Penetrating contamination (It was assumed that the epoxy resin coating has been damaged.)	Penetrating contamination	Surface layer contamination
Material	RC + epoxy	RC + epoxy	Stainless steel
Area	440㎡	260㎡	70㎡
Decontamination method	Scabbler	Water jet	Chemical (foam-based) decontamination
Reason for selection	• Highest chipping capability. • Highest work speed.	• Chipping is possible for the floor surface with cracks and some irregularities.	• Effectiveness was confirmed particularly for metallic material in a decontamination test using actual wastes.
Expected effects	• According to the literature, the radioactivity level at a depth of 5 mm from the surface is about 1/100 of the level at the surface.	• According to the literature, the radioactivity level at a depth of 5 mm from the surface is about 1/100 of the level at the surface (The radioactivity level reduction rate for cracked parts is unknown).	• The radioactivity level was reduced to 1/10 or less by the decontamination work.
Typical external appearance of the equipment			
Applicable to	Area A and Area D	Area B	Area C

3. Decontamination Work

[Decontamination equipment]

- The decontamination equipment consists of a scabbler body, which is a self-propelled vehicle equipped with a scabbler head, and a container frame that houses a drive, a sucking system, and a drum for holding the small debris generated by the chipping.

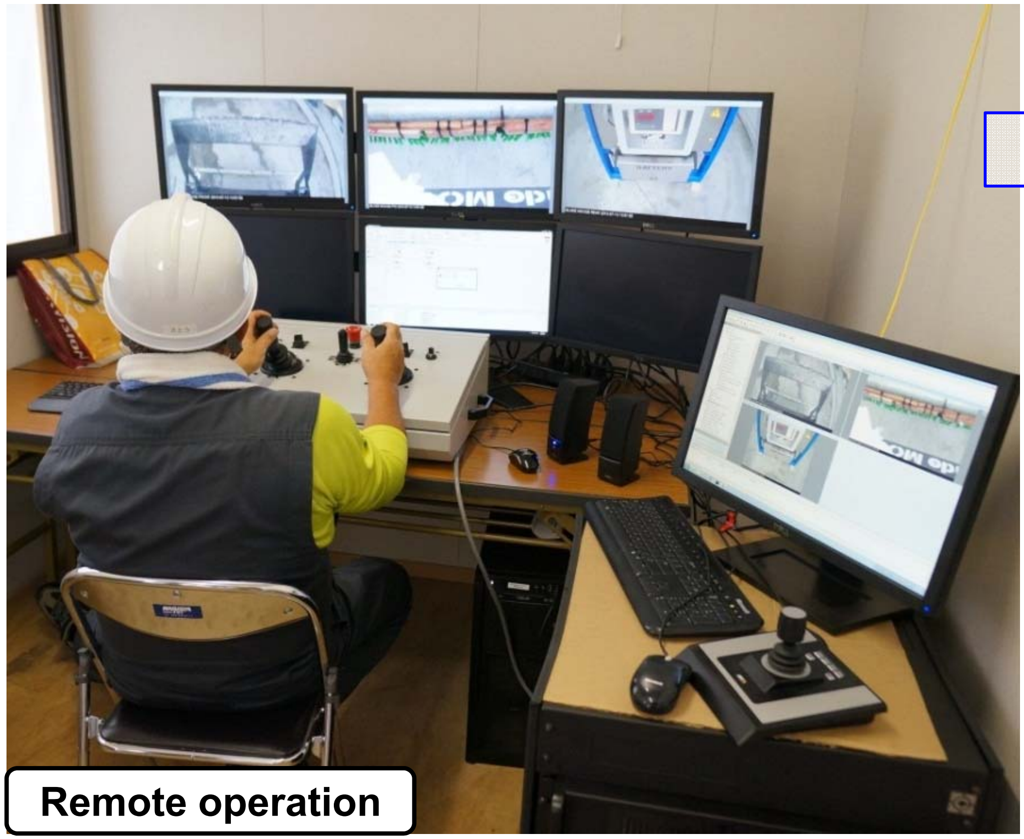


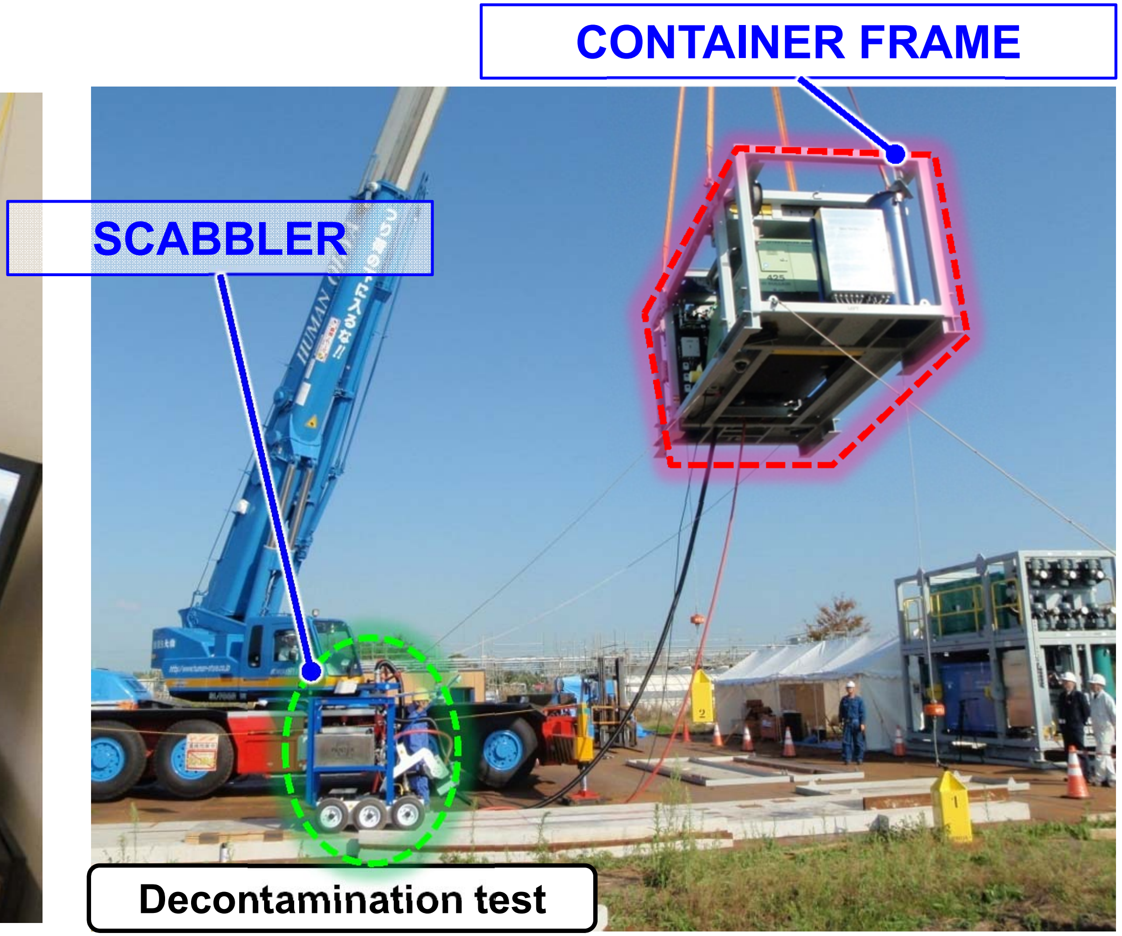


3. Decontamination Work

[Decontamination equipment]

- The scabbler and the container frame are transferred to the work area using a crane.
- The system is operated from a remote operation room using a camera equipped on the scabbler.





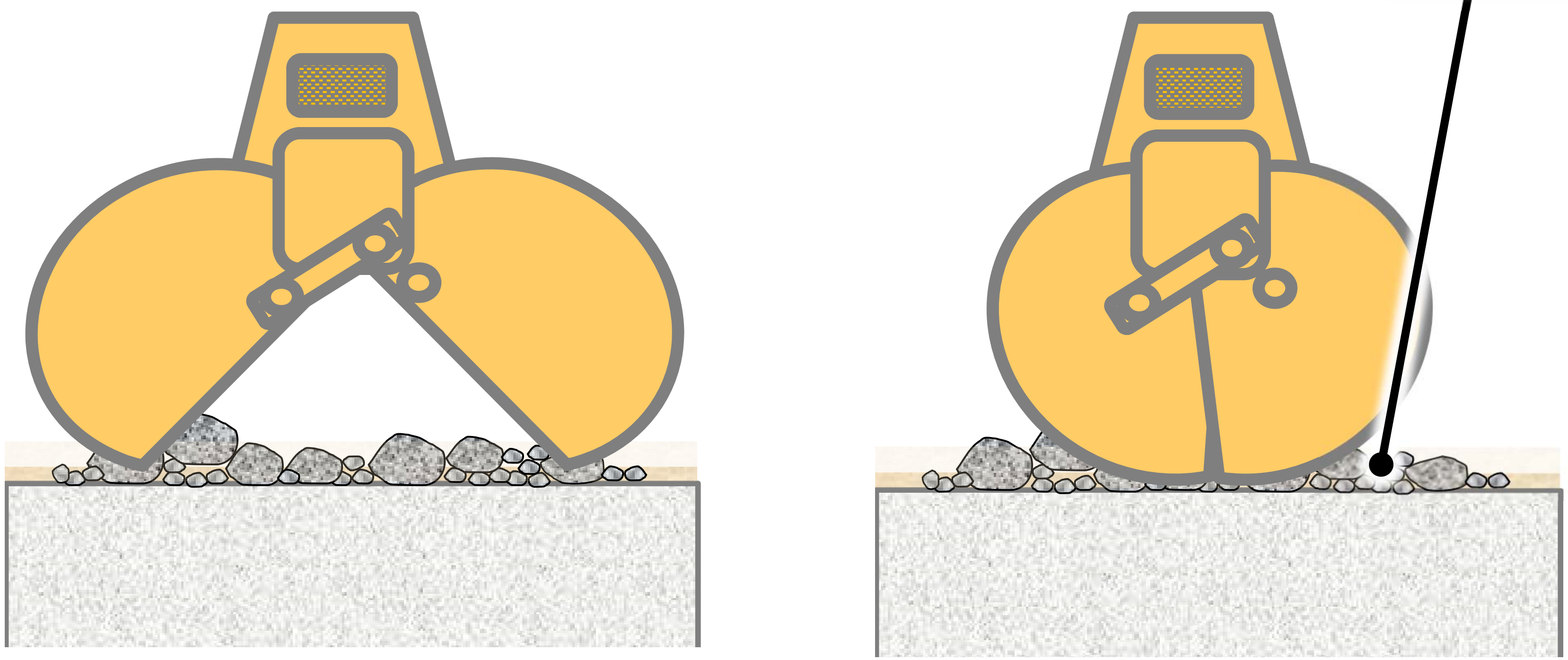
3. Decontamination Work

[Removing debris and dust]

- Immediately after the demolition, the upper part the refueling floor is covered with many small pieces of debris smaller than a human head and a large amount of dust.
- It is difficult to use either the scabbler or water jet on the refueling floor in such a state although large pieces of debris have been removed with large heavy equipment.

It is necessary to remove the residual debris!

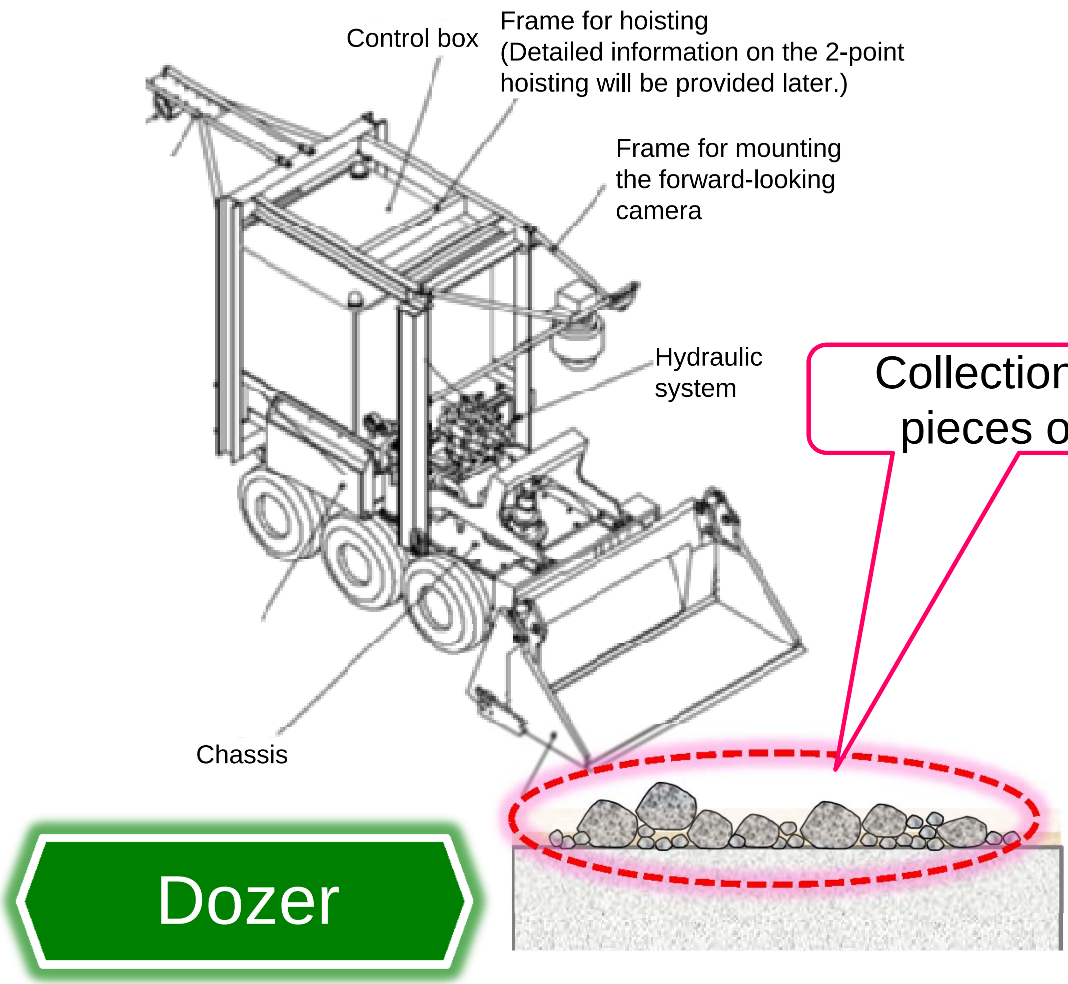
Small pieces of debris that cannot be picked up with a bucket

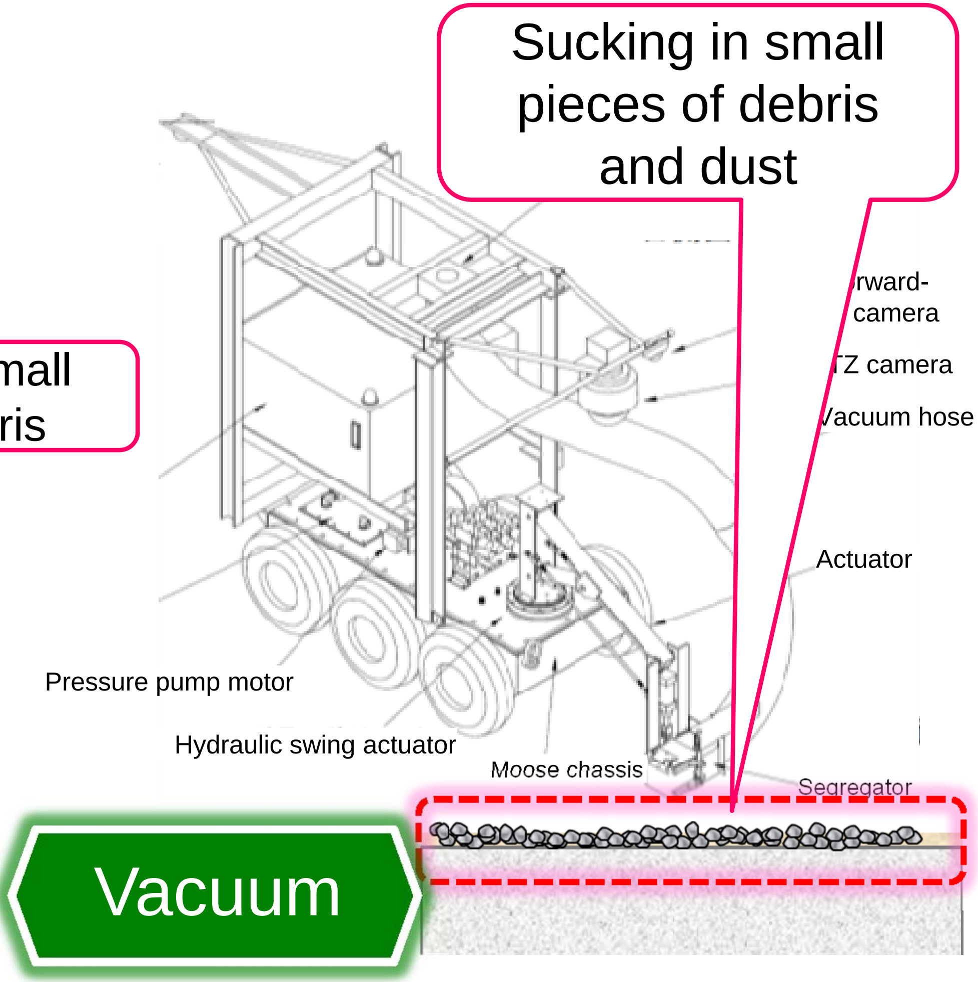


3. Decontamination Work

[Removing debris and dust]

- A study to develop the “Dozer” and “Vacuum” to collect small pieces of debris and dust was added.





3. Decontamination Work

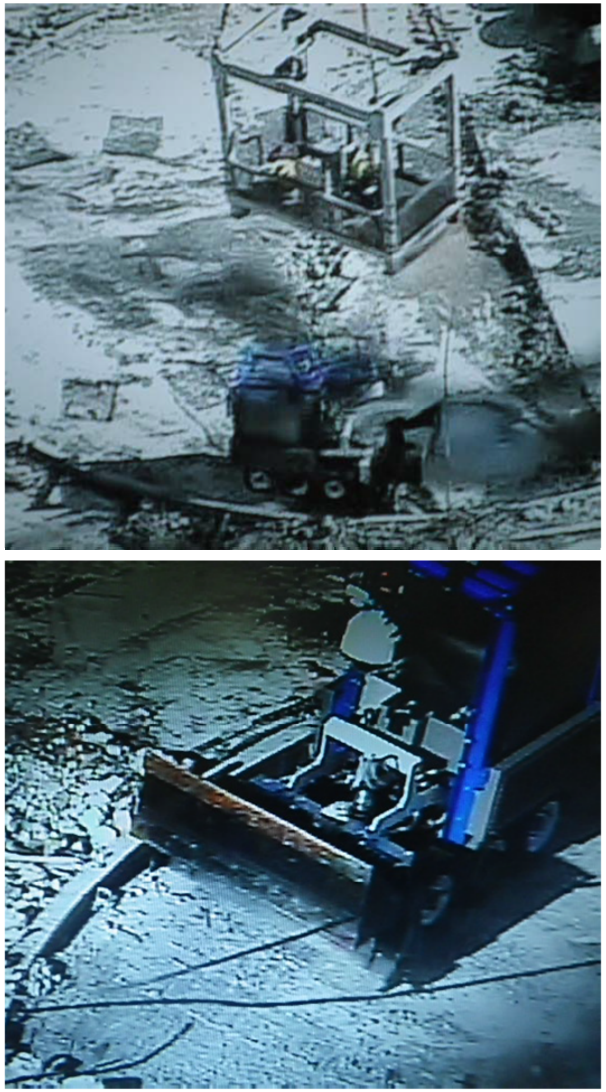
[Mock-up experiment]

Dozer

Vacuum

3. Decontamination Work

[Photos of the decontamination equipment in operation]



Dozer

Vacuum

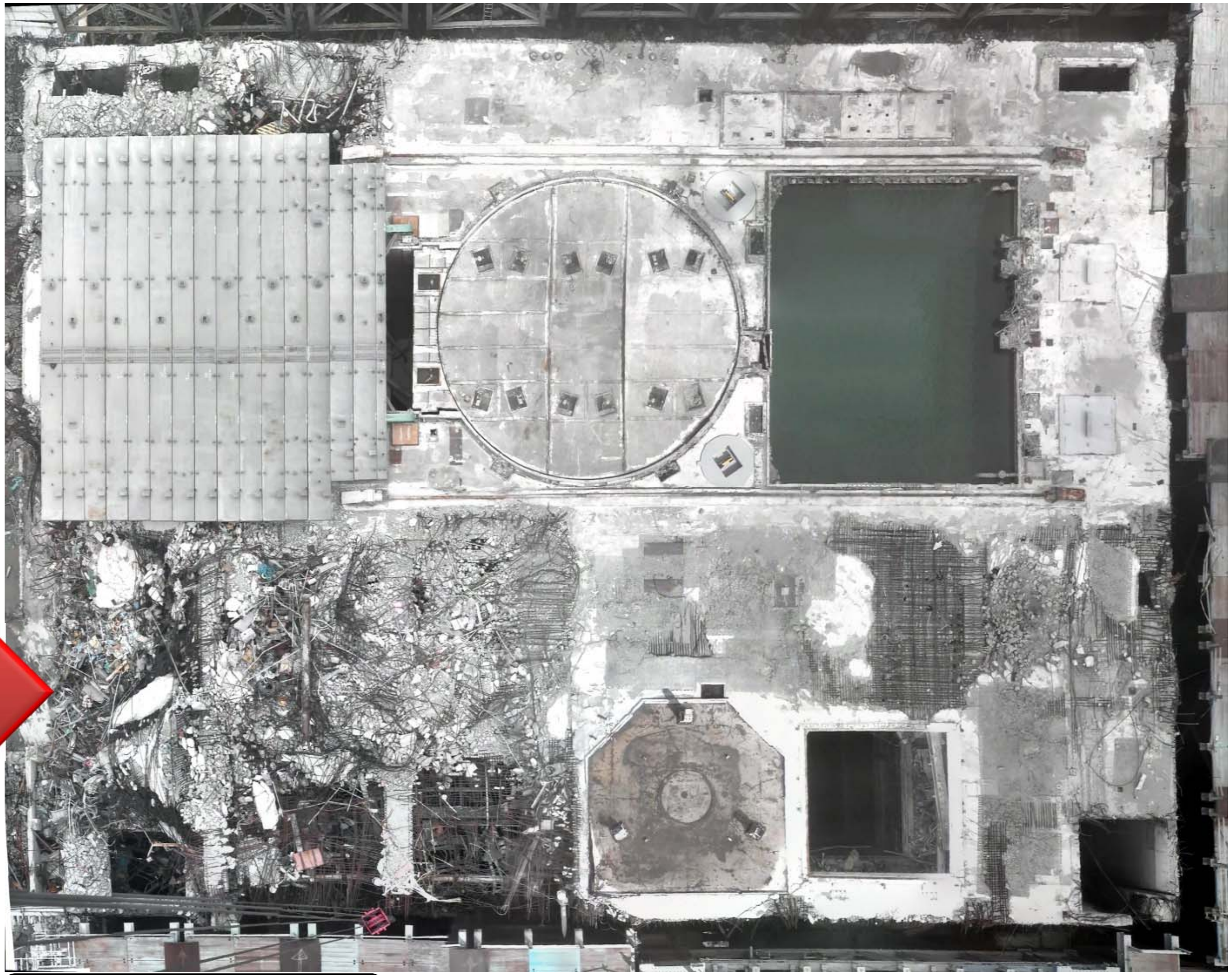
Scabbler

3. Decontamination Work

[Completion of decontamination]

The photograph on the right shows the state after completion of the decontamination as seen from above.
* In Block E, which is not a decontamination target area, the shields have been installed in advance of other blocks.

Before decontamination



After decontamination

4. Shielding Work

[Shielding measures]

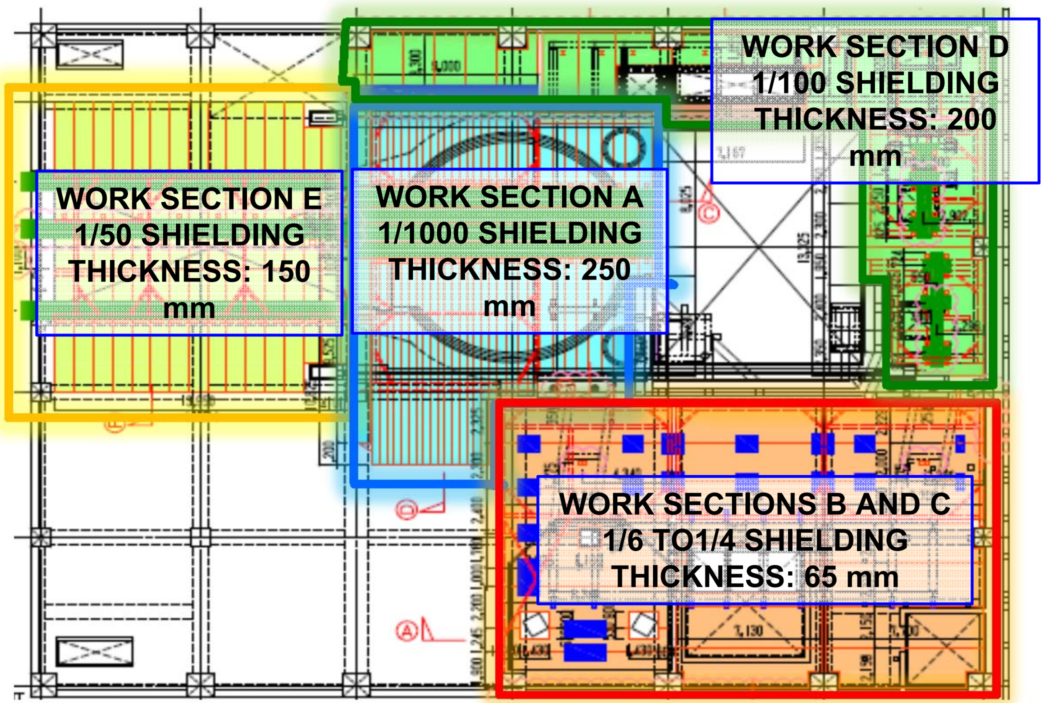
- The installation site of the shields and the shield thickness for each area were determined based on the dose rate and the damage of the structure body.

(1) Work Section A (directly above the well)
Because high dose rates in excess of 700 mSv/h had been observed, the 1/1000 shielding specification was adopted. Taking account of the possibility that installing and loading the shielding on top of the well would consequently affect the fuel in the lower part, the use of long-span shields which span the well was examined.

(2) Work Sections B and C (directly above the well)
Although the dose rate was in excess of 100 mSv/h, the maximum shielding achievable was approx. 1/6 to 1/4 because of the shield weight constraint of the structure which did not seem to be sound.

(3) Work Section D
Because it was assumed that the structure body was sound and would withstand a dose rate of 100 mSv/h, the 1/100 shielding specification was adopted. It was planned that the load of the shields would be transmitted to the beam.

(4) Work Section E
Despite the dose rate being in excess of 100 mSv/h, it was determined that 1/50 shielding specification would be sufficient from the viewpoint that the dose in manned work areas would be low.



4. Shielding Work

[Shield material]

Material	Lead	Iron	Concrete
Thickness	The highest density and the smallest thickness.	Twice as thick as lead.	7 times as thick as lead.
Structure	Steel frame for keeping the shape is required.	S construction which allows the shields themselves to serve as the structure	Concrete construction (PC/SC/RC construction)
Workability	Because lead is toxic, handling is difficult and surface coating is required.	No additional processing is needed to lift the shields. Joining is possible.	Because shields are thick, each shield has to be divided into the upper half and lower half.
Earthquake resistance	Inferior to iron.	Highly resistant to earthquakes because of the low height.	Inferior to iron.
Processing in the field	Not possible because of the coating.	Processing in a field assembly yard is possible.	Difficult
Overall evaluation	△	◎	○

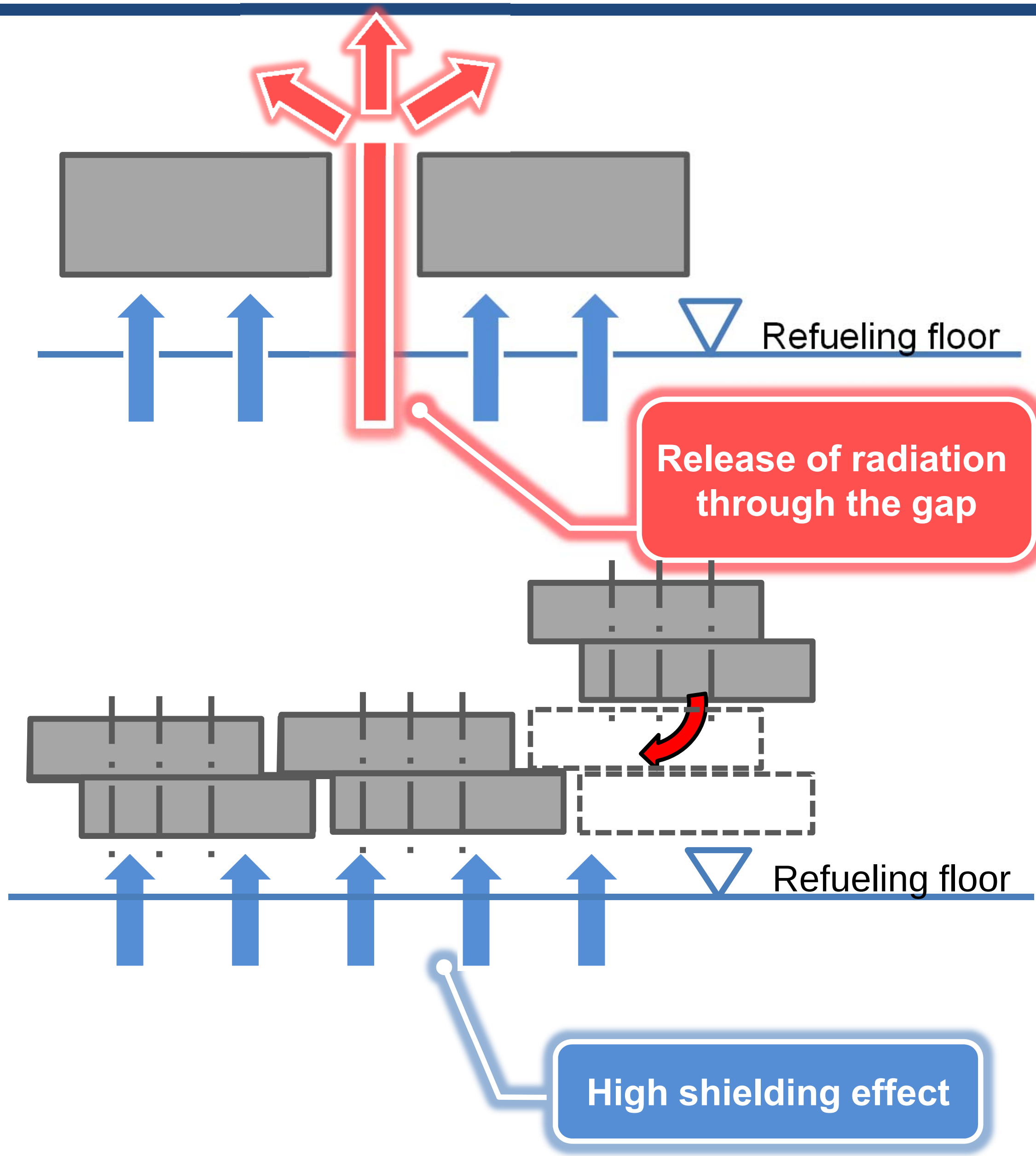
4. Shielding Work

[Shape of shield]

- It is difficult to eliminate gaps in remote operation.
- Presence of a gap may lead to a high risk of radiation.

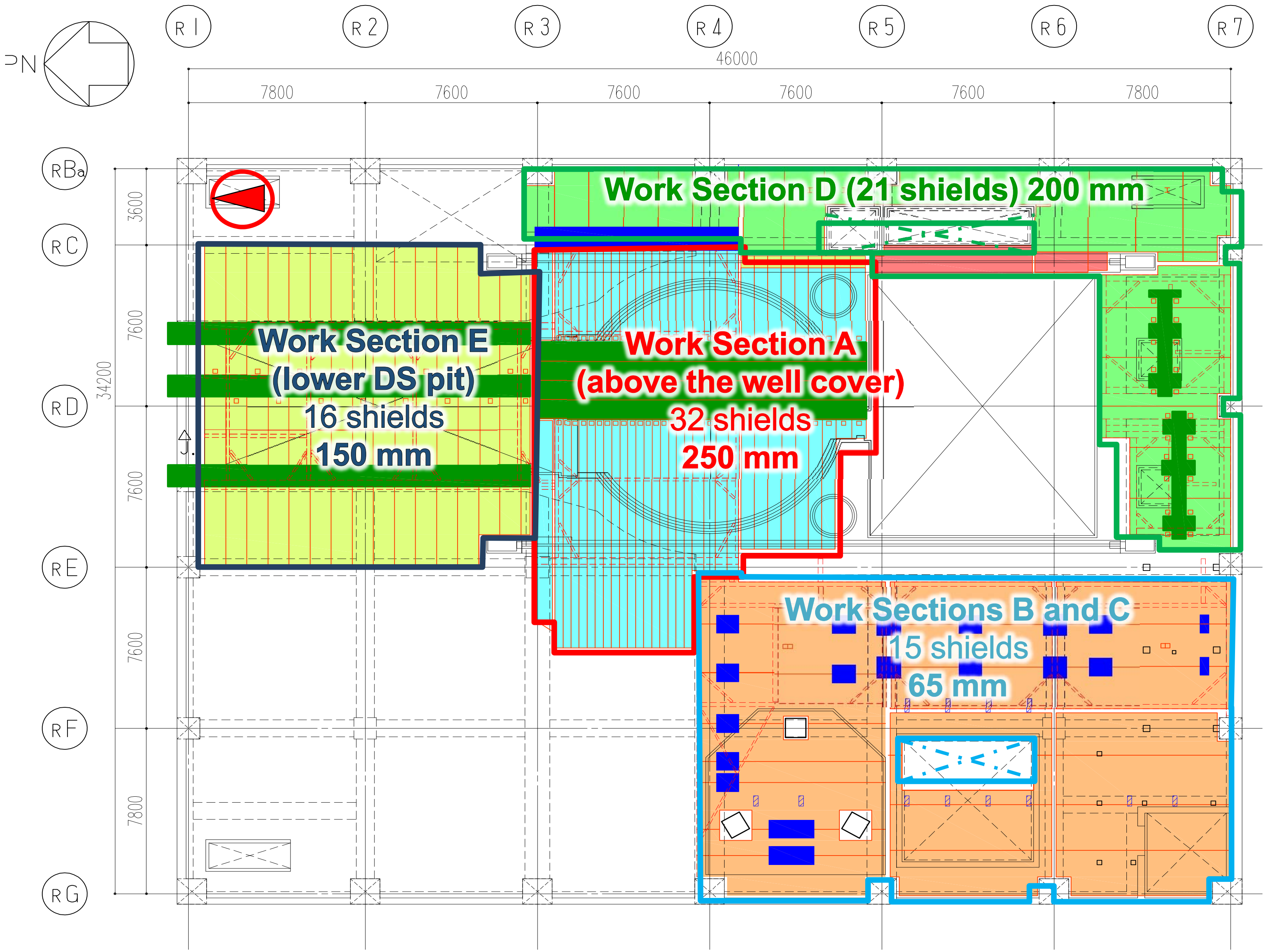
- Gaps can be minimized by installing shields shaped to have keys mating with each other.
- The shields with keys were formed by bolting together two iron blocks that were placed one top of one another with certain offset on each side.

* These production and installation methods were used for Work Sections A and D.



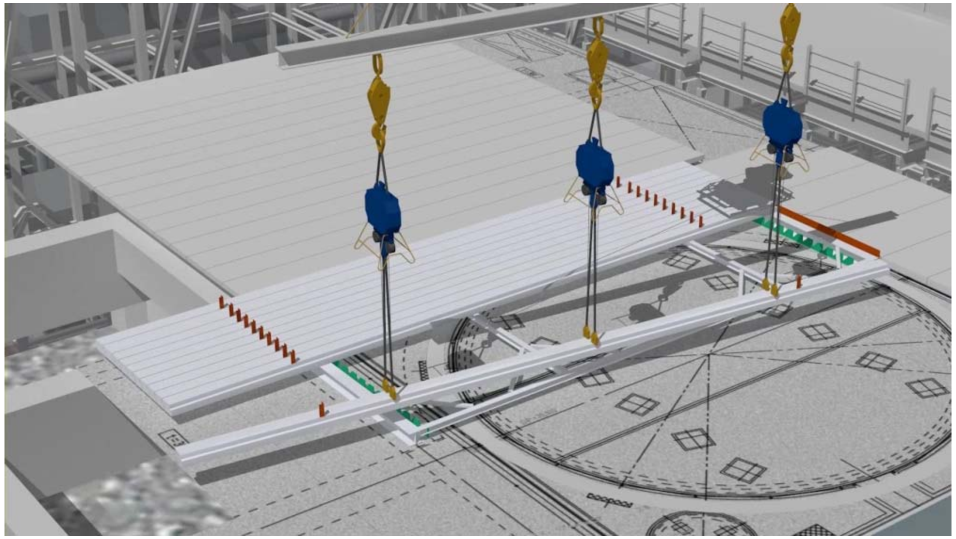
4. Shielding Work

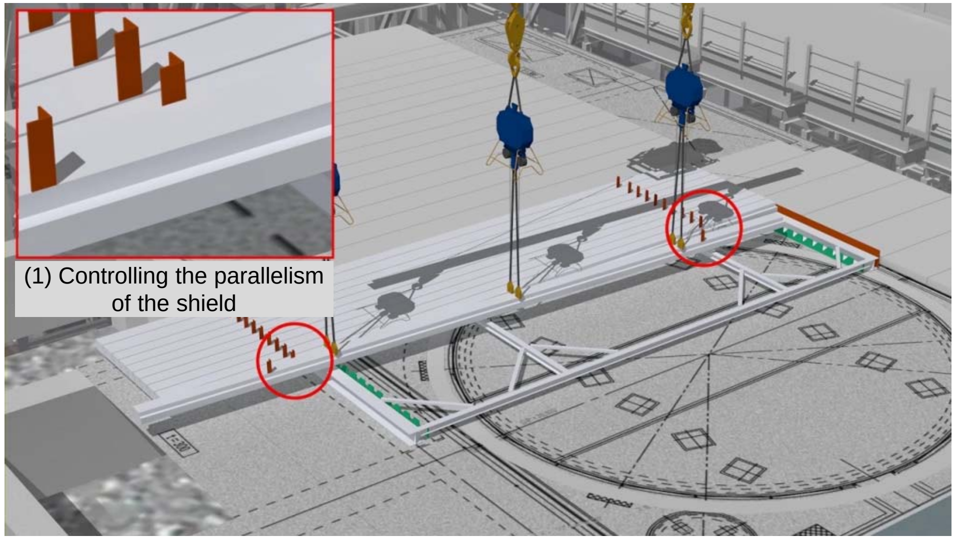
[Number of shields to be installed]

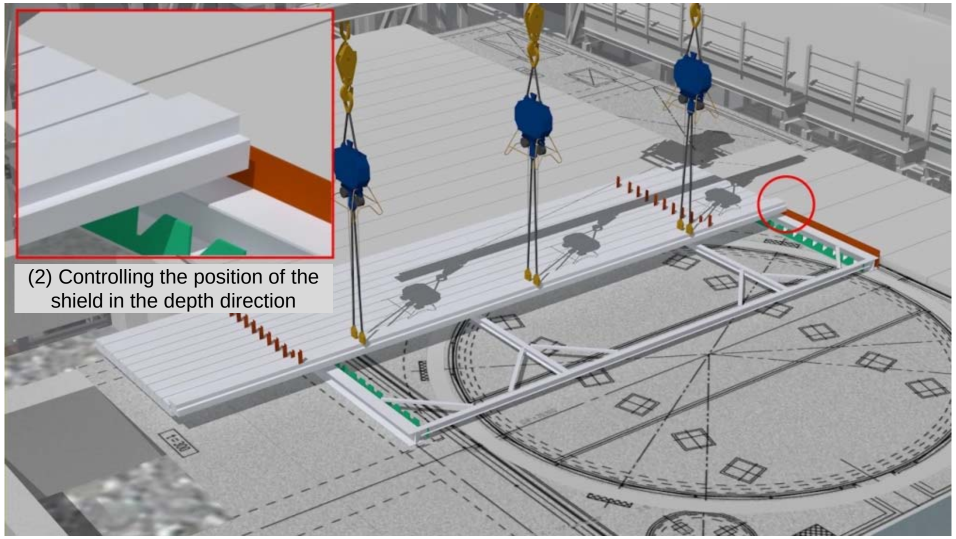


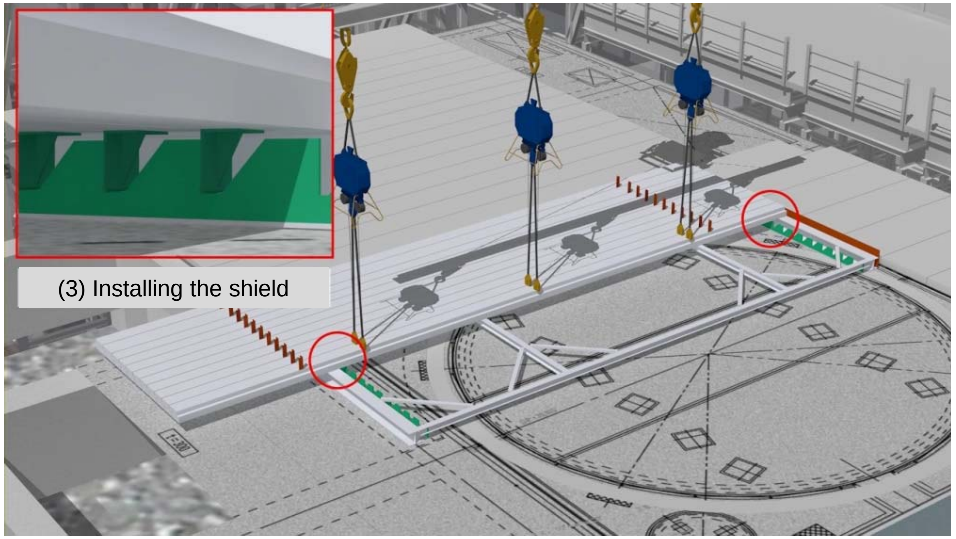
4. Shielding Work

[Shield installation method (centering by remote operation)]



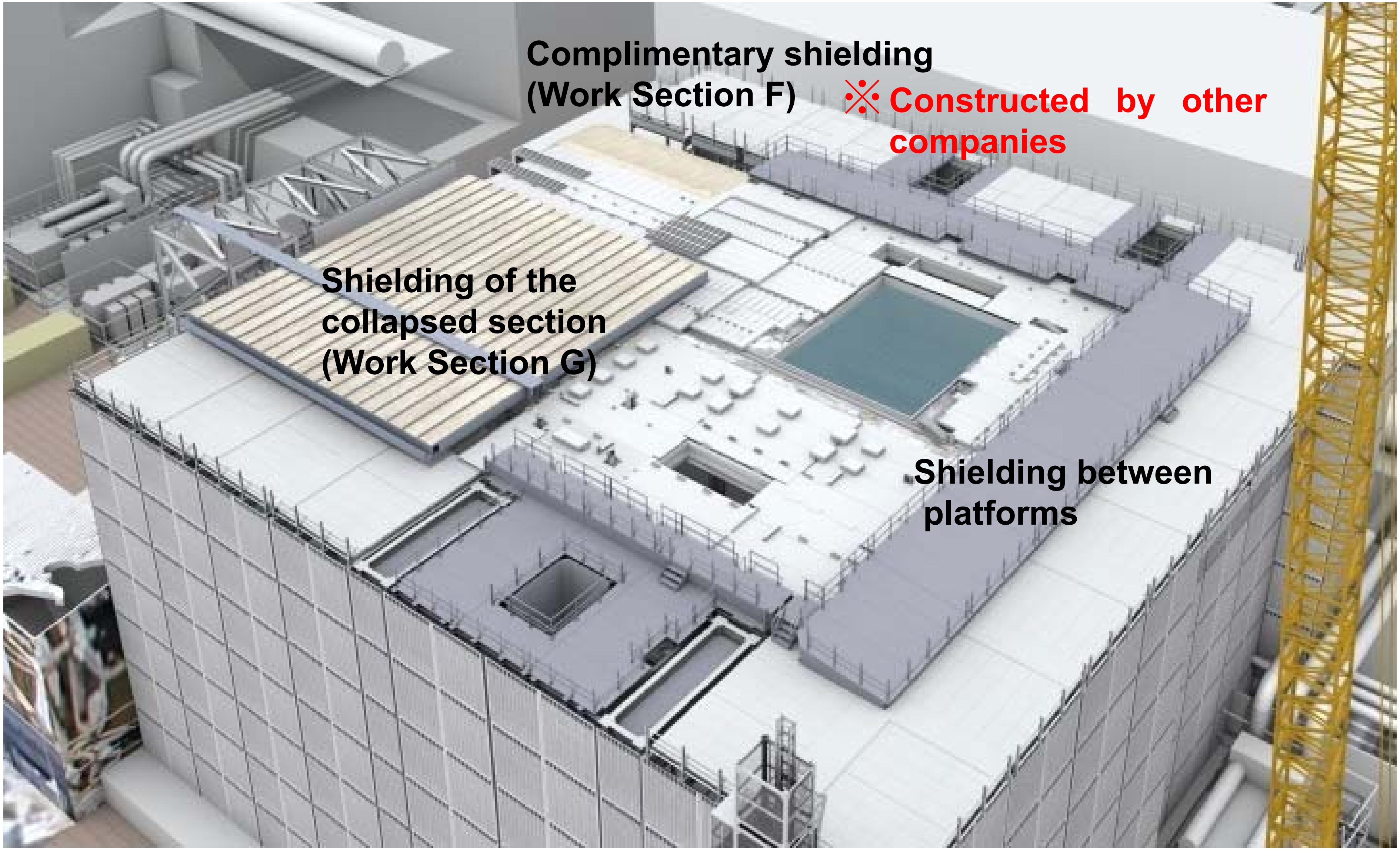






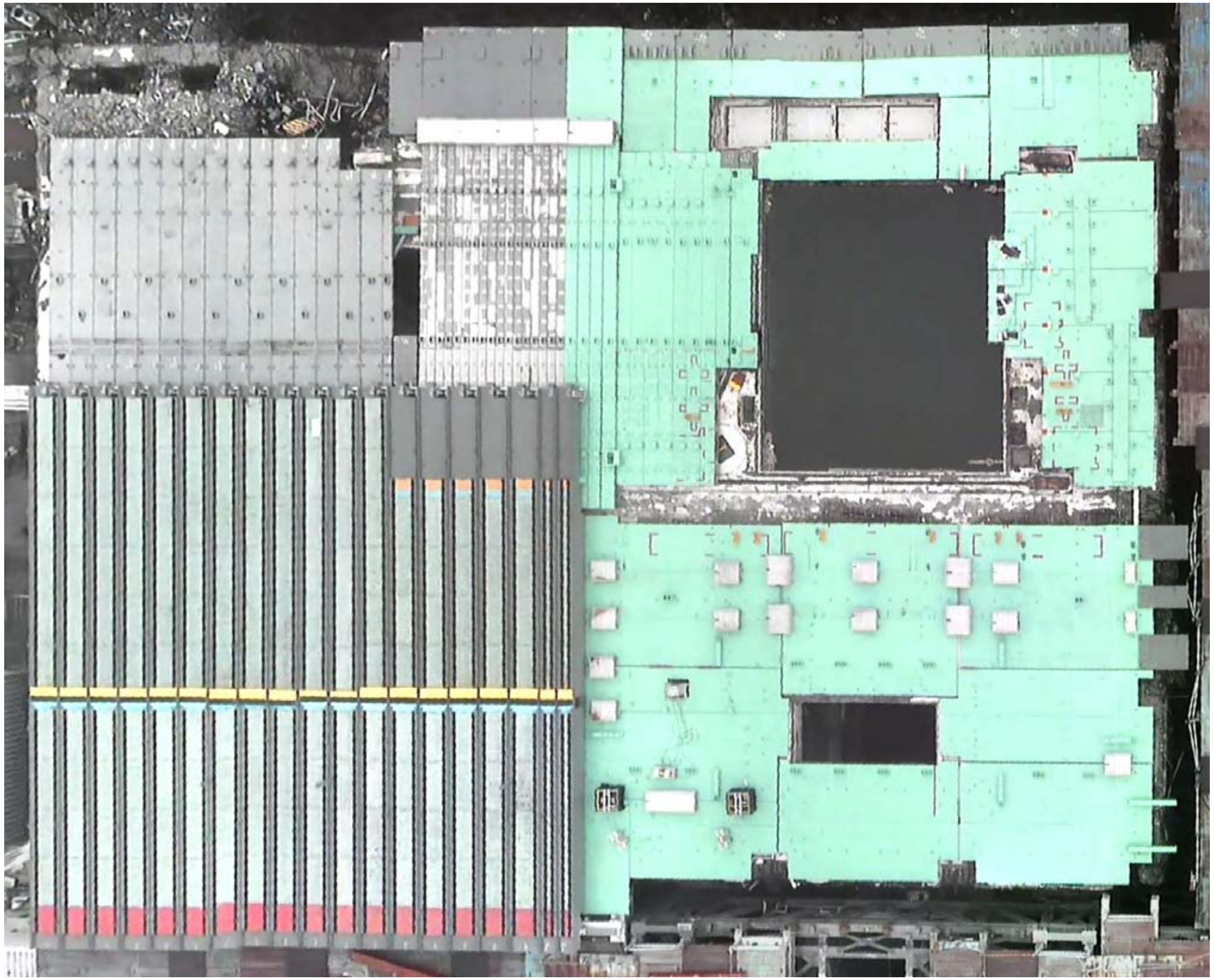
4. Shielding Work

[Additional shielding measures]



4. Shielding Work

[The shields as installed (photographed on September 20, 2016)]



5. Effects of the Decontamination Work and Shielding Work

[Dose rate measurement]

- To confirm dose rates on the refueling floor, the dose rate measurements before and after the decontamination and the shielding taken at 130 points on the “(1)-(13) × b-k” grid shown in the figure below will be compared.

Measurement before decontamination

↓

Decontamination work

↓

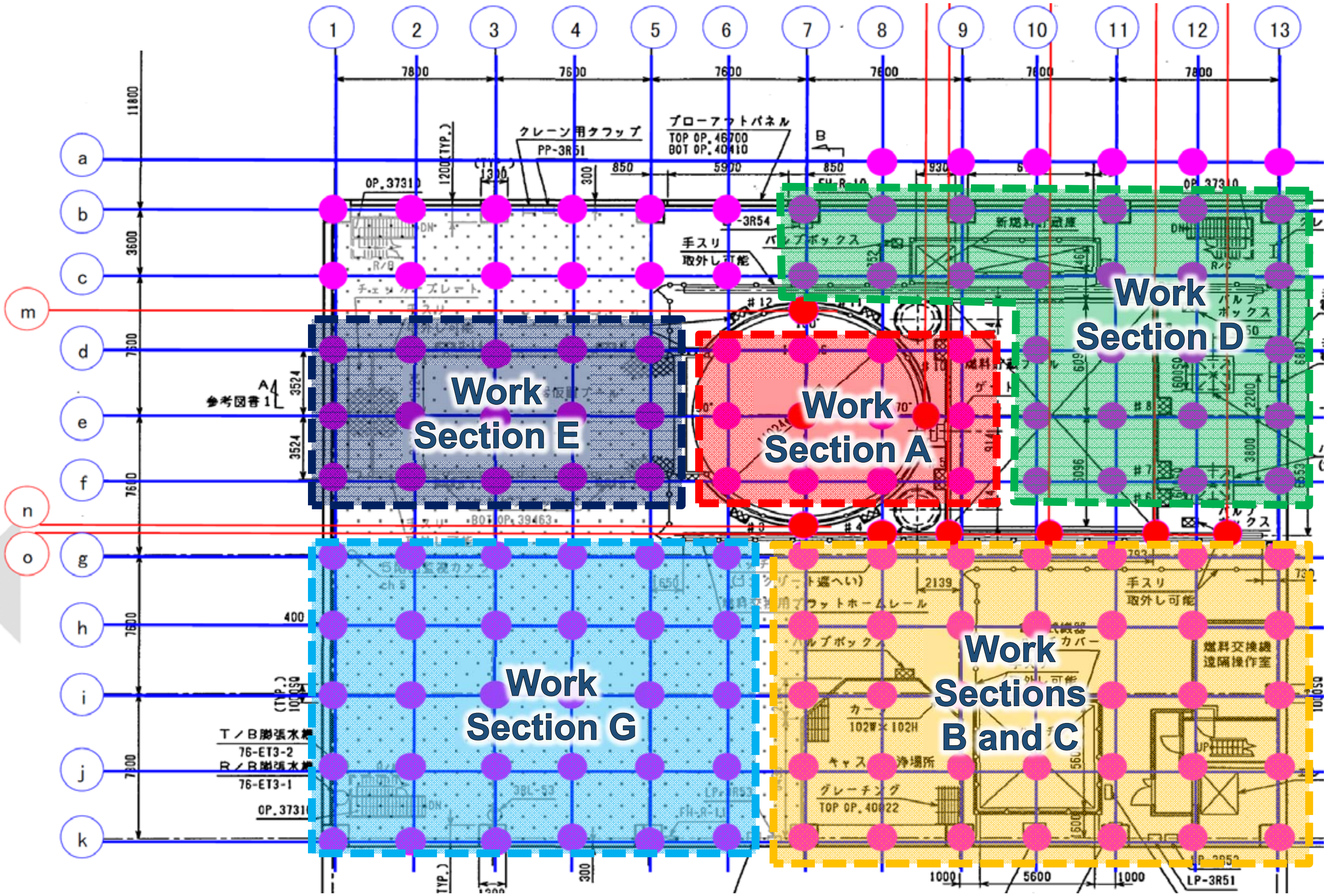
Measurement after decontamination (with Work Section E shielded)

↓

Shielding work

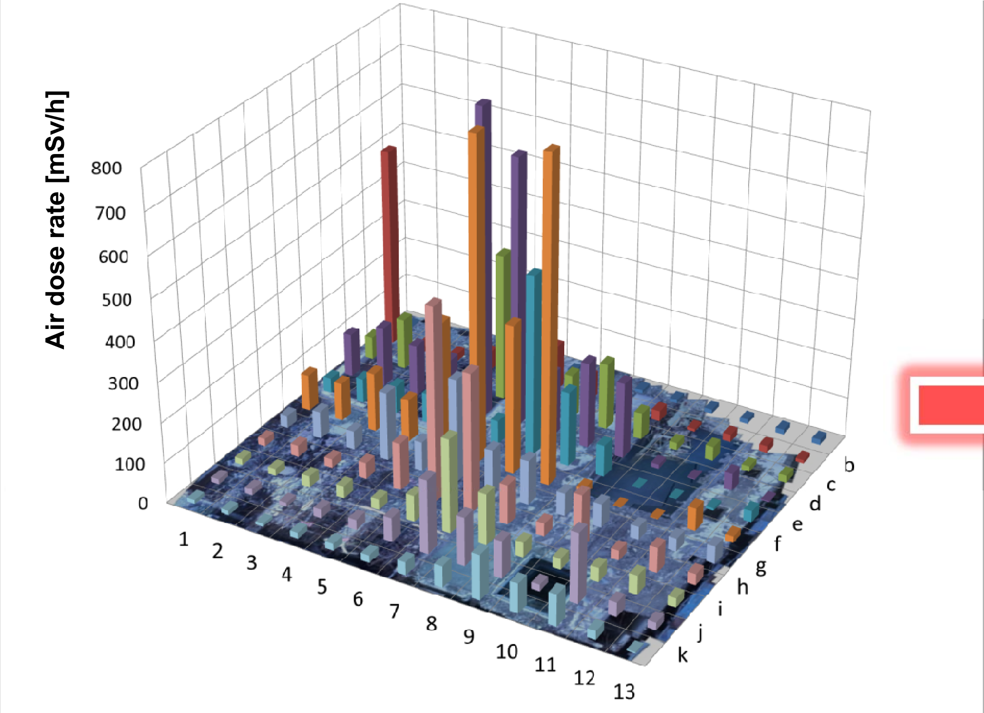
↓

Measurement after shielding

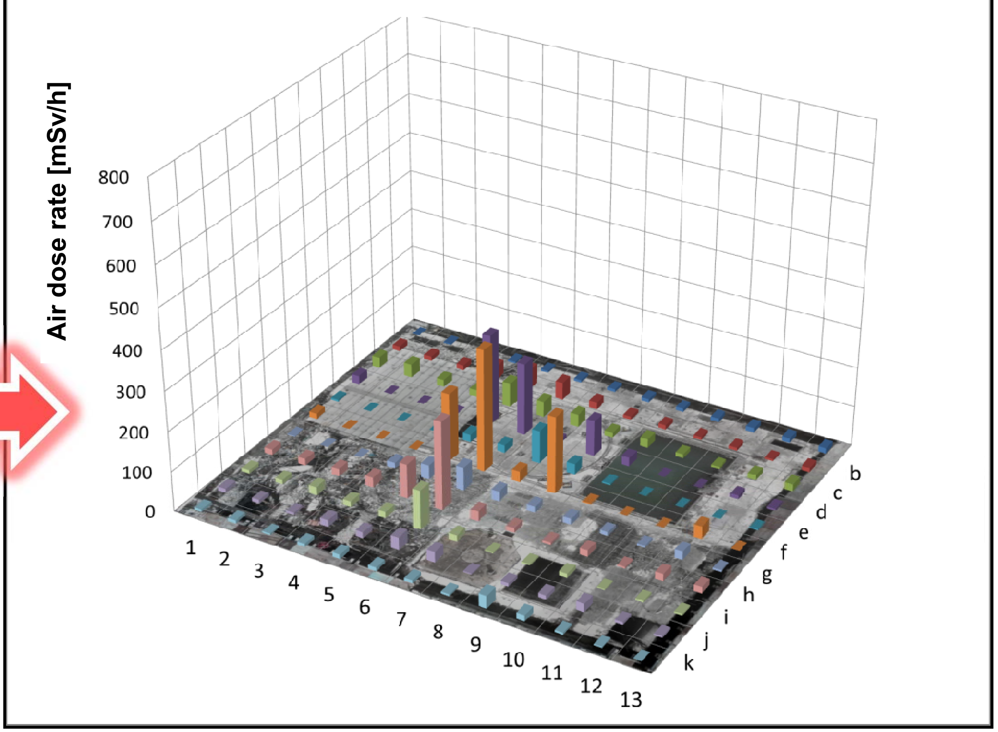


5. Effects of the Decontamination Work and Shielding Work

Result of the dose rate measurement conducted after completion of decontamination and with Work Section E shielded



Result of the dose rate measurement conducted after completion of shielding



Result of the dose rate measurement conducted after completion of decontamination and with Work Section E shielded [mSv/h]

* The figures marked with a red rectangle are the measurements that exceeded the maximum value on the vertical axis of the graph (100 mSv/h).

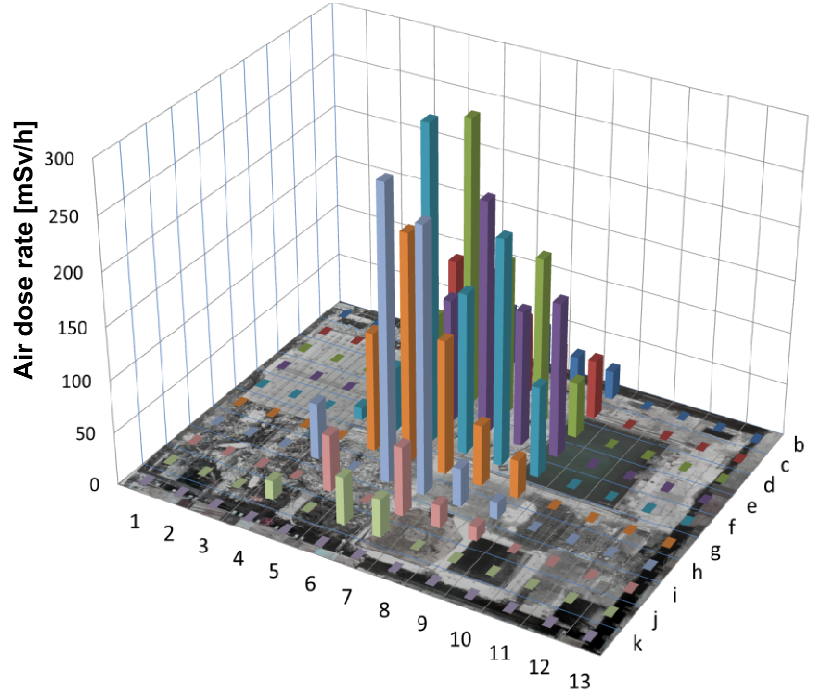
	1	2	3	4	5	6	7	8	9	10	11	12	13
b	500.0	18.3	18.3	48.0	136.3	114.7	61.3	50.7	26.3	6.5	19.0	17.0	9.0
c	57.0	128.3	46.0	36.3	367.6	95.7	111.0	166.3	66.7	17.3	35.3	12.7	17.1
d	108.0	150.3	129.7	117.3	769.1	670.3	160.0	213.9	189.3	10.1	2.0	43.3	2.7
e	37.3	61.0	68.7	74.3	104.6	59.3	448.7	185.3	79.2	0.7	0.8	5.6	28.0
f	90.7	95.0	147.0	106.3	326.8	890.9	371.0	1457.1	20.3	0.6	1.2	56.0	15.7
g	31.3	68.3	45.7	170.3	72.3	257.0	108.3	110.0	56.3	59.0	31.3	32.3	42.7
h	18.0	29.0	22.0	40.0	117.3	479.3	344.6	99.0	32.0	132.3	24.3	61.6	27.7
i	15.0	18.0	27.0	30.7	26.0	64.3	232.3	126.7	36.3	27.3	35.0	46.7	22.0
j	12.0	15.3	9.9	22.0	25.7	59.7	182.3	120.3	92.7	16.0	173.0	35.3	18.3
k	9.2	11.3	7.6	14.7	17.3	19.0	31.7	53.0	112.0	73.0	78.3	21.7	3.0

Result of the dose rate measurement conducted after completion of shielding [mSv/h]

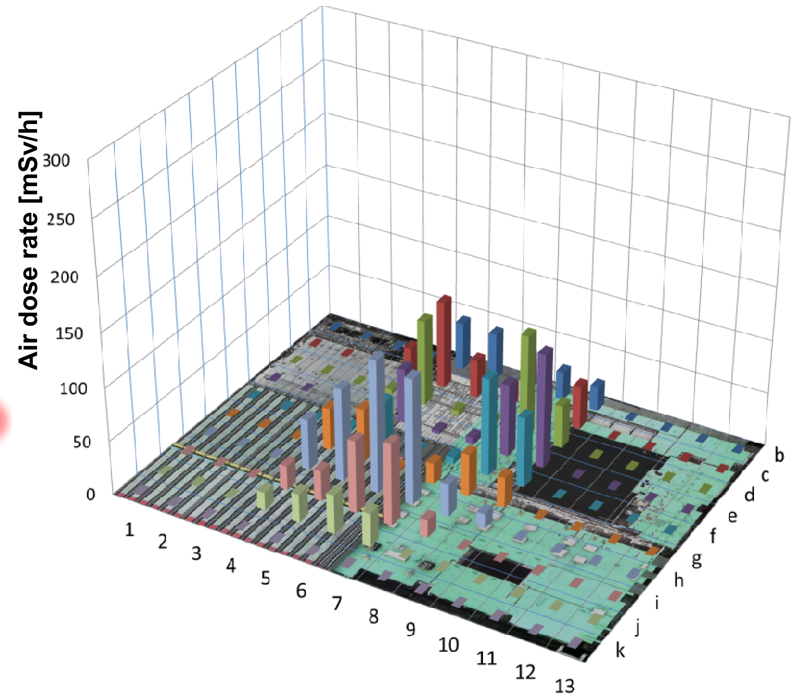
	1	2	3	4	5	6	7	8	9	10	11	12	13
b	13.3	10.9	13.0	35.9	51.8	44.1	18.8	7.8	10.9	7.6	7.2	4.7	10.3
c	26.6	34.3	18.8	16.6	61.5	39.6	32.1	11.7	22.1	10.7	5.8	12.7	17.1
d	21.5	0.1	0.1	0.1	230.1	183.0	10.5	89.2	21.7	0.1	0.1	9.1	4.7
e	4.5	0.1	0.1	0.1	19.6	18.5	82.8	25.7	3.7	0.1	0.1	1.0	3.3
f	13.4	0.1	0.1	0.1	171.2	307.8	27.6	193.8	2.5	0.1	0.1	32.2	1.0
g	1.6	0.1	0.1	13.9	35.5	57.6	25.7	16.2	14.4	9.6	5.1	20.3	4.4
h	13.6	16.7	18.5	24.8	86.2	221.2	24.6	12.5	5.6	15.6	4.1	17.4	15.6
i	8.5	11.3	21.2	13.5	15.4	98.6	15.1	1.9	3.8	10.1	2.2	5.1	3.7
j	9.7	9.1	5.9	16.6	14.6	31.5	25.3	2.2	8.2	9.9	20.1	6.4	4.8
k	6.8	7.8	3.8	8.2	10.7	8.7	8.1	4.7	32.0	15.3	5.0	2.4	0.1

5. Effects of the Decontamination Work and Shielding Work

Result of the dose rate measurement conducted after completion of decontamination and with Work Section E shielded



Result of the dose rate measurement conducted after completion of shielding



Note that the values in the following tables (surrounded by blue lines) show those measured at the surrounding area of Section A, which was the only place measured, as of 30 September 2016, after shielding installation.

Result of the dose rate measurement conducted after completion of decontamination and with Work Section E shielded [mSv/h]
* The figures marked with a red rectangle are the measurements that exceeded the maximum value on the vertical axis of the graph (100 mSv/h).

	1	2	3	4	5	6	7	8	9	10	11	12	13
b	13.8	—	22.2	—	49.4	57.9	48.1	31.6	27.4	17.9	15.6	16.1	9.7
c	20.6	—	22.2	—	114.2	109.8	75.5	56.2	56.2	28.5	24.5	12.7	17.1
d	0.0	1.9	-	10.2	77.0	274.2	148.2	162.6	53.2	26.3	18.3	30.9	9.3
e	10.7	—	3.2	—	61.1	120.1	223.2	129.5	147.9	24.4	16.8	14.4	8.5
f	—	2.4	-	12.1	61.3	329.9	153.5	214.2	86.7	18.8	15.1	17.2	5.3
g	9.6	—	23.0	-	114.2	217.3	127.2	58.0	35.9	22.5	19.2	24.8	11.8
h	—	23.6	-	54.1	-	278.5	250.5	36.7	15.6	25.7	18.6	31.2	11.9
i	13.2	—	32.2	—	53.9	-	65.2	21.7	12.9	18.0	16.4	12.4	9.1
j	—	11.0	-	18.2	-	45.1	36.1	12.2	14.5	16.8	22.5	12.0	6.9
k	8.8	—	8.2	—	15.4	-	13.2	9.2	19.4	15.7	14.0	6.2	3.6

Result of the dose rate measurement conducted after completion of shielding [mSv/h]

	1	2	3	4	5	6	7	8	9	10	11	12	13
b	—	—	—	—	45.5	44.7	32.9	26.6	22.9	—	—	—	—
c	—	—	—	27.9	82.9	35.8	19.7	26.6	41.0	—	—	—	—
d	—	—	—	4.3	81.4	4.5	5.8	96.9	40.3	—	—	—	—
e	—	—	—	—	51.9	2.8	6.8	68.0	107.0	—	—	—	—
f	—	—	—	2.7	38.3	2.8	6.5	91.6	65.4	—	—	—	—
g	—	—	—	40.0	49.6	4.0	19.5	38.9	28.0	—	—	—	—
h	—	—	—	47.3	86.8	123.8	116.9	29.8	13.5	—	—	—	—
i	—	—	—	22.5	28.8	67.7	75.8	16.2	0.0	—	—	—	—
j	—	—	—	16.6	26.2	36.4	30.9	—	—	—	—	—	—
k	—	—	—	—	—	—	—	—	—	—	—	—	—

5. Effects of the Decontamination Work and Shielding Work

[Effects of the Decontamination Work and Shielding Work]

- Setting the dose rates before decontamination as the standard (100%), the average of the ratio of the dose rates of each area after decontamination and shielding, as percentages of the dose rate before decontamination.
- Both decontamination and shielding reduced the dose rates. It is expected from this outcome that both decontamination and shielding will greatly assist in reducing the exposure of workers in the fuel removal-related manned work that will follow.

	After decontamination	**After shielding**
Work Section A	18.6%	32.9% Further dose reduction is expected when measured after shielding installation
Work Sections B and C	18.8%	To be measured
Work Section D	41.4%	To be measured
Work Section E	28.5%	To be measured
Work Section G	—	To be measured