Project of Decommissioning, Contaminated Water and Treated Water Management

(Research and Development of Processing and Disposal of Solid Waste
(Preliminary Investigation of Technological Option to Establish Flexible and Reasonable Waste Management))
FY2023 Subsidy Project Results

September, 2024

Veolia Nuclear Solutions Japan Corporation

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Outline of the Project

We have implemented the following grant projects to confirm the applicability of GeoMelt® ICV™ to Fukushima Daiichi Nuclear Power Station (1F) water treatment secondary waste.

- Subsidy program (the First solicitation) for the "Project of Decommissioning and Contaminated Water Management (Research and Development of Processing and Disposal of Solid Waste)" in the FY2017/18 Supplementary Budget
- Subsidy program (the First solicitation) for the "Project of Decommissioning and Contaminated Water Management (Research and Development of Processing and Disposal of Solid Waste)" starting FY2021

The FY2023 grant project consisted of the following two tasks to confirm the applicability of GeoMelt® ICV™ to a wide variety of 1F wastes.

Task 1: Investigation of bulk solidification technologies for rubbles

Task 2: Investigation of technologies to process dehydrated ALPS slurry together with a container

1. Introduction

Task 1: Investigation of bulk solidification technologies for rubbles

A large amount of miscellaneous rubbles such as concrete, electrical boards, and metallic steel materials generated as a result of decommissioning is generated in 1F. Many of these items have high radiation doses, and it is difficult to segregate them according to material as a front-end process. In addition, it is assumed that the removal of equipment in the buildings will proceed in the future in conjunction with the decommissioning and debris removal work. Some of these devices were immersed in highly contaminated water in the basement of the building and are expected to have a higher radiation dose, making it impossible to segregate them at a level equivalent to normal decommissioning. Therefore, this task examined a technology to solidify these miscellaneous rubbles in one batch without segregation.

Items implemented

- Survey of miscellaneous rubbles
- Melting tests for bulk solidification technologies for miscellaneous rubbles
  - PNNL* glass formation analysis
  - Small-scale test (1-ton batch melter, 4 times in total)
- Conceptual study of actual facilities based on melting tests

Miscellaneous rubbles being stored in the soil covered storage area (L)

* PNNL: Pacific Northwest National Laboratory

1. Introduction

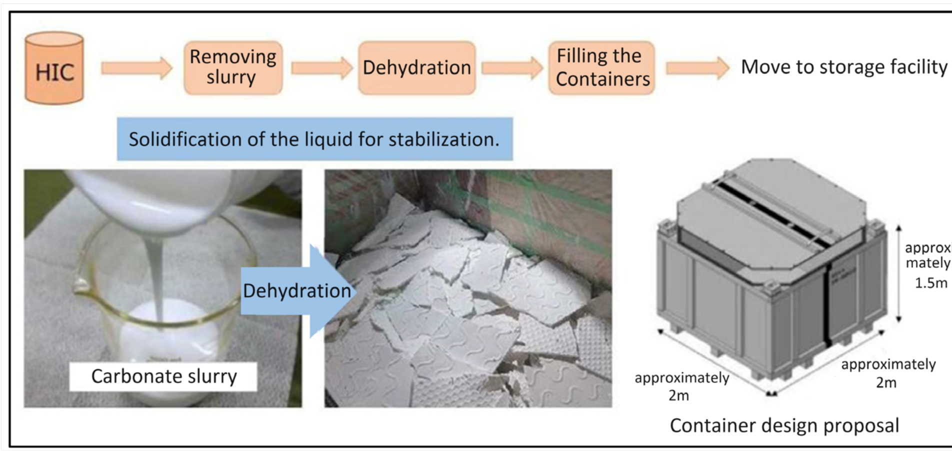
Task 2: Investigation of technologies to process dehydrated ALPS slurry together with a container for dehydrated materials

ALPS slurry, a secondary waste product from water treatment, is planned to be dehydrated in a filter press and stored in storage containers. However, when removing the dehydrated ALPS slurry from the storage container, there are possible problems such as the dehydrated material sticking to the inner walls of the container.

Therefore, in this task, we researched the technology to melt the dehydrated ALPS slurry with the entire storage container.

Items implemented

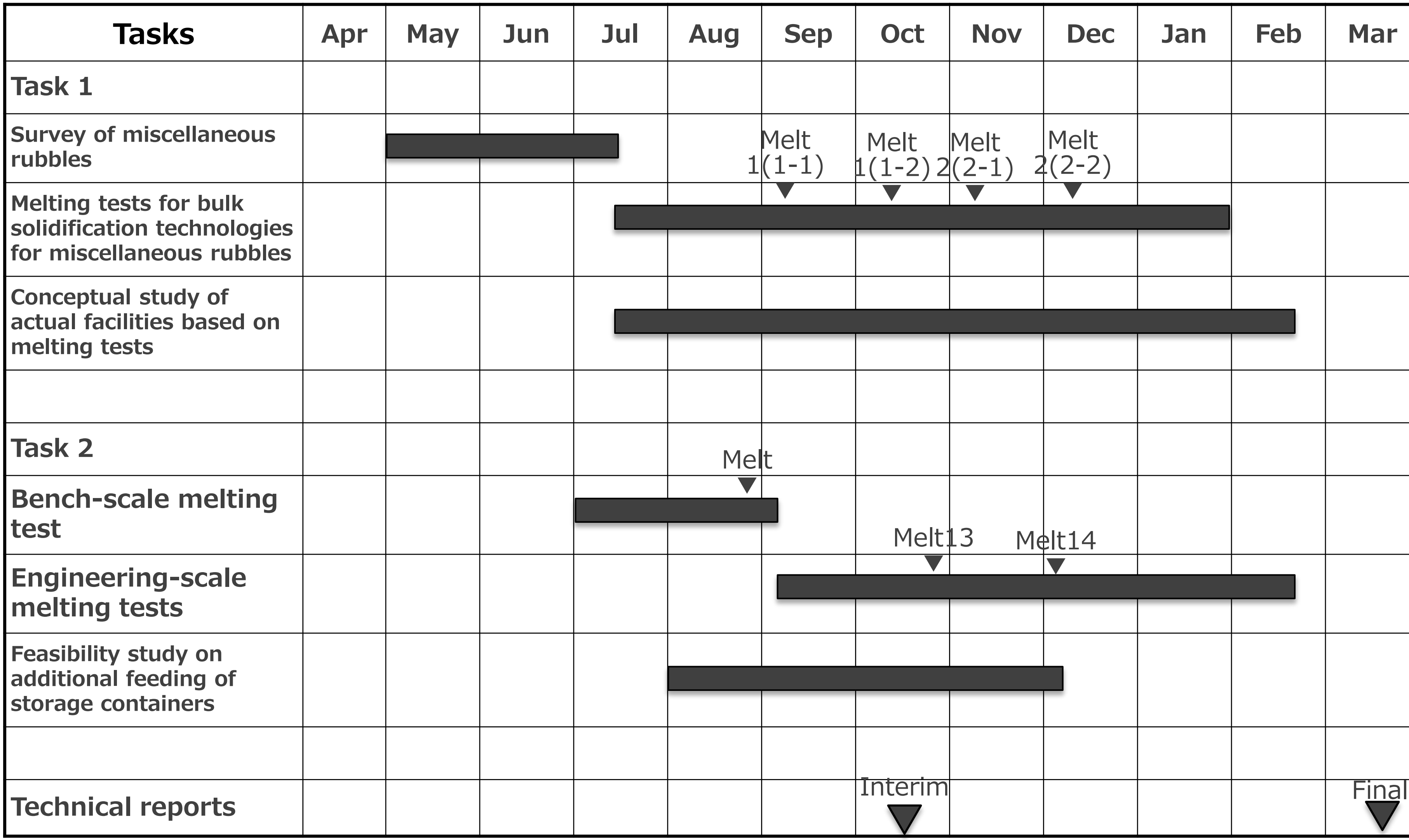
- Melting Tests
  - PNNL Glass formation Analysis
  - Bench-scale Test
  - Engineering-scale Melting Tests (about 200 kg, 2 times in total)
- Feasibility Study on Additional Feeding of Storage Containers



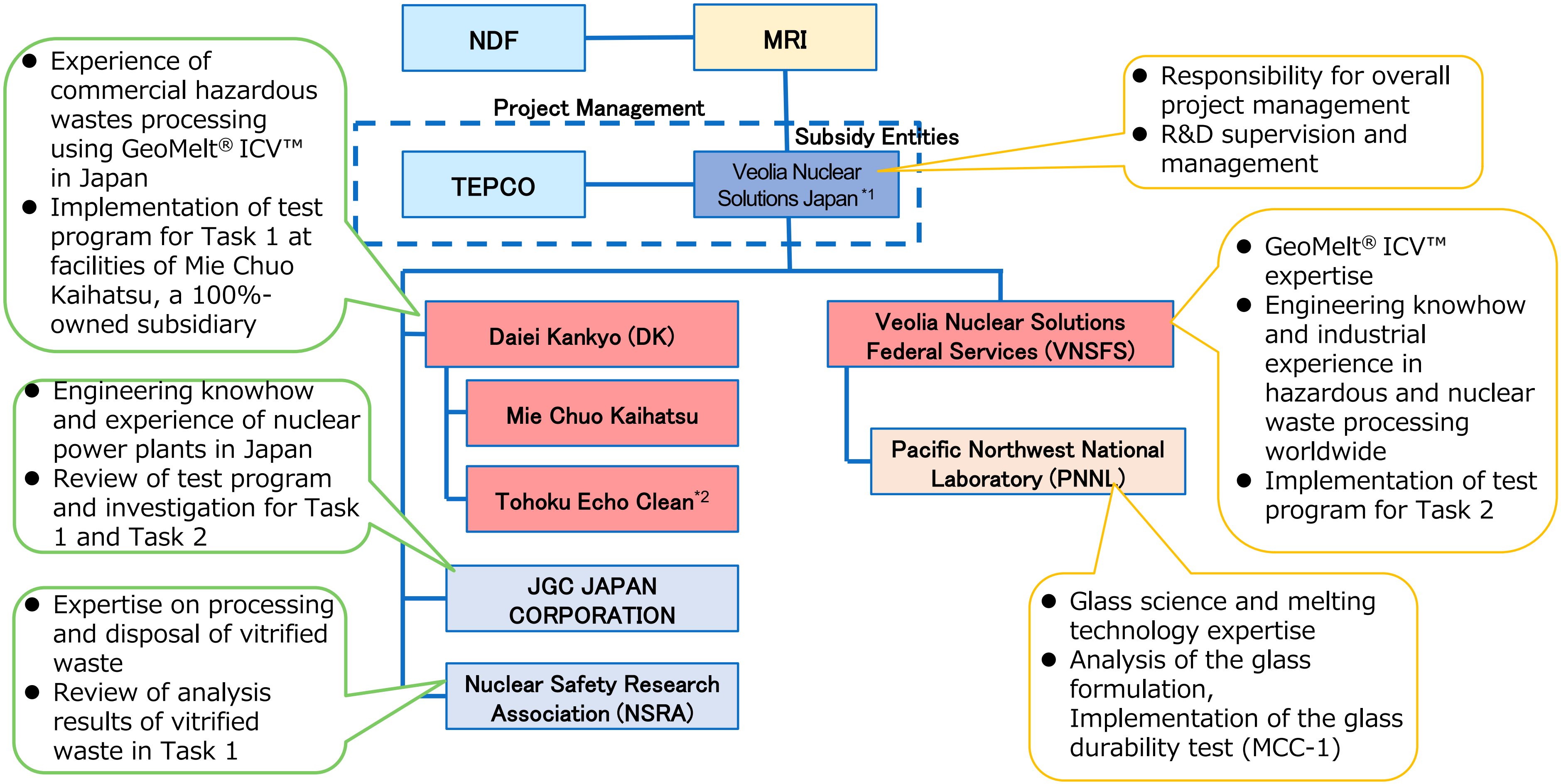
Dehydrating flow of ALPS carbonate slurry

Implementation schedule

All planned implementation tasks, including the melting tests, were completed as follows:



Implementation structure



*1 The company name was Kurion Japan at the start of the project, but the name was changed to Veolia Nuclear Solutions Japan during the project.

*2 Tohoku Echo Clean, a subsidiary of Daiei Kankyo, is a top-class company that treats and disposes of industrial waste locally in Fukushima. In order to contribute to the decommissioning of 1F, Tohoku Echo Clean will participate in this project, master GeoMelt® technology, and be in charge of miscellaneous waste treatment tests using a 1-ton batch melter at Mie Chuo Kaihatsu. For this reason, we will share the information of this project and ask them to review the test results.

2. Task1: Investigation of bulk solidification technologies for rubbles

2. Task1: Investigation of bulk solidification technologies for rubbles

Survey of miscellaneous rubbles

Information on the materials, shapes, storage conditions, hazardous materials, etc. of the miscellaneous rubbles present in 1F was investigated and sorted, and a study of the feasibility of melting the rubbles in GeoMelt® was conducted based on the physical and chemical properties of each piece of rubble.

Melting tests for bulk solidification technologies for miscellaneous rubbles

Based on the results of the survey of miscellaneous rubbles, simulated waste materials were prepared and tested to confirm the feasibility of bulk solidification.

Conceptual study of actual facilities based on melting tests

Based on the results of the melting tests, a conceptual study of the actual facilities was conducted. In this study, the following items are examined.

- ✓ Study of the operation method and process flow of the actual facilities
- ✓ Study of the economics of GeoMelt® treatment

2.1 Survey of miscellaneous rubbles

The types of rubbles and storage conditions provided as information by TEPCO HD are shown below.

(TEPCO HD data)

Group	Type of rubbles	Storage conditions
① High-dose group (1~30mSv/h)	Soil, concrete, iron, copper, aluminum, lead, electric wire (polyvinyl chloride coated, aluminum coated)	High dose rubbles (storage area L), stored in a soil covered storage area, then removed in the future and stored in metal containers in a solid waste storage buildings. **Difficult to segregate the rubbles at the same level as normal decommissioning.**
② Medium- and low-dose group (≦1mSv/h)	Assumed to be equivalent to the above	Huge amount of rubbles with medium and low radiation levels (area C), shredded and stored in metal containers as volume reduction process. **Difficult to segregate the rubbles due to shredding process.**
③ Rubbles from the removal of equipment from the basement of the building (to be generated in the future)	Electrical panels, electric motors (carbon steel), transformers and electric wires (copper, aluminum, vinyl chloride sheathed), electronic circuit boards, plastics, heat insulators for piping, etc. (glass fiber, calcium silicate) (in a mixed condition with binding steel wires and aluminum sheathing), steel frames and rebar with concrete, and insulation materials (asbestos-based materials)	The rubbles generated from the removal of equipment from the reactor building, etc., and items exposed to gas containing Cs or immersed in highly concentrated stagnant water will be included in the future, and it will be **impossible to segregate them at a level equivalent to that of normal decommissioning.**

- The types of rubbles were considered to consist of soil, concrete (with steel reinforcement), iron (carbon steel), copper, aluminum, lead, electrical wires (copper, aluminum, polyvinyl chloride coated), plastic and pipe insulator, heat insulator (asbestos), and electrical panels, etc. For the melting tests, the meltability of these simulated materials would be confirmed in mixed conditions.

2.1 Survey of miscellaneous rubbles

1F soil

In the miscellaneous rubbles, contaminated soil has a high composition of Si, a glass forming element. Consider utilizing soil as the primary glass-forming material and melting the other wastes.

Sampling location of 1F soil samples

Sample Name	Sampling Date	Sampling Location	Sampling Depth (cm)	Weight (g)	Dose rate※1 (μSv/h)
S2-D2-1	2015.3.24	Area D	0~5	106	13
S2-F1-1	2015.3.30	Area F	0~5	106	8
S2-I2-1	2015.4.16	Area I	0~5	105	6
S2-K2-1	2015.3.16	Area K	0~5	105	< 0.5
S2-L1-1	2015.4.20	Area L	0~5	106	< 0.5
S2-P1-1	2015.5.8	Area P	0~5	110	6

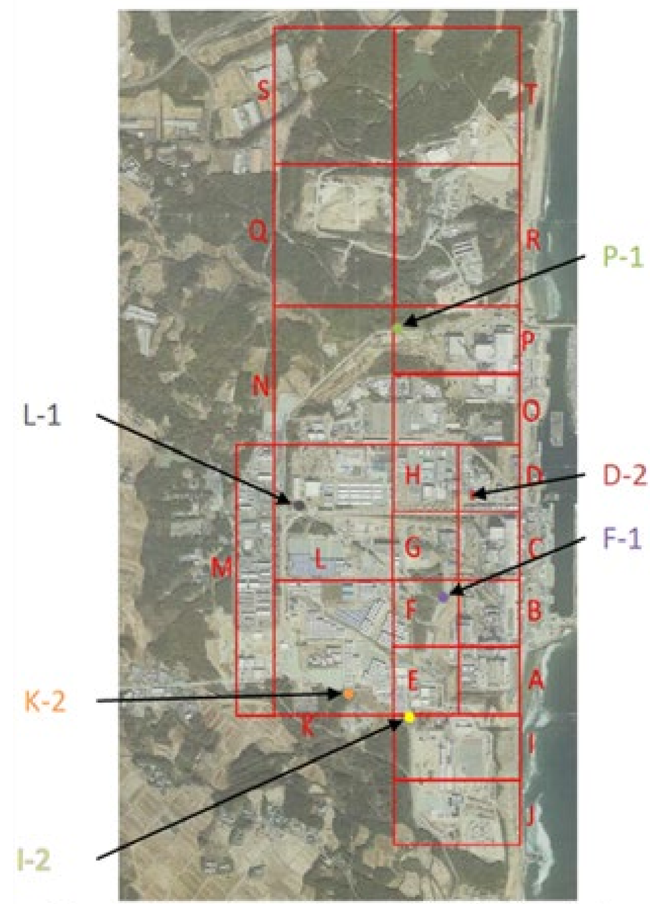
Elemental composition of the samples

Sample Name	Element (mg/g)							TOC
	Na	Mg	Al	Si	K	Ca	Fe	(mg/g)
S2-D2-1	6.9	4.0	52.6	235	8.5	3.6	23.4	24.4
S2-F1-1	6.7	3.2	62.1	258	10.8	2.3	30.3	15.5
S2-I2-1	3.1	5.8	40.4	107	6.7	7.6	23.7	48.4
S2-K2-1	3.1	3.7	60.3	183	8.2	24.2	31.7	24.9
S2-L1-1	6.6	3.6	44.5	175	8.7	3.0	18.2	28.9
S2-P1-1	6.4	4.1	51.1	194	7.4	7.6	20.7	30.7

Converted to mass fraction of oxide
(Calculated by this project)

Unit: wt%

	Na_2O	MgO	Al_2O_3	**SiO_2**	K_2O	CaO	Fe_2O_3	total amount
average	1.3	1.3	17.2	**70.1**	1.8	2.1	6.3	100



Sampling Location of Soil Samples

* IRID, Analytical results of waste samples (Soil, incineration ash, and water at the doorway of the water treatment facilities (Cesium Adsorption Apparatus, Advanced Liquid Processing System)) Mar 30 2017, revised Apr 25 2019

Assumption of melting behavior for each material in rubbles

The melting behavior of each rubble type based on past experience is assumed to be as follows. Melting tests were conducted with a mixture of these types of rubbles to confirm the behavior and to verify the feasibility of bulk solidification.

Type of rubbles	Assumption of melting behavior
Iron	• The resistance is low, and electrical shorts occur if iron is in contact with 2 or more electrodes when the glass is directly energized. Therefore, the glass must be melted by heat transfer from the molten glass, requiring a glass temperature of about 1550°C above the melting point of iron. • Once melted, it submerges and accumulates at the bottom due to density differences.
Copper	• Behavior after melting is similar to that of iron (melting point of copper is 1083°C)
Soil	• By adding glass additives to improve durability, it can be utilized as a glass-forming material.
Concrete (with steel reinforcement)	• The concrete is melted and becomes part of the glass. • The rebar portion is melted and submerges or accumulates at the bottom due to density differences.
Flame retardant (PVC)	• It burns and does not dissolve in glass. • Dioxins and hydrogen chloride are generated. • Incomplete combustion results in soot (unburned carbon).
Heat insulator (calcium silicate)	• It is melted and becomes part of the glass.
Aluminum	• Because of the reducing atmosphere in the molten glass, it is not oxidized and is retained as a metal. However, due to its low density (2.7 t/m^3), it is dispersed in the molten glass.
Lead	• Dispersed in the molten glass (in small quantities).
Items with interior space, such as electrical panels	• During housing melting, molten glass may flow into the interior space, reducing the amount of molten glass between the electrode rods that can be energized, which may interfere with energization.

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.1 Objectives and plans of melting tests (1) Objectives of the test

Based on the results of the miscellaneous rubbles survey, the feasibility of detoxifying and vitrifying hazardous substances contained in miscellaneous rubbles with treatment technology by GeoMelt® ICV™ was evaluated through the following Melting Tests.

- Melting Test 1 was to check the effects of changing the metal percentage in the basic material to be treated.
- In the Melting Test 2, electrical panel, heat insulator (calcium silicate), and flame retardant (vinyl chloride) were further added to confirm melting behavior, etc.

Test		Objective
Melting Test 1		Check the meltability of the the basic objects to be processed (mixture of 1F soil simulant, 1F concrete block simulant, and metal steel).
	Melt 1-1	Confirmation test for basic objects to be processed.
	Melt 1-2	Check the effect on the melting of **metals** (current VNSFS operation control upper limit: **about 30wt%**).
Melting Test 2		Based on the results of Melting Test 1, check the effects on melting properties of **electrical panels** with internal spaces**, heat insulators**, **and flame retardant materials.**
	Melt 2-1	Confirmation test for basic objects to be processed plus electrical panels, heat insulators, and flame-retardant materials.
	Melt 2-2	In addition to checking the meltability of heat insulating materials and flame retardants, **about 30wt%** of the metals could not be completely melted in Melting 1-2, so the same amount of metals was filled and the conditions necessary for melting were re-verified.

2.2.1 Purpose and plan of melting test (2) Test plan

Based on the objectives on the previous page, the following four tests were conducted using the following parameters: the ratio and form of metals (bolts, electrical panels with internal spaces, etc.), the presence and form of heat insulator (in its original form and in the crushed form), and the presence and amount of flame retardant materials.

The following two points were common.
(1) Use glass formulations based on 1F soil simulant and 1F concrete block simulant.
(2) Install silica sand lining on the inside of the cast refractory vessel integrated with the outer vessel of the melter.

In each test, the process data behavior of the GeoMelt® ICV™ melting system, off-gas components, and the physical properties of the vitrified waste were evaluated.

Melting test		Main components of the simulated material to be treated	Quantity of simulated material to be treated	
			kg	Percentage of metals
1	Melt 1-1	1F soil simulant + 1F concrete block simulant + metal steel	714	12.3%
	Melt 1-2	Melt 1-1 + **increased ratio of metals (including lead blocks)**	637	26.7%
2	Melt 2-1	Melt 1-1 + **electrical panel** + **heat insulator** + **flame retardant material**	487	10.8%
	Melt 2-2	Melt 1-1 + **increased ratio of metals** + **heat insulator** + **flame retardant material**	569	32.7%

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.1 Purpose and plan of melting test (3) Summary of test conditions

Combination conditions for 1F soil simulants, high-tension bolts, lead, flame retardant materials, heat insulators, etc. are shown in the table below.

			Melt 1-1	Melt 1-2	Melt 2-1	Melt 2-2
Date of melting test			9/11 - 9/13/2023	10/9 - 10/11/2023	11/13 - 11/15/2023	12/18 - 12/20/2023
Initial feed[*1]	1F soil simulant		✓	✓	✓	✓
	Metal	High tension bolt	✓	✓	✓	✓
		Painted iron sheet	✓	✓	✓	✓
		Housing	✓ **(Pull box)**	✓ **(Pull box)**	✓ **(Electrical panel)**	
		Copper, aluminum cable	✓	✓	✓	✓
		Lead grain (225 mg/kg)[*3]	✓	✓	✓	✓
		Lead block[*3]		✓		
	Heat insulator				✓ **Original form (cylindrical)**	✓ **Original form (cylindrical)**
	Flame retardant (e.g. pressure-resistant hose)		(Cable sheath only)	(Cable sheath only)	✓	✓
Additional feed[*2]	1F soil simulant		✓	✓		
	Metal	High tension bolt	✓	✓		✓
	Heat insulator				✓ **Original form (cylindrical)**	✓ **Crushed**
	Flame retardant (pressure-resistant hose)				✓ **(Length approx. 100mm)**	

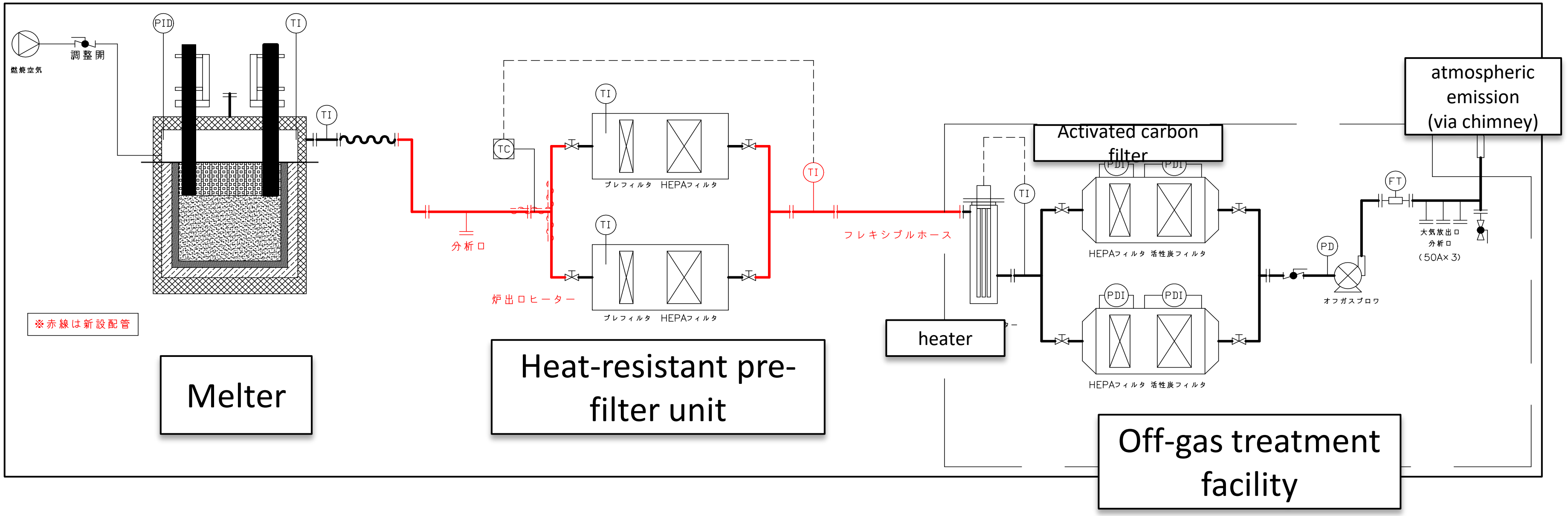
[*1] Simulated rubbles fed into the melter before melting.

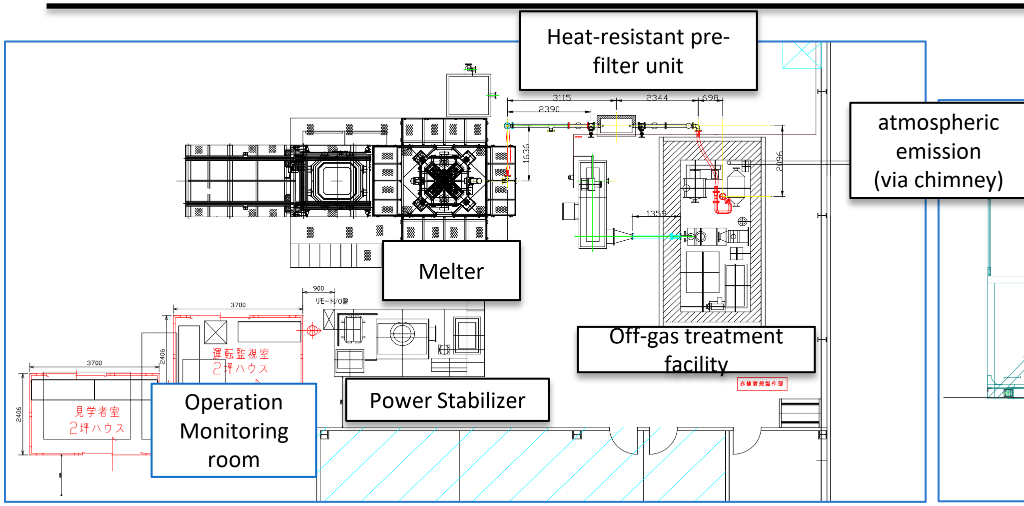
[*2] Simulated rubbles additionally fed into the melter during melting for the purpose of volume reduction.(Only its behavior is verified in this project.)

[*3] Lead grains are a simulator of solder, etc. in electrical products. On the other hand, lead blocks simulate lead as a shielding material.

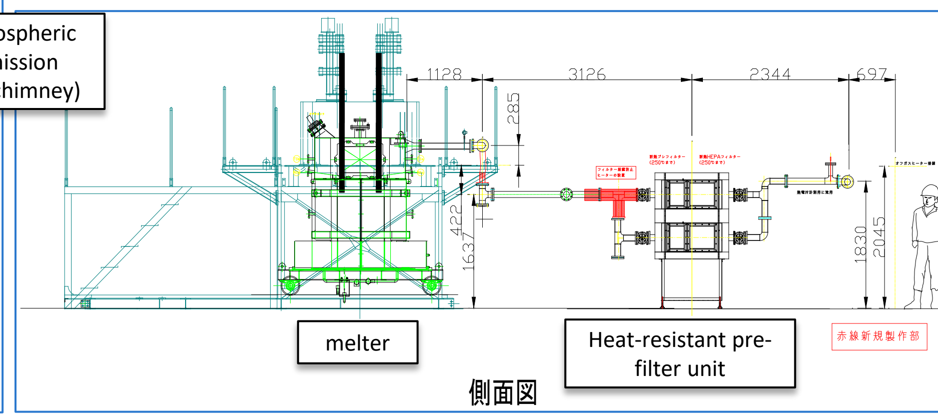
2.2.2 Configuration and preparation of test equipment

(1) Flow and layout of melter facility





ground plan



side view

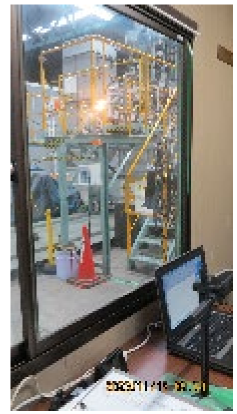
2.2.2 Configuration and preparation of test equipment

(2) Appearance of test equipment

Operation monitoring room

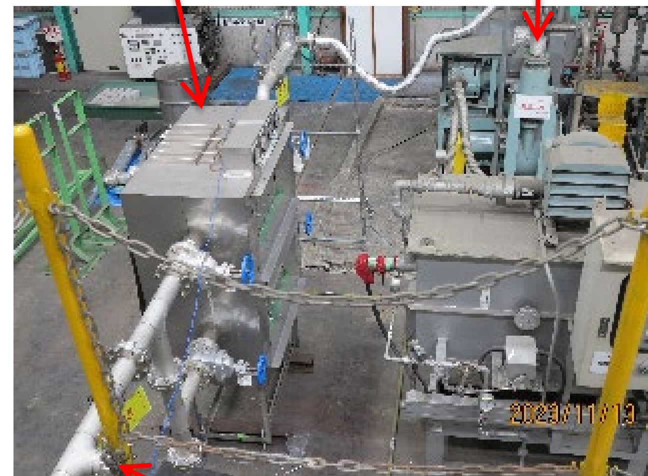
Melter (main body)

In the operation monitoring room



Heat-resistant pre-filter unit

off-gas processor



Melter side

Constant velocity off-gas Stack sampling branch

Basic gas sampling branch

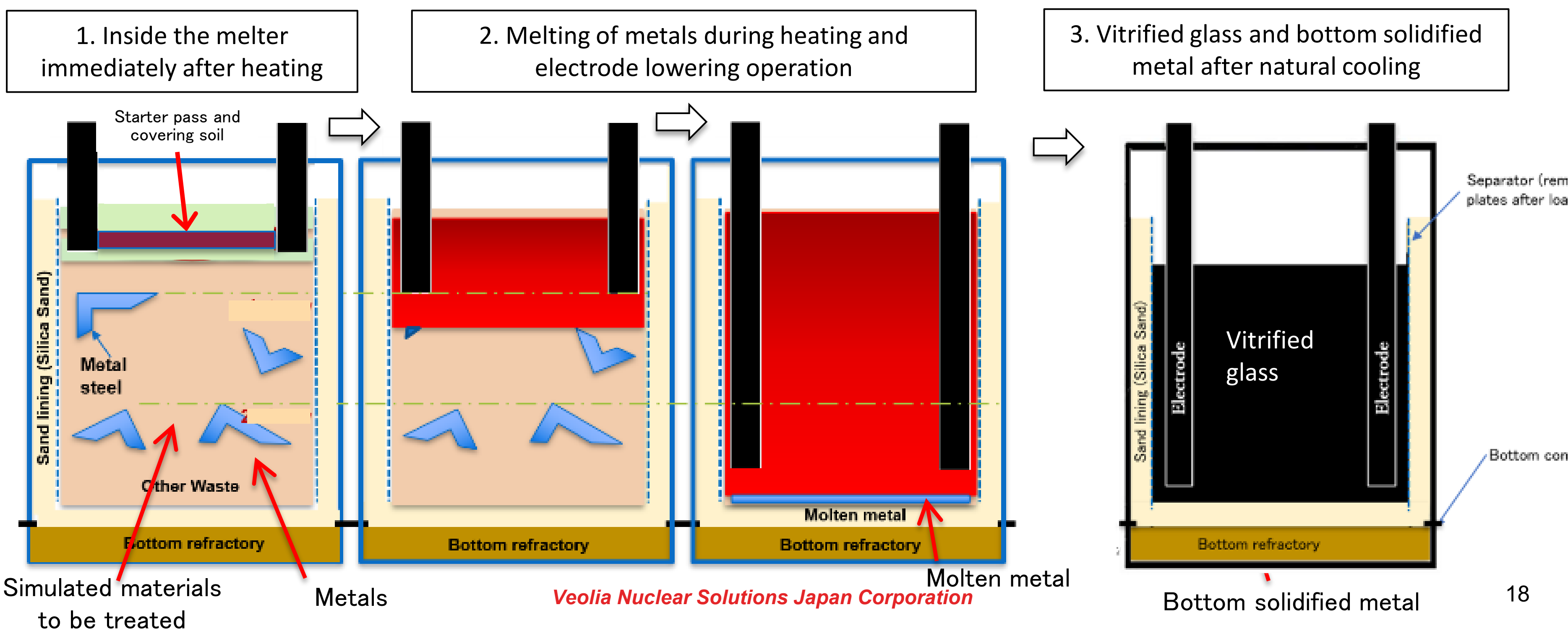
Power Stabilizer

Heat-resistant pre-filter unit side

Off-gas treatment facility

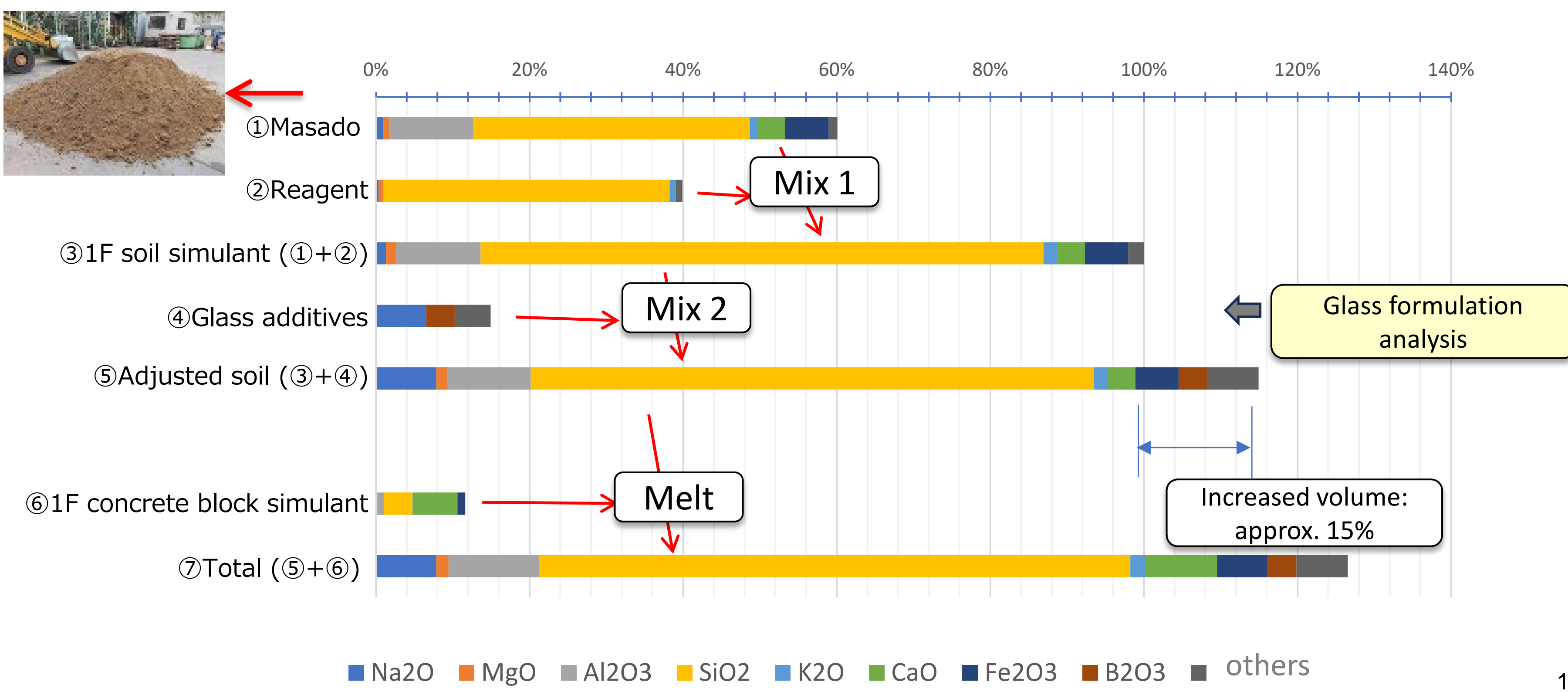
2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.2 Configuration and preparation of test equipment
(3) Overview of Top-Down Method and Electrode Descent Control

- As preparatory work, the melter is filled with initial feeds (simulated material to be treated, starter path, and covering soil).
- In the melting test, the starter path is first heated by the power supply to form molten glass around it, and then the melting of the 1F soil simulant is accelerated downward, and the metals in the lower layer are also melted sequentially and submerged at the bottom.
- To prevent electrical shorts due to contact between the electrodes and metals, proper electrode drop position was maintained while monitoring resistance changes between the electrodes.
- After the completion of the melting process, the product is naturally cooled in the melter, and finally a vitrified glass and a bottom solidified metal layer are formed.



2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.2 Configuration and preparation of test equipment
(4) Component adjustment of soil simulant

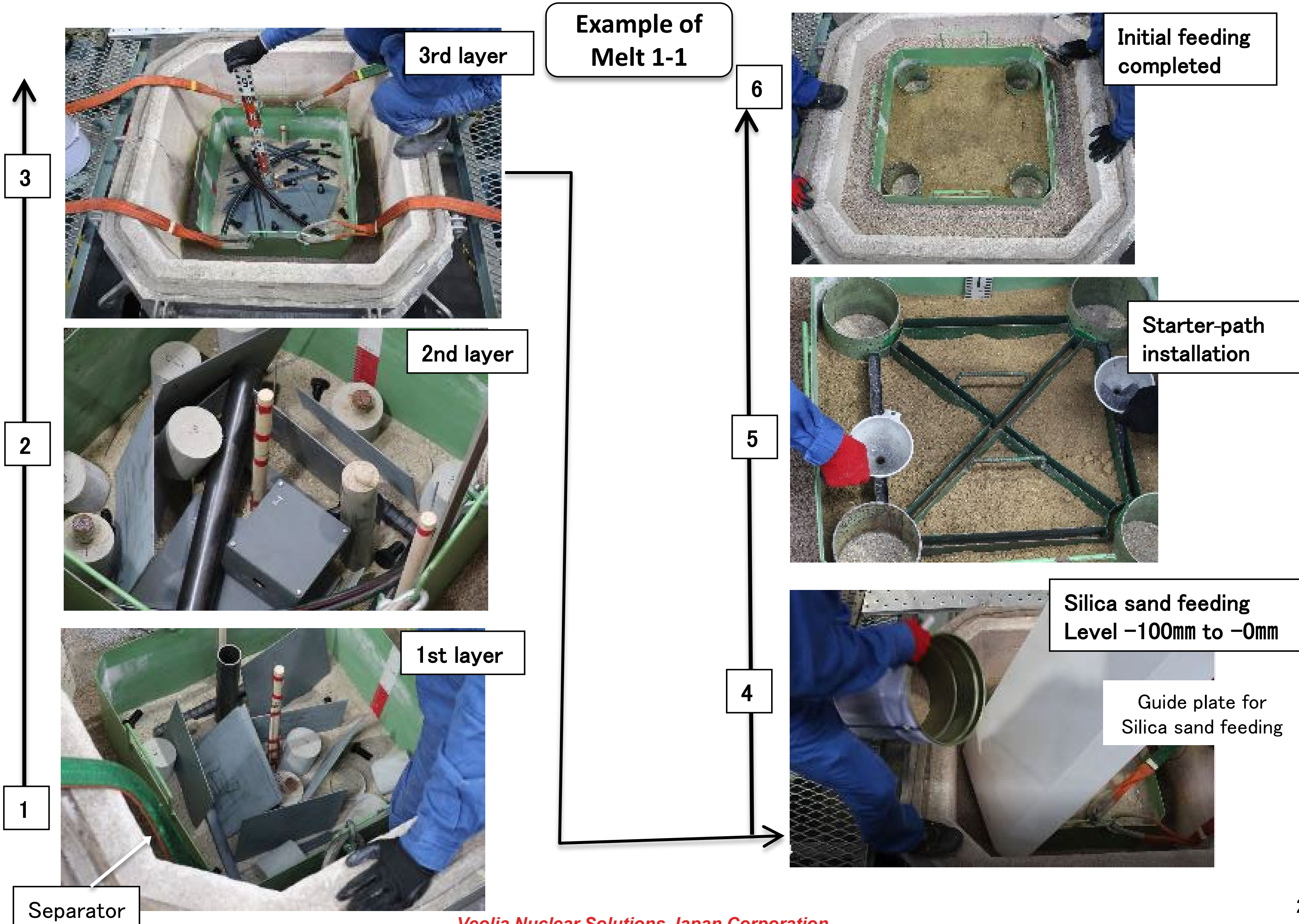
- The 1F soil simulant was prepared by adding reagents to fresh sand soil (masado) based on its actual composition (Mix 1 below).
- In addition, to obtain a glass composition that allows for high temperature melting of the steel (1550°C or higher), glass additives were added based on the results of the glass formulation analysis (Mix 2 below). In addition, in the glass formulation analysis, the composition of the 1F concrete block simulant, which is also the glass forming material, is also taken into account.



2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles

2.2.2 Configuration and preparation of test equipment

(5) Initial feeding procedure for simulated material to be treated



2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.3 Test results and evaluation (1) Summary of operation results

- A summary of all four melting tests is shown in the table below.
- The melting process itself was generally completed without problems during filling, temperature rise, melting, and melter cooling.
- An electrical short circuit between the electrode rods and the metal occurred in Melt 2-2, but it was immediately recovered by raising up the electrode rods, and did not significantly affect the operation.

Item (data)	unit	Melt 1-1	Melt 1-2	Melt 2-1	Melt 2-2
Total input	**kg**	**714.08**	**637.38**	**484.62**	**569.41**
Total metal	**kg**	**87.69**	**170.27**	**52.31**	**186.26**
Percentage of total metal	**wt%**	**12.3**	**26.7**	**10.8**	**32.7**
Melting time	**h**	**50**	**31**	**41**	**51.5**
Test result 1: Generation of solidified products		**OK: Well generated**	**OK: Well generated**	**OK: Well generated**	**OK: Well generated**
Test Result 2: Melting of metal steel		**OK: Completely melted**	Many unmelted steel materials	**OK: Completely melted**	**OK: Completely melted**
Test Result 3: Effect of additional feeding		**OK: No impact**	**OK: No impact**	Generation of black smoke due to thermal decomposition of pressure-resistant hose Insufficient melting of prototype heat insulator	**OK: No impact**
Test Result 4: Stability of off-gas systems		**OK: No abnormality**	**OK: No abnormality**	**OK: No abnormality except increase in filter differential pressure due to soot when additional pressure-resistant hose is fed**	Zinc paint on metallic steel material becomes white smoke, increasing the off-gas system filter differential pressure
Test result 5: Other confirmed events			Lead block with low melting point melts and solidifies at the bottom of the melter		One electrode broken (The sound part of the upper part of the electrode rod is lowered to continue the operation)

2.2.3 Test results and evaluation (2) Observation results of vitrified waste

Cross-sectional photographs of the vitrified waste produced in each test are shown below.

Although unmelted metallic steel was observed in Melt 1-2 (described in detail on page 24), a solidified metallic layer was observed in Melt 1-1 and Melt 2-2 tests. A dense glass phase was also formed in all tests.

Melt 1-1

Vitrified waste cracked and separated

Melt 2-1

Melt 1-2

Melt 2-2

Glass phase

Solidified metal layer

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.3 Test results and evaluation (3) Summary of analysis results

- The physical properties, retention rate, elution rate,etc. of the vitrified waste produced in each test were confirmed. As with previous grant projects, good results were obtained.
- Behavioral data on off-gas components was also confirmed.

No.	Item (data)	Object of measurement	unit	Melt 1-1	Melt 1-2	Melt 2-1	Melt 2-2
1	Retention of vitrified waste	Cs	%	98.34	92.30	84.34	78.87
		Sr	%	99.98	99.92	99.95	99.93
2	Basic properties of vitrified waste	Density	g/cm3	2.3 or higher	2.3 or higher	2.3 or higher	2.3 or higher
		Uniaxial compressive strength	MN/m2	280	75.3 (Partial breakage in the middle)	373	442
3	Composition of vitrified waste	Various components	mass percent	No significant variation in main components (Al_2O_3,SiO_2) and tracers (Cs, Sr) of glass			
4	Composition of vitrified waste (average value)	Cs	mg/kg	326	231	180	220
		Sr		365	277	260	328
5	Elution rate (MCC-1 Test)	Mass loss NL(Na)	g/m2	Not analyzed	Below 7 after 4 weeks: Sufficiently lower than Japan's high-level vitrified waste		Not analyzed
6	Content and elution of vitrified waste	Pb	mg/kg, mg/L	Satisfies the standard value (Content: ≦150mg/kg, Elution: ≦0.3mg/L)*1			
7	Solidified metal layer	Iron and other various components	wt%	Iron: 89.9%	*2	Iron: 88.8%	Iron: 81.9%
8	White smoke in off-gas (filter capture)	ZnO content of paint origin	wt%	Not analyzed	75	Not analyzed	58
9	Processed gas ①	Dioxin	ng-TEQ/Nm3	Not analyzed	Satisfies the standard value (≦5ng-TEQ/Nm3)*3		Not analyzed
10	Processed gas ②	HCl, NOx	mg/Nm3, ppm	Not analyzed	Satisfies the standard value (HCl≦700mg/Nm3, NOx≦250ppm)*4		Not analyzed

*1 The standard value of the content is based on the Soil Contamination Countermeasures Act, and the standard value of the elution is based on Regulations of Waste Management and Public Cleansing Law Enforcement Regulations Article 1-2.
*2 Component analysis was not performed because the filled metals could not be completely melted.
*3 Based on the Act on Special Measures against Dioxins Enforcement Order Article 1.
*4 Based on the Air Pollution Control Act Enforcement Order Article 2 and 5.

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.4 Characteristic test results (1) Melt 1-2 (unmelted metal and lead blocks)

- In Melt 1-2, the simulated amount of material to be treated was reduced (714 kg → 637 kg), melting time was shortened (50h → 31h), and the content of metals was increased (12.3% → 26.7%) (target of approximately 30%, of which 2 lead blocks (total 23 kg) were treated).
- As a result, unmelted metallic steel was observed at the bottom. We believed that the cause was insufficient heating power, and the melting time of 31 hours in Melt 1-2 was extended to over 40 hours in Melting Test 2. As a result, in Melt 2-2, no unmelted metallic steel material was observed even under the condition of a metal content of 32.7%.
- The lead supplied as a block was not dispersed into the vitrified glass, but was found to melt and submerge and accumulate at the bottom.

Cut surface of vitrified waste

Lead block before melting(200x100x50mm)

Lead lumps submerged on the bottom

Molten lead lumps

2.2.4 Characteristic test results

(2) Melt 2-1 (Initial feeding: electrical panel, heat insulator, flame retardant material)

- In Melt 2-1, two electrical panels (approximately 17 kg), which are metallic items with a large interior space, heat insulator (cylindrical calcium silicate), and flame retardant materials (PVC pressure-resistant hose) were initially fed, and a melting test was performed.
- During operation, there were no particular anomalies in energization, etc., and no differences from Melting Test 1 were observed. And no particular differences were observed in the operation of flame retardant materials.
- These initial feeds were not observed in the vitrified waste produced, and all are considered to have been melted or pyrolyzed.

Initial feed status (2nd layer)

Pressure-resistant hose

Heat insulator (cylindrical type) (split in half, 30mm thick)

Electrical panel

2.2.4 Characteristic test results

(3) Melt 2-1 (Additional feeding: heat insulator, flame retardant materials)

- In Melt 2-1, heat insulator (cylindrical type, cut size 30 mm) and flame retardant material (PVC pressure-resistant hose) were added.
- The 17 heat insulators (0.43 kg) remained on the surface of the molten glass, and there was no sign of them melting or settling into the molten glass. In order to melt the heat insulator by cutting off contact with the low-temperature gas phase, the remaining heat insulator (0.81 kg) and TOF (30 kg of glass frit) were additionally fed 4 hours after the first heat insulator was fed. As a result, although some of the heat insulator floated on the surface of the molten glass and could not be melted, most of it was able to be melted.
- The flame retardant material (2 pieces, 0.32kg) burned out with incomplete combustion on the surface of the molten glass. At this time, black smoke filled the off-gas hood, making it difficult to visually see inside, and the differential pressure in the off-gas filter rose sharply due to soot and other factors. The black smoke in the melter settled down after about 20 minutes, and the inside of the melter became visible.

Additional feed: Heat insulator (cylindrical 30 mm cut)

Before TOF feeding Residual on molten surface

After TOF feeding

Additional feed: Flame retardant (2 pieces)

13th hour: additional feeding

Incomplete combustion and black smoke (Continues for approximately 20 minutes)

2.2.4 Characteristic test results

(4) Melt 2-2 (Additional feeding: heat insulator (crushed))

- In Melt 2-2, heat insulator (approx. 2kg) was crushed and additionally fed in to form a layer, and its melting behavior was checked. This is based on the expectation that the heat insulator (crushed) at the bottom can be melted by cutting off contact with the gas phase. The heat insulator (crushed) formed a small pile immediately after feeding, but the pile gradually collapsed as the material was melted from the bottom. After about 1.5 hours, most of the heat insulators were melted.

Additional heat insulator (crushed)

Status of heat insulators (crushed) inside the melter
(IR camera (Infrared camera) image)

Heat insulator (crushed)
in small pile

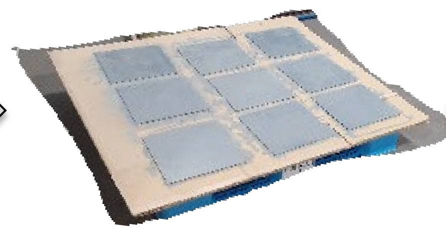
Mostly molten heat insulator
(crushed)

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.4 Characteristic test results (5) Melt 2-2 (white smoke (zinc compound))

- In Melt 2-2, white smoke (particulate material) was generated during melting, resulting in reduced visibility in the melter and increased differential pressure in the off-gas filter.
- Dust samples from off-gas filters (pre-filters) contained 36-75% zinc. The steel plates initially fed as metals were coated with zinc paint, and the mass balance with zinc in the dust indicated that almost all of the zinc had migrated to the off-gas, although the zinc in the recovered dust was estimated to have a larger weight in the calculation due to a large error, as shown in the table below.
- Since it is assumed that a large amount of such steel plates are included in the 1F miscellaneous waste, it is necessary to study the reflection of such steel plates in the off-gas treatment facilities in the future.

Steel plate and paint before painting

Steel plate after painting



Visibility inside the melter reduced due to white smoke

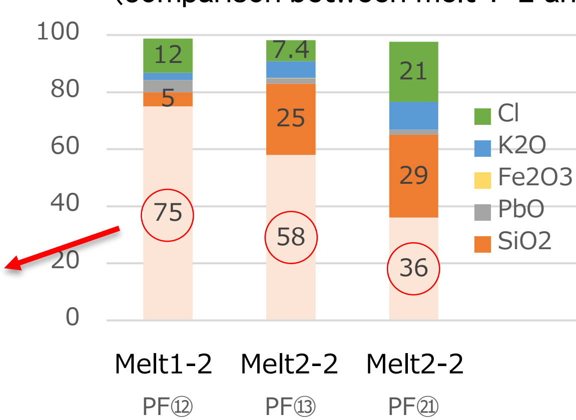
Pre-filter clogging condition

Mass balance with zinc [*1]

Items	Melt 1-2	Melt 2-2
Total amount of zinc coated on steel plates (kg)	**1.25**	**1.74**
Zinc in recovered dust (①×②)(kg)	**1.4**	**3.0**
①Amount of recovered dust (kg)	1.88	6.38
②Percentage of zinc in dust	75wt%	47wt%[*2]

[*1] The weight of zinc is the weight converted to ZnO.
[*2] Averaged the analytical results of two samples.

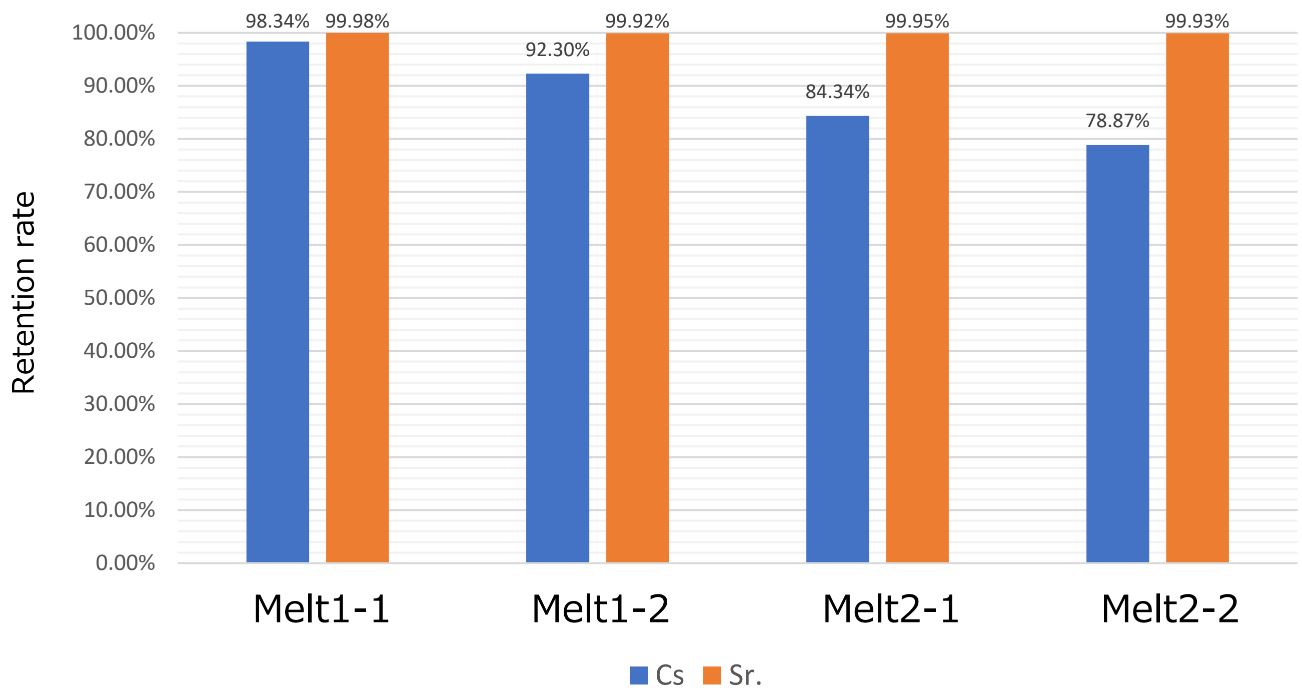
Composition of dust samples from pre-filters (PF)
(comparison between melt 1-2 and melt 2-2)



(Unit: %, ⑫⑬㉑ is PF exchange number (PF was replaced multiple times during the melting test))

2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.4 Characteristic test results (6) Melt 2-2 (Retention of Cs and Sr in vitrified waste)

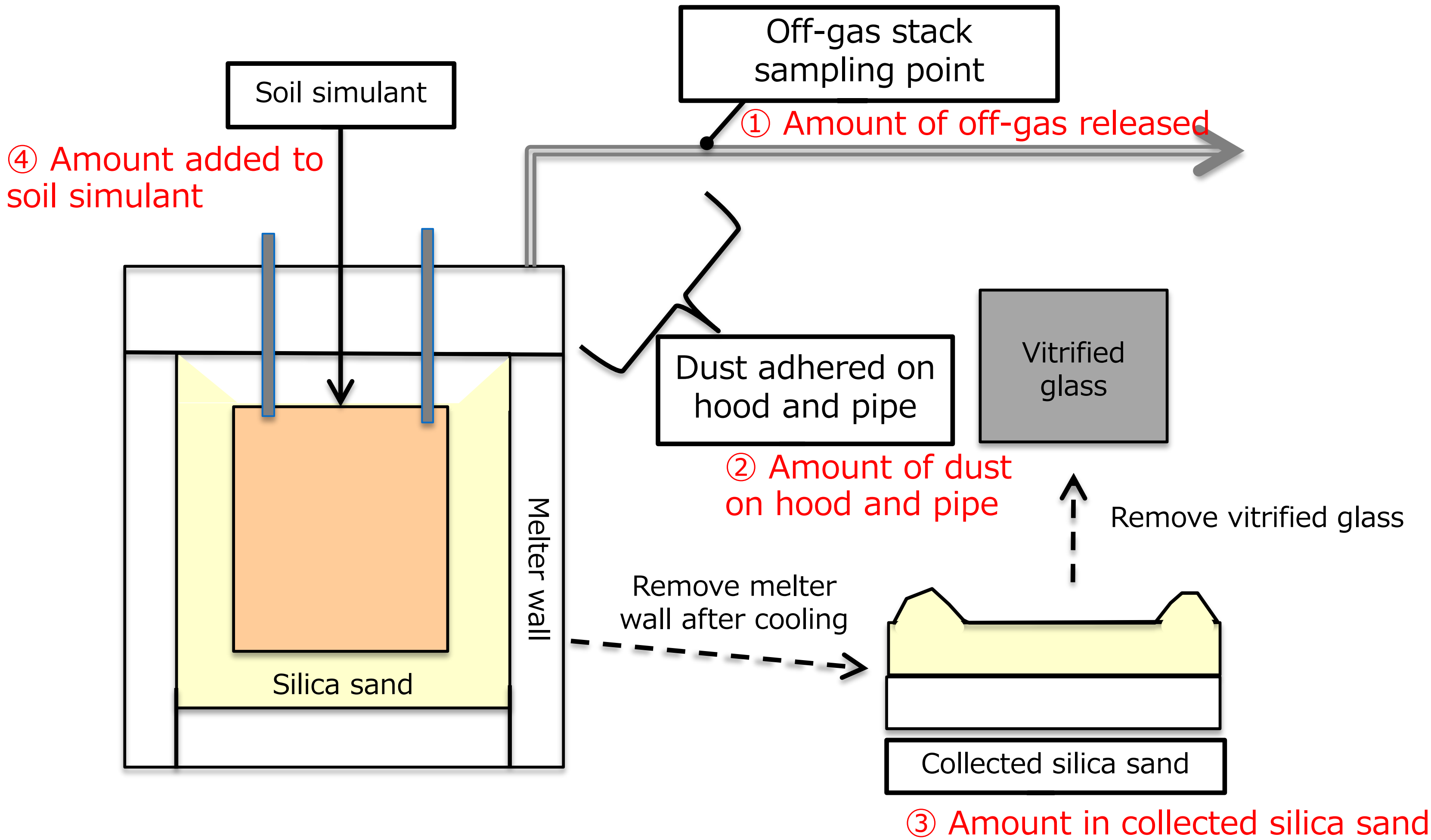
- Retention of Cs and Sr in vitrified waste was evaluated from off-gas stack sampling and wipe sampling in the hood and off-gas piping. See next page for calculation details.
- The retention of Cs in Melt 2-2 was 78.9%, the lowest among all four melting tests. This was lower than the retentions in previous grant projects, where retentions of over 90% were obtained under conditions where a sufficient cold cap was formed by the bottom-up method. Thus, the retention may be lower in the treatment of miscellaneous rubbles, so it will be necessary to study off-gas treatment facilities.
- Note that the off-gas stack sampling of the melting tests was only conducted for 4 hours due to limitations of the analytical equipment. In the calculation of retention, the results for 4 hours were converted to the total melting time (51.5 hours), which is considered to have a very large error. In the future, it will be necessary to consider measures to enable sampling of the total melting time.



2.2 Melting tests for bulk solidification technologies for miscellaneous rubbles
2.2.4 Characteristic test results (6) Melt 2-2 (Retention of Cs and Sr in vitrified waste)

- The retention of Cs and Sr was calculated from the amount of Cs and Sr transferred to off-gas using the formula below. See next page for results for each melting test.

$$\text{Retention rate (\%)} = \frac{(1-(\text{① Amount of off-gas released} + \text{② Amount of dust on hood and pipe} + \text{③ Amount in collected silica sand}))}{\text{④ Amount added to soil simulant}} \times 100$$



2.2.4 Characteristic test results (6) Melt 2-2 (Retention of Cs and Sr in vitrified waste)

List of data on retention of Cs and Sr for each melting test

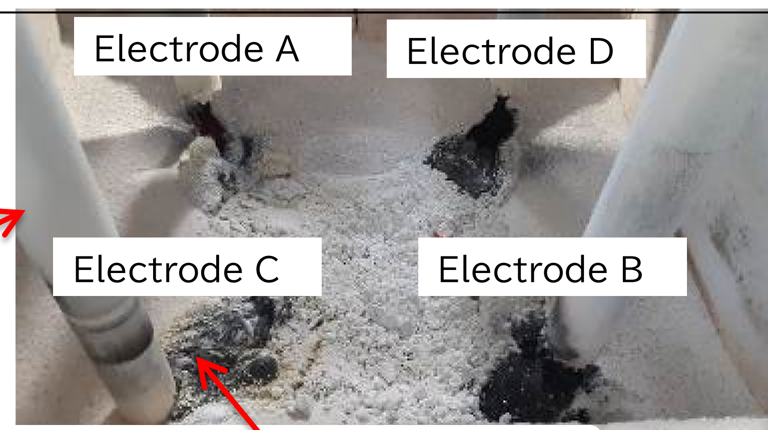
No.	Items	Unit	Melt 1-1		Melt 1-2		Melt 2-1		Melt 2-2	
			Cs	Sr	Cs	Sr	Cs	Sr	Cs	Sr
①	Amount of off-gas released (=①'×①''×3.6)	g	5.22	2.95×10^{-3}	10.3	6.19×10^{-3}	20.2	1.76×10^{-2}	30.8	1.13×10^{-2}
①'	Off-gas mass release rate (Sampling period)	mg/s	0.0290	1.64×10^{-5}	0.0924	5.55×10^{-5}	0.137	1.21×10^{-4}	0.166	6.08×10^{-5}
			(20-24h from start of melt)		(20-24h from start of melt)		(20-24h from start of melt)		(20-24h from start of melt)	
①''	Melting times	h	50		31		41		51.5	
②	Amount of dust on hood and pipe	g	0.010	0.037	0.022	0.0051	0.65	0.0052	1.4	0.012
③	Amount in collected silica sand	g	0.038	0.027	0.097	0.12	0.022	0.059	0.023	0.065
④	Amount added to soil simulant	g	318	340	135	167	133	151	152	133
Retention rate		%	98.3	100.0	92.3	99.9	84.5	100.0	78.9	99.9

2.2.4 Characteristic test results (7) Melt 2-2 (electrode rod breakage)

- Oxidized thinning of four electrode rods (Φ75 mm) progressed gradually due to prolonged melting test, and among them, the electrode C broke near the surface of the molten glass at 47 hours after melting started. Although energization was temporarily stopped, the sound part of the upper part of the electrode C was lowered, immersed in molten glass again, and energization was resumed.
- In a top-down method such as melting tests implemented in this study, the risk of electrode rod breakage is potentially high because the molten glass surface, which is prone to oxidative thinning, is hot from the beginning.
- In melting tests to be implemented in the next step of the study, it will be necessary to consider measures to reduce the electrode failure concern by using an electrode rod that is one rank thicker and controlling oxidation by electrode movement and waste feeding.

Status of electrode rod C after 47 hours of melting

After completion of melting and cooling
Wear and tear of each electrode rod



2.2 Melting tests for miscellaneous rubbles
2.2.5 Summary of test results

The behavior assumed in the survey of miscellaneous rubbles in Section 2.1 was confirmed in the test conducted in Section 2.2, and the results were summarized as follows.

Material in rubbles	Assumption of melting behavior (Section 2.1)	Results of melting tests (Section 2.2)
Iron	• Low electrical resistance and direct energization will cause an electrical short circuit. Therefore, it must be melted by heat transfer from the molten glass, requiring a molten glass temperature of about 1550°C above the melting point. • Once melted, it submerges and accumulates at the bottom due to density differences.	• Melting behavior is as expected. • **Zinc in the paint is volatilized and almost all of it is transferred to the off-gas system.** Off-gas treatment facilities should be considered in the future.
Copper	• Behavior after melting is similar to that of iron (melting point of copper is 1083°C)	• As expected.
Soil	• By adding glass additives, it can be utilized as a glass-forming material.	• As expected. The **glass** was produced with **excellent uniformity, strength, and durability.**
Concrete (with rebar)	• The concrete is melted and becomes part of the glass. • The rebar portion melts and submerges due to density differences, and accumulates at the bottom.	• As expected.
Flame retardant material (PVC)	• It burns and does not dissolve in glass. • Dioxins and hydrogen chloride are generated. • Incomplete combustion results in soot (unburned carbon).	• Initial feeding had no effect, but **additional feeding produced black smoke (soot) during combustion. Need to consider operation methods, such as feeding amount, feeding interval, etc.** • Dioxin and hydrogen chloride are as expected. Off-gas treatment facilities should be considered in the future.

2.2 Melting tests for miscellaneous rubbles

2.2.5 Summary of test results

Material in rubbles	Assumption of melting behavior (Section 2.1)	Results of melting tests (Section 2.2)
Heat insulator (calcium silicate)	• It is melted and becomes part of the glass.	• **The initial feeding was able to melt without problems, whereas the additional feeding was able to melt by grinding and forming a layer during feeding.** • If the energizing power can be increased, it may be possible to promote melting, but the optimal supply method also needs to be considered.
Aluminum	• Because of the reducing atmosphere in the molten glass, it is not oxidized and is retained as a metal. However, due to its low density (2.7 t/m3), it is dispersed in the glass.	• As assumed. Since a large amount of aluminum was eluted in the content test (eluted with 1M hydrochloric acid) based on the Soil Contamination Countermeasures Law, it is assumed to be dispersed in the glass as a metal, not as an oxide.
Lead	• Dispersed in glass. (in small quantities)	• When the amount is small (0.0225 wt%) and granular, it dispersed in the glass as expected and the elution rate is acceptable. • When the amount is large (4.7 wt%) and lumpy, it separated from the glass and deposited at the bottom.
Items with interior space, such as electrical panels	• During housing melting, molten glass may flow into the interior space and interfere with energization.	• There was no particular impact on the continuation of energization. • The actual electrical panel includes copper wire, flame-retardant coating, plastic, etc., in addition to the steel of the housing. **Melting behavior as a composite material needs to be studied in the future.**

2.3 Conceptual study of actual facilities based on melting tests

Contents of study in this section

- In this section, the feasibility test results are organized from the following perspectives, which are elements that depict the concept of actual facilities.

  - Study of the operation method and process flow of actual facilities

    Based on the results of the feasibility study of bulk solidification technology for rubbles, the operation method and treatment flow envisioned for the actual facilities will be examined.

  - Study of the economics of GeoMelt® treatment

    The volume of waste body, which is assumed to have a significant impact on the cost of treatment and disposal of miscellaneous rubbles, will be compared with vitrified waste and cement solidified waste.

Assumption of operation method in actual facilities

- First, regarding the melting method, the melting test of this study used the current equipment and a proven operating method to confirm the melting behavior of miscellaneous rubbles. However, the following operation methods are assumed in the actual operation.

Item (data)	This study	Assumption for actual	Description
Additional feeding	Almost never	Yes (repeated)	• Since melting reduces the volume of miscellaneous rubbles, **further volume reduction** can be expected by **feeding additional** rubbles into the space inside the container. • Metals are also deposited at the bottom of the melter by melting, so housings can significantly reduce the original space volume.
Melting method (See next page)	Initial filling method (top-down method)	Molten pool formation method (bottom-up method)	• Miscellaneous rubbles includes **high-dose rubbles. In the case of the initial filling method, it is difficult to manually fill the melter with rubbles** as was done in this study. Heavy machinery and remote equipment would be required, which would increase costs.
Melting container	Silica sand liner	Refractory container	• Silica sand liners are more or less contaminated with radioactive materials during melting. After melting, there is concern about **contamination of the facility** by **contaminated silica sand** during vitrified glass transfer.

2.3 Conceptual study of actual facilities based on feasibility tests
2.3.1 Study of the operation method and process flow of the actual facilities

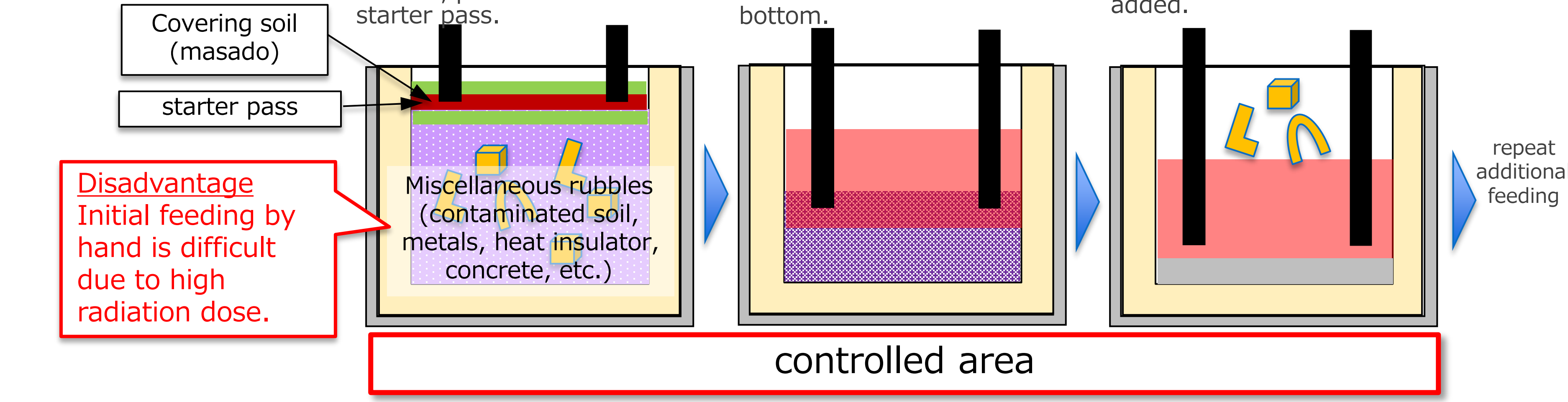
(1) Outline of the operation of the initial filling method (top-down method)

***Proven method for PCB-contaminated soil treatment**

After filling the refractory container with miscellaneous rubbles, place a cover and starter pass.

Melting downward. The electrode rod is lowered to melt the rubbles at the bottom.

After melting the initially filled rubbles, additional rubbles are added.



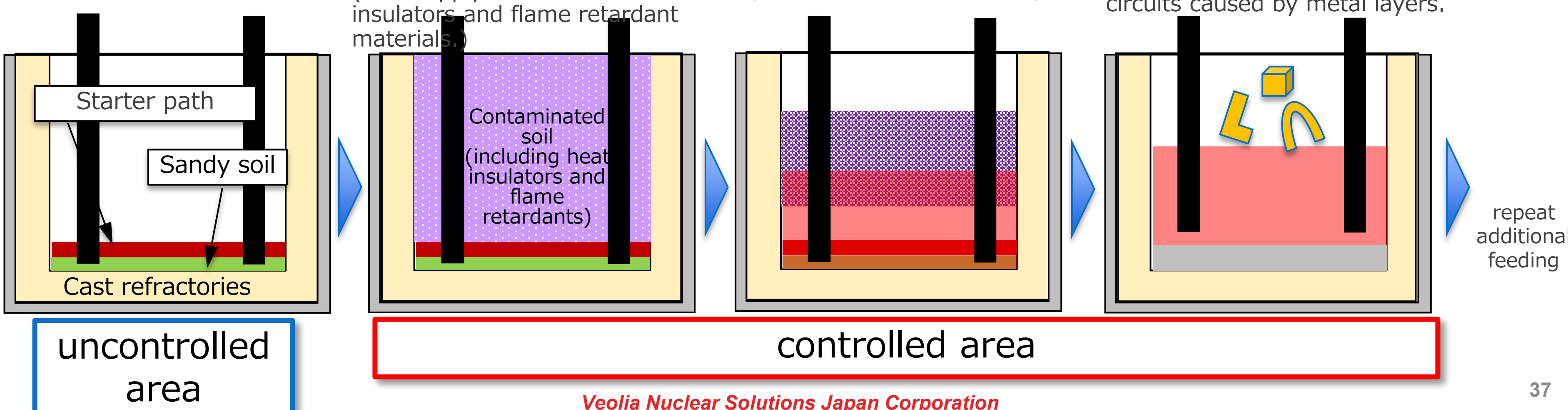
(2) Outline of the operation of the molten pool formation method (bottom-up method)

Install starter path and electrodes.

After moving to the controlled area, supply contaminated soil. (Also supply stand-alone heat insulators and flame retardant materials.)

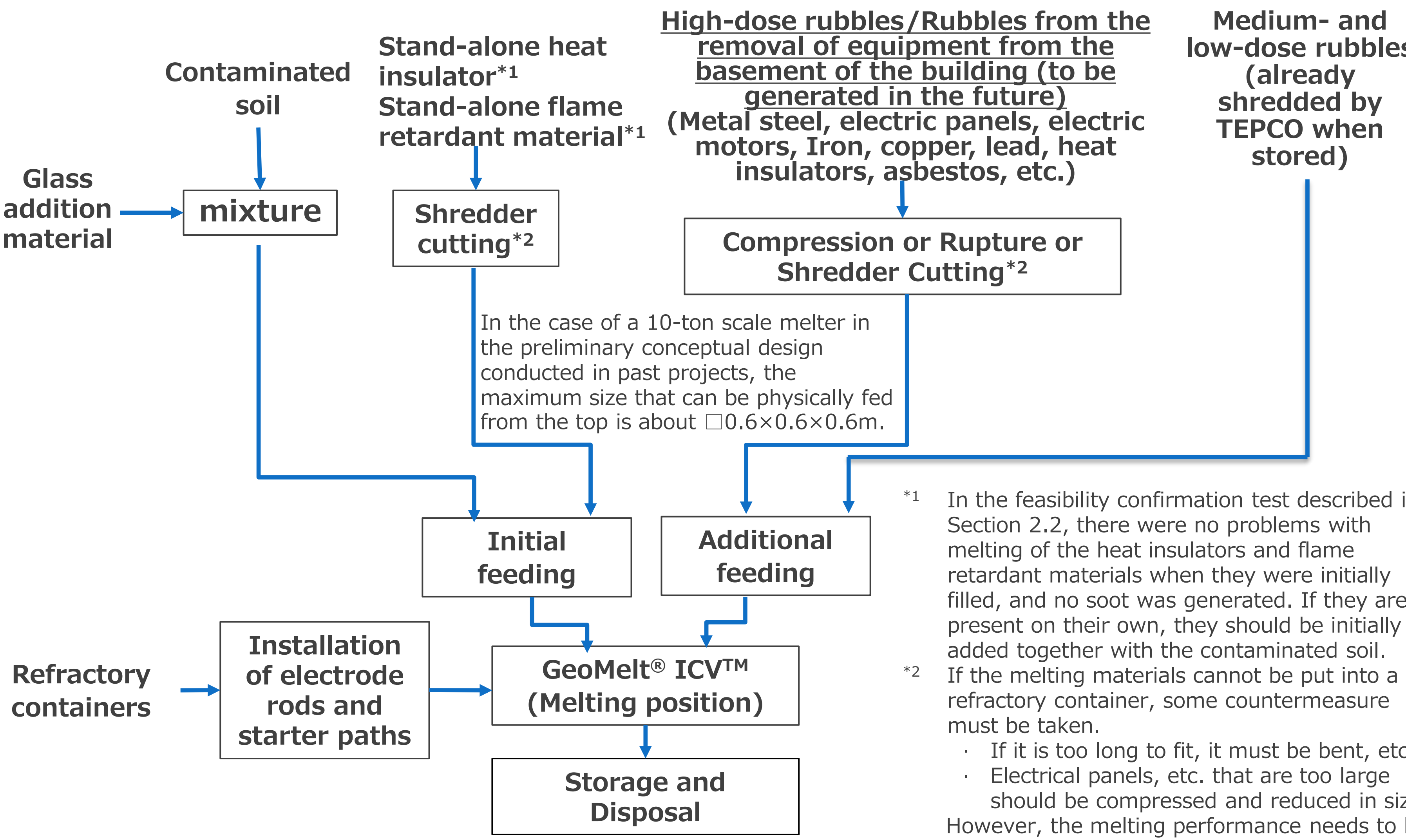
The initial feeds are melted upward to form a molten pool.

Put the waste into the molten pool. Gradually raise the electrode rods to prevent short circuits caused by metal layers.



2.3 Conceptual study of actual facilities based on feasibility tests
2.3.1 Study of the operation method and process flow of the actual facilities

Based on the results of these melting tests for the types and storage conditions of miscellaneous rubbles shown on pages 10 and 11, the following miscellaneous rubbles treatment flow is assumed for actual facilities using the molten pool formation method.



*1 In the feasibility confirmation test described in Section 2.2, there were no problems with melting of the heat insulators and flame retardant materials when they were initially filled, and no soot was generated. If they are present on their own, they should be initially added together with the contaminated soil.

*2 If the melting materials cannot be put into a refractory container, some countermeasure must be taken.
- If it is too long to fit, it must be bent, etc.
- Electrical panels, etc. that are too large should be compressed and reduced in size

However, the melting performance needs to be verified in the future.

How to proceed with the study of the economics efficiency

Calculate the volume of waste expected from vitrification of miscellaneous rubbles. The same calculations are also made for cement solidification, which has a good track record as a low-level radioactive waste, and the economic efficiency is evaluated by comparing the two.

Assumed breakdown of miscellaneous rubbles (e.g. Melt 2-2)

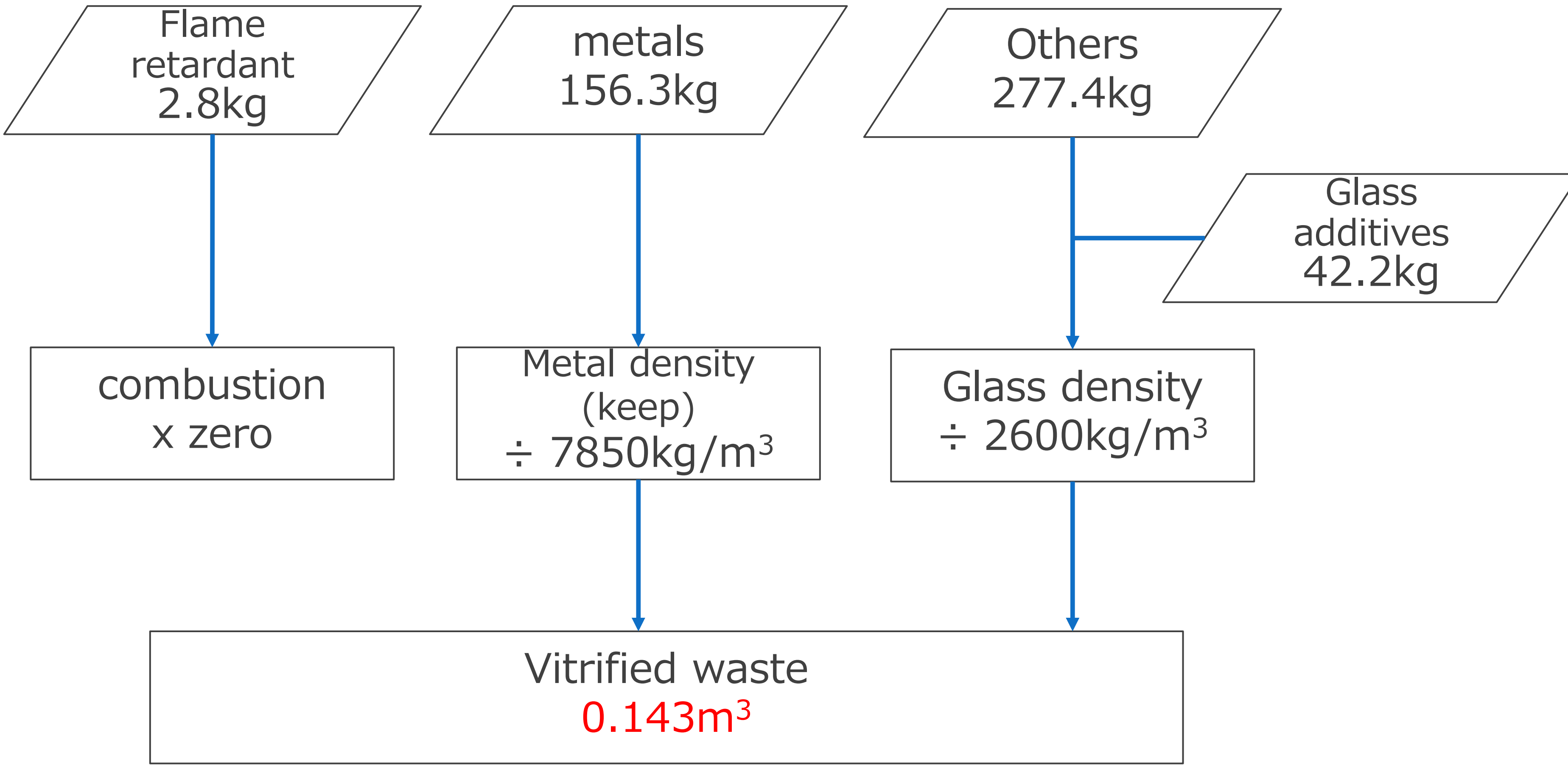
The breakdown of miscellaneous rubbles is based on the waste initially filled in the previous four melting tests. As an example, the breakdown of waste in Melt 2-2 is shown below.

Waste initially filled in Melt 2-2

Waste	Weight kg	Density kg/m^3	Calculated volume m^3
1F soil simulant	241.0	1100	0.219
Concrete	32.9	2300	0.014
Metals	156.3	7850	0.020
Heat insulator (calcium silicate)	3.5	200	0.017
Flame retardants (PVC products)	2.8	1400	0.002
Total waste	436.5	-	0.273

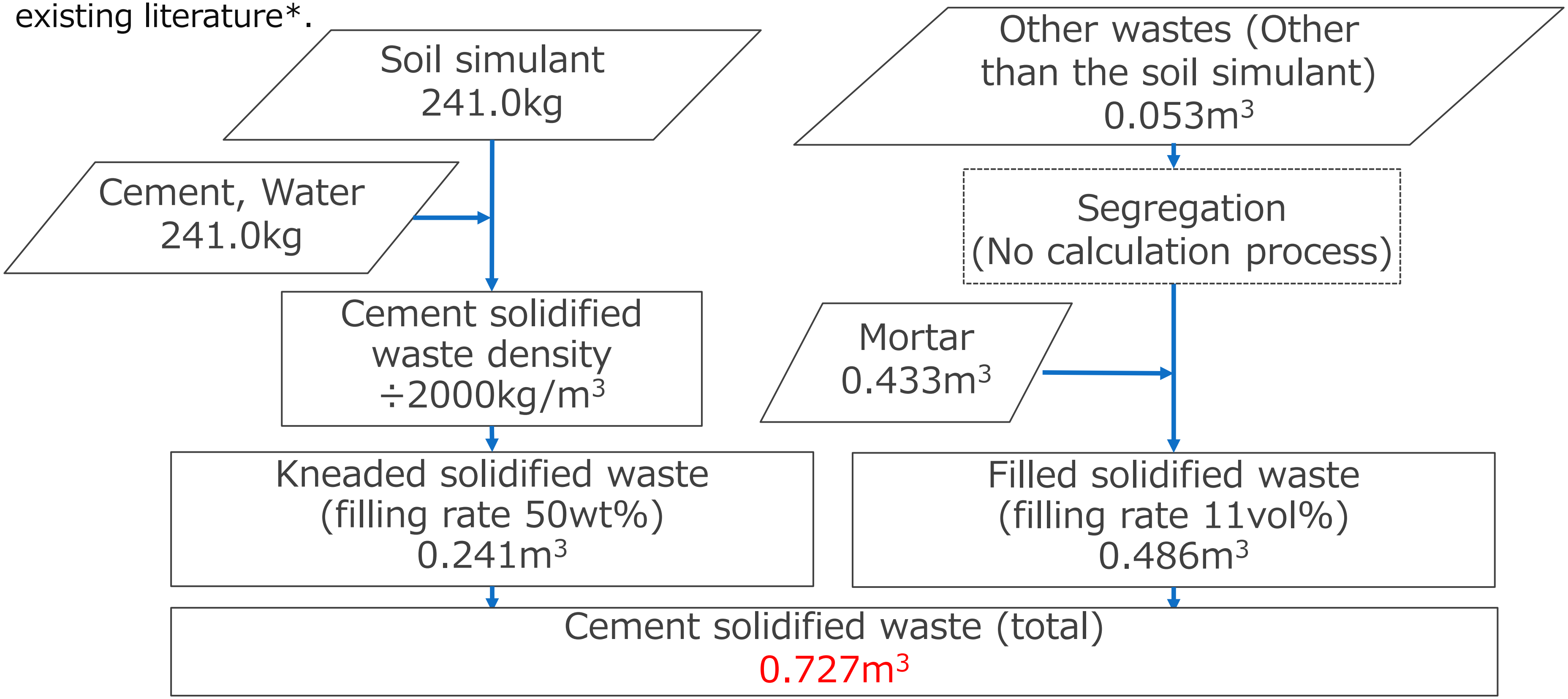
Calculation for the volume of vitrified waste

Flame retardant materials are assumed to burn and weigh zero. Metals are assumed to keep the same density before molten. For other wastes (contaminated soil, concrete, heat insulation materials), the weight of the glass additive material is added, and the volume is calculated from the glass density of 2600 kg/m^3.



Calculation for the volume of cement solidified waste

It is assumed that the contaminated soil will be mixed with cement and water to produce a kneaded solidified waste with a filling rate of 50wt%. Other waste (concrete, metals, heat insulator, flame retardant materials, etc.) will be separated and solidified with mortar (a mixture of cement, sand, and water) to create a filled solidified waste. The filling rate is set to 11 vol% based on existing literature*.

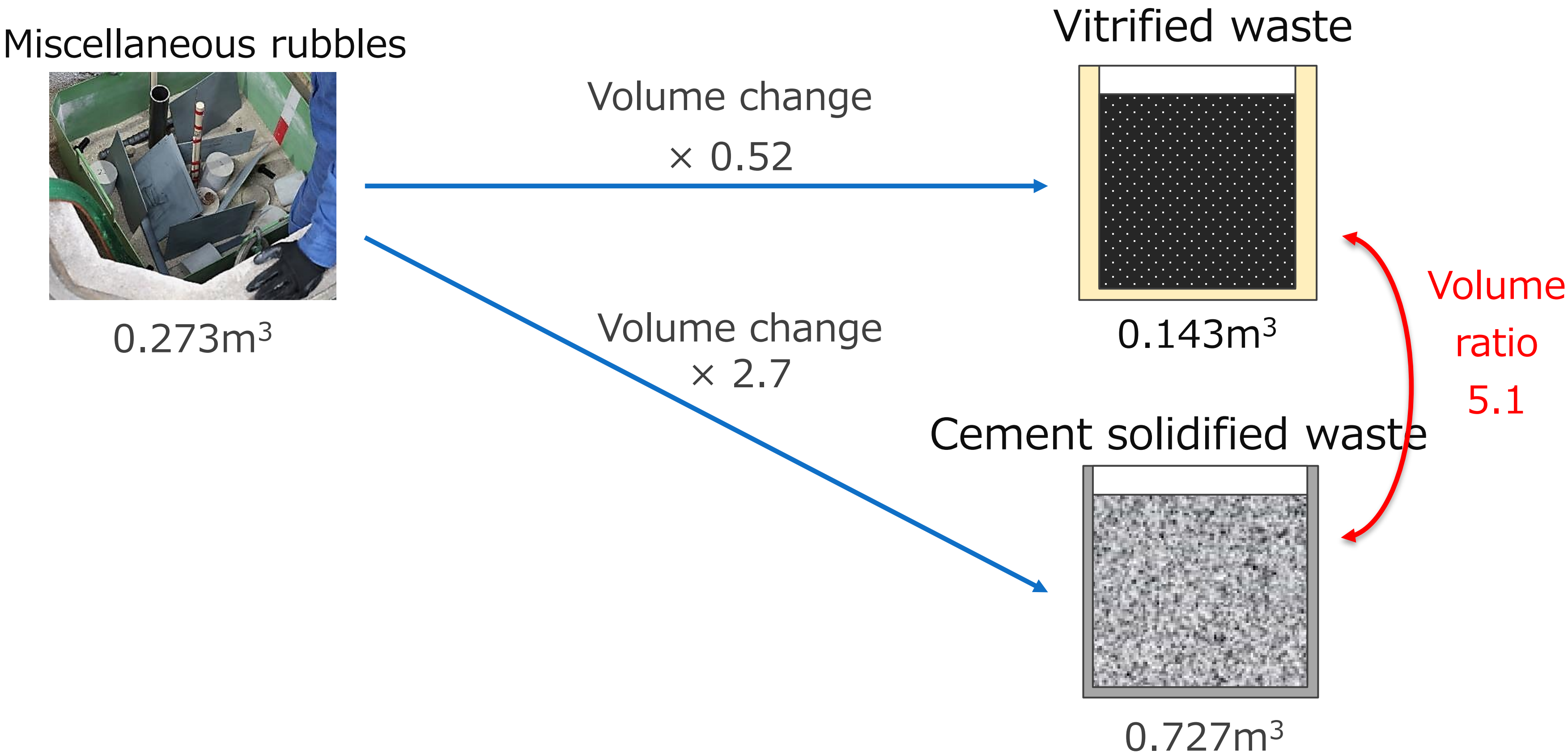


* Nuclear Environmental Management Center, Waste body production technology for low-level radioactive waste disposal (various solid wastes), 1998

2.3 Conceptual study of actual facilities based on feasibility tests
2.3.2 Study of the economics of GeoMelt® treatment

There is a 5.1 times difference in volume between the vitrified waste and cement solidified waste.

In the case of vitrification, a large amount of contaminated soil or concrete can be used as a glass forming material, and only a small amount of additives can be used, whereas in the case of cement solidification, a large amount of cement must be added.



2.3 Conceptual study of actual facilities based on feasibility tests
2.3.2 Study of the economics of GeoMelt® treatment

The evaluation results of waste volume in all four melting tests for the vitrified waste and the cement solidified waste are shown.

The larger the volume ratio of waste other than the soil simulant, the larger the volume ratio of the vitrified waste and the cement solidified waste tends to be, i.e., the greater the effect of volume reduction leading to economic efficiency.

Melting test		Waste: Soil simulant m^3(vol%)	Waste: Other waste (other than the soil simulant) m^3(vol%)	Solidified waste: Glass m^3	Solidified waste: Cement m^3
Melt 1	1-1	0.377 (93.0)	0.028 (**7.0**)	0.215	0.672
		Total : 0.405m^3		Volume ratio : **3.12**	
	1-2	0.245 (87.3)	0.036 (**12.7**)	0.155	0.594
		Total : 0.280m^3		Volume ratio : **3.84**	
Melt 2	2-1	0.221 (86.6)	0.034 (**13.4**)	0.130	0.552
		Total : 0.255m^3		Volume ratio : **4.25**	
	2-2	0.219 (80.4)	0.053 (**19.6**)	0.143	0.727
		Total : 0.273m^3		Volume ratio : **5.09**	

2.3 Conceptual study of actual facilities based on feasibility tests
2.3.3 Summary

- Based on the results of the feasibility test, we examined the basic operating method and the flow of processing miscellaneous rubbles, and created an operational concept assumed for the actual facilities. In this study, it was considered that the molten pool formation method and the additional feeding of rubbles could be used to achieve processing with a low risk of radiation exposure.
- Regarding economic efficiency, it was found that vitrified waste is superior to cement solidified waste in terms of volume reduction, and has the potential to reduce costs during storage and disposal.
- Based on the above, although there are still matters to be considered and evaluated in the future, it is thought that GeoMelt® could be the most rational method for disposing of miscellaneous rubbles.

3. Task 2: Investigation of technologies to process dehydrated ALPS slurry together with a container

3. Task 2: Investigation of technologies to process dehydrated ALPS slurry together with a container

Melting Test

Melting tests (one bench-scale test and two engineering-scale tests) with dehydrated ALPS carbonate slurry simulant and storage container are conducted to confirm the following.

- Confirmation that dehydrated ALPS slurry can be **melt-processed with the entire storage container**
- Confirmation of **no occurrence of steam explosions** due to moisture in dehydrated materials
- Demonstrate **operation to avoid electrical shorts** through storage containers**, and operation to restore them in the event of a short circuit.**
- Evaluation of **migration rate of Cs and Sr into off-gas** during melting (engineering-scale tests)
- Confirmation of homogeneity and durability of Cs and Sr in vitrified glass (engineering-scale test)

Feasibility Study on Additional Feeding of Storage Containers

In the melting tests, basically one storage container is treated (Limited additional feeding is conducted for engineering-scale test Melt 14). However, in order to increase the waste feed in the cast refractory and reduce the final waste volume, it is necessary to melt multiple storage containers in a single cast refractory for the actual facilities.
Therefore, assuming a full-scale melter, conduct a desk study on feeding of additional storage containers.

3.1 Melting tests

To confirm that the dehydrated ALPS carbonate slurry can be melt-processed with the entire dehydrated material storage container, melting tests were conducted as follows.

Glass Formulation Analysis

- Establish a glass formulation that satisfies the following
  - ✓ High molten glass temperatures (≥1550°C) capable of melting storage containers
  - ✓ Durability equivalent to Japanese simulated high-level waste glass P0798

Test material (PNNL Recipe)*		wt%
Dehydrated ALPS carbonate slurry		27.5
KUR-EH		57.1
Glass additives	Al_2O_3	1.18
	B_2O_3	3.06
	SiO_2	9.64
	ZrO_2	1.53
Total		100.0

Bench-scale Test

- Demonstration of the concept by melting dehydrated ALPS slurry with the entire storage container in a small-scale facility.

Engineering-scale* Melt 13, 14

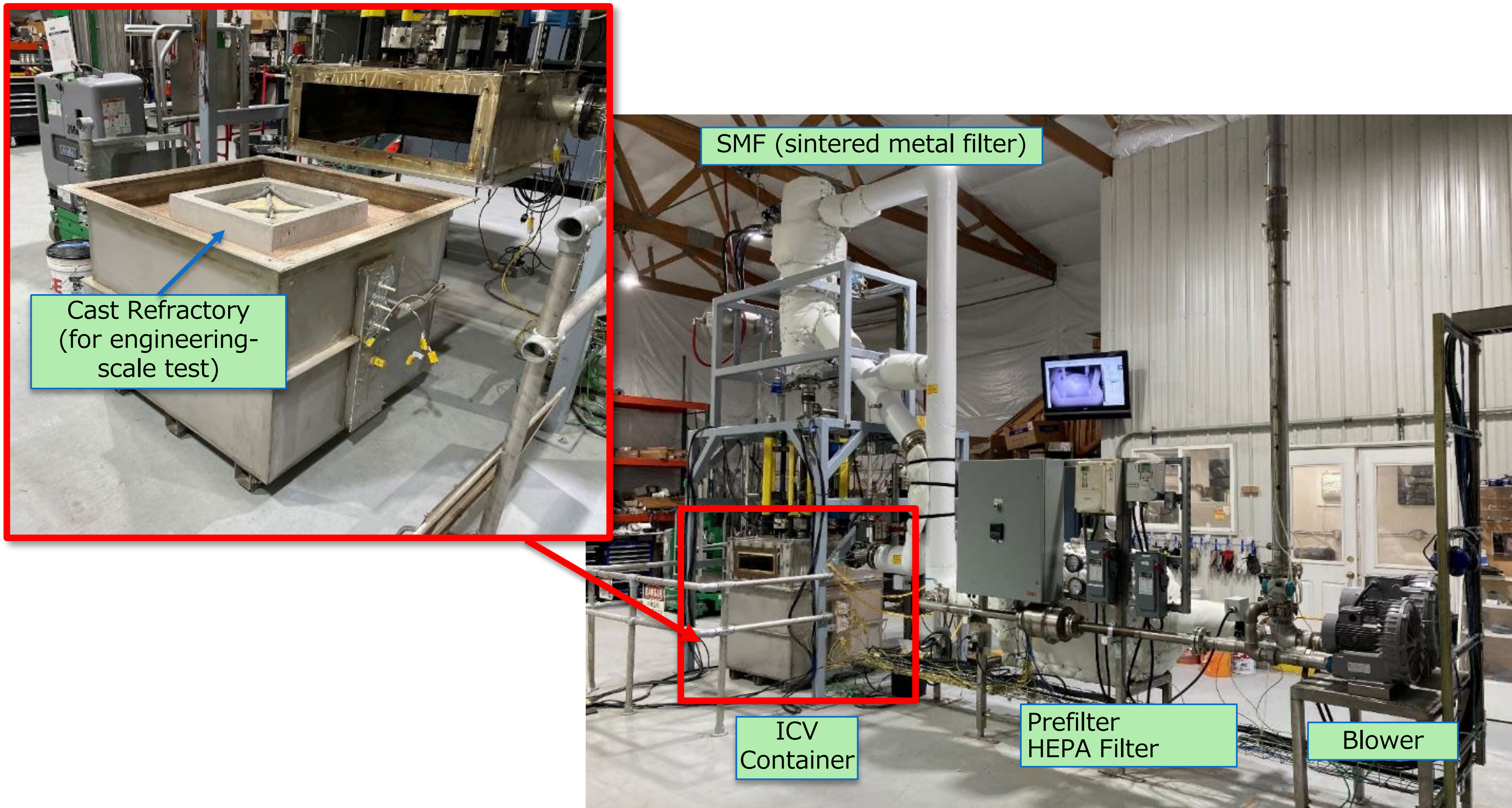
- Melting tests in a scaled-up system.

*The numbers of the engineering-scale melting tests are sequential numbers from past grant projects.

3.1 Melting tests

Melting test facility

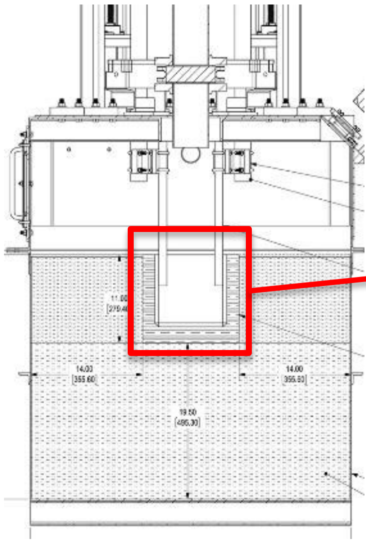
Use of the engineering-scale test facility in Richland, USA, which has been used in past grant projects. (Bench-scale test also uses the ICV container at this facility.)



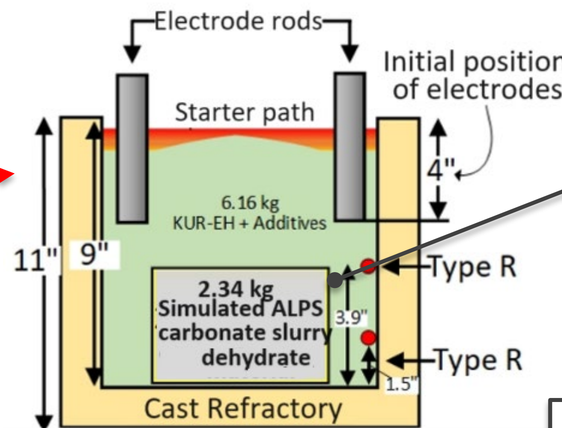
Veolia Nuclear Solutions Japan Corporation

3.1 Melting tests

Configuration for Bench-scale Test



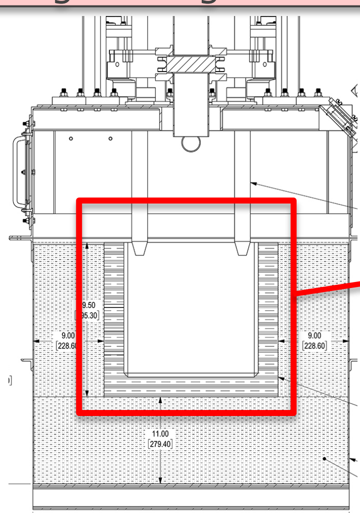
Top-down melting



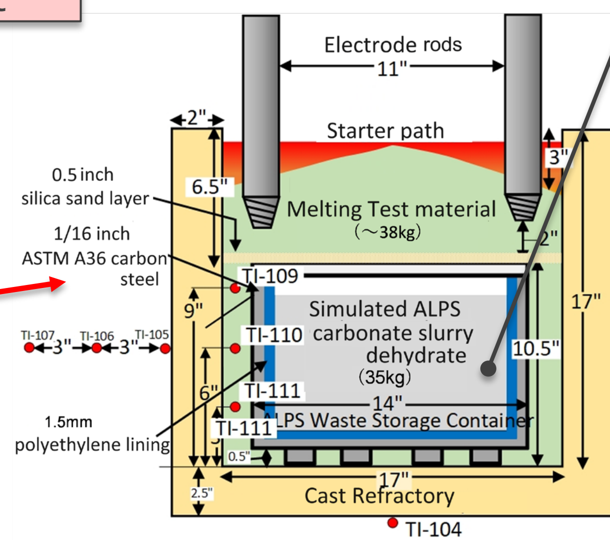
Storage Containers
(ASTM A36*)
□6"×6"×3.9", t:1/16"

KUR-EH: Zeolite adsorbent

Configuration for Engineering-scale Test

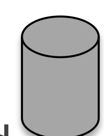


Top-down melting



Storage Containers
(ASTM A36*)
□14"×14"×10.5", t:1/16"

Small-scale storage container
(tinplate steel)
Φ3''×4.4", t:0.025"
only for Additional feed
of Melt 14 (see page 59)



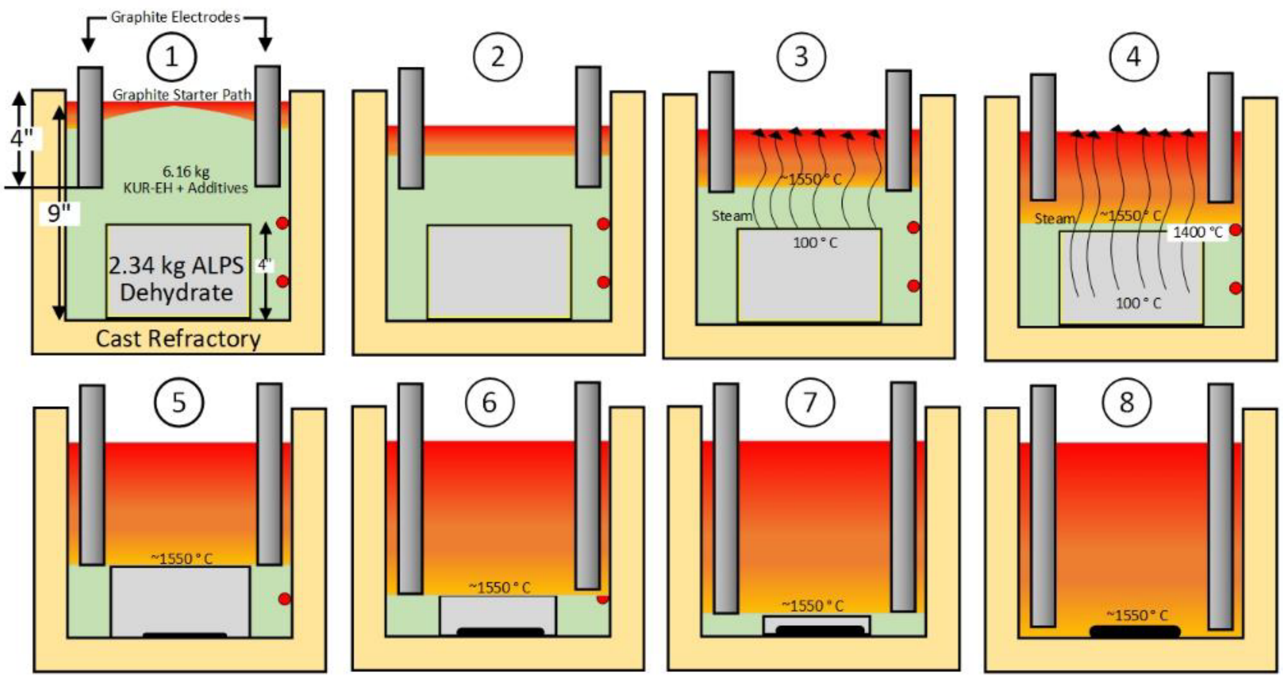
*ASTM A36 is equivalent to SS400.

3.1 Melting tests

3.1.1 Bench-scale melting test Overview

Test Site: GeoMelt® Engineering-scale Test Facility - Richland, USA
Test Date: August 14, 2023 (melting time 13.5h)
Test Method:

- Storage container with dehydrated material, KUR-EH and glass additives (hereinafter referred to as "KUR-EH mixture") filled into cast refractory.
- The glass is melted from the upper KUR-EH mixture by electric current heating to form a molten glass layer.
- The electrodes are gradually lowered to allow the molten glass layer to progress downward, melting the storage container.
- During electrode rod descent, monitor current values and stop the descent if extreme oscillations are observed. If a short circuit occurs, the electrodes are raised up and the transformer is restarted.

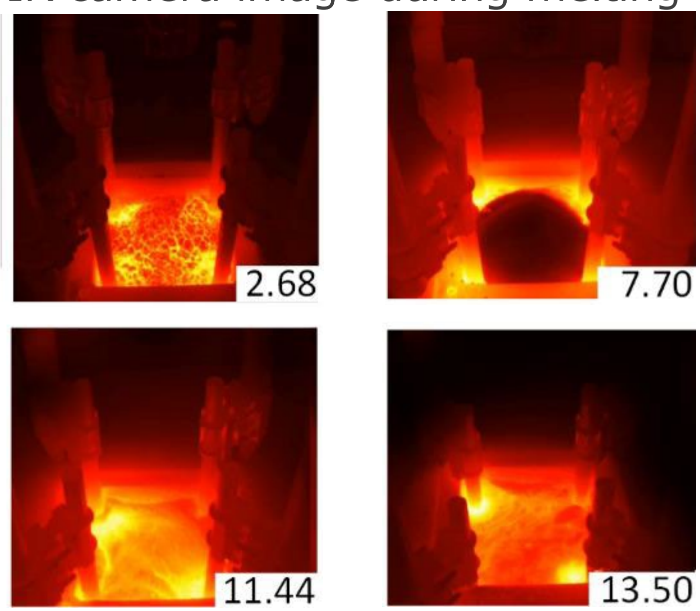


3.1 Melting tests
3.1.1 Bench-scale melting test Results

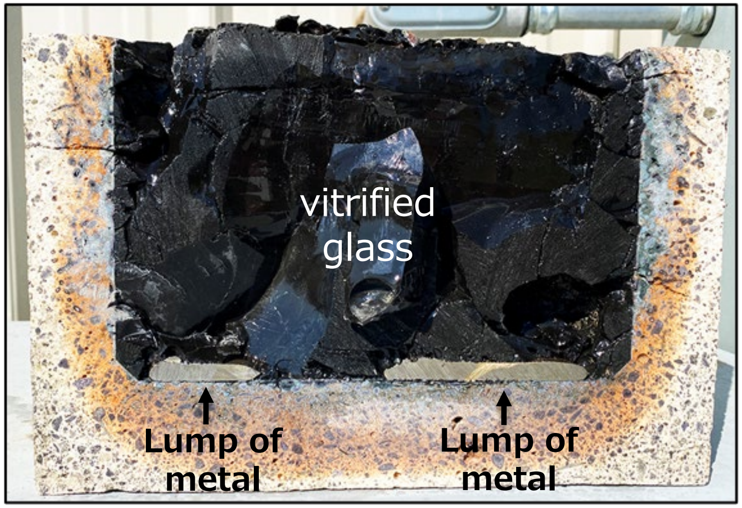
Result Summary

- Both the dehydrated slurry and the KUR-EH mixture could be melted, and the storage container was also melted to form a metallic mass at the bottom of the melter.
- There were no steam explosions or effects of excessive steam generation.
- Although a short circuit occurred during electrode descent, it was quickly recovered and did not affect the operation.

IR camera image during melting



Cross section of vitrified glass

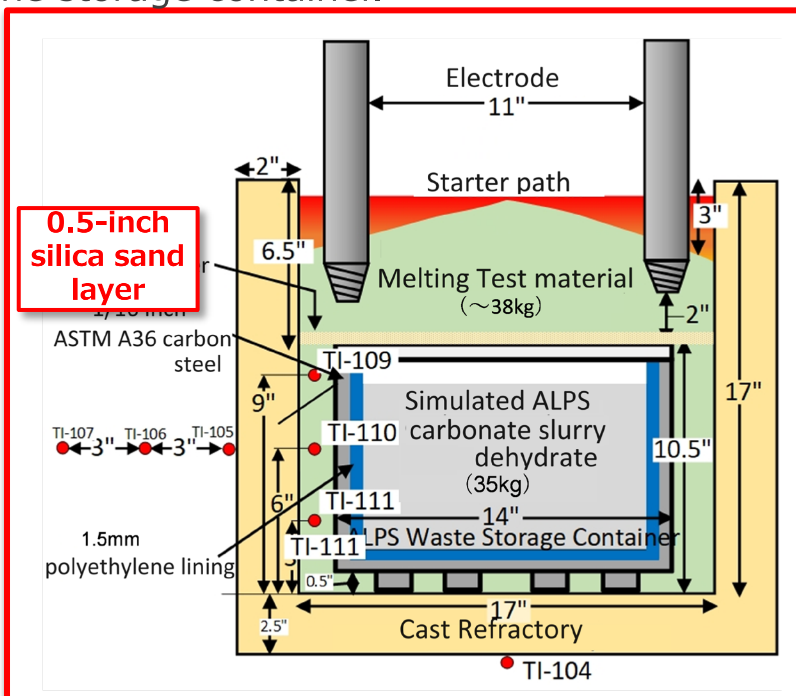


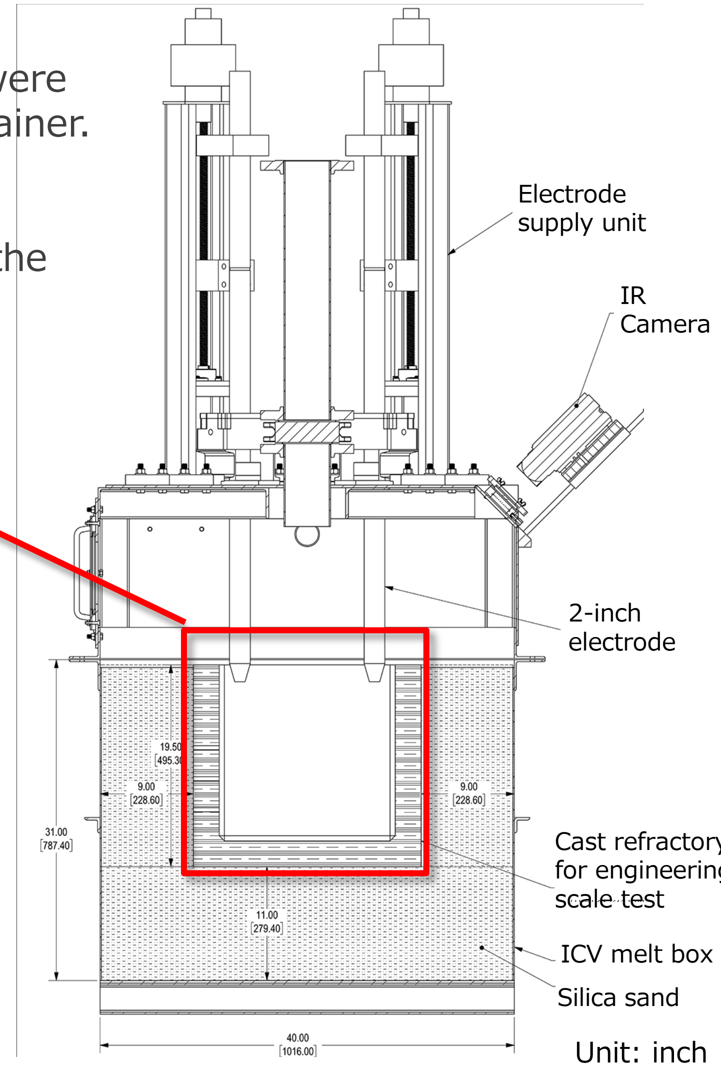
3.1.2 Engineering-scale melting test Melt 13　Overview

Test Site: GeoMelt® Engineering-scale Test Facility - Richland, USA
Test Date: October 12-13, 2023 (melting time 23h)

Test Method:

- Top-down melting as in bench-scale test.
- During the bench-scale test, the tip of electrode rods were nearly exposed to the gas phase at the top of the container. As a countermeasure, a 0.5-inch silica sand layer is installed during the preparation phase to allow the formation and maintenance of a molten glass layer at the top of the storage container.

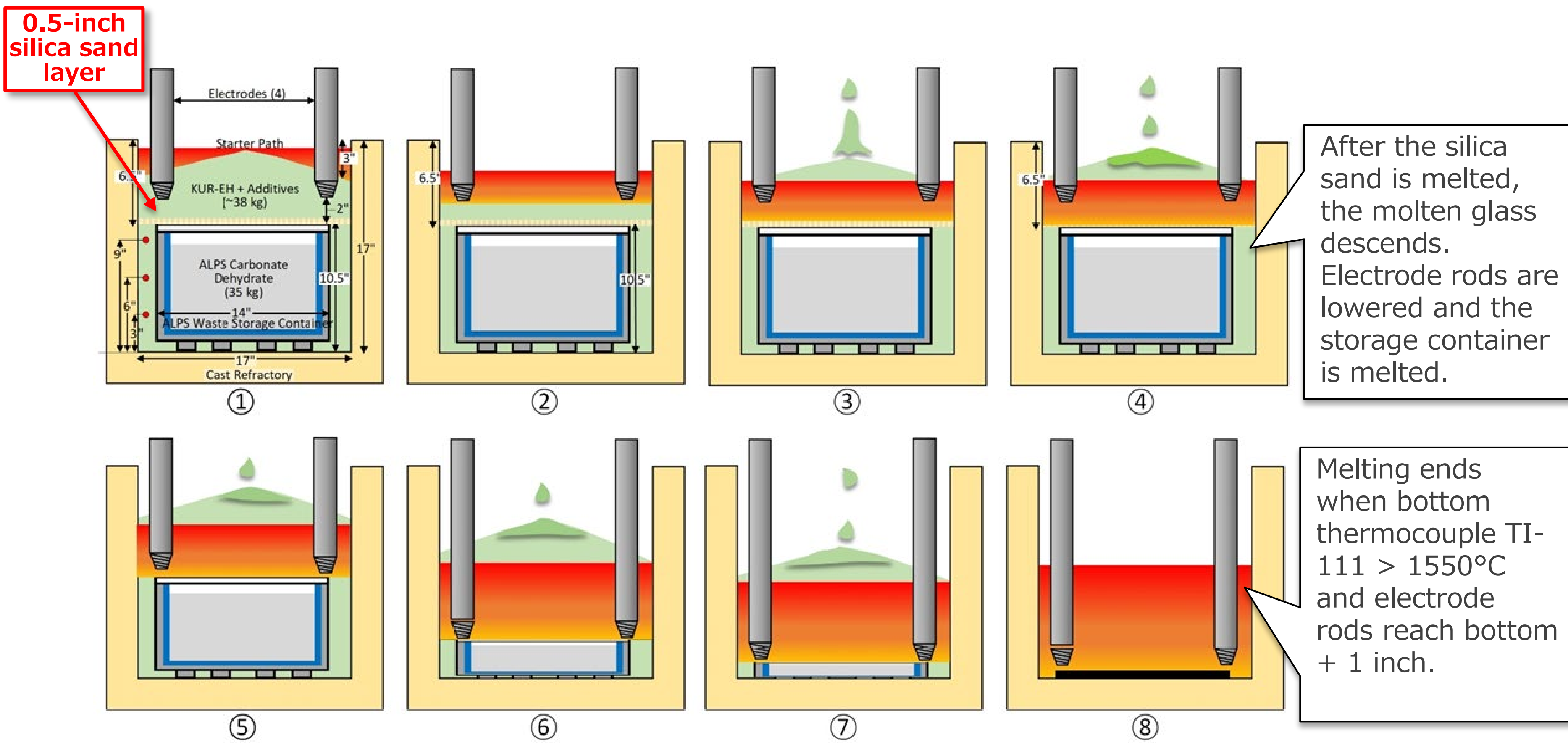




3.1.2 Engineering-scale melting test Melt 13 Overview

Role of silica sand layer

- Melting of silica sand requires a temperature of 1700°C, which can temporarily inhibit the descent of molten glass.
- This prevents the electrode rods from being exposed to the gas phase and allows a high-temperature molten glass layer (molten KUR-EH mixture) to form at the top of the container.

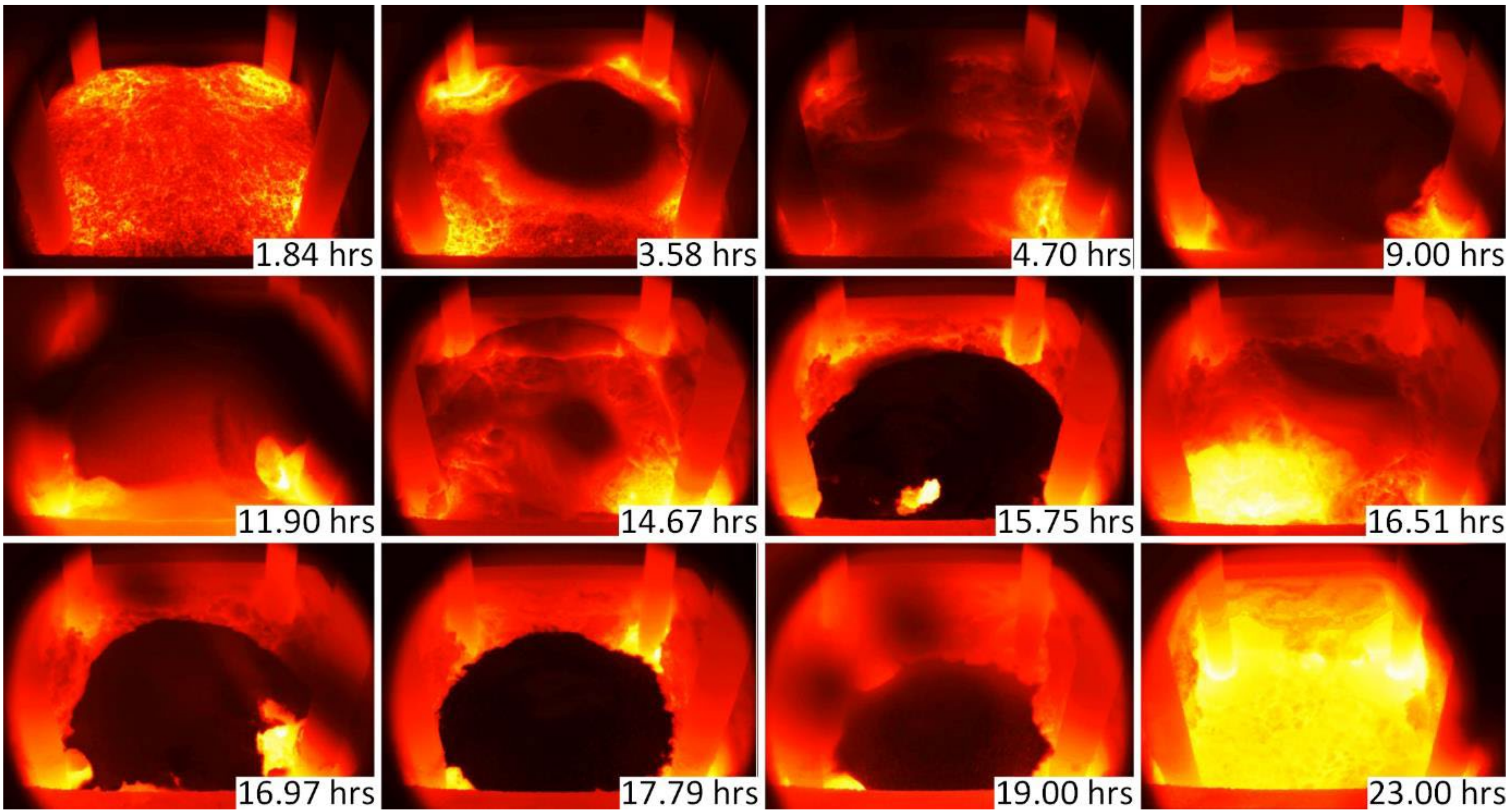


3.1.2 Engineering-scale melting test Melt 13　Results

Formation of molten glass

- The upper glass surface is checked with an IR camera and KUR-EH mixture is fed.
- Melting could continue without exposure of the electrode rods to the gas phase.

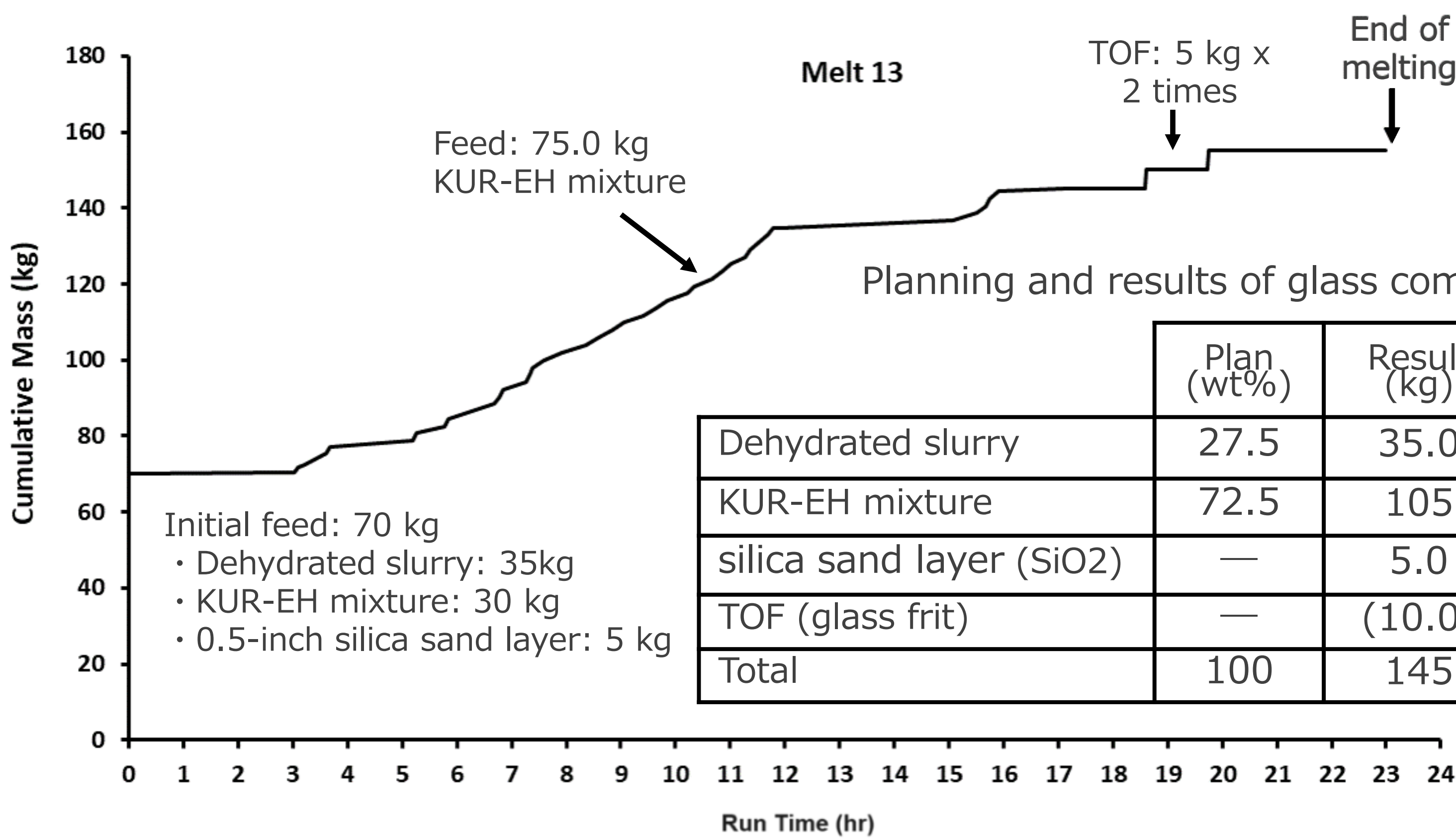
IR camera image during melting



3.1.2 Engineering-scale melting test Melt 13　Results

Improved filling rate of dehydrate slurry

- Due to the effect of the silica sand layer, sufficient molten glass layer was formed in the early stage of melting, which made it possible to control the amount of KUR-EH mixture fed. This allowed us to achieve the dehydrated slurry filling rate almost as planned.



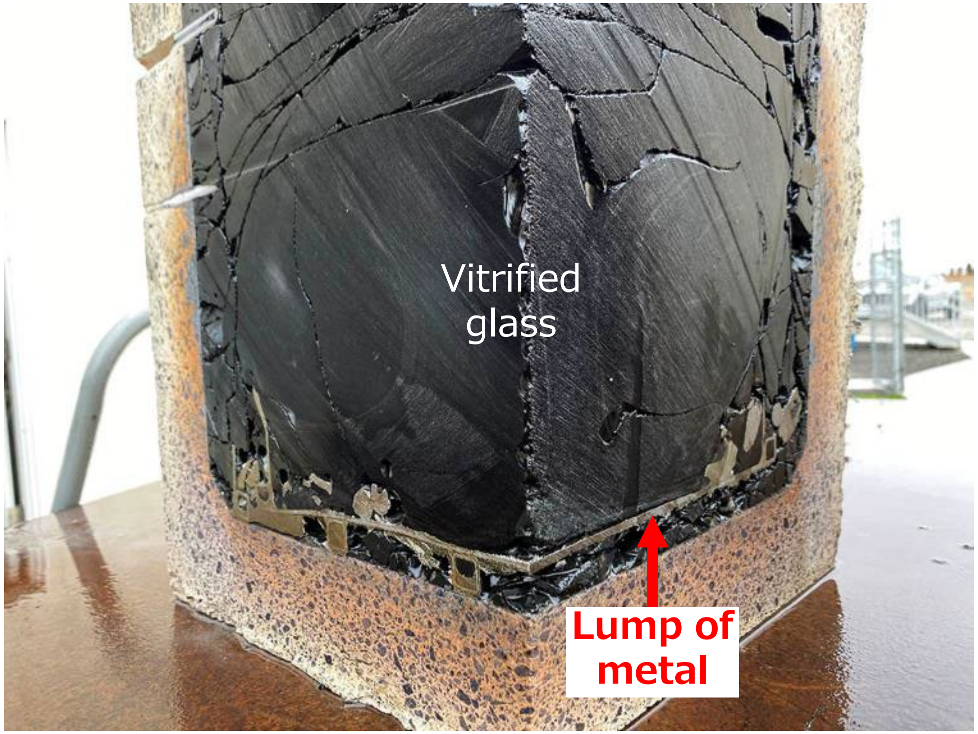
Planning and results of glass composition

	Plan (wt%)	Result (kg)	Result (wt%)
Dehydrated slurry	27.5	35.0	**24.1**
KUR-EH mixture	72.5	105	72.4
silica sand layer (SiO_2)	—	5.0	3.4
TOF (glass frit)	—	(10.0)	—
Total	100	145	100

3.1.2 Engineering-scale melting test Melt 13 Results

Cross-sectional observation of vitrified glass (1/4 block)

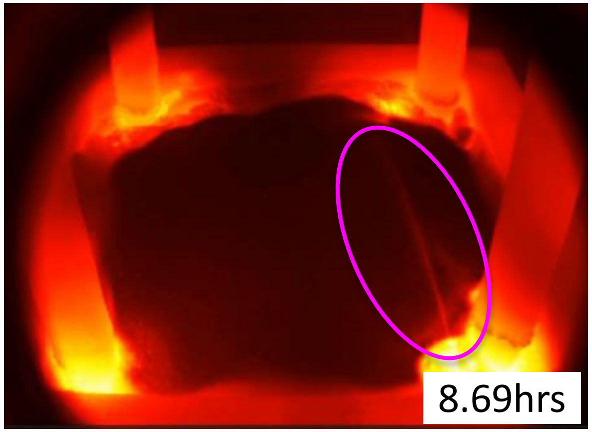
- As in the bench-scale test, both the dehydrated slurry and the KUR-EH mixture could be melted, and the storage container was also melted, forming a metal mass at the bottom of the melter.



3.1.2 Engineering-scale melting test Melt 13 Results

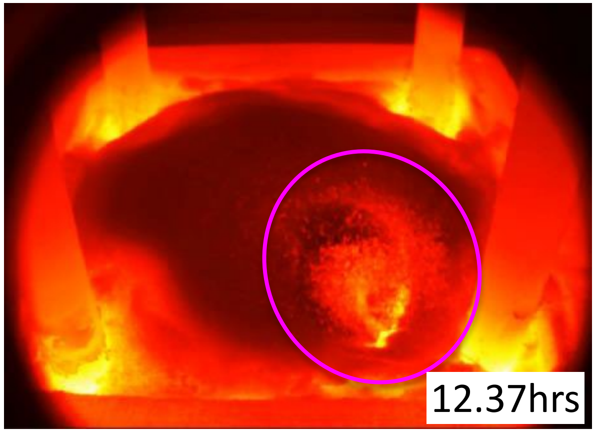
Steam eruption and scattering of KUR-EH mixture

- Gas generation, which appeared to be steam, was observed from around 9 hours after the electrode reached the height of the top of the storage container.
- Around 11 hours after the start of melting, an excessive steam eruption and the resulting scattering of unmelted KUR-EH mixture were observed.
- The stream eruption problem was solved by a temporary reduction in power to the melt. This is a routine operator response.



Steam eruption

Steam eruption

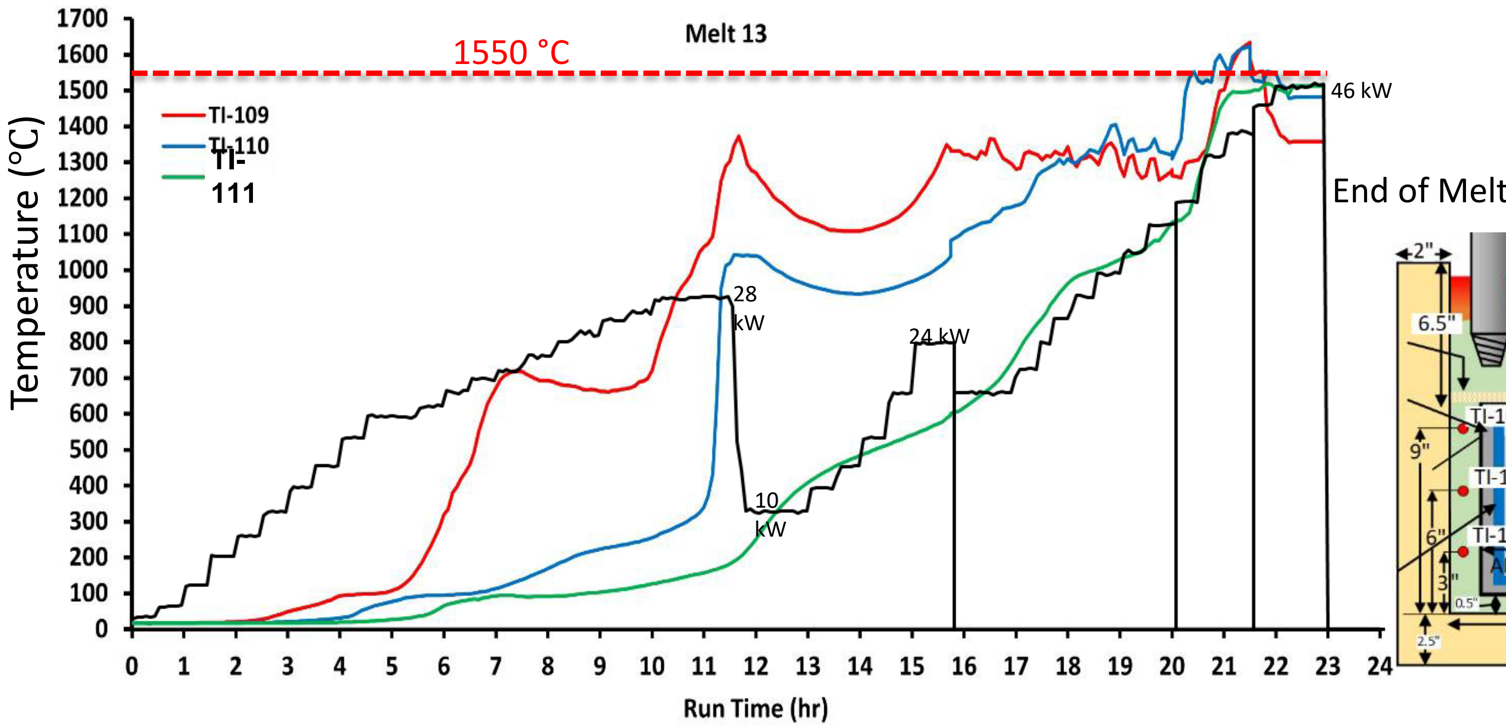


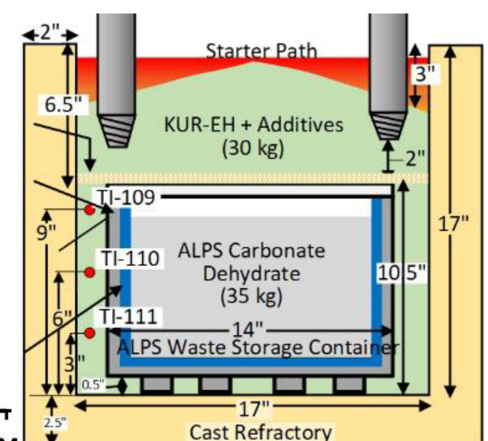
Scattering of unmelted KUR-EH and glass additives

3.1 Melting tests
3.1.2 Engineering-scale melting test Melt 13 Results

Effects of steam eruption

- At the same time (around 11 hours after the start of melting), a rapid increase in the thermocouple temperature of TI-110 at the middle of the container was observed. The sudden downward drop of the upper molten glass is thought to have caused the temperature inside the storage container to rise rapidly, resulting in an excessive steam eruption.
- To prevent excessive steam eruption, power was reduced from 28 kw to 10 kw at 11.45 hours into melting. This resulted in lower glass temperatures and reduced steam eruption, but led to longer melting times. It was decided to address the steam eruption in Melt 14.





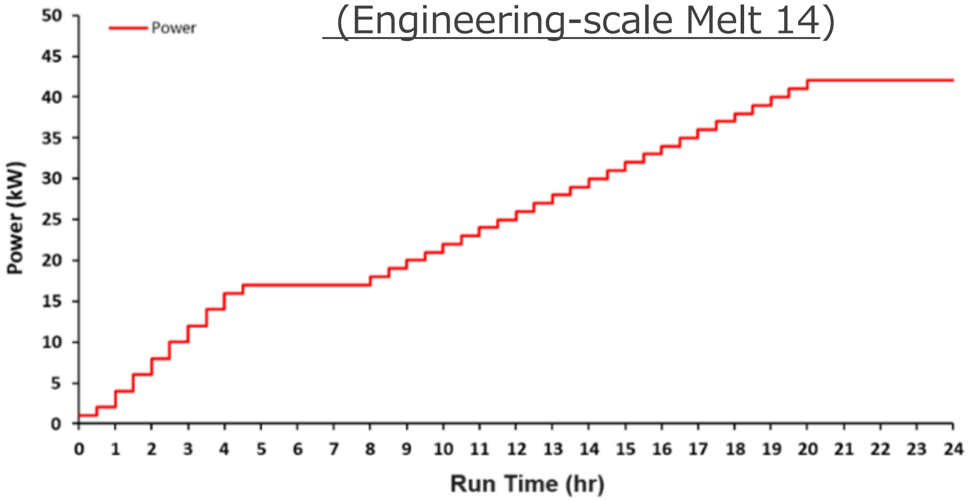
3.1.3 Engineering-scale melting test Melt 14　Overview

Test Site: GeoMelt® Engineering-scale Test Facility - Richland, USA
Test Date: January 11-12, 2024 (melting time 22h)
Test Method:

- The melting of the storage container for the initial feeding is the same configuration as in Melt 13.
- To prevent excessive steam eruption, the power ramp-up is stopped for 4.5 to 8 h after the start of melting.
- Cylindrical 0.4L small containers (0.5kg dehydrated slurry inside)* are additionally fed from 16.65h after the start of melting to check melting behavior.

*As described in section 3.2 "Feasibility study on additional feeding of storage containers", a 10-ton melter can be fed with a container as large as a 200-liter drum, which is assumed for an actual melter. In this study, a small container of about 1/500 scale of a 200L drum can was used for the test, so that they could be fed into an engineering-scale test facility.

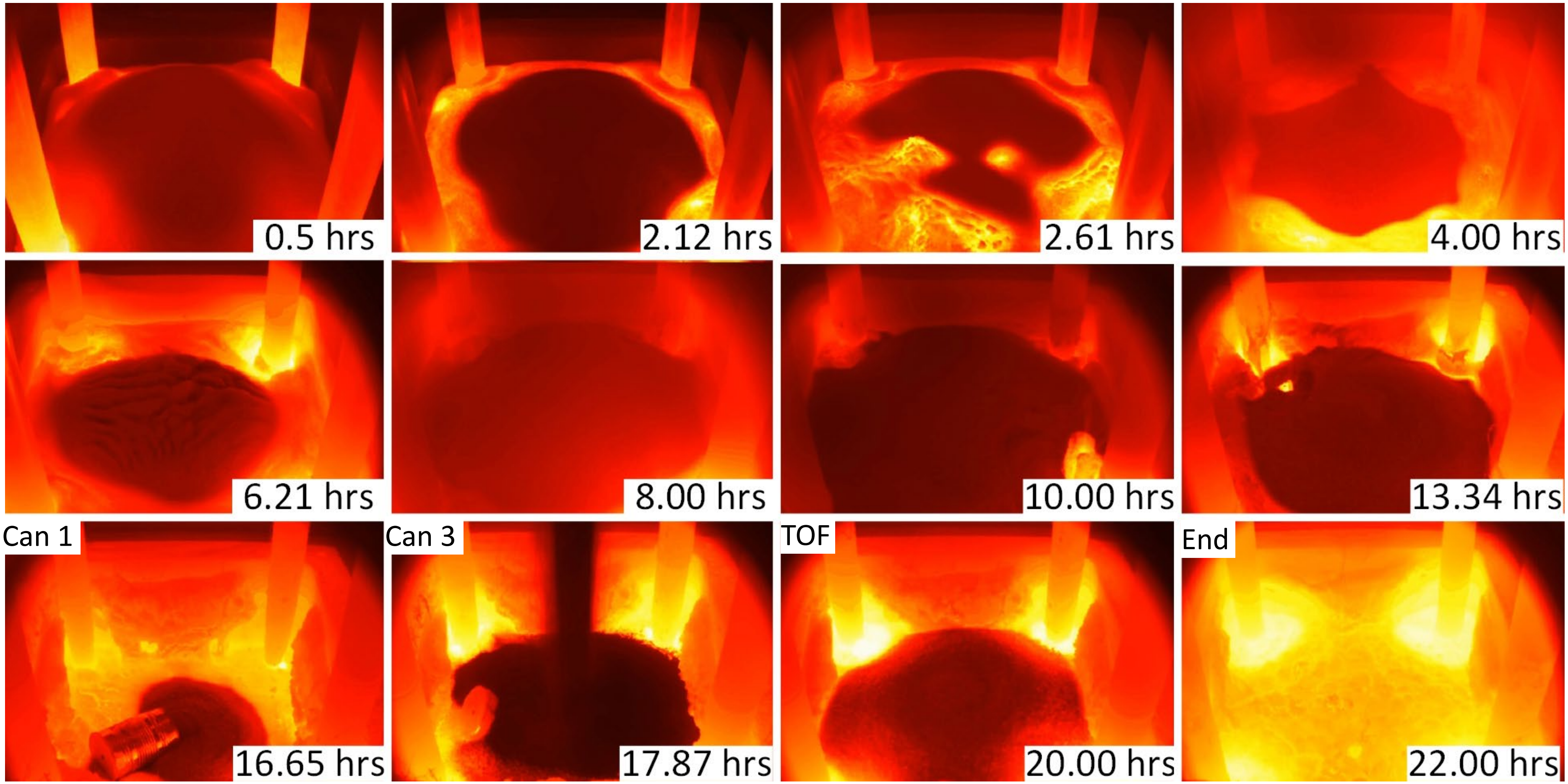
Power Coordination Plan (Engineering-scale Melt 14)



Small containers for additional feed

3.1.3 Engineering-scale melting test Melt 14 Results

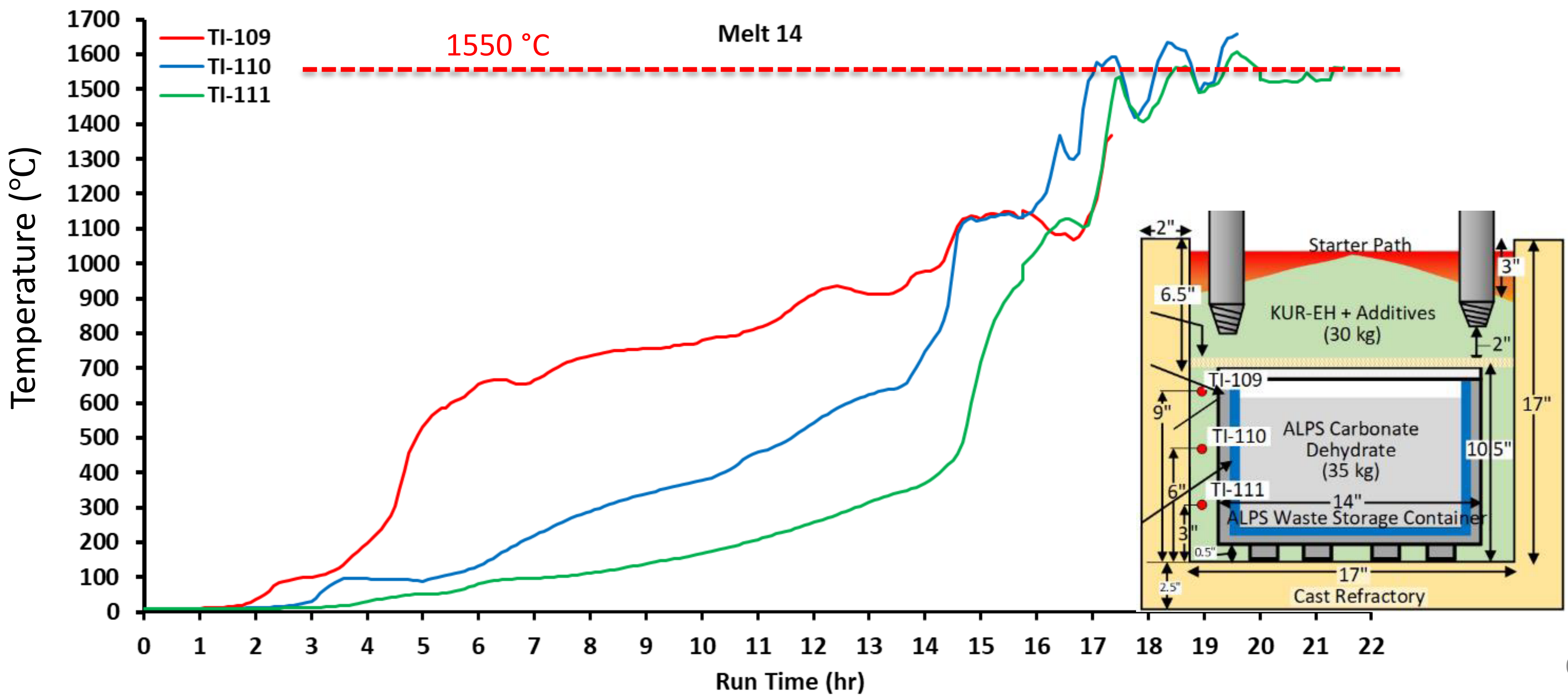
IR Photos of Various Times during the Melt



3.1 Melting tests
3.1.3 Engineering-scale melting test Melt 14 Results

Verification of power coordination

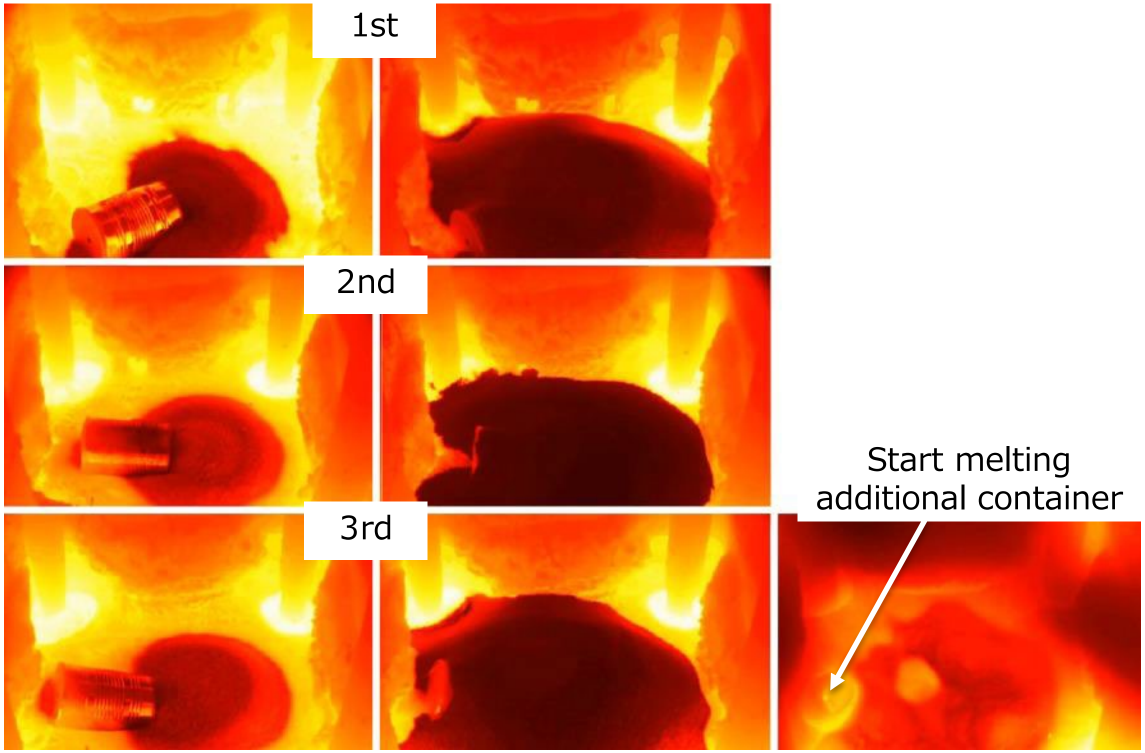
- As a result of the change in power increase, the molten glass temperature continued to rise gently, and the TI-111 thermocouple temperature at the bottom of the container also exceeded 1550°C (an indicator suggesting that the storage container was being melted) at 18 hours into melting. (In engineering-scale Melt 13, 1550°C was reached at 22 hours after melting began.)
- There was no excessive steam eruption or scattering of the KUR-EH mixture which suggests that the planned power ramp pause was successful.



3.1.3 Engineering-scale melting test Melt 14 Results

Melting behavior of additional containers

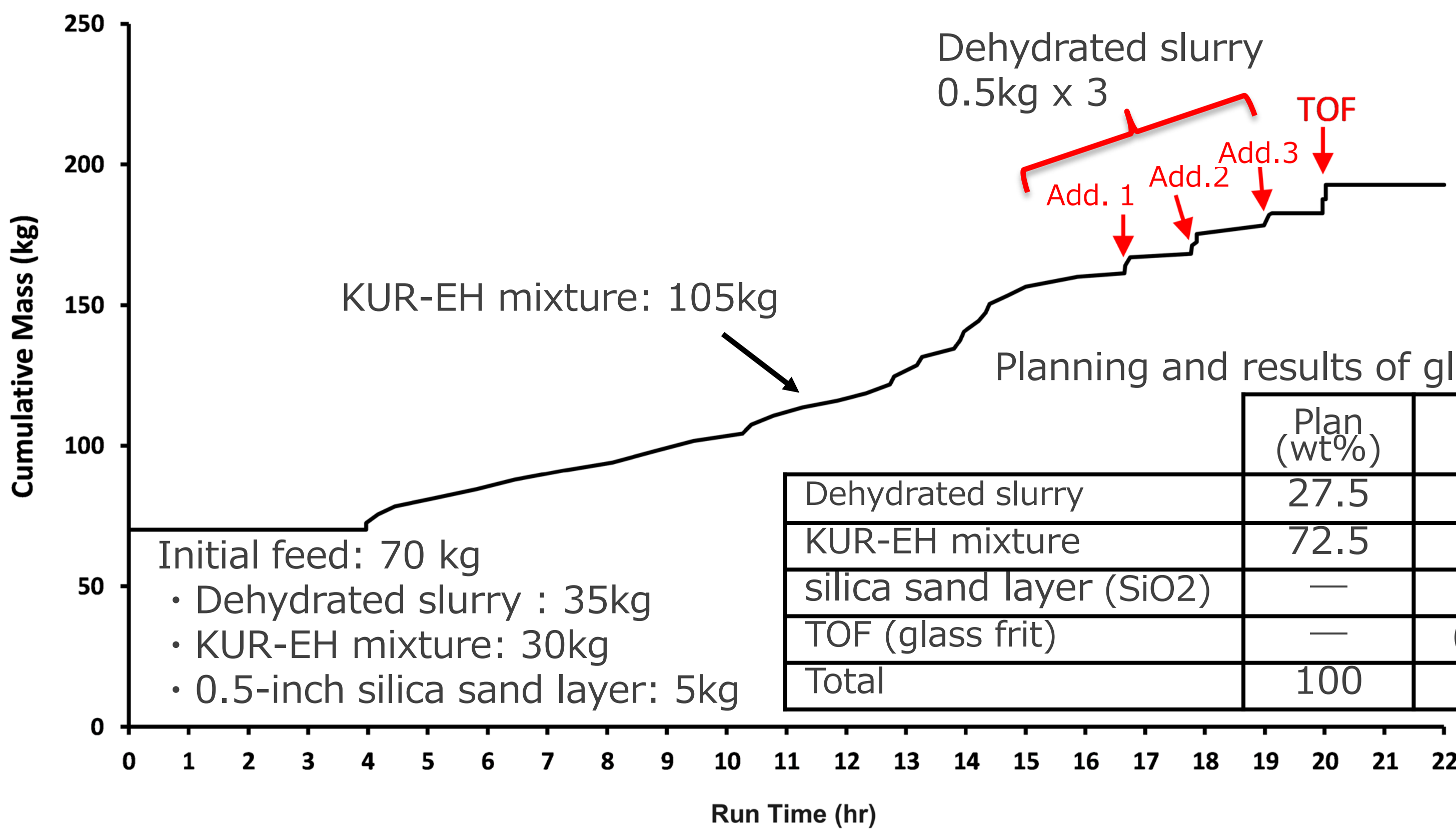
- Additional containers were fed in three installments approximately every hour at 16.7, 17.8, 18.9 hours after the start of melting.
- After feeding the container, an additional 3.0 kg of KUR-EH mixture was fed and the container was covered (to promote melting through heat insulation and retention).
- The container disappeared completely from the molten surface within approximately one hour before the next container was fed in. It is believed that the container melted and submerged in the molten glass during this time.



3.1 Melting tests
3.1.3 Engineering-scale melting test Melt 14 Results

Filling rate of dehydrated slurry

- The dehydrated slurry filling rate was lower than in Melt 13, at 20.7%, because the KUR-EH mixture was also fed in the additional feeding (3.0kg x 3, as shown on the previous page). (Melt 13: 24.1%)
- In the future, the amount of KUR-EH mixture to be fed at the same time should also be reduced in order to improve the filling rate with additional feeding.



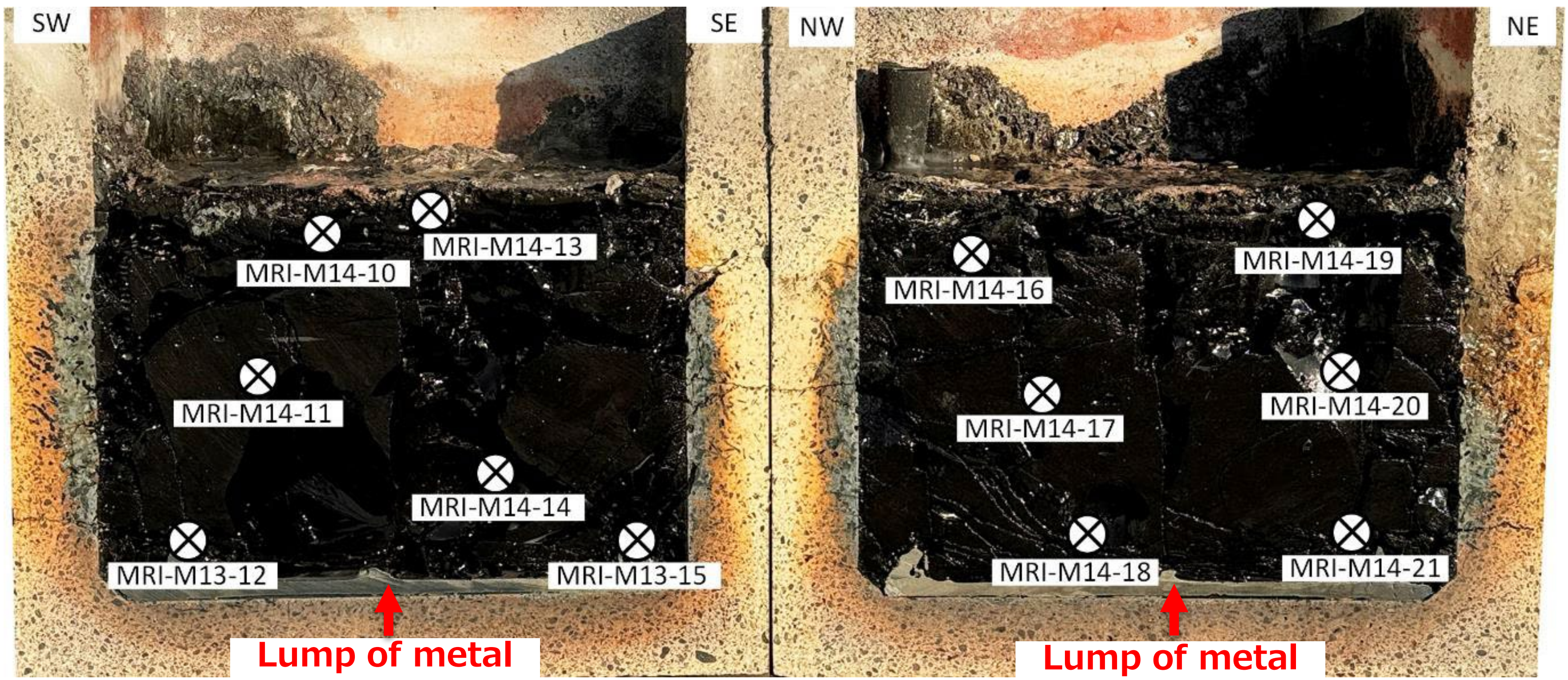
Planning and results of glass composition

	Plan (wt%)	Result (kg)	Result (wt%)
Dehydrated slurry	27.5	36.5	**20.7**
KUR-EH mixture	72.5	135	76.5
silica sand layer (SiO_2)	—	5.0	2.8
TOF (glass frit)	—	(10.0)	—
Total	100	176.5	100

3.1.3 Engineering-scale melting test Melt 14 Results

Cross-sectional observation of vitrified glass (1/2 block)

- A uniform and dense glass layer was formed. No storage containers with melt residue were identified in the glass, and a metallic mass was observed at the bottom of the melter.

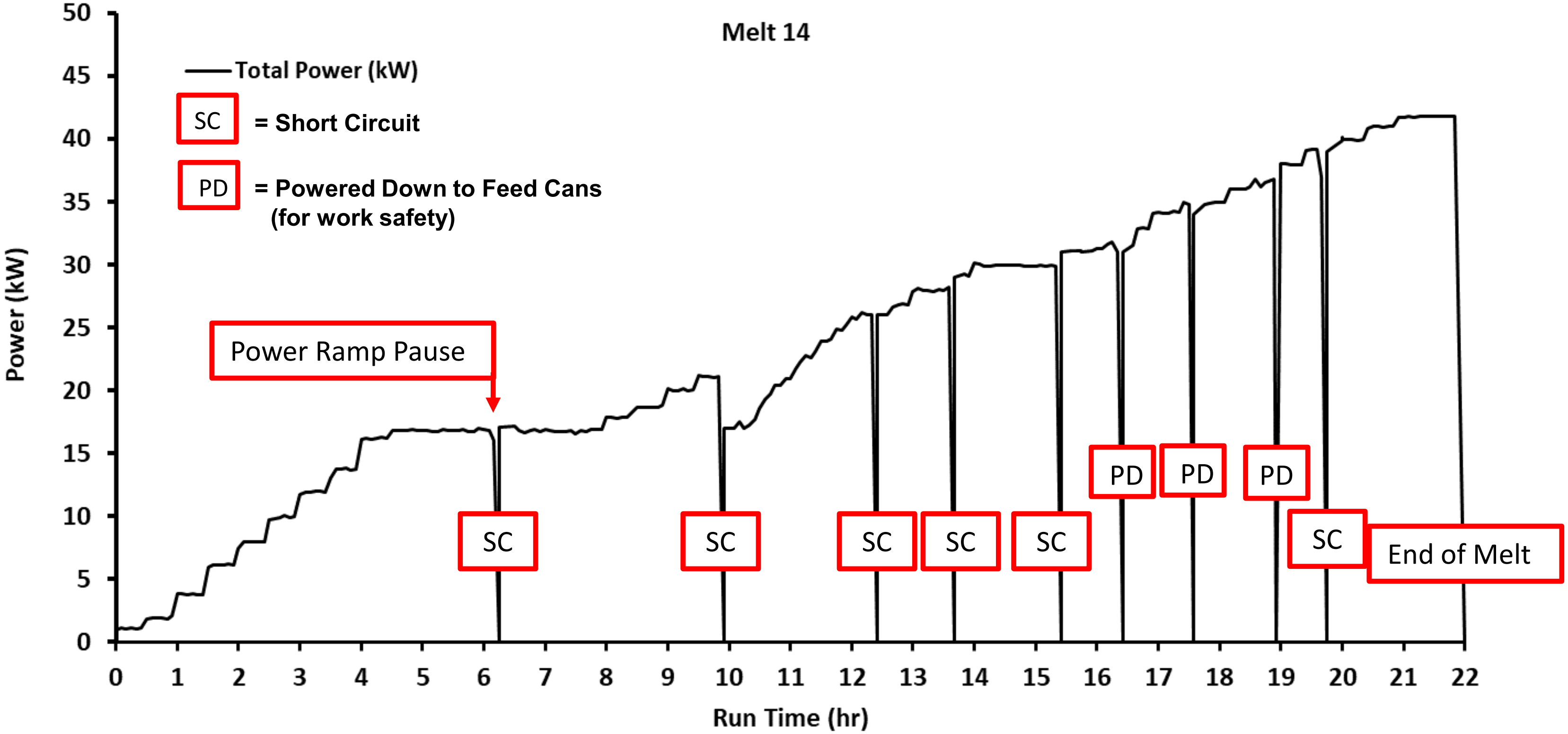


※ X marks in the figure indicate sampling locations. The number is the sampling number.

3.1.3 Engineering-scale melting test Melt 14 Results

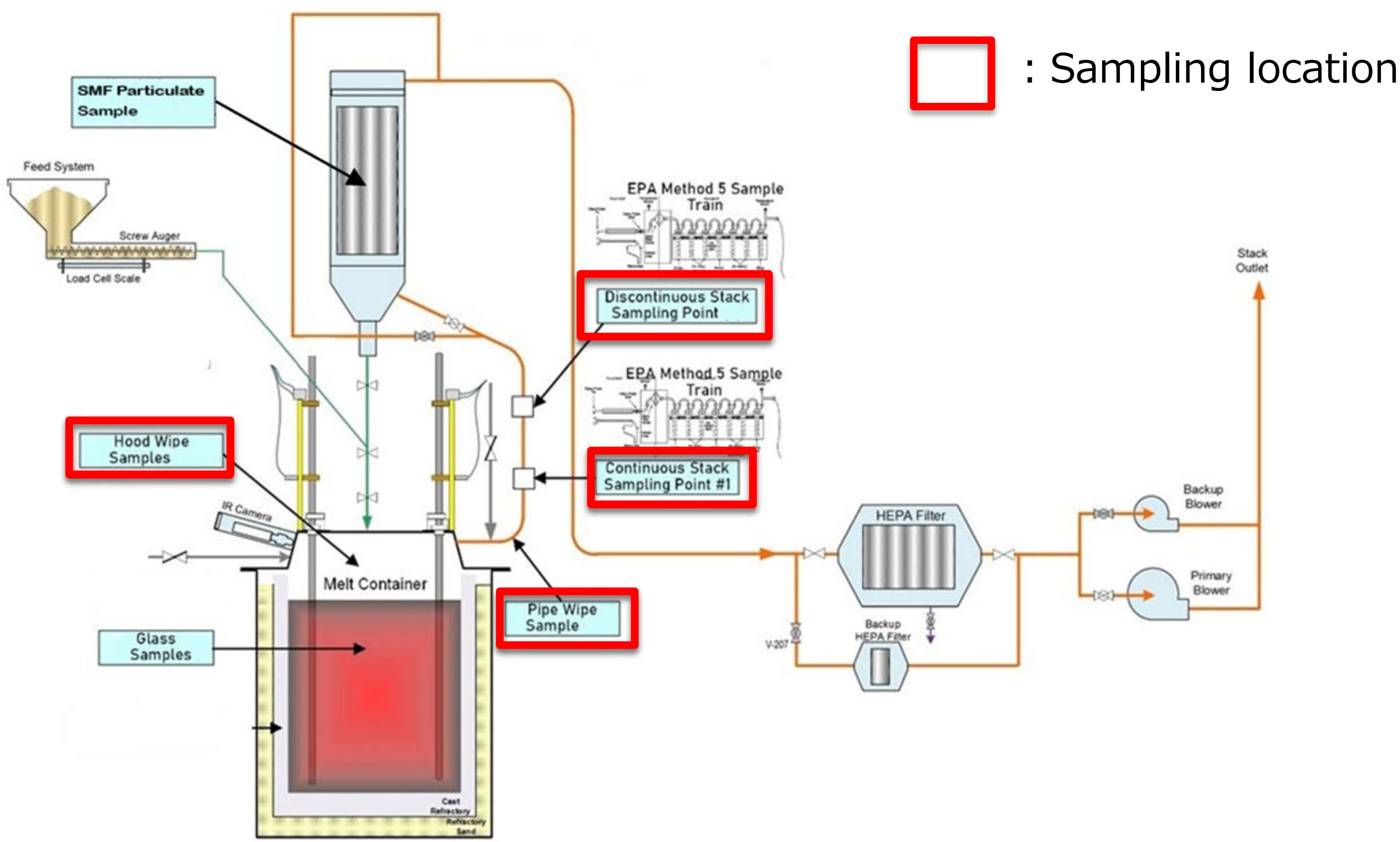
Short circuits and recovery operations

- The melt experienced multiple short circuits as electrodes touched the storage container as they were lowered down. In each case, the electrode causing the short circuit was raised slightly and power could be resumed with no problem.
- Since no sudden increase in current was observed until the electrode touched the storage container, operation to avoid a short circuit seems inherently difficult.
- In actual facilities, it would be reasonable to assume that a short circuit will occur, and to design the equipment with a highly reliable circuit protection and to re-power quickly.



Retention of Cs and Sr in glass

- In engineering-scale melting tests 13 and 14, stable Cs and stable Sr (hereinafter referred to as Cs and Sr) were added to the KUR-EH mixture and dehydrated slurry as radionuclide simulants such as Cs137 and Sr90. Off-gas stack sampling and wipe sampling of the melt hood and off-gas piping were performed to evaluate glass retention of Cs and Sr.



3.1 Melting tests
3.1.4 Analysis results

- The retention rates in each test are as follows. The retention rates of Cs are in the 60% range, which is lower than the retention rates of 86.8-98.0% (engineering-scale melting tests 9-12) for the FY2021 grant project.
- This is thought to be due to the thinner cold cap, since this melting test is a top-down method, melting from the top, unlike the previous bottom-up method.
- Thus, if it is difficult to control the transfer of Cs to the off-gas by the cold cap, the capture and recovery of Cs by the sintered metal filter is considered to be more important. Note that in the FY2021 grant project, the Cs capturing rate in the sintered metal filter was more than 99.98%.
- On the other hand, for Sr, which is less volatile, the retention rate is over 99.9%.

Melt 13

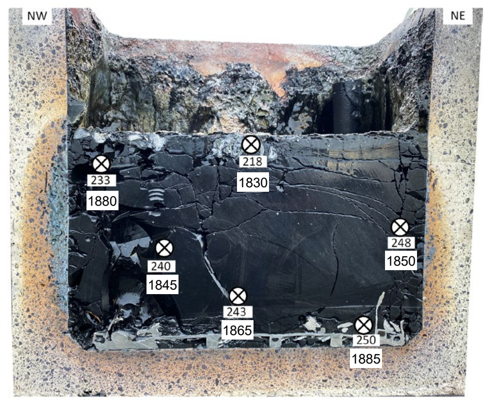
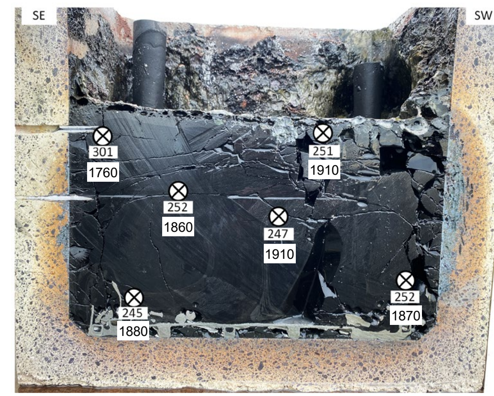
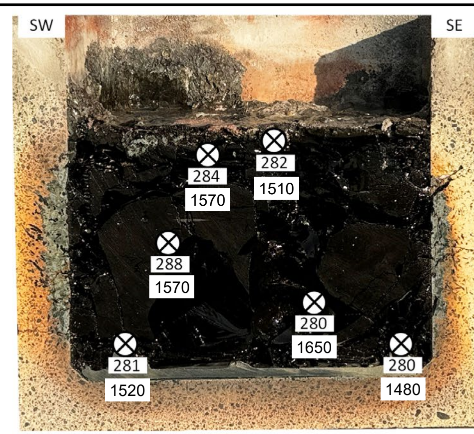
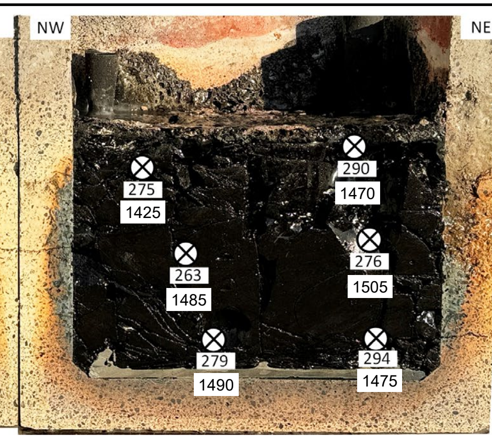
	Input Mass Mass in feed (g)	Mass in off-gas (g)	+ Mass in Hood, First Section of Pipe(g)	= Output Mass	$DF = \frac{input\_mass}{output\_mass}$	$Retention\ in\ glass = 1 - \frac{1}{DF}\ x\ 100$ Retention in glass (%)
Cs	55.40	20.89	0.10	20.99	2.64	62.10
Sr	245.54	0.067	0.002	0.069	3,549.24	99.97

Melt 14

	Input Mass Mass in feed (g)	Mass in off-gas (g)	+ Mass in Hood, First Section of Pipe(g)	= Output Mass	$DF = \frac{input\_mass}{output\_mass}$	$Retention\ in\ glass = 1 - \frac{1}{DF}\ x\ 100$ Retention in glass (%)
Cs	79.57	27.59	0.11	27.70	2.87	65.19
Sr	275.63	0.149	0.002	0.151	1,824.13	99.95

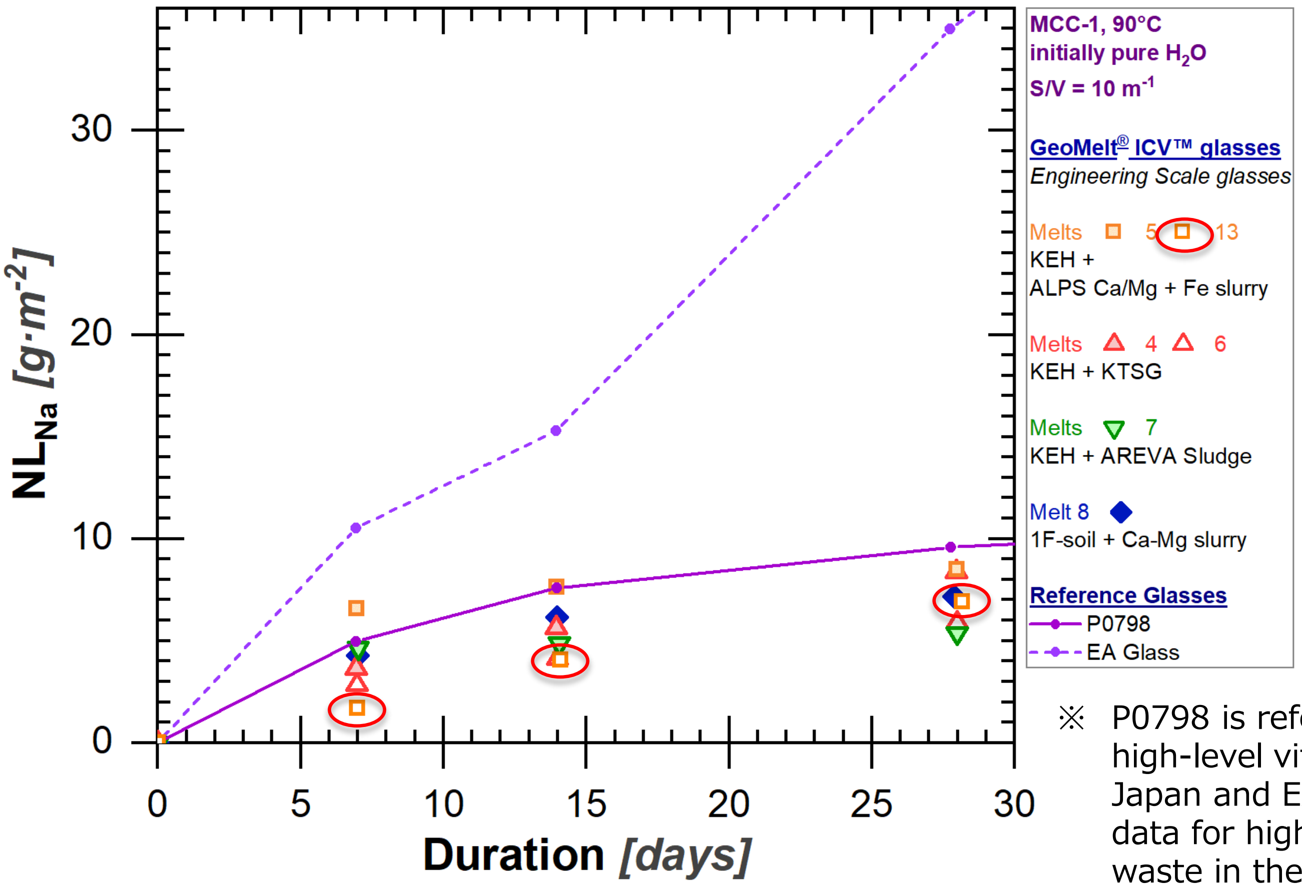
Homogeneity of glass

- Twelve samples were taken from each of the vitrified glasses from the engineering-scale melting tests 13 and 14, and the concentrations of the tracers, Cs and Sr, were analyzed. The coefficients of variation (standard deviation/mean) for both Cs and Sr were small and there was no concentration bias by location, confirming the homogeneity of the vitrified glass.

Coefficient of Variation (standard deviation/mean) of analytical values (mg/kg)	Analysis value for each sampling point (mg/kg) (Upper value: Cs、Lower value: Sr)
<u>Melt 13</u> Cs: 7.42% Sr: 2.06%	 
<u>Melt 14</u> Cs: 2.72% Sr: 3.76%	 

Durability of glass

- MCC-1 (glass durability test) was conducted for 28 days on the vitrified glass from the engineering-scale Melt 13.
- As in past grant projects, the durability was confirmed to be equivalent or better than that of Japanese simulated high-level waste glass P0798.



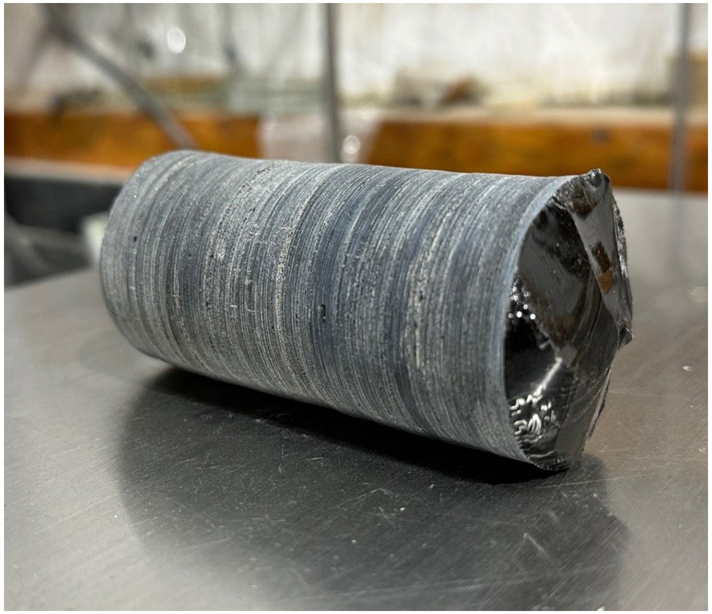
※ P0798 is reference data for high-level vitrified glass in Japan and EA Glass is reference data for high-level vitrified waste in the United States.

Uniaxial compressive strength of glass

- Uniaxial compressive strength was measured for the vitrified glass in engineering-scale Melt 13 and 14.
- The results are as follows. As in past grant projects, the strengths are over 1.470 MPa, as specified in the acceptance criteria for the current buried facilities.

Melt 13: 110.0MPa

Melt 14: 102.5MPa



Melt 13 Glass Core Sample for Uniaxial Compressive Strength Testing

3.1 Melting tests

3.1.5 Summary of melting tests

The results for each of the confirmation items in the melting tests are shown below.

In the melting method in which the storage container is initially filled and then melted in the top-down process, the possibility of melting the entire storage container with the dehydrated ALPS slurry has been obtained. The possibility of melting the additional feed was also demonstrated.

Confirmation item	Result
Ability to melt dehydrated ALPS slurry with the entire storage container	This could be demonstrated by top-down operation. The molten glass temperature was also confirmed to be above the target of 1550°C.
Whether or not a steam explosion occurs due to moisture contained in dehydrated materials	No steam explosion occurred. Although there was excessive steam eruption, it was confirmed that it could be controlled by optimizing the power rise.
Demonstrate operation to avoid electrical shorts through storage containers, and operation to restore them in the event of a short circuit.	It was difficult to avoid short circuits by changing the current value. However, it was confirmed that there was no impact on electrical equipment due to the protection circuit, and that it was possible to restore the system quickly and that there was no impact on operation.
Evaluation of migration rate of Cs and Sr to off-gas during melting (engineering-scale test)	The retention rates of Cs were low, in the 60% range, suggesting that sintered metal filters will become more important in the future. On the other hand, the retention of Sr was high at over 99.9%.
Confirmation of homogeneity and durability of Cs and Sr in vitrified glass (engineering-scale test)	The Cs and Sr concentrations in the vitrified glass confirmed their homogeneity. MCC-1 test confirmed that the durability of the vitrified glass is equivalent or superior to that of P0798, a high-level glass.

3.2 Feasibility study on additional feeding of storage containers

Objective:

To increase the waste fill in an ICV container and reduce the volume of the final wastes, a desk study is conducted to process multiple storage containers of dehydrated materials in a single cast refractory by feeding additional containers, assuming a full-scale melter.

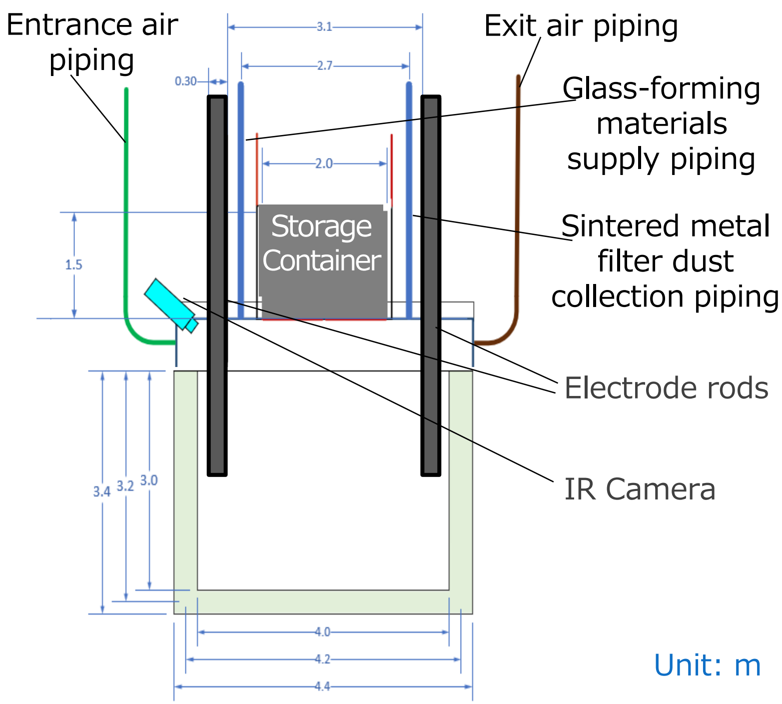
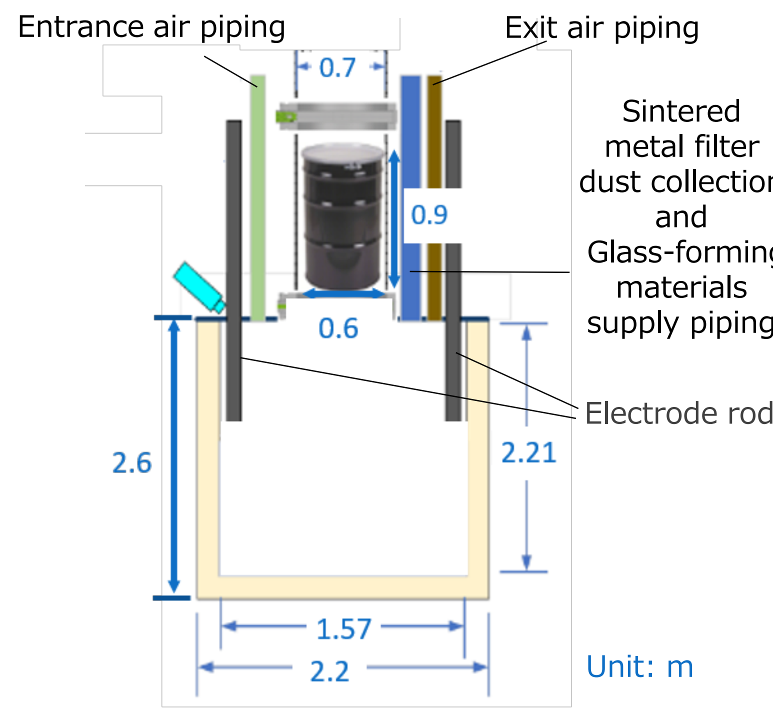
Considerations:

The following is examined for a storage container of □2m x 2m x 1.5m and, as an example, with container dimensions of about 200L drums.

(1) Size of cast refractory required for processing storage containers
(2) Additional feeding operation method
(3) Number of storage containers that can be processed in one melting
(4) Issues and development elements related to additional feed

3.2 Feasibility study on additional feeding of storage containers
(1) Sizes of cast refractory required to process storage containers

- Additional feed of the storage containers has to be done from the center of melter, avoiding the four electrode rods, due to the layout constraints of the melter hood. This determines the placement of the electrode rods and piping, etc. associated with the melter.
- As a result of the above study, the minimum required size of the cast refractory is assumed to be as follows.

<table>
<tr><th></th><th>□2m x 2m x 1.5m storage container</th><th>Storage container about 200L drum</th></tr>
<tr><td>Cast refractory Size</td><td>Internal dimensions: 4m x 4m x 3m
External dimensions: 4.4m x 4.4m x 3.4m
⇒ Container size for approx. 100 t scale</td><td>Internal dimensions: 1.57m x 1.57m x 2.21m
External dimensions: 2.2m x 2.2m x 2.6m
⇒ Container size for approx. 10 t scale</td></tr>
<tr><td>Rough sketch</td><td>
</td><td>
</td></tr>
</table>

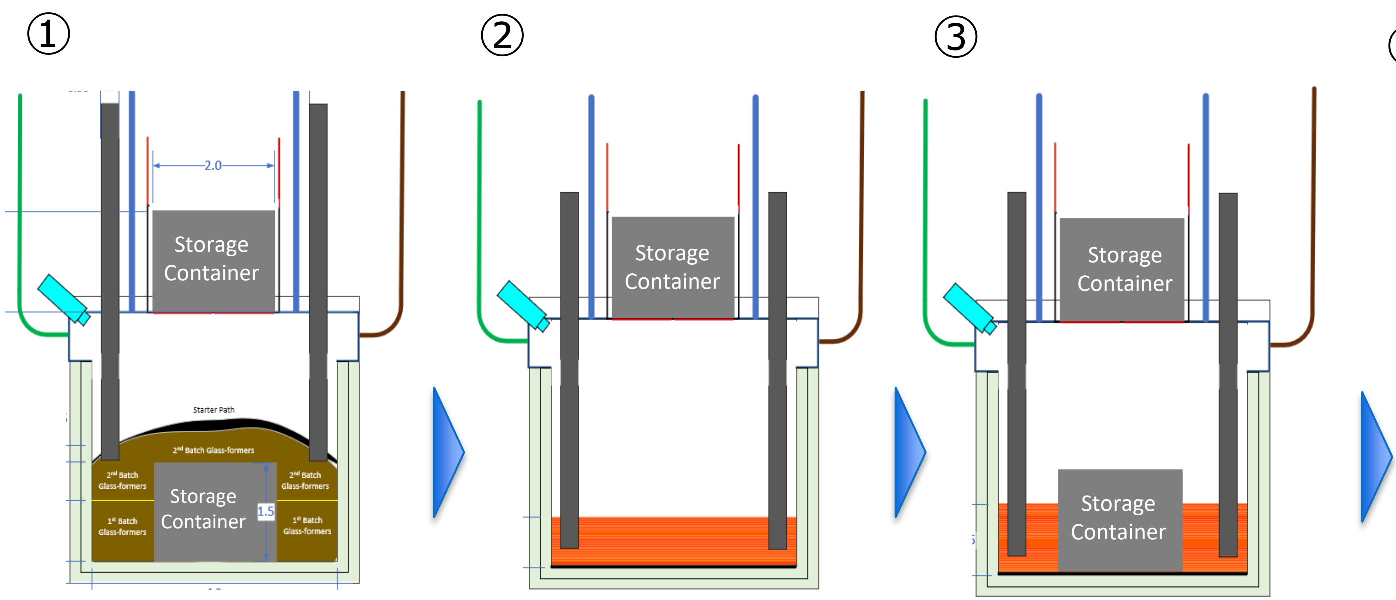
3.2 Feasibility study on additional feeding of storage containers
(2) Operation method for additional feeding (□2m x 2m x 1.5m case)

① Initially put one storage container and two batches of glass forming material, and start melting (in order to prevent exposure of the electrodes due to a drop in the glass liquid level during melting, supply a large amount of glass forming material at the beginning). (Lessons learned from bench-scale tests)

② Melt the initial input of storage containers and glass-forming materials.

③ Feed one additional storage container.

④ The glass-forming material and the storage container are then fed alternately and repeatedly melted.



Repeat alternate feeding of glass-forming material and storage containers.

3.2 Feasibility study on additional feeding of storage containers
(2) Operation method for additional feed (keeping negative pressure) (□2mx2mx1.5m)

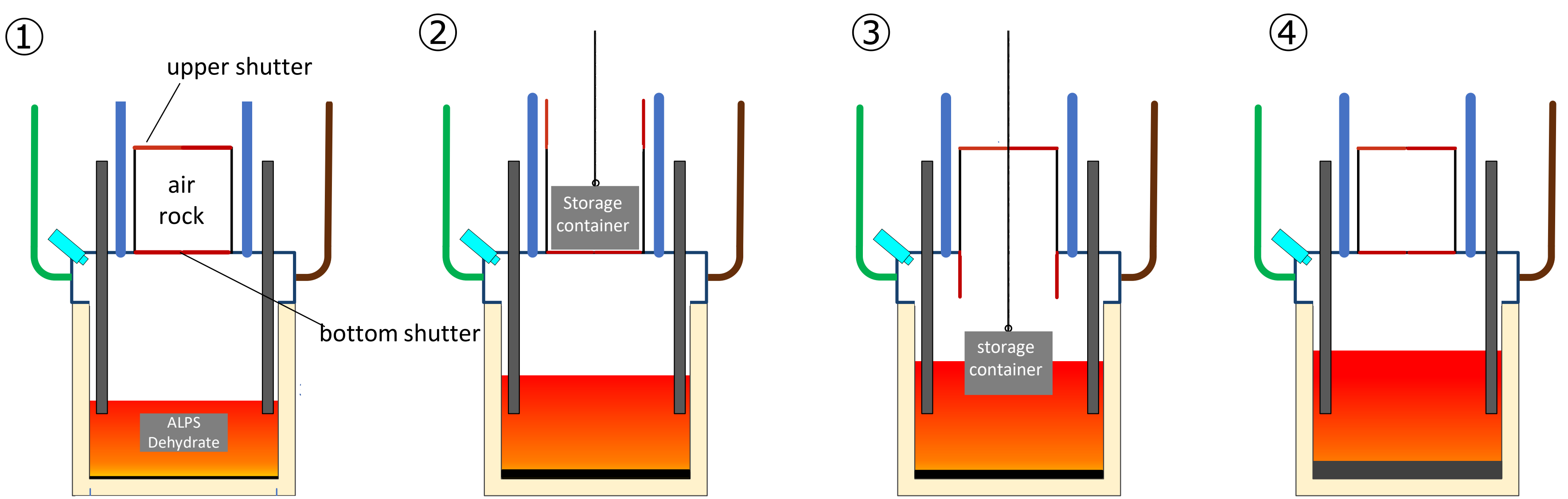
It is also necessary to maintain negative pressure inside the melter during additional feeding (at the time of ③ on the previous page). For this purpose, an airlock mechanism with a double shutter is installed on the top lid of the melter. The following is an overview of additional feeding using the airlock mechanism.

① Before additional feeding

② Only the upper shutter is opened and the storage container is suspended in the airlock.

③ The upper shutter is closed, the lower shutter is opened, and the storage container is placed in the melter.

④ Lower shutter is closed to continue melting.

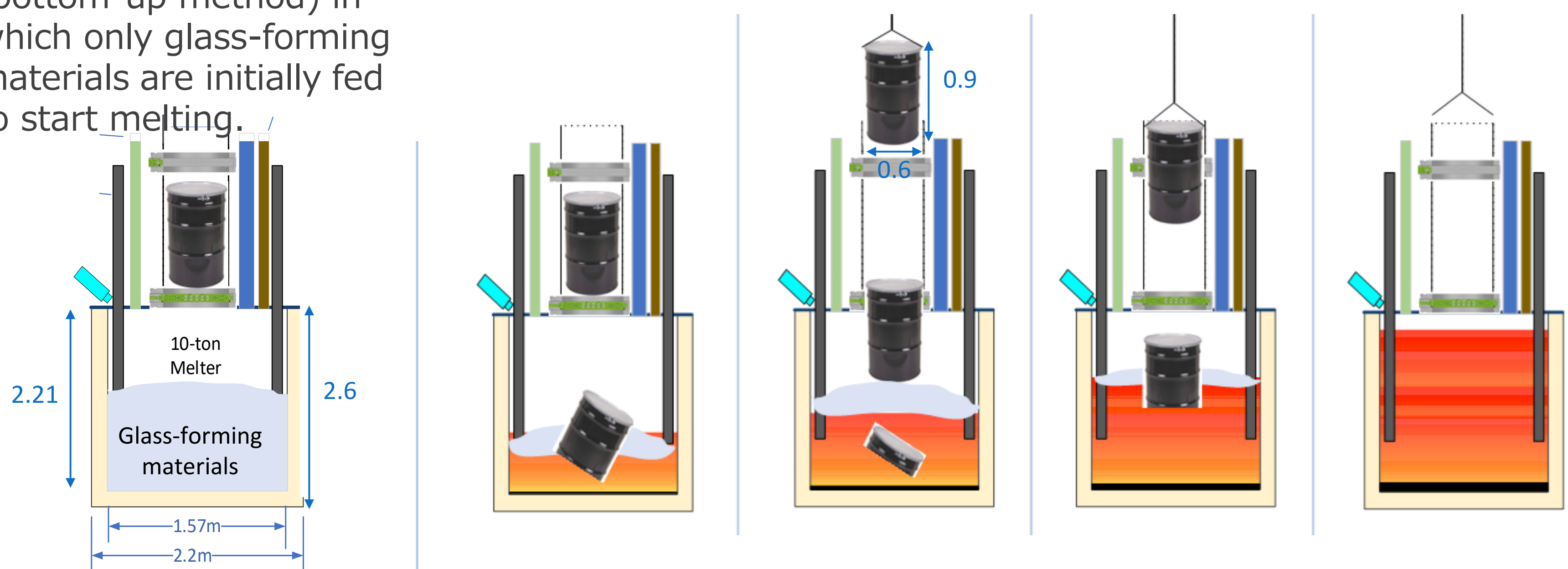


3.2 Feasibility study on additional feeding of storage containers
(2) Operation method for additional feeding (approx. 200L drum)

Even in the 200L drum size, the airlock mechanism maintains negative pressure inside the melter while feeding additional storage containers. Due to the small size compared to the large size □2m x 2m x 1.5m, it is assumed that if there is a cold cap on the top surface of the molten glass, feeding by free fall is also possible.

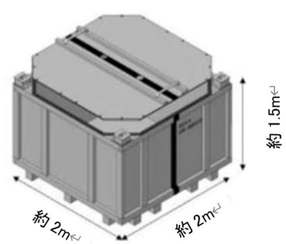
Compared to the large □2m x 2m x 1.5m, we assume that operation by the molten pool formation method (bottom-up method) is better, as in Task 1, because it is relatively easy to feed additional storage containers and a large amount of glass-forming material is initially required to prevent exposure of the electrodes.

Assumes a molten pool formation method (bottom-up method) in which only glass-forming materials are initially fed to start melting.



3.2 Feasibility study on additional feeding of storage containers
(3) Number of storage containers that can be processed in one melt

- The amount of dehydrated material (number of storage containers) that can be processed in one melting was calculated based on the filling rate of 27.5% of dehydrated ALPS carbonate slurry, which was set in the glass formulation analysis, assuming that the glass is filled to 90% of the melter volume.
- Calculations were made to account for the weight loss of H_2O and CO_2 in the dehydrated product as they are released from the system during the melting process.

	Storage container □2m x 2m x 1.5m	**Storage container approx. 200L drum**
90% melter volume	43.2m^3 (Internal dimensions: 4m x 4m x 3m)	4.90m^3 (Internal dimensions: 1.57 x 1.57 x 2.21 m)
Number of storage containers that can be fed	 6 pcs.	 19 pcs.

3.2 Feasibility study on additional feeding of storage containers
(3) Number of storage containers that can be processed in one melt (comparison of volumes before and after melt processing)

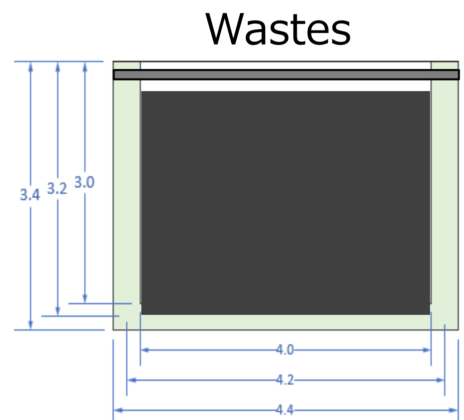
A comparison of the volume of the wastes after the melt treatment and the volume of the wastes in storage before the melt treatment is shown below.
In both storage containers, the volume of the wastes was found to be larger than before melting. To further reduce the volume, the current filling rate of 27.5 wt% for the ALPS carbonate slurry should be increased.

Storage container of □2m x 2m x 1.5m

x 6

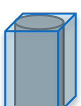
Volume: 36 m^3

Volume ratio: 183%



Volume: 65.8 m^3

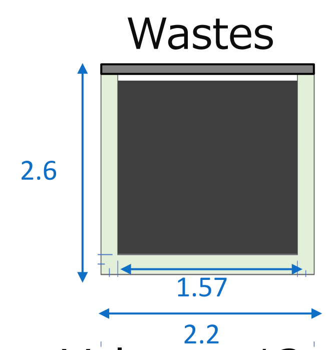
Storage container of 200L drum size



x 19

Volume: 6.2 m^3

Volume ratio: 204%



Volume: 12.6 m^3

※ 200L drum is calculated as a rectangle of □0.6 x 0.6 x 0.9 as the space volume for storage.

3.2 Feasibility study on additional feeding of storage containers
(4) Issues and development elements related to additional feeding

The issues and development elements identified through the feasibility study of the additional feeding are organized by category as follows.

- Improved filling rate of dehydrated ALPS carbonate slurry for volume reduction (See next page)
- Storage container handling
  - Can the storage container be loaded without coming in contact with the electrode rods?
  - Feasibility of maintaining negative pressure in the melter with an airlock
  - Method of drilling vapor vent holes in storage containers
- Melting behavior of storage containers
  - Sedimentation of storage containers into molten glass
  - Time required for melting

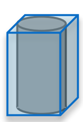
The engineering-scale Melt 14 showed that it is a simple method, but additionally fed storage containers can be melted. In the future, further tests and design studies should be conducted on the above points, and the reduction of waste volume by additional feeding should be considered.

Improved filling rate of dehydrated ALPS carbonate slurry for volume reduction

In the GeoMelt® treatment, the filling rate of dehydrated ALPS carbonate slurry should be increased to over 50 wt% to reduce the volume of the dehydrated ALPS carbonate slurry according to the calculations.

The current filling rate (27.5%) is a filling rate set with the goal of having the same durability as Japanese simulated high-level waste glass P0798. However, The requirements for GeoMelt® vitrified wastes have not yet been determined, therefore, as the need to ensure the durability of the solidified body is also unknown. There is a possibility that the filling rate could be increased to ensure waste volume reduction, although less durability than in the current study, depending on the results of future studies on disposal.

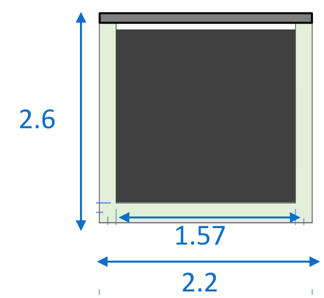
200L drum size



x 39

Volume ratio: 100 →

Wastes



(Dehydrated material filling rate:
46.3% ⇒ about 50%)

Volume: 12.6 m^3

Volume: 12.6 m^3

4. Conclusion

4. Conclusion

In this year's grant project, both Task 1 and Task 2 showed promise for vitrification of each waste material through melting tests and desktop studies.

On the other hand, in both tasks, it is necessary to allow repeated additional feeding to reduce the volume of waste. The following issues shown on the next page (Task 1) and the next page of it (Task 2) have also been identified, and we would like to consider solving these issues along with additional feeding in the future.

4. Conclusion

Task 1: Investigation of bulk solidification technologies for rubbles

- Since almost all of Zn in the zinc coating of steel migrates to the off-gas system, it is necessary to consider methods to collect Zn in the off-gas system and to control the increase in differential pressure.
- Cs retention dropped to 78.9% due to higher molten glass temperatures at the top and longer melting times than in the past. This should be considered to ensure that it can be collected in the off-gas system together with Zn.
- We were unable to obtain data on the extent to which metals, flame retardant materials, etc. can be treated in GeoMelt®, and further study is needed to establish a range of treatment possibilities with GeoMelt®.
- Breakage of electrode rods due to prolonged melting was confirmed. In the future, it is necessary to confirm the melting time in repeated additional feeding operations, to examine the breakage of electrode rods, and to consider measures to deal with the breakage if necessary.

4. Conclusion

Task 2: Investigation of technologies to process dehydrated ALPS slurry together with a container

- In order to reduce the volume of waste after melting, it is necessary to increase the filling rate of dehydrated ALPS carbonate slurry from 27.5 wt% to 50 wt%. It is necessary to confirm whether the filling rate can be increased while checking the condition of the glass by crucible tests, etc.
- The filling rate discussed above should be verified by melting tests in which additional storage containers are repeatedly fed to achieve the target filling rate.
- In addition, it is necessary to maintain negative pressure in the melter during additional feeding, and the method should be studied and also confirmed by testing.