IRID

Subsidy Project of Decommissioning and Contaminated Water Management in the FY2018 Supplementary Budget

Development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (Development of technology for dust collection system of fuel debris)

FY2020 Final Report

July 2021

International Research Institute for Nuclear Decommissioning (IRID)

*This project *was* named as *Development of Technology for Retravel of Fuel Debris and Internal Structure (Development of technology for dust collection system of fuel debris)* , when the project started. According to the development plan of decommissioning research in FY 2020 disclosed at the 75th Secretariat Team Meeting for Countermeasures for Decommissioning and Contaminated Water Treatment, the project name was changed *to Development of Technology for Further Increasing the Scale of Retravel of Fuel Debris and Internal Structures (Development of technology for dust collection system of fuel debris)* .

Contents

1. Background and Purpose
1. 1 Reasons why this research is necessary

Various fuel debris machining methods corresponding to the characteristics of fuel debris have been studied and developed for machining fuel debris such as cutting, etc. On the other hand, radioactive materials from which dust migrates to the gas phase due to machining were evaluated conservatively without considering prevention of dust dispersion. (*1)

In future, the actual value of dust that migrates to the gas phase as a result of machining fuel debris needs to be verified, while designing a reasonable environmental control system and developing a maintenance and operation plan.

In this research, a dust collection system for collecting the dust generated while machining fuel debris will be developed and data on dust dispersion while machining fuel debris (*2) (dust migration rate in gas-liquid phases, dust collection efficiency) will be acquired.

*1: Refer to the Central Research Institute of Electrical Power Industry *Hand-book on Environmental Impact Assessment for Decommissioning Work (Third edition)*

*2: In this research, Uranium oxide (UO_2), ceria and fuel claddings simulating actual 1F fuel are used.

1. Background and Purpose

1. 2 Reflection of results and contribution thereof

Dust collection and dispersion-prevention system for the dust generated while machining fuel debris are developed to contribute to the acquisition of data on dust dispersion during fuel debris machining.

Research results

◆ The following information obtained from the vicinity of the part being processed

- Loss of volume of the test piece
- Particle size distribution of the dust dispersed into the air
- Total amount of dust that does not get dispersed but falls or migrates into water

↓

Exposure assessment during machining and environmental control system impact assessment (Gas phase, liquid phase)

◆ Exposure assessment

- Site exposure assessment associated with dust dispersion

◆Environmental control system impact assessment (Gas phase, liquid phase)

- Monitoring in the event of an abnormality and optimization of the ventilation system
- Evaluation of dust concentration in the liquid phase inside the PCV* (Assessment of impact on the water treatment system)

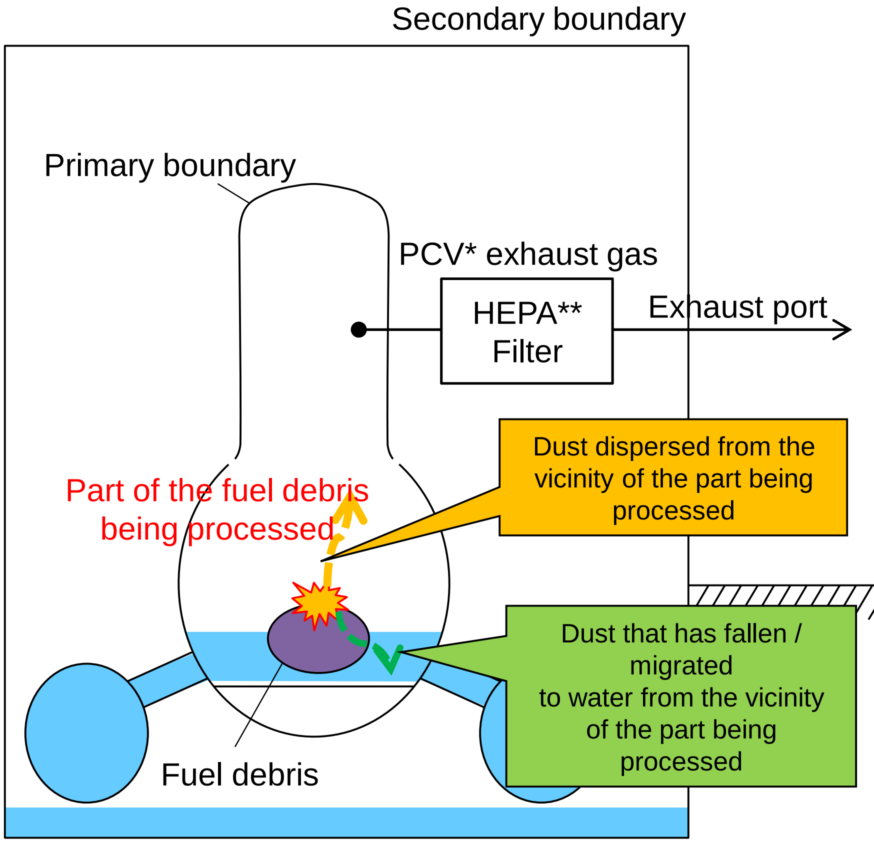


Illustration of dust that has dispersed, fallen / migrated to water from the vicinity of the part being processed

* PCV: Primary Containment Vessel
** HEPA: High Efficiency Particulate Air Filter

2. Implementation items and goals of the project

2. 1 Implementation items and goals of the project

(1) Development of dust collection and dispersion-prevention system
In order to prevent dispersion of dust, etc. while machining fuel debris, the field applicability of the dispersion-prevention structure in the vicinity of the machining point, efficient collection technology and dispersion-prevention technology will be evaluated based on existing technology.

(Goal) ① To conceptually design the dust collection and dispersion-prevention system and the machining head and evaluate the applicability to the actual equipment
② To define the basic specifications of the dust collection and dispersion-prevention system and the machining head, and design the system

(2) Development of remote maintenance technology for dust collection and dispersion-prevention system
As the fuel debris retrieval equipment and devices (fuel debris cutting and dust collection system, container or work table, monitoring device or robot arm for handling it, etc.) are installed in areas with high radiation, as a general rule, maintenance needs to be carried out remotely. Hence equipment and device maintenance method that takes handling of fuel debris into consideration, will be studied.

(Goal) ① Remote maintenance method and conceptual design of the required equipment

(3) Evaluation test of dust collection and dispersion prevention
A representative machining method will be selected from the machining methods selected as part of “Development of technology for retrieval of fuel debris and reactor internal structures”, and test guidelines, test matrix and testing system concerning that selected machining method will be studied. Moreover, a test will be conducted wherein dust evaluation and testing apparatus will be designed and test manufactured, a test piece simulating fuel debris will be tested for dust dispersion with said testing apparatus, and the in-air migration rate and underwater migration rate of dust into the space around the machining head will be evaluated.

(Goal) ① Development of dust collection and dispersion-prevention evaluation guidelines
② Evaluation test of dust collection and dispersion prevention

2. Implementation items and goals of the project

2. 2 Project issues

The effectiveness of dust dispersion prevention by using the dust collection and dispersion-prevention system (mist, water ejector) was evaluated under the Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budget “Upgrading of fundamental technology for retrieval of fuel debris and internal structures” (Implemented in FY2017-18). The issues encountered in this project using these results are listed below.

(Project issues)

・A conceptual study of dust collection and dispersion-prevention system in the vicinity of the fuel debris machining point in air and underwater, that takes into consideration the field applicability of remote maintenance, etc.

⇒The issue will be addressed through the following implementation items

(1) Development of dust collection and dispersion-prevention system

(2) Development of remote maintenance technology for dust collection and dispersion-prevention system

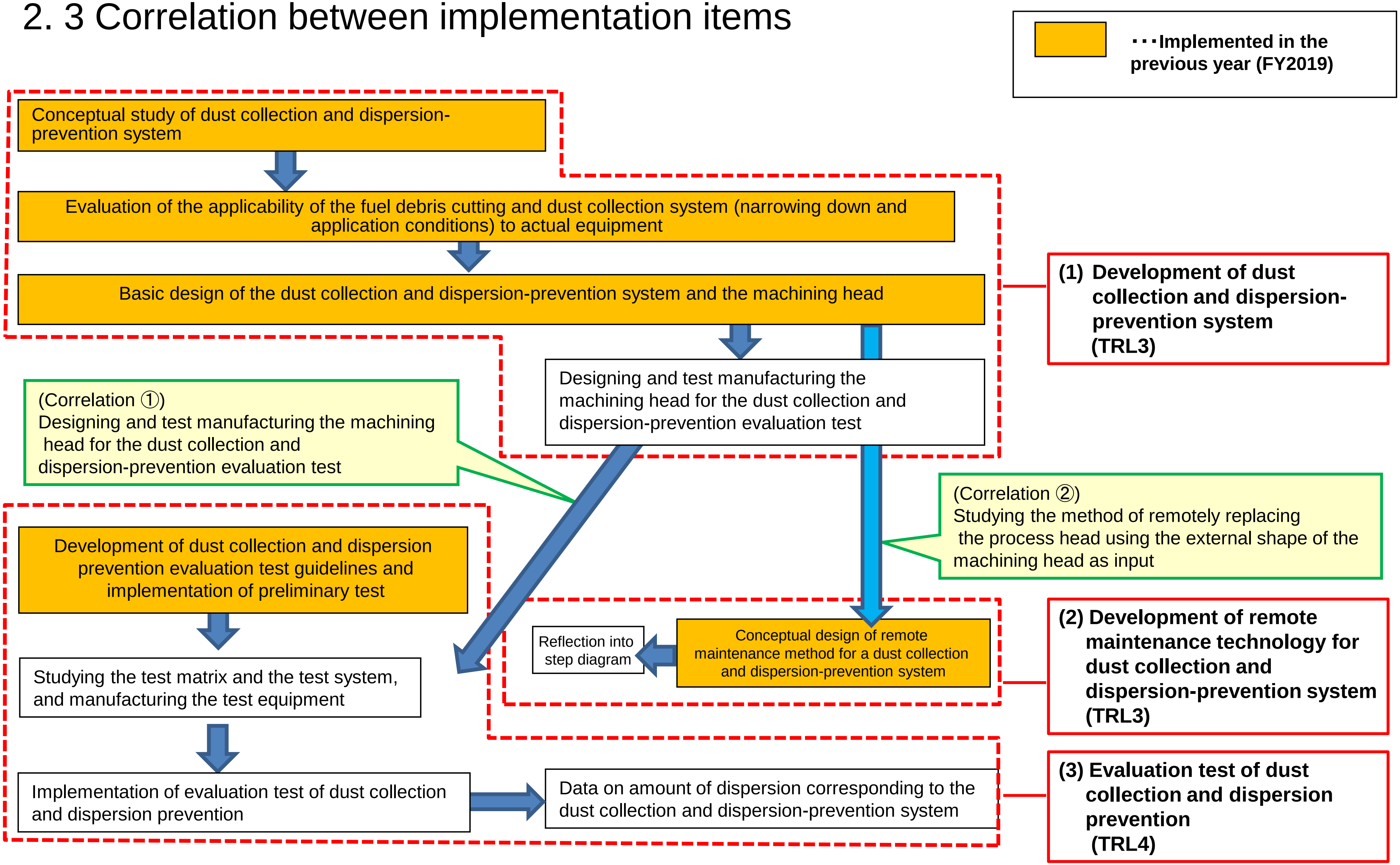
・Evaluation of the dust migration rate in gas-liquid phases during machining of each part inside the PCV, and the dust collection efficiency

⇒The issue will be addressed through the following implementation items

(3) Evaluation test of dust collection and dispersion prevention

2. Implementation items and goals of the project

2. 3 Correlation between implementation items



3. Collaboration with other research

Project issues in the fuel debris retrieval study

① In order to avoid exceeding the radioactivity concentration control value from the perspective of ensuring safety in the space where workers enter, the generation and dispersion of dust in the vicinity of the part being processed needs to be prevented as much as possible, depending on the machining method.

② The throughput needs to be evaluated based on the constraints imposed by the control value of the above-mentioned environmental control system while taking the fuel debris machining method (type and machining pattern) into consideration.

③ The filter replacement and waste transfer frequency need to be assessed based on the decontamination factor (DF) of the environmental control system.

① Development of technology for further increasing the scale of retrieval of fuel debris and reactor internal structures

- Study of fuel debris retrieval method
- Analysis of airflow inside PCV

② Development of analysis and estimation technology for characterization of fuel debris

- Study of the behavior of radioactive airborne particles associated with fuel debris machining

Main IRID projects progressing in cooperation

Input information for this PJ

1) Machining method expected to be applied (①)

2) Analysis of airflow inside PCV (①)

3) Environmental control system and radioactivity concentration control target value (②)

4) Conversion factor for calculating the radioactivity concentration of the item being processed based on the amount of dust (②)

⇒ Goals and results of this PJ

1) Conceptual design of the machining head that is expected to be extensively used and evaluation of the dust removing performance of the machining head that generates a large amount of dust

2) Applicability (additional equipment, handling method, etc.) of actual dust collection and dispersion-prevention system to actual equipment giving due consideration to maintenance performance

Throughput considering the impact of dust

4. Project organization

At the International Research Institute for Nuclear Decommissioning (IRID), technology development has been carried out in cooperation with Toshiba Energy Systems & Solutions Corporation for developing technology for retrieval of fuel debris and reactor internal structures (technological development of fuel debris dust collection system). IRID is conducting overall management of the project.

Tokyo Electric Power Company Holdings, Inc.

○ Various coordination for site application
(・Coordination to reflect the status of permission and authorization
・Coordination to reflect the status of the decommissioning site Etc.)

International Research Institute for Nuclear Decommissioning (IRID)

○ Coordination of overall planning and technology management
○ Coordination of technology administration including technology development progress management

Toshiba Energy Systems & Solutions Corporation

[Elemental test, technical development]
1) Development of dust collection and dispersion-prevention system
2) Development of remote maintenance technology for dust collection and dispersion-prevention system
3) Evaluation test of dust collection and dispersion prevention

Project teams to cooperate for technological development

- Development of technology for further increasing the scale of retrieval of fuel debris and reactor internal structures
- Development of analysis and estimation technology for characterization of fuel debris
- Development of technology for collection, transfer and storage of fuel debris
- Development of criticality control technology for fuel debris
- Research and development for treatment and disposal of solid waste

4. Project organization

Tokyo Electric Power Company Holdings, Inc.

- Various coordination for site application
  (・Coordination to reflect the status of permission and authorization
  ・Coordination to reflect the status of the decommissioning site Etc.)

International Research Institute for Nuclear Decommissioning (IRID)

- Coordination of overall planning and technology management
- Coordination of technology administration including technology development progress management

Toshiba Energy Systems & Solutions Corporation

Toshiba Development & Engineering Corporation
・Development of dust collection and dispersion-prevention system
(Creation of retrieval work step diagram based on the conceptual design)
・Development of remote maintenance technology for dust collection and dispersion-prevention system
(Creation of work step diagram assuming the use of remote maintenance technology)

Actovide Ltd.
・Development of dust collection and dispersion-prevention system
(Machining device preparation and operation services)
・Evaluation test of dust collection and dispersion prevention
(evaluation test apparatus design)

Watari Co., Ltd. (Tokyo Dylec Corp.)
・Development of dust collection and dispersion-prevention system
(Dust particle size distribution measurement services)

Shin Nippon Air Technologies Co., Ltd.
・Development of dust collection and dispersion-prevention system
(Dust evaluation test visual measurement services)

Nihon System Co., Ltd.
・Development of dust collection and dispersion-prevention system
(Machining device model construction and CFD implementation)
・Evaluation test of dust collection and dispersion prevention
(Dust collection and dispersion-prevention system analysis model construction and CFD implementation)

Tanabe Corporation
・Evaluation test of dust collection and dispersion prevention
(Manufacturing of simulated fuel debris melt)

Kojundo Chemical Laboratory Co., Ltd.
・Evaluation test of dust collection and dispersion prevention
(Material 1 for simulated melt - oxide material -)

Nihon Denkei Co., Ltd. (Sanyo Special Steel Co., Ltd.)
・Evaluation test of dust collection and dispersion prevention
(Material 2 for simulated melt - metal material -)

Niitaka Rika Industry Co., Ltd.
・Evaluation test of dust collection and dispersion prevention
(Material 3 for simulated melt - cement material -)

Daiichi Cutter Kogyo K.K.
・Evaluation test of dust collection and dispersion prevention
(Simulated fuel debris melt test piece machining)

Manufacturing of simulated MCCI (Molten Core Concrete Interaction)(hereinafter, simulated MCCI) test piece

Nippon Nuclear Fuel Development Co., Ltd.
・Evaluation test of dust collection and dispersion prevention
(Study of test guidelines for evaluating dust at the time of cutting, using a simulated test piece such as stubby fuel, etc.)

Project teams to cooperate for technological development

- Development of technology for further increasing the scale of retrieval of fuel debris and reactor internal structures
- Development of analysis and estimation technology for characterization of fuel debris
- Development of technology for collection, transfer and storage of fuel debris
- Development of criticality control technology for fuel debris
- Research and development for treatment and disposal of solid waste

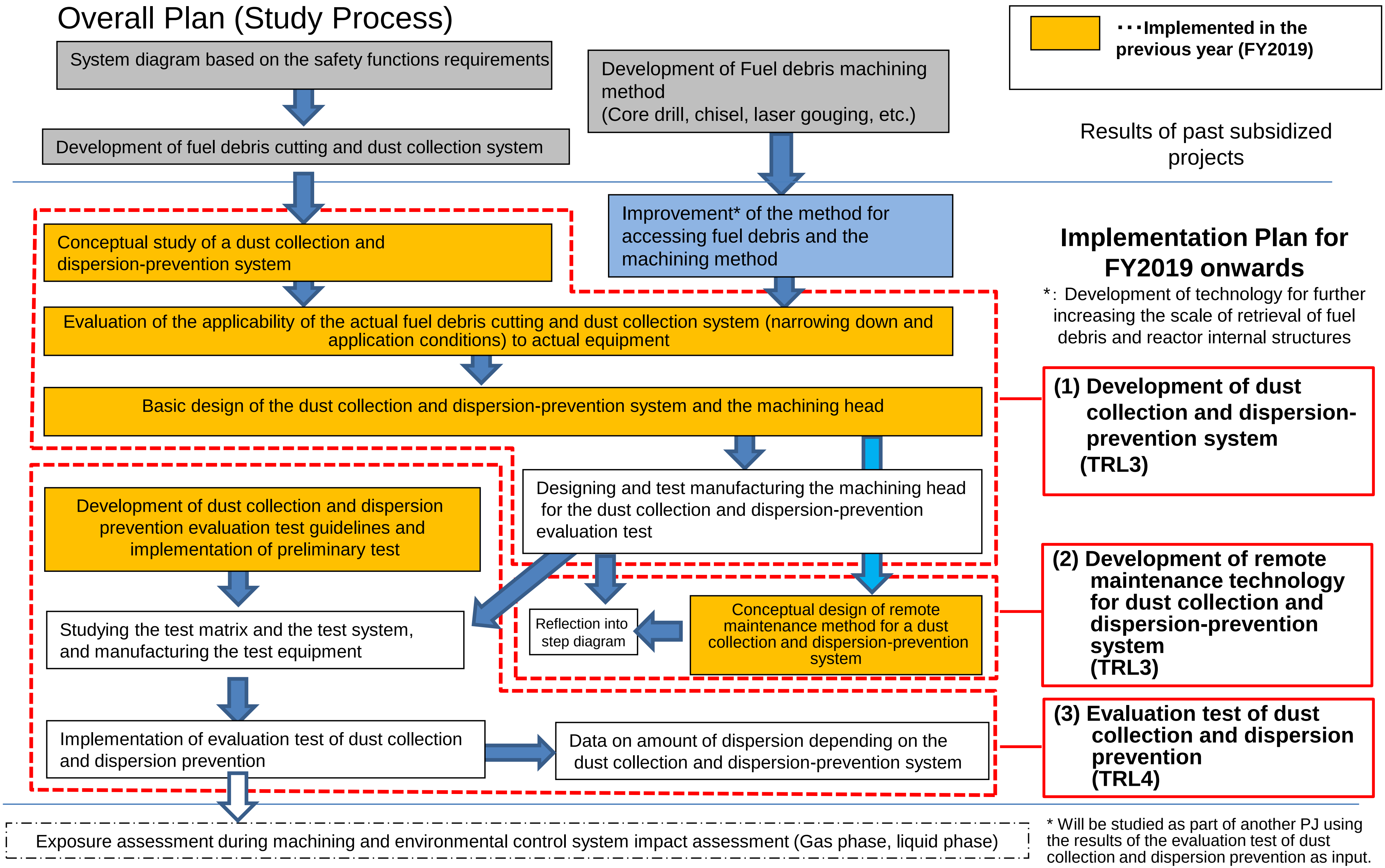
5. Implementation schedule

Large classification	Small classification	Schedule (FY2019 Apr–Mar / FY2020 Apr–Mar)	Remarks (status)
1) Development of dust collection and dispersion-prevention system Conducted by Toshiba ESS	a. Conceptual study of the dust collection and dispersion-prevention system and evaluation of its applicability to actual equipment	Conceptual study of the dust collection and dispersion-prevention system and evaluation of its applicability to actual equipment	• Manufacturing of the dust collection and machining head for the dust dispersion evaluation test using simulated fuel has been completed.
	b. Development of basic specifications of the machining head, its system design and evaluation	Development of basic specifications of the machining head, its system design and evaluation	
	c. Designing of the machining head	Basic designing of the machining head Designing of the machining head Manufacturing the machining head	
	d. Summary	Summary	
2) Development of remote maintenance technology for dust collection and dispersion-prevention system Conducted by Toshiba ESS	a. Consolidation of the approach towards the maintenance method	Consolidation of the approach towards the maintenance method	• Reflection of the step diagram for maintenance work during an emergency (failure) has been completed.
	b. Study of maintenance method, creation of the step diagram	Study of maintenance method, creation of the step diagram Reflection of the step diagram in the machining head designed during 1) Development of dust collection and dispersion-prevention systems	
	c. Summary	Summary	
3) Evaluation test of dust collection and dispersion-prevention Conducted by Toshiba ESS	a. Development of the dust collection and dispersion prevention evaluation guidelines	Development of the dust collection and dispersion prevention evaluation guidelines Preliminary tests Study of test matrix, test system and test equipment	• Dust dispersion evaluation test using simulated fuel has been completed.
	b. Evaluation test of dust collection and dispersion prevention	Manufacturing the test apparatus and test piece Evaluation test of dust collection and dispersion prevention	
	c. Summary	Summary	
	Major milestones	▲ Decision on subsidy (May 2019) ▲ Interim report (Oct 2019) ▲ Annual report (Mar 2020) ▲ IDR* (Jul 2020) ▲ Interim report (Nov 2020) ▲ IDR (Mar 2021) △ Final report (Mar 2021)	

(Legend)
- Grey bar · · · Planned schedule
- Grey dashed bar · · · Schedule that was moved up
- Black bar · · · Actual implementation

*IDR: IRID Design Review Meeting

6. Implementation Items



6. Implementation Items

6. 1 Development of dust collection and dispersion-prevention system

Implementation details and level of achievement
(Black font: Details of FY2019 implementations, Blue font: Details of FY2020 implementations)

(1) Development of dust collection and dispersion-prevention system (*1)			Implementation details / Level of achievement
① Conceptual designing of the dust collection and dispersion-prevention system and the machining head and evaluation of its applicability to the actual equipment	Upon investigating the past dust collection technology, the advantages and disadvantages in case of using the dust collection technology for the machining method selected in "Development of technology for retrieval of fuel debris and reactor internal structures" was to be evaluated. The results of evaluating the applicability to actual equipment for the side access method and top access method of the dust collection technology was to be presented. (Target TRL at completion: Level 3)	Evaluation of the advantages and disadvantages in case of using the dust collection technology for the machining method selected in "Development of technology for retrieval of fuel debris and reactor internal structures"	The advantages and disadvantages in case the dust collection technology is used was evaluated with respect to 3 points, namely, filter, water ejector, and mist, and it was confirmed that water ejector and mist were superior from the perspective of applicability to actual equipment and maintenance performance. (Completed in FY2019)
		Evaluation of the applicability to actual equipment in case of the side access method and top access method of the dust collection technology	It was confirmed that the external dimensions and weight of the machining head, the reaction force and power supply while machining, and the utility are suitable from the perspective of applicability to actual equipment. (Completed in FY2019)
② Defining of the basic specifications of the dust collection and dispersion-prevention system and the machining head, and designing the system	A chart listing the basic specifications of the dust collection and dispersion-prevention system and the machining head for the machining method selected in "Development of technology for retrieval of fuel debris and reactor internal structures", the system diagram and the conceptual design diagram were to be presented. (Target TRL at completion: Level 3)	Chart listing the basic specifications of the dust collection and dispersion-prevention system and the machining head	A chart listing the basic specifications of the machining head, including the external dimensions and weight, the reaction force and power supply while machining, and the utility, was created. (Completed in FY2019)
		System design, conceptual design	・System design and conceptual design of the machining head was created. (Completed in FY2019) ・Designing and manufacturing of the machining head for the (3) Evaluation test of dust collection and dispersion prevention was completed in the first half of FY2020, based on the basic design of the machining head with the dust collection and dispersion-prevention function studied in the previous year (FY2019). (Completed in FY2020)

*1: From 8. Specific goals for achieving the purpose of the project

6. Implementation Items

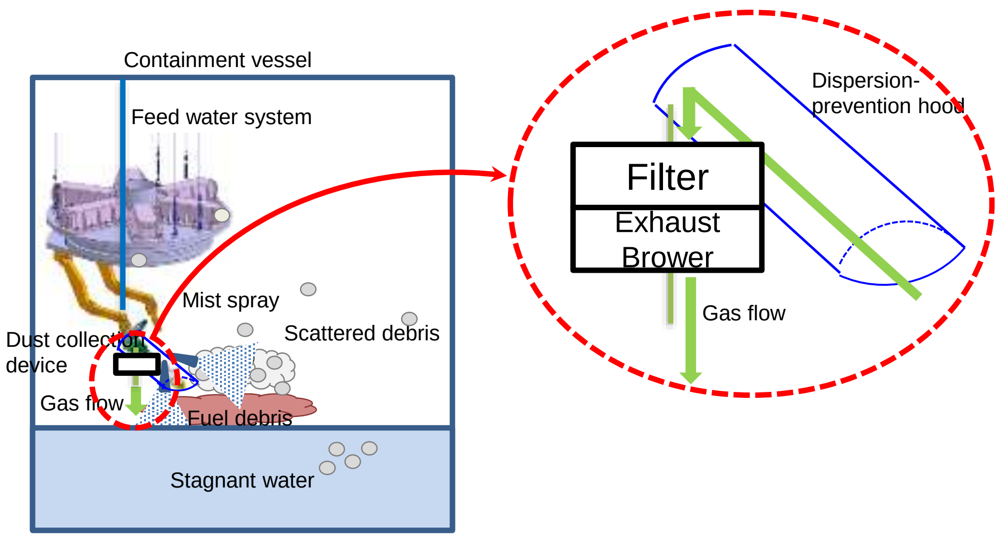
6. 1 Development of dust collection and dispersion-prevention system

[Evaluation of advantages and disadvantages for the dust collection technology from the perspective of applicability to actual equipment and maintenance performance]

○ Configuration images of the dust collection and dispersion-prevention system

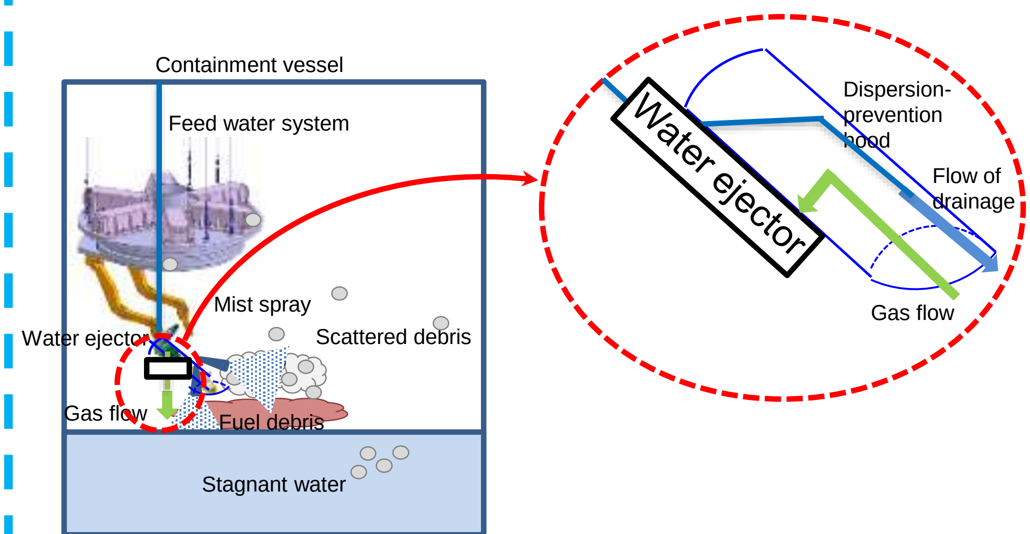
(Filtering method)

Combination of A) Collection (suction collection) method with the help of exhaust Brower + filter and C) Mist coagulation and water migration method



(Water ejector method)

Combination of B) Water ejector suction and water migration methods and C) Mist coagulation and water migration method



6. Implementation Items

6. 1 Development of dust collection and dispersion-prevention system

[Evaluation of advantages and disadvantages for the dust collection technology from the perspective of applicability to actual equipment and maintenance performance]

・Applicability to actual equipment

Items	A: Filter	B: Water migration (Water ejector)	C: Mist
Dust collection effectiveness *1	**Low (As suction strength is likely to reduce if the filters becomes wet)**	Yes	Yes
Installation scale *2	Small to medium (Included in fuel debris retrieval device preparation)	Small to medium (Included in fuel debris retrieval device preparation)	Small to medium (Included in fuel debris retrieval device preparation)
Advance installation work of the equipment outside the PCV	Not required (As a small collection device is mounted on the machining device)	Not required (As a small collection device is mounted on the machining device. Some of the machining water is used)	Not required (As a small collection device is mounted on the machining device. Some of the machining water is used)
Advance installation work of the equipment inside the PCV	No advance installation work (Connection/disconnection of the machining head and collection device)	No advance installation work (Connection/disconnection of the machining head)	No advance installation work (Mounting on to the machining device, connection/disconnection of the machining head)

・Maintenance performance of actual equipment

Items	A: Filter	B: Water migration (Water ejector)	C: Mist
Filter replacement	**Required (Transferred as waste. Frequency uncertain)**	Not required	Not required
Collection water treatment *3	Not required (Drains inside the PCV in the case of backwashing filter)	Not required (As water drains inside PCV)	Not required (As water is sprayed inside the PCV)
Amount of waste	**Large**	Small	Small
Anticipated maintenance work other than the above-mentioned work	1) Machining head replacement (If it is mounted on the machining device and a tool changer is used)	1) Machining head replacement (If it is mounted on the machining device and a tool changer is used)	1) Machining head replacement (If it is mounted on the machining device and a tool changer is used)

*1: Dust collection effectiveness for the particle size distribution in the atmosphere inside PCV, which has a major impact on exposure assessment
*2: If the installation work load is high, the retrieval work throughput and the maintenance work load increases.
*3: Indicates the necessity to treat the machining water collected while machining, other than the contaminated water treatment of water that normally accumulates inside the PCV.

The water ejector and mist are superior from the perspective of applicability to actual equipment and maintenance performance, therefore the system focusing on water ejector and mist was developed in this PJ.

6. Implementation Items

6. 1 Development of dust collection and dispersion-prevention system

[Machining method selected in “Development of technology for retrieval of fuel debris and reactor internal structures”]

1) Mechanical cutting
- Disc cutter
- Chisel
- Core boring
- AWJ (abrasive water jet)

2) Thermal cutting
- Laser gouging
- Laser
- Plasma

Structure	Classification	Tools				
		Side retrieval			Top retrieval	
		PLAN-A	PLAN-B	PLAN-C	Route A	Route B
Shield plug	Solid radioactive waste	-	-	-	Wire saw	Wire saw
DS Slot plug	Solid radioactive waste	-	-	-	-	Wire saw
PCV head	Solid radioactive waste	-	-	-	Laser / Plasma	AWJ
RPV Insulation Material / Piping	Solid radioactive waste	-	-	-	Laser / Plasma	AWJ
RPV head	Solid radioactive waste	-	-	-	Laser / Plasma	AWJ
Steam dryer	Solid radioactive waste	-	-	-	Band saw	AWJ
Shroud head (including steam separator)	Solid radioactive waste	-	-	-	Disc cutter	Disc cutter
Upper grid plate	Fuel debris	-	-	-	Laser	AWJ
Shroud	Fuel debris	-	-	-	-	AWJ
Jet pump	Fuel debris	-	-	-	-	AWJ
Core fuel debris	Fuel debris	-	-	-	Laser gouging	AWJ
Core Support Plate	Fuel debris	-	-	-	Laser	AWJ
Fuel debris at RPV bottom	Fuel debris	-	-	-	Laser gouging	Laser
RPV bottom	Fuel debris	-	-	-	AWJ Laser	AWJ
Fuel debris adhering to RPV lower part / CRD housing	Fuel debris	Disc cutter	Disc cutter	Disc cutter	AWJ Laser	AWJ
Pedestal internals	Fuel debris	Disc cutter	Disc cutter	Disc cutter	Disc saw	AWJ Laser
CRD changer	Fuel debris	Disc cutter	Disc cutter	Disc cutter	Disc saw	AWJ Laser
Fuel debris in pedestal	Fuel debris	Clumps: Core boring Pebbles: Collection tool Granular: Suction and collection device	Chisel Core boring Laser gouging	Disc cutter	Chisel	Laser
Fuel debris outside pedestal	Fuel debris	Clumps: Core boring Pebbles: Collection tool Granular: Suction and collection device	Chisel Core boring Laser gouging	Disc cutter		

(Legend)
Blue: Cutting by means of metals such as blades, etc.
Orange: Cutting by means of laser

(Supplementary information)
Various fuel debris retrieval methods / routes have been studied. Each of the studies is named differently.
An overview of each plan/route is given below.

- Side retrieval PLAN-A: Method in which an opening is made on the side of the PCV and multiple cells are installed.
- Side retrieval PLAN-B: Method using an access tunnel regardless of the unit
- Side retrieval PLAN-C: Method using X-6 penetration

- Top retrieval Route A: Route wherein the cell used for fuel debris retrieval from the refueling floor is shielded and the fuel debris is transported

- Top retrieval Route B: Route wherein shielding is carried out by retaining the shield plug of the refueling floor and the fuel debris is transported

Source: *1) Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budget “Upgrading of fundamental technology for retrieval of fuel debris and internal structures” (FY2018)

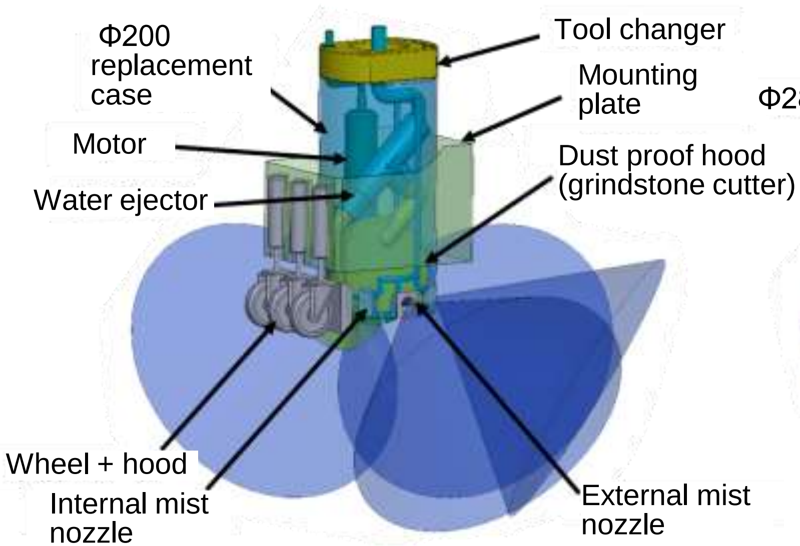
Application of the above-mentioned cutting and machining method has been assumed in the past subsidized projects by the government.

6. Implementation Items

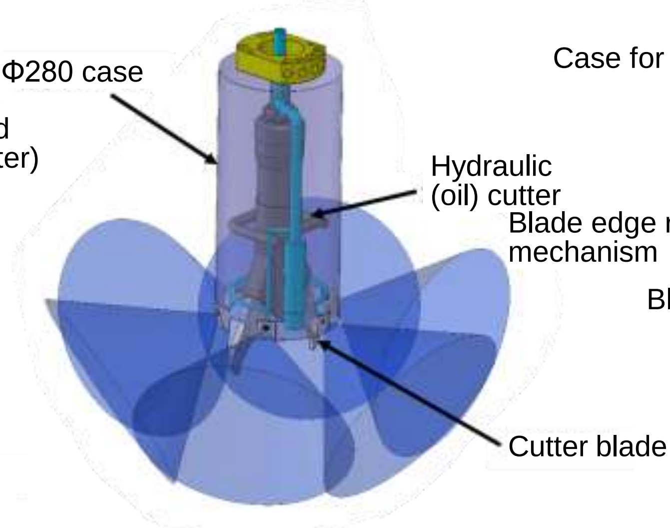
6. 1 Development of dust collection and dispersion-prevention system

[Conceptual study of a dust dispersion-prevention machining head]

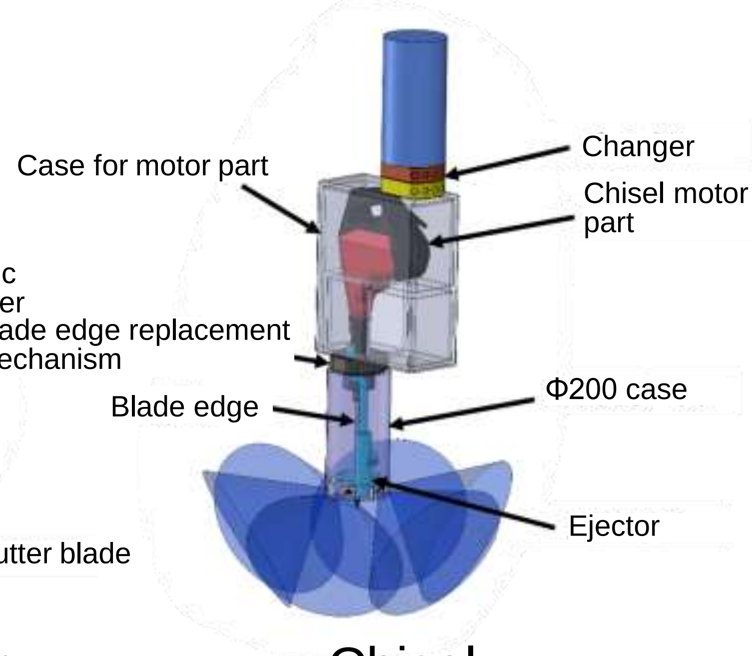
○ Machining head for mechanical cutting



Disc cutter



Hydraulic (oil) cutter

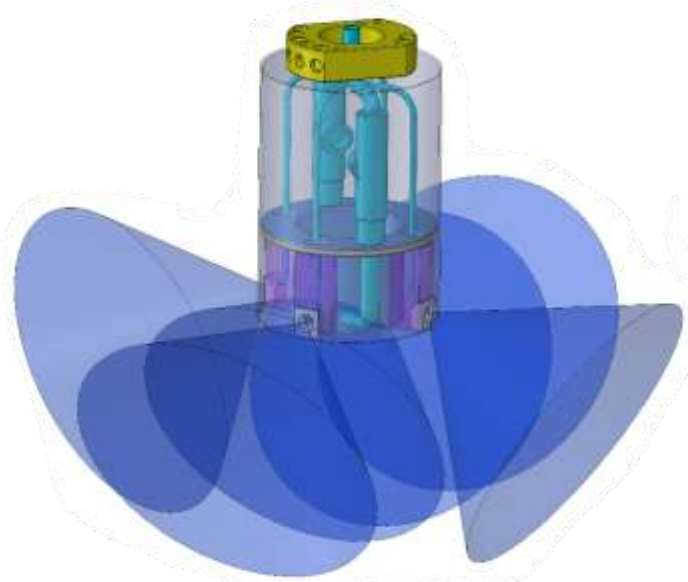


Chisel

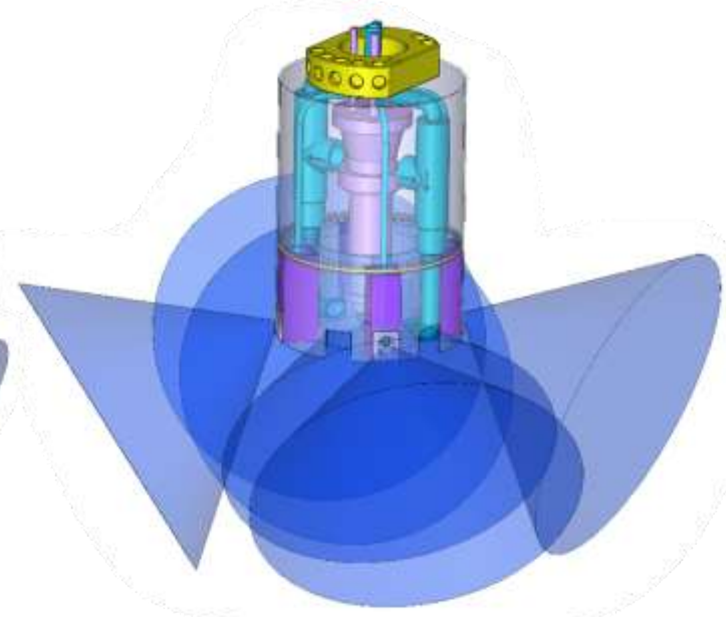
6. 1 Development of dust collection and dispersion-prevention system

[Conceptual study of a dust dispersion-prevention machining head (continued)]

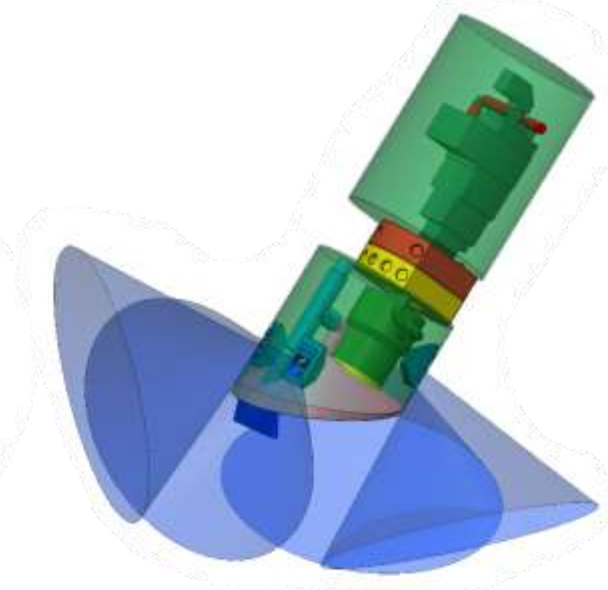
○ Machining head for thermal cutting



General purpose dust collection and dispersion-prevention head (90°)



Laser cutting (90°)



Laser gouging (60°)

Since the water ejector and mist are small and light weight, it was confirmed that these are applicable for the machining head that can be used for fuel debris retrieval.

6. 1 Development of dust collection and dispersion-prevention system

[Evaluation of applicability of the machining head to actual equipment]

Items	Basic design results	Evaluation of applicability to actual equipment	Criteria
Shape and dimension constraints of the object to be processed	None in particular	○	1) It can be used for accessible surfaces 2) There shall be no limiting conditions such as requirement to access the opposite surface of the surface to be processed, applicable dimensions, etc.
Machining tool external dimensions [mm]	Length approx. 270 x width approx. 200 x height approx. 530	○	The dimensions shall be such that it can be carried in/out to connect/disconnect inside the PCV. Reference guideline: ＜□1m (provisional)
Machining tool weight	Approx. 500N or less	○	The resultant force shall be less than the operating force of the manipulator. (Reference guideline: Lower than the 2000N payload of general power manipulators)
Counterforce during machining	Approx. 1000N or less (Preliminary test results)	○	
Power supply specifications	Three phase AC 200V, 10A	○	The power supply shall be applicable to the 1F site. (100V, 200V, etc.)
Volume of water used	Approx. $1.2m^3/h$	○	Average volume of water used $2.2m^3/h$[1] or less

＜ Source: [1] Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary Budget "Development of fundamental technology for retrieval of fuel debris and internal structures Research Report (Final Report) March 2017

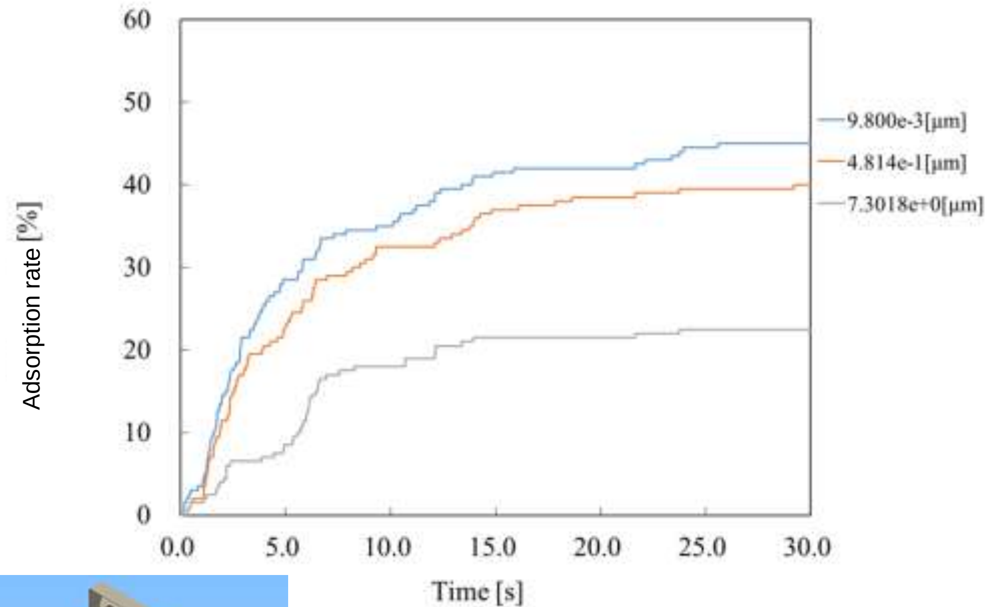
It was confirmed that the external dimensions and weight of the machining head, the reaction force and power supply while machining, and the utility are suitable from the perspective of applicability to actual equipment.

6. Implementation Items

6. 1 Development of dust collection and dispersion-prevention system

[Basic design of a disc saw with dust collection and dispersion-prevention function]

The basic design of a machining head with dust collection and dispersion-prevention function is as follows: A hood is installed around the disc saw, the air inside the hood is sucked with an air ejector, dust is moved to the drainage, and the dust that is released in the surroundings is collected by mist spray.
The machining head with dust collection and dispersion-prevention function was subjected to airflow analysis.

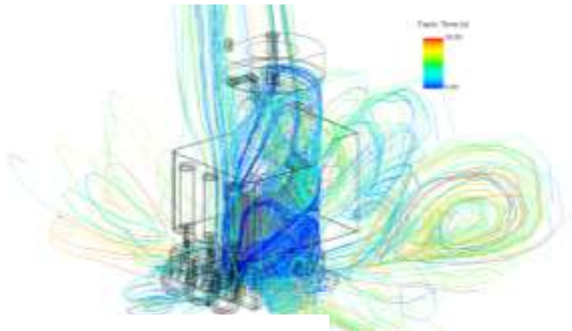


Ejector suction rate (*1)

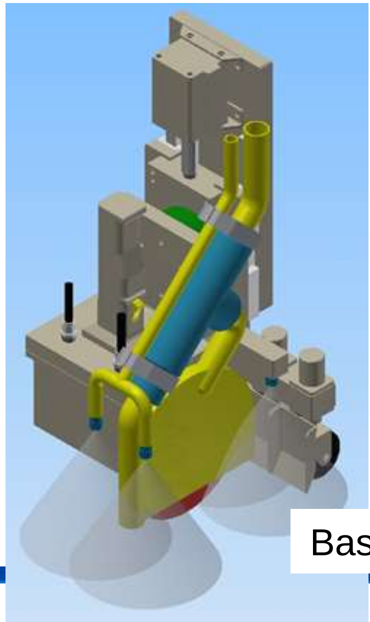
・Analysis findings

- It was confirmed that by installing the dust collection hood the ejector suction velocity increased.
- It was confirmed that the physical barrier (shavings guard, external cylindrical structure) restricts airflow and is thus effective in dust dispersion prevention.

(Note)
*1: Percentage of dust that gets sucked by the ejector



Results of airflow analysis and particle behavior analysis



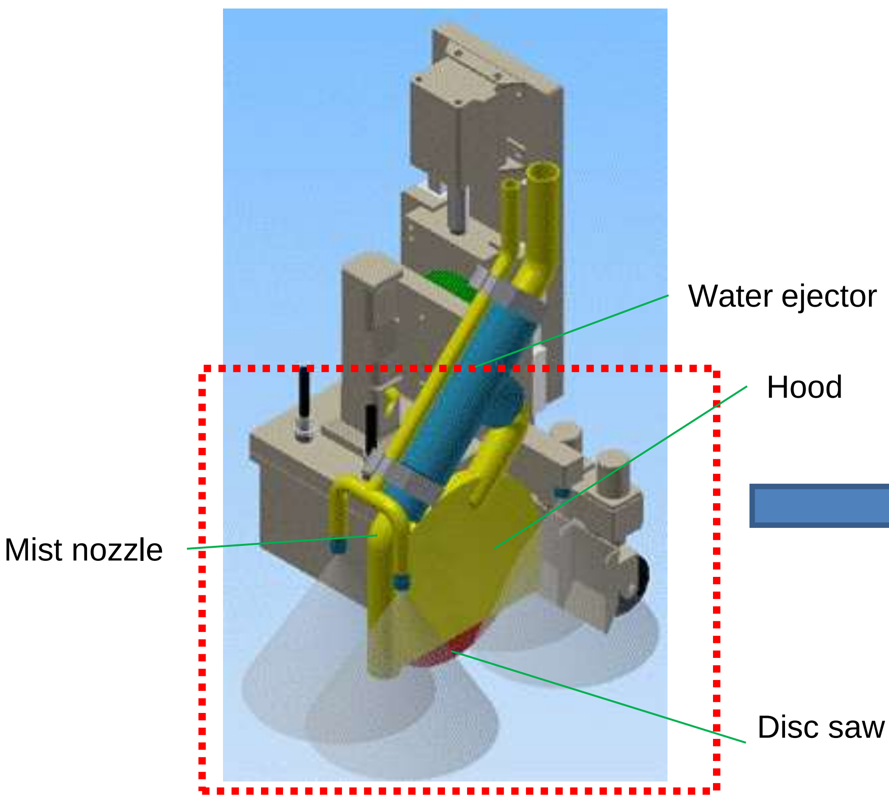
Basic design results

6. Implementation Items

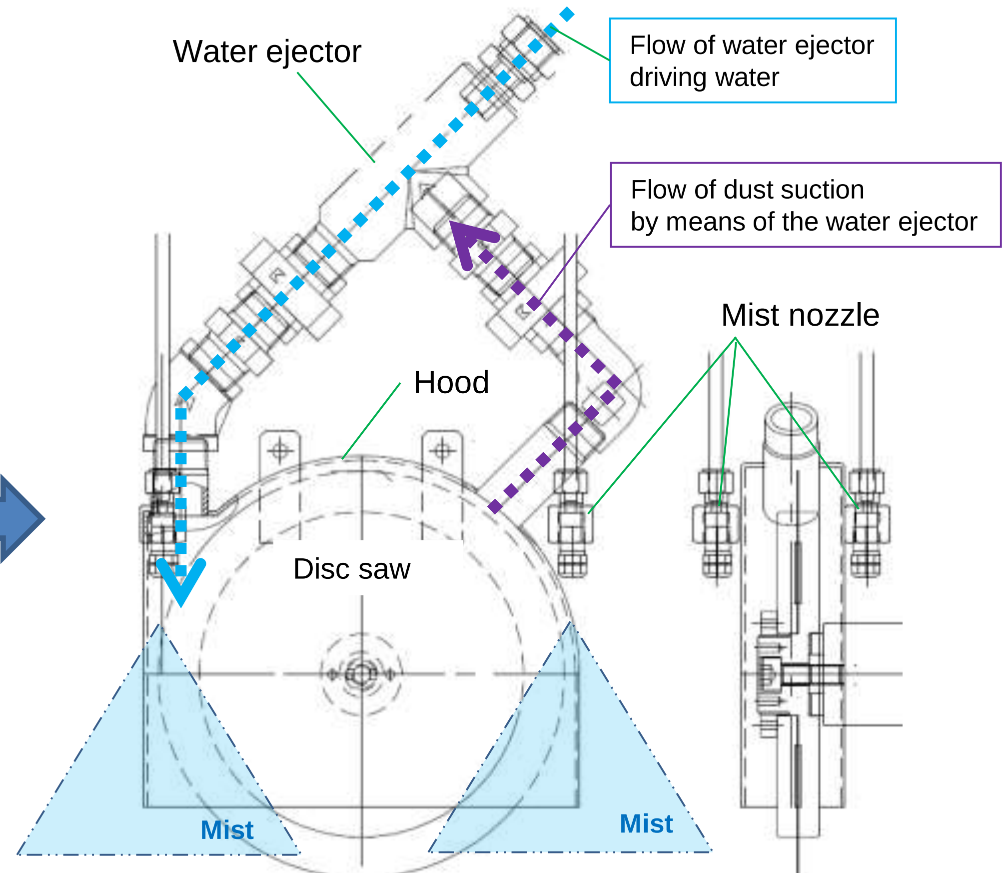
6. 1 Development of dust collection and dispersion-prevention system

[Designing the machining head for the (3) Evaluation test of dust collection and dispersion-prevention]

・The machining head for the (3) Evaluation test of dust collection and dispersion-prevention will be designed based on the aforementioned basic design of the machining head with the dust collection and dispersion-prevention function.



Machining head studied in FY2019



Machining head for the (3) Evaluation test of dust collection and dispersion-prevention

(Supplementary information 1) Dust suction by means of water ejector and dust collection by means of mist

Negative pressure is created inside the ejector due to the water ejector driving water and the dust dispersed inside the hood is sucked in.

The dust that is sucked in gets mixed with the ejector driving water and falls down in liquid state.

Also, the dust that is dispersed outside the hood is collected by means of the mist sprayed through the mist nozzle and falls down in liquid state.

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Implementation details and level of achievement

(Black font: Details of FY2019 implementations, Blue font: Details of FY2020 implementations)

(2) Development of remote maintenance technology for dust collection and dispersion-prevention system (*1)			Implementation details / Level of achievement
① Remote maintenance method and conceptual design of the required equipment	The method and concept of the dust collection and dispersion-prevention system and machining head including the line of flow of devices for remote maintenance during normal times and in the event of failures, replacement parts, waste, etc., their schematic placement, volume of waste, need for and method of decontamination, etc. was to be presented in a step diagram. (Target TRL at completion: Level 3)	･Extraction of waste ･Creation of replacement step diagram	･A step diagram was created for extracting replacement parts or waste, and for remotely replacing the machining head assuming remote maintenance during normal times and in the event of failures. (Completed in FY2019) ・The replacement process and step diagram that was studied in the previous year (FY2019) was reflected in the first half of FY2020 in the step diagram for the machining head that was designed during the (1) Development of dust collection and dispersion-prevention system. (Completed in FY2020)

*1: Refer to title No.8 “Specific goals for achieving the purpose of the project”

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

[Extraction of replacement parts or waste assuming remote maintenance during normal times and in the event of failures (emergencies)]

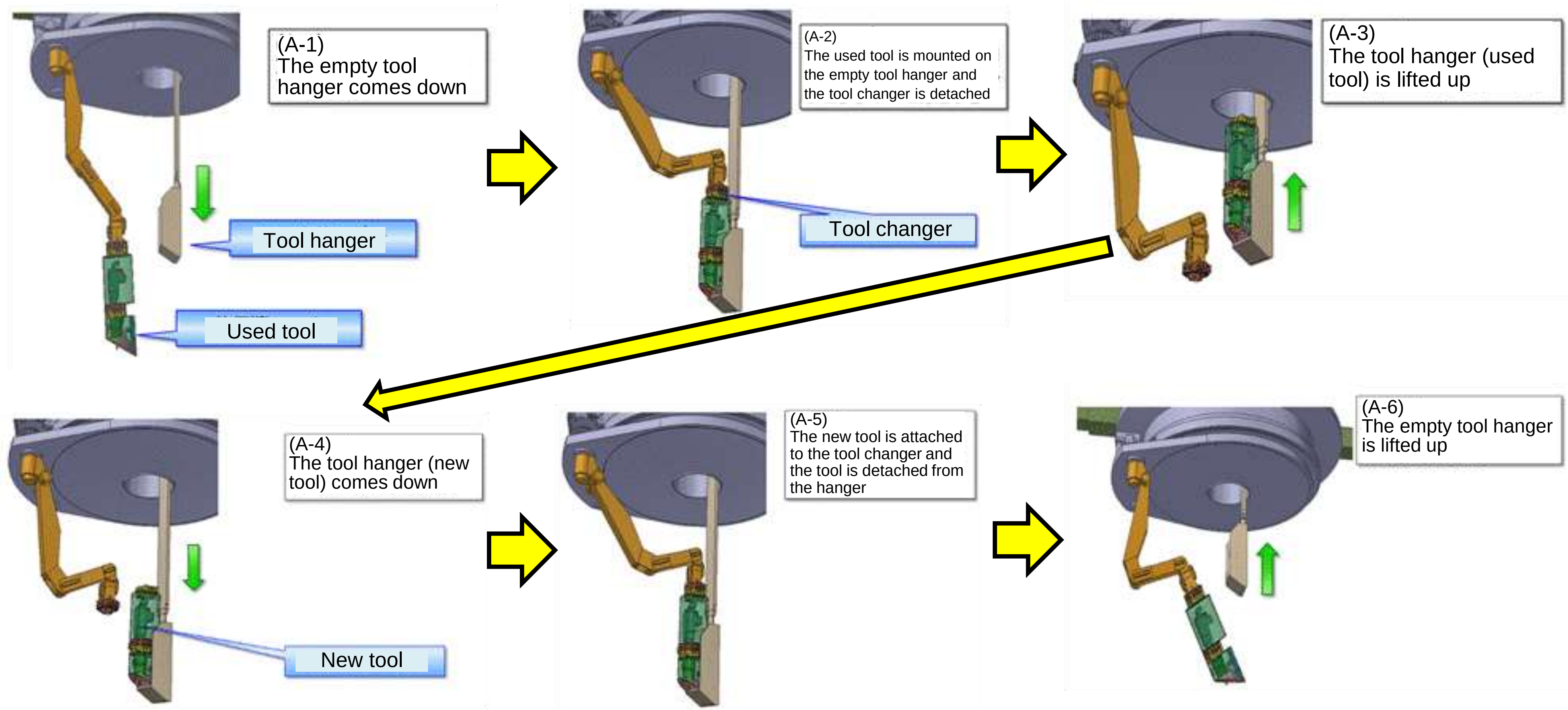
	Machining method			Waste	
		At normal times	In the event of failures	At normal times (expendables)	In the event of failures (faulty goods)
Mechanical cutting	Chisel	・Blade edge blunt, defective, damaged ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Bending of rotating axis ・Motor shutdown ・Coming off of tool changer	・Chisel blade ・Mist nozzle ・Ejector hose ・Mist hose	・Ejector / Chisel blade edge ・Motor case
	Core boring	・Blade edge blunt, defective, damaged ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Bending of rotating axis ・Motor shutdown ・Coming off of tool changer	・Core boring blade ・Mist nozzle ・Ejector hose ・Mist hose	・Core boring tool
	Disc saw	・Blade edge blunt, defective, damaged ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Bending of rotating axis ・Motor shutdown ・Coming off of tool changer	・Disc blade ・Mist nozzle ・Ejector hose ・Mist hose	・Disc saw tool (In future, replacing only the disc will be considered)
	Hydraulic (oil) cutter	・Blade edge blunt, defective, damaged ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Blade not returning to original position ・Motor shutdown ・Hydraulic (oil) pump pressure drop ・Coming off of tool changer	・Cutter blade ・Mist nozzle ・Ejector hose ・Mist hose	・Hydraulic (oil) cutter tool
	AWJ	・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Pressure drop in hydraulic (water) pump for WJ	・Mist nozzle ・Ejector hose ・Mist hose	・AWJ tool
Thermal cutting	Laser gouging	・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Laser output reduction ・Pressure drop in hydraulic (water) pump for laser	・Mist nozzle ・Ejector hose ・Mist hose	・Laser gouging tool
	Laser cutting	・Lens fogging ・Optical fiber depletion ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Laser output reduction	・Lens ・Optical fiber cable ・Mist nozzle ・Ejector hose ・Mist hose	・Laser tool
	・Plasma jet	・Degradation of electrode or nozzle ・Clogging of mist nozzle ・Degradation of the ejector hose and mist hose due to radiation	・Plasma gas pressure drop	・Electrode ・Nozzle ・Mist nozzle ・Ejector, water hose ・Mist hose	・Plasma jet tool

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

[Study of machining tool replacement methods]

The process for replacing the machining tool using the opening through which the unit can moves up and down while using the top retrieval method, and the step diagram were studied.

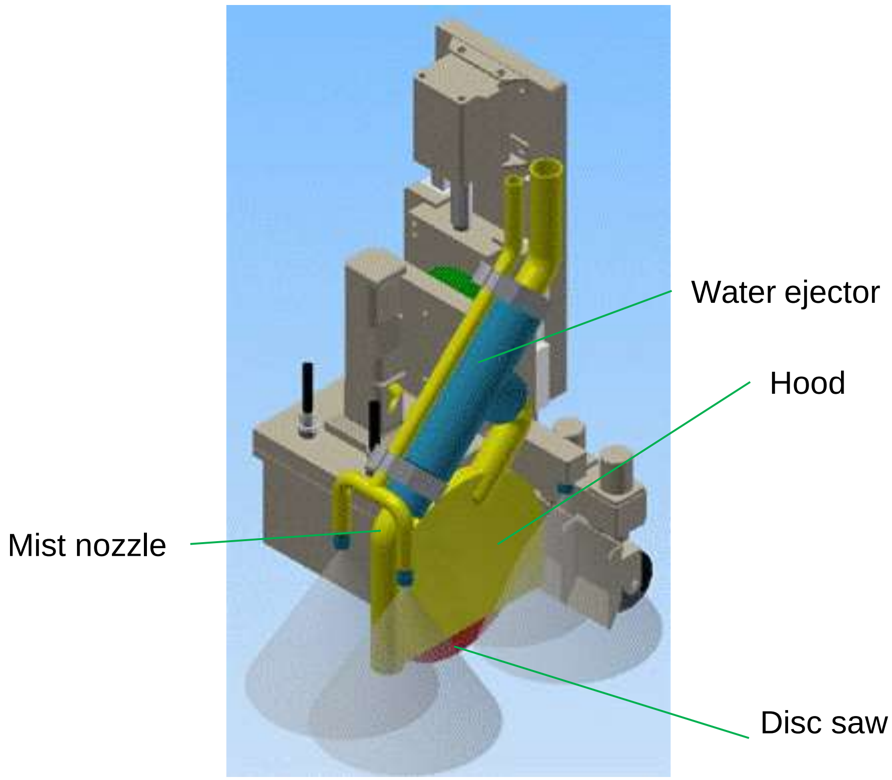


6. Implementation Items

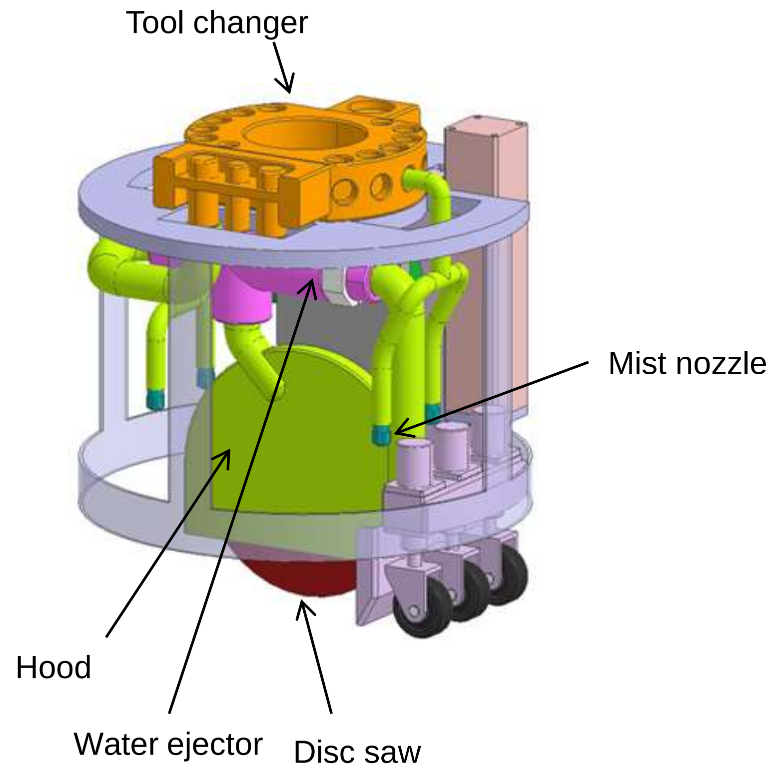
6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Study of machining tool replacement methods

The replacement process and step diagram that was studied (in FY2019) as mentioned on the previous slide will be reflected in the step diagram for the machining head that was designed during the (1) Development of dust collection and dispersion-prevention systems. Further, this step diagram includes handling of the machining head during emergencies (damage) / failures.



Machining head studied in FY2019



Machining head studied in this year

(Supplementary information) Differences in the machining head studied this year as compared to the one studied in FY2019

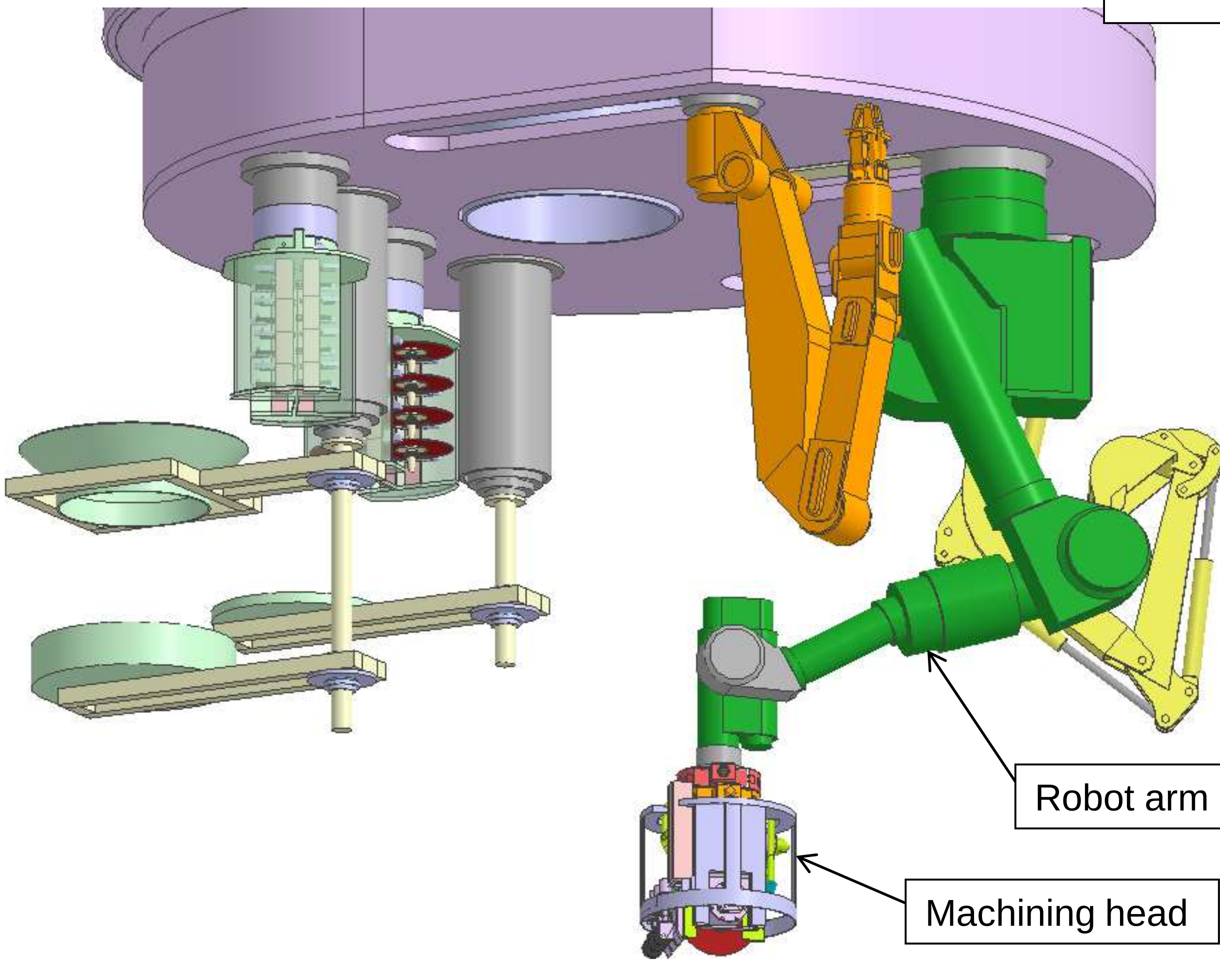
・The size of the machining head was designed to fit into the unit can. (No changes in disc saw, mist nozzle and water ejector)

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

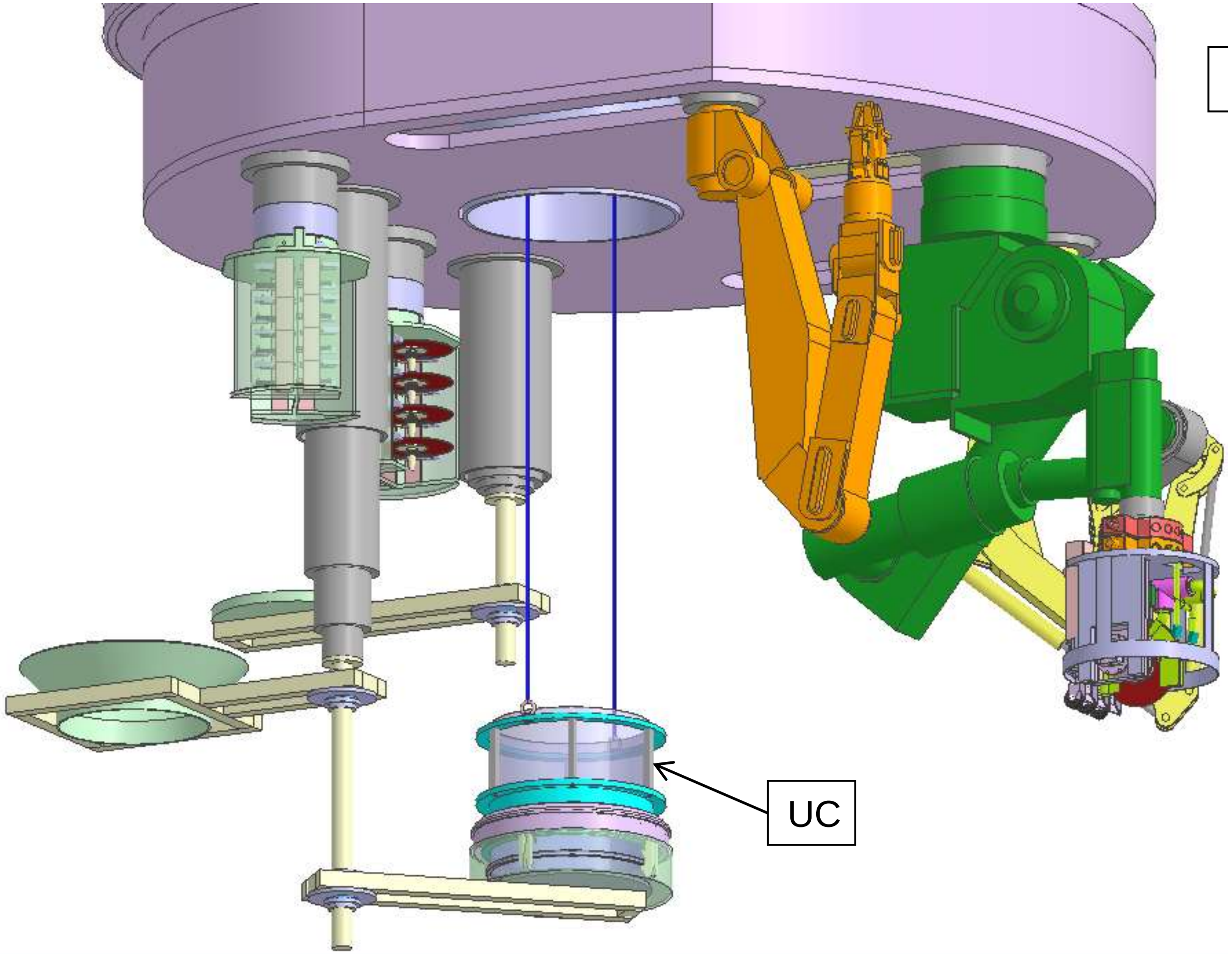
① State of machining head while starting replacement



6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement



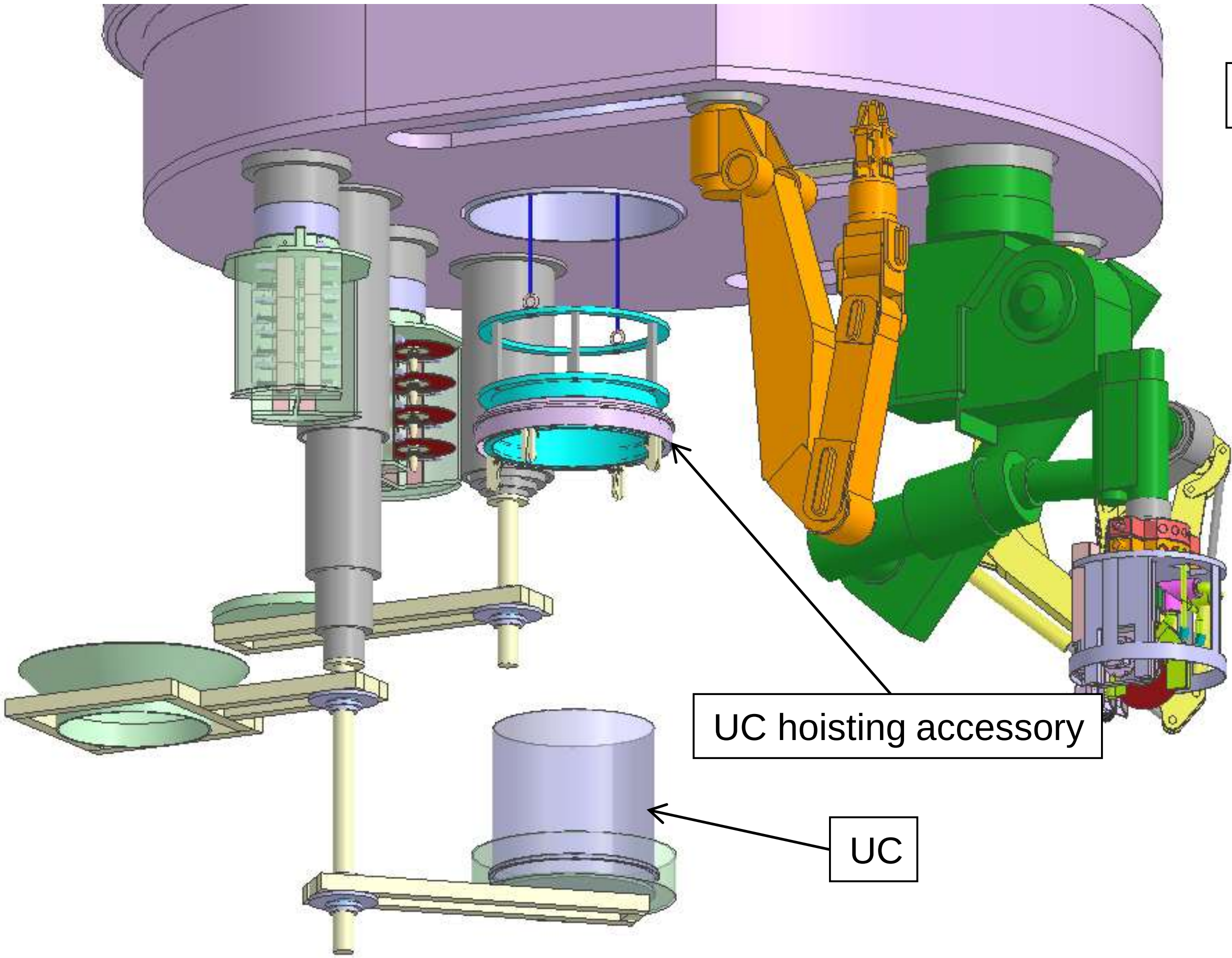
② Lowering the unit can (hereinafter, UC)

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

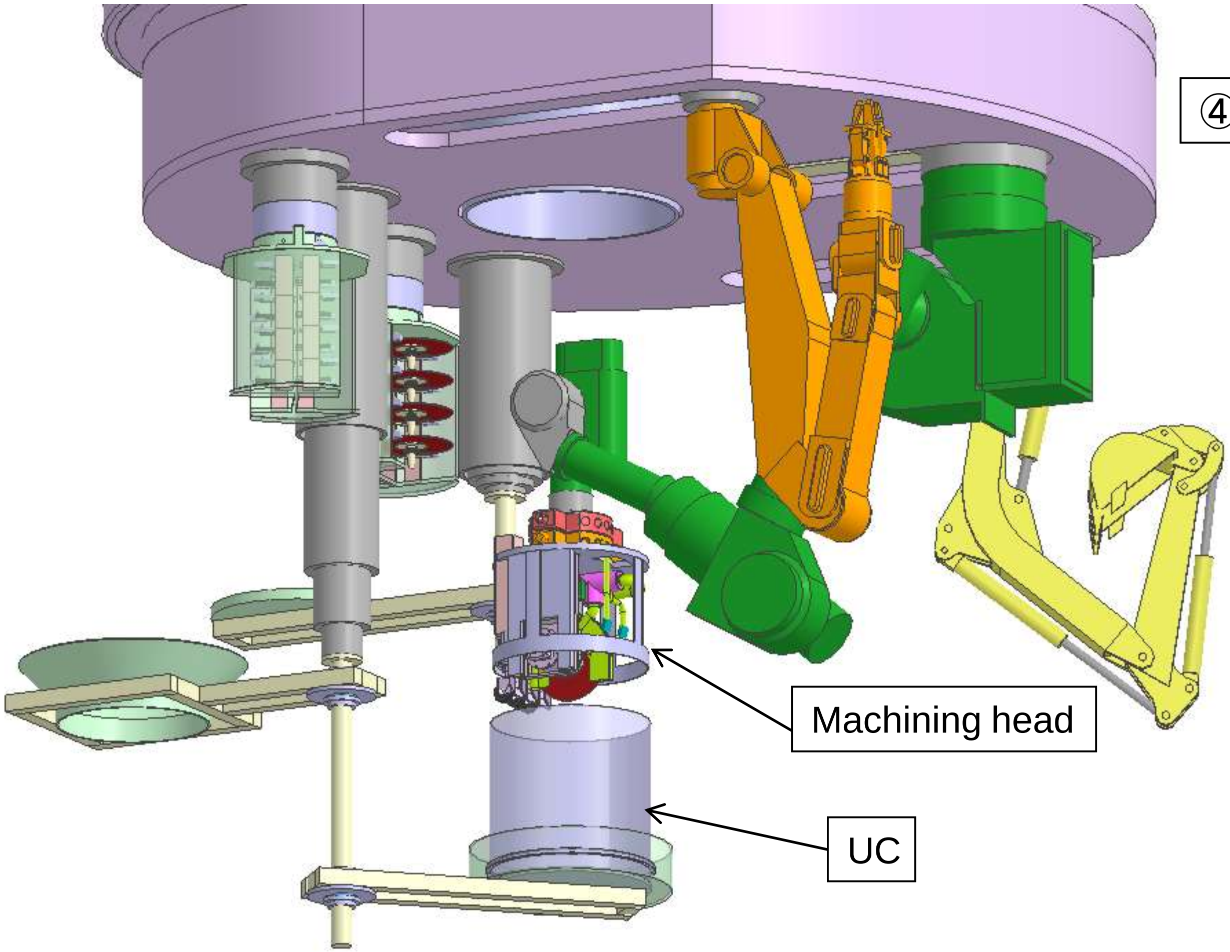
③ Retreating of the UC hoisting accessory



6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

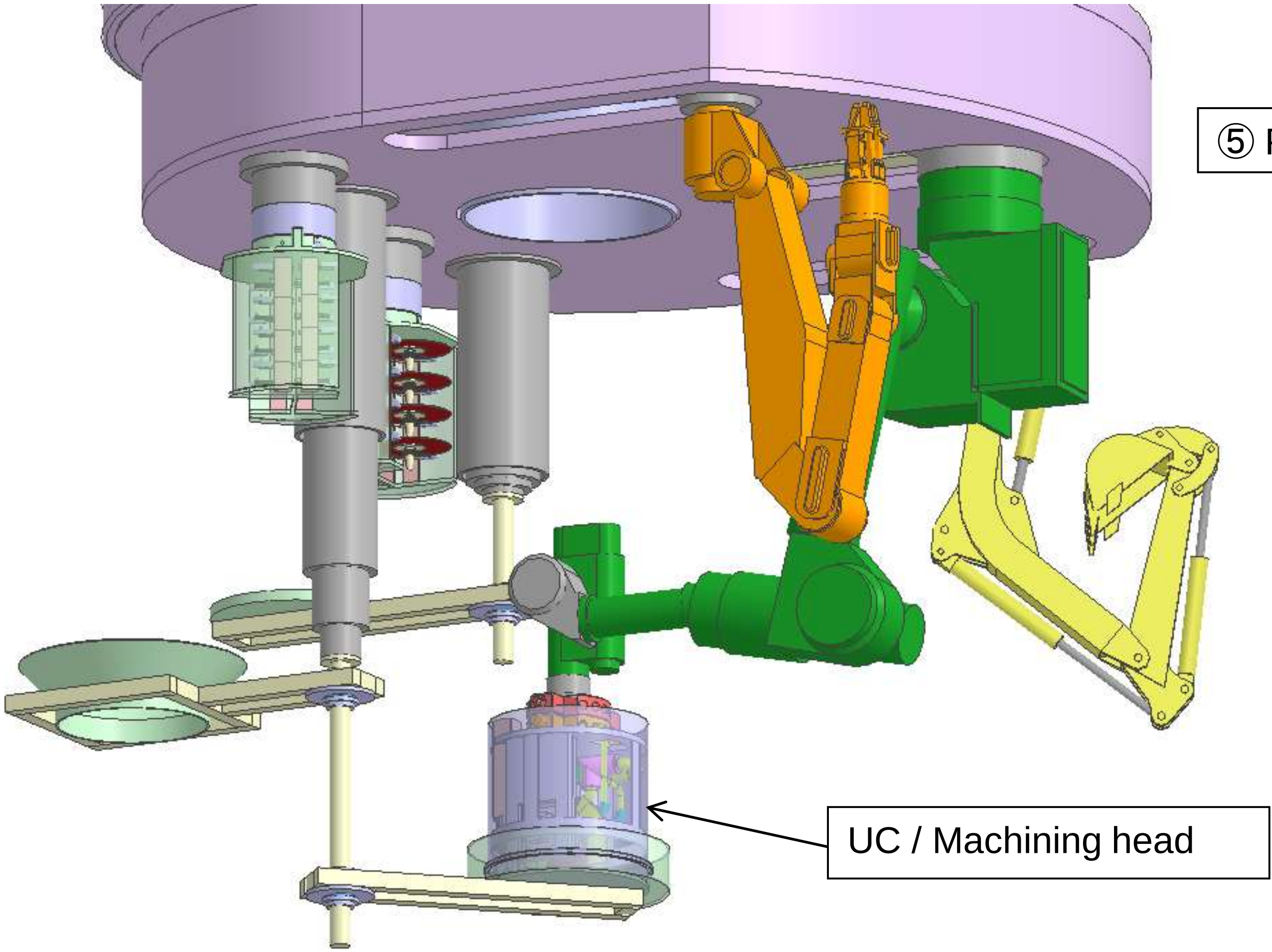


④ Moving the machining head above the UC

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

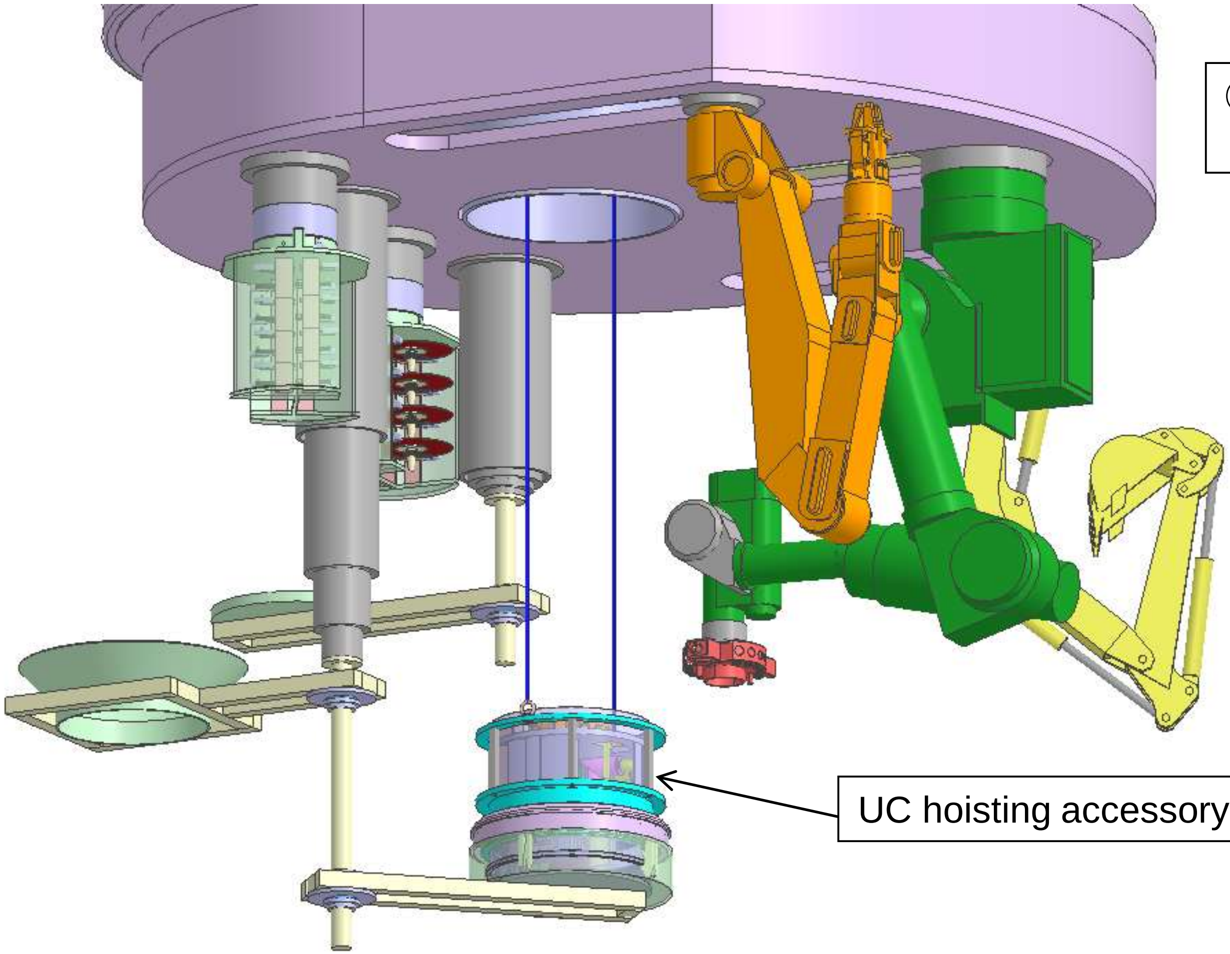


⑤ Placing the machining head into the UC

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

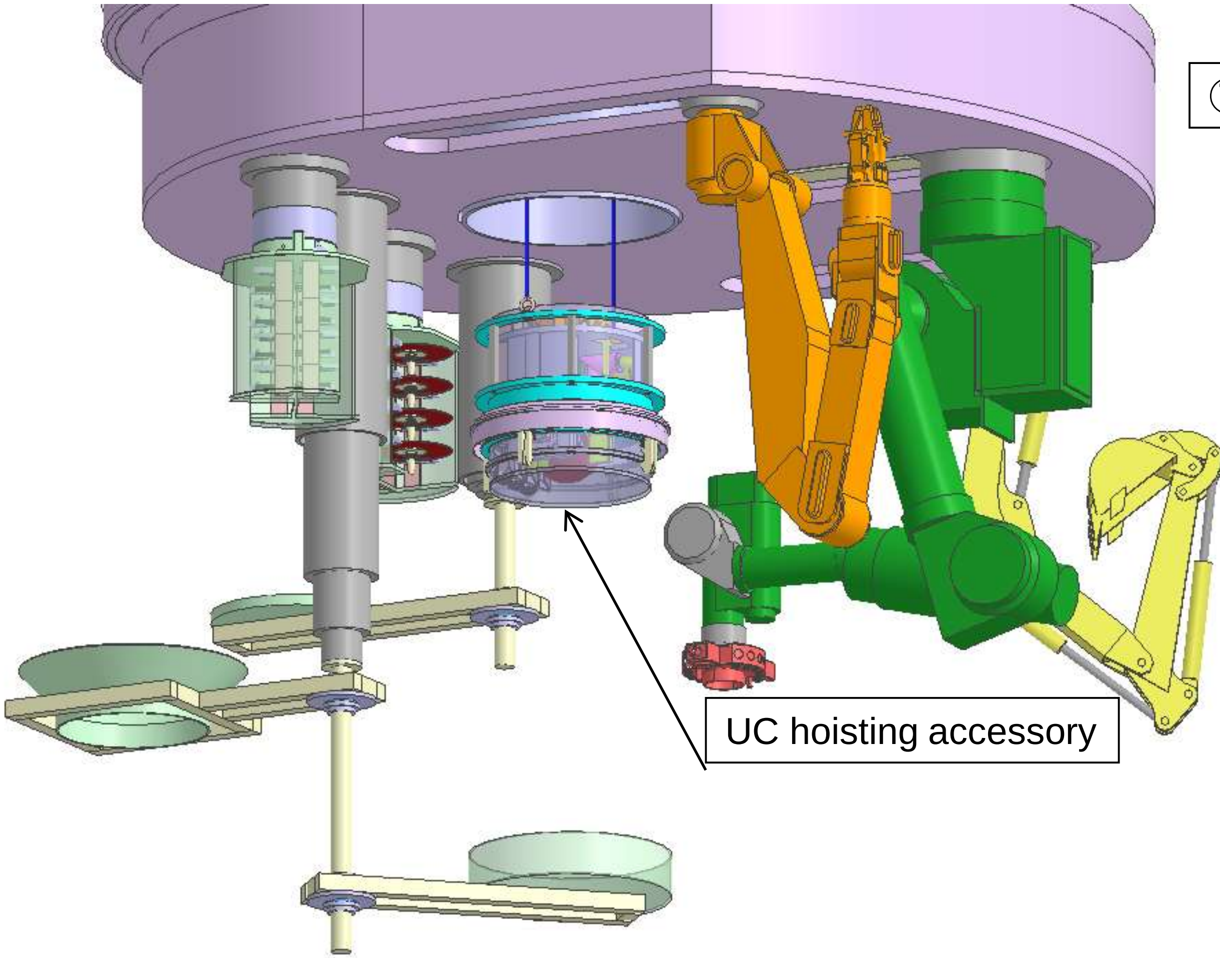


⑥ Installing the UC hoisting accessory on to the UC

6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

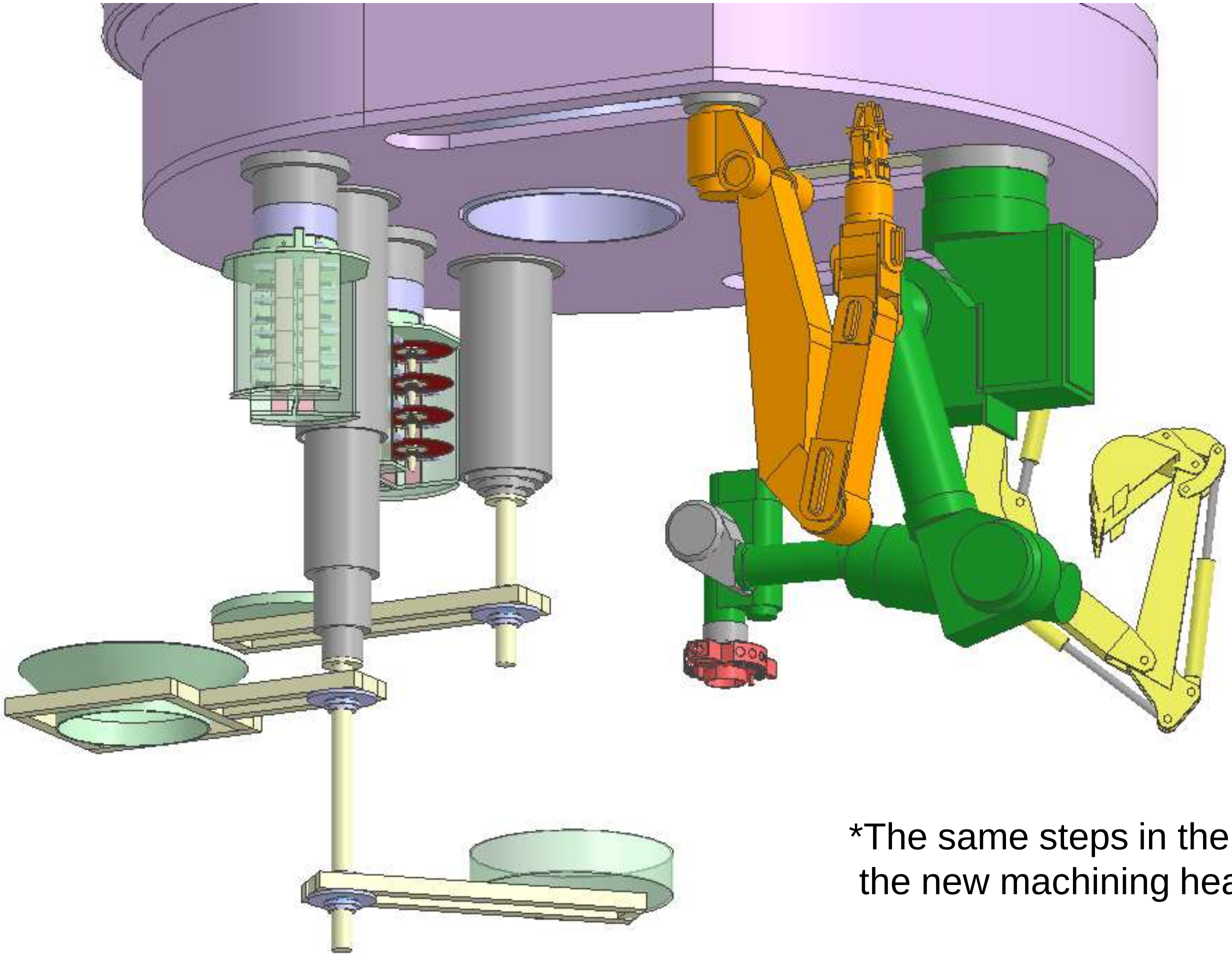


6. Implementation Items

6. 2 Development of remote maintenance technology for dust collection and dispersion-prevention system

Step diagram of machining head replacement

⑧ Completion of retrieving malfunctioning machining head



*The same steps in the reverse order shall be followed for mounting the new machining head on the robot arm.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

Implementation details and level of achievement

(Black font: Details of FY2019 implementations, Blue font: Details of FY2020 implementations)

(3) Evaluation test of dust collection and dispersion prevention (*1)			Implementation details / Level of achievement
① Development of dust collection and dispersion-prevention evaluation procedures	The tests conducted within Japan and overseas for evaluating dust generated during machining, were to be investigated, and evaluation test procedures suitable for evaluating the machining method to be applied to actual equipment were to be established. (Target TRL at completion: Level 4)	Investigation of tests conducted within Japan and overseas for evaluating dust generated during machining	Tests conducted within Japan and overseas for evaluating dust generated during machining were investigated. (Completed in FY2019)
		Establishment of dust evaluation test guidelines	Dust evaluation test guidelines such as test procedures and configuration were established. Moreover, preliminary tests were conducted in accordance with the same test guidelines and it was confirmed that the dust evaluation test guidelines and configuration of test apparatus are valid. (Completed in FY2019) The test matrix and test system were studied. (Completed in FY2020)
② Evaluation test of dust collection and dispersion prevention	A representative method was to be selected from the machining methods selected as part of “Development of technology for the retrieval of fuel debris and reactor internal structures; machining test and evaluation of test samples simulating fuel debris and contaminated structures, etc. were to be conducted using the designed and manufactured elemental test equipment presuming a machining head that can be used in the actual equipment; data such as migration rate into air and into water depending on the machining speed was to be acquired; and the amount of waste generated as a result of the operation of dust collection and dispersion-prevention system was to be measured. Moreover, the chart mentioned in 1) ② Basic Specifications was to be revised as required. (Target TRL at completion: Level 4)	Selection of a representative method from the machining methods	A disc saw that can be used in the controlled areas was selected as the representative method for conducting a dust dispersion evaluation test for the dust near the actual fuel debris in 1F. (Completed in FY2019)
		・Measurement of the dust dispersion rate into the gas and liquid phases. ・Measurement of the amount of waste (Dust dispersion rate into gaseous phase / liquid) generated due to the operation of the dust collection and dispersion-prevention system	The rate of dust migration into the gas and liquid phases and the rate of dust dispersion into the gaseous phase / liquid resulting from the operation of the dust collection and dispersion-prevention system, were measured. (Completed in FY2020)

*1: Refer to title 8 “Specific goals for achieving the purpose of the project”

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Investigation of tests conducted in Japan and overseas for evaluating dust generated during machining]

Tests conducted within Japan and overseas for evaluating dust generated during machining were investigated for formulating the evaluation test guidelines.

Items	Laser gouging test equipment (*1)	Underwater parameter test equipment (*2)	Geometry dependence verification test equipment (*2)	Saclay Research Institute laser cutting equipment (*3)
Scale	Small scale	Medium scale	Medium scale	Large scale
Machining method	Laser gouging	Underwater plasma arc cutting	Plasma arc cutting in air	Underwater laser cutting
Airborne dust collection environment	Inside acrylic case under aerial environment	Cleaning with clean air inside clean house	Cleaning with clean air inside clean house	Cleaning by infusing pure nitrogen
Measurement of dust concentration	–	ELPI (Electrical Low Pressure Impactor) measurement	ELPI (Electrical Low Pressure Impactor) measurement	ELPI (Electrical Low Pressure Impactor) measurement
Measurement of particle size distribution	Particle size segregation and collection	Particle size segregation and collection	Particle size segregation and collection	–
Measurement of the generated amount of airborne fine particles	–	Separation, conversion and measurement using particulate matter sampler	Separation, conversion and measurement using particulate matter sampler	Measurement of the particulate matter collected from the filter at the last stage
Study of airborne gas components	Target components: H_2, O_2, N_2, CO, CO_2	–	–	–
Measurement of precipitate particles	Sorting by sieve, and weight measurement	–	–	–
Investigation of underwater floating matter	Weight measurement, investigation of metallic components	–	–	–
Analysis of underwater ions	Investigation of the metallic components of the material that has passed through 0.2μm filter			

Results of the investigation confirmed that particle size classification collection (Cascade impactor/ELPI) is applied for evaluation of dispersed dust and, filtration separation and weight measurement for fallen dust are used.

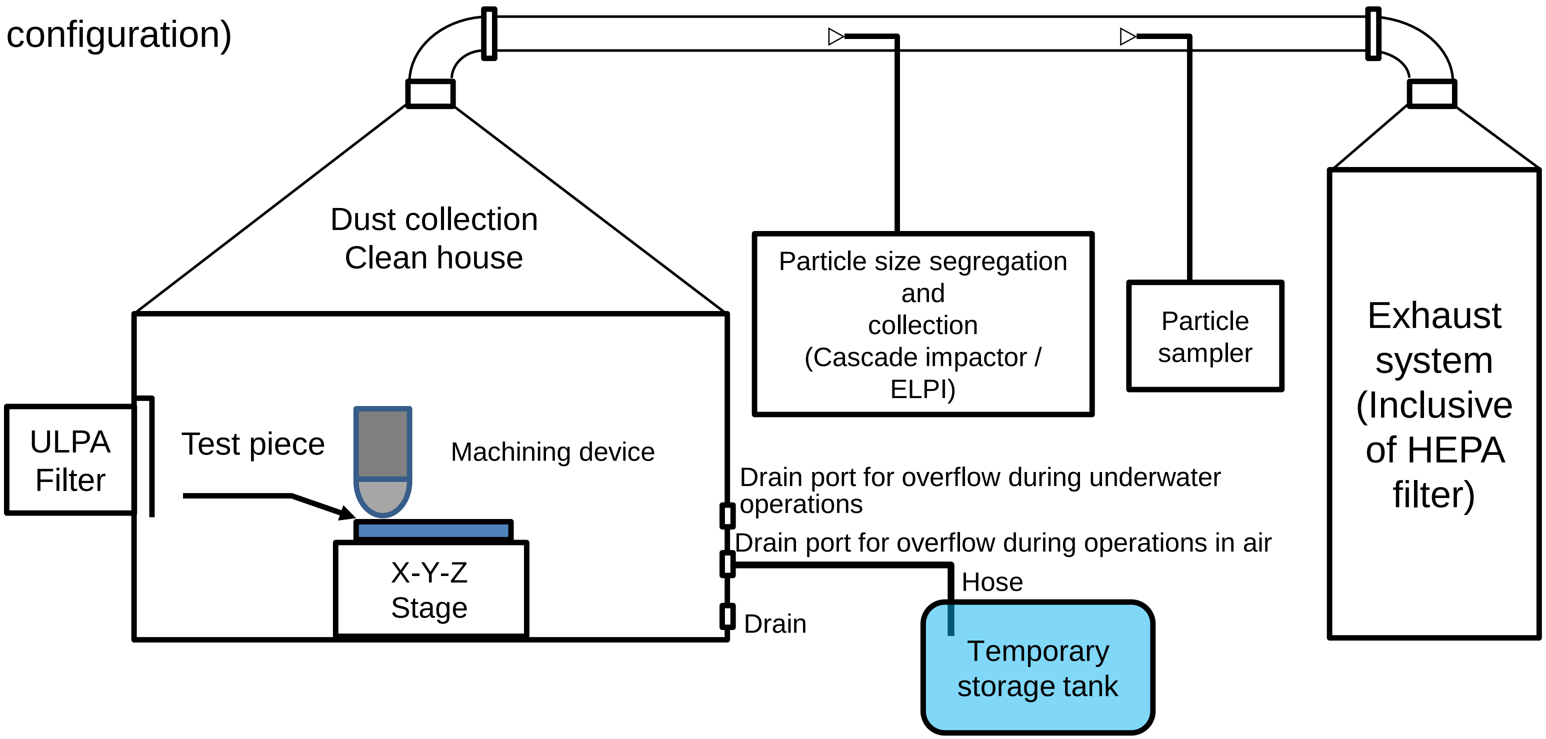
Source:
*1) Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary Budget “Development of fundamental technology for retrieval of fuel debris and internal structure FY2016 Final Report March 2017
*2) “FY2006 Investigation of the technology for evaluating the environmental impacts of decommissioning the commercial power reactor facility (Investigative research on environmental impact assessment parameters)” (FY2006 METI Commissioned Research) March 2007
*3) “Subsidy Project of Decommissioning and Contaminated Water Management (Development of technology for fuel debris characterization and analysis)” in the FY2016 Supplementary Budget Research Report (Final Report) March FY2019

6. 3 Evaluation test of dust collection and dispersion prevention

[Establishment of test guidelines for the dust evaluation test]

Dust evaluation test guidelines such as test configuration, procedures, etc. were established based on the result of investigating the dust evaluation tests.

(Test configuration)



(Test procedures)

① Infuse water into the dust collection clean house (Water level shall be set according to test conditions).
② Start the operation of particle sampler.
③ Process the test piece using machining device (Amount of machining and machining duration shall be set according to test conditions).
④ Collect the specimen from the particle sampler.
⑤ Clean the inside of the dust collection clean house (Drain the residual water, clean the inner surface of the house and clean inside the pipe).

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Preliminary test for disc saw tool]

Preliminary test was performed in accordance with the aforementioned test guidelines.

[Test details]

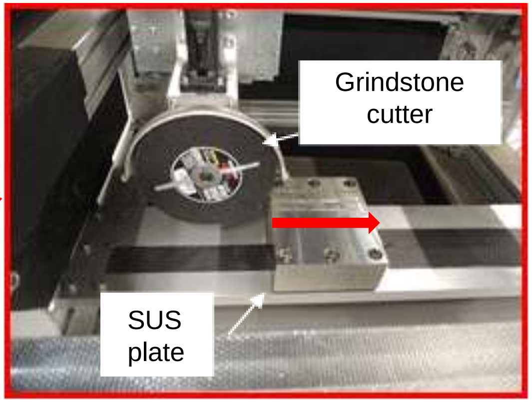
The SUS plate was processed with a Φ180 mm grindstone cutter to measure the level of dust dispersion.

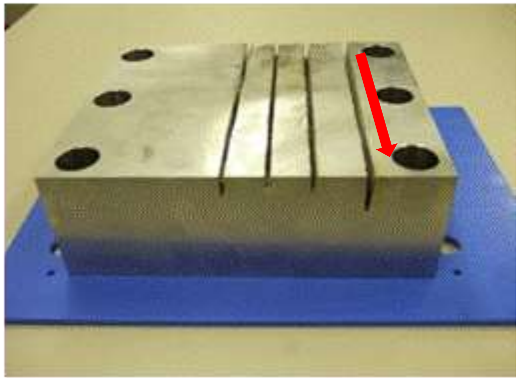
・Fine particles visualization test (using laser light source)

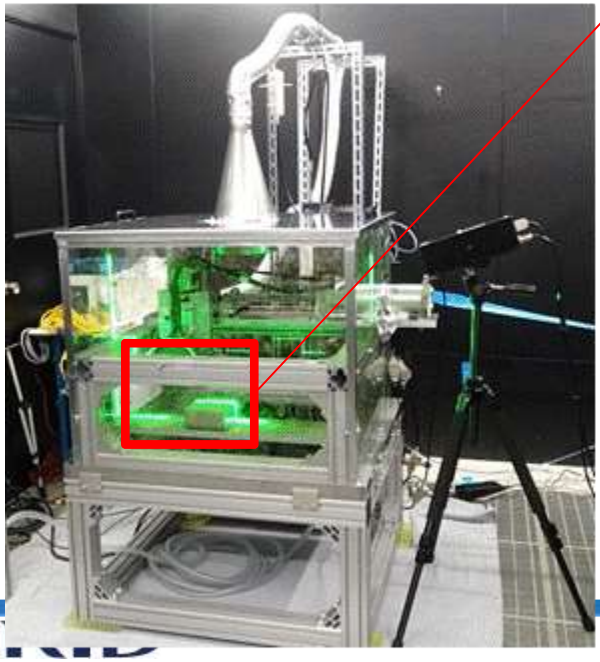
1) Picture images were captured with an ultra-sensitive camera
2) Picture images was captured with a high-speed camera and the speed vector was obtained.

・Dust measurement

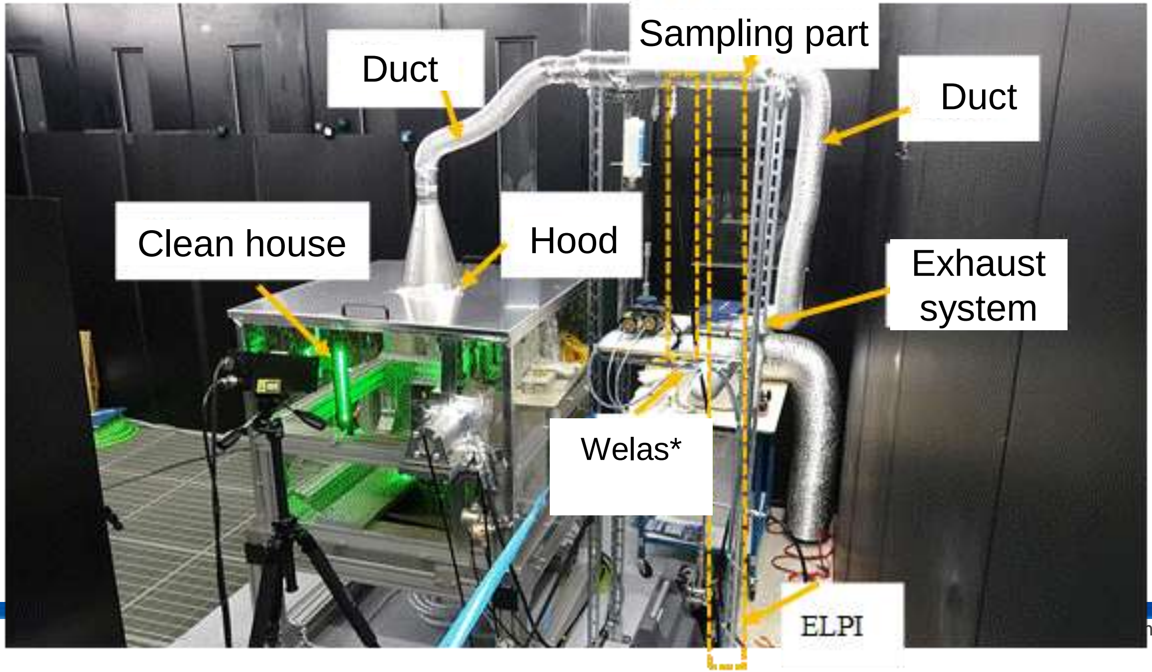
1) Measurement of particle-size distribution using ELPI and Welas.
2) Collection/observation of dust sample







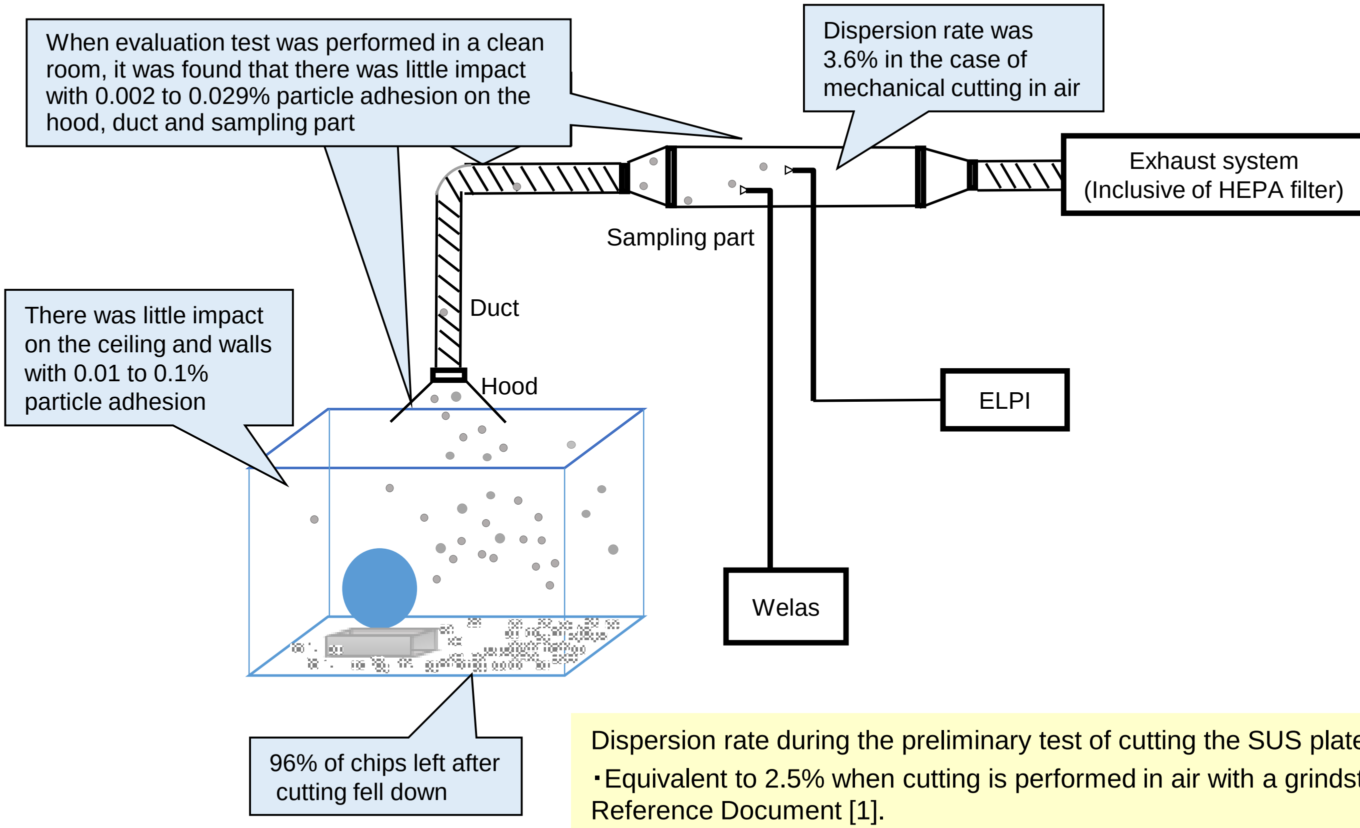
*Welas (White Light Aerosol Spectrometer)



6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Preliminary test for disc saw tool (continued)]



Dispersion rate during the preliminary test of cutting the SUS plate in air with a disc saw: 3.6%
・Equivalent to 2.5% when cutting is performed in air with a grindstone cutter, as per the Reference Document [1].

→ It was confirmed that the evaluation of dust dispersion rate with this test method is valid.

Source: [1] Central Research Institute of Electric Power Industry (CRIEPI), FY2000 Research on technology for assessing the environmental impact of decommissioning commercial power generating nuclear facilities (Investigation on environmental impact assessment parameters), 2001.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

Study of the test plan for the evaluation test of dust collection and dispersion-prevention

[Background of this project so far and implementation details in the current fiscal year (FY2020)]

(FY2019)

- Investigation of tests conducted within Japan and overseas for evaluating dust generated during machining
- Development of dust collection and dispersion-prevention evaluation test guidelines and implementation of preliminary test.
  (Test on cutting with SUS plate and dust dispersion during the process)

⇒ It was confirmed that the machining head, dust evaluation test guidelines and test apparatus configuration are valid.

(Change of plan in FY2019)

- The following tests were added in order to obtain additional data that can contribute towards dust control measures when machining fuel debris etc.
  ① Test for evaluating generation of dust during UO_2 fuel pelletizing process
  ② Test for evaluating generation of dust during zircaloy machining

- In collaboration with Project of Development of Fuel Debris Retrieval Method, a rotary cutter that has dust collection and dispersion-prevention function are provided is selected as dust evaluation test.

  (Reasons for selection in this test)
  Since data is not available for the test conducted to evaluate the dust generated during the UO_2 fuel pelletizing process, a rotary cutter that can be used in the controlled area (*) within the facility for evaluation test of dust collection and dispersion-prevention, was selected so as to prioritize the said fuel pellet test.

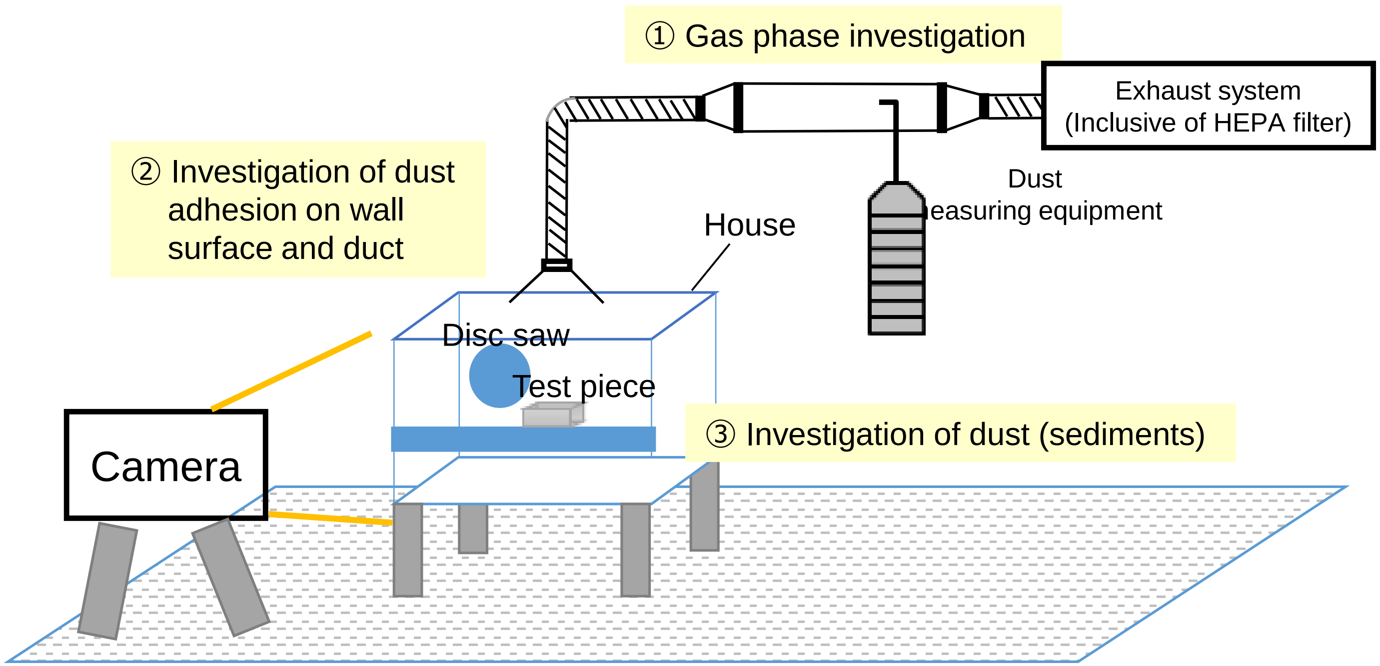
(FY2020)

- Dust evaluation test was conducted using UO_2 pellets and zircaloy as test pieces.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test overview]
Measurement of dust particle size distribution using a disc saw



6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test pieces]

No.	Name	Test pieces	Status of study
1	Fuel debris inside PCV and RPV	Simulated UO_2 pellets ① Unirradiated BWR fuel pellets*1 ② Ceria pellets*1	Refer to (i) on the next slide
		Simulated stump-shaped fuel ③ Fuel cladding + ceria pellets	Refer to (ii) on the next slide
2	Structures to which fuel debris has adhered	Test piece solidified with melting and solidifying ceria pellets and stainless steel	Refer to (iii) on the next slide. *2
3	Simulated MCCI (Molten Core Concrete Interaction)	Simulated MCCI 	･Completed production of 1 unit based on FY2018 results conducted by IRID/Hitachi GE.

(Note) *1: Dust evaluation test was performed by the cutting method using a rotary machine in RI controlled area.
*2: The structures were not simulated assuming that adhesion to the clad and oxide film on the surface of the structures before the adhesion of molten materials constitutes a fractional percentage of loss occurred during cutting and the impact on dust test is minimal.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Study of simulant material]

(i) Simulant material for comparison with UO_2 pellets

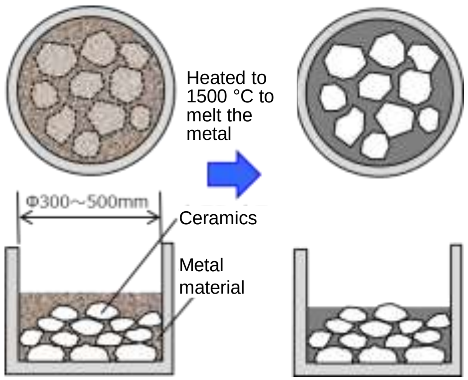
- UO_2 is calcined into pellets as unirradiated BWR fuel to be used in the evaluation test.
  (Reason for selection) Since chemical formula, specific gravity and manufacturing method are the same as the actual fuel (However, natural uranium is used)
- Due to work restrictions in the RI controlled area, ceria is calcined into pellets as UO_2 simulant material to be used in the evaluation test.
  (Reason for selection) Since specific gravity of ceria is high (7.3g/cm^3) and hardness is almost same as UO_2 it can be calcined just like UO_2.
  Further, it has been used in other projects as a simulant material for UO_2.

(ii) Simulated stump-shaped fuel

- Simulated fuel rods consisting of ceria pellets loaded in zircaloy cladding are used for the evaluation test.
  (Reason for selection) The same zircaloy used for actual fuel was selected for the cladding. The above-mentioned ceria pellets were used as residual fuel inside the cladding.

(iii) Simulated structures to which fuel debris has adhered

- Test piece to be used in the evaluation test is manufactured by melting and solidifying metal and ceramics.
  (Reason for selection) Simulant material consisting of molten and solidified metal and ceramics is used in this case since it is assumed that the structures melted due to the adhesion of fuel debris and got solidified along with fuel debris. It was decided to manufacture the test piece for the machining that was studied during the Fuel Debris Characterization Project and hence ceria was selected for the ceramics portion and stainless steel (SUS304) was selected for the metal portion.



Method for manufacturing the test piece consisting of molten and solidified metal and ceramics[1]

(1) Before heating
(material is loaded in a crucible)

(2) After heating
(after removing from the crucible)

Illustration of external appearance of the manufactured test piece consisting of molten and solidified metal and ceramics[2]

[1] "Fuel Debris Characterization" FY2014 Interim Report

[2] "Development of technology for fuel debris retrieval" FY2015 Annual Report

6. Implementation Items of This Project

6. 3 Evaluation test of dust collection and dispersion-prevention (coating agent for dispersion-prevention)

- **Fuel debris simulant material (one type) coated with coating agent is used in the evaluation test.**
- **Liquid glass type neutron absorption material*) which was developed in the Criticality Control PJ is used as the coating agent.**

(Reason for selection) Since it is expected to be effective in preventing dust dispersion and also in preventing criticality. Further, apart from fundamental characteristics, it is confirmed that there are no major issues in terms of transportability, workability, secondary effects, etc.

*) Neutron absorption material Gd_2O_3 is mixed with liquid glass. It is in liquid state, and gets solidified over time. It can be applied to uneven surfaces, slanting surfaces, etc. in addition to flat surfaces. It is applied on the surface before removing fuel debris in order to prevent criticality. It is made available for the test since it forms a coated layer on the surface of fuel debris and in this way, it is expected to be effective in preventing criticality and also in preventing dispersion of the powder formed during fuel debris machining.

		Liquid glass type neutron absorption material (TX-10)	Filler material (Osaka University/JAEA) (Sumecton ST + Polymer gel)	Coating material (Tokyo University/JAEA) (Geopolymer)*7	Super heavy mud water (Waseda University/Chiba Institute of Technology/Japanese Geotechnical Society)
Representative components		Sodium silicate (No. 1) ($Na_2 \cdot nSiO_2 \cdot xH_2O$), cement ($SiO_2$, CaO, Al_2O_3, Fe_2O_3, $CaSO_4$), primary sodium phosphate ($NaH_2PO_4 \cdot 2H_2O$), ion-exchange water (H_2O), gadolinium oxide (Gd_2O_3) (*1)	Synthetic magnesium silicate $Na_{0.33}Si_4Mg_{2.67}O_{10}(OH)_2$ Sodium polyacrylate $(C_3H_3NaO_2)_n$ Distilled water H_2O (*5, 6)	Metakaolin $2.13SiO_2+1Al_2O_3$ Sodium hydroxide NaOH Liquid glass $2.18SiO_2+1Na_2O+8.96H_2O$ Ultra-pure water H_2O ($3.8SiO_2:1Al_2O_3:1Na_2O:13H_2O$ at the time of viscosity measurement)	Sodium bentonite Baryte Disodium phosphate Tap water (*8)
Curability		Viscosity increases approximately in 90 minutes*2	Remains in gel condition	Viscosity increases gradually in atmosphere	—
Viscosity [mPa・s]		Approx. 1,000 *3	Approx. 60 to Approx. 7,000*5	2,000 to 5,000	Approx. 30 to 10,000,000*8
Thermal stability		Stable up to 400° C*3	Stable up to approx. 523° C*5	—	—
Irradiation characteristics (γ rays)	In-air irradiation	No cracks and no discoloration at 36MGy*3	Bubbles are produced at 3MGy*5	Hydrogen, oxygen and nitrogen are produced at 1.15 and 0.35 MGy	—
	Underwater irradiation	Apparent value G of hydrogen formation is less than the designed value G *3	— (Concern about hydrogen formation) *5	—	—
Transportability		Transportable to 50m or above by means of pipes *2	—	—	—
Workability		Gap penetration, inclined surface cladding and cladding thickness are relatively good *2, 3	—	—	—
Secondary effects	Rust-preventive measures	Water quality needs to be adjusted *1	—	—	—
	Subsequent process	The storage canister environment is according to the design and waste has been evaluated *3, 4	—	—	—

*1 Subsidy Project of Decommissioning and Contaminated Water Management in the FY2018 Supplementary Budget "Development of technology for retrieval of fuel debris and reactor internal structures" FY2019 Interim Report
*2 "Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary Budget "Development of Criticality Control Technology for Fuel Debris)" FY2016 Report
*3 Subsidy Project of Decommissioning and Contaminated Water Management in the FY2015 Supplementary Budget "Development of Criticality Control Technology for Fuel Debris)" FY2017 Report
*4 Subsidy Project of Decommissioning and Contaminated Water Management in the FY2017 Supplementary Budget "Upgrading of Approach and Systems for Retrieval of Fuel Debris and Internal Structures (Development of Technologies for the Establishment of Criticality Control Methods)" FY2018 Report
*5 JAEA-Review-2019-029
*6 SDS
*7 JAEA-Review-2019-037
*8 52nd Annual Meeting of the Japan National Conference on Geotechnical Engineering -July 2017 D-03 (Calculated from the relation between shear rate and shear stress)

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Concepts of setting up the test matrix]

- As the evaluation test of dust collection and dispersion prevention, a dust dispersion test was conducted for the mist and water ejector individually and in combination using ceria pellets that are simulant material for UO_2, in order to confirm the basic dust dispersion prevention effects of the dispersion prevention system (mist and water ejector).

- Dust dispersion test was performed with/without the operation of dispersion prevention system (mist and water ejector) in order to verify the effects of dust dispersion prevention using other test pieces (simulated stump-shaped fuel, structures to which fuel debris is adhered, simulated MCCI (Molten Core Concrete Interaction).

- Since MCCI might be submerged at the reactor bottom of the primary containment vessel (PCV), dust dispersion test was performed by using simulated MCCI in conditions both in submerged state and in air.

- Dust dispel
- rsion test was performed by changing the upward flow in order to verify the impact of upward flow on dust dispersion. Cutting test was carried out for ceria pellets which were sprayed with dispersion preventing material to confirm the impact of dispersion preventing material. Additionally, another cutting test in case of changing the rotational speed was performed in order to confirm the impact of cutter rotational speed.

(Supplementary information)

・Diamond cutter was used in this test. Since diamond cutter is weak against heat, water was applied while cutting as a machining aid whenever necessary.

・From the safety aspect in the controlled area (from the perspective of fire prevention), water was used during cutting as a machining aid in the UO_2 pellets test.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test matrix]

Objects to be cut	Cutting in air	Dust dispersion prevention using water						
		Mist alone	Ejector alone	Machining aid (Water) alone	Mist + ejector	Machining aid (Water)		
						Mist	Ejector	Mist + ejector
UO2 pellet	−	−	−	○	−	−	−	−
Ceria pellet	○	○	○	○ *1 *2 *3	○	○	○	−
Fuel cladding + ceria	○	−	−	−	−	−	−	○
Structures to which debris is adhered	○	−	−	−	○	−	−	−
Simulated MCCI*	○ *4	−	−	−	○	−	−	−

*1 Upward flow 0.03 m/s, 0.10 m/s
*3 Rotational speed 500 rpm, 1000 rpm

*2 With/without anti-scattering agent
*4 In-air and underwater test
*MCCI: Molten Core Concrete Interaction

○ : Implemented
- : Not implemented

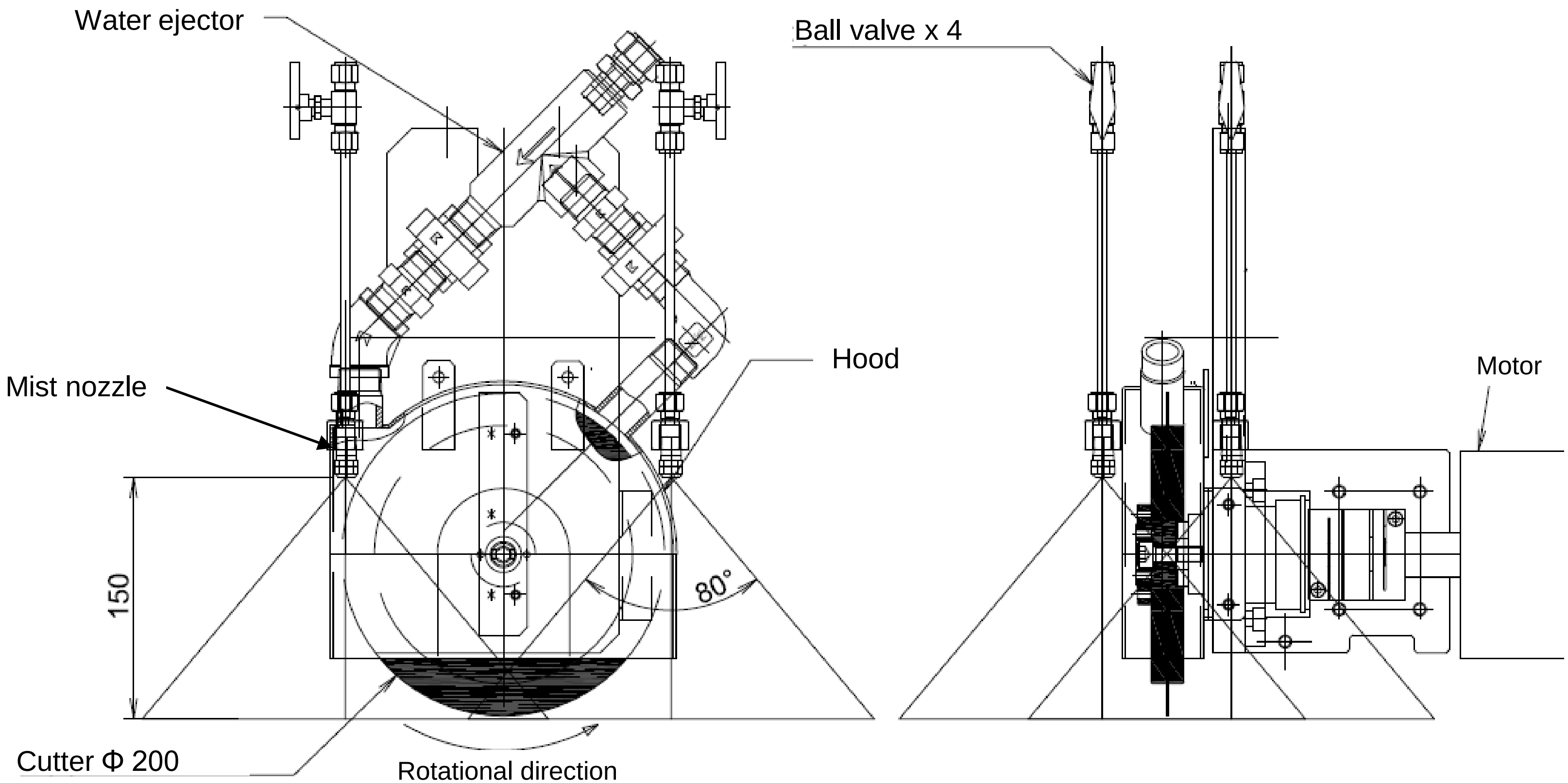
6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test configuration]

Detailed structure of cutting part is illustrated below.

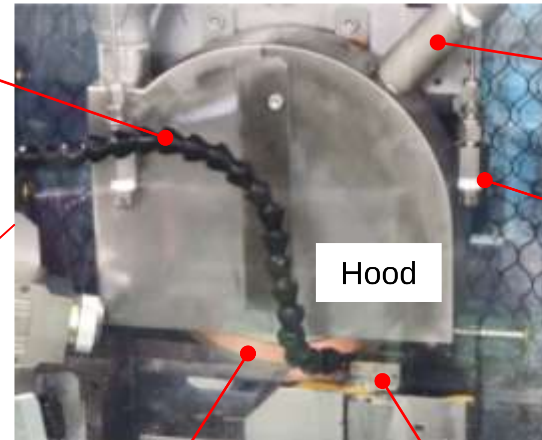
Water ejector and mist nozzle were mounted around the diamond cutter as a means for dust collection and dispersion-prevention. Further, part of the tests was conducted while sprinkling a small amount of water on the cutting part in order to protect the cutter.

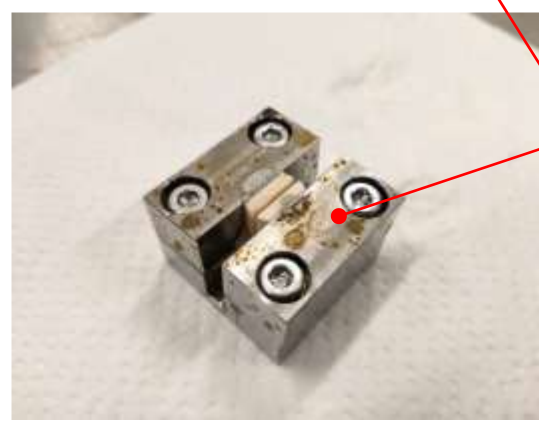


6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test configuration (external view)]





6. Implementation Items

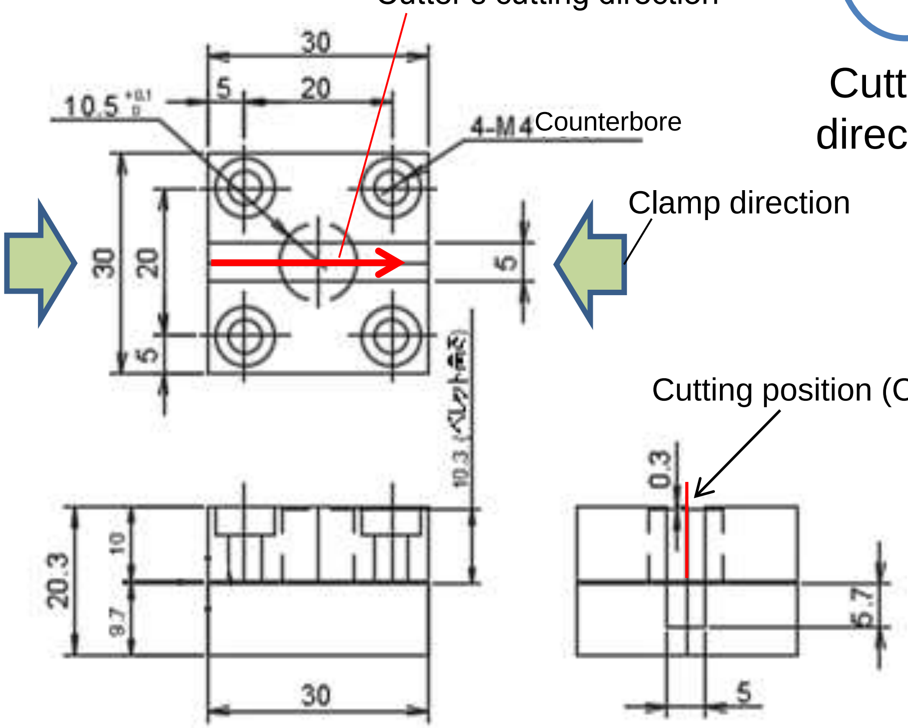
6. 3 Evaluation test of dust collection and dispersion prevention

[Test piece]

1 piece of UO_2 / ceria pellet;

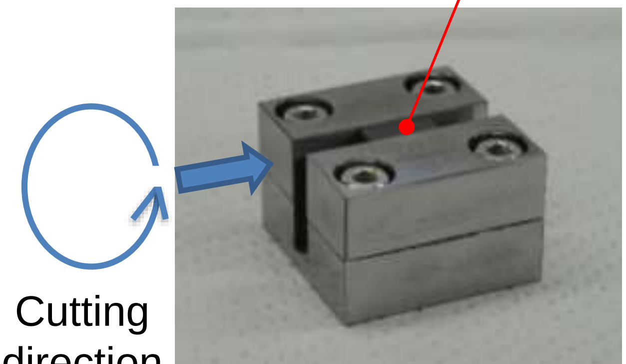
1 piece of either UO_2 pellet or ceria pellet was loaded.

Anti-scattering agent (neutron absorber) was applied.

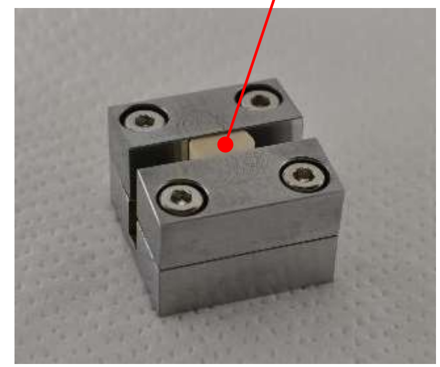


Cutting direction

UO_2 pellet



Ceria pellet



Ceria pellet

(Neutron absorber was applied.)

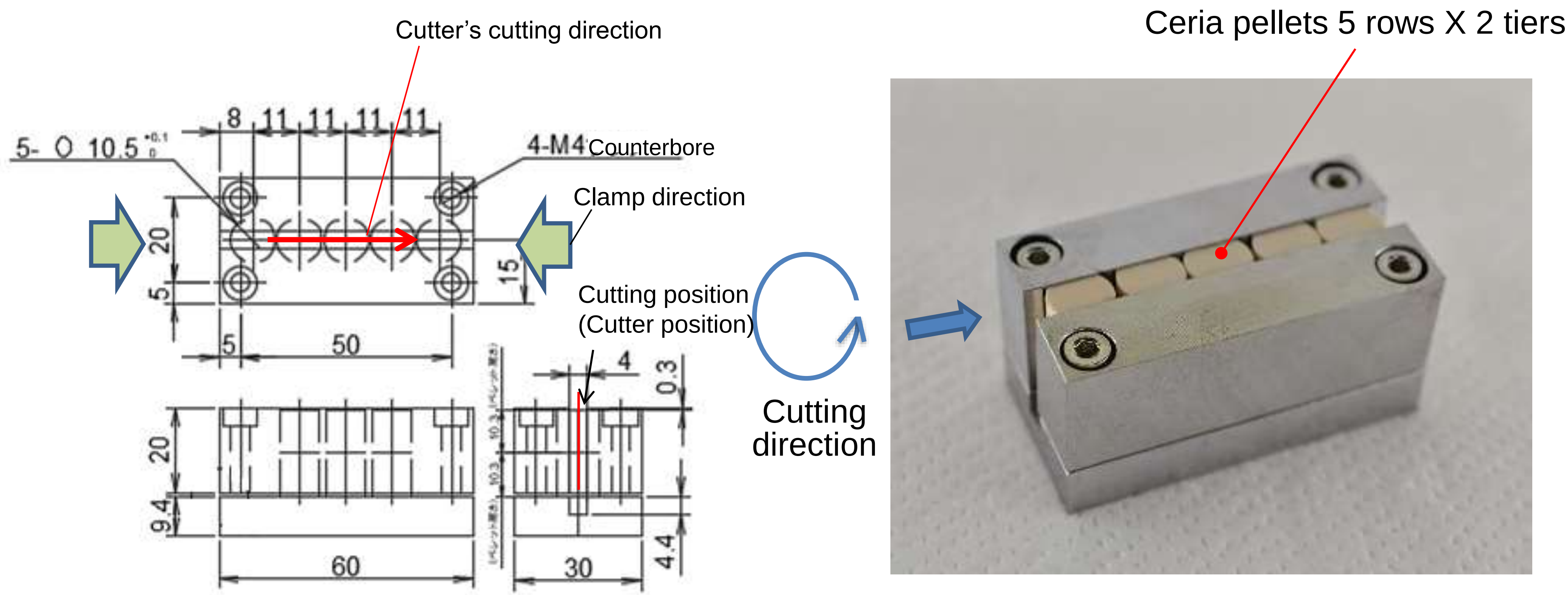
6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test piece]

10 pieces of ceria pellets;

10 ceria pellets were loaded in 5 rows and 2 tiers to increase the amount of dust dispersion.



6. Implementation Items

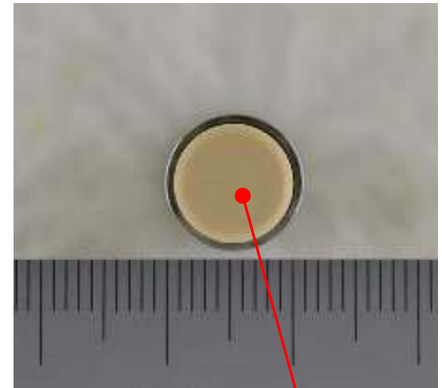
6. 3 Evaluation test of dust collection and dispersion prevention

[Test piece]

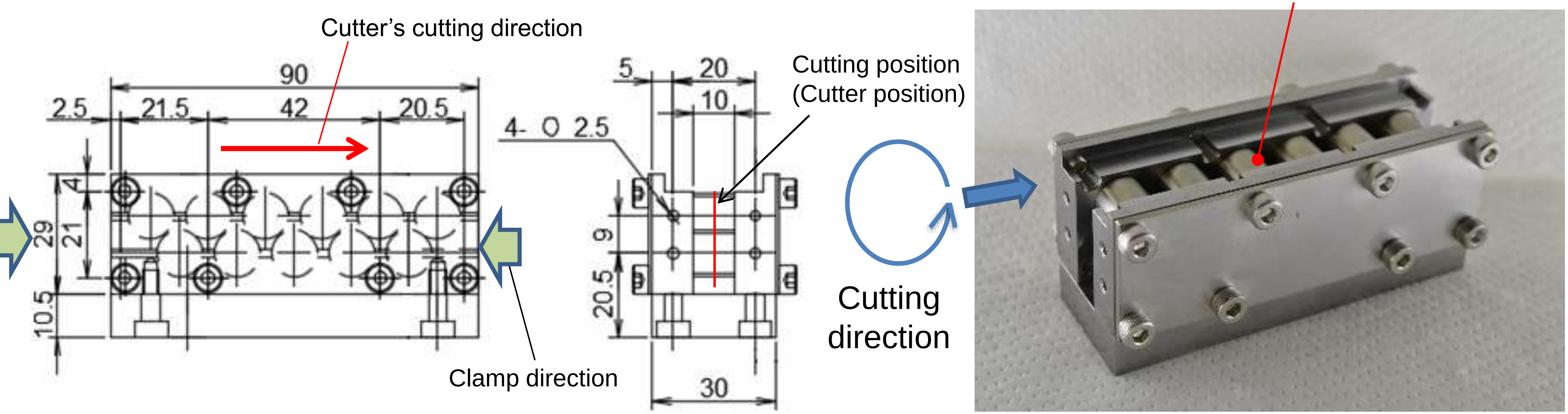
Fuel cladding + ceria pellets;

11 ceria pellets inserted into zircaloy fuel claddings were loaded.

(The gap between fuel cladding and ceria pellet was approximately 0.1mm)



Fuel cladding + Ceria pellet (11 pieces)



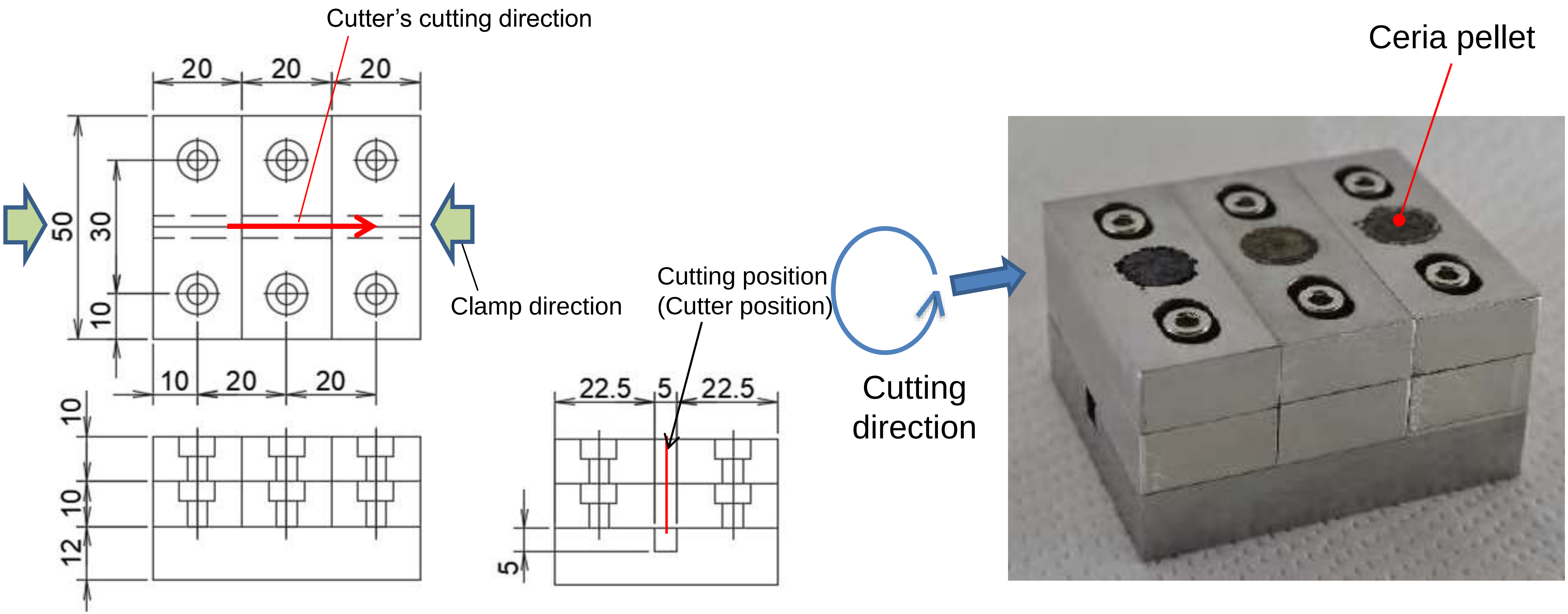
6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test piece]

Structures to which fuel debris has adhered;

Ceria pellets were solidified together with molten SUS304, and cut into 6 test pieces (3 rows X 2 tiers) and loaded.

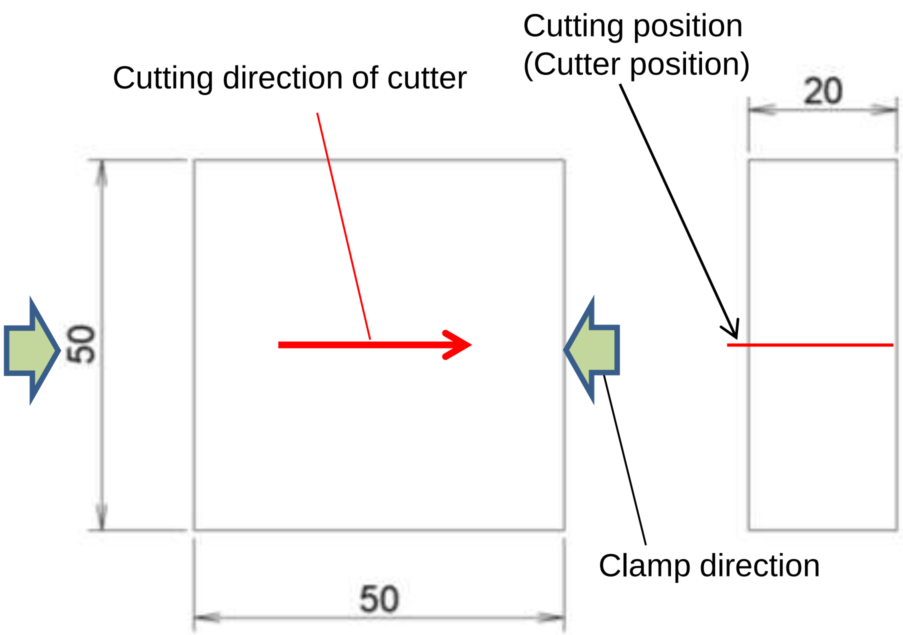


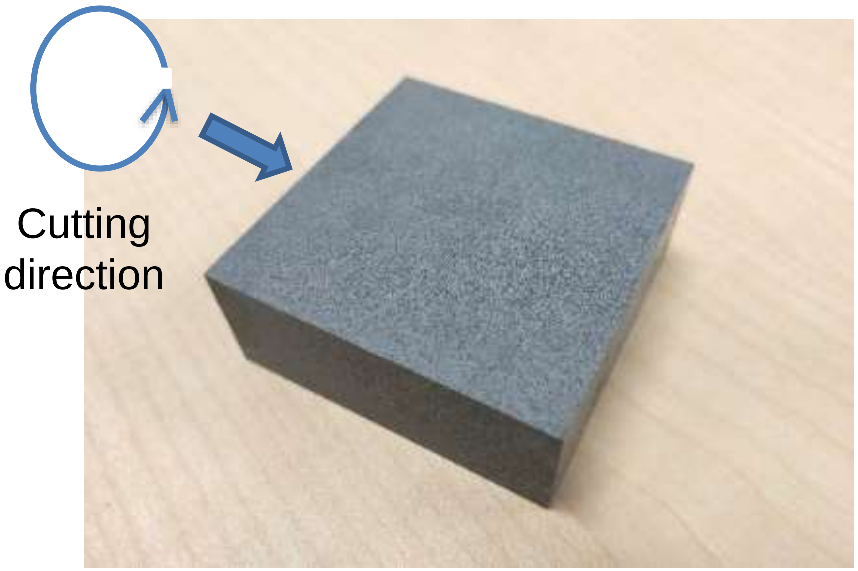
6. 3 Evaluation test of dust collection and dispersion prevention

[Test piece]

Test piece was cut out from simulated MCCI (Molten Core Concrete Interaction) that consists of materials such as Ceria powder, ZrO_2 powder, SUS (steel use stainless) powder, cement, etc.

Simulated MCCI





6. 3 Evaluation test of dust collection and dispersion prevention

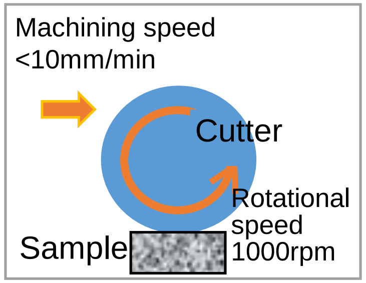
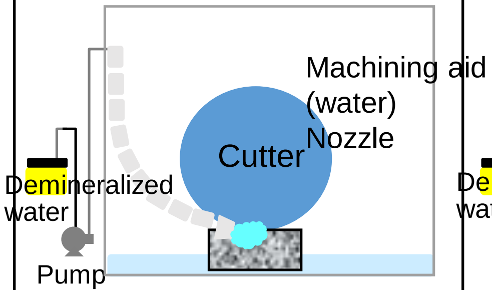
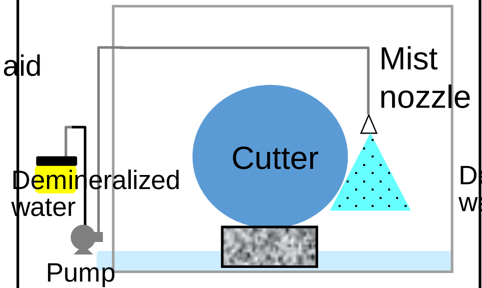
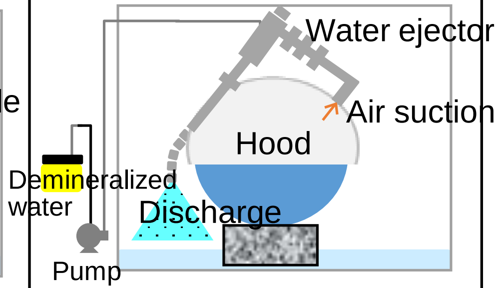
[Machining Conditions and Test Conditions]

< Machining Conditions>*
Rotary cutter (Cutter with metal alloy)
Rotational speed: 1000rpm
Machining speed: 10mm/min

*Based on the selection in the Fuel Debris Retrieval PJ


Cutter with metal base

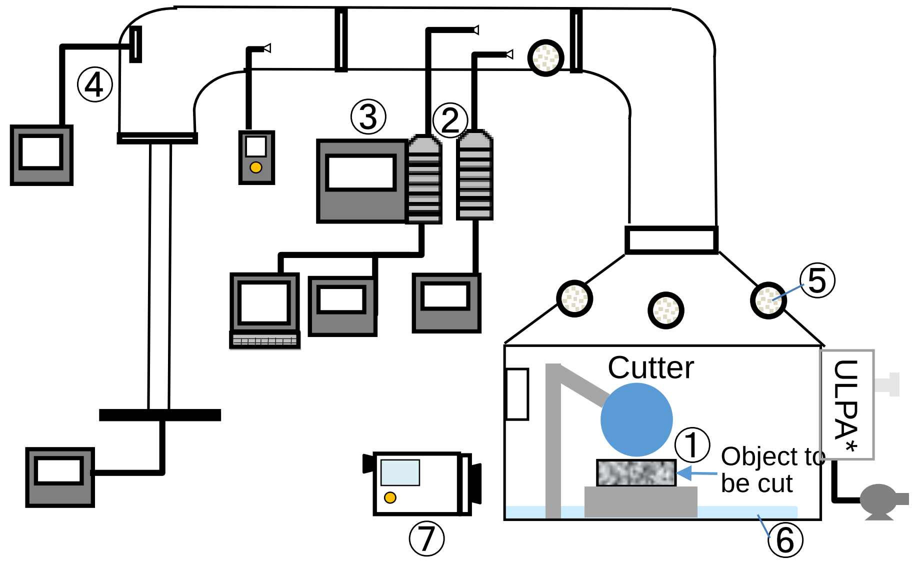
<Test Conditions>

<table>
<tr><th rowspan="2"></th><th rowspan="2">Cutting in air</th><th colspan="3">Dust removal method (water spray)</th></tr>
<tr><th>Cutter machining aid (water)</th><th>Mist</th><th>Ejector</th></tr>
<tr><td>Illustration for testing</td>
<td></td>
<td></td>
<td></td>
<td></td></tr>
<tr><td>Volume of water [L/min]</td><td>0</td><td>1</td><td>0.05</td><td>17.75</td></tr>
<tr><td>Other</td><td>—</td><td>—</td><td>Mist particle size 20μm</td><td>—</td></tr>
</table>

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Evaluation Method]

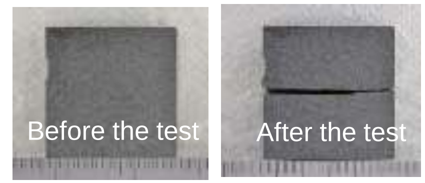


<Evaluation>

- Dust collection & dispersion rate(①･④),
  ② if ④ is detection limit
- Particle size distribution of dispersed particles (②･③)
- Adhesion of particles on walls and ceiling (⑤)
- Analysis of cutting drainage water(⑥)
- Visibility check(⑦)

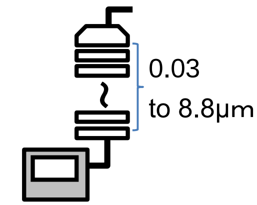
*ULPA: Ultra Low Penetration Air Filter

① Cutting weight



Cutting weight: Difference in the weight of the test piece and cutter before and after the test is calculated.

②･③ Cascade impactor dust



Particle size distribution: Difference in the weight of dust collecting plate before
and after the test is calculated.
If the weight is less than the detection limit, it is calculated based on the assessment of number of particles by means of observation with the help of a SEM*.

④ Dust sampler dust collection

Illustration after dust collection

Collection weight: Difference in weight of the filter paper before and after the test is calculated.

⑤ Verification of adhesion impact

Illustration after dust collection　SEM observation image

Piece of filter paper or carbon tape is fitted on the walls.
Amount of dust adhered is calculated based on the number of adhered particles (SEM**) and composition (XRF***) after the test.

⑥ Amount of solid content in the cutting drainage water and particle size distribution

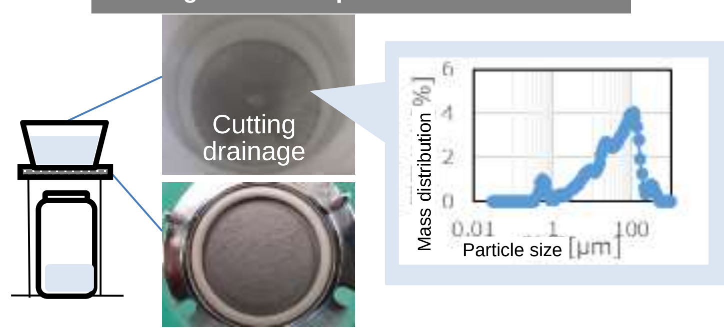
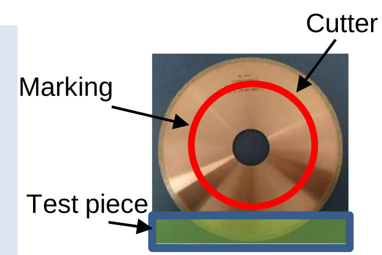


Illustration after solid-liquid separation

⑦ Visibility check



**SEM: Scanning Electron Microscope

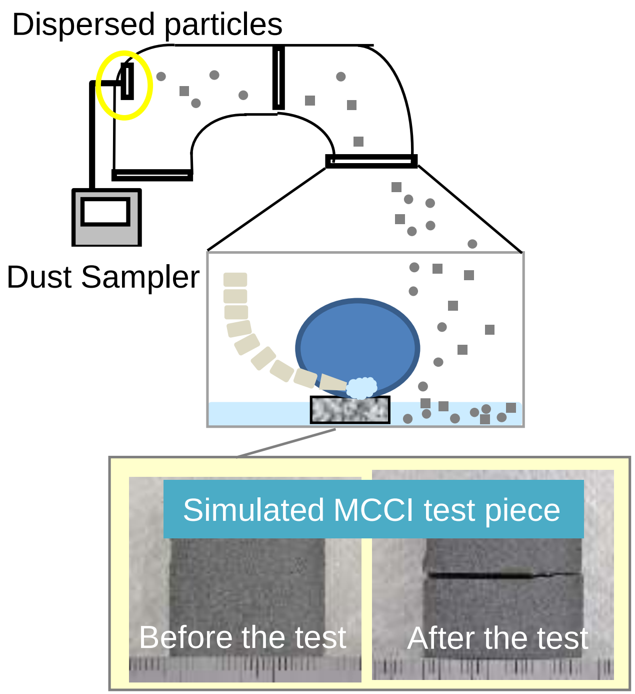
***XRF: X-ray fluorescence spectrometer

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

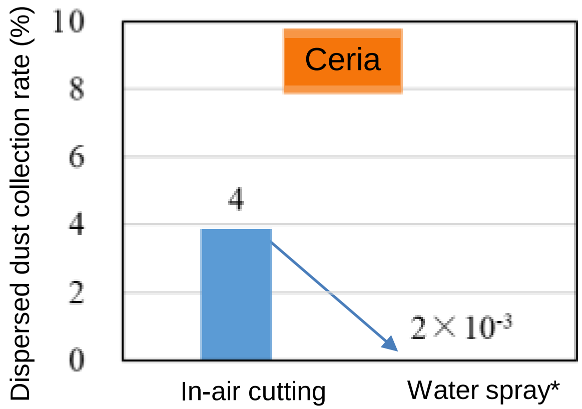
[Test results]

- Effects of preventing dust dispersion using water were verified.
- Impact on dust collection and dispersion rate, and dispersion prevention by using test piece were verified.

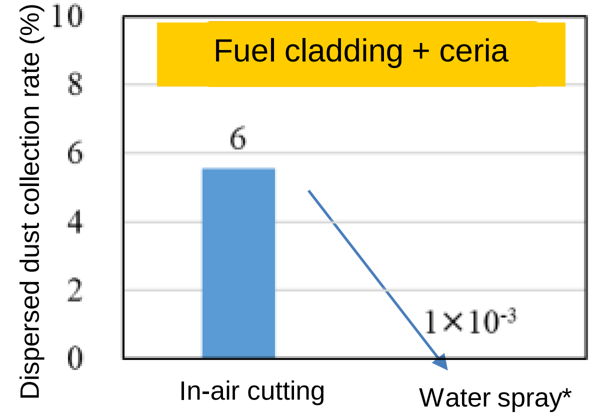


$$\text{Dust collection and dispersion rate [\%]} = \frac{\text{Dispersion weight}}{\text{Cutting weight}} \times 100$$

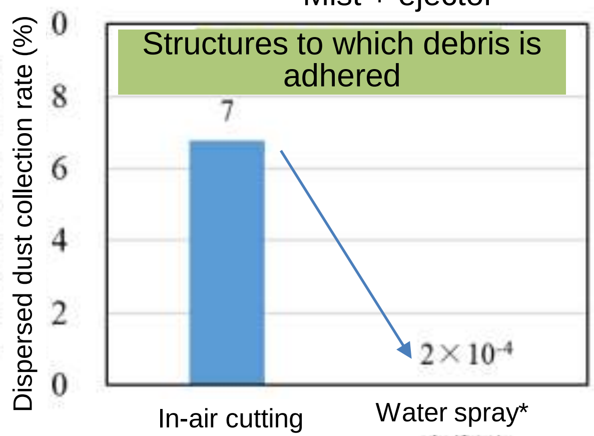
Cutting weight: Difference in the weight of the test piece before and after the test + cutter damage weight
Dispersion weight: Difference in dust sampler collection weight before and after the test



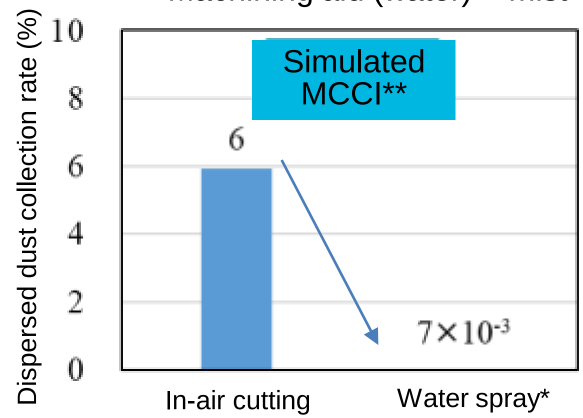
* Mist + ejector



* Machining aid (water) + mist + ejector



* Mist + ejector



* Mist + ejector

- Dispersed dust collection rate was 4 - 7% during cutting in air
- Verification of dust dispersion prevention effect with water spray (mist, machining aid (water), ejector) (Dispersion prevention rate 86 - 99%)
- No major differences were noticed in the impact of the test piece on the dispersed dust collection rate and dispersion prevention effect.

6. 3 Evaluation test of dust collection and dispersion prevention

[Test results]

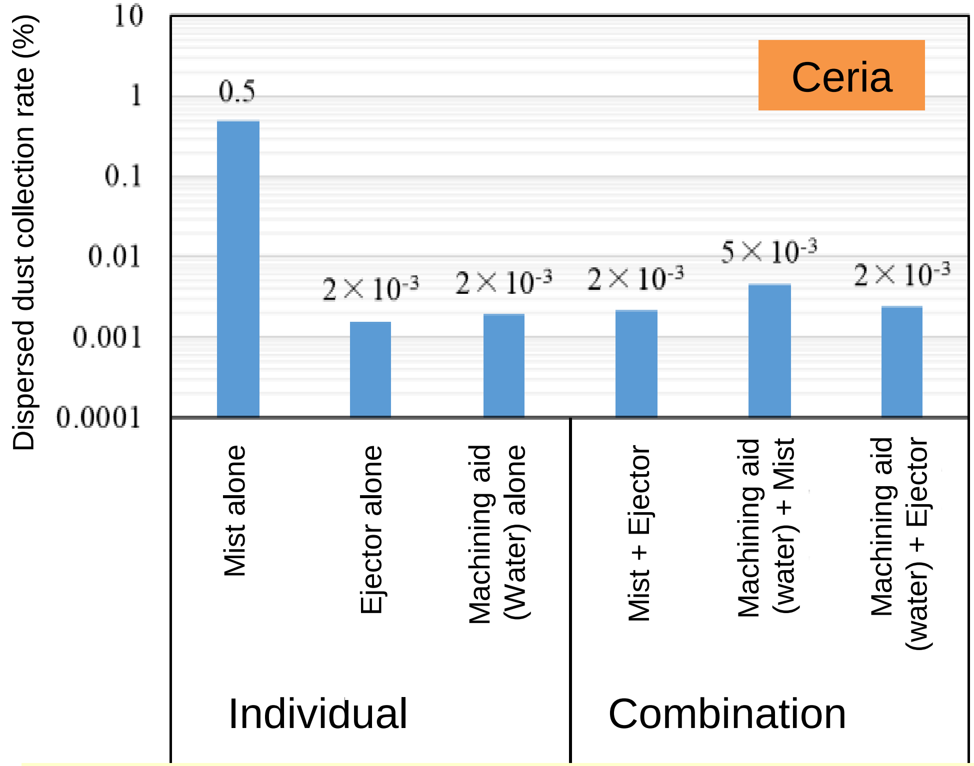
- Effect of dust dispersion prevention using water was compared.
- Impact on dust dispersion prevention effect by the dust dispersion prevention method using water was verified.

$$\text{Dispersion prevention rate [\%]} = \frac{A-B[mg]}{A[mg]} \times 100$$

A: Dispersion weight in the case of cutting in air, B: Dispersion weight after dust dispersion prevention* using water

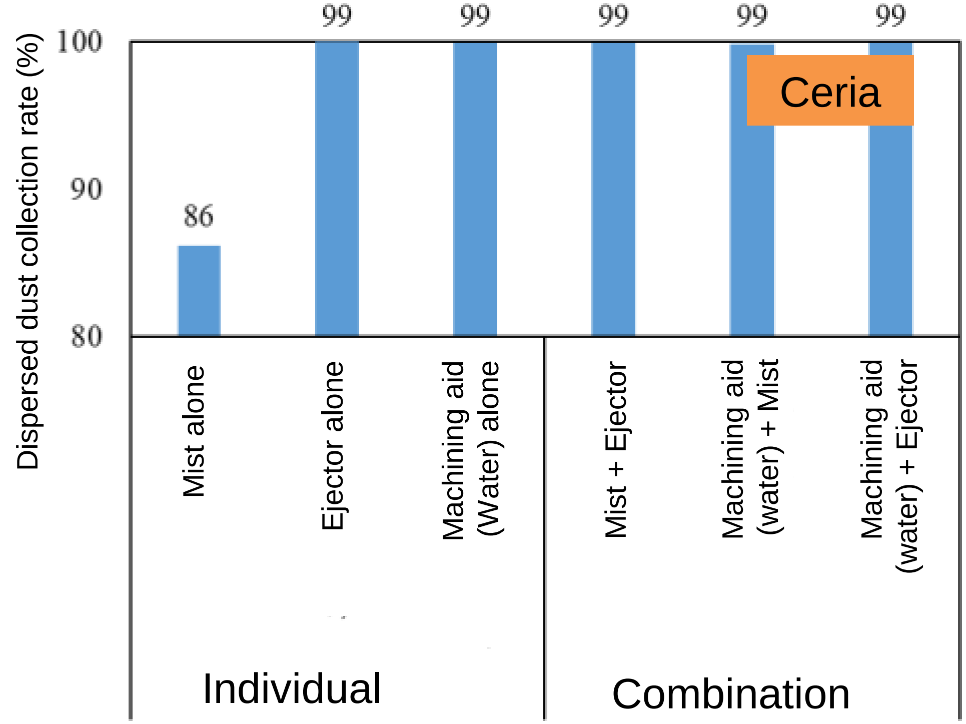
Dispersion prevention*: Mist, ejector, spraying of machining aid (water) etc.

Dispersed dust collection rate



- Comparison of the dispersed dust collection rate by water spray method
- Approx. 1/10 of cutting in air (4%) using mist alone
  Approx. 1/1000 of cutting in air (4%) using other means

Dispersion prevention rate

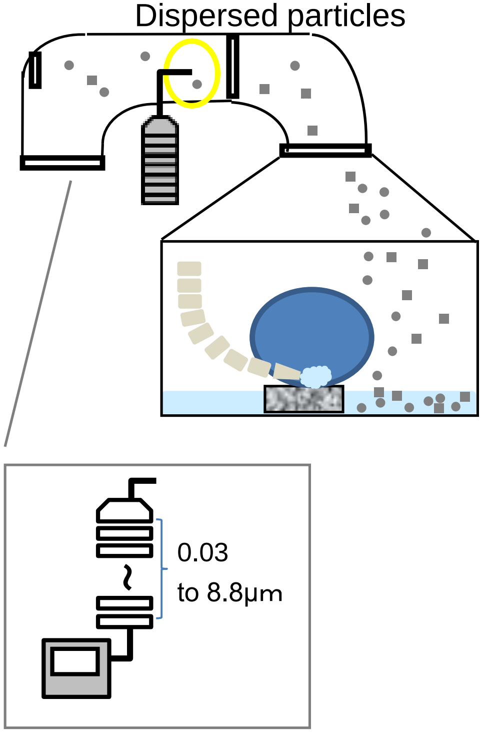


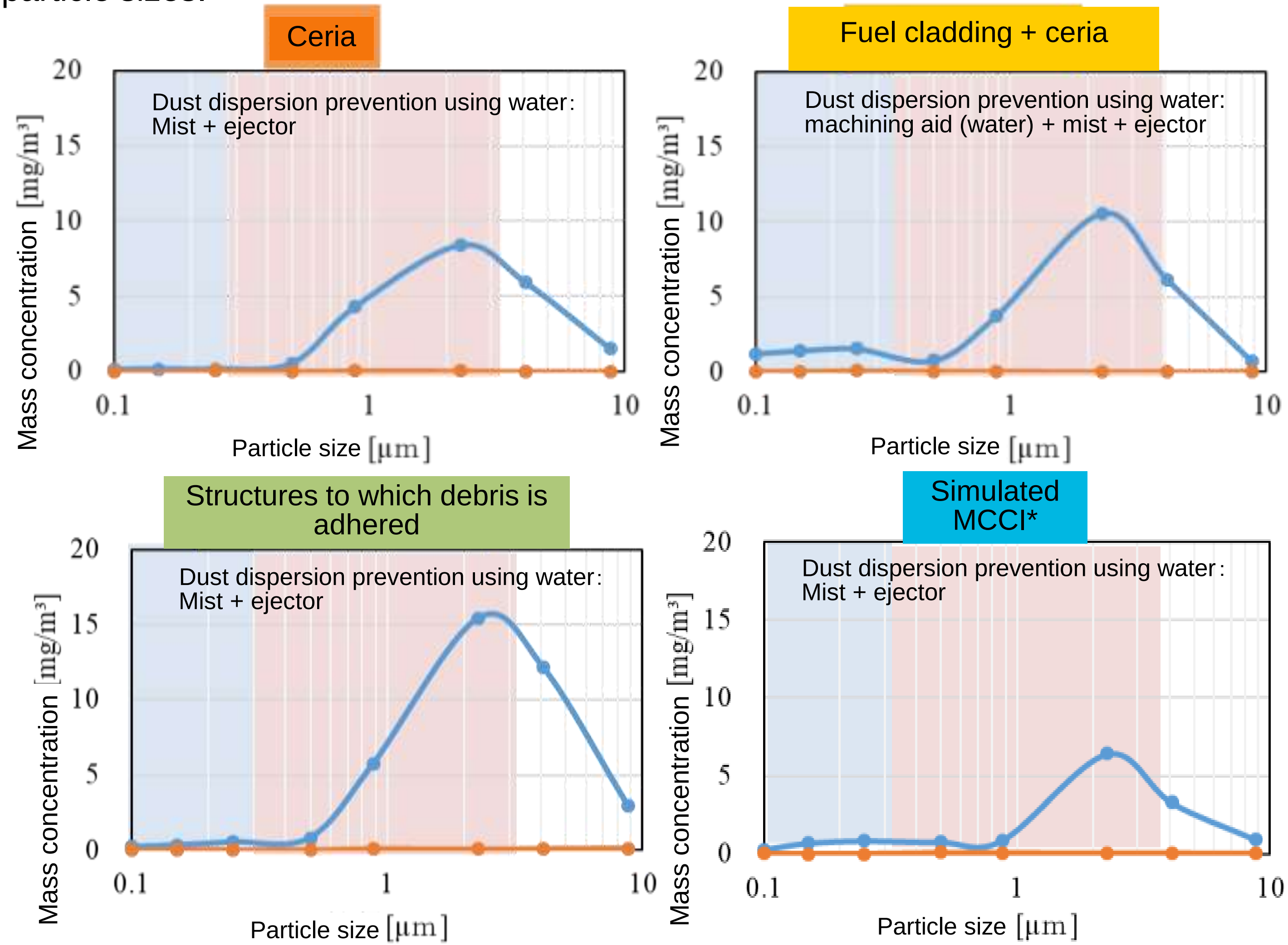
- Comparison of the dispersion prevention rate by water spray method
- Dispersion prevention rate is 86% using mist alone
  99% and more using other means

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] The water prevention method impacted on the distribution of dispersed dust particle sizes.





0.1 - 0.3μm
Range between which HEPA dust collection is difficult

0.3 - 3μm
HEPA dust collection target range

- In case of cutting in air, the peak for particle size distribution is 2 - 3 μm in any case.
- The evaluation test confirmed that that dust dispersion can be effectively prevented by means of the dust dispersion prevention system.

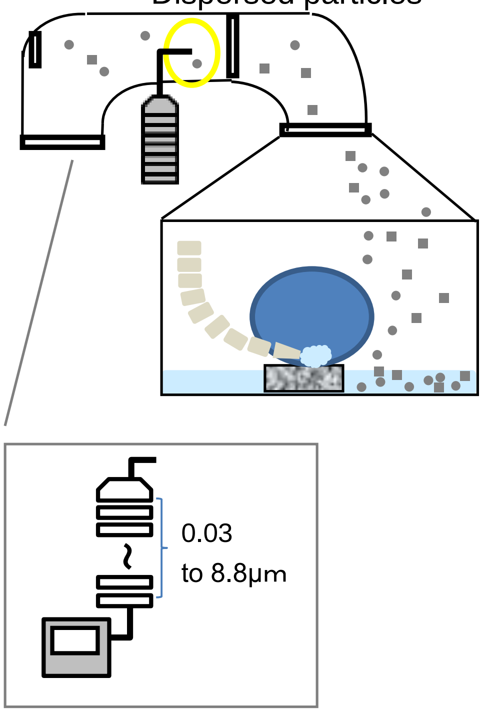
6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] The water prevention method impacted on the distribution of dispersed dust particle sizes.

Cutting in air

Dust dispersion prevention using water

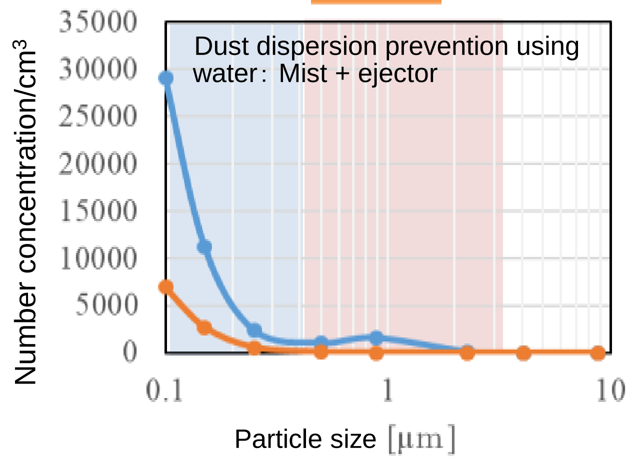
Dispersed particles



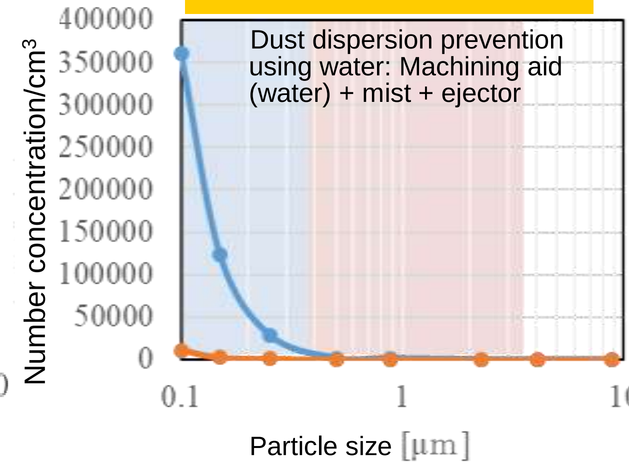
0.1 - 0.3μm
Range between which HEPA dust collection is difficult

0.3 - 3μm
HEPA dust collection target range

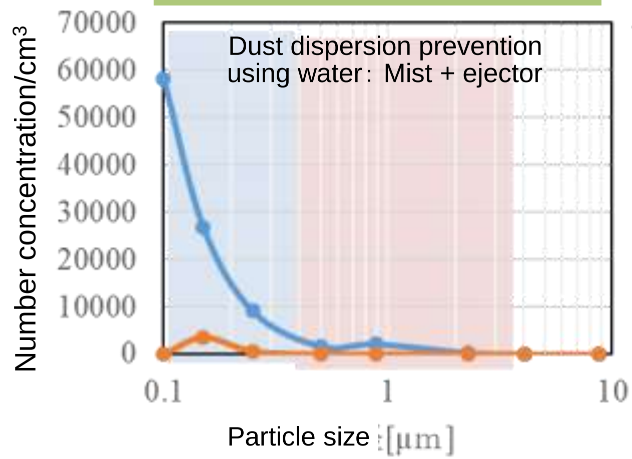
Ceria



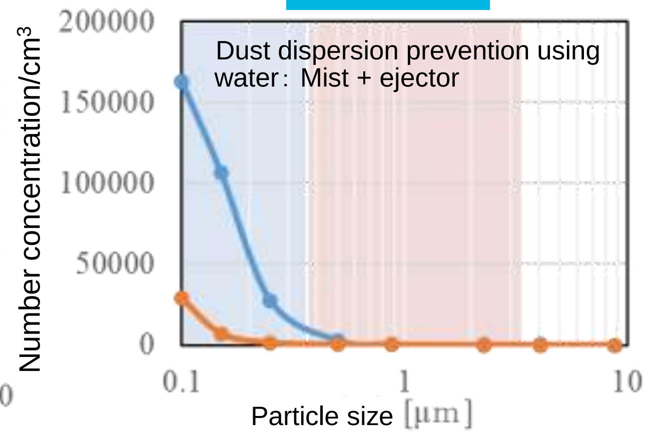
Fuel cladding + ceria



Structures to which debris is adhered



Simulated MCCI*



*Molten Core Concrete Interaction: MCCI

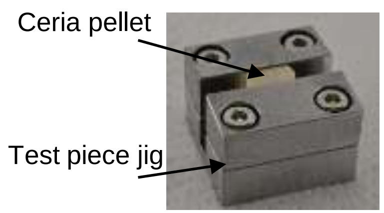
Effect of preventing the dispersion dust with particle size of 0.1 - 0.3 μm which is difficult to collect by HEPA filter was verified.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

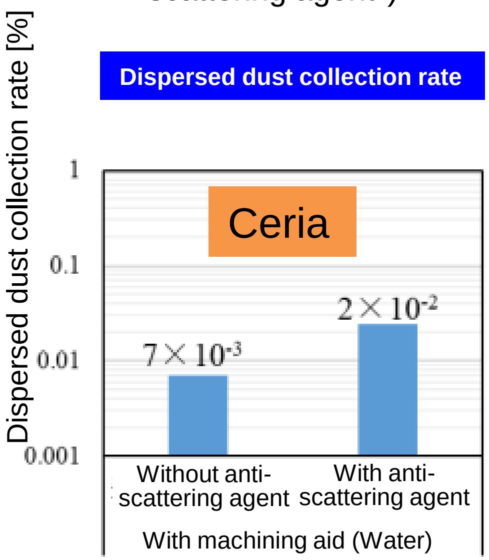
[Test results] The impact on the dispersion prevention effected by using anti-scattering agent and underwater cutting was verified.

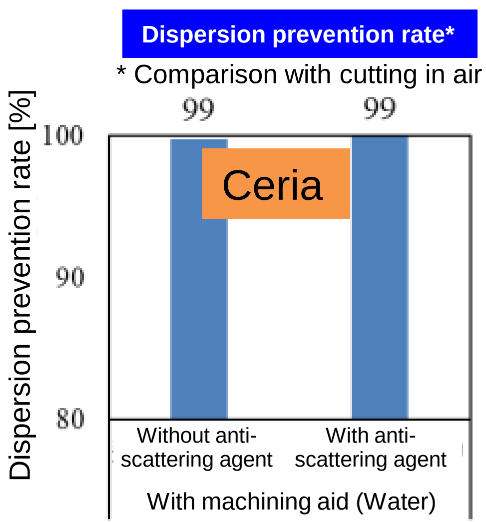
○ Impact on dispersion prevention effect by using anti-scattering agent



Ceria (Without anti-scattering agent*)

Ceria (With anti-scattering agent*)

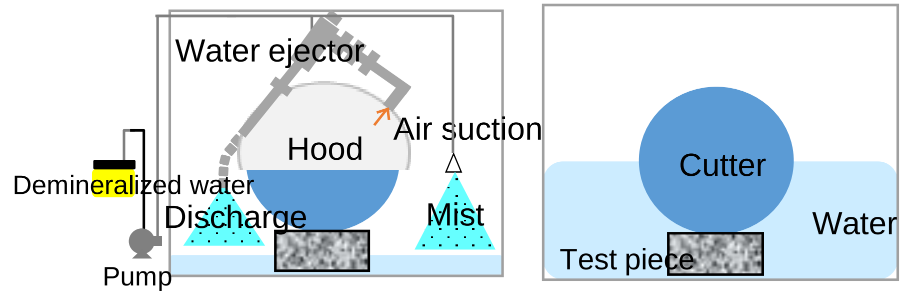


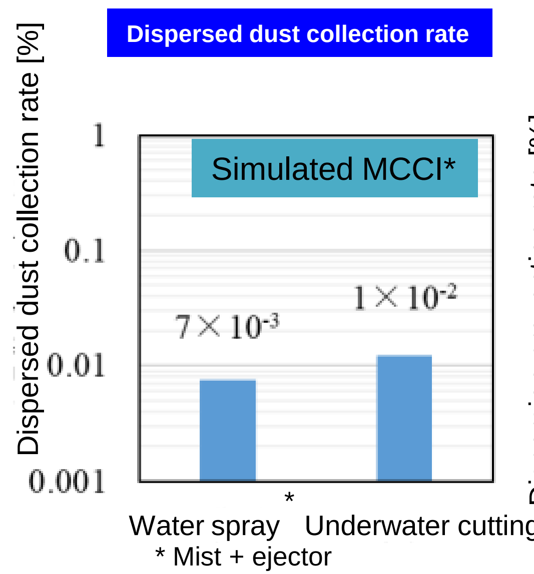


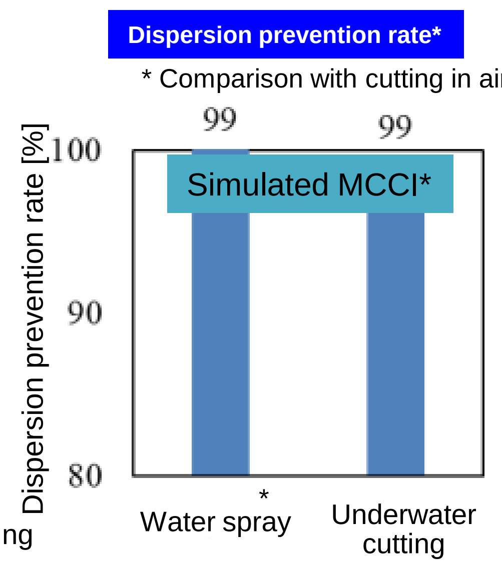
・There was no impact on the dispersion prevention effect in the test using water

It is assumed that this is because water has a major dust removal effect.

○ Impact on dispersion prevention effect by underwater cutting







・There was no difference in the dispersion prevention effect of underwater cutting and water spray.
・It was confirmed that the dispersion prevention effect was >99% in the case of underwater cutting.

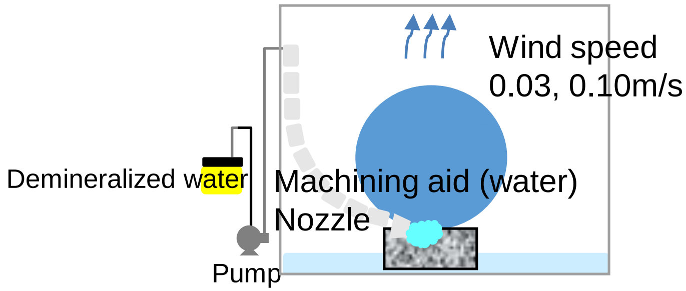
* Liquid glass type neutron absorption material (TX -10)

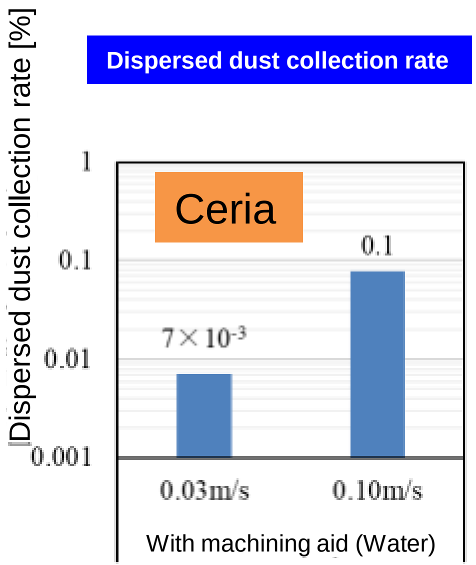
*Molten Core Concrete Interaction: MCCI

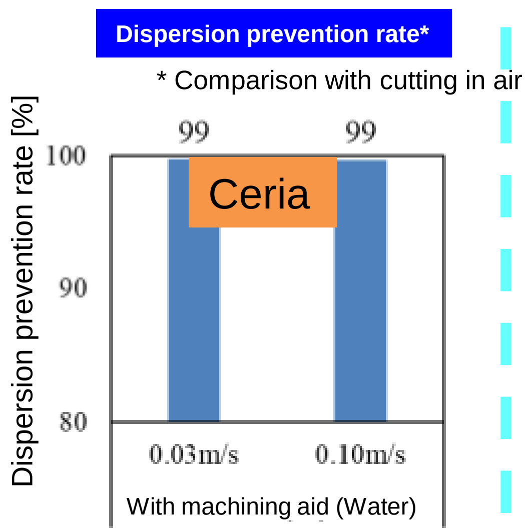
6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] The impact on the dispersion prevention effected by wind speed and cutter rotational number was verified.

○ Impact **on** dispersion prevention effected by wind **speed**

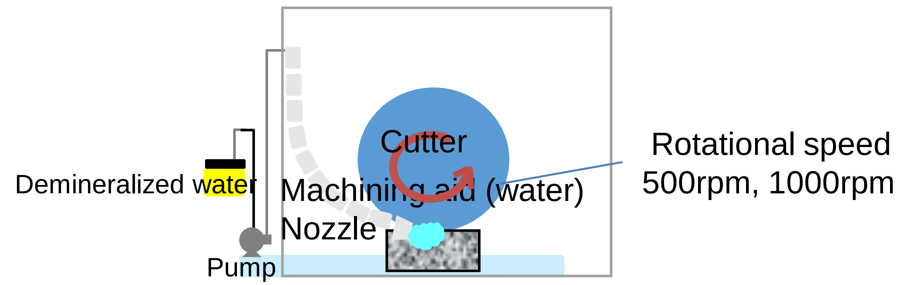


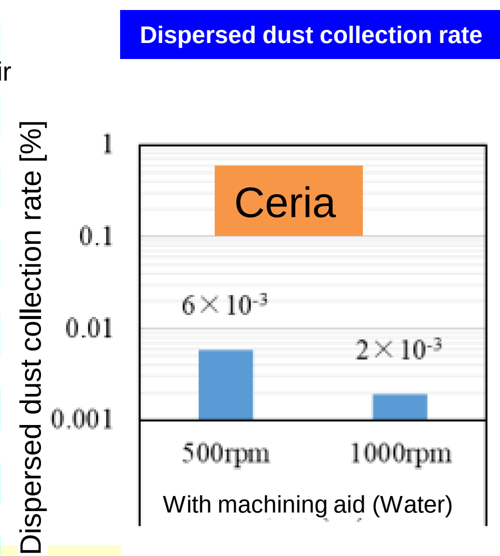


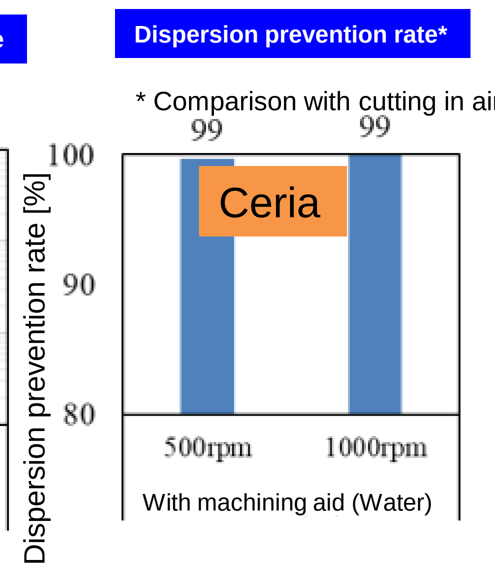


・Results of the test confirmed wind speed dependency; if wind speed is high, dispersed dust collection rate tends to increase
・There was no impact on the dispersion prevention effect in the test using water

○ Impact on dispersion prevention effected by cutter rotational speed







・There was no impact on the dispersion prevention effect in the test using water

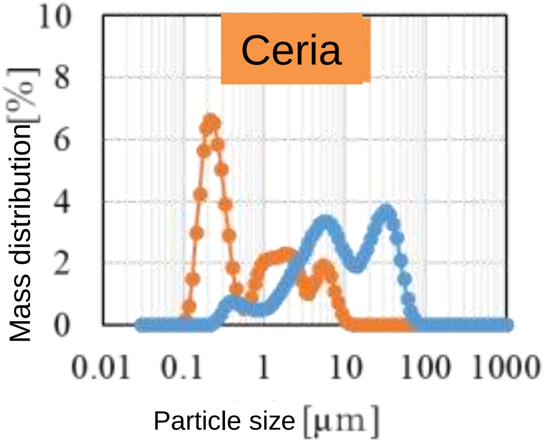
6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test results]

Dispersion prevention by using water impacted on the dust in the drainage.

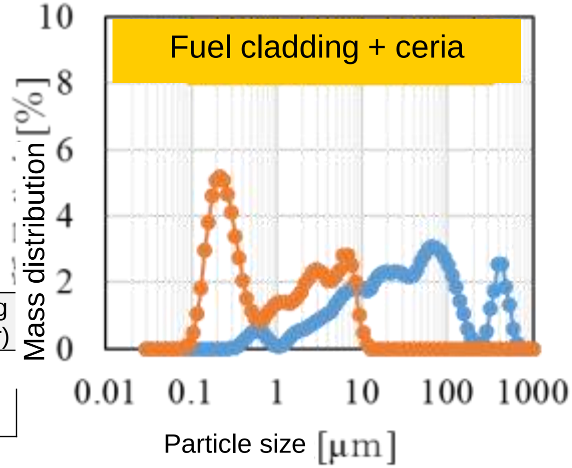
Cutting in air
Dust dispersion prevention using water



	Cutting in air	Water spray*
Average particle size [μm]	8	1

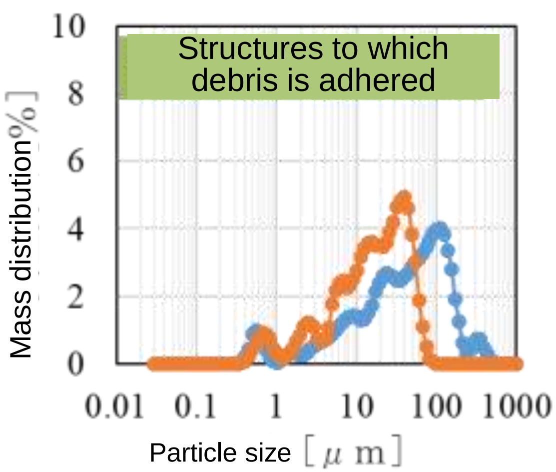
* Water spray: Mist + ejector

	Mist	Ejector	Machining aid (water)
Average particle size [μm]	1	0.4	0.7



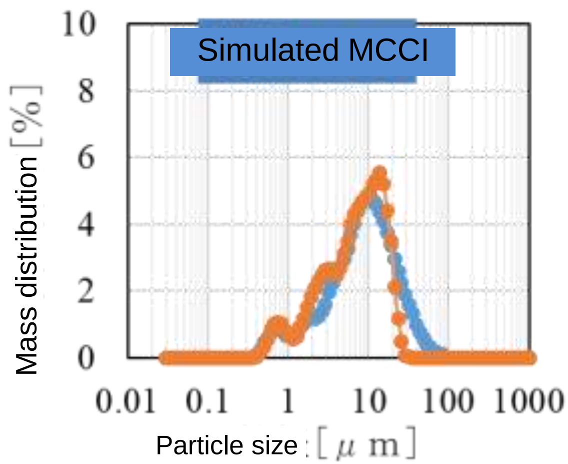
	Cutting in air	Water spray*
Average particle size [μm]	32	0.5

* Water spray: Machining aid (water) + mist + ejector



	Cutting in air	Water spray*
Average particle size [μm]	42	16

* Water spray: Mist + ejector



	Cutting in air	Water spray*
Average particle size [μm]	8	7

* Water spray: Mist + ejector

Particle size distribution of the dust in drainage water when using the dispersion prevention system tends to be lower that when cutting is done in air.

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] Visibility confirmation test

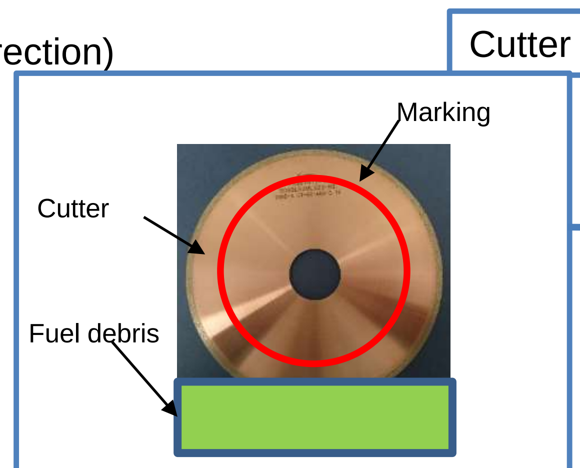
[Ideal Situation]
Visibility confirmation method when machining fuel debris

(Visibility confirmation method in the planar direction)
The target rod is installed in parallel with the cutter and is cut while making sure that the target rod is outside the already existing cut marks formed by the cutting with the cutter.

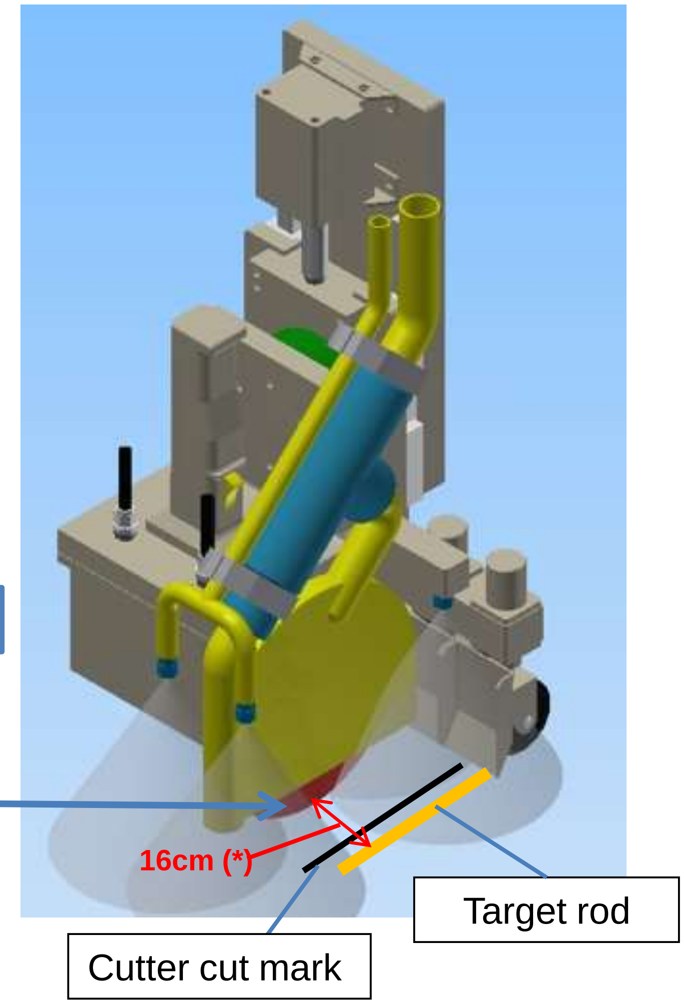
*If the target rod is outside the cut marks, it means that the fuel debris can be cut at max. 16cm.

(Visibility confirmation method in the depth direction)
A concentric circle is marked on the cutter and by visually checking the marking, it is confirmed that the rod is cut only till the specified depth.

Visibility confirmation method in the test is described on the next page.



Cutter marking (Image diagram)



* : Distance between the cutter and target rod

Target rod installation (Image diagram)

6. Implementation Items

6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] Visibility confirmation test

Visibility test for the 3 points specified below is conducted in parallel to the process of cutting the test piece.

① Visibility of cutting width of cutter

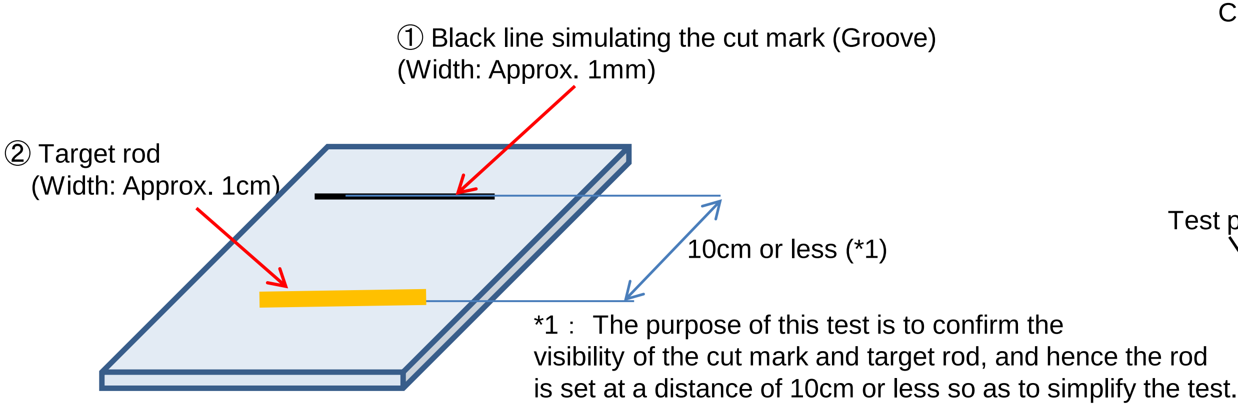
It is confirmed that the black line simulating the cut mark formed as a result of cutting with the cutter is visible.

② Visibility of the tip of the target rod

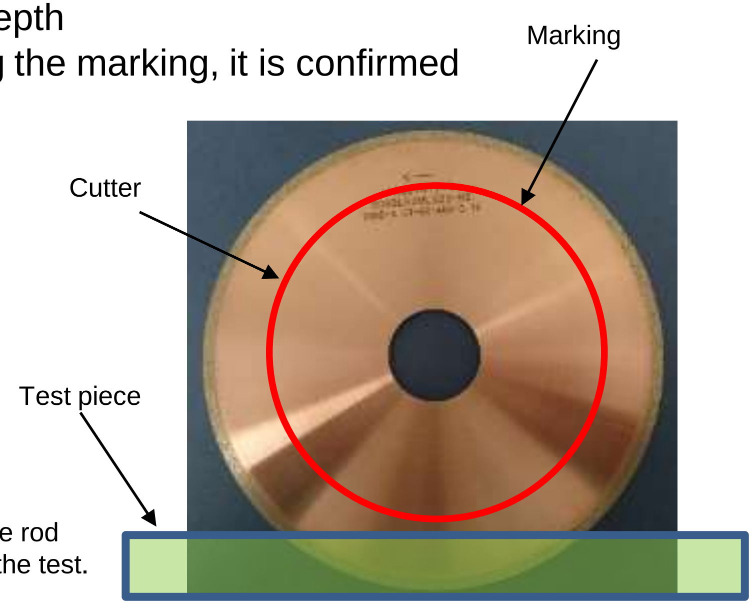
It is confirmed that the target rod is visible.

③ Visibility of the concentric circle marked for checking the cut-out depth

A concentric circle is marked on the cutter and by visually checking the marking, it is confirmed that the rod is cut only till the specified depth.



① Visibility of the cutting width of cutter,
② Visibility test of the tip of the target rod
(illustration)



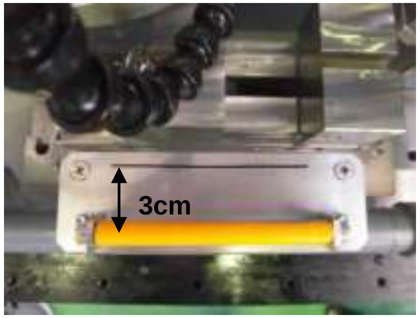
③ Confirmation of cut-out depth
Visibility test of the concentric circle mark (illustration)
※This diagram shows the view of the cutter and the test piece, from the position immediately lateral to the cutting direction.

6. 3 Evaluation test of dust collection and dispersion prevention

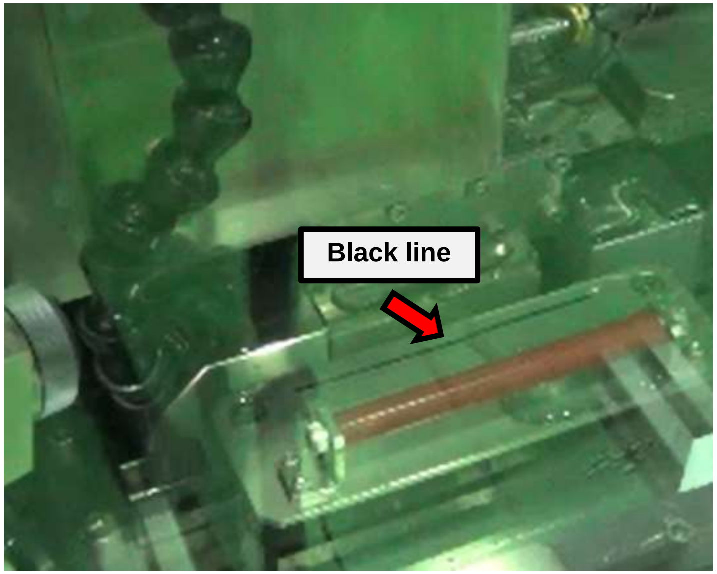
[Test results] Visibility confirmation test

The camera footage of the visibility confirmation test is shown below. The black line for the purpose of checking the cutter's cutting width, a concentric circle for checking the cut-out depth and tip of the target rod were verified.

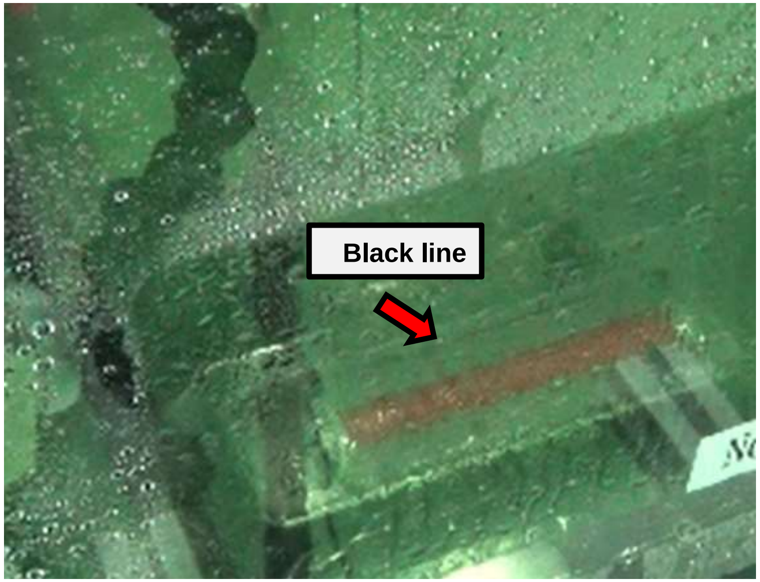
4. 9. 1 Verification of cutter's cutting width (Black line, target rod)



Distance between black line and target rod



Before cutting

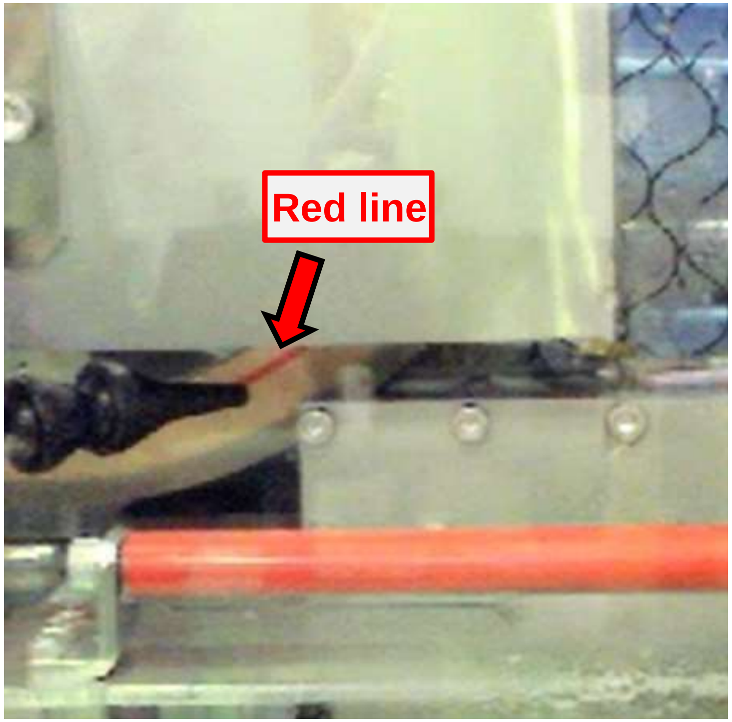


During cutting

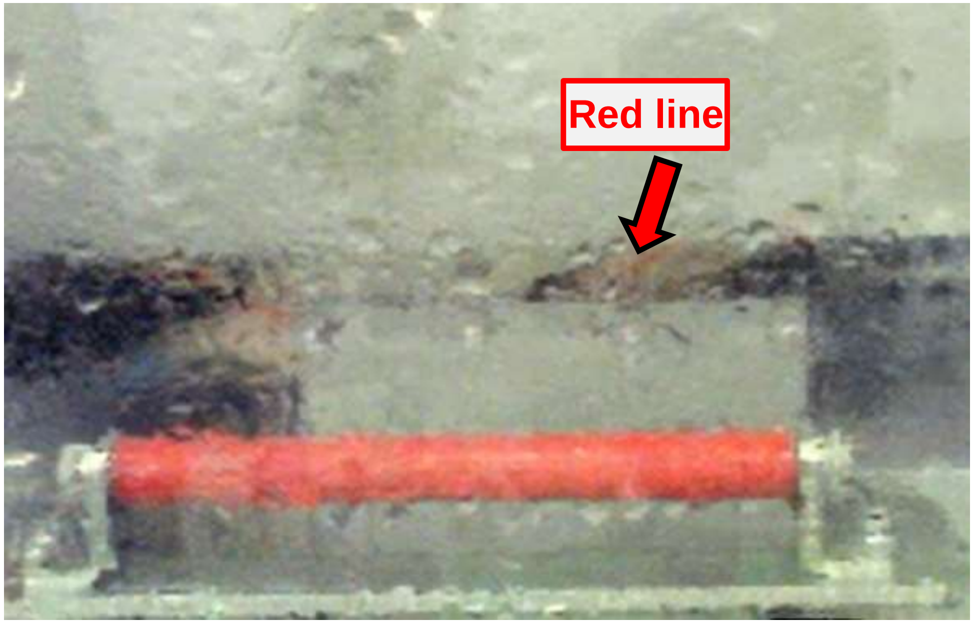
6. 3 Evaluation test of dust collection and dispersion prevention

[Test results] Visibility confirmation test

4. 9. 2 Verification of cut-out depth (Concentric circle)



Before cutting



During cutting

6. 3 Evaluation test of dust collection and dispersion prevention

[Summary of test results]

- The dispersed dust collection rate for all the test pieces was in the range of 4 to 7% when dust dispersion was not prevented.
- Particle size distribution of dispersed particles peaked at 2 to 3μm with respect to mass concentration and was mostly 0.3μm or less with respect to number concentration; and every test piece showed the same tendency.
- When mist spray was applied, the dispersed dust collection rate reduced up to approximately 1/10.
- When water ejector or machining aid (water) was used, the dispersed dust collection rate reduced up to approximately 1/1000.
- In the 3 cases, namely when only water ejector was used, only machining aid (water) was used and when the combination of water ejector + machining aid (water) + mist were used, no major difference was noticed in reduction effect on the dispersed dust collection rate.
- When dust dispersion was prevented, there was noticeable effect of dispersion prevention of dust with a particle size of 0.1 to 0.3 μm, which is considered difficult to be collected by HEPA filter.
- There was no impact on dispersion prevention in the test in which neutron absorber was used.

7. Summary

The objective of this project was accomplished when the project team completed assessment of applicability of the dust collection and dispersion-prevention system to actual equipment, the basic design, conceptual design for remote maintenance, designing and manufacturing of dust evaluation test apparatus and verification of the performance of the dust collection system through the dust evaluation test.

1) Development of the dust collection and dispersion-prevention system

A conceptual study on dust collection and dispersion- prevention system to reduce dust in the air in the vicinity of the machining point was conducted ; the applicability of said system and machining head to actual equipment was assessed and basic designing was carried out; a machining head with mist or water ejector was designed and manufactured.

2) Development of remote maintenance technology for the dust collection and dispersion-prevention system

As a conceptual design of the remote maintenance method for the dust collection and dispersion-prevention system, a method was explored wherein consumables such as machining tools etc. in PCV or within the primary boundary cell are replaced by remote operation, the machining tool replacement process was clearly specified and a step diagram was created.

3) Evaluation test of the dust collection and dispersion prevention

The dust evaluation test guidelines, test matrix and testing system for the selected machining method (disc saw) were studied and a dust dispersion test was conducted.

It is expected that the data obtained in this project will be effectively used in future in the development of technologies as specified below.

- Machining tool design in the field of fuel debris retrieval technology
- Equipment design and operation/maintenance plans in the field of environmental control
- Equipment design and operation/maintenance plans in the field of water treatment technology

8. Specific goals for achieving the purpose of the project

Clarification of test conditions or development specifications

Before starting elemental tests and equipment design, the level of technology required for decommissioning work shall have been thoroughly studied in advance and the compatibility level of existing technologies in this connection shall have been quantitatively assessed (Presentation of Current Technology Readiness Level (TRL)). The test conditions and design specifications shall be formulated after sharing in advance with the parties concerned, information regarding the extent of precision in ensuring the required level of technology through the aforementioned tests and the development of equipment.

Level	Definitions corresponding to this project	Field
7	Stage at which implementation is complete.	For practical use
6	Stage at which field verification is conducted.	Field demonstration
5	Stage at which a prototype is manufactured based on the actual equipment and verified in a simulated environment at the plant, etc.	Simulated demonstration
4	Stage at which functional tests are implemented at the test manufacturing level as a development and engineering process.	Research for practical use
3	Stage at which development and engineering are being carried out by applying or combining past experiences. Or, stage at which development and engineering are being carried out based on fundamental data in domains in which there is no prior experience	Applied research
2	Stage at which development and engineering are being carried out in domains in which there is almost no applicable prior experience, and the required specifications are being defined.	Applied research
1	Stage at which specific details pertaining to the development and engineering targets are clarified.	Basic research

8. Specific goals for achieving the purpose of the project

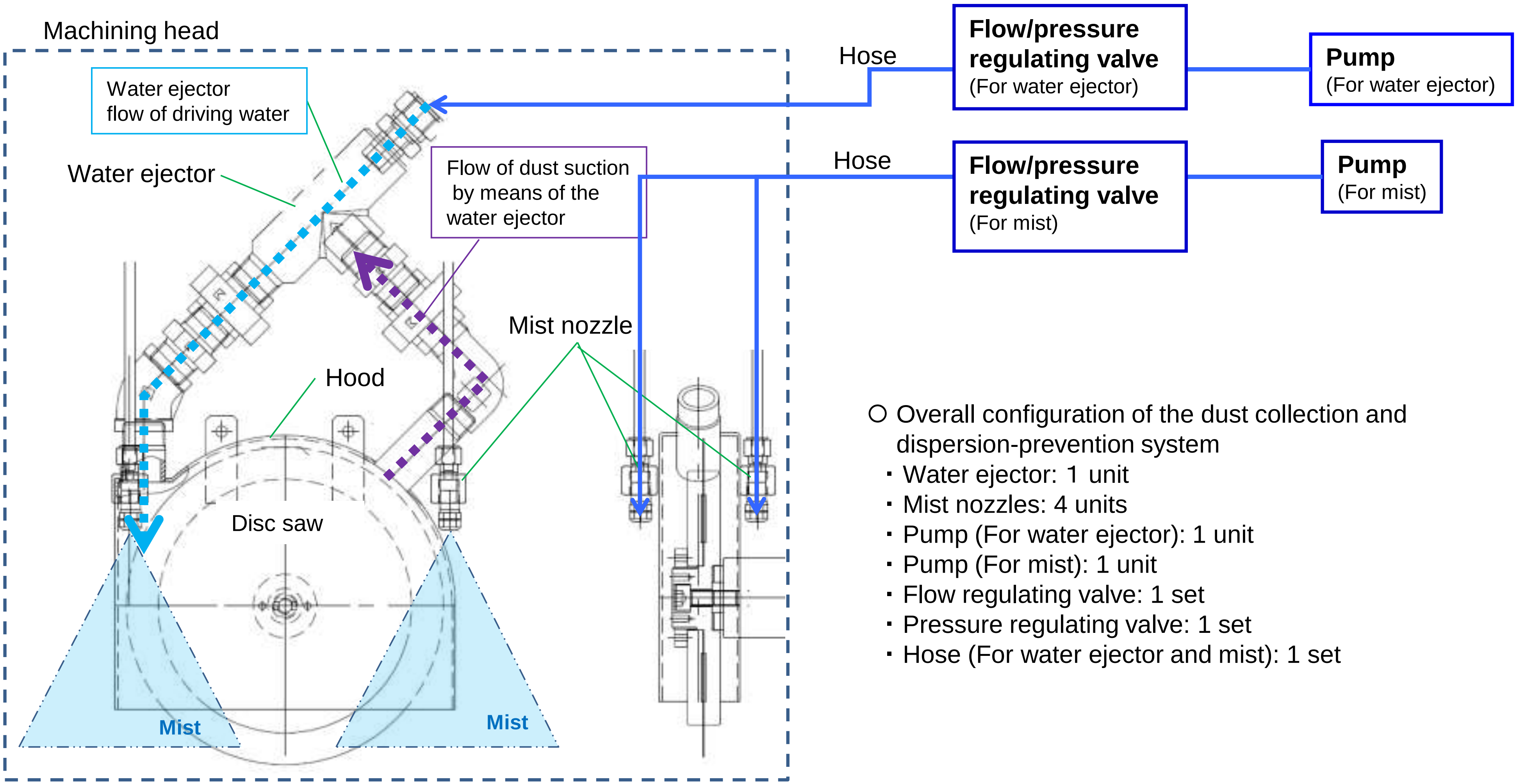
1) Development of the dust collection and dispersion-prevention system	
① Conceptual designing of the dust collection and dispersion-prevention system and the machining head and evaluation of the applicability to the actual equipment	Upon investigating the past dust collection technology, the advantages and disadvantages in case of using the dust collection technology for the machining method selected in “Development of technology for retrieval of fuel debris and reactor internal structures” will have been evaluated. The results of evaluating the applicability to actual equipment for the side access method and top access method of the dust collection technology will have been presented. (Target TRL at completion: Level 3)
② Defining of the basic specifications of the dust collection and dispersion-prevention system and the machining head, and designing the system	A chart listing the basic specifications of the dust collection and dispersion-prevention system and the machining head for the machining method selected in “Development of technology for retrieval of fuel debris and reactor internal structures”, the system diagram and the conceptual design diagram will have been presented. (Target TRL at completion: Level 3)

8. Specific goals for achieving the purpose of the project

2) Development of remote maintenance technology for the dust collection and dispersion-prevention system	
① Remote maintenance method and conceptual design of the required equipment	The method and concept of the dust collection and dispersion-prevention system and machining head including the line of flow of devices for remote maintenance during normal times and in the event of failures, replacement parts, waste, etc., their schematic placement, volume of waste, need for and method of decontamination, etc. will have been presented in a step diagram. (Target TRL at completion: Level 3)
3) Evaluation test of dust collection and dispersion prevention	
① Development of dust collection and dispersion-prevention evaluation guidelines	The tests conducted within Japan and overseas for evaluating dust generated during machining, will have been investigated, and evaluation test guidelines suitable for evaluating the machining method to be applied to actual equipment will have been established. (Target TRL at completion: Level 4)
② Evaluation test of dust collection and dispersion prevention	A representative method will have been selected from the machining methods selected as part of "Development of technology for the retrieval of fuel debris and reactor internal structures; machining test and evaluation of test samples simulating fuel debris and contaminated structures, etc. will have been conducted using the designed and manufactured elemental test equipment presuming a machining head that can be used in the actual equipment; data such as migration rate into air and into water depending on the machining speed will have been acquired; and the amount of waste generated as a result of the operation of dust collection and dispersion-prevention system will have been measured. Moreover, the chart mentioned in 1) ② Basic Specifications will have been revised as required. (Target TRL at completion: Level 4)

Attachments

Overall configuration of the dust collection and dispersion-prevention system (mist and water ejector)



○ Overall configuration of the dust collection and dispersion-prevention system

- Water ejector: 1 unit
- Mist nozzles: 4 units
- Pump (For water ejector): 1 unit
- Pump (For mist): 1 unit
- Flow regulating valve: 1 set
- Pressure regulating valve: 1 set
- Hose (For water ejector and mist): 1 set

(Reference) Tool changer

An overview of the tool changer is provided below; It has been mentioned as the mechanism for connecting the robot arm and machining head in the Development of remote maintenance technology for dust collection and dispersion-prevention system.

(Note) These details provide general information about tool changer but do not indicate the usage during the actual fuel debris retrieval.

(Structure)

Fixation Method: Ball Locking Method

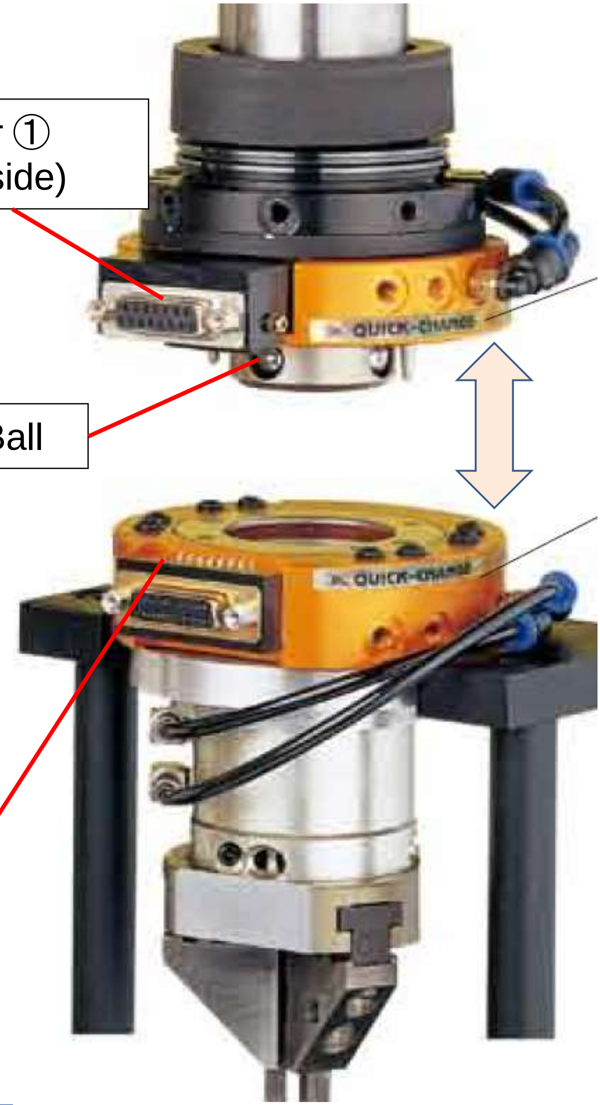
(The ball inside the tool changer ① operates by air pressure and gets anchored to the tool changer②)

(Characteristics)

- Tool can be attached/detached by remote operation.
- Utility connection (liquid, air, cable run) is allowed.
- It is commonly used technology and is highly reliable.

(Main uses)

- Machining operation and assembly operation using robot arm



Photograph of the exterior of the tool changer

(Source) Catalog of BL Autotec, Ltd. (Trade Name: Quick Change)

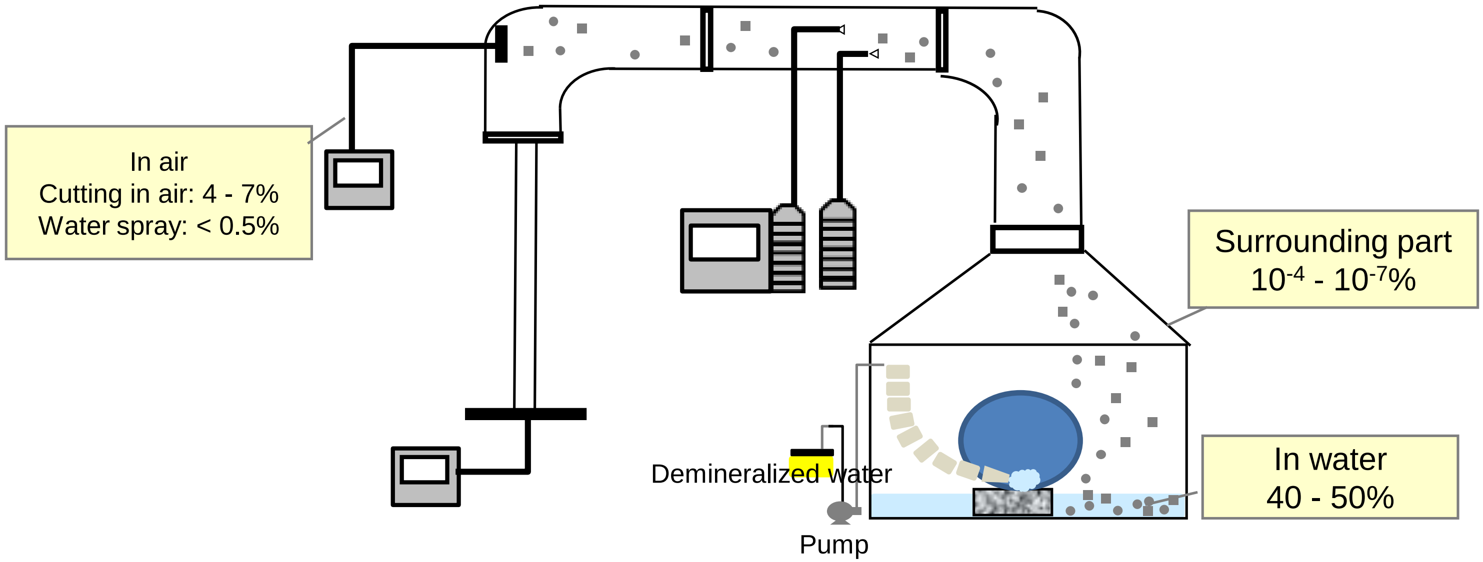
Selection of UO_2 simulant material (Comparison of materials)

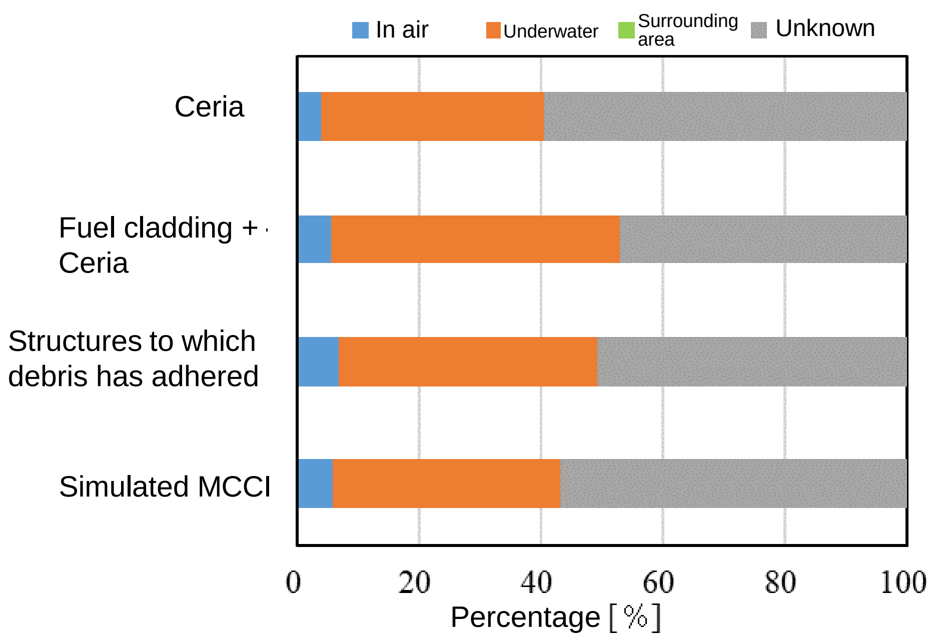
Materials	Specific gravity (g/cm^3)	Melting point (℃)	Vickers hardness (GPa)	Thermal conductivity (W/m・K)	Previous usage experience in other projects	Special notes
UO_2	10.96 [1]	2878 [1]	6 [2]	10 [2]	Used in the Fuel Debris Characterization Project as the raw material for the large simulated debris test performed overseas and small simulated debris test performed in Japan.	In this project, calcined UO_2 was used as fallen fuel UO_2 pellets and fuel debris.
Ceria (CeO_2)	7.22 [6]	2600 [1]	4 - 5 [5]	17 [4]	Used in the Fuel Debris Retrieval Project as UO_2 simulant material for manufacturing large MCCI test pieces.	Ceria with a relatively higher specific gravity and with hardness almost the same as UO_2 was used in this project as UO_2 simulant material.
Al_2O_3 (Alumina)	3.6 - 3.9 [3]	2050 [1]	12 -17 [3]	12 - 32 [3]	Used in Fuel Debris Retrieval PJ as fuel debris simulant material for the machining experiment.	Since specific gravity is low, it is not used in the evaluation test of dust collection and dispersion prevention.
ZrO_2 (Zirconia)	3.6 - 3.9 [3]	2720 [1]	11 -13 [3]	3 [3]	Used in Fuel Debris Retrieval PJ as fuel debris simulant material for the machining experiment.	Since specific gravity is low, it is not used in the evaluation test of dust collection and dispersion prevention.
$(U,Zr)O_2$ Fuel debris	6 -11 [2]	2500 - 2700 [2]	6 - 14 [2]	1 - 10 [2]	Physical properties of the fuel debris collected from TMI-2 during the Fuel Debris Characterization PJ were assessed.	Physical property values were referred from the Fuel Debris Characteristics List [2]

<Sources>

[1] Iwanami's Dictionary of Physics and Chemistry 4th edition - Iwanami Shoten Publication 1987
[2] IRID - Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary budget “Development of technology for fuel debris characterization”- Research Report (Interim Report) - March 2016
[3] CHARACTERISTICS OF KYOCERA FINE CERAMICS April 2020
（https://www.kyocera.co.jp/prdct/fc/index.html）
[4] 2018 Fall Meeting of the Atomic Energy Society of Japan, Iwasa et.al., ID05
[5] Data furnished by IRID union members
[6] S. J. Duclos, et.al.,Phys. Rev. B 38, 7755 (1988).

Mass balance evaluation (1/2)

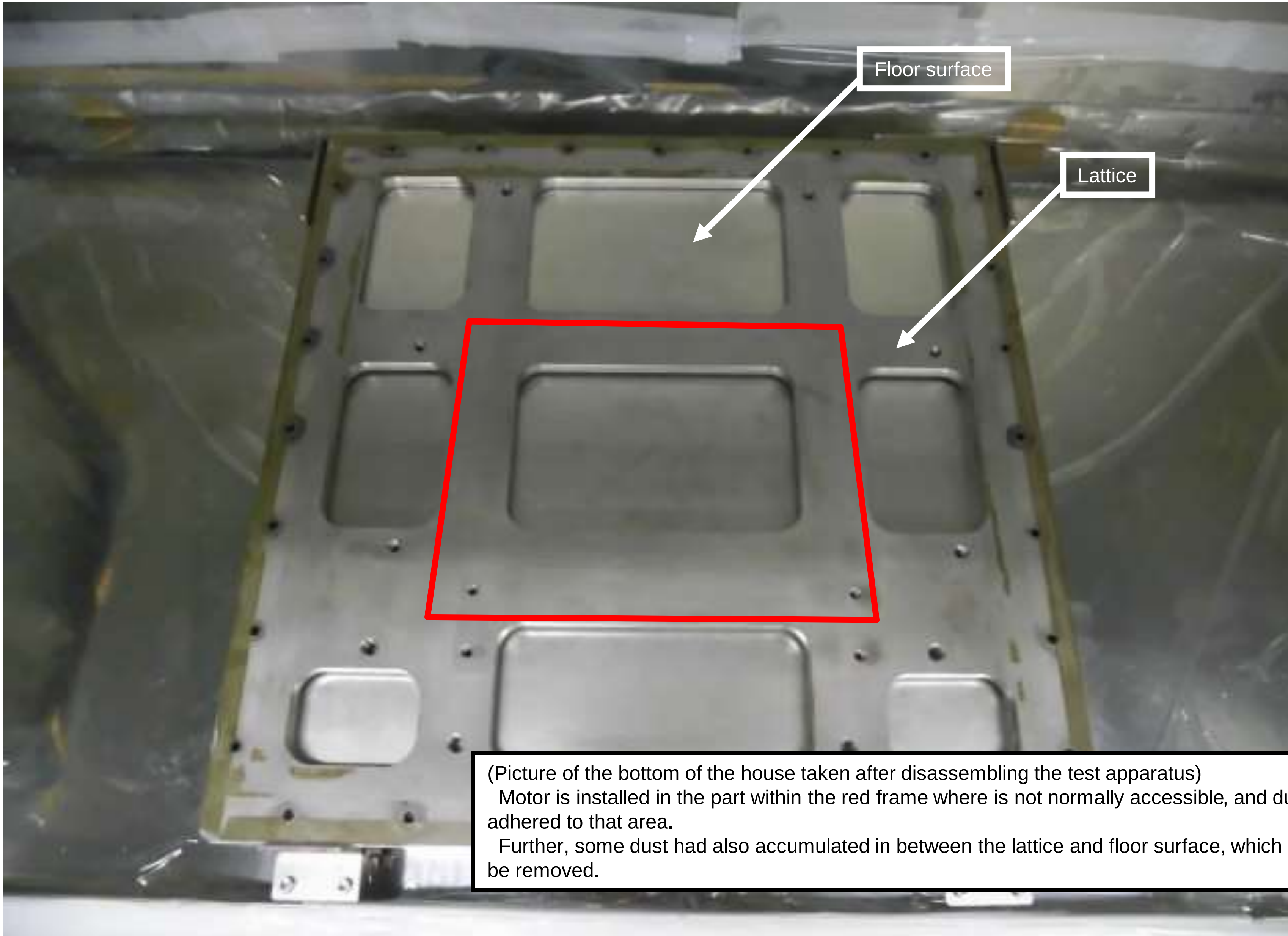




The figure indicates that there are many unknown dust (dust that cannot be collected) regarding the fallen dust and dust in drainage water, and the dust collection rate is low.

⇒This may be because of the dust remained at the bottom of the test equipment (Refer to next slide).

Mass balance evaluation (2/2)



(Picture of the bottom of the house taken after disassembling the test apparatus)
Motor is installed in the part within the red frame where is not normally accessible, and dust had adhered to that area.
Further, some dust had also accumulated in between the lattice and floor surface, which cannot be removed.