

Innovative Approach for Fuel Debris Retrieval Results of Request for Information (RFI)

April 25, 2014

International Research Institute
for Nuclear Decommissioning

Process from issuing an RFI to receiving information

Purpose of Request for Information (RFI)

- ❑ IRID has been entrusted by Agency for Natural Resources and Energy with technical investigation on Innovative Approach for Fuel Debris Retrieval and conducted Request for Information (RFI) as part of this technology investigation.
- ❑ In this RFI, we verify innovative approach for Fuel debris retrieval which was proposed in the Mid-long-term roadmap*¹ Thus we collect information from wide range of organization from the industry to academic institutions to government agencies to determine the technology required.
- ❑ Information collected will be utilized for Conceptual Study (C/S) and technological Feasibility Study (F/S)*² in the future.
- ❑ Also, we hope this RFI will be the opportunity for the people involved in this project to collaborate with link to other parties around the world.

*1: "The technology to submerge up to the upper part of a reactor containment affected by a severe accident has difficult challenges in its many steps. Therefore it is assumed that it might be difficult to submerge up to the upper parts of the reactor containments. In addition, methods of retrieving the fuel debris without filling the PCVs with water will be studied as alternative methods." (from Mid-long-term roadmap)

* 2: To be held in Spring/Summer of 2014 depending on the condition of government budget.

Contents of RFI

Topic A: Internal PCV/RPV investigation

A-1: Conceptual study of method (following are samples)

1. Method of inserting investigation device such as cameras inside.
 - a. Utilize current throughbore such as piping/penetration.
 - b. Create new throughbore .
 - c. Methods of Shielding penetrations and of equipment operation in terms of reduction of radiation exposure.
2. Method of detecting fuel debris location by measurement outside, etc.

A-2: Required technologies (following are samples)

1. Advanced measurement technology (camera, dosimeter, thermometer etc.)
 - a. High performance optical equipment(camera etc.), other measurement technology (ultrasonic, laser etc.)
 - b. Control technology of measuring instrument, and information transmission technology .
2. Technology to detect whether the substance in the reactor is fuel debris or not.

Topic B: Fuel debris retrieval

B-1: Conceptual study of method (following are samples)

1. Access to fuel debris from the top of PCV underwater
 2. Access to fuel debris from the top of PCV in the air*¹
 3. Access to fuel debris from the side of PCV in the air*¹
 4. Access to fuel debris from the bottom of PCV in the air*¹
- *¹ including partial submergence

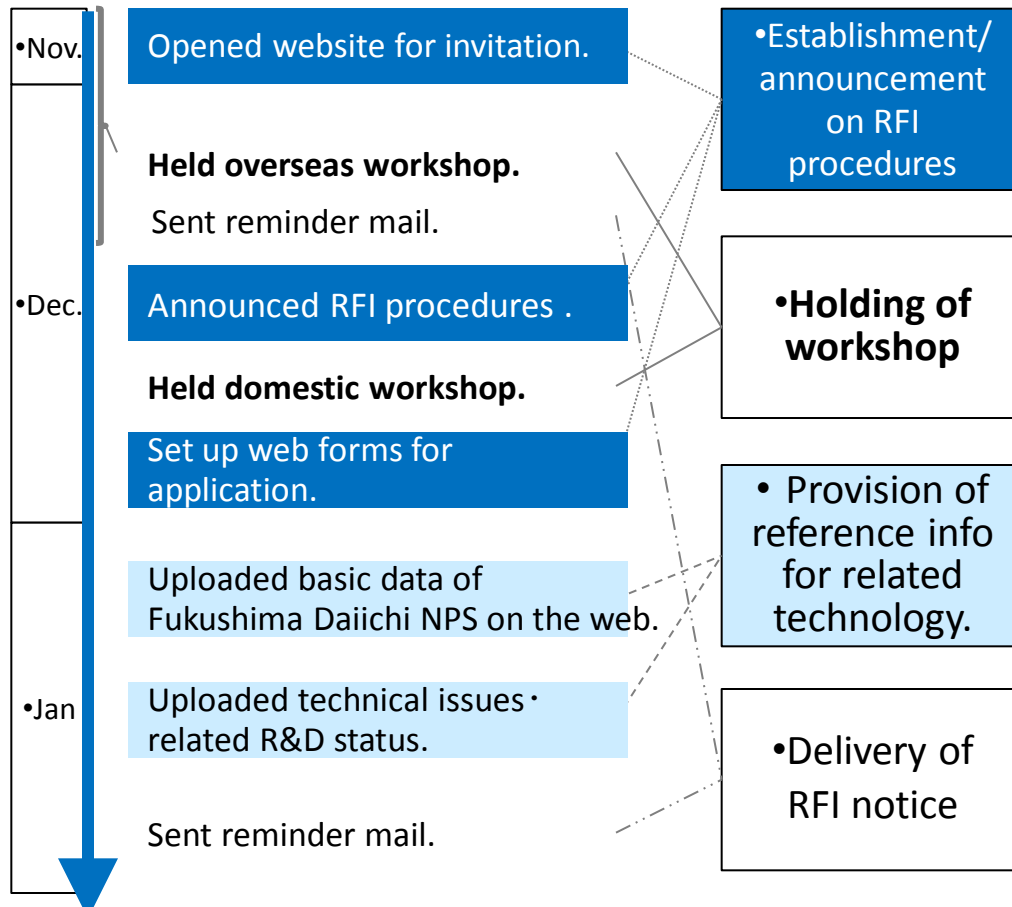
B-2: Required technologies (following are samples)

1. Technology regarding fuel debris retrieval (cutting, suction).
2. Equipment/device such as remote control manipulator, with superior control capability from long distance.
3. Technology of shielding against fuel debris with high radiation.
4. Device and equipment under the high radiation environment.
5. Equipment/device to create a borehole on the building concrete and PCV to access from the side or bottom of the PCV.
6. Technology to store fuel debris safely in PCV/RPV before retrieving.

Announcement on RFI procedures and promotion for invitation

IRID has been promoting publication and application for RFI, and announcement of RFI procedures since fall of 2013 as well as providing reference information necessary for the study.

Announcement of RFI procedures and Promotion activity of RFI invitation



Outline of activities

- Established **Entry form** as well as opened **website for application** and announced procedures for RFI for applicant's convenience.
- **Held workshop in Japan and overseas for the publication of background and purpose of RFI and promoted invitation.**
Venue : UK, France, US, Canada, Germany and Japan.
 - Tens of people attended from related company, R&D agency for each workshop.
 - About 130 participants from Japan.
- **Disclosed reference technology data on the website for information collection for RFI**
 - Basic data of Fukushima Daiichi NPS (Structure /external dimension etc.)
 - Technical issues and status of R&D in Japan/overseas.
- Made announcements regarding implementation of RFI and uploading of reference information for followings.
 - Overseas and domestic related academic meeting , and industry organization.
 - Companies participated in previous workshop .

Results of RFI

About 60% of information was provided from Japan, and about 40% from overseas countries.

•Field of information for RFI		Total	Breakdown by country							
			JPN	US	UK	GER	FRA	BEL	CAN	RUS
Internal PCV/RPV investigation Topic A	A-1 : Conceptual study for the method.	33	20	7	3	-	2	-	1	-
	A-2 : Required technology	58	32	6	10	6	2	2	-	-
Fuel debris retrieval Topic B	B-1 : Conceptual study for the method	43	23	8	3	2	5	-	1	1
	B-2 : Required technology	60	41	7	3	4	2	2	-	1
Total (No. of items of information)		194	116	28	19	12	11	4	2	2

We deeply appreciate your valuable information.

Explanatory CG for Submersion Method for Fuel Debris Retrieval

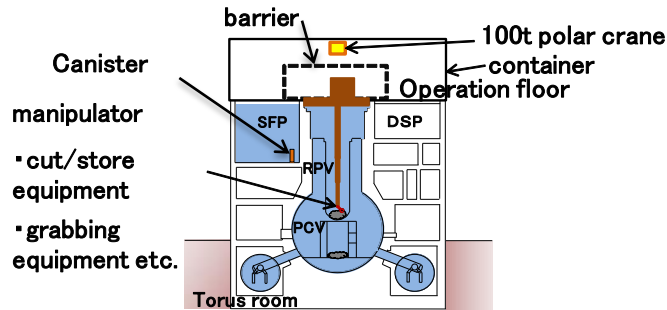
Definition of Technical Terms

Submersion method Method to retrieve fuel debris in a submerged condition in which fuel debris is cut and stored under water

Dry method Alternative method, in which fuel debris is cut and stored in air, or cut underwater but stored in air, against the Submersion method

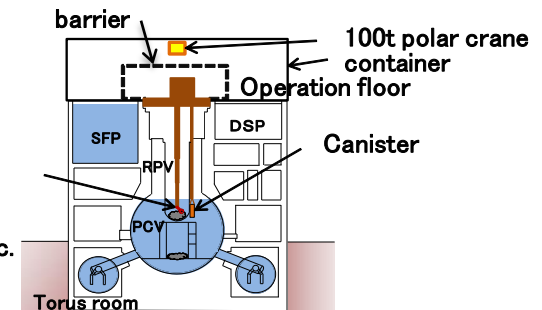
Examples

Submersion method



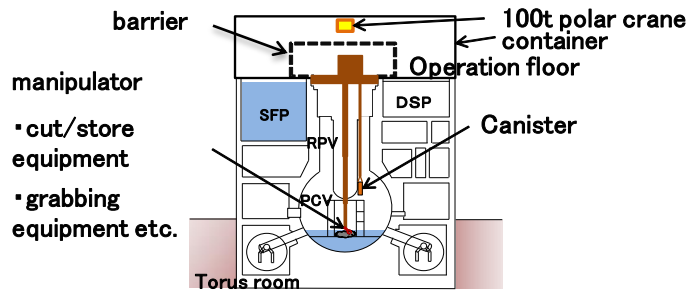
Fuel debris cut and stored under water

manipulator
 • cut/store equipment
 • grabbing equipment etc.

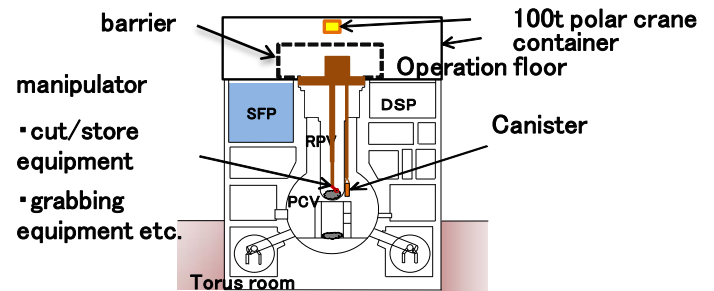


Fuel debris cut and stored under water (PCV partial submersion)

Dry method



Fuel debris stored in air



Fuel debris cut and stored in air

Categorizing Provided Information

Information handling process in IRID

Study of Provided Information



Brain Storming



Categorizing and Sorting



Clarification of Technological Key Factors

A variety of information was categorized and sorted out to obtain the grand view of the provided information.

表3 燃料デブリ取り出し代替工法についてご提供いただいた情報の分類とキーワード

トピックス	大分類	No.	中分類	提案内容*	キーワード
A-1: 概念検討	機体を内部に投入	1	上部(新たに穿孔して)	1	コアボーリング、SFPアクセス
		2	側面(既存のベネを通して)	3	スケーラム、水中からのアクセス、潜水艇型ハッチ、エアロック
		3	側面(新たに穿孔して)	3	遠隔操作、マニピュレータ、予知、廃棄、遊水の経路
		4	側面	2	コブリン、V線、X線、放射線
		5	下部	1	導流
	直接測定	6	放射線	8	中性子、γ線カメラ、スネーク型ロボット、SiC半導体検出器、放射線検出器マッピング、分光計、ダイヤモンドセンサ、放射線センサ、モニタリングセンサ
		7	熱	1	熱画像
		8	元素分析	2(4)	レーザー誘起プラズマ分光法(LIBS)、パルスレーザー、ラマン、質量、遠隔分析
		9	カメラ	10	内視鏡測定ツール、PIZカメラ、放射線センサ、温度センサ、光線電線、冷却機、放射線検出器、検出器、外部カメラ、水中
		10	ファイバースコープ	2	水中カメラ、石炭ガス、放射線
		11	超音波	6	ソナーマッピング、超音波、超音波、水中センサ(WBS)、3Dマッピング
		12	レーザースキャナ	2	測手法、水中、空中
		13	その他	1	放射線マッピング
		14	モニタリング	4	3D、可視化
		15	X線、γ線、中性子	3	γ線計測器、固体角検出器、デジタル線/カメラ検出器
A-2: 必要とされる技術	環境整備	16	AES	1	内部放射性レベル、音波、電気信号受検、非破壊的評価
		17	放射線管理-放射線量シミュレーション	5	3D、米臨界状態の確認、希ガス、K-88、シミュレーションソフト、パーソナルリアリティ、放射線分布地図
		18	水位	2	Sの水位、超音波浮力計(UF)、中性子後方散乱計測機、壁面移動車両
		19	ロボットセル	1	放射線計測、化学分析、除塵
		20	廃棄	1	シールドレーン、固体廃棄物、空輸廃棄物
	アクセス技術	21	マニピュレータ	5	モバイルプラットフォーム、ロボットセル、設置機
		22	ロボット(水中)	2	潜水艇、潜水ロボットシステム
		23	ロボット(陸上)	6	クローラ、滑車、測定器搭載
		24	ロボット(水陸兼用)	6	スケーラム、固定装置、可搬装置、試験環境、ロボット性能向上、遠隔操作無人搬送機、スイングドランツァ、小気流装置、アクセスプラットフォーム
		25	切断・穿孔	6	ハイビットコアドリル、遠隔、超高温液体窒素冷却付けによる穿孔、研摩材進入による腐蝕抑制、レーザー切断、高圧水、高圧水、高圧水、高圧水
		26	放射線検出器	10	電子線線、固体角検出器、無線LAN、遠隔用光ファイバケーブル、石英ガラススロッド、ダイヤモンドセンサー、放射線、放射線、放射線
		27	上部	5	放射線ガスで汚染したデブリを浮上させる方法、遊離させ止水する方法など
		28	下部	2	遊離させ止水してからアクセスする方法
		29	上部	7	閉鎖プラグを用いた工法、プラットフォームを下り上りから上に解体する工法、マニピュレータを用いた方法、上部から放射線吸収材のカバーを設置する方法、放射線シールドによる放射線遮蔽する方法など
		30	上部・側面併用	7	プラットフォームを下り上りから上に解体する工法、開口部に遠隔操作可能な部屋を設ける工法など
B-1: 概念検討	長工中工*	31	側面	7	デブリ・炉内構造物を搬出し、ロボットアームで取り出す工法、新たなエアロックを設ける工法など
		32	下部	4(1)	遠隔で高温高圧で回収する方法など
		33	化学的方法	3	放射線化学的方法による回収、電気メッキ手法
		34	RPV/PCV以外	2	RPV/PCV以外の場所にデブリがある場合の回収方法
		35	その他	2(4)	遠隔で回収する方法など
	環境整備	36	機械的	5(2)	放射線、カメラ、フロッピーディスク、超高温液体窒素、放射線検出器
		37	閉鎖(プラグスチ)	1	アーク、ジレット
		38	熱的(レーザー)	8(1)	遠隔、ファイバレーザ、レーザー誘起プラズマ装置、超音波による距離把握、水中切断、気中切断、CO2レーザ
		39	真空固化	4	Hot Isostatic Pressing, Impenetrable Graphite Mtn、保管計画立案
		40	分選	1	中性子γ線によるデブリの測定
		41	容器(一時保管)	4	輸送、廃棄、コンテナ、キャニスター
		42	継ぎ目管理	2	表面汚染サーベ-設備、シミュレーションソフト、3Dパーソナルリアリティ
		43	遊離	5(1)	ガス分離装置、中性子遮蔽材料、黄鉄鉱を用いた重コンクリート、鉄スケール、遊離剤、液体状遊離剤、遊離剤
		44	除去	3	化学除去、RTVレジシ
		45	止水	2(2)	流動性セメント、流動性グラウト材
アクセス技術	46	充填機	3	パルス、スライダ、可動装置、ロボット駆動	
	47	マニピュレータ	12	パルスレーザー、放射線マニピュレータ、遠隔操作付、モバイルプラットフォーム、大型マストアーム、遠征式、双腕型グリッパ、放射線検出器、CFRP製	
	48	ロボット(デブリ除去)	3(1)	キャット、遠隔操作機、遠隔操作機	
	49	切断・穿孔	1	高圧水スライダ、遠隔操作機	
	50	デブリセル	7	固定装置、スタック制御防止、自立非遊離空中放射線検出装置、公害方法など	
Q-その他	デブリセル	50	デブリセル		

(Please see handout)

Categorizing Provided Information

A: PCV/RPV internal investigation

A-1: Conceptual study

1 st tier classification	No.	2 nd tier classification	Number of responses
Placing equipment in PCV/RPV	1	From top (through new boreholes)	1
	2	From side (through existing penetrations)	3
	3	From side (through new boreholes)	3
Measurement from outside of PCV	4	From side	2
	5	From bottom	1

A-2: Support technology

1 st tier classification	No.	2 nd tier classification	Number of responses
Direct measurement	6	Radiation	8
	7	Thermal	1
Direct observation	8	Element analysis	2 (2)
	9	Camera	10
	10	Fiber scope	2
	11	Ultrasonic waves	6
	12	Laser scanner	2
	13	Others	1
Indirect measurement	14	Muon	4
	15	X-rays, γ-rays and neutron	3
	16	AE method	1
Work environments maintenance	17	Criticality control & exposure simulation	5
	18	Water level	2
	19	Hot cell	1
Access technology	20	Lighting	1
	21	Manipulator	5
	22	Robot (underwater)	2
	23	Robot (land)	6
	24	Robot (amphibious)	6
	25	Cutting and boring tools	6
	26	Radiation-resistant components	10

* Category of topics may be different from the one registered by applicant since IRID individually re-evaluates the information. The number in the bracket is the one of RFI submitted for Contaminated water issue, which is re-evaluated from the viewpoint of RFI for fuel debris.

Categorizing Provided Information

B: Debris retrieval from PCV/RPV / C: Others

B-1: Conceptual study

1 st tier classification	No.	2 nd tier classification	Number of responses
Submersion method	27	From top	5
	28	From bottom	2
Dry method	29	From top	7
	30	From top - from side (combined approach)	7
	31	From side	7
	32	From bottom	4 (1)
Others	33	Chemical method	3
	34	Other than PCV/RPV	2
	35	Others	2 (6)

B-2: Support technology

1 st tier classification	No.	2 nd tier classification	Number of responses
Debris cutting	36	Mechanical	5 (2)
	37	Thermal (plasma)	1
	38	Thermal (laser)	8 (1)
Debris retrieval	39	Sorting	4
	40	Category	1
	41	Container (for temporary storage)	4
Work environments maintenance	42	Exposure management	2
	43	Shielding	5 (1)
	44	Decontamination of containers	3
	45	Water stoppage	2 (2)
	46	Water treatment	3
Access technology	47	Manipulator	12
	48	Robot (for debris retrieval)	3 (1)
	49	Cutting and boring tools	1

C: Others

1 st tier classification	No.	2 nd tier classification	Number of responses
Outside the scope of RFI	50	Outside the scope of RFI	7

- Submersion method (both processes of cutting off fuel debris and storing into storage container are carried out underwater).
- Dry method (either or both processes of cutting and storing fuel debris is carried out in the air).

Introduction of Provided Information

- Methods -

Internal investigation

Major issues

- Ensure work space
- Ensure boundaries

Transport equipment

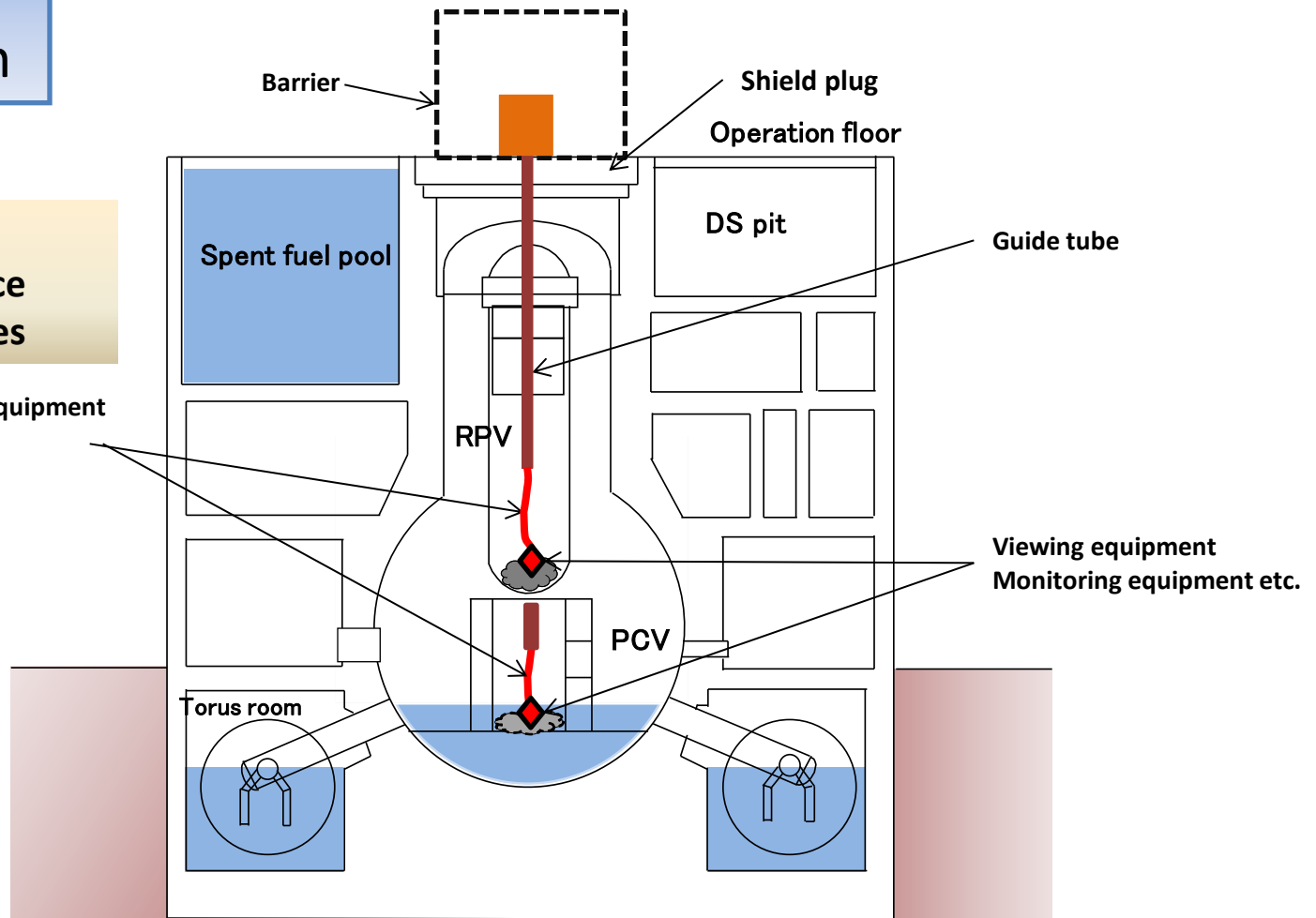


Fig 1. Method to drill from the top (from shield plug) 【category 2nd tier No.1】

Internal investigation

Major issues

- Ensure boundaries
- Location of drilling/drilling technology

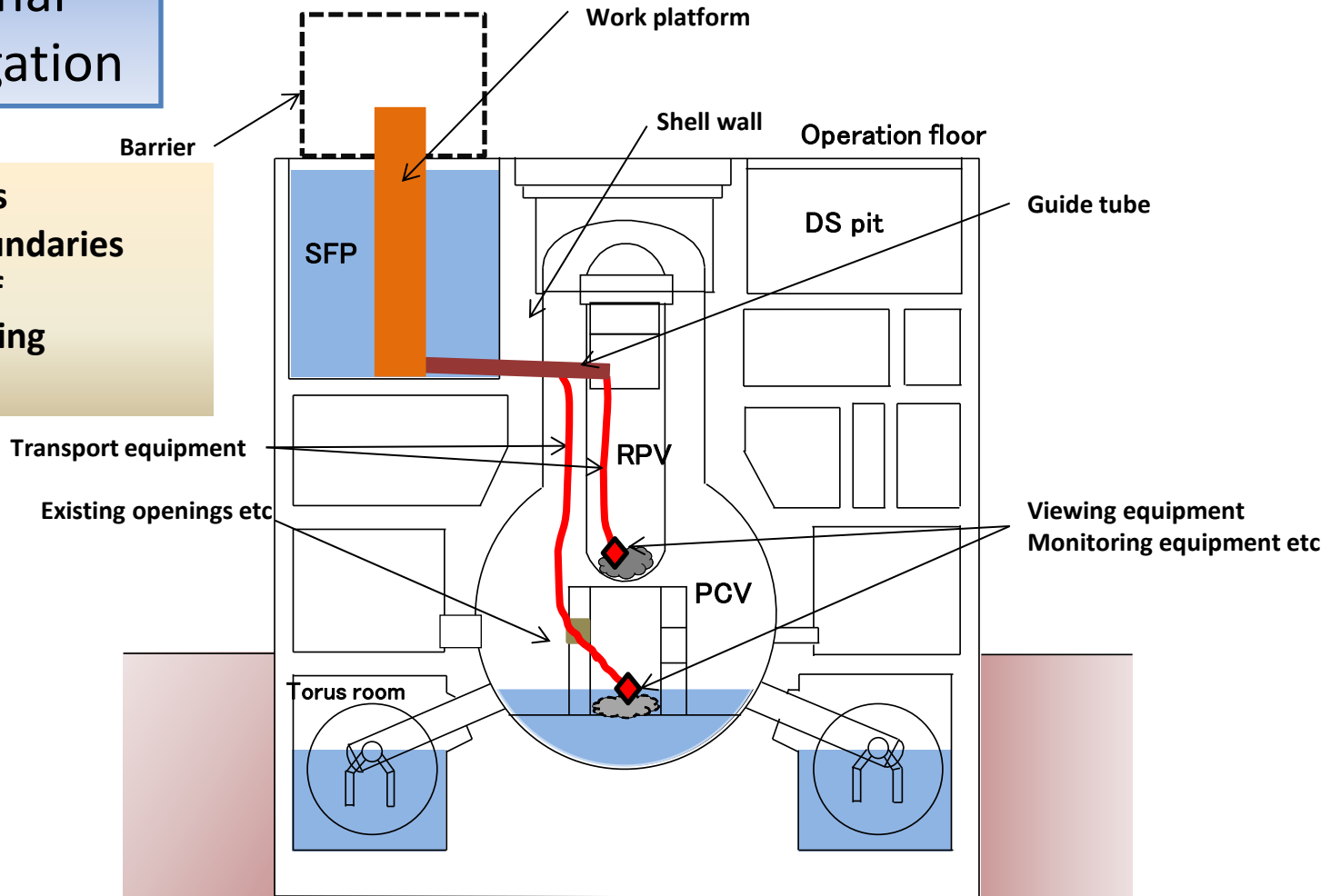


Fig 2. Method to drill from the top (from SFP) [category 2nd tier No.1]

Internal investigation

Major issues

- Access distance
- Access method to RPV

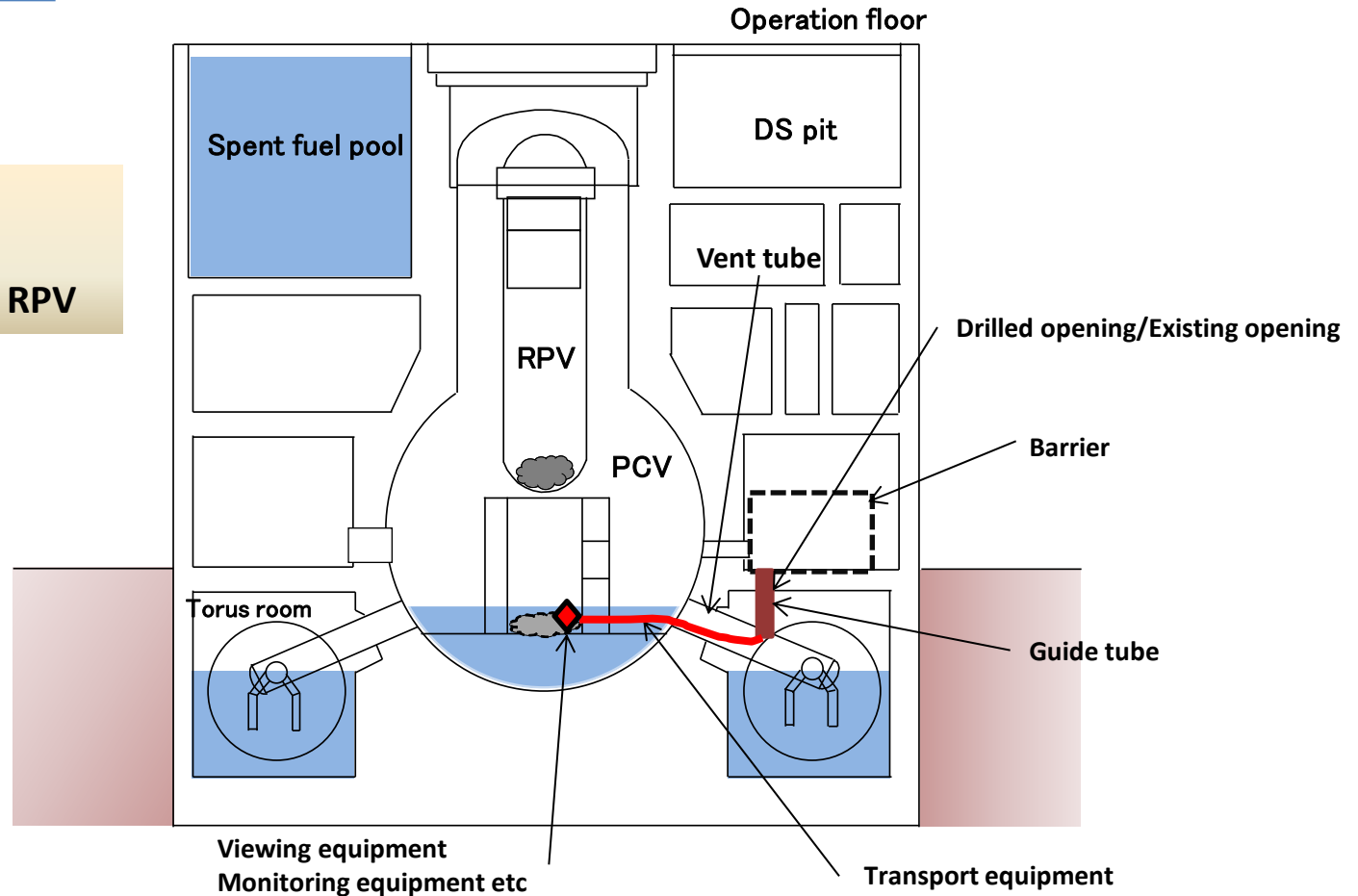
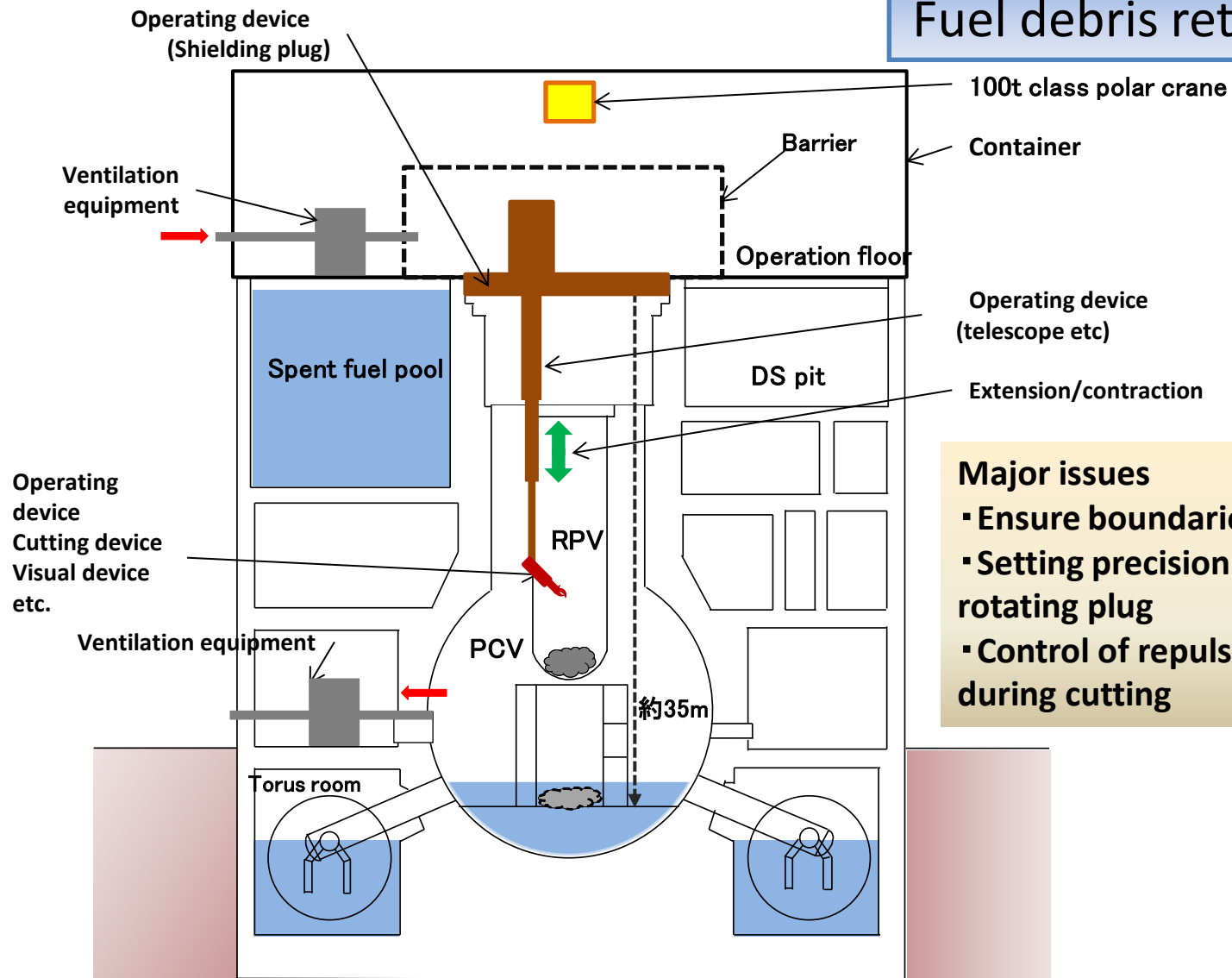


Fig 3. Method to survey lower PCV from vent tube [category 2nd tier No.2]

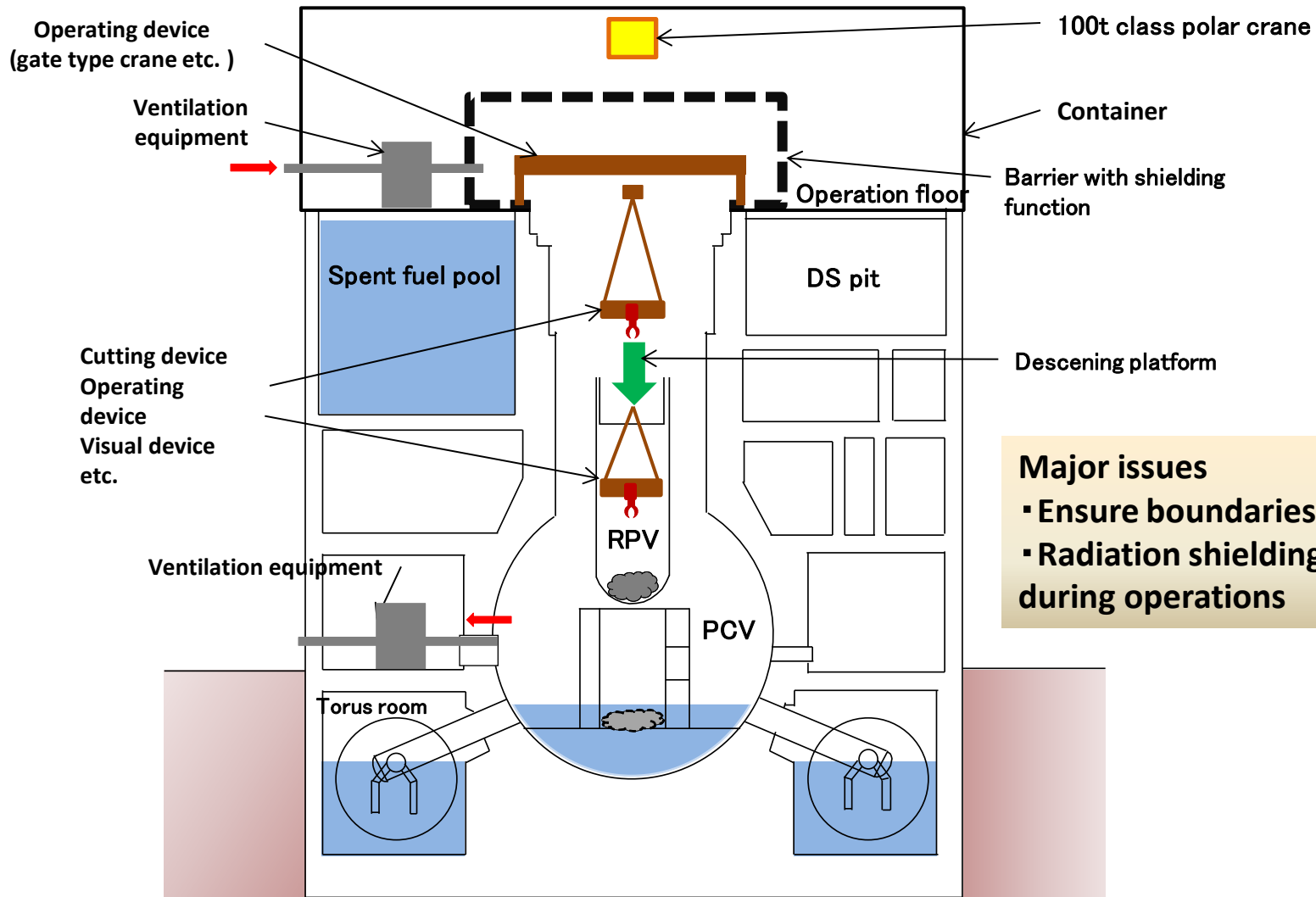
Fuel debris retrieval



- Major issues**
- Ensure boundaries
 - Setting precision of the rotating plug
 - Control of repulsive force during cutting

Fig 4. Method to retrieve fuel debris in air by rotating plug 【category 2nd tier No.29】

Fuel debris retrieval



Major issues

- Ensure boundaries
- Radiation shielding during operations

Fig 5. Method to retrieve fuel debris in air by descending work platform

【category 2nd tier No.29】

Fuel debris retrieval

Major issues

- Ensure boundaries
- Radiation shielding during operations
- Location of entrance opening

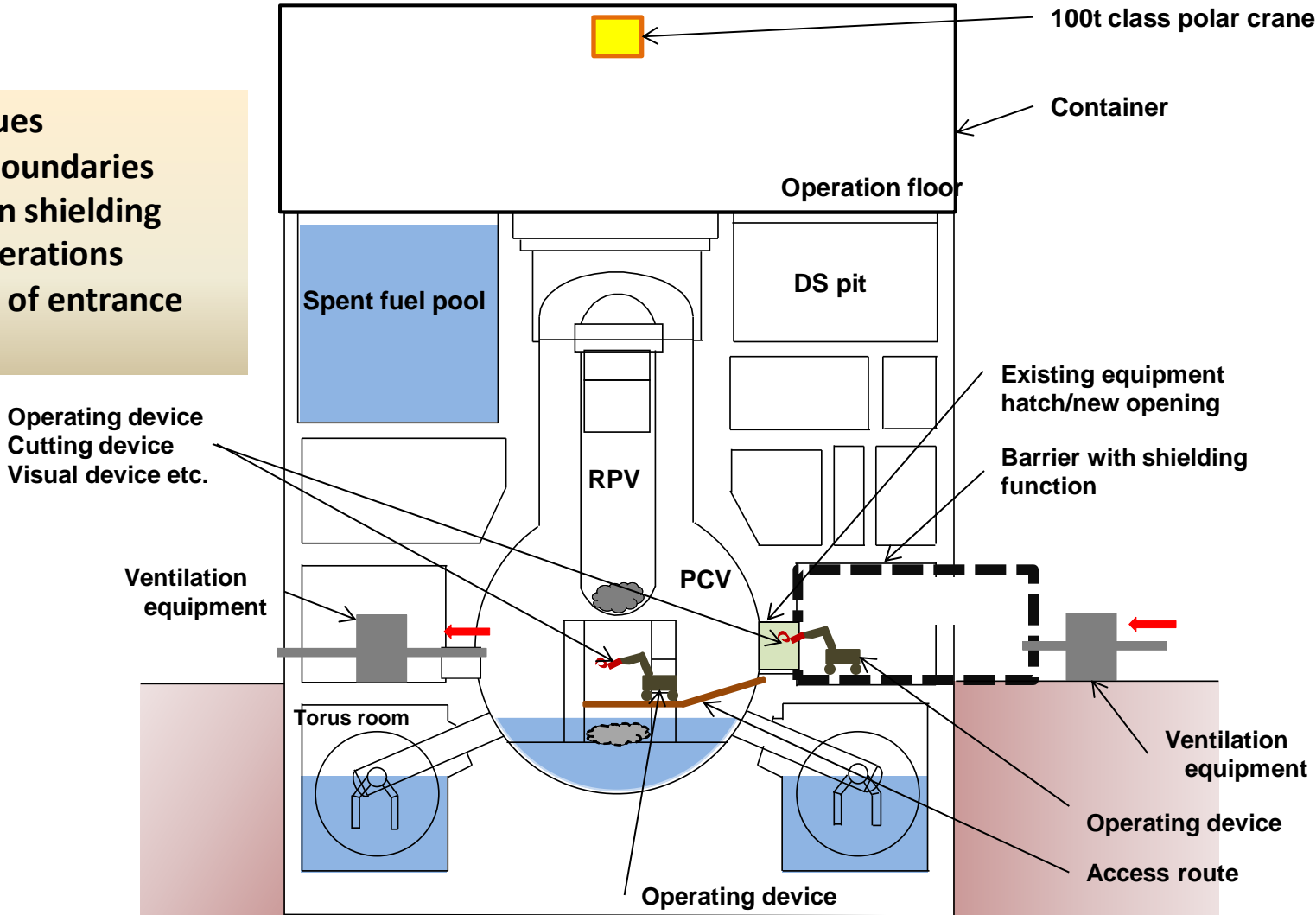


Fig 6. Method to retrieve fuel debris in air from the side [category 2nd tier No.31]

Introduction of Provided Information

- Technology -

Visual technology e.g. Camera, endoscope, and fiber scope

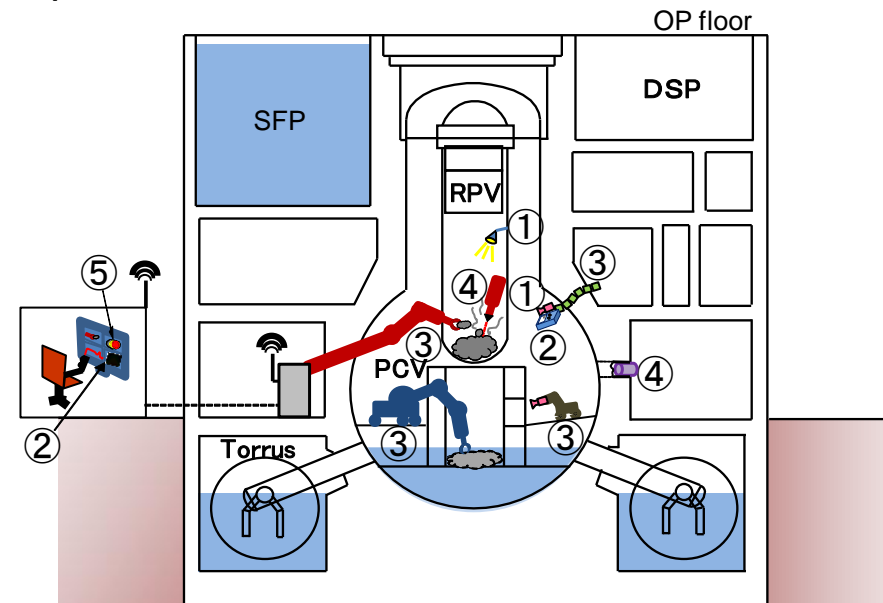
Monitoring technology e.g. Radiation measurement, ultrasonic probe, laser scanner, and element analysis

Transport technology e.g. Self-propelled robot (snake type, crawler type, and submergence type), manipulators (elevator, moving mechanism)

Cutting technology e.g. Plasma cutting, laser cutting, mechanical cutting, and core boring

Supporting technology e.g. Criticality control, debris stabilization/solidification, radiation resistant parts, etc.

A variety of technological information from the radiation resistant camera to various manipulators to laser cutting techniques was provided.



Key Factors for Methods and Technology

- **Maintain boundaries** to prevent release of radioactive materials and contamination
- **Enable remote control** to keep low exposures for workers
- **Avoid interference** with existing structures
- **Adapt to operations in air** (high dose and high humidity)
- **Facilitate maintenance** and/or enable long continuous use

In addition, for fuel debris retrieval operations,

- **Establish support facility**, such as, ventilation/water filtering/fuel debris cooling
- **Consider fitness** of large scale equipment to conditions of each unit
- **Ensure superb radiation resistance** for operations in fuel debris vicinity

These factors will be reflected to the specifications of RFP.

Category and Keywords of Information Provided for Innovative Approach for Fuel Debris Retrieval

Topics	1 st tier classification	No.	2 nd tier classification	Number of responses ^{*1}	Keywords	
A: PCV/RPV Internal Investigation	A-1: Conceptual study	Placing equipment in PCV/RPV	1	From top (through new boreholes)	1	Core boring, Access from SFP
			2	From side (through existing penetrations)	3	Snake-arm, Access from under the water, Submarine-type hatch, airlock
			3	From side (through new boreholes)	3	Remote-control, Manipulator, Decommissioning, Decontamination, Track record
		Measurement from outside of PCV	4	From side	2	Muon, γ-ray, X-ray, Ultrasonic wave
			5	From bottom	1	Sound wave
	A-2: Support technology	Direct measurement	6	Radiation	8	Neutron, γ-ray camera, Snake type robot, SiC semiconductor measuring instrument, Radiation Intensity Mapping, Spectrometer, Diamond sensor, Radiation Resistance Sensor, Sensor Assembly
			7	Thermal	1	Decay heat
			8	Element analysis	2 (2)	LIBS (Laser-Induced Breakdown Spectroscopy), Pulse laser, Plasma, Bright line, Remote analysis
		Direct observation	9	Camera	10	Bore camera, PTZ camera, Sensors (radiation, temperature), Photoconductor, Cold cathode, Radiation resistance, Resolution, Outer cover, Underwater
			10	Fiber scope	2	Revolver, Quartz glass, Radiation resistance
			11	Ultrasonic waves	6	Sonar mapping, Image analysis, Ultrasonic velocity profiler method, Non-linear method, WBS (Water-Borne Sensor), 3D mapping
			12	Laser scanner	2	"as-built" dimension survey, Underwater, In-the-air
			13	Others	1	Debris location search
		Indirect measurement	14	Muon	4	3-D, Visualization
			15	X-rays, γ-rays and neutron	3	γ-ray measuring instrument, Solid state track records, Digital x-ray panel detector
			16	AE method	1	Internal elastic energy, Sound wave, Electric signal conversion, NDE
		Work environments maintenance	17	Criticality control & exposure simulation	5	3D, Sub-criticality monitoring, Inert gas, Kr-88, Simulation software, Virtual reality, Radiation dose rate map
			18	Water level	2	S/C water level, UT probe, Neutron back-scattering, On-the-wall vehicle
			19	Hot cell	1	Radioactive specimens, Chemical analysis, Isolation
			20	Lighting	1	Scintillators, Zinc sulfide, Solar power
		Access technology	21	Manipulator	5	Multi-segment arm, Long-reach, Weight reduction
			22	Robot (underwater)	2	Submersibles, Submarine robot system
			23	Robot (land)	6	Crawler, Submergence, Sensor-loading
			24	Robot (amphibious)	6	Snake-arm, Magnetic adhesion, Spring steel, Surrogate environments, Test facility, Improvement of robotic systems performance, Remotely operated vehicle, Swing-drive mechanism, Small linkage system, Archimedes screw
			25	Cutting and boring tools	6	High-speed core drill, Remote control, NitroJet boring, Steel plate cutting with abrasive, Laser cutting, Compact repulsive force, Tunneling technology
	26		Radiation-resistant components	10	Electronic devices, Water-driven controller, Wireless LAN, Optical fiber cable, Quartz glass large diameter fiber, High light energy transmittance, High power laser beam, 1MGy radiation resistance, Integrated circuits.	
B: Debris retrieval from PCV/RPV	B-1: Conceptual study	Submersion method ^{*2}	27	From top	5	Collecting floating crushed debris by carbon dioxide gas, Water stoppage by freezing etc.
			28	From bottom	2	Access from the bottom in the state of being submerged.
		Dry method ^{*2}	29	From top	7	Rotating plug method, Dismantling from top portion by pulling down the platform, Using manipulator, Pulling down the capsule storing equipment from the top, Shielding by iron cube
			30	From top - from side (combined approach)	7	Hanging type work platform, Setting up a room with opening equipped with shielding function
			31	From side	7	Retrieving the cut debris and reactor internals by robot arm, Installing new airlock
	32		From bottom	4 (1)	Collecting from the bottom of the building through the drilled hole	
	Others	33	Chemical method	3	Dissolution of debris by chemical agents, Electroplating	
		34	Other than PCV/RPV	2	Removing debris in the areas other than RPV/PCV	
		35	Others	2 (6)	Embedding the building itself etc	
	B-2: Support technology	Debris cutting	36	Mechanical	5 (2)	Excavator, Cutter, Water jet, High pressure liquid nitrogen, Electric discharge impulse crushing
			37	Thermal (plasma)	1	Arc, jet
			38	Thermal (laser)	8 (1)	Remote-control, Fiber laser, Removal apparatus for laser coating film, Detecting distance by ultrasonic measurement, Underwater cutting, Dry cutting, CO2 laser
		Debris retrieval	39	Sorting	4	Hot Isostatic Pressing, Inprementable Graphite Matrix, Storage plan
			40	Category	1	Differentiation of debris and non-debris by neutron or γ-ray
			41	Container (for temporary storage)	4	Transport, Treatment, Container, Canister
		Work environments maintenance	42	Exposure management	2	Surface contamination meter, Simulation software, 3D virtual reality
			43	Shielding	5 (1)	Gamma-ray-shielding materials, Neutron shielding, Heavy concrete using pyrite, Iron scale, shield analysis, Liquid shielding, High specific weight resin
			44	Decontamination of containers	3	Chemical decontamination, RTV resin
			45	Water stoppage	2 (2)	Flexible cement or grout
46			Water treatment	3	Gelation, Sludge, Polyphosphoric acid, Chelate collection	
Access technology		47	Manipulator	12	Lifting telescope, Lifting wires, Movable leg, MTP (Mobile Tool Platform), Large mast arm, Oil pressure type, Double gripper, Radiation resistant ability, CFRP	
		48	Robot (for debris retrieval)	3 (1)	Caterpillar, Construction robot w/o human intervention	
		49	Cutting and boring tools	1	Dry type drill, Remote dismantling machine	
C: Others	Outside the scope of RFI	50	Outside the scope of RFI	7	Search strategy, Stack fall-down prevention, Aerial radiation monitoring by drone, RFI/RFP method etc.	

*1 Category of topics may be different from the one registered by applicant since IRID individually re-evaluates the information. The number in the bracket is the one of RFI submitted for Contaminated water issue, which is re-evaluated from the viewpoint of RFI for fuel debris.

*2 Submersion method (both processes of cutting off fuel debris and storing into storage container are carried out underwater), Dry method (either or both processes of cutting and storing fuel debris is carried out in the air).