DECOMMISSIONING PLAN AND CONSIDERATION OF DISMANTLING METHODS FOR RESEARCH REACTOR JRR-4

Yasuhiro ISHIKURO

Department of Decommissioning and Waste Management
Japan Atomic Energy Agency

1. INTRODUCTION

1.1 Outline of JRR-4 (Japan Research Reactor No.4)
1.2 Post-quake situation
1.3 Determination of decommissioning
1.4 Carrying out spent fuel

2. DECOMMISSIONING PLAN

2.1 Target of decommissioning
2.2 Evaluation of radioactivity
2.3 Evaluation of total amount of waste
2.4 Evaluation of exposure
2.5 Selection of maintain facilities
2.6 Decommissioning program

3. EXPORT FUEL,ETC

3.1 Permanent shutdown
3.2 Export of fuel

4. CONSIDERATION OF DISMANTLING METHODS

4.1 Sampling for pre-evaluation
4.2 measurement high activity facilities of dose rate
4.3 Confirmation of validity of evaluation results and identification of radioactive source nuclide
4.4 Consideration of dismantling method

1. INTRODUCTION

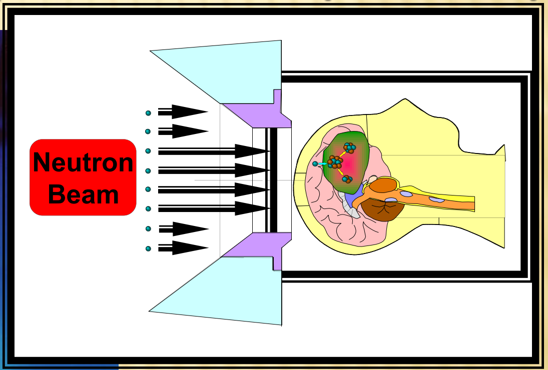
1.1 OUTLINE (1/7) (SPECIFICATION)

Reactor Type	Swimming pool type reactor moderated and cooled with light-water
Date of first critical	With high enriched fuel :1965.1.28 With low enriched fuel :1998.7.14
Maximum Thermal Power	3.5MW
Maximum Thermal Neutron Flux	$7 \times 10^{17} n/m^2/s$
Maximum Pressure	0.1 MPa
Maximum Coolant Temperature	60 ℃
Control Rod	Boron added Stainless Steel
Operation Mode	Daily Operation

1.1 OUTLINE (2/7) (UTILIZATION)

Radiation shielding experiment

Medical irradiation
(Boron Neutron Capture Therapy)

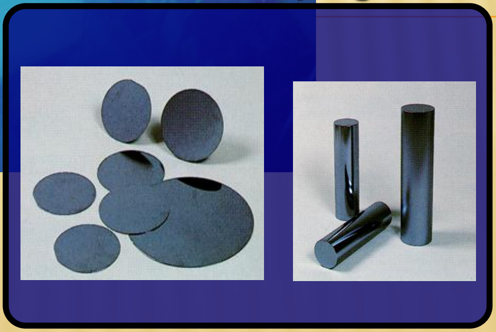


Production of Radioisotopes

Education and training for engineers

Neutron Activation Analysis

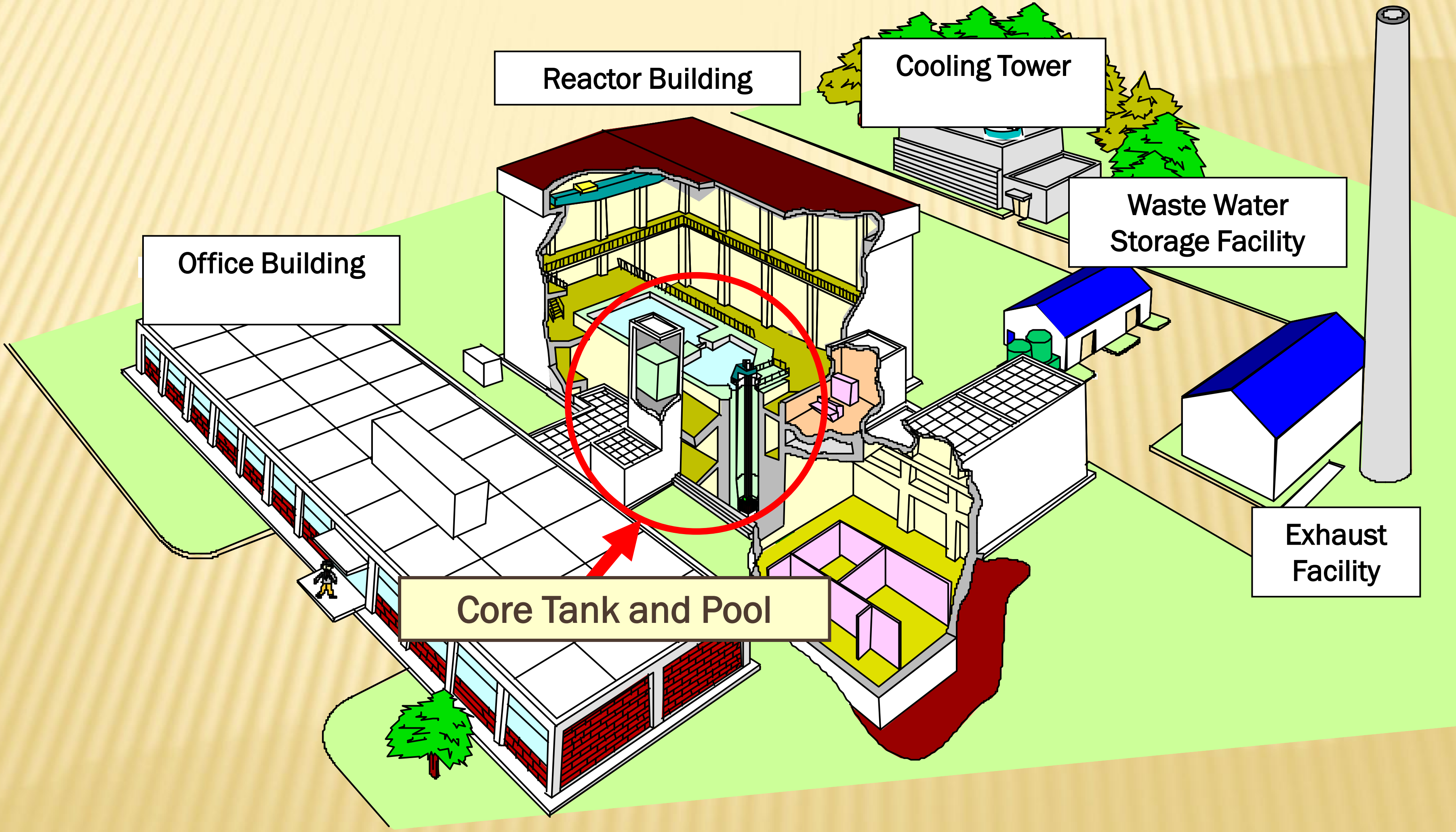
Silicon doping



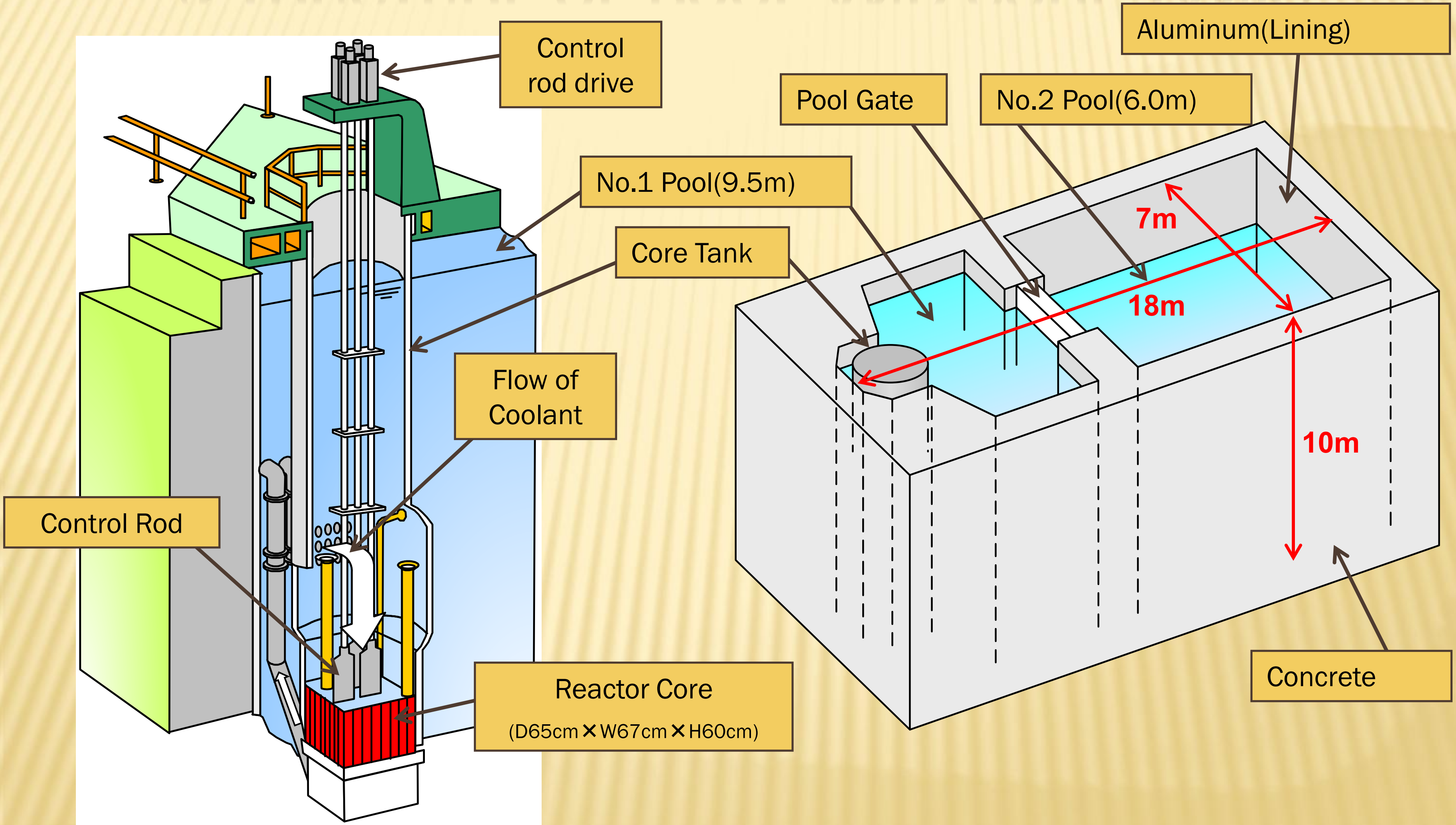
1.1 OUTLINE (3/7) (HISTORY)

Date	Item
Jun. 1962	Beginning of JRR-4 construction
Jan. 28,1965	Initial criticality with HEU fuels
Nov. 1965	Beginning of 1000kW operation
Nov. 1965	Shielding experiment
Mar. 1966	Power up to 2500kW
Jun. 1969	Beginning of Joint utilization operation
Oct. 1976	Power up to 3500kW
Jan. 12,1996	Terminated the reactor operation with HEU fuels ・ total output power: 58,666Mwh ・ total operation times: 29,379 hours
Jan. 1996	Beginning of modification works
Jul. 14, 1998	Criticality with LEU fuels
Dec. 24, 2010	Terminated the reactor operation with LEU fuels ・ total output power: 20,868Mwh ・ total operation times: 9,441 hours
Mar. 11,2011	The Great East Japan Earthquake
Sep. 2013	Determination of decommissioning of JRR-4

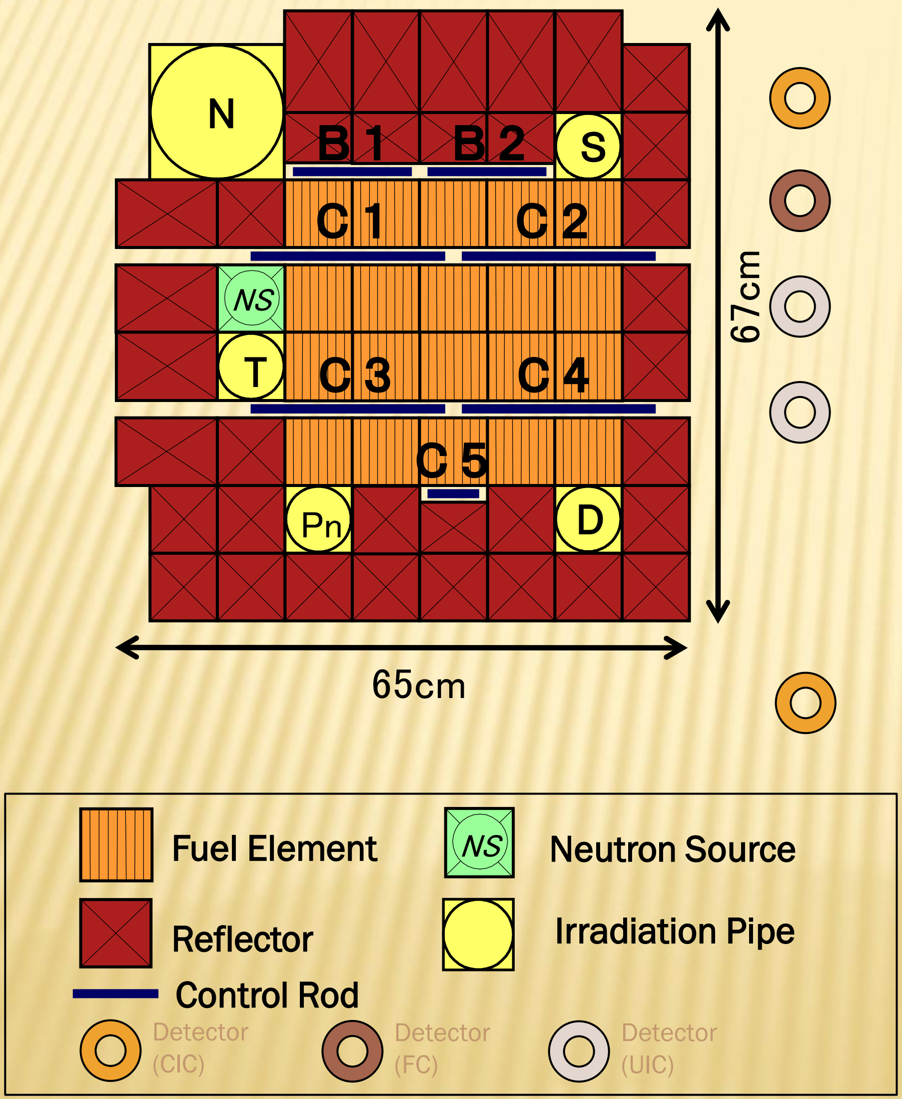
1.1 OUTLINE (4/7) (BIRD'S EYE VIEW)



1.1 OUTLINE (5/7) (STRUCTURE OF POOL AND CORE TANK)

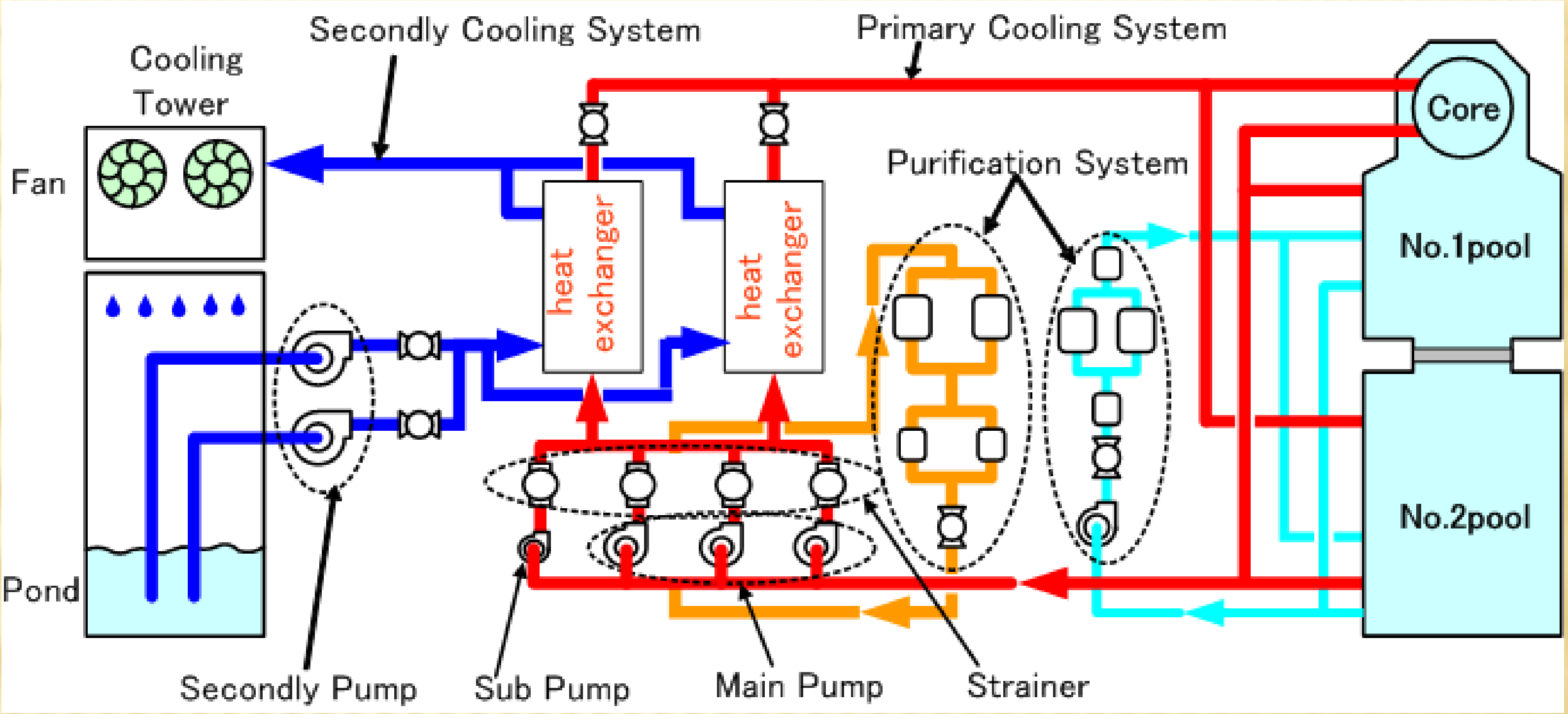


1.1 OUTLINE (6/7)
(LAYOUT OF REACTOR CORE)

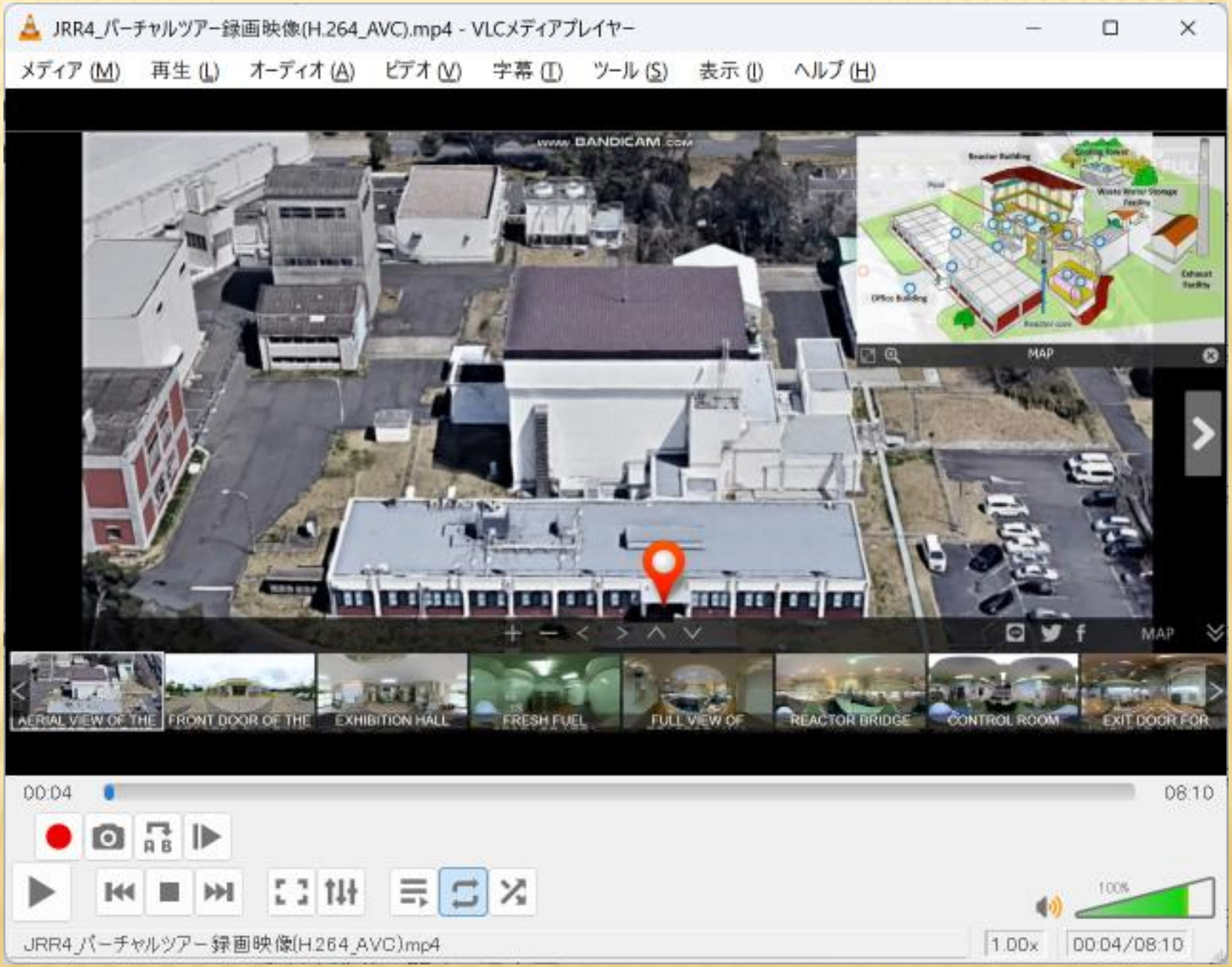


- Number of Fuel Element
  20 Elements
- Control Rod
  - C1~C4 : Shim Safety Rod
  - C5 : Regulating Rod
  - B1,B2 : Backup Safety Rod (for emergency shut down)
- Reflector
  Graphite(covered by aluminum case)

1.1 OUTLINE (7/7) (COOLING SYSTEM)

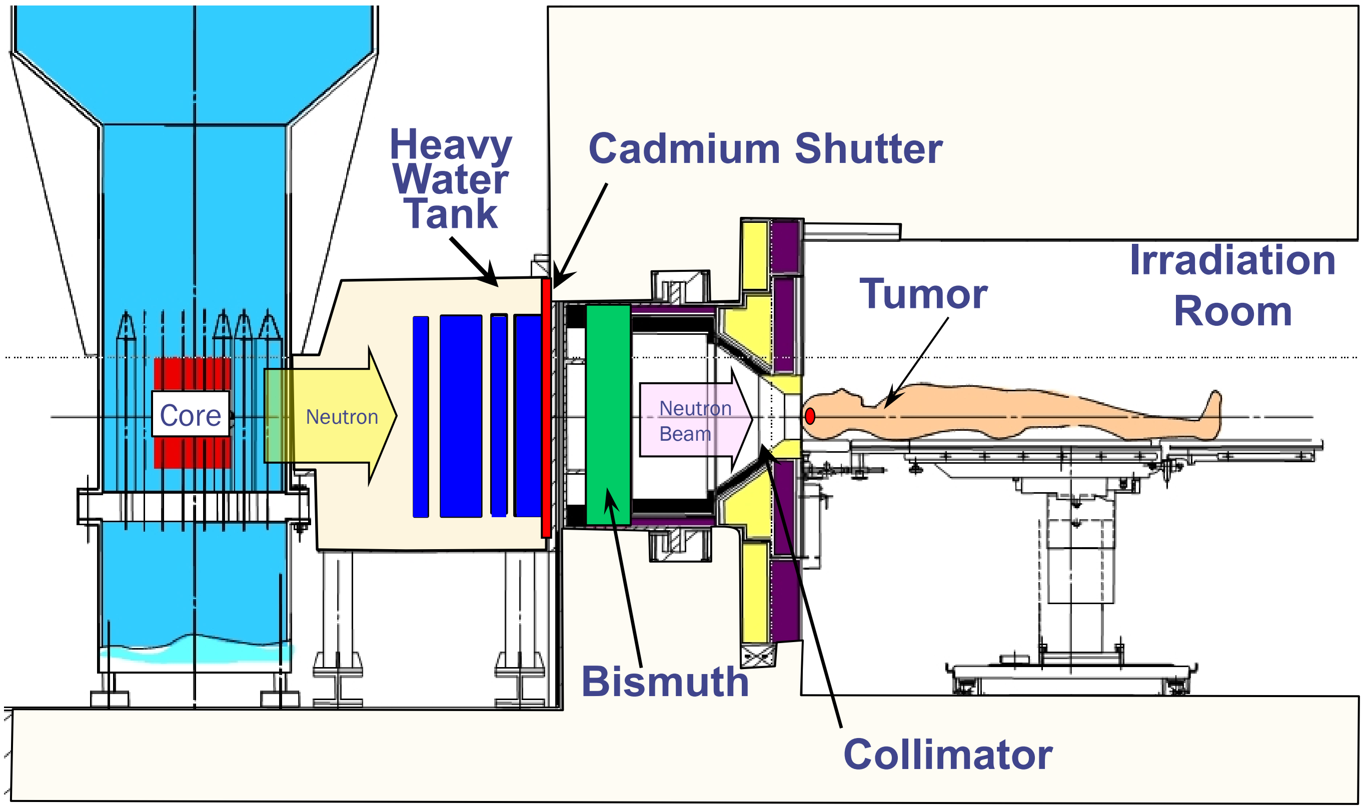


WATCH THE VIRTUAL TOUR OF THE JRR-4



Appendix BNCT(1/2)

Research for BNCT (Boron Neutron Capture Therapy)



Neutron Beam Facility for BNCT

History of clinical trials of BNCT in JRR-4

1999～ :BNCT with thermal neutron beam

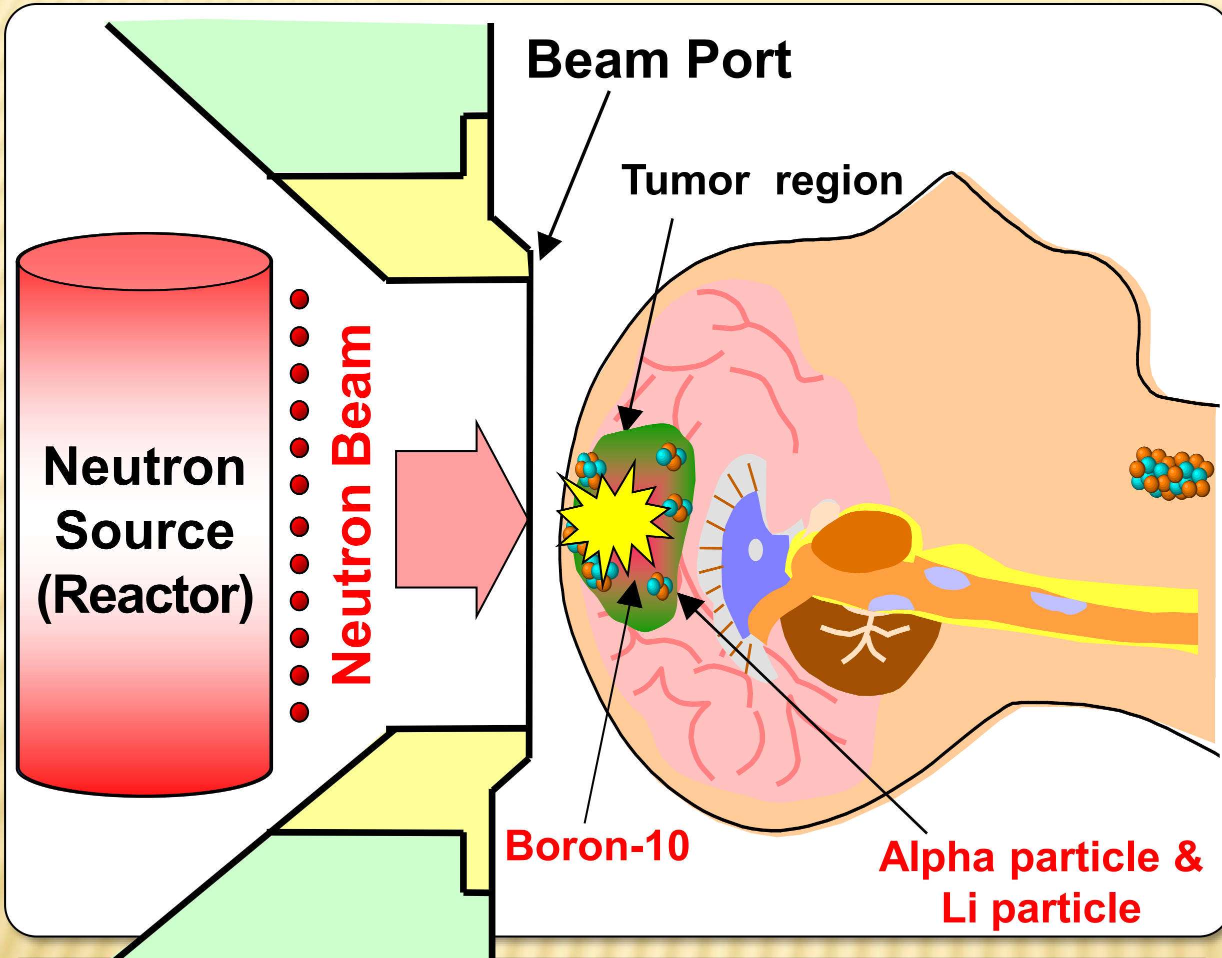
2004～ :BNCT with epithermal neutron beam

2005～ :BNCT for Melanoma and Head-&-Neck cancer

2006～ :BNCT for Pulmonary sarcoma

Appendix BNCT(2/2)

Principle of Boron Neutron Capture Therapy (BNCT)



Irradiation room

BNCT in the world

JRR-4(Japan)	KUR(Japan)
MITR-Ⅱ(USA)	BMRR(USA)
BGRR(USA)	FiR(Finland)
TRIGA Ⅱ (Italy)	RA-3(Argentina)
THOR(Taiwan)	HANARO(Korea)
IHNI-1(China)	
HFR(Netherlands)	

At present, BNCT is conducted using accelerator in stead of reactor. Because one is that it is now possible with accelerators, and the other is that regulations for accelerators, which are radioactive facilities, are more relaxed than for reactors.

1.2 POST-QUAKE SITUATION

【March 11, 2011 (Fri.) 14:46 】

- The Great East Japan Earthquake occurred with the seismic energy of magnitude 9.0.
- JRR-4 was not operated for periodic inspection.
  - Nuclear fuels and reactor containment systems were checked.
  - Fuels stayed in normal position. No damage.
  - Containment systems were not serious damage.
  - No radioactive leakage
- All recovery works have almost been completed until 2013.

1.3 DETERMINATION OF DECOMMISSIONING

Because of earth quake, Japanese regulation was very strict. Moreover budget was decreased.

- Nuclear facilities in JAEA were planned to be decommissioned considering
  - Importance
  - Aging condition
  - Necessary expense
  - etc.

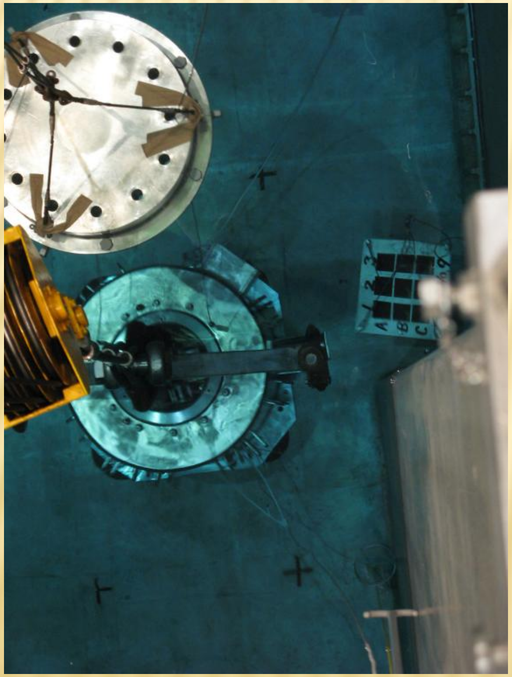
JRR-4 was decreasing needs before quake, aging, very high cost to apply for new regulation.

- We have determined to decommission JRR-4 In September 2013.

1.4 CARRYING OUT SPENT FUEL

- After decommissioning decision, before applying for decommissioning plan, spent fuel were carried out from JRR-4 based on the current permission of the operation stage.

  - Risk reduction
  - Limited maintenance facilities



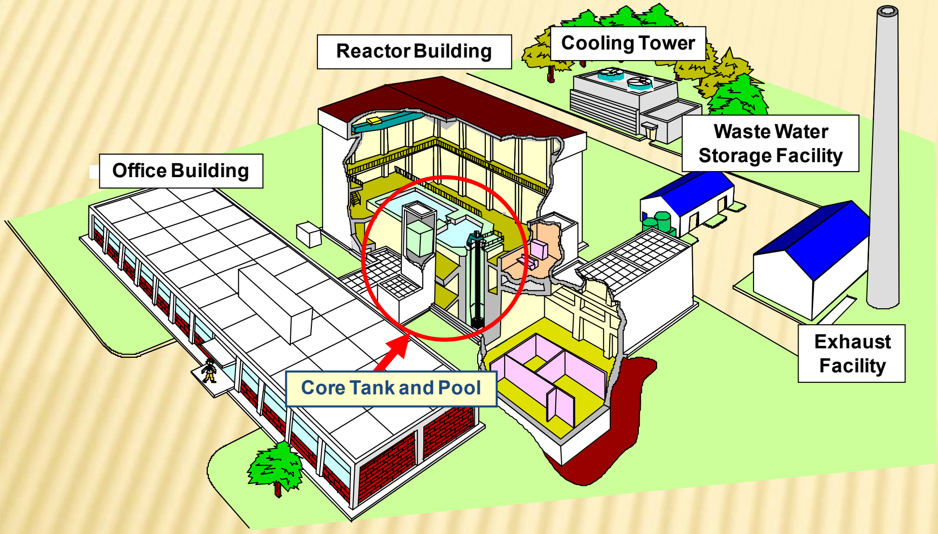
Opening the spent fuel cask

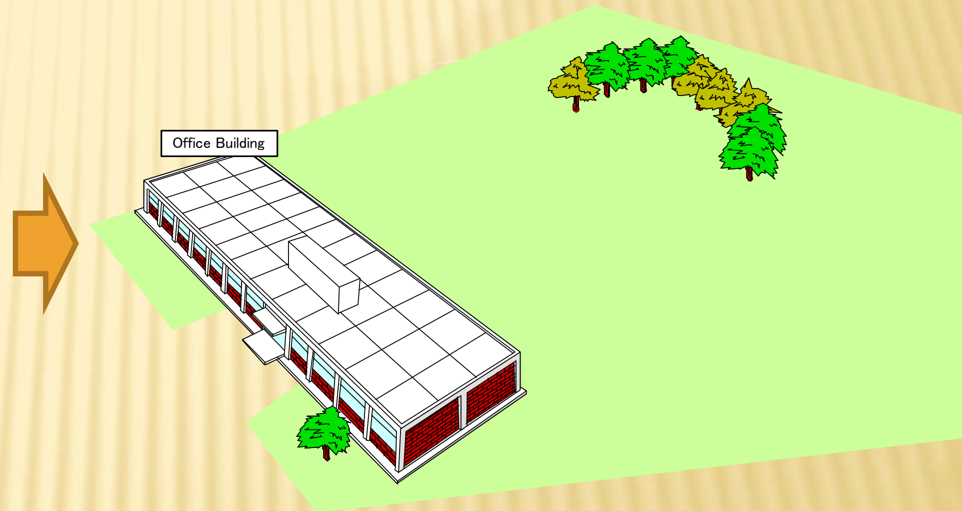
Measurement of spent fuel cask

2. DECOMMISSIONING PLAN

- It is necessary to get the approval of decommissioning plan from the nuclear regulatory body for decommissioning research reactors in Japan.
- Decommissioning plan includes several contents
  - Target of decommissioning
  - Evaluation of radioactivity
  - Evaluation of total amount of waste
  - Evaluation of exposure
  - Selection of maintain facilities
  - Decommissioning program
  - Etc.
- We have submitted the decommissioning plan of JRR-4 to the Nuclear Regulatory body and have received approval of it on June 7, 2017.

2.1 TARGET OF DECOMMISSIONING





Before decommissioning

After decommissioning

2.2 EVALUATION OF RADIOACTIVITY(1/4)

● Activation radioactivity
- It exists near the reactor core
- Effective dose near the reactor core is very high.
- It is important to evaluate the activation radioactivity accurately for the purpose of the reduction of excess waste and costs.

↓

Evaluation using Calculation code

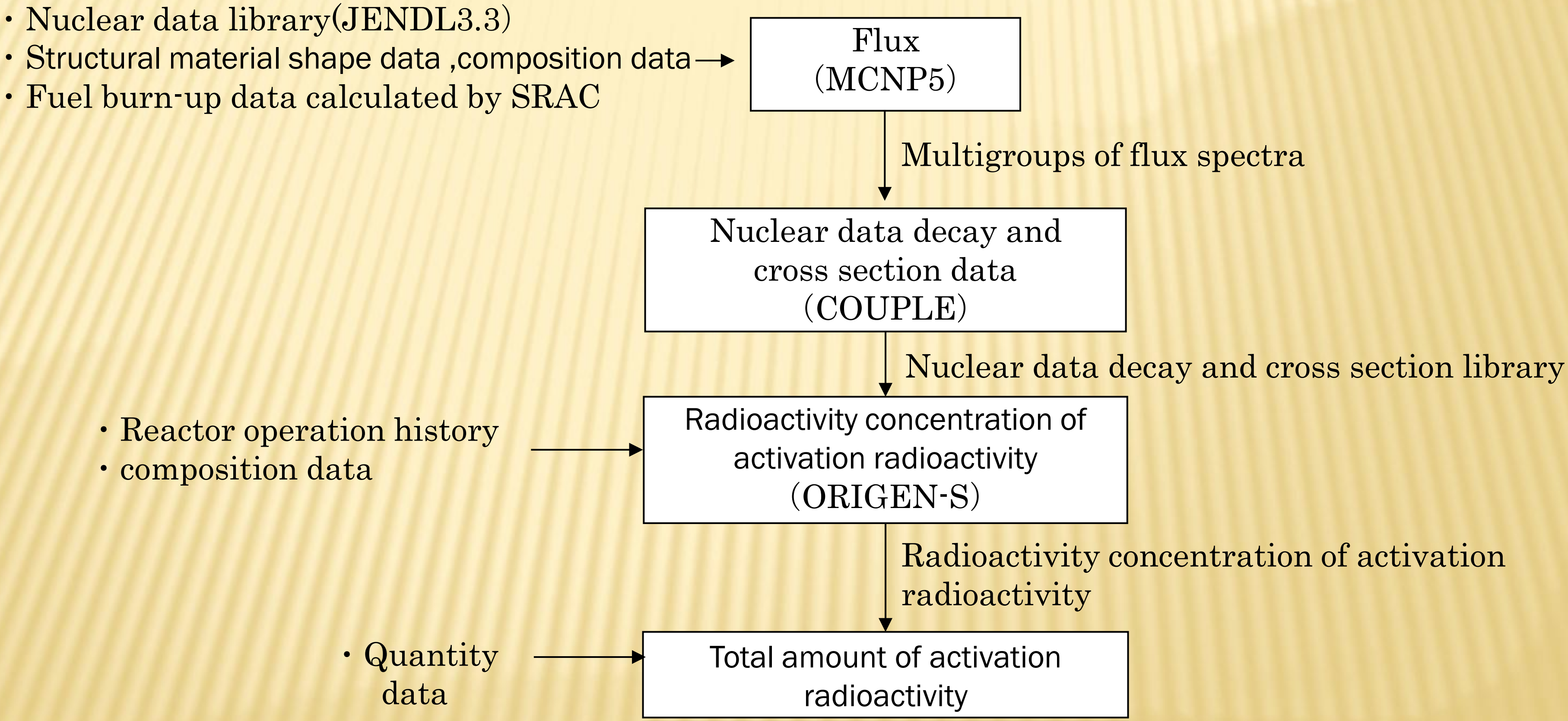
● Contamination radioactivity
- Contamination radioactivity is activated radioactivity that has been transported and attached to other facilities..
- It exists the surface of the primary cooling system, the reactor core and the pool and so on.
- Even maximum area the effective dose is very low.

↓

Evaluation using measured data directly.

2.2 EVALUATION OF RADIOACTIVITY(2/4)

● How to calculate Activation radioactivity evaluation procedure



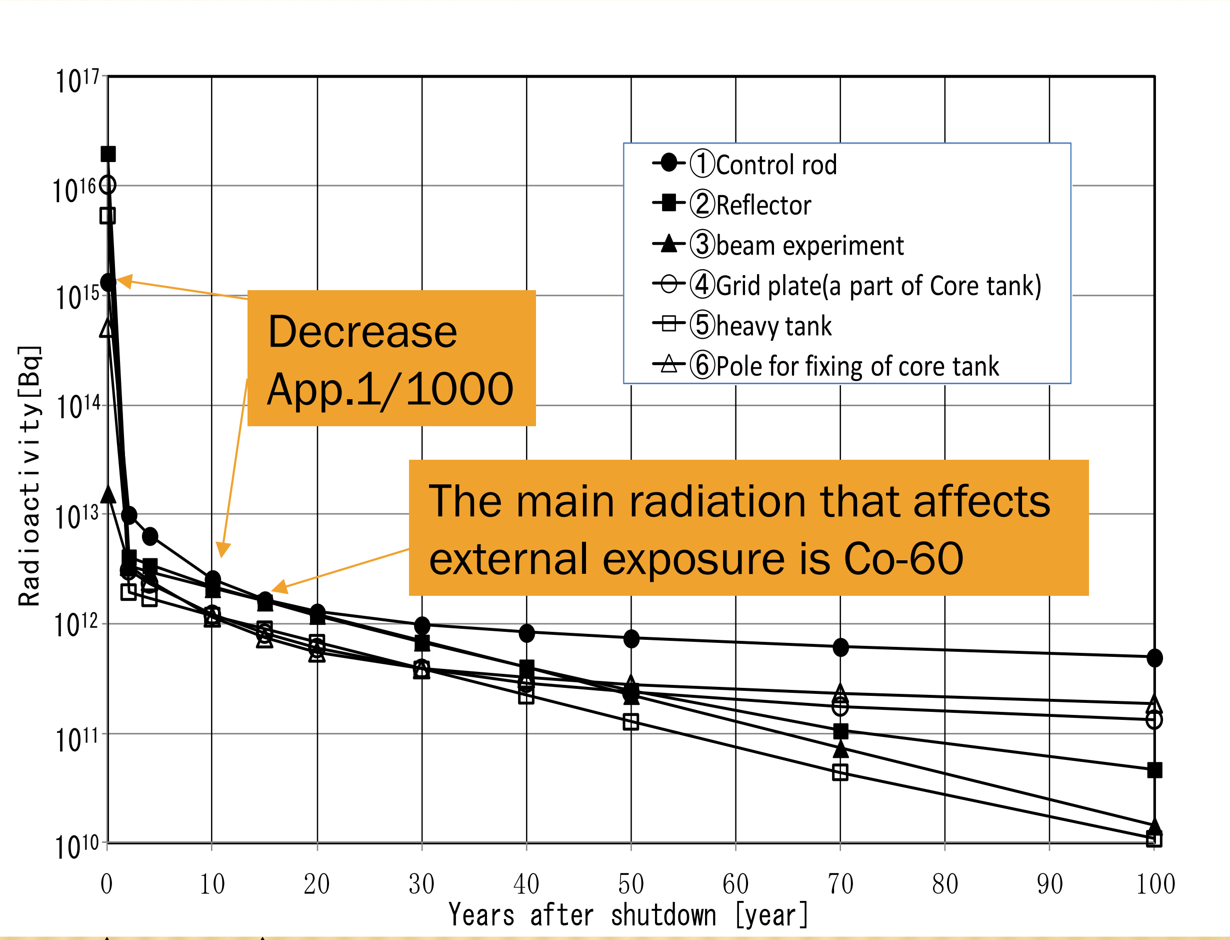
2.2 EVALUATION OF RADIOACTIVITY(3/4)

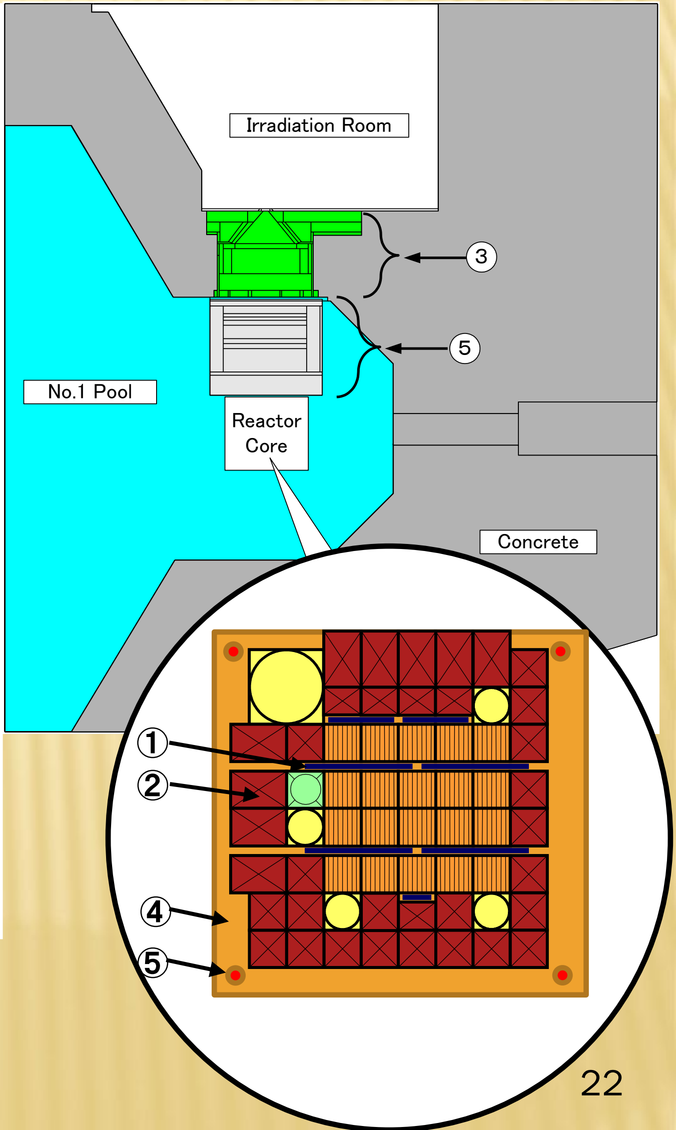
- Results in mar. 2015

	nuclide	(Bq)	Remarks
Activation radioactivity	H-3	1.3×10^{13}	Almost of H-3 is generated by Li-6 (n,α) H-3 reaction in LiF and aluminum.
	Fe-55	6.7×10^{12}	
	Co-60	3.5×10^{12}	
	Others	1.8×10^{12}	
	Total	**2.5×10^{13}**	
Contamination radioactivity	Co-60	2.7×10^{7}	
	H-3	6.4×10^{10}	All exists in Contained heavy water in heavy tank.
	Total	6.4×10^{10}	
Total		**2.5×10^{13}**	

2.2 EVALUATION OF RADIOACTIVITY(4/4)

●The change of the activation radioactivity of main structures





↑ (Stopped) Dec. 2010

↑ (Now) June. 2025

2.3 EVALUATION OF TOTAL AMOUNT OF WASTE

Classification	Main structure	material	Weight(ton)*	
Reactively higher level radioactive waste (L1)	Pole for fixing of core tank	Metal	0.002	0.002
		Concrete		
		Others		
Reactively lower level radioactive waste (L2)	Control rod, Reflector, Grid plate	Metal	2	3
		Concrete		
		Others	1	
Very low level radioactive waste(L3)	Beam experiment, heavy tank, Concrete near reactor core	Metal	286	783
		Concrete	490	
		Others	7	
Waste that need not to be treated as radioactive waste(clearance)	Concrete	Metal	894	8453
		Concrete	7547	
		Others	12	
Non-radioactive waste (NR)	Concrete	Concrete	4250	4250
Total	-	-	-	**13490**

✱ Provisional value

2.4 EVALUATION OF EXPOSURE

- For the evaluation of public exposure, two types of exposure, normal exposure and accidental exposure, are required to get the approval of decommissioning plan from the nuclear regulatory body.

- Normal public exposure

Normal public exposure is further evaluated separately for gas waste, liquid waste, and solid waste, and it is confirmed that each does not exceed the limit of 50 μSv/y.

- Accident public exposure

Accident public exposure is evaluated assuming the accident where the most radioactive material is released, and it is confirmed that one accident does not exceed the limit of 5 mSv at a time.

2.5 SELECTION OF MAINTAIN FACILITIES

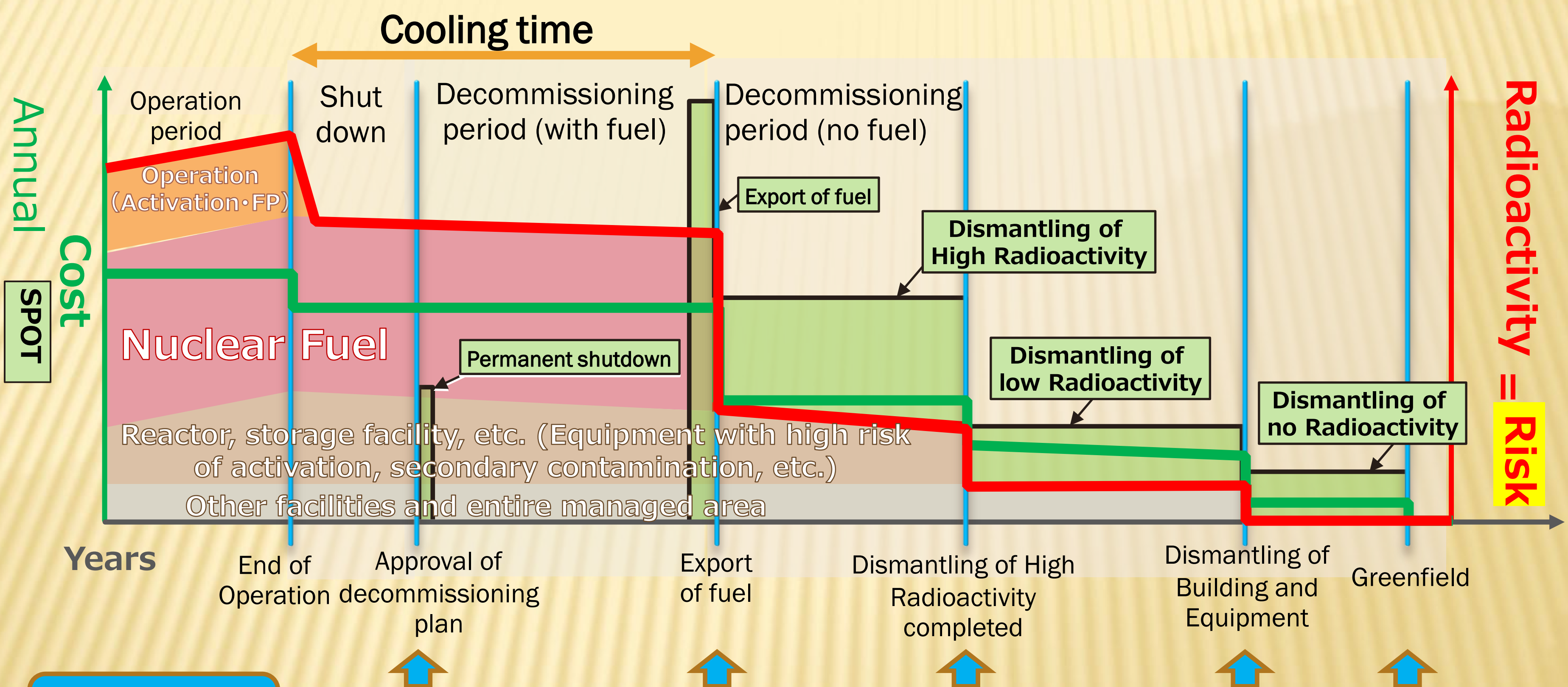
JRR-4 is not in operation, it is no longer necessary to maintain many facilities such as the reactor shutdown circuit.

Therefore, we have limited maintenance equipment to the followings.

- Facility for shielding the core, which is a highly radioactive substance: pool
- Facility for storing nuclear fuel material: Fresh Fuel storage
- Facility for purification pool water: Pool water purification facility
- Facility for disposing of radioactive waste: air supply exhaust facility and waste liquid storage tank
- Facility for reactor storage: Reactor building

2.6 DECOMMISSIONING PROGRAM(1/3)

Relationship between costs and risks for each end state of JRR-4



Appropriate End State

Maintenance

PP Management Release

Clearing Difficult Areas

Controlled Area Release

Dismantling

2025(Now)

In order to reduce risks and annual costs,JRR-4 will dismantle high radioactivity(ex. Control rods) by 2029, while veterans who are familiar with the facility remain.

2.6 DECOMMISSIONING PROGRAM(2/3)

Decision to dismantle high radioactivity

- In the case of operating reactor, it is important to generate profits.(ex. generating electricity, using radiation utility)
- On the other hands, **decommissioning reactor has no profits.** And **it is important to dismantle cheaply while maintaining safety.**
- Moreover **dismantling high radioactivity facility is very difficult because it cannot be done directly.** (ex. underwater dismantling)
- Therefore, most decommissioning facilities do not dismantle highly radioactive facilities.
- But, **dismantling highly radioactive facilities can reduce significantly risk and cost.**
- And because generated radioactive waste is low,no need buried facility.
- **Finally, we decided to dismantle high radioactivity facilities by accurately evaluating the amount of radioactivity and using that to consider the optimal dismantling method.**

2.6 DECOMMISSIONING PROGRAM(3/3)

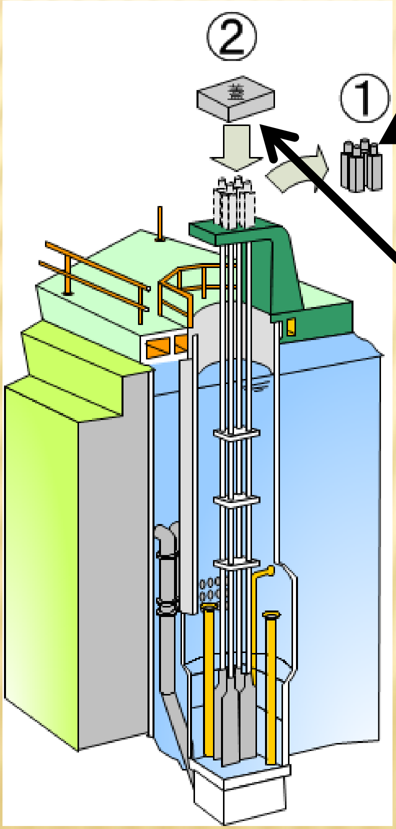
20years

	Past	Future	
Year	2017-2024(performed)	2025-2029	2030-2036
Phase	Phase 1(Maintenance) ▪ Permanent shutdown(Performed) ▪ Export of fuel(Performed) ▪ Sampling for pre-evaluation(Performed)	Phase 2（Dismantlement） Dismantling high radioactivity (ex. Control rod)	Phase 2（Dismantlement） Dismantling low radioactivity

3 EXPORT FUEL,ETC (1/2)

3.1 Permanent shutdown (Performed)

Permanent shutdown is removal of control rod drive and fixing Control rod with a metal lid.



⓪Before work

①Removal of control rod drive

②Fixing control rods with a metal lid

3 EXPORT FUEL,ETC (2/2)

3.2 Export of fresh fuel (Performed)

Fresh fuel was carried out. In difference spent fuel, fresh fuel was not stated in the permission of the operation stage. Therefore, we have approved this permission in the decommissioning plan. After that it was transported to the U.S. DOE.

Fresh fuel cask

Fresh fuel cask in container

4. CONSIDERATION OF DISMANTLING METHODS (1/7)

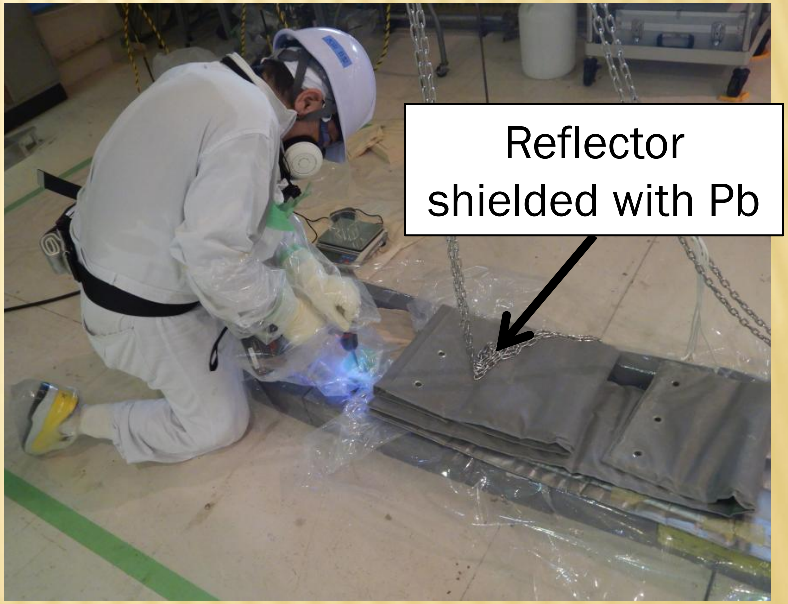
4.1 Sampling for pre-evaluation (Performed)

In order to verify the evaluation result of the inventory and to consider the dismantling method, it is necessary to take a sampling from the dismantling facilities before dismantling.

In the case of JRR-4, high radioactivity is stainless steel(short for SUS), but it's hard, so it could not be collected. Therefore, Aluminum part of the reflector, which has a relatively high dose, was collected like right.

Analysis revealed that Co-60 was detected.

About SUS, It was decided to evaluate by other way.



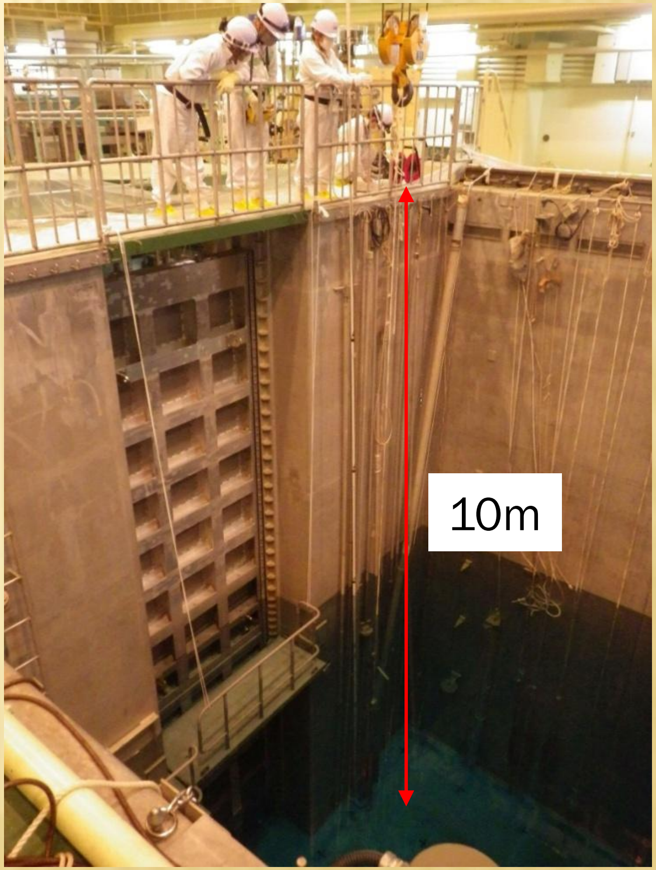
Sampling of the Aluminum part of the reflector

4. CONSIDERATION OF DISMANTLING METHODS (2/7)

4.2 measurement high activity facilities of dose rate (1/2) (Performed)

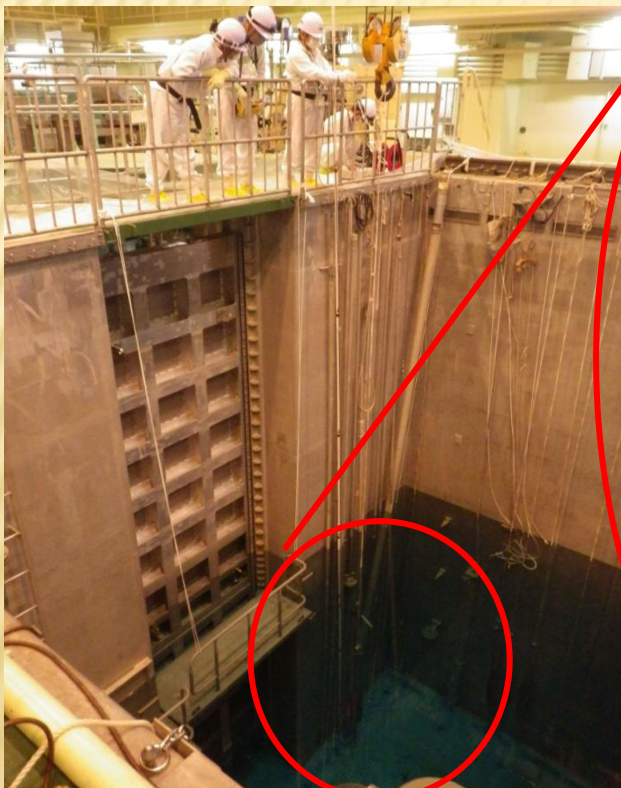
As other way, In order to verify the evaluation result of the inventory and to consider the dismantling method, it is necessary to measure high activity facilities before dismantling.

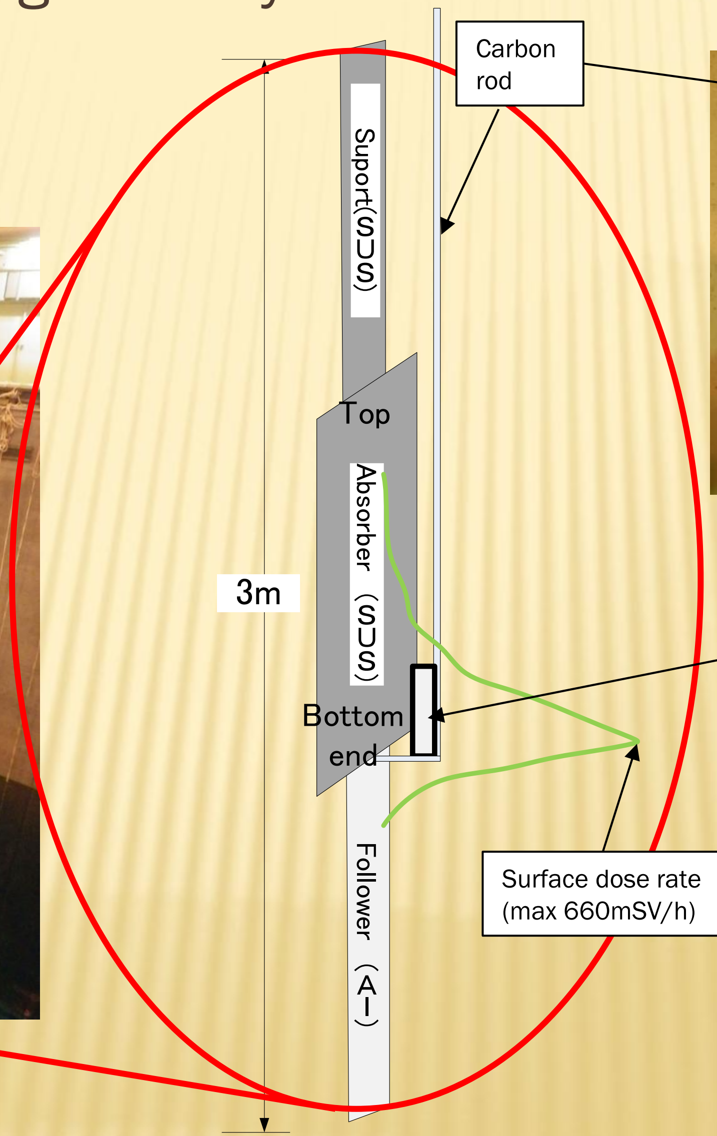
In the case of JRR-4, Control rod is made of SUS, and high activity, and we measured dose rate of it in detail. Since the radiation dose is too high, it was measured underwater as shown on the right.

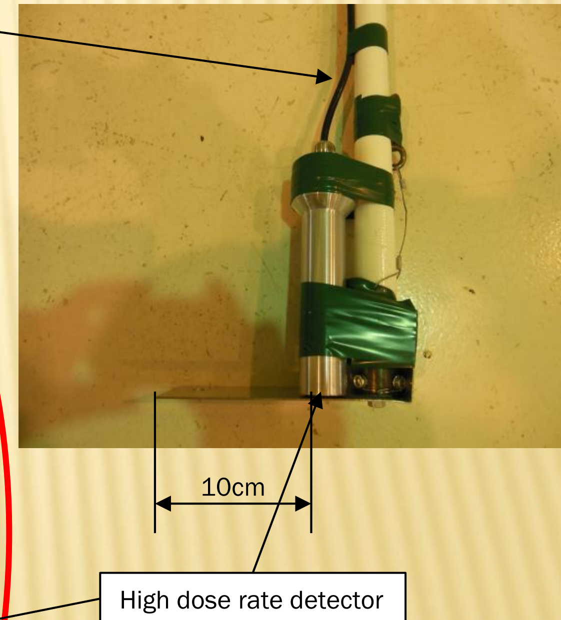


4. CONSIDERATION OF DISMANTLING METHODS (3/7)

4.2 measurement high activity facilities of dose rate(2/2) (Performed)







Measurements are taken at two points, surface dose and at10cm, every 10cm in height.

4. CONSIDERATION OF DISMANTLING METHODS (4/7)

4.3 Confirmation of validity of evaluation results and identification of radioactive source nuclide (Performed)

Dose calculation

To simulate non-homogeneous distribution, Dose calculations are performed using the system shown in the figure on the right

⇩

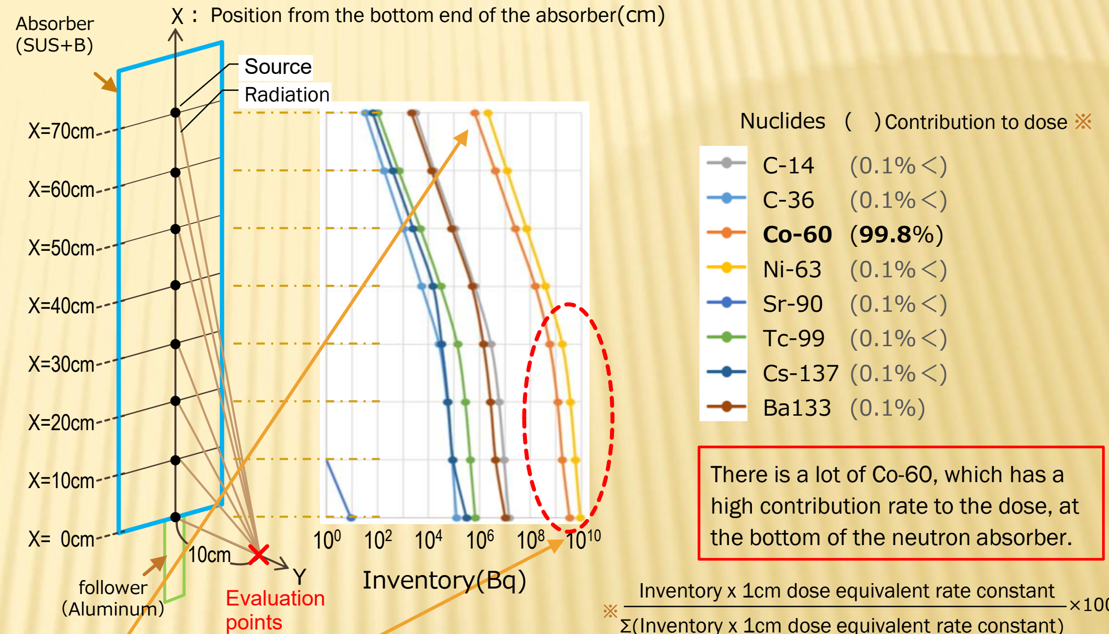
Compared with measured values(at10cm) to confirm reliability (average C/E=1.2※)

⇩

The radioactive source nuclide is Co-60 (99.8%)

⇩

A safe and economical dismantling method is planned



Dose calculation system and inventory results

The inventory is extremely high (10^{10}Bq) at the bottom end of the neutron absorber (X = 0cm) near the center of the core, on the other hand, it is 1/10000 (10^{6}Bq) at the top of the neutron absorber (X = 70cm).

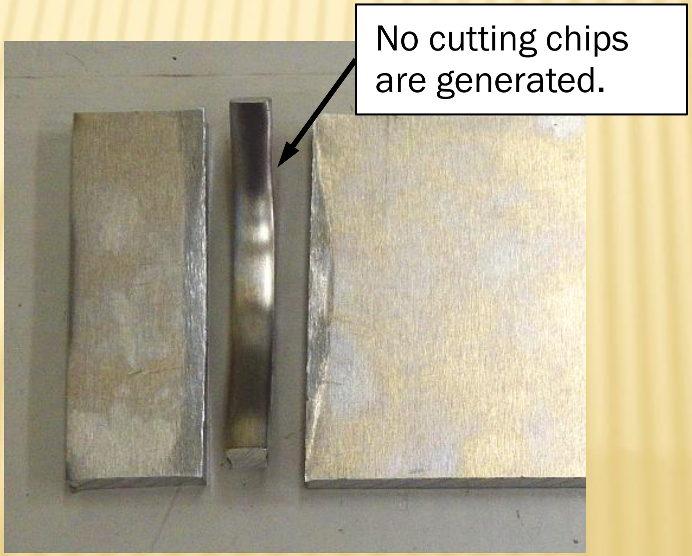
※ See reference materials

4. CONSIDERATION OF DISMANTLING METHODS (5/7)

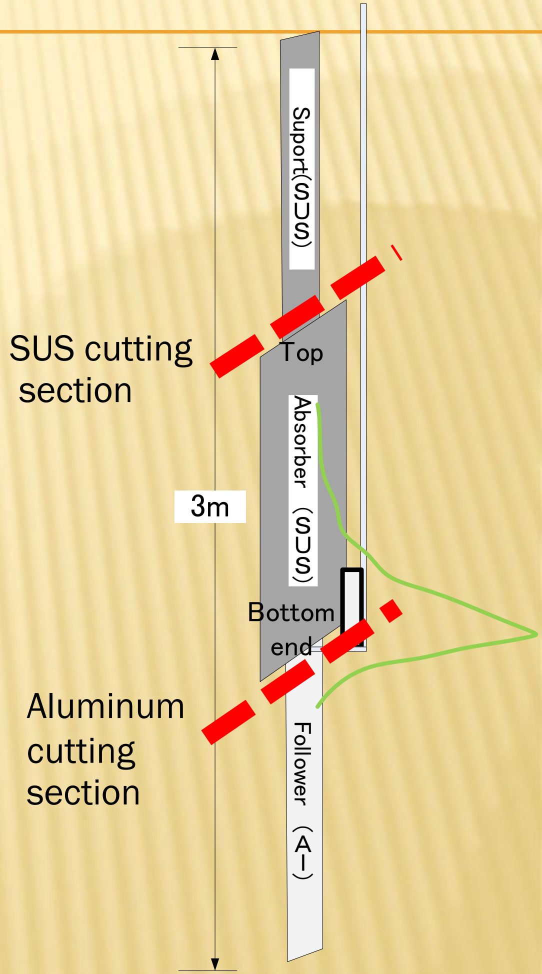
4.4 Consideration of dismantling method(1/3)

•Control rod is cut into three pieces, as shown in the right figure, each about 1m long.
•The SUS part cutting location (8mm thick) is far from the high activation area, so direct cutting will be performed after shielding is placed between the radiation source and the cutting point.
•The aluminum part cutting location (8mm thick) is close to the high-activation area, so remote underwater cutting will be performed using a hydraulic shearing machine.


Hydraulic shearing cutter



Example using cold saw

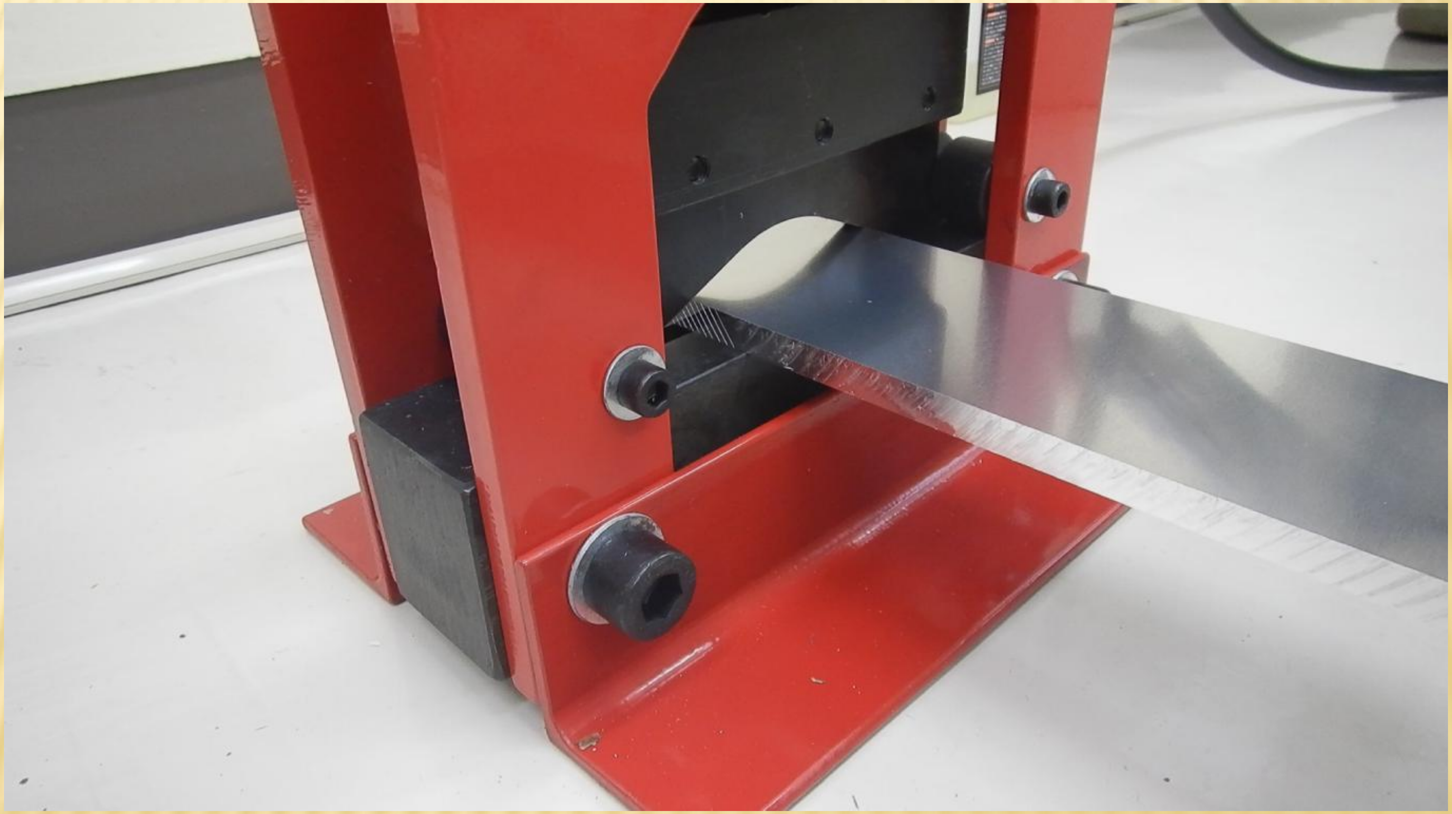


Control Rod

4. CONSIDERATION OF DISMANTLING METHODS (6/7)

4.4 Consideration of dismantling method(2/3)

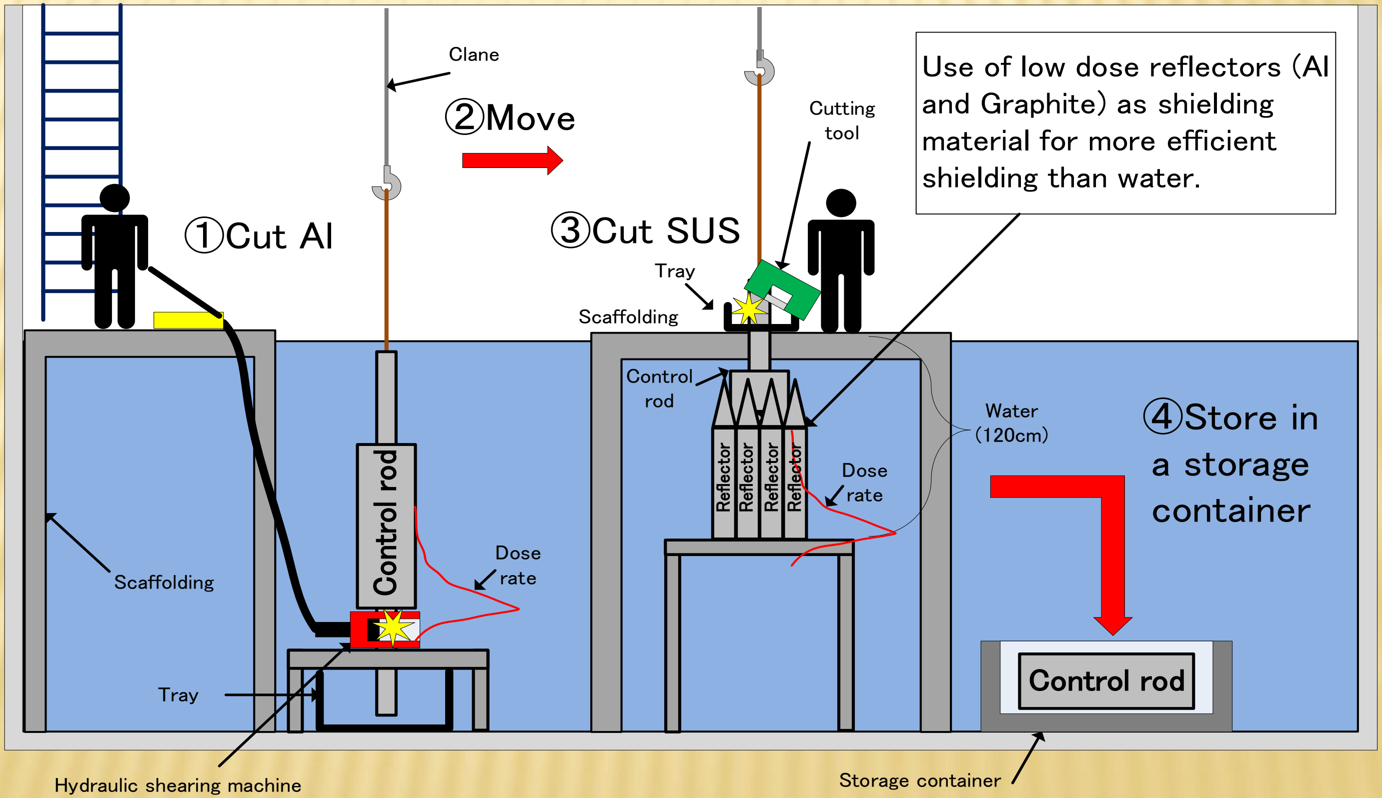
WATCH THE ALUMINUM CUTTING VIDEO.



4. CONSIDERATION OF DISMANTLING METHODS (7/7)

4.4 Consideration of dismantling method(3/3)

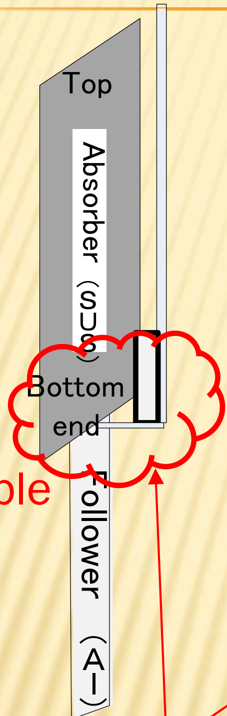
① Cut the Aluminum part underwater remotely with hydraulic shearing machine.
② Move
③ Cut the SUS part directly with water and reflector shielding.
④ Store in a storage container.
Cutting chips are collected in a tray and captured by a foreign object collection pump.

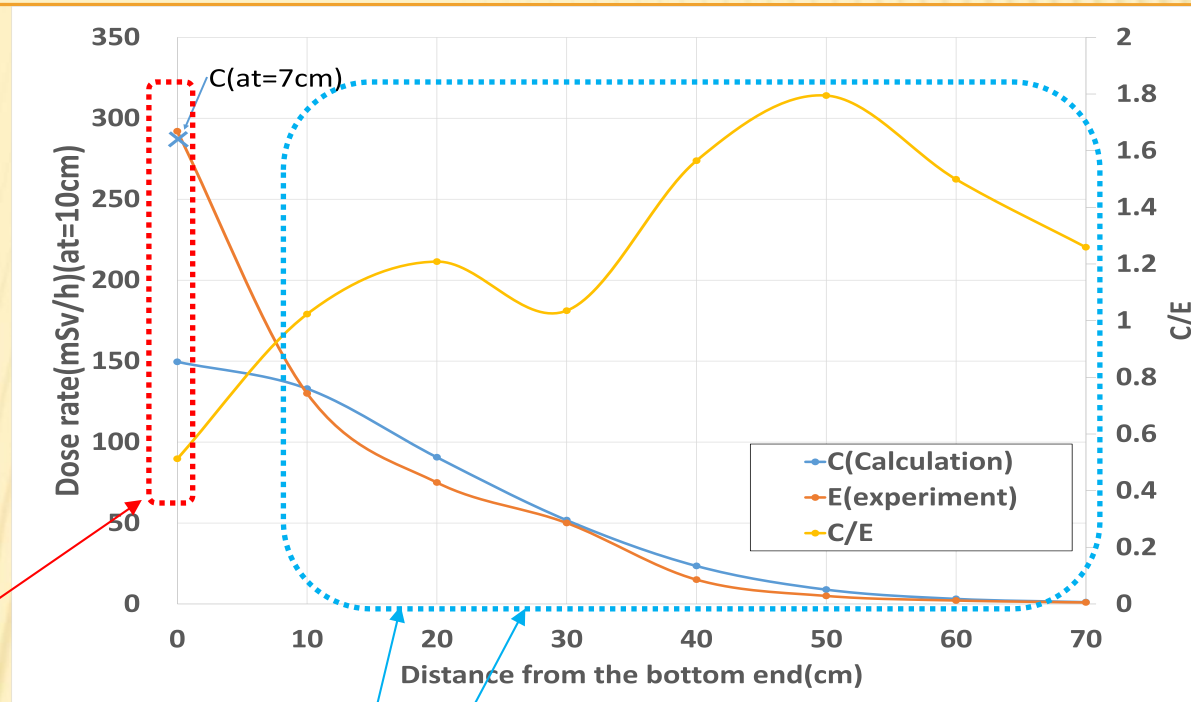


Control Rod dismantling method


Thank you for your attention!
(JRR-4 CORE AT 3500kw)

Comparison of calculated and measured dose (at 10cm) for Control rod





- C for the bottom end was significantly different from E (C/E = 0.51), but the bottom end is the joint between the neutron absorber and the follower, so it is more unstable than the other measurement points. Therefore, it is highly likely that the dosimeter was too close to the neutron absorber, resulting in a large measurement value.
- For all evaluation points except the bottom end (x=0), the calculated value (C) is almost greater than the experimental value (E). ($1.02 < C/E < 1.79$)

- Taking into account the measurement error, C/E is 1 or more for all evaluation points except the bottom end (x=0) (almost 1 at 0.99 for the bottom end), and the average value is 1.2, which is in good agreement.