Unloading and Handling Technology of the Fuel Assembly in Prototype Fast Breeder Reactor “Monju”

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ABSTRACT

The prototype fast breeder reactor Monju is currently in its first stage of decommissioning. The fuel handling facility system provided by Fuji Electric was used to unload and handle the fuel assembly as scheduled. Fuji Electric provided technical assistance, such as dispatching engineers to the JAEA, and overcame problems that had not arisen before to complete the project, thus proving our solid technology for the unloading and handling of the fuel assembly. We will continually acquire and evaluate actual operation data on the fuel handling facility system. Reflecting the results into the design will contribute to the development of next-generation fast reactors, which are essential part of supporting a low-carbon society.

1. Introduction

Monju is a prototype reactor of fast breeder reactors (nuclear reactors designed for breeding nuclear fuel) (see Fig. 1). Light water reactors are common nuclear reactors that use water as a coolant, whereas fast breeder reactors use sodium (liquid metal).

In 2016, the decision was made to decommission Monju. As the first stage of decommissioning, the unloading and handling of the fuel assembly*[1], started in June 2017 and is scheduled to be completed in approximately five and a half years, by December 2022 (see Fig. 2). The unloading and handling of the fuel assembly, including the two processing of fuel assembly and the one unloading of the fuel assembly from the

Fig.1 Prototype fast breeder reactor Monju
(Photo courtesy of the Japan Atomic Energy Agency)

Stage	1st stage Period for unloading and handling of fuel assembly	2nd stage Preparation period for dismantling	3rd stage Decommissioning period I	4th stage Decommissioning period II
Fiscal year	2018 to 2022	2023 to 2047		
Main implementation items	Unloading and handling of fuel assembly			
		Preparations for dismantling sodium equipment		
			Dismantling and removal of sodium equipment	
	Evaluation of the contamination distribution			
		Dismantling and removal of power generation facilities such as water and steam systems		
				Dismantling and removal of buildings
	Processing and disposal of radioactive solid waste			

Fig.2 Decommissioning schedule
(Figure courtesy of the Japan Atomic Energy Agency)

*1: Unloading and handling of fuel assembly: A general term that corresponds to both the processing of the fuel assembly and unloading of the fuel assembly from the core. A fuel assembly is an assembly of nuclear fuel to be loaded into a nuclear reactor.

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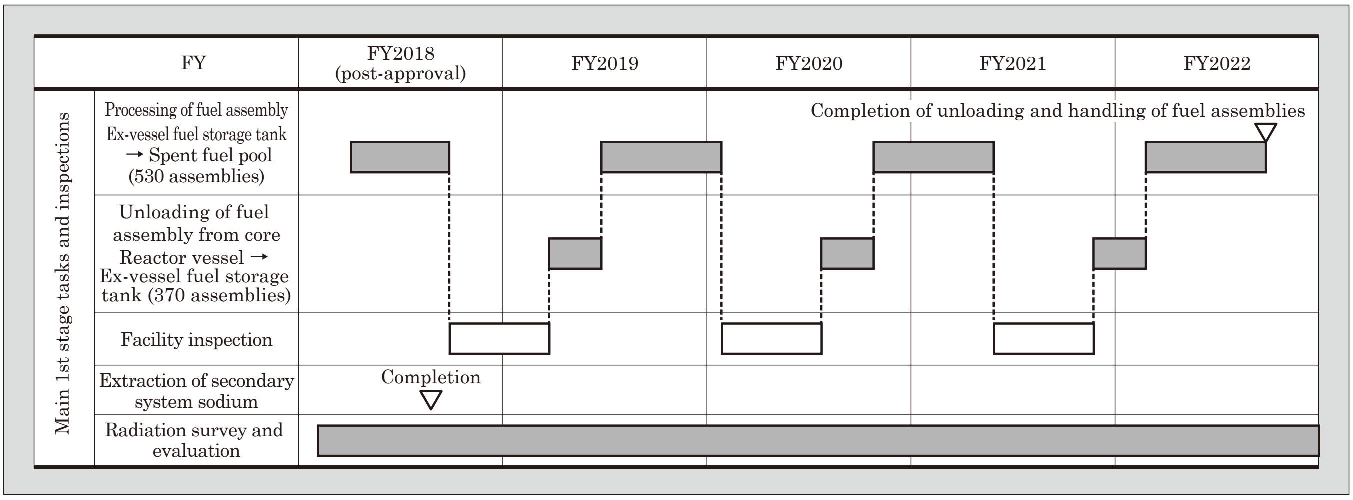

Fig.3 First stage (period for unloading and handling of fuel assembly) schedule
(Figure courtesy of the Japan Atomic Energy Agency)

core, was performed by June 2020 on schedule using the fuel handling facility system that Fuji Electric had delivered (see Fig. 3).

Fuji Electric collaborated with the reactor's operator, Japan Atomic Energy Agency (JAEA), and provided technical assistance such as dispatching engineers and overcame several problems that had not arisen before to complete the project.

In this paper, we will provide an overview of the operation and technologies required in the unloading and handling of the fuel assembly.

2. Monju situation

The decommissioning of Monju started with the fuel assemblies remaining loaded in the shutdown reactor. National and local governments demanded that the fuel assembly and sodium, which is a hazardous material that is highly reactive with water, be removed as quickly as possible as a top priority.

It is planned that the processing of 530 fuel assemblies and the unloading of 370 fuel assemblies from core will be completed in the first stage (until December 2022). As of June 2020, the processing of 260 fuel assemblies and the unloading of 100 fuel assemblies from core have been completed as scheduled.

3. Technology for Unloading and Handling of the Fuel Assembly

Figure 4 shows the fuel handling and storage facilities for unloading and handling of the fuel assembly. Figure 5 shows the transfer route for unloading and handling the fuel assembly, and Table 1 shows the operation process and respective facility. Several facilities are rationally combined to share required functions, such as fuel assembly grabbing and releasing, lifting and lowering, transferring, cooling, cleaning,

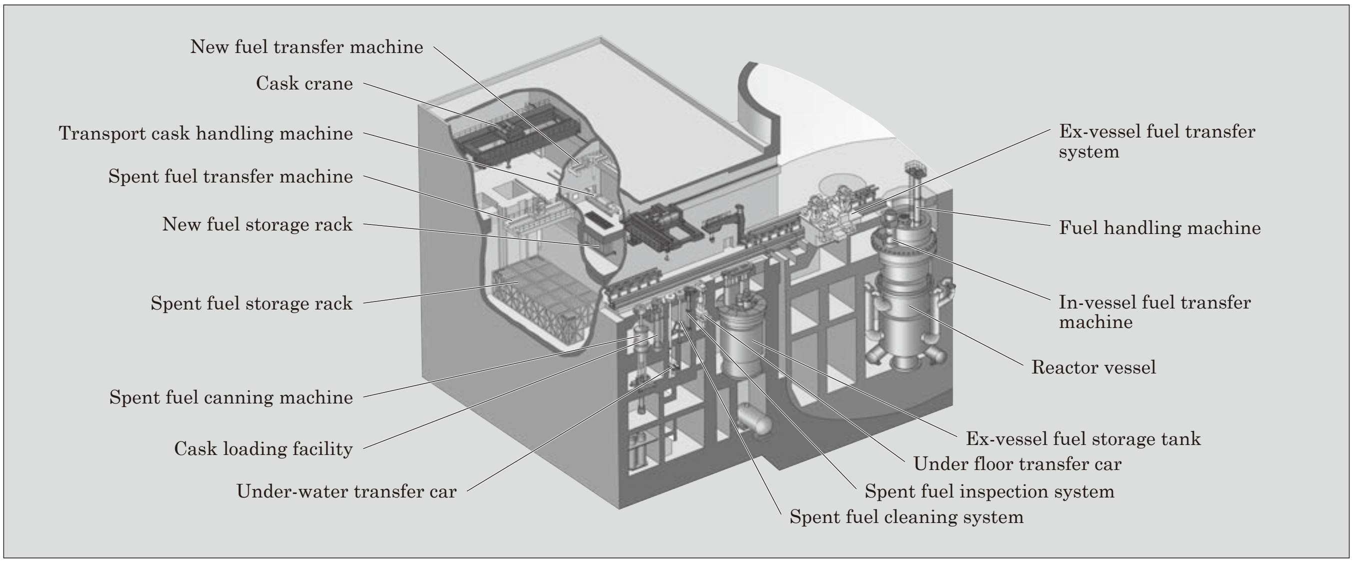

Fig.4 Fuel handling and storage facilities

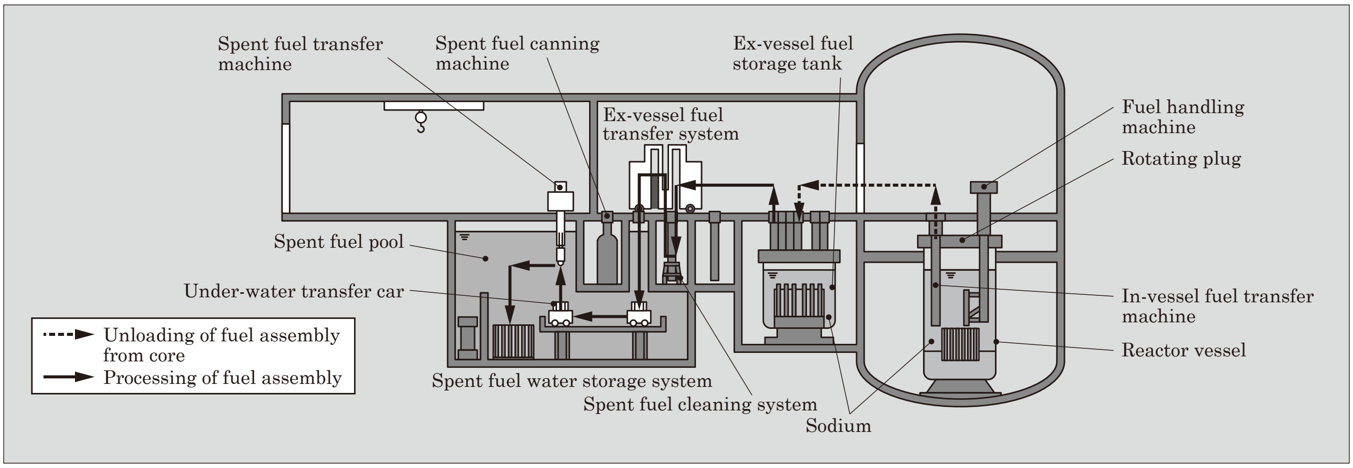

Fig.5 Transfer route for unloading and handling of fuel assembly

Table 1 Process and facility used in the unloading and handling of the fuel assembly

Process	Details	Equipment used
Unloading of fuel assembly from core	Transfer of fuel assembly from the reactor vessel to the ex-vessel fuel storage tank	Reactor fuel handling machine system
		Ex-vessel fuel transfer system
		Ex-vessel fuel storage tank
Processing of fuel assembly	The fuel assembly are temporarily stored in the ex-vessel fuel storage tank, transferred to the spent fuel cleaning system to clean (remove) the adhered sodium, and then stored in the spent fuel pool.	Ex-vessel fuel transfer system
		Ex-vessel fuel storage tank
		Spent fuel cleaning system
		Spent fuel canning machine
		Under-water transfer car, spent fuel transfer machine and spent fuel storage rack
		Under floor transfer car, new fuel transfer machine and new fuel storage rack

sealing, and shielding.

Unloading and handling of the fuel assembly needs advanced technologies to remotely and safely handle fuel assembly stored in sodium or water. In particular, the fuel assembly soaked in sodium is invisible because sodium is a liquid metal.

When sodium adheres to the fuel assembly, it reacts extremely easily with oxygen and water vapor in the air. Therefore, it is necessary to prevent contact with the air. Moreover, it has to be maintained above 100 °C to prevent solidification (coagulation). These challenges have made it difficult to handle the fuel assembly.

3.1 Processing of the fuel assembly

During the processing of the fuel assembly, the fuel assembly that has temporarily stored in the ex-vessel fuel storage tank is transferred to the spent fuel cleaning system to clean (remove) the adhered sodium and then stored in the spent fuel storage rack in the spent fuel pool.

(1) Facility used

The following facilities of the fuel handling and storage facilities (see Fig. 4) are used for the fuel assembly processing operation.

(a) Ex-vessel fuel transfer system (see Fig. 6)

The ex-vessel fuel transfer system transfers the fuel assembly between the reactor vessel and other facilities, such as ex-vessel fuel storage tank. It is the main facility used in the fuel assembly processing operation. The ex-vessel fuel transfer system includes following two fuel handling machines: Ex-vessel fuel transfer machine A, which handles the sodium-adhered fuel assembly, and Ex-vessel fuel transfer machine B, which handles the sodium-removed fuel assembly.

○ Ex-vessel fuel transfer machine A

This machine handles fuel assembly in sodium-filled environments or in sodium-mist

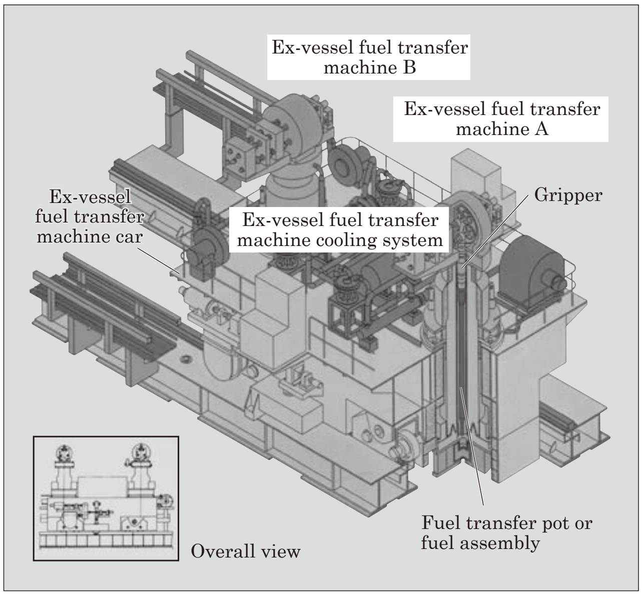

Fig.6 Ex-vessel fuel transfer system

atmospheres in which sodium metal particles are dispersed in the argon gas. The inside of its machine is hermetically sealed and filled with argon gas.

○ Ex-vessel fuel transfer machine B

This machine handles fuel assembly in water-filled environments or in humid atmospheres. The inside of its machine is hermetically sealed and filled with air.

○ Ex-vessel fuel transfer machine cooling system

This system, consists of equipment and piping that supplies and discharges (circulates) cooling gas, removes the heat generated from the spent fuel assembly stored in the ex-vessel fuel transfer machine. Two types are available designed for the machine A and machine B.

○ Ex-vessel fuel transfer machine car

This car travels with the machine A, machine B and cooling system mounted so that they can be precisely positioned on the respective piece of facility.

(b) Ex-vessel fuel storage tank

This facility is used for intermediate storage of fuel assemblies and radioactive-decay-awaiting storage of spent fuel assemblies in the sodium tank.

(c) Spent fuel cleaning system

This system cleans (removes) sodium from spent fuel assembly with steam and water. This system prevents rapid reaction of sodium and water by first supplying steam and then allowing sodium and water to gradually react.

(d) Spent fuel canning machine

This machine performs water canning of fuel assembly after cleaning. Water canning refers to the encapsulation of fuel assemblies with water in a can using the spent fuel canning machine.

(e) Under-water transfer car, spent fuel transfer machine and spent fuel storage rack

They are used for receiving spent fuel assembly, which is non-encapsulated or water-canned, from ex-vessel fuel transfer system and storing it in water in preparation for storage off-premises.

(f) Under floor transfer car, new fuel transfer machine and new fuel storage rack

They are for receiving dummy assembly (dummied external shape of fuel assembly) and the can that has been carried in the premise for temporary storage in indoor air before the processing of the fuel assembly.

During the processing of fuel assembly, these facilities are used to deliver the dummy assembly or can to the ex-vessel fuel transfer system.

(2) Overview of fuel assembly processing

An overview of the operation of the fuel assembly process for water canning is as follows. In order to ensure safety and allow multiple facilities to be combined, just pressing a blinked push button on the panel will remotely and automatically operate this facility.

(a) The ex-vessel fuel storage tank holds liquid sodium at approximately 200 °C. The spent fuel assembly is removed from this storage tank, cleaned, water canned, and stored on spent fuel storage rack.

(b) The dummy assembly is removed from the new fuel storage rack and then stored at the same location of the ex-vessel fuel storage tank where the removed fuel assembly was stored. Before loading into the ex-vessel fuel storage tank, the fuel assembly is preheated to reduce the temperature difference with sodium.

In order to shorten the total operating time while ensuring safety in handling each fuel assembly and dummy assembly, the operation program is designed to subdivide processes (a) and (b) and combine sequential and parallel operations appropriately.

(3) Results of fuel assembly processing

(a) 1st: August 2018 to January 2019

The goal was to process 100 fuel assemblies. However, due to several issues that we had not undergone yet, described in Section 4, we only processed 86 fuel assemblies and transferred 86 dummy assemblies.

(b) 2nd: February 2020 to June 2020

The goal was to process 130 fuel assemblies. We effectively utilized the corresponding countermeasures based on the experience of our first attempt to process 174 fuel assemblies and transfer 140 dummy assemblies.

3.2 Unloading of fuel assembly from core

The fuel assembly is unloaded from the reactor (core) and loaded (temporarily stored) in the ex-vessel fuel storage tank. Dummy assembly is then loaded at the core position where the fuel assembly was loaded.

(1) Facility used

The following facilities of the fuel handling and storage facilities (see Fig. 4) are used during the process of unloading the fuel assembly from the core.

(a) Reactor fuel handling machine system

This system consists of the following facilities that transfer fuel assembly in sodium inside the reactor vessel.

○ Fuel handling machine

This machine inserts and removes fuel assembly in and out of the core.

○ In-vessel fuel transfer machine

This machine delivers fuel assembly between the fuel handling machine and ex-vessel fuel transfer machine A.

(b) Ex-vessel fuel transfer system (see Fig. 6)

During the process of unloading the fuel assembly from the core, it transfers the fuel assembly between the reactor vessel (in-vessel fuel transfer machine) and ex-vessel fuel storage tank.

(c) Ex-vessel fuel storage tank

(2) Overview of unloading fuel assembly from core

The unloading of the fuel assembly from the core is operated remotely and automatically in the same manner as fuel assembly processing.

The spent fuel assembly is pulled out from the reactor (core), transferred, and stored in an ex-vessel fuel storage tank. The dummy assembly is unloaded from the ex-vessel fuel storage tank and transferred and inserted at the same position of the core where the fuel assembly had been loaded. One fuel assembly or dummy assembly is processed at a time. To shorten the total operating time and ensure safety, the operation program is designed to subdivide processes and combine sequential and parallel operations appropriately.

(3) Results of unloading of fuel assembly: September 2019 to October 2019

We successfully unloaded 100 fuel assemblies and transferred 100 dummy assemblies just as planned.

4. Overcoming Challenges That Have Not Been Experienced

The initial fuel assembly processing was the first substantial operation of its kind. This resulted in various new kinds of challenges. We will now describe the major challenges we faced and corresponding measures we took.

(1) Torque increase due to adhesion of sodium compounds

(a) Overview of phenomenon

Ex-vessel fuel transfer machine A (see Fig. 7) grabs and releases fuel assembly by opening and closing the fingers of the gripper (see Fig. 8). Stainless steel tape is wound in and out from the gripper drive unit at the top to grab, release, lift, and lower fuel assembly. The torque at the time of opening and closing the gripper fingers was higher than the designed value.

(b) Estimation of cause

When visually checking the gripper, we found that many sodium compounds were adhering to the surface of the gripper (see Fig. 9) and that these adherents interfered with the opening and closing of the fingers. When handling fuel assembly, sodium adhered to the gripper and stainless steel tape. This adhered sodium converted into compounds such as sodium hydroxide and sodium oxide and solidified, causing the sliding parts to stick and the torque to increase.

During the cleaning process of the spent fuel cleaning system, the water in the fuel cleaning tank is drained after the cleaning is completed. After this, the inside of the fuel cleaning tank is dried so that it can receive the sodium-adhered fuel assembly from ex-vessel fuel transfer machine A. We supposed that, when the machine A and the fuel clean-

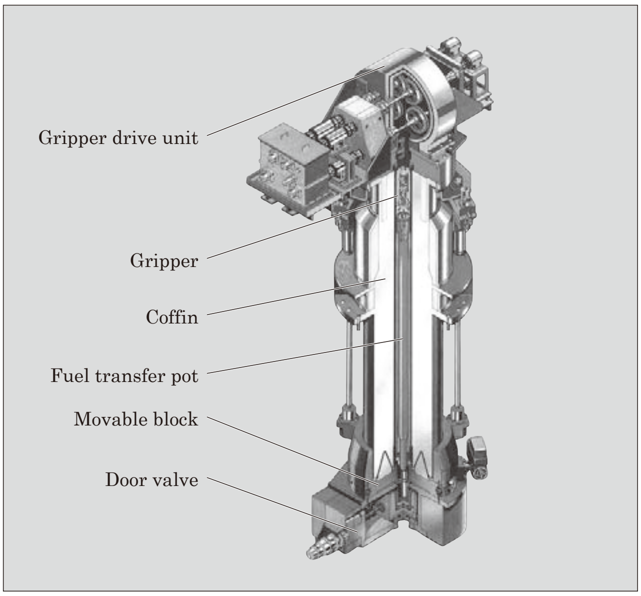

Fig.7 Ex-vessel fuel transfer machine A
(Machine B basically has the same configuration.)

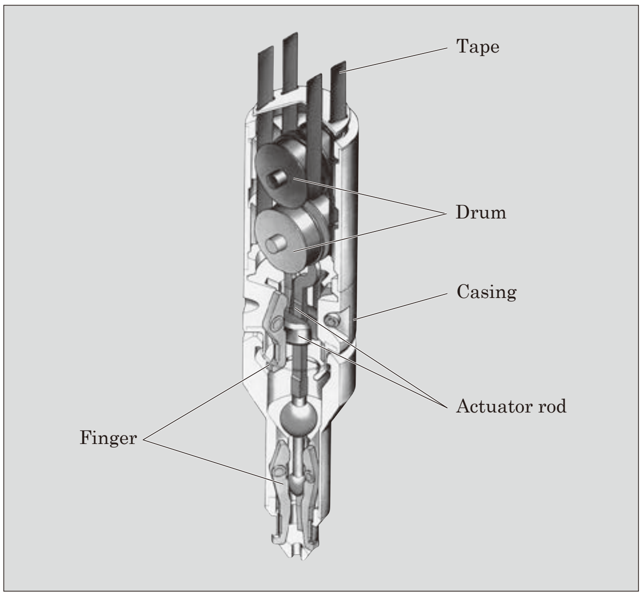

Fig.8 Ex-vessel fuel transfer machine A gripper

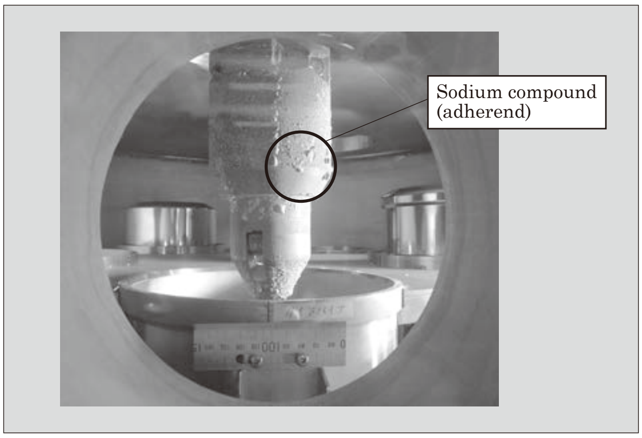

Fig.9 Appearance of lower part of gripper

ing tank were connected and the drying process and gas replacement were insufficient, the gripper was exposed to a high dew point atmosphere or moisture penetrated into the machine A, which resulted in the torque increase.

Therefore, we measured the dew point temperature in the fuel cleaning tank and found that the drying process after cleaning was insufficient. We also discovered that the residual moisture due to insufficient drying in the fuel cleaning tank caused the compounding of the sodium that was adhered to the gripper.

(c) Implementing countermeasures

In order to improve the drying function in the fuel cleaning tank, we added heaters and heat insulators to the fuel cleaning tank and surrounding piping. We also lengthened the drying process time to the extent that the total operation time was not prolonged and increased the number of gas replacements. After taking these measures, we proceeded with the second fuel assembly processing work.

(d) Effect of countermeasures

During the second fuel assembly processing work, we initially observed the same abnormal increase in torque that we saw during our first attempt, but the phenomenon thereafter disappeared and the torque stabilized.

The dew point temperature in the fuel cleaning tank also stabilized, decreasing to −60 °C or lower. This indicated a definite improvement.

(2) Door valve incomplete closure due to adhesion of sodium compound

(a) Overview of phenomenon

After the fuel assembly are stored in the machine, the door valve at the bottom of the unit is fully closed in normal operation. However, the door valve was not closed completely, causing seal leakage at the valve seat.

(b) Estimation of cause

We supposed that the sodium that had dripped on the valve entered the gap between the door valve and the casing and solidified into a compound such as sodium hydroxide or sodium oxide, preventing the valve element from moving and the valve seat from sealing. The cause of the formation of the compound was due to insufficient removal of moisture, similar to the case of the increased torque during opening and closing of the gripper fingers described in the previous section.

(c) Implementing countermeasures

Similar to the previous section, we improved the drying process in the fuel cleaning tank.

(d) Effect of countermeasures

During the second fuel assembly processing operation, there was no door valve incomplete closure unlike our first attempt. We confirmed that the opening and closing of the door valve had stabilized.

5. Postscript

In this paper, we described the unloading and handling technology used for the fuel assembly in the prototype fast breeder reactor “Monju.” Fuji Electric collaborated in the unloading and handling of the fuel assembly with the Japan Atomic Energy Agency, and provided technical assistance throughout the project, such as dispatching engineers. This contributed to the completion of the operation, which included overcoming some issues that had not been experienced before.

We have also demonstrated our fuel assembly removal technology during the fuel assembly handling operation. We have obtained the actual operation data on the fuel handling facility system. We will continue to collect this data in the future. Fuji Electric will evaluate actual operation data and reflect the results into the design of next-generation fast reactor facility, positively contributing the development of fast reactors that will pave the way for a low-carbon society.

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