REMOTE DISMANTLING OF ACTIVATED REACTOR INTERNALS WITH PLASMA ARC TORCH

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ABSTRACT

The decommissioning program of the Japan Power Demonstration Reactor (JPDR) has been carried out since 1981 in the Japan Atomic Energy Research Institute (JAERI) in order to develop techniques applicable to future commercial power reactor decommissioning. In this program, a technical development for an underwater plasma arc cutting system has been carried out for dismantling activated steel structures in the reactor pressure vessel (RPV). The major aim of the development was to establish a safe and reliable remote dismantling system for the objects which are hardly accessible by workers because the radioactivity of the objects was very high and, in addition, the objects were located in a limited working space. In particular, major emphasis was placed on the development of the underwater plasma arc cutting system to minimize worker radiation exposure. Until now, a part of the steel structures in the RPV had been dismantled underwater with the plasma arc torch operated by a developed general-purpose robotic manipulator. Through the dismantling of these steel structures (reactor internals), various kinds of knowledge and experience were obtained.

1. Introduction

Stainless steel structures located in a confined space inside a reactor pressure vessel (RPV) are highly activated and, in addition, are contaminated with radioactive materials during reactor operation. These steel structures (reactor internals) must, therefore, be remotely dismantled to reduce radiation exposure to workers. Thus, a reliable cutting technique, which is easy of handling in a limited space, must be developed.

Underwater plasma arc cutting technique has been developed in JAERI in order to dismantle the reactor internals of JPDR. At the first step in the development, fundamental cutting tests were conducted by a prototype cutting machine to obtain optimum cutting conditions. On the basis of the test results, a remote controlled dismantling system was designed and fabricated for dismantling of JPDR reactor internals. As a final check-out of the system, mock-up test was conducted using test steel structures in a water pool simulating the RPV.

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*This program is being performed by JAERI under contract from the Science and Technology Agency (STA) of Japan.

Following these tests, three reactor internals were dismantled in 1988 using the developed plasma arc torch combined with a general-purpose power manipulator (JARM-25) which had been developed for reactor dismantling.

This paper describes the development of plasma arc cutting technique and also the experience obtained from the actual dismantling of the reactor internals.

2. JPDR reactor internals

Figure 1 schematically shows the JPDR reactor internals. The reactor internals having intricate structure, are closely located in confined space inside the RPV. Several reactor internals are up to 110 mm in thickness. Radioactivity of the reactor internals close to the reactor core is so high that remote cutting underwater is required for safety assurance of workers.

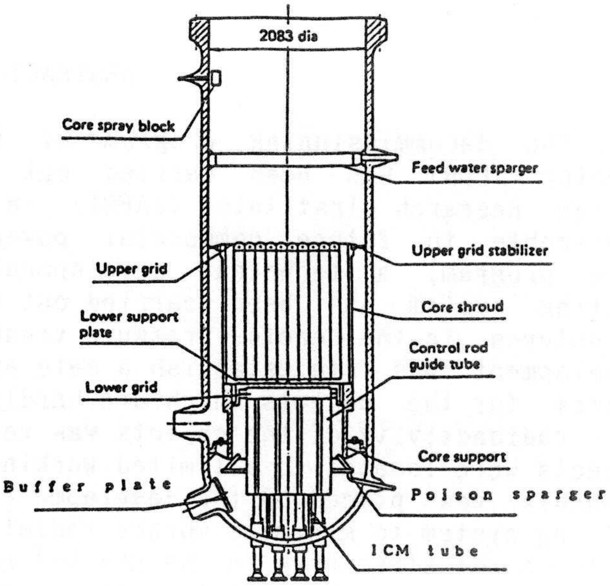

Figure 1 JPDR reactor internals

3. Development of underwater plasma arc cutting technique

In plasma arc cutting, a large amount of heat is concentrated on a metallic object in such a way that both plasma gas and electric arc are forced through a small nozzle. When the high temperature plasma stream and electric arc strike the metal, the transmitted heat rapidly melts the metal and the high velocity gas blows the melted metal away.

3.1 Fundamental cutting test

In a fundamental cutting test, parametric tests were performed to collect basic data on underwater plasma arc cutting. First, stainless steel plates were cut to obtain optimum underwater cutting conditions. In these cutting tests, cutting parameters such as thickness of plate, arc current, torch speed, species of supplying gas and gas-flow rate were changed within ranges as shown in Table 1.

Table 1 Test parameters

Thickness of plates	3~130 (mm)
Arc current	150~1000 (A)
Torch speed	30~1000 (mm/min.)
Supplying gas	He, He-N_2, He-H_2, Ar, Ar-N_2, Ar-H_2
Gas-flow rate	30~120 (l/min.)

The result of these cutting tests showed that a 1000A-type torch can cut a stainless steel plate 130 mm thick underwater. Optimum combination of the cutting parameters was also found as shown in Fig. 2. In these cutting tests, the plasma arc torch was moved by a numerically controlled torch-drive device with four degrees of freedom (two horizontal directions, a vertical direction and a rotation around the vertical direction).

In the actual dismantling of reactor internals, structures with various shapes and thicknesses must be cut. Additional underwater cutting tests were, therefore, performed to confirm applicability of the numerically controlled torch-drive device to stainless steel structures such as plates with unevenness on their surface, curved plates, pipes and rods.

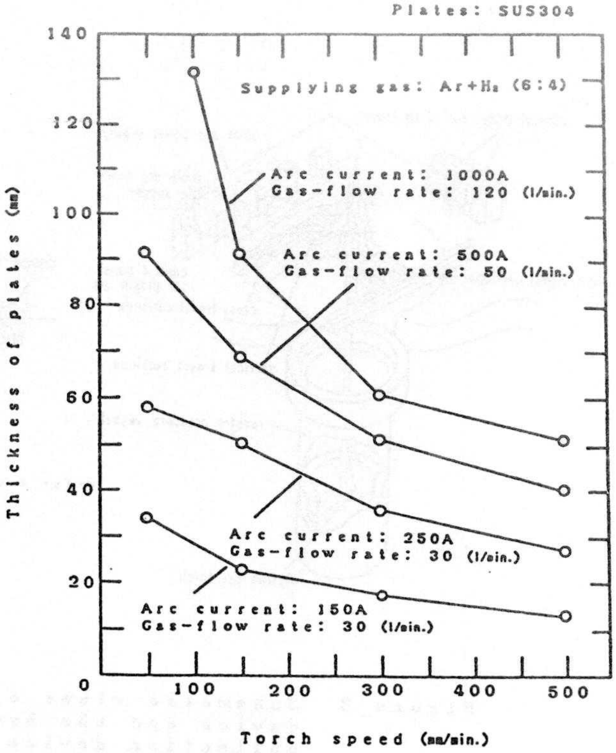

Figure 2 Optimum combination of cutting parameters (thickness of plate, arc current, torch speed, species of supplying gas, gas-flow rate)

The test results showed that the basic design of the torch-drive device can be applied in designing the device for dismantling of the reactor internals because each of the stainless steel structures could be cut by the plasma torch and the torch-drive device.

3.2 Mock-up test

On the basis of the fundamental cutting test results, an underwater plasma arc cutting system was designed and fabricated to dismantle the JPDR reactor internals. The plasma arc cutting system consists of several components such as a plasma torch, a DC-power supply, a torch-drive device, a by-product collection device, a handling device for dismantled piece and underwater TV cameras.

A mock-up test was conducted to confirm the applicability of the developed cutting system to the actual dismantling of the JPDR reactor internals. In the mock-up test, test pieces, each simulating the actual reactor internals, were set in a water pool simulating the JPDR reactor pressure vessel. Then, the components of the cutting system were carefully constructed in such a way that an arrangement of the cutting system in the test simulates that of the actual JPDR dismantling.

Figure 3 shows schematic views of the cutting device and the by-product collection device.

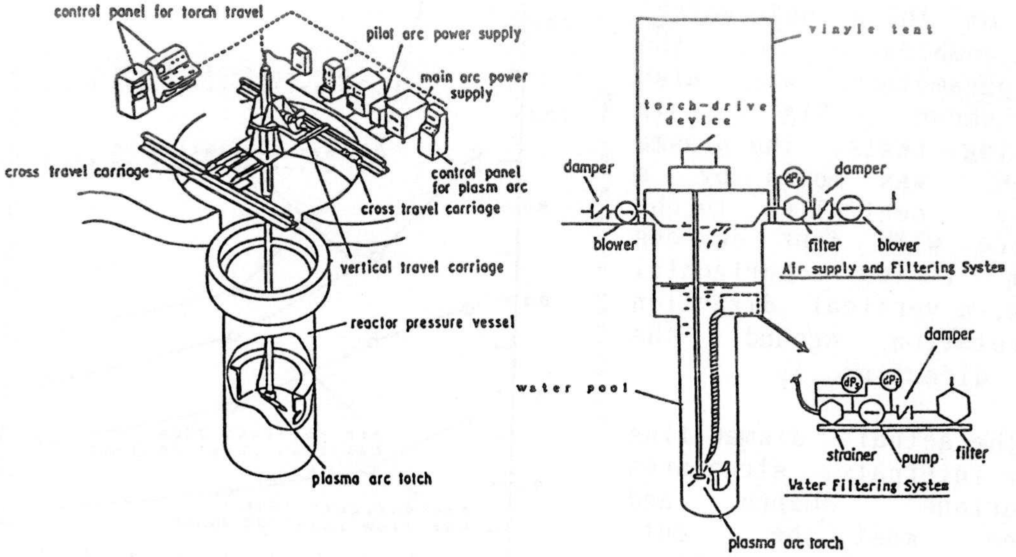

Figure 3 Schematic views of the cutting device and the by-product collection device

The results of the underwater plasma arc cutting tests are summarized in Table 2. The cutting parameters such as arc current, torch speed and gas-flow rate were carefully selected according to the thickness of the objects to be cut. Consequently, each of the test pieces could be perfectly cut as expected. As described in 3.1, it had been confirmed from the fundamental cutting tests that a stainless steel plate 130 mm thick could be cut by 1000A-type torch. The core spray block 105 mm thick was, therefore, planned to be cut using 1000A-type torch. However, it was found difficult for 1000A-type torch to approach the core spray block because the core spray block was located in a confined space. Consequently, the core spray block was cut by arcing from both sides of the block with a 500A-type torch, which is smaller than the 1000A-type torch.

Table 2 Results of underwater plasma arc cutting tests

Test Piece	Shape	Thickness of Cut (mm)	Arc Current (A)	Torch Speed (mm/min.)	Gas Flow (ℓ/min.)	Cutting Results
Core Sprary Block	Block	105	500	100	50	Successful*
Core Support Lug	Block	50, 63	500	100, 150	50	Successful
ICM Tube	Pipe	3.2	500	150	50	Successful
CR Guide Tube	Pipe	8.1	250	100	50	Successful
Poison Sparger	Pipe	5	500	100	50	Successful
Feedwater Sparger	Pipe	19 (max)	250, 500	100 ~300	50	Successful
Upper Grid Stabilizer	Rod	76 dia.	500	75	50	Successful
Core Support	Plate	55	500	100 ~ 150	50, 80	Successful
Buffer Plate	Plate	25	500	150	50	Successful
Core Shroud	Plate	12	500	300	50	Successful

* The cutting was completed by arcing from each side of the block.

The result of the cutting tests also indicated that visual observation by underwater TV cameras was indispensable to confirm the torch position, to make sure completion of cutting and to handle the dismantled pieces. Further, it was found that the underwater TV cameras had to be miniaturized, because they were too large to approach test pieces installed near the wall of water pool and/or in limited space.

Each of the test pieces, after being cut, was removed by being lifted with the handling device for dismantled piece or by being cut down into a basket hung from the top of the water pool. The dross deposited at the bottom of the water pool could be completely collected by a strainer and the water visibility could be also maintained by a water filtering system. Hydrogen concentration in the cavity above the water surface was kept below 0.1 % by a air filtering system. These devices are, therefore, considered to be applicable to the dismantling of the JPDR reactor internals.

The developed underwater plasma arc cutting system will be applied to the dismantling of the JPDR reactor internals in April, 1989.

4. Experience obtained through dismantling of JPDR reactor internals

A general-purpose robotic system applicable to various handling work in high-level radiation environment has been developed in JAERI. The developed amphibious robotic system (JARM-25) is equipped with electrically driven bilateral master-slave manipulators having seven degrees of freedom, which can be flexibly operated by selecting a mode among bilateral real-time master-slave, teach-and-playback and programmed control modes.

From January through March in 1988, three reactor internals, namely , the core spray block, the feedwater sparger and the upper grid stabilizer were dismantled using the developed underwater plasma arc torch, a part of the plasma arc cutting system, together with the JARM-25 in order to confirm the applicability of the JARM-25 to a reactor dismantling work. During the cutting work, the slave manipulator of the JARM-25 with the underwater plasma arc torch was lowered into the RPV and then locked in desired place in the RPV by a tripedal support mechanism having expandable three legs. The slave manipulator was remotely operated from the room which was located about 100 meters from the reactor enclosure. Figure 4 schematically shows an appearance of underwater dismantling of the reactor internals using the plasma arc torch together with the JARM-25 and also the control room for remote operation.

The cutting work was performed underwater at the depth of two to six meters. The cutting conditions and characteristics of the dismantled reactor internals are summarized in Table 3. The cutting paths for the reactor internals are also shown in Fig. 5.

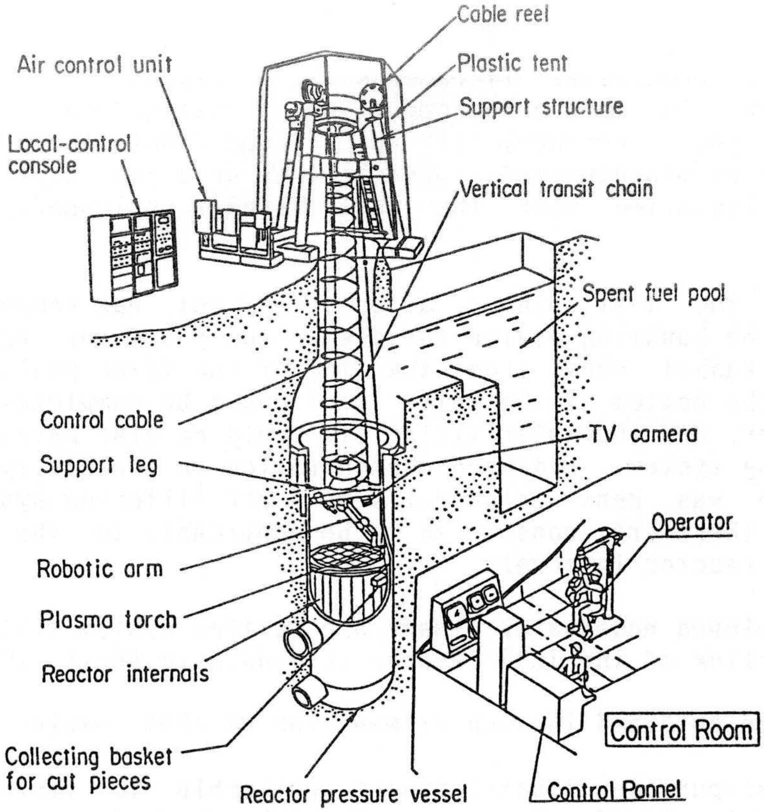

Figure 4 An appearance of underwater dismantling of the reactor internals using the plasma arc torch together with the JARM-25 and the control room for remote operation

Table 3 Cutting conditions and characteristics of the dismantled reactor internals

Reactor internals	Radioactive inventory ($Bq \cdot kg^{-1}$)	Surface dose rate (mR/h)	Major* cutting path	Cutting features			
				Arc current (A)	Torch speed (mm/min)	Thickness being cut (mm)	Length being cut (mm)
Core spray block	2.4×10^5	1.5	a	500	100	53	183
			b	500	300	35	130
Feedwater sparger	4.4×10^5	17	a	250	240 – 300	6.5	130 – 218
			a	250	160 – 300	6	65 – 95
			c	500	0	17	0
Upper grid stabilizer	2.2×10^9	400	c	500	0	20	0
			b	500	40 – 70	70	46 – 72

* The major cutting paths.
a; straight cutting
b; circumferential cutting
c; piercing

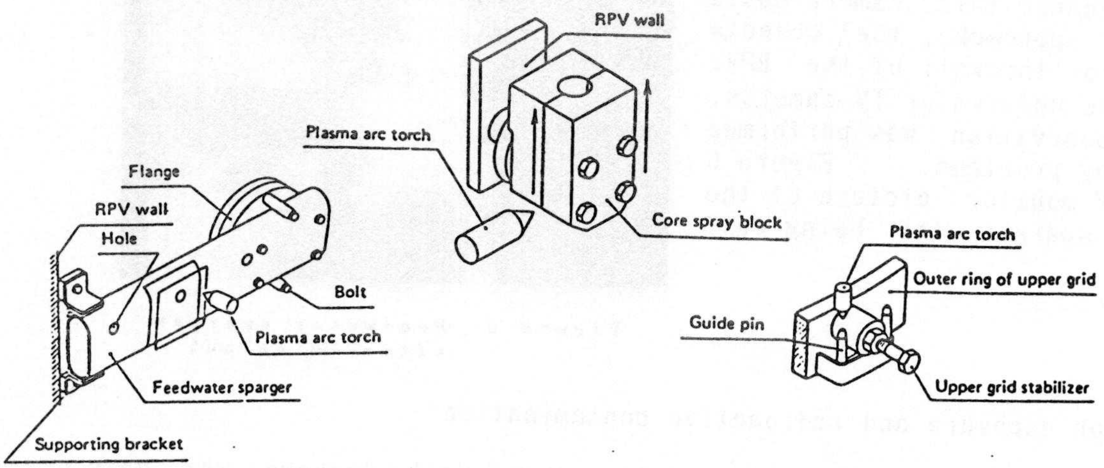

Figure 5 The reactor internals and cutting paths

Experience obtained through the dismantling work is summarized as follows:

- Working time

One hundred days were required to dismantle the three reactor internals. The working time is made up as follows:

1) Preparatory work such as assembling of the cutting device and adjusting of them : 50 days,
2) Dismantling work such as loading a computer with control programs to operate the manipulator and removing the dismantled pieces from the RPV : 40 days,
3) Removal of the cutting device after the cutting work : 10 days.

- Cutting performance

About one hour was required to cut a total length of 7.3 m during the cutting of the three reactor internals. The three reactor internals could be cut in the manner of combining basic cutting paths such as straight cutting, circumferential cutting and piercing. However, during the cutting of the core spray block, generated dross bridged the kerf so that the pieces being cut joined each other. This problem was overcome by recutting.

- Underwater TV cameras

Four underwater TV cameras, which were miniaturized to fulfill the requirements found through the mock-up test, were used during the cutting work. It was found that synchronous observation from two directions was very effective to confirm the torch position.

A subminiature TV camera was found effective to confirm completion of cutting because this camera could closely approach the objects located near the wall of the RPV. Using these underwater TV cameras, visual observation was performed without any problems. Figure 6 shows a TV monitor picture of the feedwater sparger after being cut.

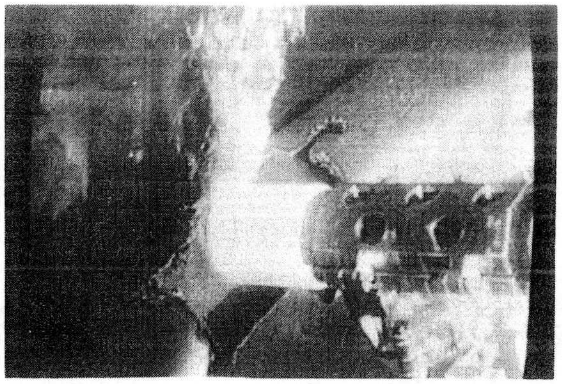

Figure 6 Feedwater sparger after being cut

- Radiation exposure and radioactive contamination

The cumulative external radiation exposure to workers was very small, $5.0*10^{-4}$ man*Sv, which mainly occured during the removal of the dismantled pieces and the packaging of them. The radioactivity concentration in air in the cavity above the water surface was measured to be $5.5*10^{-8}$ Bq/cm^3, which was about 0.2 % of the one obtained through an in-air plasma arc cutting. Therefore, it is considered that most of the radioactive fine particles generated from the melted objects are trapped in water. These results show that the remotely controlled robotic system together with the underwater plasma arc torch are very effective in minimizing the radiation exposure to workers in the dismantling work.

The slave manipulator was coated with strippable paint. Though the greater part of the surface of the slave manipulator after the cutting work was contaminated by radioactivity of about 0.15 Bq/cm^2, the contamination was easily decreased within 0.037 Bq/cm^2 by only stripping the coated paint. Consequently, it was found that the use of the strippable paint is very effective to facilitate the surface decontamination.

5. Conclusive remarks

The underwater plasma arc cutting technique has been developed in order to dismantle the reactor internals of JPDR. Using the underwater plasma arc torch together with the general-purpose robotic system, three pieces of the reactor internals could be successfully dismantled. The experience obtained through the actual dismantling work proved that the remotely controlled robotic system is very effective in minimizing the radiation exposure to workers.

The rest of the dismantling work for the reactor internals will start in April, 1989.