# SHROUD CUTTING TECHNIQUES AND COLLECTION SYSTEMS FOR SECONDARY RADIOACTIVITY RELEASE

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**Outline of shroud cutting**

Tsuruga Power Station Unit 1 of Japan Atomic Power Company (Tsuruga-1) started commercial generation in 1970. Its shroud replacement is being performed as a part of the preventive maintenance program and this will improve the resistance to Inter Granular Stress Corrosion Cracking (IGSCC) of it. Shroud is to be replaced from the material 304 SS to 316L SS which is seems to be smaller potential for IGSCC.

Figure 1 shows the procedure for shroud replacement. The items to be carried out include the following.

-Remove all fuels and removable components (like CR, CR guide tube) from reactor vessel.

-Carry out chemical decontamination in order to remove radioactive metallic oxides from surfaces of the reactor pressure vessel (RPV) and internal components.

-Remove some of the internal components, shroud, top guide, core plate and so on and transfer them to the dryer/separator pool (DSP).

-Install the in-vessel shielding panels.

-Install the new shroud and complete welding.

-Carry out secondary cutting of internal components into small pieces and load them into casks in the DSP.

Internal components have high radioactivity, the maximum radioactivity is about 2E+9

Bq/g at the cutting line on the middle height of the shroud. So secondary products cause high radiation exposure to workers during in-core shroud cutting. It is important to decrease these secondary products to realize lower radiation exposure in the in-core shroud cutting process. Collection system for secondary products is necessary to prevent diffusion into the operation floor and to keep a good work environment. This paper will describe newly developed shroud cutting techniques in reactor and its collection system for radioactive secondary products and the application of it to Tsuruga-1 shroud cutting work.

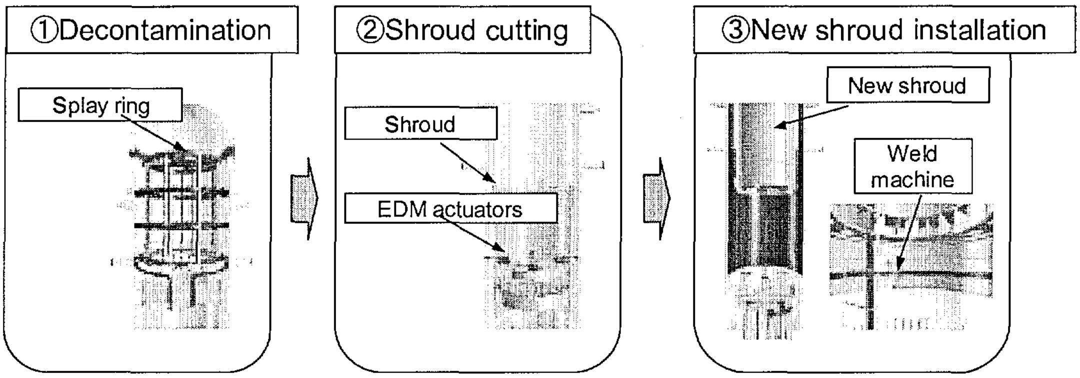


Figure 1. The procedure for shroud replacement

**Development of In-core EDM cutting system**

Electrical discharged machining (EDM) cutting proceed by electric discharge between electrode and object. EDM are generally adopted for underwater cutting because of its compactness and remote controlability.

Good remote control systems are needed for deep underwater work for in-core shroud cutting. Also a good cutting surface quality is required for new shroud welding. Therefore, EDM cutting system was applied for in-core shroud cutting in Tsuruga-1.

Fundamental EDM cutting tests were carried out to determine most suitable cutting condition and to study secondary products. Based on the test results, collection system was designed in order to prevent diffusion of secondary products. Then mock-up test was carried out in order to verify the performances of EDM cutting system and collection system.

<u>EDM shroud cutting machine</u>

Figure 2 shows the in-core shroud EDM actuator. Four EDM actuators are mounted on a rail ring that is put on the core plate when the middle part of the shroud is cut. At first, the rotated disk type electrode moves from inside and penetrates the shroud. After that, the EDM actuators change the cutting direction along the shroud on the rail ring. Each EDM actuators moves and cuts 90 degrees along the shroud circumference. The separated upper part of the shroud is moved into the DSP for secondary slicing. The lower part of the shroud is removed from the RPV to the DSP in the same way.

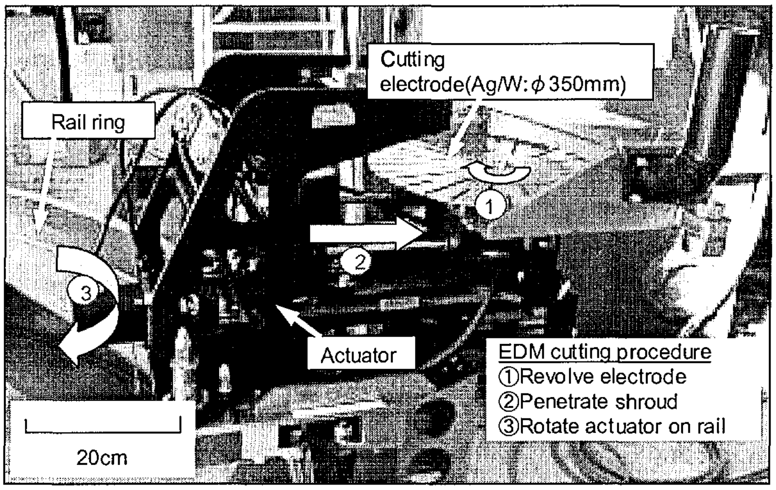


Figure 2. EDM actuator for in-core shroud cutting

<u>Selection of electrode to decrease radioactive secondary products</u>

Radioactive secondary products released in air cause the contamination of working area and the high workers' radiation exposure. Then, it is necessary to decrease the amount of radioactive secondary products as much as possible. Secondary products released into the air were studied during fundamental cold tests under several cutting conditions.

The EDM actuator and workpiece were installed in a test tank as shown in Figure 3. Ag/W or carbon were studied as the EDM electrodes. The collection system consisted of a hood, air filter, two charcoal filters and a blower. EDM electrodes and filter systems were chosen based on results of the fundamental cutting tests.

Three kinds of non-radioactive cutting object of samples, 304 SS, Stellite and Inconel-600 were used in these EDM tests. By the test of shroud material 304 SS, it was possible to estimate the total amount of secondary compounds in shroud replacement. However, the chemical content of Co in 304 SS, which is the mother nuclide of Co-60 in radiation exposed, is too small to evaluate its behavior. Then, Stellite which is about 70%-Co was adopted to evaluate the behavior of Co in cold tests. Inconel-600 was used to compare the behavior of Ni with Co and Fe. The amount of secondary products was compared as production rate to evaluate, as the weight ratio of secondary product to the lost part of a workpiece; $\mu$ g/g.

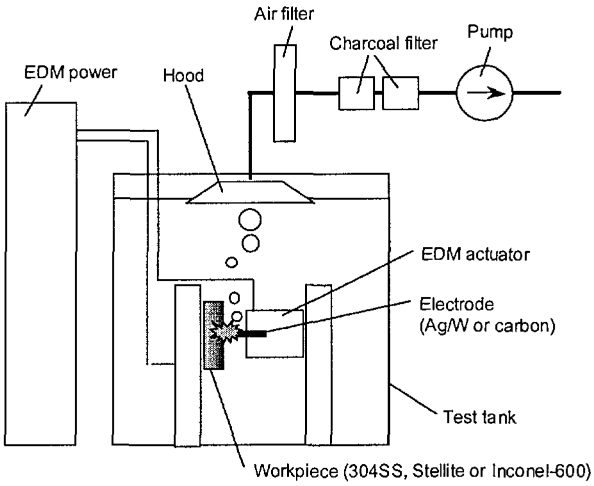


Figure 3. Schematic of basic EDM cutting test

The EDM cutting test showed that secondary products in air contained metallic elements both as aerosols and as gaseous materials. The production rates of aerosols while cutting 304 SS were about 6 $\mu$ g/g in the experiments with both Ag/W and carbon electrodes. The reason for the small difference between electrodes is considered to be explained by the aerosols generation mechanism. It can be presumed that EDM cutting produces particles by condensation of metal vapors. Condensation occurs when the vaporized metal diffuses away from the workpiece and cools, resulting in the nucleation of aerosols particles. The chemical composition of aerosols is presumed to be similar between Ag/W and carbon electrode because of the same generation mechanism.

The difference in aerosols production rate is small between Ag/W and carbon electrodes. However, as Ag/W electrode is a metal, the thickness of the electrode is designed to be thiner than that of carbon. So, the total amount of secondary products is decreased by using the Ag/W electrode plate.

Gaseous materials with Ni and Co could be detected in EDM cutting of Inconel-600 and Stellite, respectively. The production rate of gaseous material in case of cutting Inconel-600 with carbon electrode was over 100 times compared with Ag/W electrode. There was similar tendency for the generation of gaseous material in case of cutting Stellite. The amount of Co in the charcoal filter decreased under the detectable limit of atomic absorption spectrometry when using the Ag/W electrode.

The amount of metallic gaseous material was too small to be identified. But the materials should be carbonyl compounds because of the local EDM cutting environment. They were produced under conditions with high temperature, metal and carbon monoxide existence. Because EDM is a cutting method using heat, two factors of temperature and metal are satisfied with the generation of carbonyl compounds. The third factor of carbon monoxide was satisfied by the carbon electrode because carbon electrode became the base material of carbon monoxide in EDM cutting. Concentration of gases generated in EDM cutting was measured by using gas chromatography. Hydrogen and oxygen were detected by electrolysis of water. Furthermore, when using the carbon electrode, carbon-oxide compounds were generated. Carbon monoxide was about 20% of the gas phase products. Therefore, the following chemical reactions were suggested based on EDM cutting environment [1, 2]:

$$Ni+4CO \rightarrow Ni(CO)_4 \qquad (1)$$

$$2Co+8Co \rightarrow Co_2(CO)_8 \qquad (2)$$

Carbonyl compounds are low melting and boiling points which means there is a high vapor pressure at room temperature; the boiling point of nickel tetra carbonyl is 42.3℃ and the melting point of di cobalt octa carbonyl is 52℃ [3].

Because aerosols in bubbles is transferred into water by diffusion in underwater cutting [4], aerosols in the bubbles makes a relatively small contribution to increase the activity concentration in air during in-core shroud cutting. However, as carbonyl compounds are insoluble in water, most of them are expected to be released into air during in-core shroud cutting with the bubbles. Therefore, radioactive carbonyl compounds cause the high radioactivity concentration in air.

However, because carbon monoxide was less than 1% of the gas phase products when using the Ag/W electrode, the amount of carbonyl compounds was negligibly small. Therefore, the Ag/W electrode is adopted for in-core shroud cutting in order to decrease production of carbonyl compounds.

Moreover, if replacement of the electrode is necessary during in-core shroud cutting, radiation exposure of workers will increase because the EDM actuator is pull up into the air. However, the life of the Ag/W electrode was so long enough not to replace electrode during in-core shroud cutting. Therefore, it became possible to decrease radiation exposure during the cutting by using the Ag/W electrode.

Collection system for secondary products

In in-core shroud cutting, secondary radioactive products were produced as swarf (insoluble metal and oxides), ion (dissolved metal), aerosols (particles in air) and gases (carbonyl compounds). A Collection system was designed to prevent diffusion of radioactive secondary products, more specifically, to keep activity concentration in operation floor below the no-mask level and to keep transparency of water for underwater work without hindrance. The collection system consists of the ①swarf collection system, ②air clean-up system, ③water clean-up system and ④well sheet cover as shown in Figure 4.

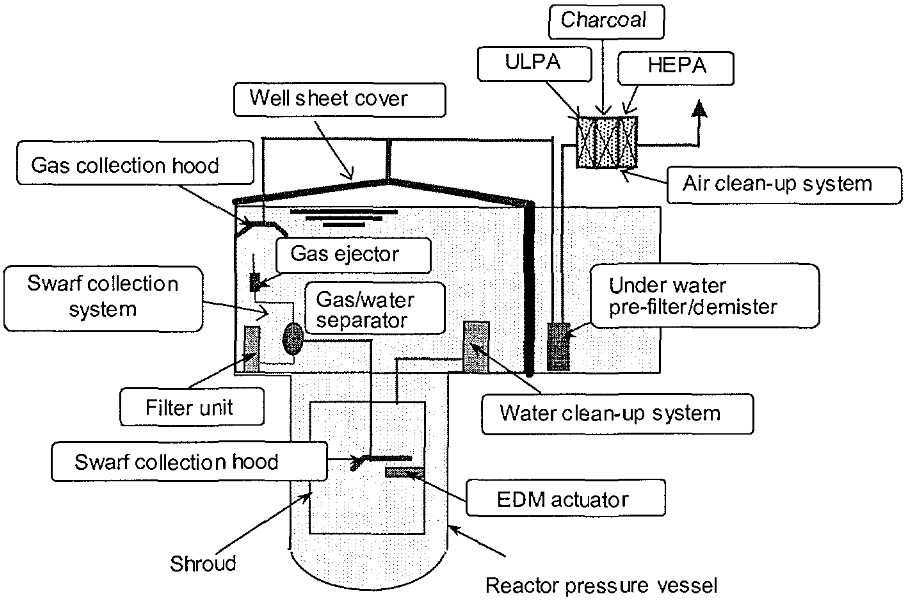


Figure 4. Collection system for secondary products in RPV

The swarf collection system consists of a hood, a suction pump, gas/water separator and filters. The hood covers the area with the rotating electrode and vacuums swarf, gases and aerosols with water to prevent their diffusion into water and the operation floor. After gases and aerosols are separated from the water, they are introduced into the air clean-up system. On the other hand, separated swarf is filtered off by a pleat type filters. The water clean-up system consists of a suction pump, pleat type filters and demineralizer to take away swarf and ions leaked from the swarf collection system into the RPV.

The air clean-up system consists of the underwater pre-filter, ULPA filter, charcoal filter, HEPA filter and blower to collect aerosols and radioactive gaseous materials generated by both EDM cutting in the RPV and secondary plasma cutting in the DSP. The pre-filter unit is located underwater in the DSP to prevent radioactive exposure because the unit is expected to involve a lot of activity. Air filters and the charcoal filter remove aerosols and radioactive gaseous materials, respectively. The exhaust air from the air clean-up system is introduced into a temporary air conditioning apparatus for the building.

The well sheet cover is mounted over the RPV. If aerosols and radioactive gaseous materials leak from the swarf collection system to the water surface, the well sheet cover prevents diffusion of aerosols and gaseous materials to the operation floor. The ventilation air in the well sheet cover is also introduced into the air clean-up system. Well sheet cover is made from conducting polymer material to prevent aerosols absorption on the inner face.

A mock-up test was carried out using EDM actuators with Ag/W electrode and collection system for secondary products. Four EDM actuators cut the simulated shroud at deep underwater. As satisfactory results were obtained for the EDM cutting system and collection system, they were applied to the in-core cutting work at Tsuruga-1.

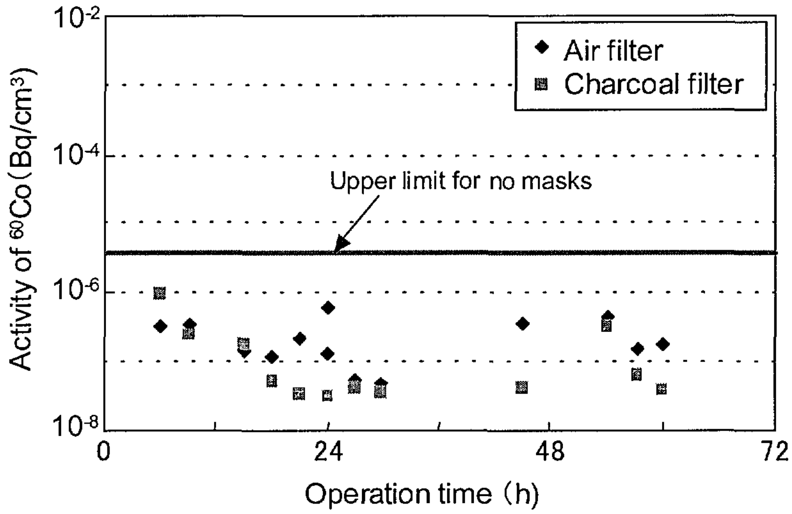


Figure 5. $^{60}Co$ concentration in well sheet cover during in-core shroud cutting through the middle part of the shroud.

<u>In-core shroud cutting in Tsuruga-1</u>

It took 60 hours to cut through the middle part of the shroud of circumference length 11m by using four EDM actuators with the Ag/W electrode. Activity concentration didn't rise beyond the limitation of mask wearing on the operation floor during in-core shroud cutting. Figure 5 shows the concentrations of activity in the well sheet cover through out the cutting time. The collection system kept the activity concentration lower than the limit of air mask charge, 4E-6 $Bq/cm^3$, even near the water surface.

The amount of gaseous materials was very small because the Ag/W electrode was adopted as shown in Figure 5. On the other hand, good water quality and transparency to be able to continue underwater works right after cutting were kept during in-core shroud cutting.

**Secondary plasma cutting in DSP**

Secondary cutting system

As a secondary cutting method, high cutting speed, good remote control and performance to cut many kinds of shapes and thickness of objects are needed. Each part was sliced into small pieces and loaded into casks in the DSP and carried to the site bunker pool.

Figure 6 shows secondary cutting equipment. The secondary cutting equipment consists of the following devices – a slicing platform moving horizontally above the DSP, a mast which can rotate and move vertically, an underwater plasma torch attached on the bottom of the mast and a gas-collecting hood mounted above the plasma torch.

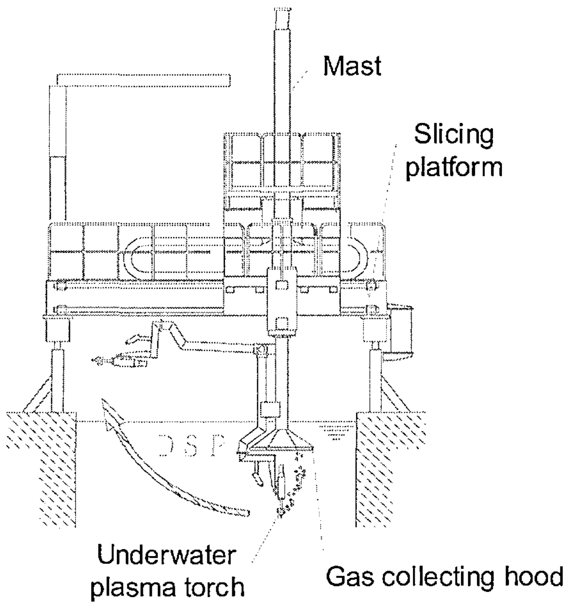


Figure 6. Secondary cutting equipment

The highly radioactive aerosols generated during the underwater plasma cutting could be collected by the gas-collecting hood that was set above the plasma torch. The inside hood was so highly contaminated that it was designed to be separated from the torch mast, by adopting a hinge type connection, during the torch maintenance. So it was possible to reduce the radiation dose during the torch maintenance.

The aerosols collected by the hood were vacuum exhausted into the air clean-up system which was shared with the EDM cutting function and filtered off. Because the amount of carbon monoxide is very low, the formation possibility of carbonyl compounds during plasma cutting was estimated as low. A clean house was set up over the DSP to prevent diffusion of leaked aerosols from the hood. For the purpose of cleaning the DSP water, a clean-up system with pleat type filter and demineralizer was installed.

The underwater cutting test for representative cutting objects was performed and suitable cutting conditions were obtained considering a balance between improvement of the cutting capability, reduction of the secondary waste volume, and long life span of the touch head. The cutting, secondary waste recovery and handling devices were designed considering reduction of radiation exposure of workers and the radioactive waste volume. Several mock-up tests for underwater cutting, handling and secondary waste recovery using test pieces which simulated typical core internals like the shroud, core plate and top guide were carried out in order to verify the device performances.

Secondary plasma cutting in Tsuruga-1

The secondary cutting work at Tsuruga-1 resulted in success from the point of reduction of the working period and radiation exposure. The working environment was kept good due to collection of most of the aerosols by the hood mounted above the plasma torch. Aerosols leaks from the hood in clean house were stopped. The amount of radiation exposure was reduced to 60% of the planned value, because of adequate decontamination of the working environment and reduction in the number of torch maintenance tasks by improvement of the underwater cutting device. Regarding collection of secondary waste, the dross was successfully collected by using a vacuum cleaner and removable plate. The aerosols was collected by the hood and clean house and introduced into the air clean-up system. Minute flotage was introduced into the water clean-up system which had the pleat type filter and demineralizer.

## Conclusions

Replacement of in-core shroud has been conducted as part of the preventive maintenance program in Tsuruga-1. The EDM and plasma cutting methods were applied to in-core shroud cutting and secondary cutting in the DSP, respectively. The cutting systems were improved in order to decrease radioactive secondary products.

1) Fundamental EDM cutting tests

Fundamental EDM cutting tests were carried out in order to study secondary products. It could be presumed that volatile Co-carbonyl compound was generated by using a carbon electrode. The Ag/W electrode was effective as EDM electrode for in-core shroud cutting to prevent generation of Co-carbonyl compound and to decrease the total amount of secondary products.

2) In-core shroud cutting in RPV

EDM cutting system with the Ag/W electrode and collection system could keep a good environment during in-core shroud cutting in Tsuruga-1. Activity concentration was lower value than limitation of mask charge level, 4E-6 Bq/cm$^3$, even near the water surface.

3) Secondary plasma cutting in DSP

The secondary cutting work was successful in the point of reduction of working period and radiation exposure. The amount of radiation exposure was reduced to 60% of the planned value, because of adequate decontamination of the working environment and reduction of number of torch maintenance tasks by improvements of the underwater cutting device.

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