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A CHEMICAL DECONTAMINATION PROCESS FOR DECOMMISSIONING OF BOILING WATER REACTORS

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ABSTRACT

The number of nuclear power plants transferred to decommissioning phase have increased in also Japan. In order to reduce the exposure dose received in dismantling process, chemical decontamination is planned in the early stages of decommi.. Hitachi-GE have developed chem. decon. technology, and applied it mainly to domestic NPPs for over 90 times before. Hitachi-GE completed the chem. decon. project for Hamaoka nuclear power plant Unit 1 and 2 of Chubu Electric Power Co. Inc. under decommi. phase. It was the first RPV decon. for decommi. BWR in Japan, and had original features (RPV decon. with steam dryer & moisture separator, inoperable condition of Recirculation pumps and so on). To respond these technical issues, Hitachi-GE conducted technical verifications such as flow simulations and mock-up tests, and completed chem. decon. work. This report introduces chem. decon. tech. for decommi. Hamaoka Unit 2 based on actual results.

INTRODUCTION

Overview of decommissioning

As of the end of 2019, more than 180 reactors in nuclear power plants (NPPs) worldwide have been permanently shut down (International Atomic Energy Agency (2020)). Among them the decomi. process for 17 reactors had been completed , and most of the others were under decomi.. Considering the fact that many nuclear power reactors are closing due to technical, political or economic reasons, an increase in the number of NPPs globally entering the decomi. phase is expected over the next few decades. The International Atomic Energy Agency (IAEA) has defined two main decomi. strategies: immediate dismantling and deferred dismantling (International Atomic Energy Agency (2018)). The immediate dismantling requires a shut-down nuclear facility to be decontaminated, dismantled and/or removed to a level that permits unrestricted or restricted release of the property. Decomi. activities begin immediately after the facility is permanently closed. On the other hand, the deferred dismantling allows a facility to be stored safely for a long period of time until the radioactivity decays to a level that permits unrestricted or restricted release of the property; afterwards, the facility is decontaminated and dismantled as required. In practice, the actual decomi. plans to be used are made by combining the immediate and the deferred dismantling strategies (Japan Atomic Energy Commission (2018)).

Chemical decontamination in decommissioning

In any of the strategies described above, decon. tech. is necessary to proceed with the decomi. process. Decon. in decomi. has three major purposes: to reduce occupational exposures, to prevent contamination from spreading during dismantling, and to reduce contamination of dismantled components with the aims of reducing the amount of radioactive waste and facilitating waste management (Nuclear Energy Agency (1998))). Different decon. technologies including chemical, electrochemical and mechanical techniques have been developed and adopted in accordance with those purposes. Chem. decon. utilizes chemical solutions to dissolve radioactive substances deposited on the surface of objects, which is suitable for decontaminating a whole system or objects with a complicated structure. Chem. decon. is generally performed before dismantling in order to reduce personnel dose and spread of contamination in further activities. For this purpose, a chem. decon. method that is used for operating plants is applicable with some modifications as needed.

Decommissioning of Hamaoka Units 1 and 2

In Japan, 9 out of 57 commercial reactors are currently under decomi.. Hamaoka NPP, located in Shizuoka Prefecture, has five reactors. Units 1 to Unit 4 are boiling water reactors (BWRs). Unit 5 is an advanced boiling water reactor (ABWR). Units 1 and 2 started commercial operation in 1976 and 1978, respectively, and both were permanently shut down in 2009. At that time, Chubu Electric Power Company submitted a decomi. plan for these units to the Nuclear Regulation Authority (NRA), which was approved. In the plan, the overall decomi. process of the two units was divided into four phases as shown in Figure 1. In the first phase, fuels of both units were removed and the status of contamination was investigated in preparation for the following dismantling activities. The units entered the second phase of decomi. in fiscal year 2015, and they are currently undergoing dismantling of their peripheral areas. The third phase, which is supposed to begin in fiscal year 2023, includes dismantling and removal of the two reactor areas. In the final phase, the site is ultimately supposed to be released after completion of dismantling and removal of all the facilities by the end of fiscal year 2036 (Chubu Electric Power Co., Inc. (2016)). In proceeding to the third phase, system decon. is being carried out in Units 1 and 2 in order to reduce occupational exposures and to prevent the spread of contamination during dismantling activities. The decon. targets in phase 2 are common to both units and are shown in Figure 2: the reactor pressure vessel (RPV), the residual heat removal (RHR) system outside the drywell and the reactor water cleanup (RWCU) system outside the drywell. Hitachi-GE applied the chem. decon. which was named of 'HOP(II)' to Unit 2 from February to March 2021. This paper provides a brief explanation of design considerations and technical measures in adapting it to the RPV decon. of Hamaoka Unit 2 and provides results of the actual decon..

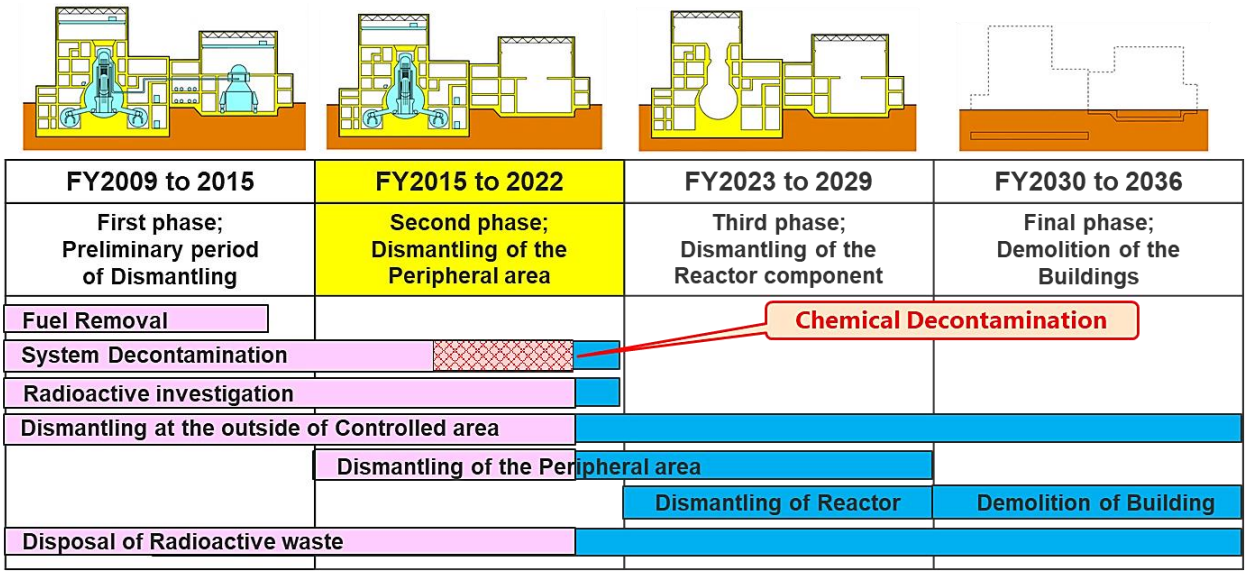


Figure 1 Overall decomi. plan for Hamaoka Units 1 and 2. (Chubu Electric Power Co., Inc. (2016))

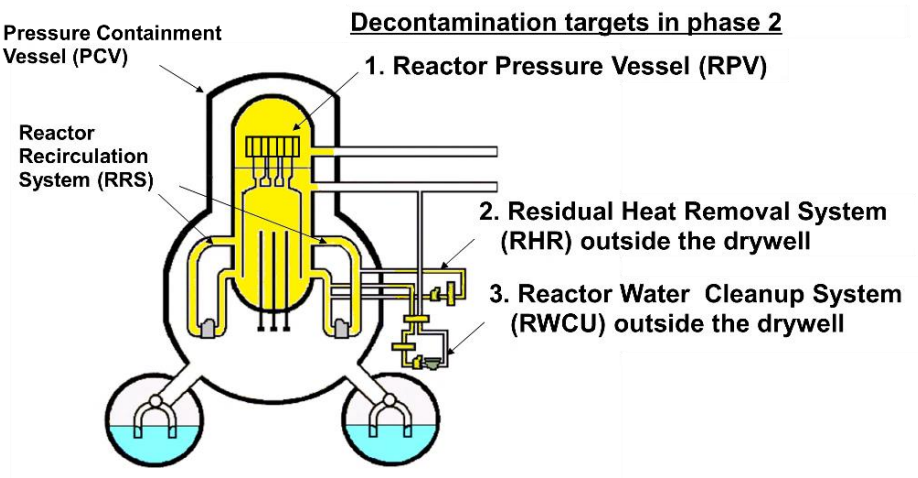


Figure 2 Decontamination targets in the second phase of Hamaoka Units 1 and 2 decomi. (Chubu Electric Power Co., Inc.(2015))

Chemical Decontamination for Decommissioning Hamaoka Unit 2

Plant-specific requirements and design considerations

Since Hamaoka Unit 2 had experienced hydrogen water chemistry (HWC) during its operating lifetime, HOP(II) was chosen as a decon. method. Compared to the chem. decon. of the RPVs for plants in service that we have performed to date, Hamaoka Unit 2 decon. had some plant-specific requirements as listed in Table 1. We considered two measures to address each design consideration and describe them in the next two subsections.

Table 1 Plant-specific requirements and design considerations

No	Plant-specific requirements	Design considerations	Measures
1	RRS pumps are unavailable.	To secure flow rates in the RPV.	Adding two temporary circulation pumps to secure necessary flow rates in the PRV.
2	The steam dryer is to be decontaminated simultaneously with the RPV.	To secure sufficient solution turnover around the steam dryer	Raising and lowering the water level at the steam dryer to encourage turnover of decon. solution in the area.

A measure to secure necessary flow rates in the RPV

From our past field experiences, we accessed that securing a suitable flow rate of the decon. solution is necessary to obtain a sufficient decon. outcome. Therefore, in our earlier RPV decon. projects, the RRS pumps of the plants were operated during decon. to secure the necessary flow rate. The RRS pumps of Hamaoka Unit 2, however, were no longer available as the plant had been out of service for more than a decade. This meant that securing a sufficient solution flow would be difficult, which could result in a poor decon. outcome. From the viewpoint of securing the solution flow, we considered connecting temporary circulation pumps to the RRS. Figure 3 shows the results of RPV flow analyses with and without temporary circulation pumps. The results suggested that utilizing temporary circulation pumps will secure the

necessary flow rate in most of the decon. areas; however, around the steam dryer the flow would not be enough. Hence we decided to apply the temporary circulation pumps with the same specifications as in the analyses. And we looked for a measure to get the necessary flow for the steam dryer.

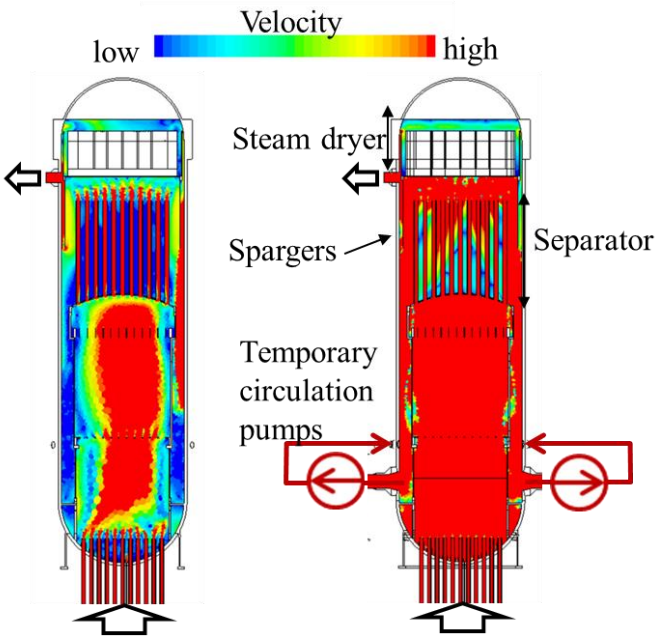


Figure 3 Results of RPV flow analyses with and without temporary circulation pumps

A measure to promote solution turnover in the steam dryer

In our HOP (II) applications to RPVs, the steam dryer and the moisture separator were removed prior to starting the decon. process. On the contrary, in Hamaoka Unit 2 decomi., the steam dryer was required to be decontaminated simultaneously with the RPV. As we noted in discussing Figure 3, using the temporary circulation pumps was not expected to provide the necessary flow rate around the steam dryer. Furthermore, hardly any decon. solution flowed inside the steam dryer because the steam dryer contained a lot of corrugated plates to remove moisture from the steam generated in the reactor core. As a measure to promote turnover of decon. solution in the steam dryer, we considered raising and lowering the water level in the RPV (water level up/down operation) as shown in Figure 4.

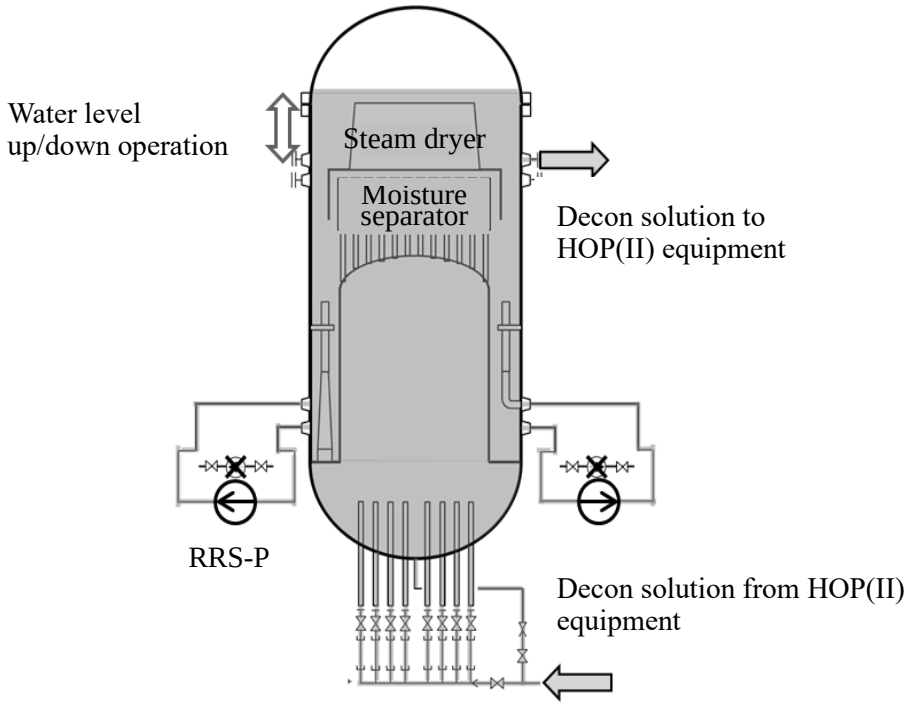
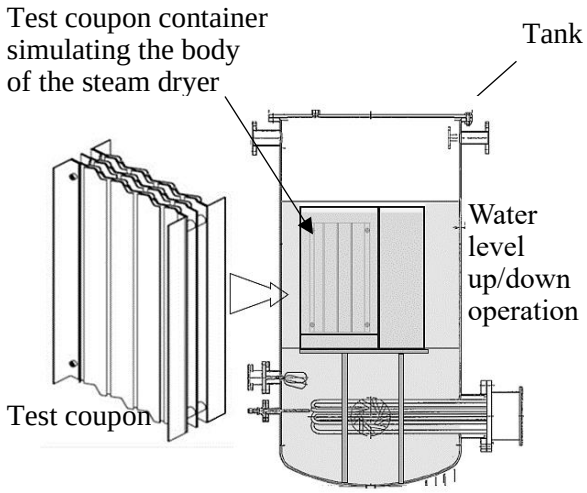


Figure 4 Strategy to improve decon. effect of the steam dryer

To assess the effect of the measure, a mock-up test was carried out under the test conditions shown in Figure 5. The mock-up system simulated chem. decon. of the steam dryer when the water level up/down operation was applied. A test coupon simulated the corrugated plate of the steam dryer. Oxide film was formed on the surface of the test coupon before the test by atmospheric oxidation. The mock-up test results are summarized in Figure 6. We verified that the water level up/down operation ensured the corrugated plate had contact with the decon. solution in each step of the HOP(II) method because the oxide film on the coupon was completely removed. Thus we decided to implement the measure during chem. decon., with the expectation we would get a certain improvement in the decon. effect for the steam dryer.



Test coupon conditions	
shape and material	corrugated stainless steel plates
oxide film creation	atmospheric oxidation
Decontamination conditions	
temperature	90 ℃
oxidant	permanganic acid (200ppm)
oxidation duration	5 hours
reductant	oxalic acid (2000ppm), pH2.5
reduction duration	24 hours
number of cycles	2 cycles

Figure 5 Mock-up system and test conditions

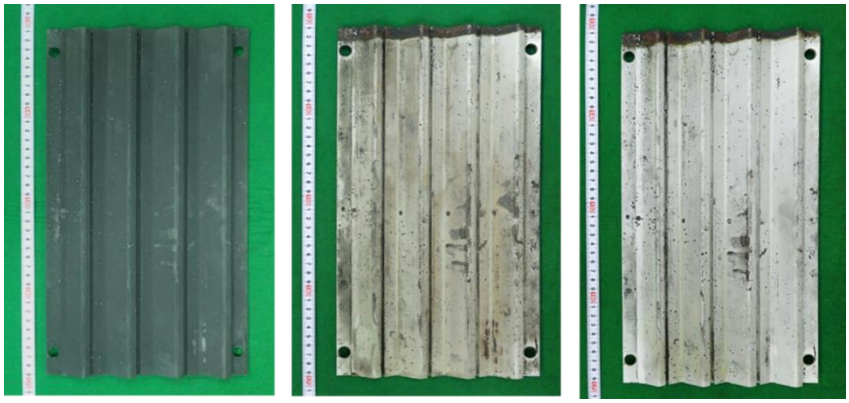


Figure 6 Results of the mockup test simulating a corrugated plate of the steam dryer

Results of the chemical decontamination for Hamaoka Unit 2

Photos of the feed water sparger and dryer in the RPV of Hamaoka Unit 2 before and after chem. decon. are shown in Figure 7. Corrosion products incorporating radionuclides such as Co-60 (S. Uchida, *et al*., (1982)) had formed on the surface of the feed water sparger, but after chem. decon., no corrosion products were observed. This process had removed the corrosion products and their radioactivity.

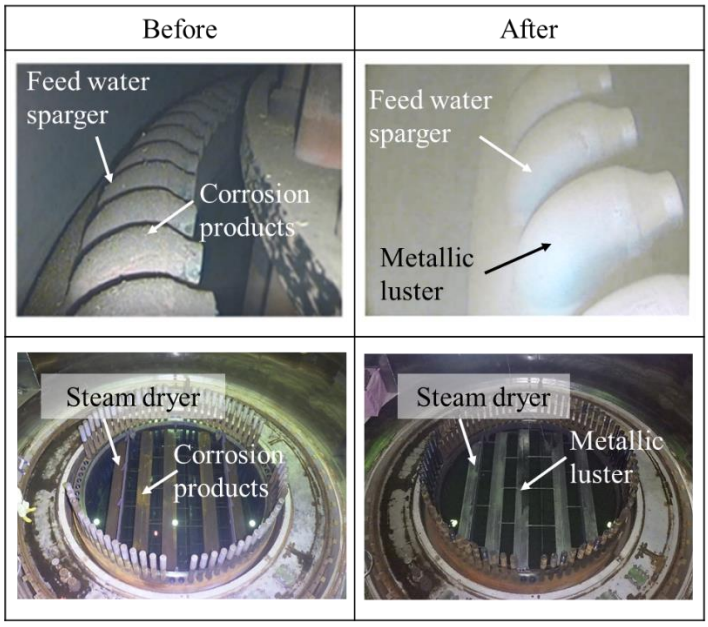


Figure 7 Feed water sparger and steam dryer in the RPV of Hamaoka Unit 2 before and after chem. decon.

The RPV dose rates which were obtained by γ-ray measurements before and after the chem. decon. are summarized in Table 2. Dose rates were measured at seven points to confirm the effect in the RPV by the chem. decon.. The average of the decon. factors (DFs) was 38.

Table 2 Dose rates of RPV before and after chem. decon.

No.	Dose rates before decon [mSv/h]	Dose rates after decon [mSv/h]	DFs [-]
1	0.13	0.0028	46
2	0.18	0.0020	90
3	0.080	0.0022	36
4	0.10	0.0052	19
5	0.14	0.0033	42
6	0.22	0.0059	37
7	0.20	0.0074	27
		Average	38

Conclusion

For chem. decon. prior to dismantling in the decomi. process of nuclear power reactors, the chem. decon. method that is used for operating plants is applicable. In chem. decon. for decommissioning, required specifications and available plant equipment are different from those of a plant in service. Therefore, design and procedures of decon. need to be optimized accordingly. In the decon. of Hamaoka Unit 2, RRS pumps were unavailable and the steam dryer was required to be decontaminated simultaneously with the RPV. We considered technical measures to address the design considerations related to these plant-specific requirements, and we verified the effectiveness of the measures by flow simulation and mock-up test prior to the actual application. Satisfactory decon. results were obtained when the measures were applied to the Hamaoka Unit 2.

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