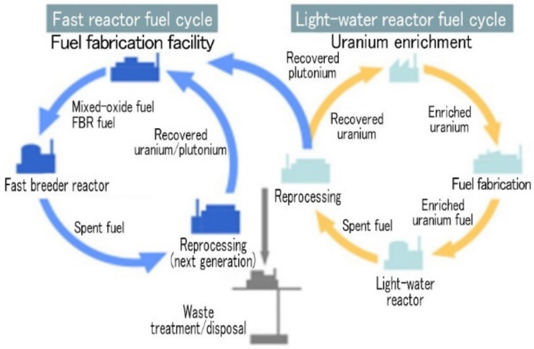
Activities for Establishment of Nuclear Fuel Cycle



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Japan is promoting the nuclear fuel cycle as a basic policy. Mitsubishi Heavy Industries, Ltd. (MHI) has been working on the early launch of a nuclear fuel reprocessing plant (hereinafter the "Rokkasho Reprocessing Plant"), as well as a MOX (Mixed Oxide) fuel fabrication plant, currently being constructed in Rokkasho Village, Aomori Prefecture, by Japan Nuclear Fuel Limited. These plants are going to be the key facilities for the establishment of the nuclear fuel cycle. As the lead manager of this project, we are taking various measures in order to ensure the completion of construction in full compliance with the new regulations and related requirements.

1. Introduction

Japan positions nuclear power as quasi-domestic energy in its strategic energy plan [(1)] and is promoting the nuclear fuel cycle as a basic policy, where plutonium and other substances recovered after reprocessing spent fuel are utilized effectively, from the viewpoint of the efficient use of resources and a reduction in the volume of high-level radioactive waste and its degree of harmfulness.

The Rokkasho Reprocessing Plant was at the final stage of active testing (confirming the performance with actual spent fuel), but testing has been suspended due to the new regulatory standards coming into force after the Great East Japan Earthquake. We are currently working on various measures in order to comply with the new standards [(2)]. **Table 1** shows our major efforts and actions.

Table 1 Engineering work conducted to comply with new regulatory standards at Rokkasho Reprocessing Plant and MHI's efforts.

No.	countermeasure item	MHI's major efforts
1	Internal overflow	Installing an emergency isolation valve Applying water-stop/water-proof treatment
2	Tornadoes	Installing a protective board and guard net in the primary exhaust stack and water-cooling tower of safety cooling water Installing an additional water-cooling tower of safety cooling water
3	Internal fire	Installing fire extinguishers Making the penetrating portions fire-resistant
4	Construction of emergency response center	Undertaking installation work for mechanical and electrical service facilities in the emergency response center
5	Seismic resistance enhancement	Performing an assessment of various equipment and undertaking reinforcement work
6	Additional specialized severe accident facilities	Installing equipment for preventing evaporation to dryness Constructing criticality accident response facilities

The MOX fuel fabrication plant was also under construction, but just like the Rokkasho

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Reprocessing Plant, various changes must be incorporated in the design to comply with the new regulatory standards before construction can resume.

This report will explain an overview of the deliberations concerning the additional construction of criticality accident response facilities at the Rokkasho Reprocessing Plant, as well as an advanced ventilation simulation tool at the MOX fuel fabrication plant, as part of our efforts for the establishment of the nuclear fuel cycle.

2. Installation study for criticality accident response facilities at the Rokkasho Reprocessing Plant

The Rokkasho Reprocessing Plant produces uranium powder and MOX powder from the spent fuel assemblies of light-water reactors after going through the following treatment process:

- Storing spent fuel assembly
- Shearing and dissolving spent fuel assembly (Assembly → Solution)
- Separation and refinement (Solution → Uranium solution and plutonium solution)
- Denitration (Uranium solution and plutonium solution → Uranium powder and MOX powder)

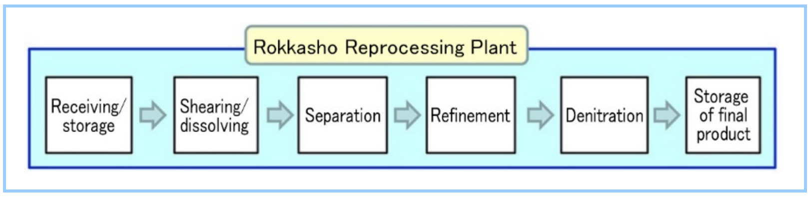

Figure 1 Overall process of spent fuel reprocessing

This treatment process follows the defense in depth philosophy and takes necessary measures against foreseen abnormal events in order to prevent them from occurring or spreading, as well as to mitigate their impact if they do occur. Then, the following abnormal events, which would have a significant radiation impact on the public if they were to occur, are regarded as severe accidents:

- Criticality accident
- Evaporation to dryness due to the loss of cooling capacity
- Hydrogen explosion caused by radiolysis
- Fire and explosion caused by organic solvent, etc.
- Criticality in the spent fuel storage pool
- Radiation leaks

Among the above events, a criticality accident is one of the severe accidents unique to reprocessing plants, for which various preventive measures have been conventionally taken, taking into account the setting of the nuclear limit with a sufficient safety margin and the possibility of a single failure.

Furthermore, in the new regulatory standards, severe accidents are expected to occur under harsher conditions than those defined in the design, based on which effective measures for preventing further spread and mitigating the impact are required.

At the time of a criticality accident caused by the liquid solution in which spent fuel is dissolved, radioactive gases (noble gases such as Kr and Xe, as well as iodine (I)) are generated and would be emitted into the air as it is very difficult to collect them completely with the gaseous waste treatment system during normal operation.

As a measure for mitigating this impact, MHI has built a new system that compresses radioactive gases, stores them temporarily in the system and emits them in a controlled manner after the radiation is sufficiently reduced, in order to reduce emissions into the air by as much as possible.

(1) Attenuation effect of radioactive gases (noble gases such as Kr and Xe, as well as iodine (I))

Radioactive gases decay over time after being generated and the amount of radioactive materials decreases in a relatively short time. Therefore, trapping the generated gases in the system for a certain period after a criticality accident has occurred is expected to have a certain effect in mitigating the impact on the public. (**Figure 2** shows the attenuation effect.) We have been working on the design of the waste gas storage facility for the Rokkasho Reprocessing

Plant that would store the generated radioactive gases inside the system for more than one hour in order to reduce the radiation does from exposure to these gases by more than 95%.

(2) System configuration

Figure 3 illustrates the system configuration of the waste gas storage facility. The radioactive gases generated at the time of a criticality accident would be fed into the newly installed waste gas storage facility by closing the isolation valve before being emitted outside the gaseous waste treatment system. The waste gas storage facility consists of a waste gas storage tank and a gas compressor. The gas compressor stores the waste gases efficiently by raising the pressure to about 0.4Mpa. The waste gas storage tank is designed to have a capacity sufficient to store radioactive gases for more than 1 hour after the occurrence of a criticality accident. The gas compressor utilizes a special method called water ring type which can compress hydrogen or other gases including radioactive noble gases and was specifically developed for use in nuclear power plants. This gas compressor is highly reliable and offers a wide range of practical applications in many nuclear power plants.

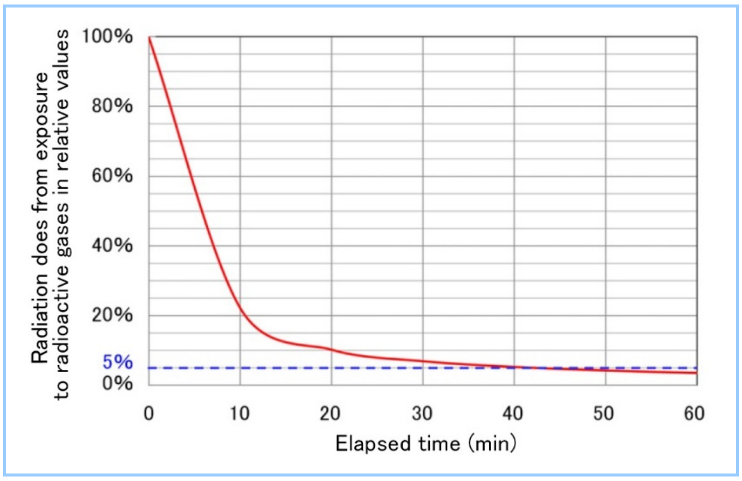

Figure 2 Attenuation effect of noble gases and iodine

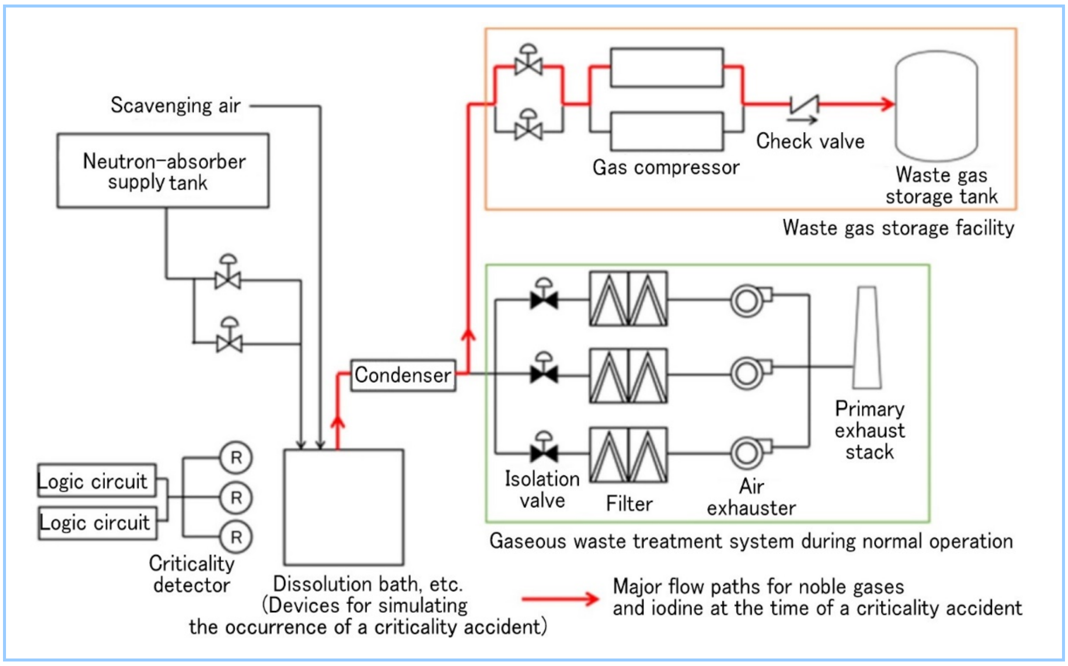

Figure 3 System configuration of the waste gas storage facility

3. Advancement in ventilation simulation tool for MOX fuel fabrication plant

3.1 Overview of the MOX fuel fabrication plant

The MOX fuel fabrication plant is being constructed next to the Rokkasho Reprocessing Plant as the first commercial manufacturing plant of MOX fuel assembly in Japan. MHI is organizing its construction as the lead manager in accordance with the basic design provided by Japan Nuclear Fuel Limited.

MOX fuel is produced by mixing plutonium and uranium recovered in spent fuel reprocessing. The utilization of MOX fuel in light-water nuclear power plants would lead to fuel resource saving. Therefore, the MOX fuel fabrication plant will play a central role in the nuclear fuel cycle.

With regard to the construction the MOX fuel reprocessing plant, various measures including those for containment and radiation shielding have been taken just like in the Rokkasho Reprocessing Plant, taking into account the characteristics of MOX fuel and its use domestically and overseas, in order to comply with the new regulatory standards that came into force after the Great East Japan Earthquake.

The process for MOX fuel fabrication is illustrated in **Figure 4**. The MOX fuel fabrication plant consists of the fuel fabrication facilities and surrounding facilities for analysis, disposal, emergency power generation, air-conditioning and ventilation.

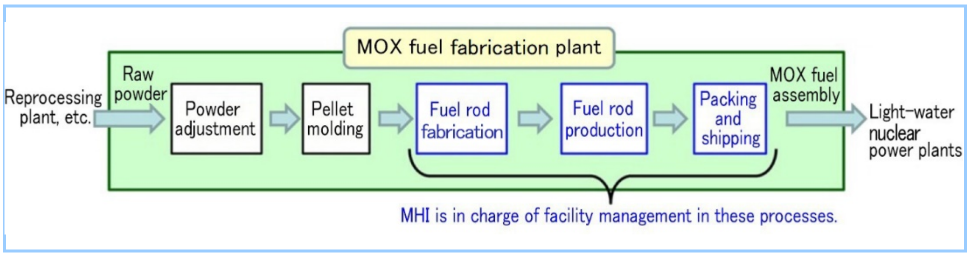

Figure 4 MOX fuel fabrication process

3.2 Advancement in ventilation simulation tool

The inside of the MOX fuel fabrication plant maintains negative pressure that decreases in a gradual manner in order from the glove box that encases radioactive materials, the room where the glove box is located and the building itself, for the purpose of containing radioactive materials. The inside of the glove box is, for the purpose of maintaining the quality of the MOX fuel produced, filled with a nitrogen atmosphere. The air-conditioning and ventilation equipment shoulders these functions. In the test run of this equipment, it is necessary to adjust the ventilation balance in order to maintain the negative pressure at the designated level in the glove box, which as noted above is filled with a complex combined nitrogen atmosphere. Dampers, which adjust the openings for controlling the ventilation balance, are located in more than 1,000 locations. Accordingly, MHI has been working on the development of a ventilation simulation tool in order to perform test-run adjustment properly and efficiently, to shorten the period needed for adjustment and to reduce the burden on workers. **Figure 5** illustrates the ventilation simulation in action.

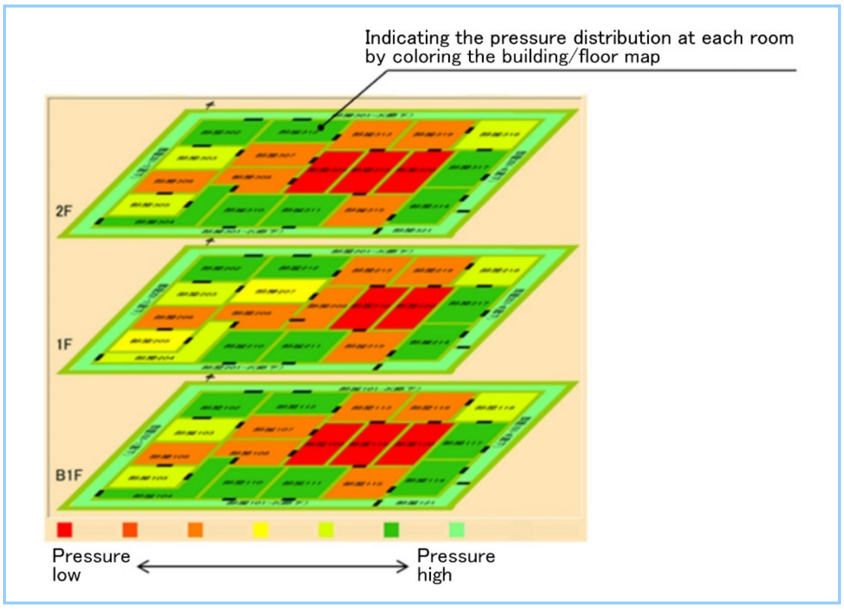

Figure 5 Image of ventilation simulation tool in action *
* The building layout, etc. are not those of MOX fuel fabrication plant.

(1) Elaboration of ventilation simulation model

The system of air-conditioning and ventilation mainly consists of air blowers/fans, filters, ducts and dampers. In order to accurately simulate the pressure drop characteristics of the complex combination of various mechanisms, we collect test data from the individual components including their operating characteristics and refine the ventilation simulation model by incorporating the data as resistance elements. With regard to the air blowers/fans, the coast-down characteristics at the time of shut-down are incorporated in the ventilation simulation model as well in order to increase the accuracy in recreating transient changes in the system. Accordingly, in the actual operation of the plant after its completion, finer tuning of the negative pressure is possible in order to manage an even tighter containment atmosphere.

(2) Shortening analysis time through the application of multivariable optimization technology

MHI is working on the further advancement of the ventilation simulation tool so that it is capable of achieving the predicted target adjustment according to the plant conditions that change on a daily basis during the adjustment period, by not only predicting the target prior to adjustment, but also by giving feedback on the various outcomes, which we intend to apply to the on-site instant response during adjustment.

We have been upgrading the tool so that it can achieve the target negative pressure balance in a short time by incorporating multivariable optimization technology (i.e., the primal-dual interior point method*, etc.), which optimizes the numerous portions subject to adjustment all at once, as opposed to how the adjustment work has been done manually through trial and error. On top of that, as one of the advantages of the application of multivariable optimization technology, minimization of the risk of rework at the time of adjustment is an expected result of quickly detecting plant conditions not foreseen in the design scope when giving feedback on the various adjustment outcomes.

Furthermore, we can expect an even greater reduction in analysis time and the further enhancement of accuracy by adding AI (Artificial Intelligence) technology and implementing a valid adjustment method selected from an enormous number of options in accordance with the result of calculations.

The tool is being developed so that the ventilation simulation can reduce the time for adjusting damper openings significantly compared with the conventional method, and we aim at the practical application not only in the test run but also in the viewpoint of the utilization as the operation support tool after the completion.

* An algorithm for the continuous optimization problem, which converges to the optimum solution via the inside of the feasible domain and is one of the interior point methods known as the dual interior point method that solves the primary problem and dual problem at the same time.

4. Conclusion

We have introduced the criticality accident response facilities at the Rokkasho Reprocessing Plant, as well as an advanced ventilation simulation tool at the MOX fuel fabrication plant as part of the Japan's efforts toward the establishment of the nuclear fuel cycle.

MHI is also working on continued facility maintenance and improvement for the stable operation of the Rokkasho Reprocessing Plant and MOX fuel fabrication plant after completion. We are committed to making the maximum contribution to the promotion of the plutonium-thermal project (light-water reactor fuel cycle) and the realization of the fast reactor fuel cycle in the future, through the early construction and stable operation of nuclear fuel cycle-related facilities.

References

(1) Strategic Energy Plan (2018), Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry
https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/180703.pdf

(2) Article34 : Facilities to prevent the escalation of criticality accidents, compliance with new regulatory standards at the Rokkasho Reprocessing Facility, Appendix 3-2 , (2020), p.60, Japan Nuclear Fuel Limited