Phase: **Design**

Decommissioning Process **"Fuel Debris Retrieval"**
Investigation Subject **"Criticality Prevention/Cool/Hydrogen (maintaining stable conditions)"**
Issue **"Criticality control"**

Needs

1. Performing highly accurate criticality assessment

Fuel Debris Retrieval：【Short】

Desired state and reasons for it

- In order to implement realistic criticality management, it is desirable to refine the information on the criticality of fuel debris and to develop a method to accurately evaluate the difficulty and impact of criticality. At the same time, it is desirable to extract and organize the surplus portion, and to consider a reasonable evaluation target without surplus portion.
- It is desirable to comprehensively understand the criticality risk, including information on the behavior and volume of nuclides in fuel debris, and to organize technologies for understanding the current status, monitoring, controlling, etc. from the perspective of criticality management of fuel debris.

Current state against ideal

- Based on the current monitoring of the concentration of noble gas (Xe-135) (the concentration is sufficiently low compared to the criticality criterion of 1 Bq／cm^3) and the status of the expected fuel debris, the possibility of criticality in the fuel debris at Fukushima Daiichi NPS is low from an engineering point of view. However, it is necessary to understand the conditions under which criticality may occur, such as changes in the shape of fuel debris during fuel debris retrieval, and to prevent criticality in a rational and reliable manner. In the past, organization of the methods have been proceeded to evaluate the likelihood and impact level of criticality of fuel debris based on information to be obtained from internal investigations and at each stage of fuel debris retrieval. In order to evaluate them, it is planned that information on parameters that have a large impact on the criticality evaluation can be obtained in the process of internal investigations and fuel debris retrieval.
- In cases where the Uranium content rate of fuel debris is unknown, it is assumed that the safety evaluation and safety measures for criticality management and off-premises transportation are conservatively investigated using the Uranium content rate of 97-98%, which is the rate in the fuel assembly before the accident. From the calculation results of the severe accident code and the video images of the PCV internal investigation, it is highly likely that the Uranium content rate has decreased due to melting and mixing with the surrounding structural materials, though since there is no value to be used for evaluation, an excessive margin should be included in the safety measures.

Issues to be resolved

- In order to evaluate without excessive conservatism, it is necessary to obtain an index for evaluation, such as Uranium content rate.

- It is necessary to refine the information on the criticality of fuel debris based on the information obtained in the process of fuel debris retrieval and it is also required to develop a method for determining the unlikeliness and the impact of criticality. Measurement requirements should be established so that information on parameters having a large impact on criticality evaluation can be obtained in the process of internal investigation and fuel debris retrieval. It is also necessary to review the plan and improve the criticality evaluation method by updating the relevant information as appropriate.
- If the location of fuel debris can be easily identified by radiation and neutron imagers, it is expected to alleviate conservative measures in terms of criticality control and lead to efficient fuel debris removal during PCV／RPV internal investigations and fuel debris removal. The evaluation of subcriticality requires measurement of radiation resistance and rapidity of evaluation. It is also desirable to organize the "concept" of how deep subcriticality should be evaluated.

2. Establishing a system for criticality control during debris retrieval to maintain subcriticality (including shape and mass control)

Fuel Debris Retrieval：【Mid】

Desired state and reasons for it

- To prevent criticality during fuel debris retrieval, it is desirable to formulate an operational method for the criticality control system (work stoppage due to fluctuations in neutron flux, criteria for judging the injection of boric acid, a neutron absorber, etc.) and to investigate measures after the neutron absorber is injected (lowering the water level, maintaining boron concentration, etc.).

Current state against ideal

- In the early stage of fuel debris retrieval, a method that does not significantly change the shape of fuel debris is used, including grasping and suction. In addition, the processing volume is limited based on the estimated reactivity change. In the stage of expanding the scale of fuel debris retrieval and cutting, measures such as subcriticality measurement before the work and neutron absorber feeding, are considered. In addition, it is thought that fuel debris retrieval can be performed while evaluating the criticality of fuel debris by checking the amount of fluctuation of the neutron signal around the fuel debris due to the retrieval operation, thereby ensuring the prevention of criticality by combining the response by design and the monitoring and judgment by the operator.
- There are various types of neutron detectors currently available, such as fission chamber, B-10 proportional counters, semiconductor detectors, depending on the application, and it is important to select a neutron detector based on its characteristics.
- The required specifications of a neutron detector for criticality monitoring are as follows: : The neutron detector shall 1. be able to maintain the lifetime (accumulated dose (Gy)) corresponding to the work period; 2. be mountable on the target equipment (size, weight, cable diameter) or installable in the work site (size, weight, cable routing); and 3. meet the required detection efficiency (time, accuracy).
- In order to prepare for a case which the criticality of the fuel debris is found to be high, investigation on the evaluation of the required boron concentration and the feasibility of filling the debris with sodium pentaborate during normal fuel debris retrieval, while the environmental impact of the leakage and the coexistence with concrete as a structural material are being evaluated. In addition, non-soluble neutron absorbers, which can limit the effect on the PCV circulation cooling system locally, are being developed. Basic physical property tests and

radiation resistance tests were conducted so far and found that sintered B4C metal, B／Gd glass, Gd2O3 particles, and water glass／Gd2O3 granulated powder are candidates for nonsoluble neutron absorbers. For these candidate materials, effect of long-term irradiation on the storage canister integrity during fuel debris storing have confirmed, in addition to the method and the effect of spraying on fuel debris corresponding to debris processing. In FY2020, the feasibility study on a boric acid conditioning facility in the circulating water system was conducted, and technical development for on-site operation combined with neutron detectors will be promoted in the future.

Issues to be resolved

- It is necessary to consider the location of neutron detectors and formulate criteria for stopping work due to fluctuations in neutron flux or injecting boric acid as a neutron absorber.
- There is a possibility of criticality occurring in the areas outside the pedestal of the PCV bottom or in the circulating water-cooling system, including the piping, the water system filter, and the liquid waste receiving tank, where deposited with fuel debris chips uncollected and left. Although the PCV gas system can detect criticality, it is necessary to consider the feasibility of criticality approach monitoring and other countermeasures corresponding to the criticality risk scenario and evaluation.
- For subcriticality measurement, highly sensitive detectors should be selected to measure local neutrons around the retrieval site or measure weak neutron signals in a gamma-ray environment with high temporal resolution to capture short-term neutron fluctuations. Based on previous investigations, it is necessary to install lead radiation shielding mainly in a high gamma radiation environment (assuming 1000Gy／h). Therefore, the installation on the equipment (size, weight, electromagnetic noise countermeasure, etc.) and a sensitivity-based operation method (measurement period, measurement time, etc.) are issues to be considered.
- In addition, if there is a concern about criticality, the system will be shifted to a subcritical state by emergency injection of sodium pentaborate, but as a method to maintain the subcritical state after the shift, it is necessary to establish the decision criteria for the selection of lowering the water level or maintaining the boron concentration.
- When introducing non-dissolvable neutron absorbers, it is necessary to determine issues such as the impact on PCV corrosion and the environmental impact at the time of environmental release.
- In order to detect criticality approach and criticality around the fuel debris retrieval point, and to detect criticality caused by falling fuel debris and accumulation of powder debris other than the fuel debris retrieval point, it is necessary to make the criticality monitoring in the PCV gas management facility more immediate and detectors more sensitive. By measuring Kr-87／88 in addition to Xe-135, which has already been measured, it has been found that criticality detection can be accelerated and that the subcriticality of the entire PCV can be estimated and actual application should be considered in the future.
- It is necessary to select and optimize a neutron detector based on the constraints of the fuel debris retrieval method and system. It is necessary to understand the gamma dose rate and the neutron count rate around fuel debris and improve the applicability of the detector to the field by downsizing or otherwise improving it in view of continuous monitoring. In addition, in order to determine the applicability of technologies to fuel debris, which is expected to have a mixture of various compositions and properties, a plan for the demonstration of the technologies has been formulated and the applicability of the technology should be evaluated based on its result.
- Determining the necessity of sodium pentaborate injection under normal conditions based on the fuel debris composition, etc., obtained through fuel debris retrieval operations is an issue.

3. Evaluating the impact of a criticality event and developing countermeasures to deal with it

Desired state and reasons for it

- It is desirable to evaluate the effects of the criticality reached during fuel debris retrieval or in other processes and to consider and implement appropriate countermeasures.
- In order to ensure safety in case of a criticality event, it is also desirable to establish safety measures for workers through the evaluation of behaviors in a criticality event.

Current state against ideal

- In order to prevent criticality during fuel debris retrieval, criticality monitoring and criticality management systems are being developed. Although the likelihood of criticality in most operations is considered fairly low, measures are being investigated in case of re-criticality, for example, storing neutron absorbent in a container when removing structures with fuel debris attached.

Issues to be resolved

- The issues are the evaluation of the impact on structures and workers in case of criticality, and the concept and study of specific measures to ensure reasonable safety based on the results of that evaluation.
- A method of injecting B (boron), which should not be used at normal times, can be used in case of a criticality event, but a considerable amount of B may be required to return to the subcritical state. Also, in work intended to prevent the criticality, it is necessary to take into account the fact that the criticality area is not easily accessible for workers (because there are areas with high radiation dose regardless of the criticality).

Relevant Issues

- FDR-101 “Understanding status of fuel debris”
- FDR-208 “Understanding status of fuels for maintaining stable conditions”