Chapter 9

Lessons Learned from the Nuclear Power Plant Accident and Recovery Efforts

Field of expertise: Maintenance Engineering

Yutaka Watanabe & Takayuki Aoki

Translated by Catherine Sachi Kikuchi

Summary

The decommissioning of the Fukushima Daiichi Nuclear Power Plant requires an unprecedented effort to remove fuel debris while maintaining the main facilities, which are damaged and have reduced safety functions, under conditions that are difficult to access due to high radiation dose rates and contamination. To minimize the risk of additional external release of radioactive materials, it is essential to create methods for efficient and effective fuel debris removal and long-term facility maintenance management for the damaged main facilities, as well as a strategic approach for early transition from the current state to a safely manageable state. New technology development and human resource development are urgently needed for this purpose.

Keywords: nuclear power plant, accident, decommissioning, risk reduction, safety assurance, basic research, human resource development

Introduction

On March 11, 2011, the Great East Japan Earthquake occurred. This earthquake is said to be a once-in-a-thousand-year event. In addition to the magnitude of the shaking, the accompanying huge tsunami hit the Fukushima Daiichi Nuclear Power Station (hereinafter referred to as 1F) of Tokyo Electric Power Holdings Co. This triggered the first nuclear accident in Japan. Although there were no fatalities due to radiation, the accident caused serious problems, including evacuation of the surrounding residents due to the external release of radioactive materials, collapse of local communities, and environmental pollution.

1: What Happened at 1F at that time?

The reactors at 1F (Units 1-3), then in operation, shut down as control rods were automatically inserted into the reactor cores by detecting the massive shaking caused by the quake. Although the external power supply was interrupted by it, the emergency diesel generators started normally and supplied power to the pumps and other equipment, thus maintaining the cooling function for the reactors. However, about an hour later, a tsunami of 14 to 15 meters high, which was much higher than expected, came in and flooded on the site and in the buildings. The emergency power supply facilities in the buildings were flooded and became inoperable. As a result, it became impossible to supply power to important facilities such as the pumps and emergency generators used to cool the reactors, thus losing the cooling function.

Nuclear fuel generates a large amount of so-called decay heat[1], in which radioactive materials produced by fission emit α-, β-, and γ-rays, to stabilize themselves even after fission stops. Since each of the reactors in 1F Units 1-3 lost its function to remove decay heat, the coolant in the reactor gradually evaporated and the water level dropped., the coolant in the reactors gradually evaporated due to the loss of the function to remove decay heat, and the water level dropped. Therefore, as an emergency response, the injection of fresh water for firefighting was attempted from outside, and after it ran out, seawater injection was also attempted. However, these attempts were ultimately unsuccessful, resulting in a serious accident in which the fuel melted and fell through the wall of the reactor pressure vessel (RPV). In addition, the pressure in the primary containment vessel (PCV) surrounding the reactor became excessive and damaged the PCV, causing hydrogen[2] generated in the reactor core to leak out and cause an explosion. This explosion damaged the reactor buildings and led to the external release of radioactive materials, resulting in widespread contamination of the environment (Figure 9-1).

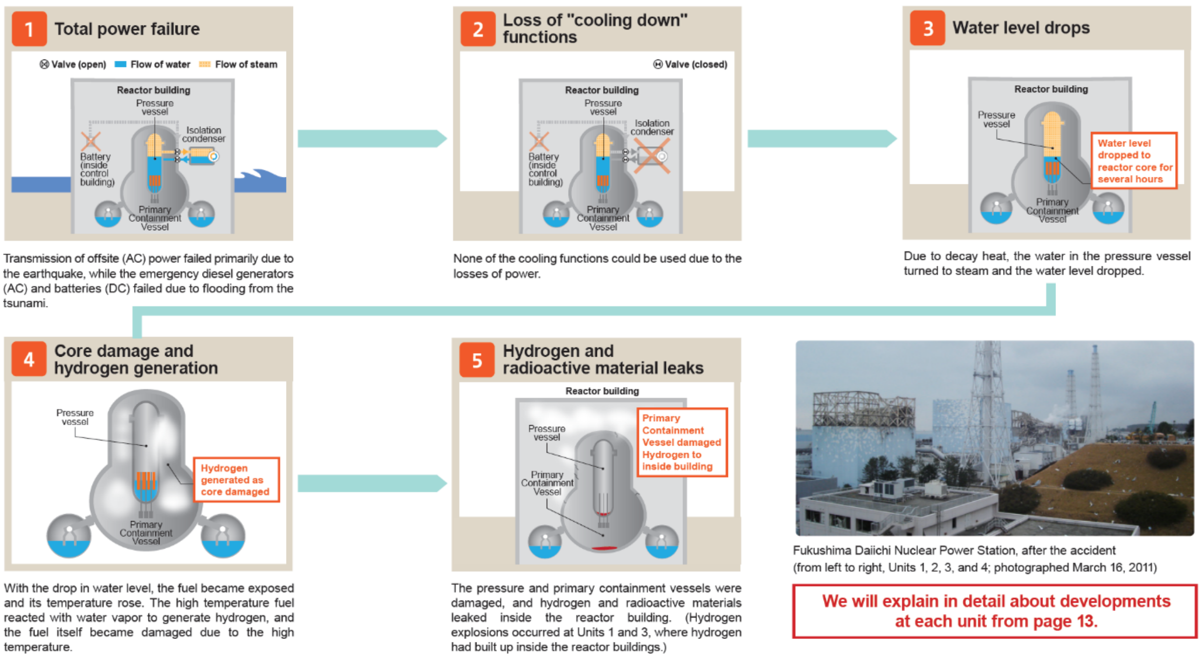

Figure 9-1. Progression of the accident at the Fukushima Daiichi Nuclear Power Station, units 1-3 (From the website of Tokyo Electric Power Company Holdings, Inc.)

As described above, at the site of the 1F accident, emergency responses to the accident that had not been anticipated so far were forced to be taken without a scenario. Meanwhile, the reactors and spent fuel pools were continuously flooded with water using fire trucks and temporary pumps to bring them under control, and the circulation cooling system that was constructed during this time has enabled steady cooling to the present day.

---

[1] Immediately after the shutdown, about 97MW of decay heat was released at Unit 1, and about 167MW at Units 2 and 3.

[2] It is known that when a loss-of-coolant accident occurs and the fuel becomes exposed, the temperatures rise to 800°C~900°C or higher, and the zirconium used in the fuel cladding reacts with water vapor to produce heat and hydrogen.

The investigation and examination of the accident at 1F has been conducted and reports have been issued by four organizations: the Fukushima Nuclear Accident Independent Investigation Commission by the National Diet of Japan (National Diet Investigation), the Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company (government investigation), the Fukushima Nuclear Accident Independent Investigation Commission (private investigation), and the Tokyo Electric Power Company Fukushima Nuclear Accident Investigation Committee (TEPCO investigation). Each of these reports concluded that the direct cause of the Fukushima accident was the loss of all power due to the tsunami, although some unresolved issues were pointed out therein. Subsequently, in 2013, the Nuclear Regulation Authority established the Study Group on the Analysis of the Accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station, which stated, "It is true that there are still some technical issues at the Fukushima Daiichi Nuclear Power Station that cannot be confirmed at this time due to the difficulty of conducting on-site surveys and other limiting factors, and that must await further investigation and study". The committee compiled an interim report in 2014, in which it stated, "In our investigations to date, we have largely completed our examination of the issues that were pointed out as unresolved in the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission report, but there are still some issues that we cannot start on-site investigations for reasons such as high radiation doses. Therefore, continued field investigations, evaluations, and studies are required. However, the report also states that at this point, no facts have been confirmed that would contradict the main events that have been reported so far and the direct causes of these events.

2: Current Status and the Decommissioning Plan of 1F

10 years after the accident, the environment inside the plant has been greatly improved, and it is now possible to enter the plant without wearing radiation protective clothing or masks. However, the inside of the reactor buildings of Units 1-3 are still highly contaminated with radioactive materials, and workers and others cannot easily access them. Therefore, investigations inside the buildings and PCVs have been conducted by strictly practicing the three principles of reducing external exposure (keeping distance, installing shielding, and limiting time), controlling areas to be entered, wearing special protective clothing, and making extensive use of remote-control equipment and robots. As a result, it was found that there was fuel debris and deposits that appeared to be structures at the bottom of the PCV under the RPV in Unit 1, deposits that appeared to be fuel debris and structures and a part of the fuel assembly (upper tie plate) in the same location as in Unit 2, and deposits that appeared to be fuel debris and structures and part of the in-core reactor core (CRD guide tube) in the same location as in Unit 3 (Figure 9-2).

To achieve the goals, set forth in the Medium- to Long-term Roadmap developed by the Inter-Ministerial Council for Contaminated Water and Decommissioning Issues and the Technical Strategy Plan[1)] to provide direction for fuel debris removal methods, etc., based on this roadmap, and the Risk Map[2)] developed by the Nuclear Regulation Authority of Japan, TEPCO announced the Medium- to Long-Term Decommission Action Plan 2020[3)] in March this year. According to the plan, TEPCO will conduct a test removal of fuel debris from Unit 2 over the next three years and will reflect the information obtained from the test removal in the design of the full-scale removal equipment, etc., to gradually expand the scale of removal. The plan for Unit 1 and Unit 3 is to proceed with the project while reflecting the experience of fuel debris removal from Unit 2 (Figure 9-3).

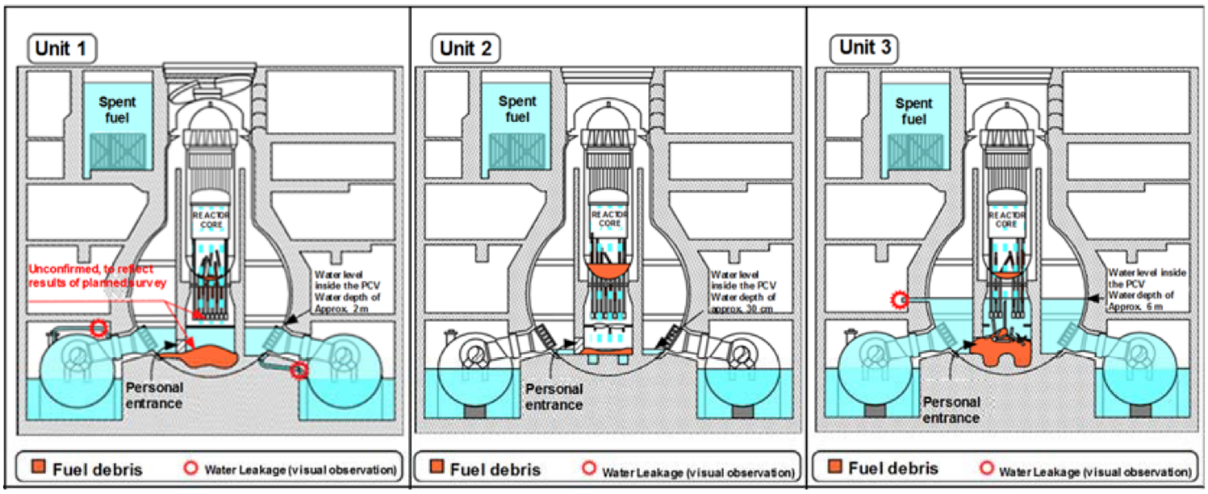

Figure 9-2. The status of the Fukushima Daiichi Nuclear Power Station, units 1-3 (From the Technology Strategy Plan[1]), Nuclear Damage Compensation and Decommissioning Facilitation Organization)

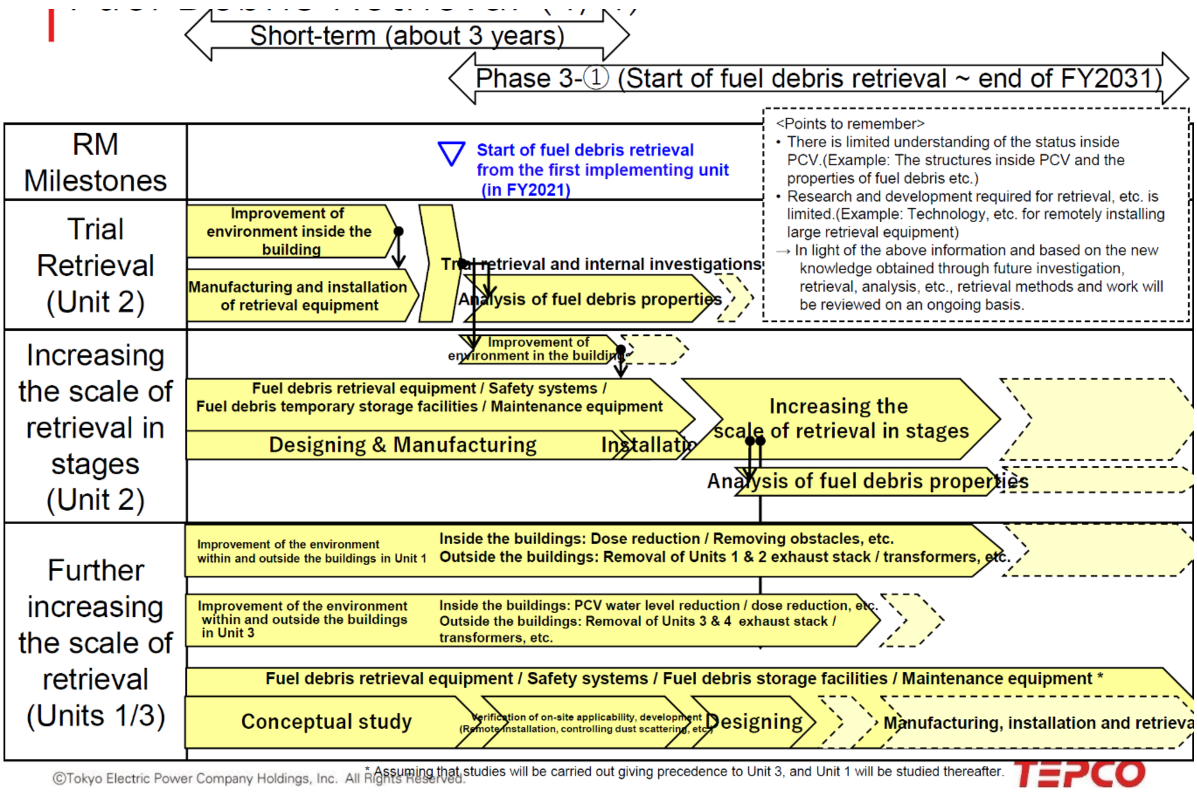

Figure 9-3. Fuel debris removal process

The decommissioning of an accident-damaged reactor such as 1F is an internationally unprecedented challenge that requires removing fuel debris while maintaining the safety functions of the main facilities that have been damaged and degraded by accident under conditions that are difficult to access due to high radiation dose rates and high contamination from radioactive materials. This is trying to execute an unprecedented project in the world. To proceed safely and steadily with this unprecedented project, strategic efforts are needed to reduce the risk of additional release of radioactive materials from the current relatively high-risk state to a state that can be safely managed at an early stage, and to ensure that the decommissioning work can proceed safely and steadily with sufficient time to spare. In addition, it is necessary to introduce efficient and effective ideas/methods for planning methods of fuel debris removal and long-term facility management of damaged main facilities to obtain and assure availability of long-term personnel, reduce radiation exposure, and secure funding. Success will require achieving a wide variety of research and technological development expansion and execution, as well human resource development and training.

3: Lessons Learned from the Accident and Future Actions

The Nuclear Regulation Authority of Japan (NRA) established standards to prevent the loss of functions due to common causes and the development of severe accidents as lessons learned from the 1F accident. These standards are based on the fact that the Fukushima accident caused a simultaneous loss of safety functions due to common causes such as earthquakes and tsunamis, and that the subsequent development of severe accidents could not be stopped (Figure 9-4).

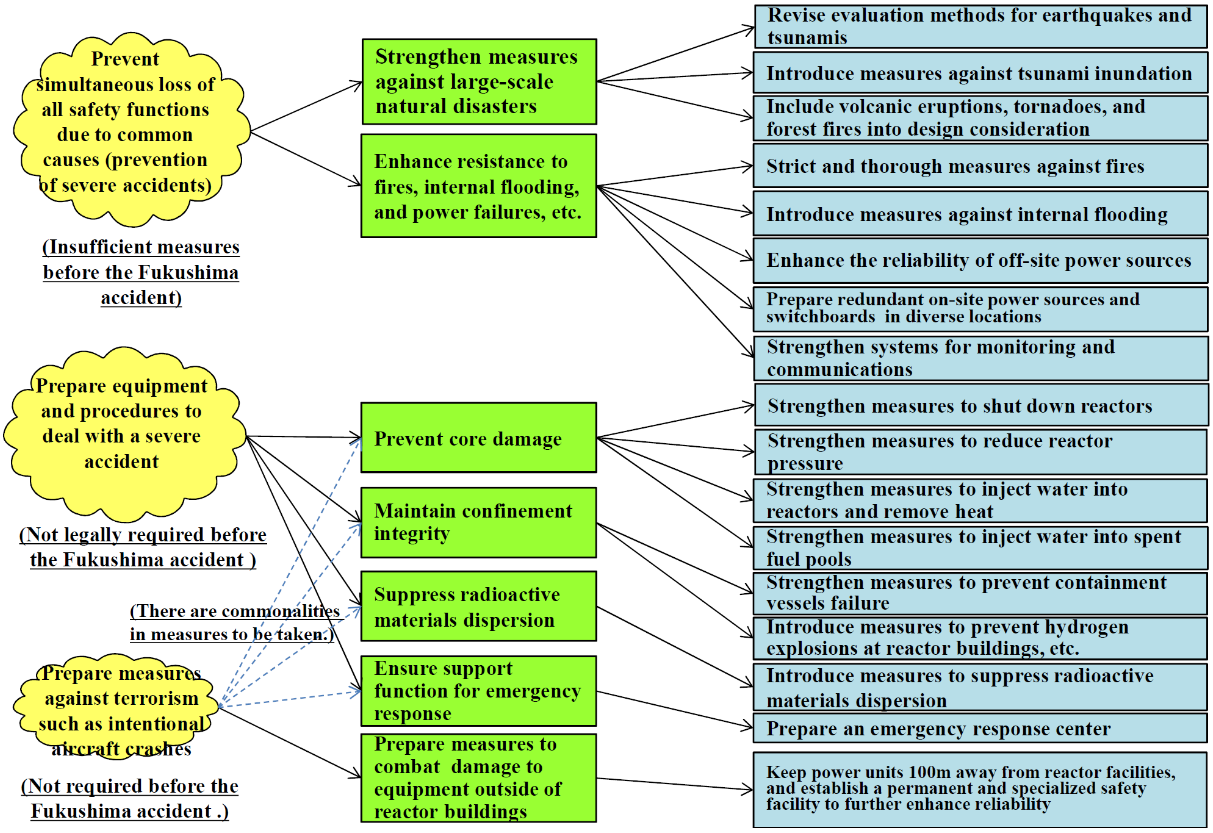

Figure 9-4. The basic concept and main requirements of the new regulatory standards

These standards are said to be the most stringent in the world, as they were formulated after a comprehensive survey of the world's codes and standards, followed by the NRA's own independent study. Given the hindsight after the accident, the question becomes why did we not anticipate this and why did we not take measures to deal with it? And once the occurrence of such an accident is assumed, it is possible to develop countermeasures to deal with it. Therefore, to prevent accidents such as the one at 1F from recurring, it is first and foremost necessary to develop the ability to assume hazards (or risks) or to imagine them. To realize this, it is important to overview the entire system including the mechanical system (or hardware system) of a nuclear power plant and the human system that implements safety activities including responses to accidents that occur in the mechanical system, and to learn risk assessment and analysis methods including probabilistic risk assessment methods. Second, it is necessary to have the ability to make appropriate decisions on whether to implement countermeasures against assumed hazards (or risk sources). For this purpose, it is essential to have a system and capability to make decisions on such issues as an organization.

4: For Safe and Steady Decommissioning of 1F: Tohoku University's Initiatives

The decommissioning of 1F, which is expected to last for more than 30 years, is a major undertaking that places the nation's prestige on the line, and the government is leading an all-Japan effort to carry it out. It is necessary for all related organizations in Japan to make concerted efforts to solve this unprecedented and globally significant problem and to proceed with the decommissioning safely and steadily.

Under these circumstances, Tohoku University's efforts for the decommissioning of 1F began the year after the accident, when the University president himself visited the 1F site and decided that we, as a university in the disaster area, must contribute to solving this unprecedented problem (the technical challenge). Our university has set "leading the reconstruction and recovery after the Great East Japan Earthquake" as its university-wide vision under the traditional principles of "research first", "open-door policy", and "respect for practical learning". As a part of this vision, we launched the " Decommissioning of Accident-damaged Nuclear Power Plant and Environmental Restoration Project" and started the Decommissioning Basic Research and Human Resources Development. This project has been engaged in basic research contributing to the decommissioning of accidental nuclear reactors and the training of young engineers and researchers who will be responsible for future decommissioning of nuclear reactors since the 2014 academic year. Based on these experiences, on December 1, 2016, the Center for Fundamental Research of Nuclear Decommissioning (CFReND) was established as a university-wide constituent organization of the Institute for Disaster Reconstruction and Regeneration Research to further develop its activities and lead Japan's basic and fundamental research on nuclear decommissioning. In April 2020, the Cooperative Research Division on Innovative Technologies for Fukushima-Daiichi Decommissioning was newly established to conduct joint research with TEPCO on 1F decommissioning (Figure 9-5). CFReND will serve as a bridge between the University and external organizations, will digest the needs of the external organizations and communicate them to the University, and will serve as an interpreter (hub function) to communicate the seeds and ideas of the University to external organizations in an easy-to-understand manner (Figure 9-6). It also contributes to the training of the next generation of human resources who will be responsible for decommissioning by utilizing this kind of practical research.

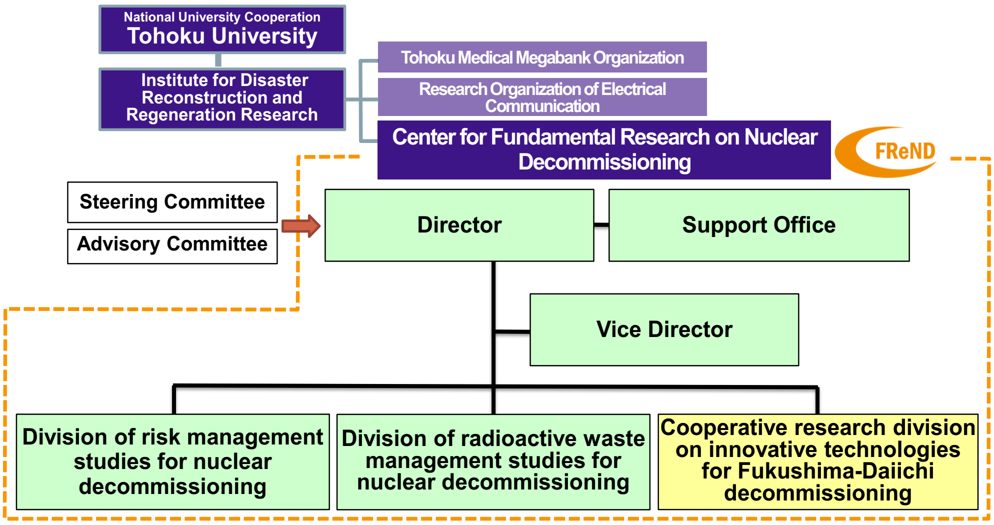

Figure 9-5. Organization Chart of the Center for Fundamental Research of Nuclear Decommissioning (CFReND)

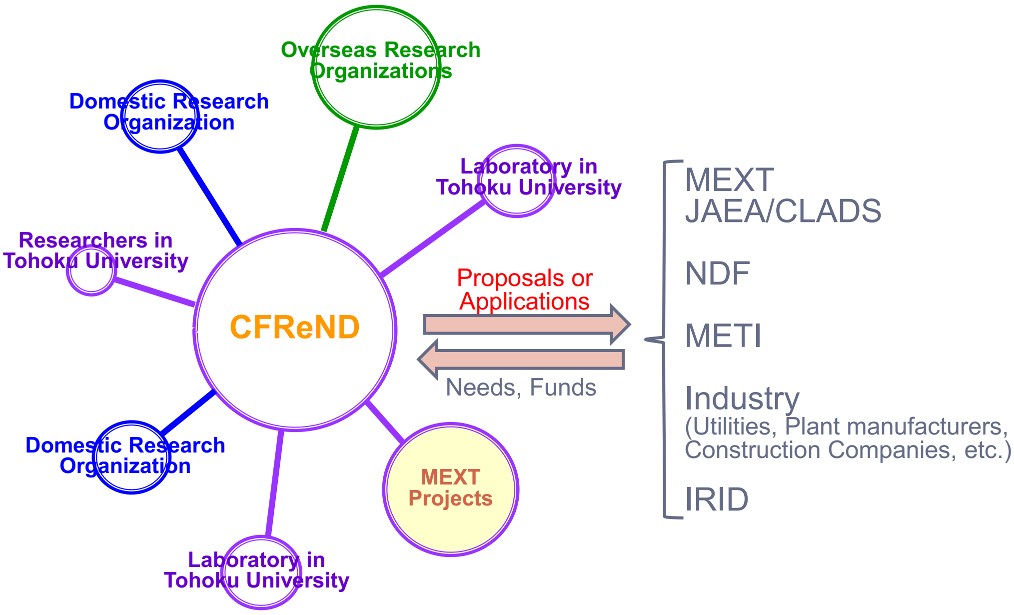

Figure 9-6. CFReND's Hub function for research collaborations

Conclusion - From the author

To complete the decommissioning of 1F that experienced a severe accident, it is essential not only to combine existing technologies but also to develop innovative technologies or to elucidate the principles of phenomena, etc., which will require a high level of challenge in a wide range of academic fields. Now that the collaboration with TEPCO has been established, the true needs and raw data of the 1F site can be obtained accurately and promptly, and it is expected that CFReND will function to contribute to the safe and steady progress of the 1F decommissioning by efficiently and effectively demonstrating the research potential of the University in all fields.

References

Ministry of Economy, Trade and Industry. (2019). *TEPCO Holdings, Inc. Mid-and-Long-Term Roadmap for Decommissioning Fukushima Daiichi Nuclear Power Station*. Decommissioning and Contaminated Water Countermeasures Meeting, Government of Japan. https://www.meti.go.jp/earthquake/nuclear/pdf/20191227.pdf (In Japanese)

Based on this roadmap, the following document has been prepared:

Nuclear Damage Compensation and Decommissioning Facilitation Corporation. (2019). *Technical Strategic Plan 2019 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.*

Nuclear Regulation Authority. (2020). *Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings Inc. Mid-Term Risk Reduction Target Map (March 2020 version)*. Cabinet of Japan. https://www.nsr.go.jp/data/000306118.pdf (In Japanese)

Tokyo Electric Power Company Holdings Inc. (2020). *Decommissioning Mid-to-Long-Term Action Plan 2020*. https://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2020/1h/rf_20200327_1.pdf (In Japanese)