Conceptual Study of Fuel Debris Retrieval System for Fukushima Daiichi Reactors – 16111

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ABSTRACT

Fuel debris retrieval in the Unit 1-3 reactors of Fukushima Daiichi Nuclear Power Station (NPS) has been one of the most primal tasks for Fukushima restoration project in Japan since the accident happened in March 2011. Various approaches for the fuel debris retrieval have been considered so far. As one of the approaches, there is the in-air fuel retrieval approach which consists of two independent systems to access fuel debris from each access route: one is “Top Side Access System” and another is “Side Access System”. The conceptual design of this approach was performed by IHI Corporation (IHI) and Kurion, Inc. (Kurion) in 2014-2015.

The Top Side Access System will be provided to access fuel debris in Reactor Pressure Vessel (RPV) from the refueling floor located on upper side of the reactor. A platform with manipulators, installed in an enclosure located on the refueling floor, is the major equipment to retrieve fuel debris for the Top Side Access System.

On the other hand, the Side Access System will be provided to access fuel debris in RPV pedestal (under part of RPV) from the first floor of the reactor building. A long-reach manipulator system is the major equipment to retrieve fuel debris for the Side Access System. It accesses the pedestal through a designated rail installed between the entrance of the pedestal and the enclosure installed on the outside of biological shield.

This paper will provide outline of the major systems for this fuel debris retrieval approach stated above.

INTRODUCTION

Mid-and-Long-Term Roadmap for Decommissioning at the Fukushima Daiichi NPS is right in the middle of the second phase. The goal of the second phase is to start retrieving fuel debris from inside the primary containment vessels (PCVs) and the RPVs at the Unit 1 to Unit 3. Start of the fuel debris retrieval operation for the first unit is currently planned in 2021[1].

Two major methods of fuel debris retrieval for Fukushima Daiichi reactors have been considered: One is the submersion method which places the PCVs in water to use the shielding effect of water, and another is the in-air method which applies fuel debris retrieval operation in-air. Many kinds of R&Ds and evaluations for applicable technologies have been performed to each method. Through those activities the method for the first unit will be decided in 2018.

IHI and Kurion performed the conceptual study for the in-air fuel debris retrieval from October, 2014 to March, 2015, as one of the subsidized project operating entities of the subsidy program “Concept study of Innovative Approach for Fuel Debris Retrieval and Feasibility Study of Essential Technology” provided by Ministry of Economy, Trade and Industry (METI) in Japanese government. The concept and major systems shown in this paper are based on this conceptual study.

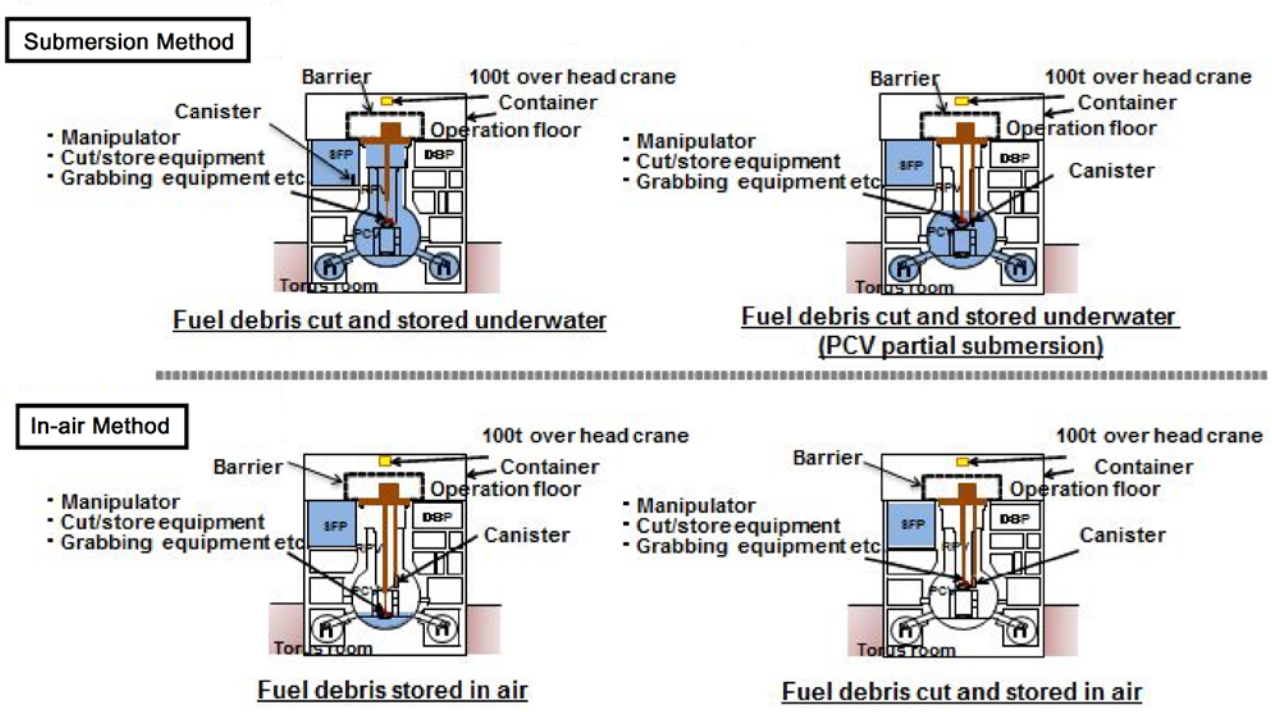

Figure 1: Concept of Submerging Method and In-Air Method for Fuel Debris Retrieval [2]

DESCRIPTION

Overview

Considering various site requirements, conditions, and efficient operations, two major systems to access the fuel debris are proposed: “Top Side Access System” and “Side

Access System". The Top Side Access System is deployed into the RPV from the refueling floor of the reactor building, allowing top-down access to the fuel debris. The Side Access System is deployed directly underneath the RPV, through a horizontal access created in the PCV from the first floor of the reactor building.

Access within the reactor building is restrictive and efficient preparation work is required to start operation for the fuel debris retrieval earlier. Thus, the systems are designed to be installed in a manner which reduces the need for building modifications as much as possible. While some limited personnel access may be available to certain areas of the reactor building, there are areas which will require complete remote installation and operation of equipment.

This approach is based on an ALARA (As Low As Reasonably Achievable) principle and provides safe, practical and efficient site operations for the fuel debris retrieval in shorter period.

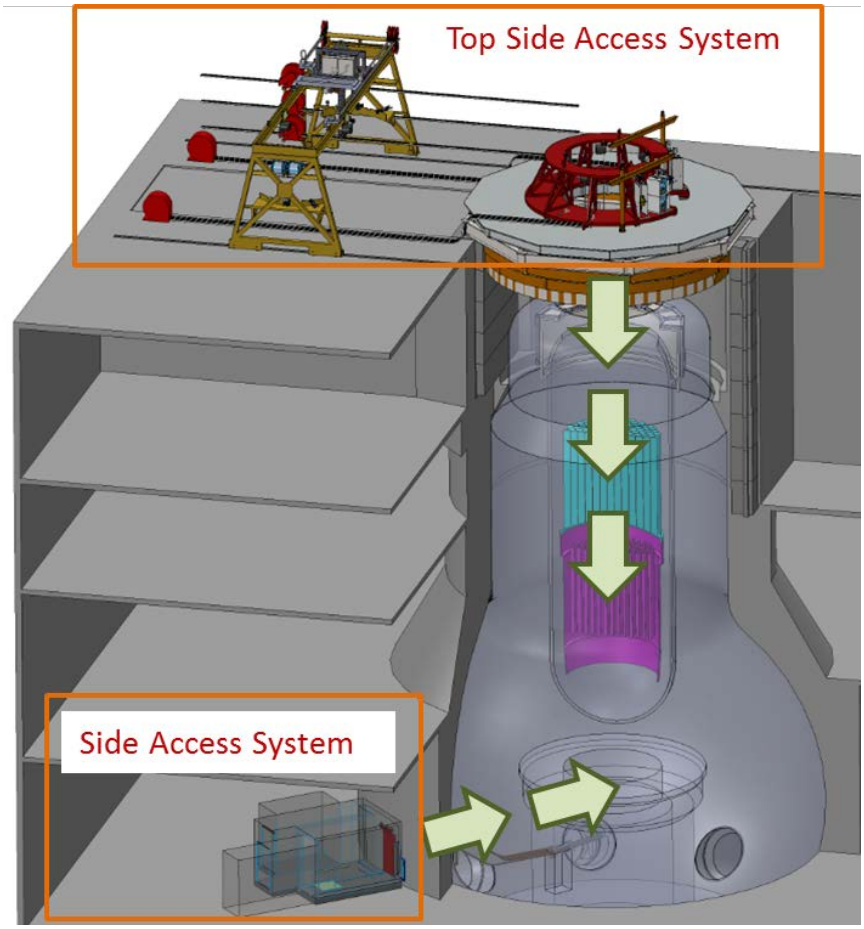

Figure 2: Top Side Access System and Side Access System

Equipment for Fuel debris retrieval is taken into consideration with the following key concepts:

1) Safety and reliability

   Equipment is required to be robust for long-period and high-level remote operation. Additionally, experienced or developed technologies are preferable.

2) Operational Flexibility and Variability

   The condition of the inside the reactor is mostly unknown and thus the equipment is required to be designed account for operations flexibility and variability (e.g. varieties of tools and arms are prepared)

3) Easy Maintenance

   Due to long period operation and very high radiation environment, easy and quick maintenance or replacement works for key components are required.

4) Rescue and recovery systems for all systems

   Any equipment has to be rescued and recovered to safety area in any conditions.

Top Side Access System

The Top Side Access System is deployed mainly for the fuel debris located in the RPV internal. It is preferred for retrieving this fuel debris to access from top side of the RPV like normal maintenance operation for the RPV internal structures. The main enclosure and the shielding hatch are installed just above the reactor on the refueling floor and construct a boundary of inside and outside of the reactor. The gantry crane with hydraulic manipulator arms and electric hoists is installed on the existing rail for the fuel exchange crane. The primary function of this equipment is to remove obstructions and allow access into the RPV for the fuel debris retrieval equipment, and to assist with the equipment operations and waste transport from the RPV as necessary. Fuel debris and RPV internal structure retrieval is performed by using the platform which has three hydraulic manipulator arms. Waste handling and inspections are performed by using some cranes, manipulators and customized equipment. The fuel debris including high radioactive structures in the reactor is put into designated canisters, stored in the spent fuel pool temporarily, and finally transported to outside of the facility.

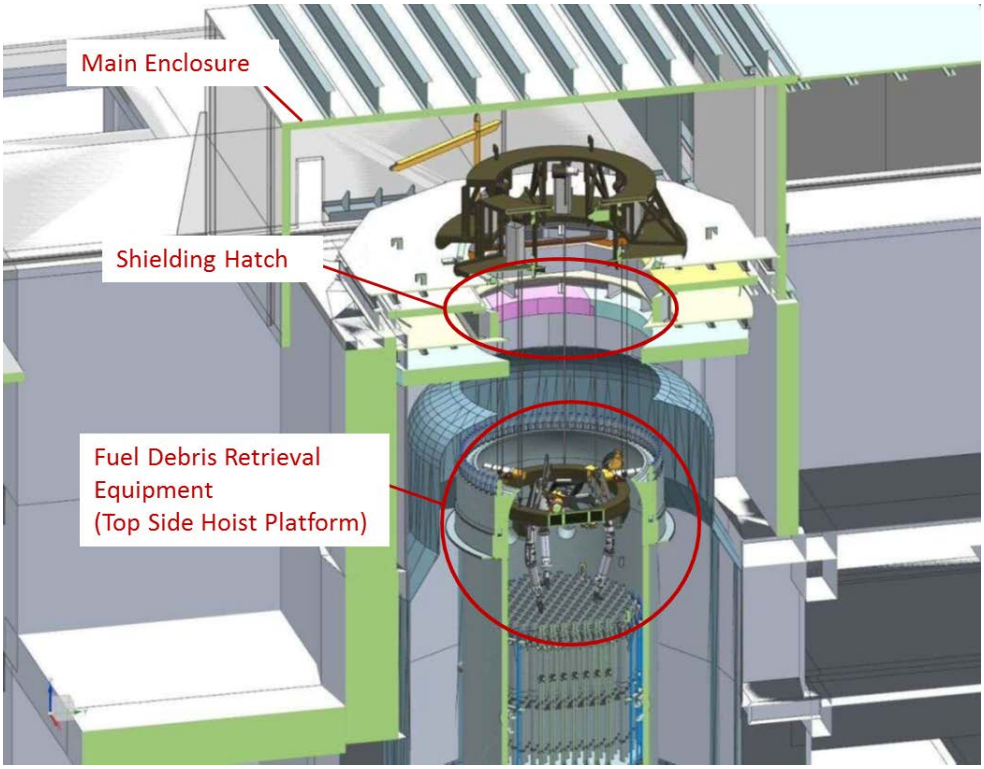

Figure 3: Top Side Access System (Major Equipment)

The fuel debris retrieval equipment for the Top Side Access System, called Top Side Hoist Platform, is used for size reducing and loading RPV components and fuel debris into waste containers for removal and packaging. The Top Side Hoist Platform mainly consists of Upper Platform, Lower Platform and Retrieval Arms (Figure 4).

The key aspects of the equipment design are the retrieval platform that provides a stable rigid operational base that can be lowered locally to the desired operations, implementation of an industrial off-the-shelf (OTS) manipulator that is commonly used in similar industrial operations, and tooling that allows for operational flexibility. Additionally the equipment incorporates design features to account for required considerations for remote nuclear equipment such as ensuring the equipment fails in a safe manner and proper provisions for remote equipment recovery from equipment failure.

The Lower Platform with the Retrieval Arms is hanged by redundant hoists mounted on the Upper Platform, and reaches around 30m lower area from the refueling floor to access fuel debris located at the bottom of the RPV. Stabilizing outriggers are also mounted to the Lower Platform structure. These outriggers extend out to press on the RPV inner wall to stabilize the Lower Platform during retrieving operation.

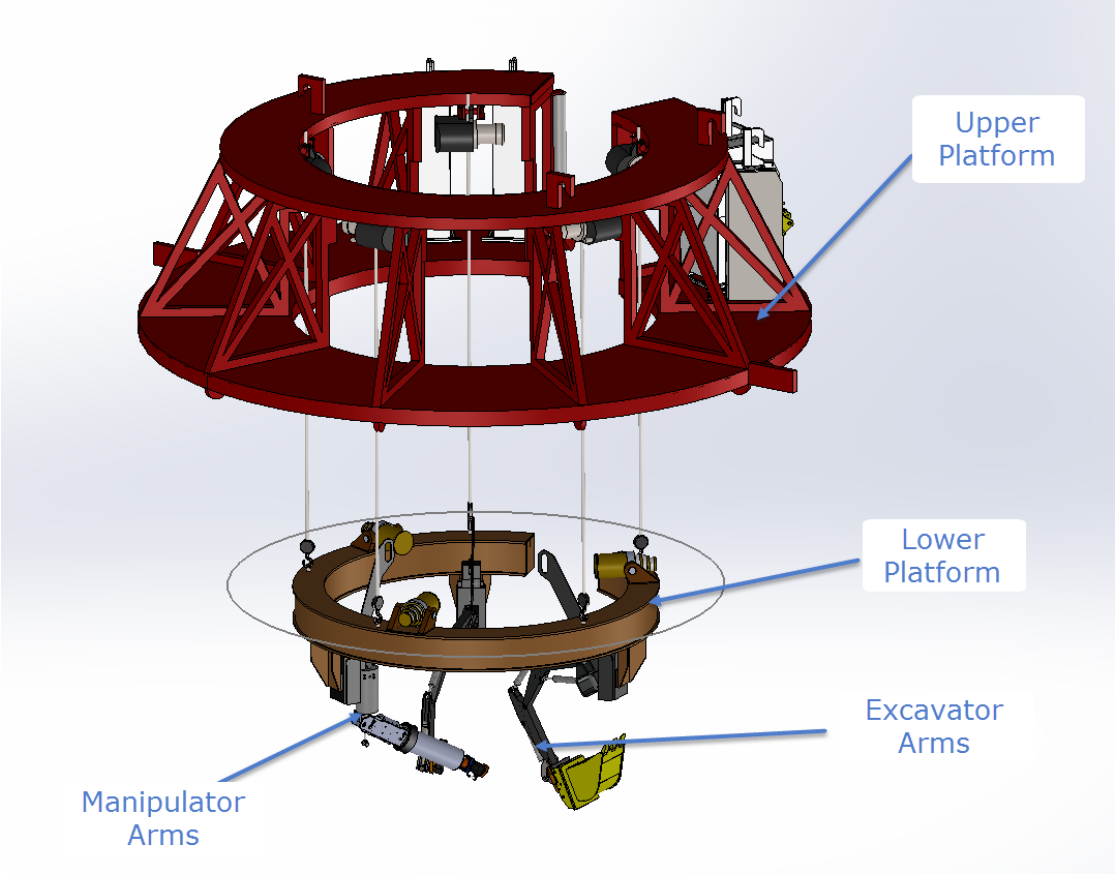

Figure 4: Top Side Hoist Platform

The Retrieval Arms connect directly using a quick-change plate which transfers electrical, hydraulic and pneumatic services to the arms. Each arm is capable of remote installation and removal from the quick-change plate (Figure 5). The Top Side Hoist Platform is initially planned to include two types of retrieval arms to assist with fuel debris retrieval as shown below, however it is possible to easily alter or change these retrieval arms as the conditions within the RPV are fully realized.

The first type of the retrieval arm is a modified off-the-shelf (OTS) excavator-style arm (Figure 6). These retrieval arms are industrial hydraulic powered compact manipulators that provide a high power-to-weight ratio. The second type of the retrieval arm is a manipulator-style arm (Figure 7). This type of arm provides more precise control over operations than the excavator-style arm, but with less lifting and moving capacity.

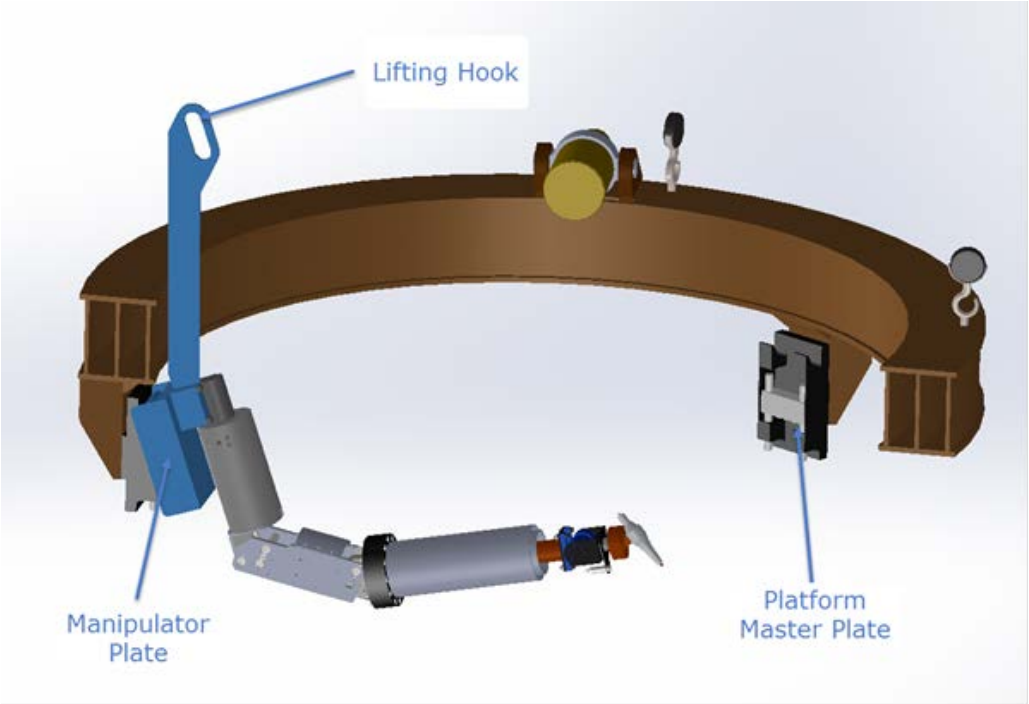

Figure 5: Retrieval Manipulator Arm for Top Side Hoist Platform

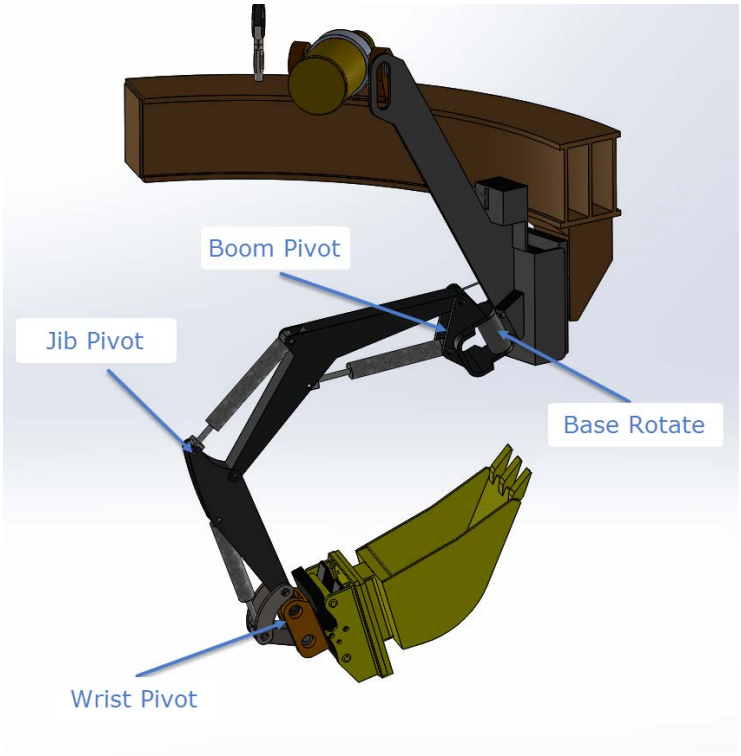

Figure 6: Excavator-Style Arm for Top Side Hoist Platform

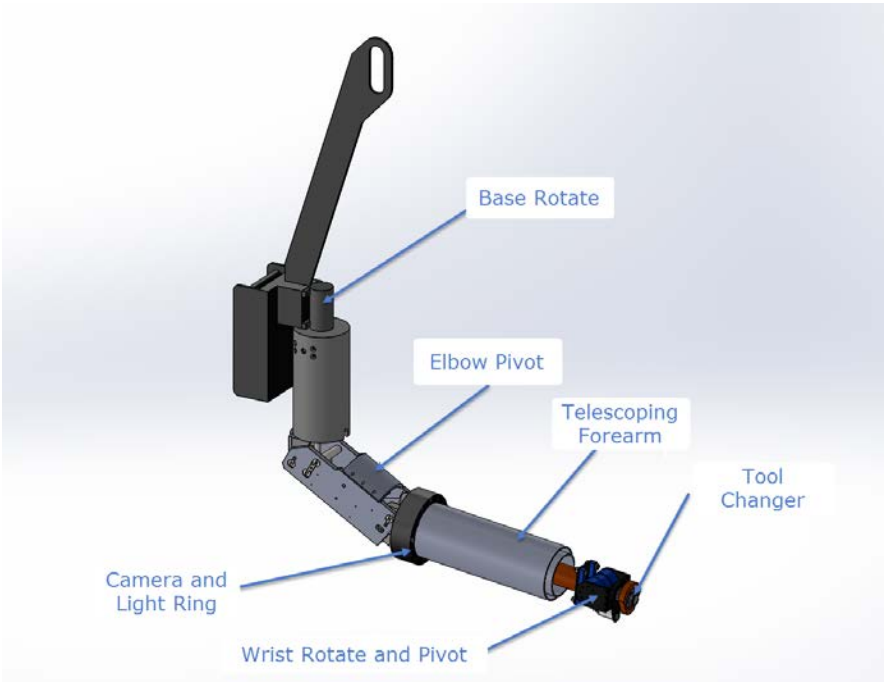

Figure 7: Manipulator-Style Arm for Top Side Hoist Platform

Each of the Retrieval Arms is equipped with remotely actuated tool change capability. This feature allows the arms to use a variety of tools, which can consist of proven OTS tooling to custom specialized tools as required for the intended operations. Additionally this flexible interface allows for tooling to be designed, fabricated and integrated into the system at later stages of the project as required or determined for the required operations. Examples of the tools for the fuel debris retrieval currently planned are shown in Figure 8.

Figure 8: Tool Examples
(Left: Laser Cutting Tool, Middle: Waterjet Cutting Tool, Right: Shear)

Side Access System

Side Access System is required to access the fuel debris located underneath the RPV (RPV pedestal) because top-down access takes much longer time to reach this fuel debris. The Side Access System mainly consists of the waste transfer system and the furl debris retrieval system. The waste transfer system is deployed in front of the entrance of the existing penetration for the control rod (CRD) drive maintenance on the first floor of the reactor building. The waste transfer cart accesses the RPV pedestal using the existing CRD drive maintenance rails and opening. The fuel debris retrieval system is deployed next to the existing penetration mentioned above. Although it is necessary to make an opening for the shield wall and the PCV, and deploy new rails to the RPV pedestal, the fuel debris retrieval equipment can access the RPV pedestal using the same existing opening at the RPV pedestal as the waste transfer route. The Entrance Enclosures with shield door are installed in front of each entrance for both the waste transfer system and the fuel debris retrieval system.

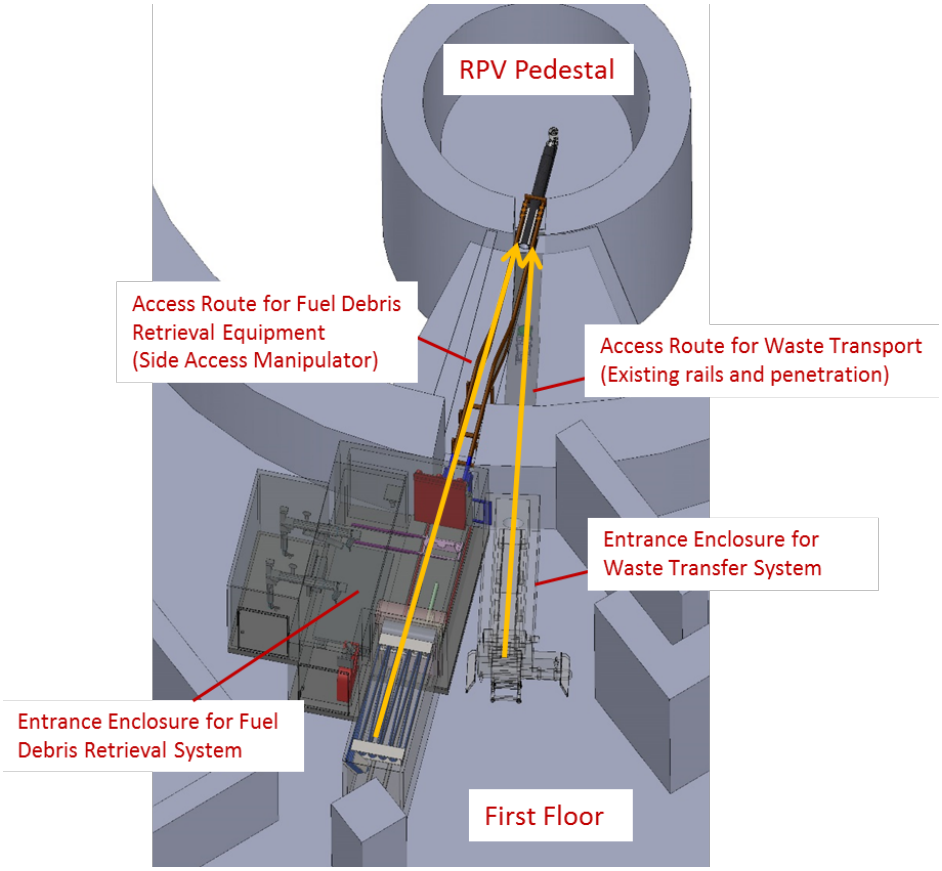

Figure 9: Side Access System Layout

The fuel debris retrieval equipment for the Side Access System, called Side Access Manipulator, is installed using a manipulator storage containment, which can be attached to the back of the Entrance Enclosure. The manipulator storage containment includes the manipulator itself as well as its cable and hose management system (Figure 10). This concept provides easy and quick replacement of the manipulator system. It makes possible to change the manipulator type flexibly as conditions of the inside of the PCV and the RPV pedestal.

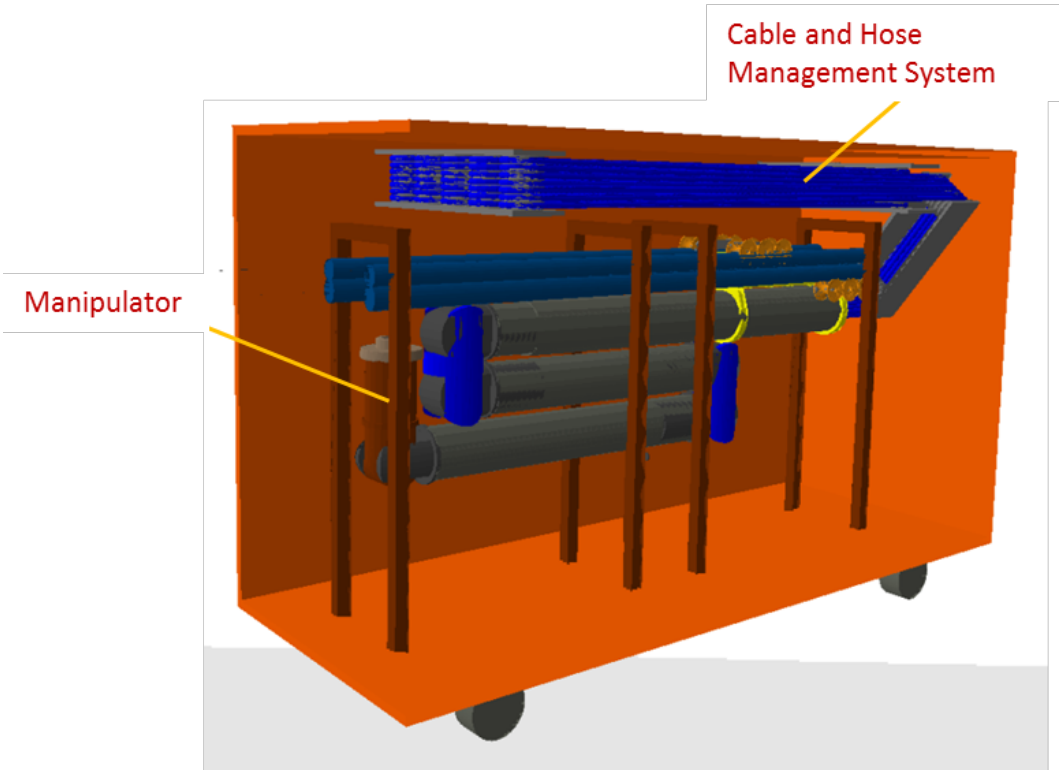

Figure 10: Manipulator Storage Containment

Once the manipulator storage containment is installed, the transfer trolley in the Entrance Enclosure is used to transport the manipulator onto the manipulator rail. Then the manipulator moves itself along the rail and into position below the RPV (Figure 11).

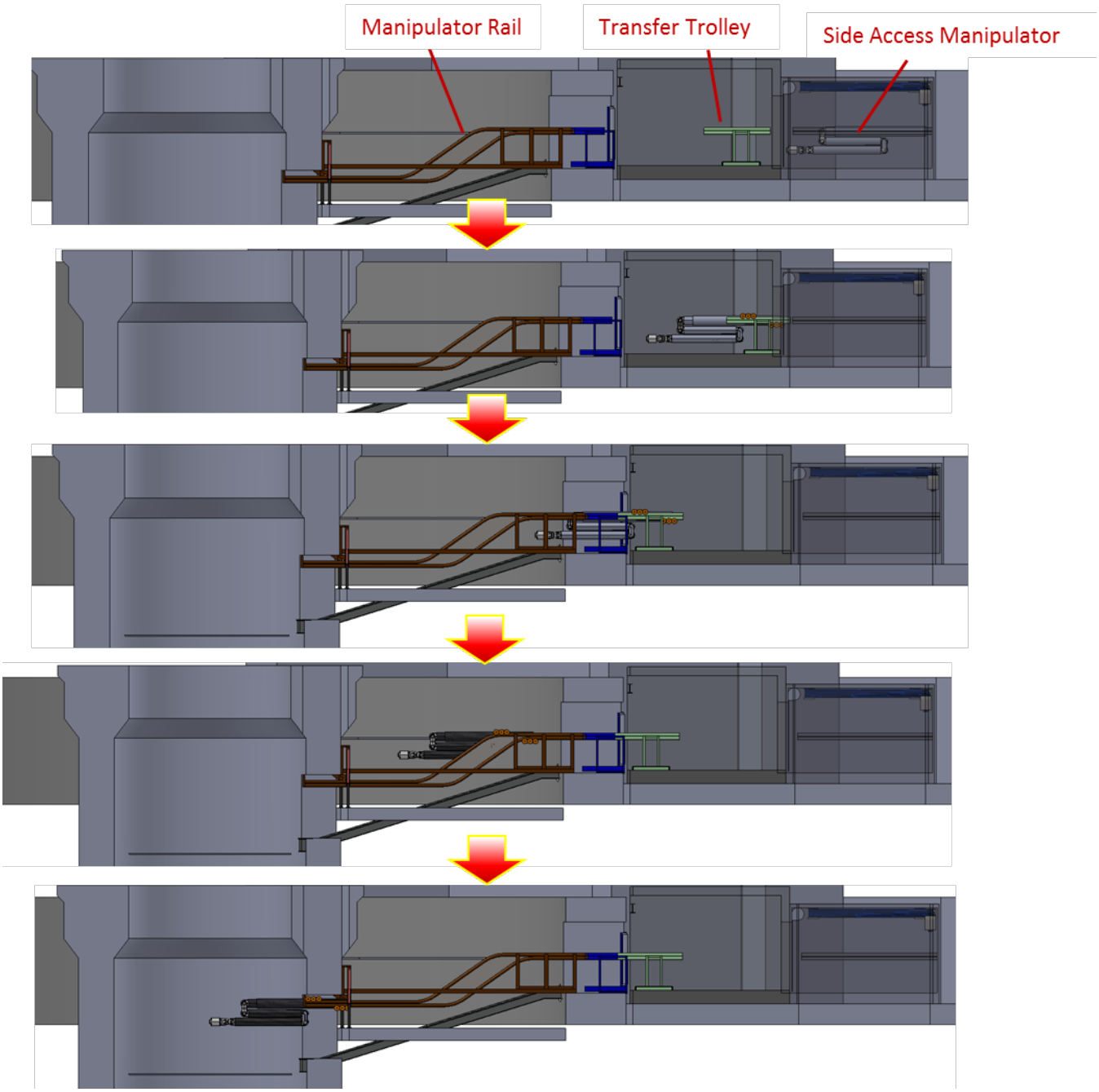

Figure 11: Side Access Manipulator Installation Sequence

The Side Access Manipulator consists of a single hydraulic manipulator arm and electric trolley. The arm which has nine axes except tool motion provides very wide range of motion and operational flexibility. It accesses all areas in the RPV pedestal, and performs a variety of operations for the fuel debris retrieval in the RPV pedestal.

Similar to the Top Side Hoist Platform, the Side Access Manipulator is also equipped with remotely actuated tool change capability.

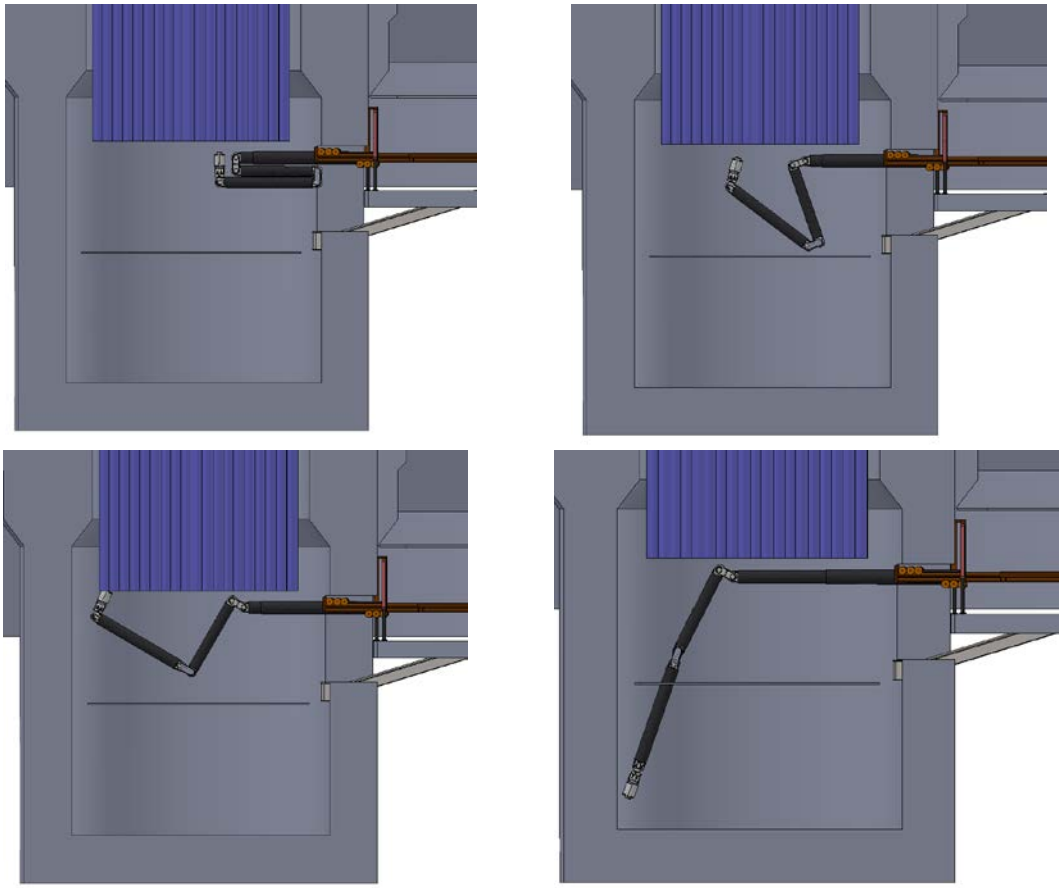

Figure 12: Side Access Manipulator - Wide Range of Motion

The Side Access Manipulator performs cutting and size reduction operations in the RPV pedestal, and placing these cut sections in a waste basket which is transported by the waste transfer cart.

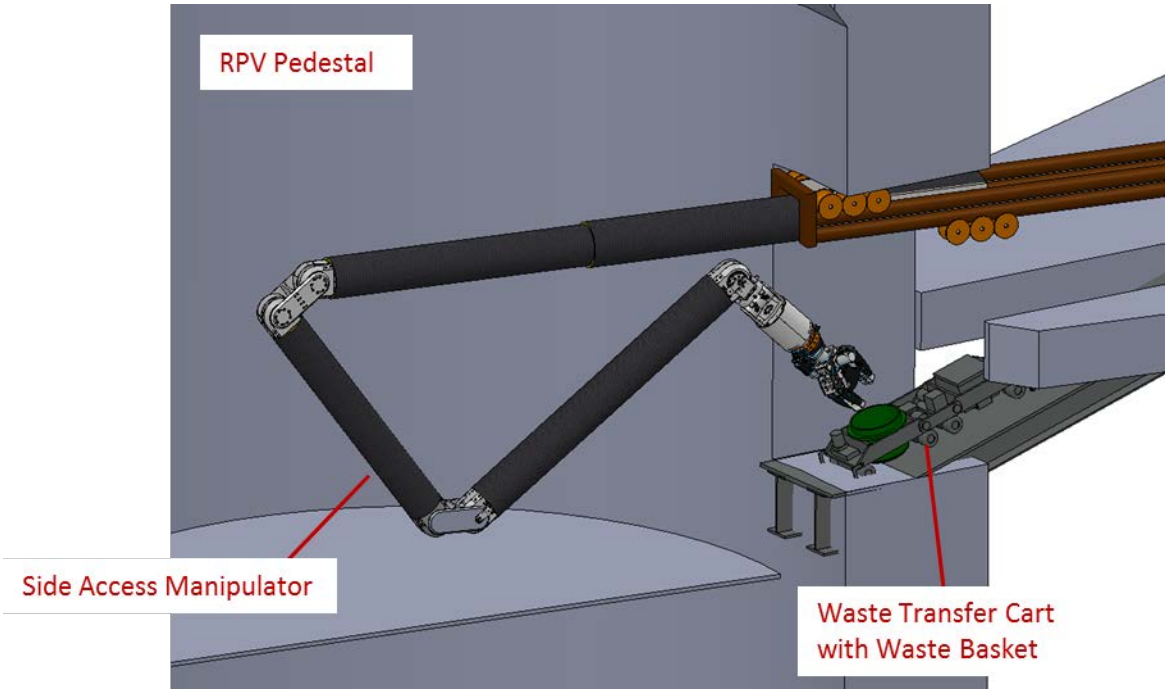

Figure 13: Fuel Debris Retrieval Operation by Side Access Manipulator and Waste Transfer Cart

CONCLUSIONS

IHI/Kurion's approach for the fuel debris retrieval in the Fukushima Daiichi reactors was introduced as one of the in-air fuel debris retrieval method. Most of the technologies applied to this approach are what have been developed and proven. However, a lot of R&D efforts will be still required to obtain more reliability and practicality, and to obtain higher efficiency work toward the actual operations.

There are many challenges to address for restoration of the Fukushima Daiichi Site but the international collaboration by the experienced Japanese and US companies will continuously make a contribution to accomplish such a very challenging project.

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