Fukushima Inspection Manipulator – 15485

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ABSTRACT

After the March 2011 nuclear accident at Fukushima Daiichi NPP it was discovered that there was a large leak inside the Reactor Pressure Vessel (RPV). During the efforts to cool the reactor vessel following the accident, water that was injected into the RPV was found in a lower portion of the facility indicating a leak in the Primary Containment Vessel (PCV). Later, TEPCO announced its high level decommissioning and recovery plan that included equipment locate these leaks and plug them so that the RPV and PCV could be filled with water. Over the past two years Toshiba, IHI and Kurion have been teamed together on projects to find and ultimately to seal these leaks.

In the first phase, which was demonstrated in August of 2014, Kurion provided a remote manipulator arm called the Fukushima Inspection Manipulator (FIM) in conjunction with a remotely operated vehicle (ROV) which was developed by Toshiba and IHI to inspect the lower portion of the PCV in Unit 2 of Fukushima Daiichi.

INTRODUCTION

In March of 2011 a tsunami and earthquake struck Japan which created a loss of power and flooding at the Fukushima Daiichi NPP. The reactors shut down but the loss of power and damage to critical systems disabled the emergency cooling systems on the reactors. This caused the reactor fuel to overheat which damaged the fuel. Subsequent venting and ignition of hydrogen gas also caused extensive damage to the upper portion of the facility. The surrounding facilities had extensive damage from the flooding and contamination from reactors.

It is believed that in some of the reactor vessels the fuel melted down and melted through the bottom of the RPV into the PCV structure. Normally, both the RPV and PCV should be sealed however due to damage the thousands of gallons of sea water which were pumped into the reactors to cool the fuel leaked into other portions of the facility which created extensive contamination issues.

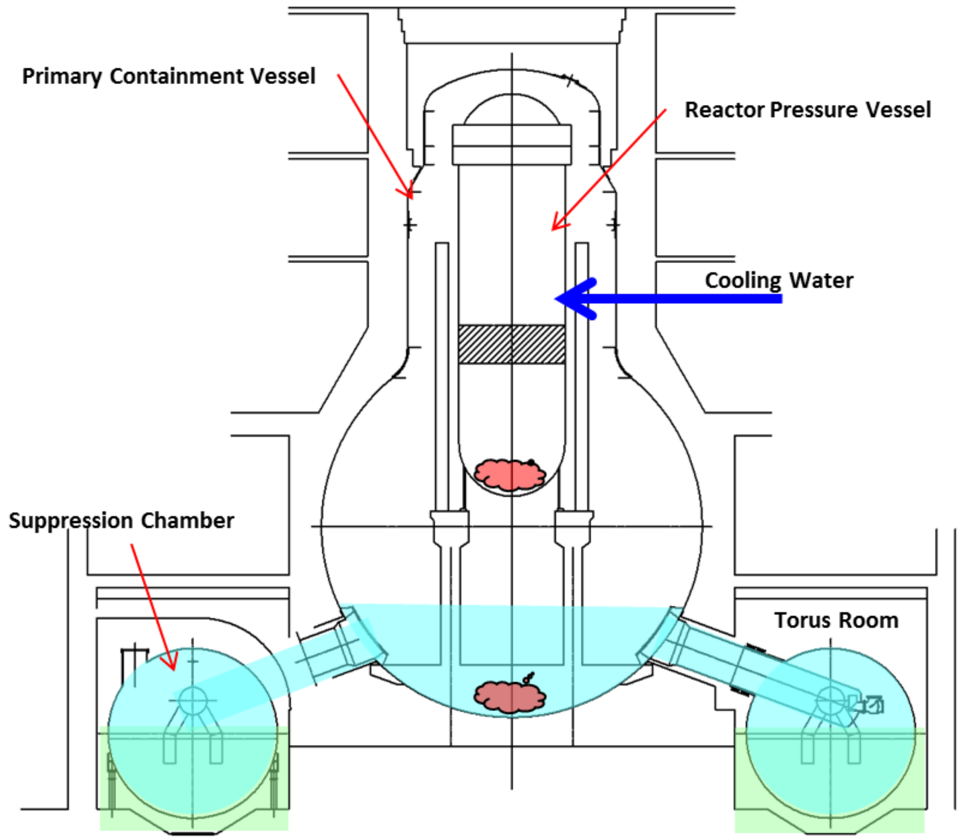

Fig. 1 – Diagram of Current Water Recirculation in Reactor

DISCUSSION

Kurion, IHI and Toshiba are currently in a collaboration to locate and seal leaks in the damaged reactors at Fukushima Daiichi NPP. The initial phase of this project which has just concluded was the first inspection of lower sections of the PCV and the next phase which is still in progress will be the inspection of any remaining areas.

Fukushima Inspection System

Due to unknown leaks in both the RPV and PCV, cooling water which was added to the inside of the RPV would be recovered in a lower section of the facility. It is currently assumed that overheated fuel melted through the bottom of the RPV to settle on a concrete pad inside the PCV. This hole in the bottom of the RPV allows water to flow into the PCV. The bottom structure of the PCV is a large vessel with 8 vent pipes that connected to a lower torus structure called the Suppression Chamber which is housed below the first floor of the reactor building in a concrete structure called the Torus Room. In theory, water entering the PCV should fill up the Suppression Chamber and fill up the PCV. However, at some location in the lower portion of the PCV water is leaking into the Torus Room where it is later recovered and recycled back into the reactor vessel.

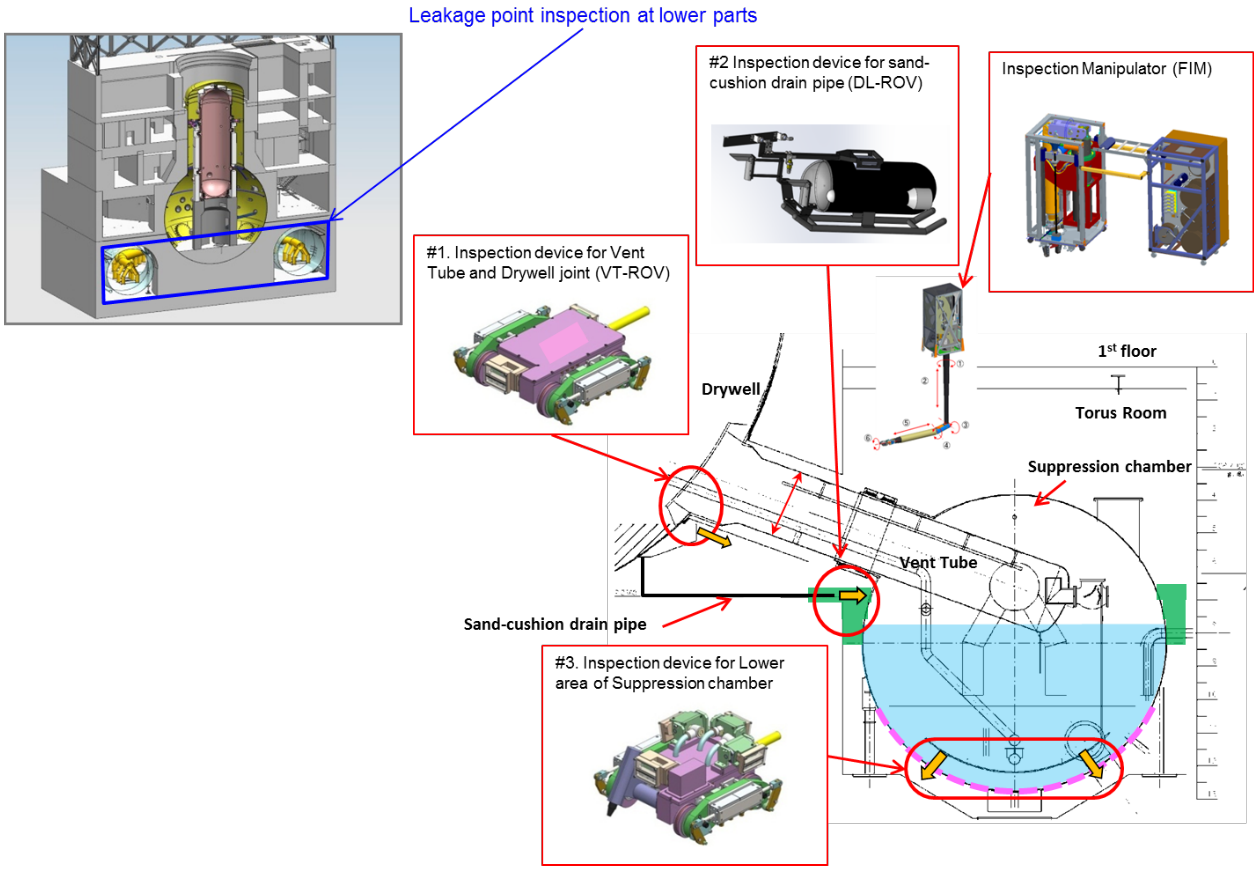

Fig. 2 – Diagram of Plan to Identify Leaks in PCV

For the last two years Kurion, IHI and Toshiba have been making an inspection system that is deployed into the first floor of the reactor building and reaches below the floor through new penetrations to inspect the vent tubes and suppression chamber. This system is composed of a manipulator arm (FIM), cable management system, cutting tools, and ROVs. All of this equipment must be installed through the existing doors and corridors inside the first floor. Penetrations are cut into the floor of the building above the location of the vent tubes in the basement. These penetrations must be placed at various places in the first floors such as hallways and valve rooms. The equipment must all be designed to fit within the existing constraints of the first floor while having the reach and payload to perform the necessary operations in the Torus Room. All of this equipment is designed to be used in a very difficult operating environment which includes water, radiation, contamination, and damaged facilities.

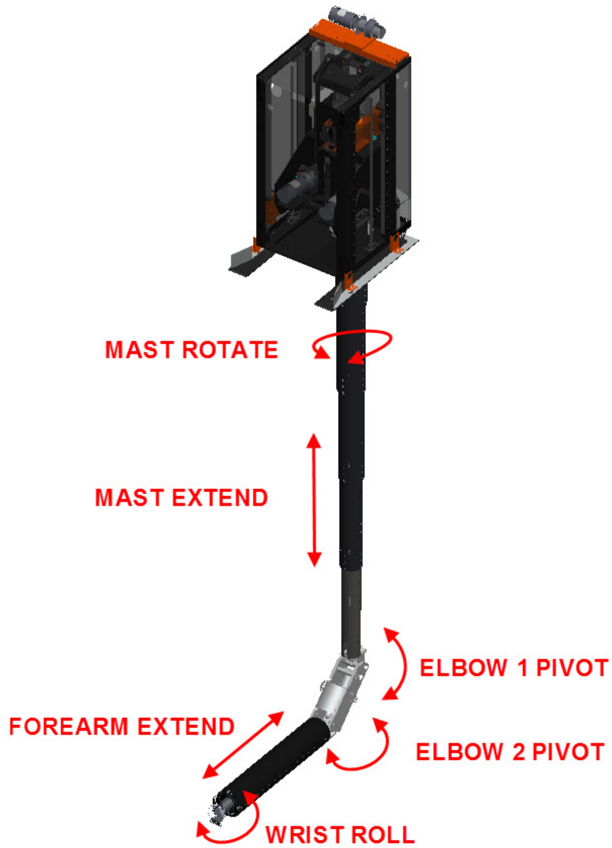

Fig. 3 – Overview of FIM Manipulator

The FIM is a long reach carbon fiber manipulator that is folded inside a transport frame. This frame is about the size of a small refrigerator and can be manually pushed through the facility, including doorways. This frame is tethered to a cable management frame which contains all the hoses and cables for operation of the manipulator. These two units are transported together although they can be separated up to 7m on a flexible tether. The FIM is moved over the penetration where it is bolted to a floor plate.

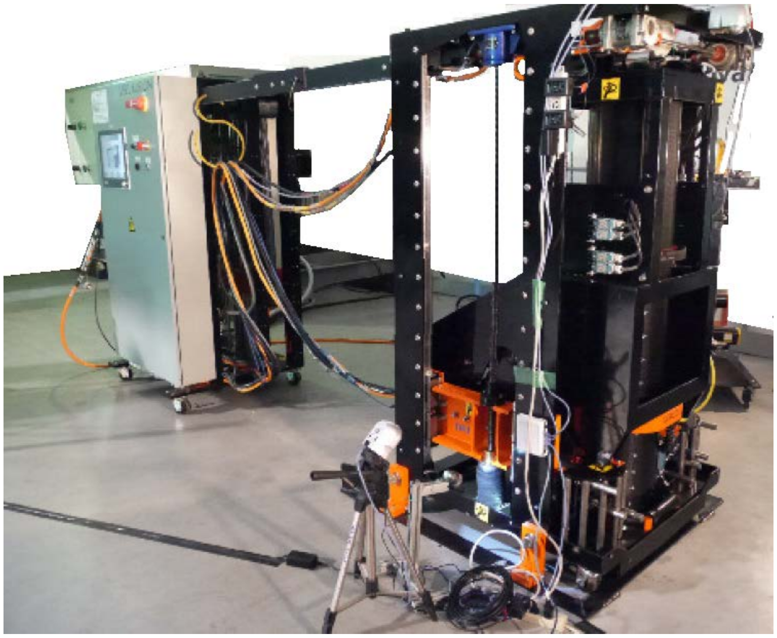

Fig. 4 – Picture of FIM and Cable Management System Deployed on Floor

The FIM is then rigidly connected to the cable management frame. The system has a number of tools which can be connected to the front of the FIM. This is done manually although all operations inside the reactor building have been designed to be done with minimal time and while wearing extensive protective equipment. Once a tool has been connected, the manipulator is installed into the penetration and the entire arm is flipped and unfolded into the hole. This folding allows a very long manipulator to be stored and transported in the frame of the FIM.

Fig. 5 – FIM Deployed in Colorado Mockup Demonstrating Long Reach Capabilities

The manipulator arm is composed of a main mast with five telescoping carbon fiber sections. This mast is rotated to allow positioning of the arm below the hole. On the end of the telescoping mast is a double elbow which allows 180° of rotation of the arm. After the elbow is a telescoping forearm section followed by an articulated wrist and remote tool plate.

All of the actuators below the floor are hydraulic with some electric actuation in the frame. The cable management system allows cables to be feed in and out of the mast during extension and retraction. This is done on a set of pulleys that are tensioned with pneumatic cylinders.

Initially the manipulator is deployed through the ceiling of the Torus Room, to reach the final inspection locations there is a possibility that existing obstacles such as piping, railing, and cabling must be removed in the Torus Room. The inspection system includes a waterjet cutter and hydraulic shear. The shear can be used for small diameter obstructions and the waterjet for larger obstacles. Both tools are connected to the remote tool plate on the end of the arm. Cables and hoses for these tools are provided separately on tool carts which manage and tension the cables during deployment. The waterjet cutter is integrated into a gripper so that beams and pipes can be held during cutting.

Once a path to the inspection location has been cleared the three Remotely Operated Vehicles (ROVs) can be deployed. Each of the ROVs is connected to a tool cart in the first floor and feed through a deployment tool on the manipulator arm. The manipulator arm can then move the ROV near the inspection locations and lower the ROV using the tether to the inspection surface.

Each ROV is designed to inspect a different area of the lower part of the PCV for leaks and is designed to match this geometry. The first ROV is a magnetic crawler that is designed to crawl along the body of the suppression chamber and look for leaks along this large steel structure. The second ROV is also magnetic but is designed to crawl along the vent tube to inspection the joint between the vent tube and main body of the PCV. The last ROV is a submersible which can swim through the water at the bottom of the Torus Room.

Fig. 6 – Picture of 3 IHI ROVs used in Inspection (Left-Right: Vent Tube, Down Leg, Suppression Chamber)

In May of 2014 Kurion finished the design and fabrication of the FIM, cable management system and tools. All this equipment was tested with the support of IHI in Kurion’s Colorado facility before being shipped to Yokohama Japan for a full system test in IHIs large mockup. This final test included the Toshiba and IHI developed ROVs and also included training for the operators that would be supporting the on-site work.

Fig. 7 – Picture of FIM and ROV Deployment Tool during Testing at IHI Mockup

In July of 2014 Toshiba and IHI installed this equipment at Fukushima and by August had completed the first inspection of the suppression chamber. This initial phase was to prove the effectiveness of the equipment.

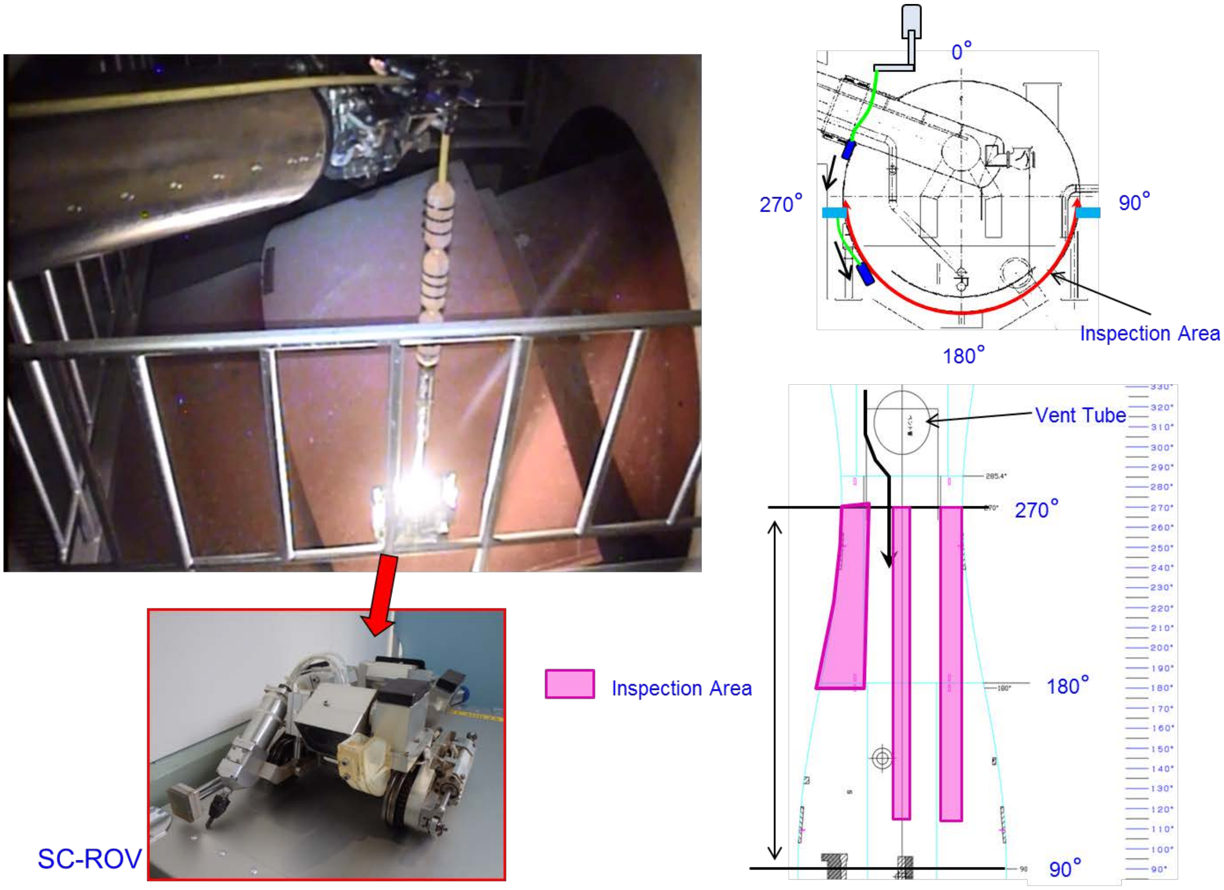

Fig. 8 – Results of Inspection and Pictures of Actual Deployment

This project not only shows how technology can be developed to address the many challenges at Fukushima but also how US and Japanese firms can successfully work together to accomplish a very challenging project.

This project has also demonstrated how advanced equipment such as long reach manipulators will be important to many other aspects of the Fukushima cleanup effort.

REFERENCES

1. "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4", Nuclear Emergency Response Headquarters, June 27th, 2013
2. "Results of Research Concerning Exterior Section under S/C (Suppression Chamber at Unit 2", Handout from Tokyo Electric Power Company, September 4, 2014

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