An Entry Point of the Emergency Response Robot for Management of Severe Accident of the Nuclear Power Plant

Jai Wan Cho* and Kyung Min Jeong
Nuclear Convergence Div., Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon, Korea
Email: jwcho@kaeri.re.kr

1. Introduction

We analyzed the operation system of Japanese nuclear emergency response robots, which were developed after JCO criticality accident on Sep. 1999, to cope with a severe accident in a nuclear power plant. We also investigated cases where their robots entered to manage or mitigate the severe accident of the Fukushima Daiichi nuclear power plant. The Moni ROBO-A robot system (weight 600kg), developed by NUSTEC (Nuclear Safety Technology Center), arrived at J-Village (off-site nuclear emergency response headquarter), but was not deployed because it was thought that it would to sever cables and hoses that were temporarily setup for electric power supply and water supply. In this paper, from the view point of DID (defense-in depth), we discuss the entry point of the nuclear emergency response robot to cope with a nuclear disaster. A Japanese nuclear disaster preparedness robot system was developed, after the JCO criticality accident in 1999, to cope with INES (International Nuclear and Radiological Event Scale) Level 3 serious incidents [1]. INES Level 3 means the loss of DID (defense-in-depth) functions. It also indicates that ESF (engineered safety features) and ECCS (emergency core cooling system) resources, which are used to prevent serious incidents from escalating to severe accidents (core melt-down), have been almost exhausted. In the unit 1 reactor accident of Fukushima Daiichi Nuclear Power Plant, escalation from INES Level 1 (Out of Limiting Condition for Operation) to INES Level 5 (serious core melting-down) took less than two hours. Major facts are briefly described here in based on data gathered immediately after the tsunami over Fukushima Daiichi Nuclear Power Plant [2].

O 15:35 on March 11, 2nd tsunami arrived.
  - 15:37, SBO (station black out)
O 15:42, Interprets as a SBO (INES Level 1)
  - Loss of DC power for Instrumentation
  (Unknown of reactor water level)
O 16:36, Loss of ECCS function (INELS Level 5)
  (Entry into a BDBA status)

The Moni ROBO-A robot of the Japan Nuclear Safety Technology Center (NUSTEC) was a nuclear disaster preparedness robot developed after the JCO criticality accident. It was the only robot that had been steadily maintained and was available at the time of the Fukushima Daiichi Nuclear Power Plant accident. However, it was not helpful in mitigating the accident because it is assumed to have arrived at J-Village after the accident had been escalated to INES Level 5 or higher. Based on the paper by S. Kawatsuma of JAEA[3] and response data gathered immediately after the tsunami [2], it is estimated that the NUSTEC's Moni ROBO-A arrived at J-Village after the designed entry point for INES Level 3. According to PSA Level II nuclear reactor safety analysis reports from the JNES (Japan Nuclear Energy Safety Agency) and the JAEA (Japan Atomic Energy Agency), in an accident scenario (the ECCS cannot be operated because A/C power sources and D/C standby electric power sources of the entire plant have been lost) like the accident in Fukushima Daiichi Nuclear Power Plant, the accident will progress toward a core meltdown (BDBA, beyond design basis accident) within two hours [4][5]. Therefore, it is estimated that, even if the robot systems developed after the JCO criticality accident had been properly maintained and were usable, by the specifications of the developed robot systems (the JAEA RaBOT and the Mitsubishi Heavy Industries Ltd. MARS-A) and the point of arrival of the NUSTEC Moni ROBO-A at J-Village, the core meltdown could not be mitigated.

2. Defense-in-Depth

A DID (Defense in Depth) is an important and fundamental philosophy in the safe operation of nuclear power stations. It underlies all safety aspects of nuclear power. A DID approach to reactor accidents includes the following three aspects [6].

O Accident prevention

Accidents are prevented by high quality design, construction, operation and regulatory control of the plant, consistent with the safety analysis. When faults are detected, they are corrected, or if repairs cannot be made, the plant is placed in a safe state.

O Accident mitigation

In accident mitigation, the overall strategy is to shut down the reactor, maintain core cooling, and seal off the radioactivity. These functions are accomplished by qualified staff using accident mitigation procedures, with the aid of safety systems (ESF and ECCS) designed especially for accident mitigation.

O Accident management

The third aspect includes emergency response procedures for managing the abnormal release of radioactive substances even when an accident has been escalated to a nuclear disaster.

From the view point of INES and DID, up to INES Level 3 (for example, complete SBO owing to a fire in T/B building) and DID aspect 2 (accident mitigation, for example, control of accidents within the design basis), the SSC (systems, structures, and components) of a plant are based on the functional plant designs. In the BDBA conditions of INES Level 4 or higher, scenario-based measures to manage accidents (nuclear disaster) are used. The emergency response robot (NUSTEC Moni-Robo A) developed after the JCO criticality accident is to be sent in INES Level 4 situations after the point of collapse of DID aspect 2 (accident mitigation). The NUSTEC robot system was developed for grasping situations (radiation measurement, sampling, and information gathering) outside the plant. The robot is considered to have arrived at J-Village at late after the Fukushima Daiichi Nuclear Power Plant accident because of the destruction of the social infrastructure due to the earthquake and traffic jams. The robot could not enter the site because its heavy weight (600kg) might have caused damage to the fire hoses and power cables for the pump operation. These had been temporarily installed at the site to cool down the reactor core using fresh water and seawater. It is assumed that if the NUSTEC's Moni ROBO-A robot was rapidly deployed by an air transportation measure, it would monitor efficiently situations outside the plant at a location where there were no interferences with the fire hoses or power cables. To grasp the vent situations of the unit 2 and 3 reactors, an interpretation of the status of the radioactive substance (high temperature steam) discharge systems (stack) was important. However, the stack status could only be read in clear weather conditions during the day; the vent situation could not be interpreted at midnight or on cloudy days. It is assumed that if a thermal infrared camera mounted on the Moni-Robo A robot system had been used to observe the stack, the vent operation of the units 2 and 3 reactor would have been much easier. If the middle-class working robots (the JAEA RaBOT and the Mitsubishi Heavy Industries Ltd. MARS-A; their missions are monitoring inside the R/B (reactor building), opening the door-lock, and manipulating handles to open or close the safety-related steam pipes) had been maintained and managed, entered the unit 1 reactor building rapidly, the vent operation could have been accomplished earlier, and the object of the robot system development, which was to respond to emergency situations, might have been satisfied. According to responses immediately after the tsunami [2], the time taken from the review of the vent operation (3/12/0:06) to success in the vent operation (3/12/14:30, completion of electric connection tests between the power center of unit 2 R/B and the electric supply truck, 3/12/15:30; unit 1 reactor building hydrogen explosion, 3/12/15:36) was 14.5 hours. The delay was due to the length of time taken to review alternative vent measures; this resulted from not to sending workers inside the reactor building due to the dose limits (100 mSv/year). However, to cope with the emergency situation of the nuclear power plant efficiently by the nuclear disaster preparedness robot systems, these middle-class working robots should have been maintained in specific equipment room inside the nuclear power plant so that they could have accessed rapidly the mission area. There should also have been sufficient workers (operators) trained to operate them skillfully.

3. Conclusions

From the viewpoint of the DID concepts, nuclear disaster preparedness robot systems should enter the nuclear power plant after the collapse point of INES Level 2, to cope rapidly with emergency situations of the plant. Therefore, the operation concept of an emergency response robot system that the robot systems would enter under the requirements of INES Level 3 or higher levels in emergency situations where an external DBT (design basis threat, for example, flood, tsunami, earthquake, aircraft collision, or terrorism that is at least at the same level as the design basis) factors have occurred, should be improved.

In the case of Fukushima Daiichi Nuclear Power Plant, since INES Level 1 (anomaly from normal operation) was escalated to INES Level 5 (accident with wider consequences) or higher level in an instant (less than 2 hours), the technology readiness levels and the operation systems of the robot systems should be redefined to prevent or mitigate the accidents situations early. The operation systems, when they are to be operated (sent) in accident situations of INES Level 3 or higher, nuclear disaster preparedness robot system (NUSTEC Moni Robo-A) developed after the JCO criticality accident, revealed many reforms.

REFERENCES

[1] IAEA, INES (The International Nuclear and Radiological Event Scale) User's Manual, 2008
[2] TEPCO, "Responses immediately after the earthquake and the tsunami at the Fukushima Daiichi Nuclear Power Station (Japanese)", 2011. 6. 18.
[3] S. Kawatsuma, "Overview and Issues to be solved on Emergency Response of Robots to Fukushima NPP Accidents (Japanese)", Journal of the RANDEC, No.46, pp14-26, 2012
[4] JNES, "PSA Level II Analysis (BWR) at the time of the Seismic Event (Japanese)", 2010. 10
[5] JAEA, "Lessens from Accidents and Directions toward the Nuclear Reactor Safety Research (Japanese)", 6th JAEA Open Seminar Presentations, 2011. 11
[6] Defense in Depth, Lecture Notes, 22107.3