Derivation of Robot Mission for Nuclear Emergency Response

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Abstract: In an accident situation which is expected to be extreme conditions such as high temperature, high pressure, and high radioactivity, human workers are restricted under such conditions. Robot, which is relatively free of restrictions on environmental conditions, can be applied to prevent and mitigate events more quickly and stably in abnormal and emergency state. In order to develop robot responding to nuclear events, it is necessary to determine the robot's mission that can contribute to the safety of the power plant. Through the review of the abnormal operation procedures, emergency operation procedures and severe accident management guidelines, we have drawn up robot missions. The criteria of robot missions are field work needs and anticipated human threats. The extracted 20 missions are listed and some of important mission scenarios are analyzed to develop robot system. And testbed will be constructed for the verification of robot performance on the basis of the mission..

Keyword: robot mission, abnormal procedures, emergency procedure

1 Introduction

Prompt and correct responses are important to prevent accidents in order to secure the safety of nuclear power plants. Nuclear power plants have been prepared responding procedure according to the plant state in the safety perspective, and this is carried out by the human operator. However, human response may be limited under adverse conditions such as high temperature, high pressure, and high radiation. If a robot, which is more resistant to environmental conditions, can be used to respond to nuclear accident, it can prevent and ease accidents more quickly and reliably. And it will be ultimately advance the safety of nuclear power plants, so it can improve the public acceptance. In order to develop robots capable of responding to nuclear accidents, it is necessary to first determine the robot's mission that can contribute to the safety of the power plant. In this paper, we reviewed procedures and guidelines for accident prevention and mitigation to derive robot missions. In the procedures and guidelines for the emergency response, the process of selecting the applicable measures of the robot among the operator measures is required. For this, two conditions are defined. Robot applicability conditions for emergency response are tasks requiring field work and threatening work for humans. Based on this, 20 applicable missions of the robot were derived and they were prioritized by analyzing the importance according to the influence and occurrence frequency of the mission performance. Among them, we examined the scenarios for three missions with the highest priority and figured out the tasks that the robot should perform. Through the clarification of the task, we were able to grasp the performance goal of the robot to cope with the nuclear emergency situation, and it is possible to verify the performance of the robot by building the testbed.

2 Analyze procedures and guidelines

Domestic nuclear power plants have various procedures and guidelines to prevent or mitigate accidents, including abnormal operating conditions of power plants. In abnormal and emergency cases, they are important that the person performing on-site response work according to the procedures and guidelines described in the manual. But there are a risk of exposure to severe environment such as high temperature, high pressure and high radioactivity. So the implementation of the measures may be delayed or not done. If the robot can perform the action, the incident response strategy presented in the procedures and guidelines can be implemented without delay. So, in order to derive an emergency mission for the robot system, the nuclear power plant procedures and severe accident management guideline documents are reviewed.

It is required to select criteria that may be required to be linked to the robot system among the operator measures listed in the above procedure and guidebook for the accident response. The following two conditions are defined for this purpose.

1) measures that require on-site working, not remote control in the control room,

2) actions that are expected to be threatened by exposure to high temperature/high pressure and high radiation respectively.

The following exclusion conditions were applied to select the possible linkage as the emergency action mission of the robot system for each measure.

1) Excluding the actions that can be performed only in the control room

2) Excluding measures that have no direct connection with facilities of the power plant

3) Except for actions that are unlikely to be exposed to high temperature, high pressure and high radioactivity

4) Excluding measures outside the power plant building

These exemptions were applied to examine all the operator actions listed in the emergency operating procedures.

3 Derivation of robot mission

The procedures and guidelines presented in the various documents of the power plant were reviewed according to the emergency action mission selection criteria defined in section 2, and a total of 20 emergency action missions were considered that could require the application of the robot system. Procedures and guidelines have been evaluated to distinguish the nature of the main actions taken in the field according to the extent of the incident.

3.1 Missions for abnormal operating state

Major field action requirements in the context of relatively low emissions of radioactive materials are reviewed in terms of identifying and isolating leaks and areas of leaks in reactor coolant systems and outflow lines. The major emergency action missions for the abnormal state of the power plant are as shown in Table 1.

Table 1 Missions for abnormal state of plant

Mission no.	Description
M-01	Check leakage area and isolation of the reactor coolant system inside the reactor building
M-02	Check leakage area and isolation of the reactor coolant system outside the reactor building
M-03	Check the tightness of the leakage area and seal in case of leakage of steam generator nozzle dam failure
M-04	Visual inspection of SCS, RCS, CVCS leakage in case of coolant inventory loss during mid-loop operation
M-05	Visual inspection of SCS, RCS, CVCS leakage in case of coolant inventory loss during shutdown operation
M-06	Check leakage area and isolation in case of outflow channel leakage
M-07	Replenish water in the spent fuel pool in the case of spent fuel pool water level reduced
M-08	Move to storage rack or reload pool until disposal plan is established in case of a nuclear fuel accident
M-09	On-site inspection and sampling to check out spill areas in case of radioactive material leakage

3.2 Missions for emergency and severe accident state

If the incident progresses beyond the abnormal state, operator action to locate or block the release of radioactive material within the reactor building is not required in the procedures and guidelines, and to prevent the accident environment from spreading outside the reactor building. And measures to survey the radiation of auxiliary buildings and turbine buildings were evaluated to be included in the major human actions. In addition, if necessary, it is required that the operator measures to spray water with a fire hose or the like to the fluid containing the radioactive material discharged from the secondary pipe of the steam generator or through the reactor building penetration part.

Where it is not possible to monitor and control the power plant in the main control room and the remote station, most of the operator actions specified in the Guidance Document have been evaluated to be on-site, assuming that the core damage has been induced site actions are included. On the other hand, in the case of an extreme disaster such as an earthquake, access to the site may be exacerbated by internal fire or flooding even if measures similar to those described above are taken. The major emergency action missions that are targeted at the power plant accident status are as shown in Table 2 and Table 3.

Table 2 Missions for emergency state of plant

Mission no.	Description
M-10	Check leakage and isolate isolation valves operated by CIAS in the event of reactor coolant loss
M-11	Open or close the secondary valve in the event of steam generator tube ruptures
M-12	Isolate isolation valves operated by CIAS in the event of accident during isolation of reactor buildings
M-13	Isolate isolation valve actuated by CSAS during reactor building temperature and pressure control

Table 3 Missions for severe accident state of plant

Mission no.	Description
M-14	Sampling of RCS, reactor recirculation water tank, reactor/aux building atmosphere
M-15	Confirmation of reactor building closure
M-16	Steam generator depressurization to inject water into the steam generator
M-17	Installation of portable shielding according to radio-activation of all routes
M-18	Water spray using fire hose to control the release of nuclear fission products from nuclear reactor building
M-19	Survey radiation level in auxiliary building with long-term concern
M-20	Open doors or make another possible opening to vent fuel storage building

4 Examples of mission scenario

4.1 Check leakage area and isolation in case of outlet flow pipe rupture

The scenario of the M-06 mission is to mitigate the accident by closing the isolation valve if the cooling water of the reactor coolant system is directly lost through piping outside the reactor building (auxiliary building) as shown in Fig. 1.

- Start of automatic operation by water level decrease of volumetric control tank
- Increase the charge flow rate by reducing the water level of the pressurizer
- Regeneration heat exchanger outlet temperature high-high signal should automatically close the effluent isolation valve in the reactor building, but the isolation failure
- Action to manually close the effluent isolation valve in the auxiliary building

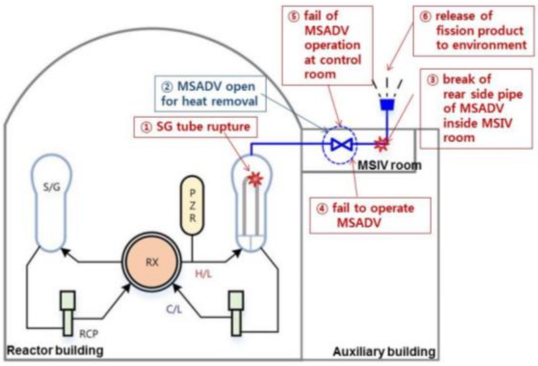

Fig.1 Scenario of mission M-06.

In the event of an accident, high temperature, high pressure and high radioactive fluids are discharged into the auxiliary building, so it is highly likely that the operator will not be able to perform an action to manually close the effluent isolation valve in the auxiliary building, If a large area of the reactor is caused to cause a reactor shutdown, the reactor will be shut down and converted to an emergency state where the application of the emergency operating procedure is required and an emergency notification is required according to the radiation emergency plan. If the failure of the safety system such as the safety injection system is accompanied, the cooling water of the reactor coolant system gradually becomes depleted, which can cause serious accidents. Therefore, if the robot system can carry out this action, it can contribute to the safety of the nuclear power plant.

4.2 Open or close the secondary valve in the event of steam generator tube ruptures

The scenario of the M-11 mission is to mitigate the accident by closing the isolation valve if the cooling water of the reactor coolant system is directly lost through piping outside the reactor building (auxiliary building) as shown in Fig. 2.

- Rupture of one or more steam generator tubes
- Reactor stop due to high level of steam generator
- Safety injection by low pressure of pressurizer Operation signal operation and high pressure safety injection
- Steam generator feed pump operation
- Secondary side heat removal through main steam atmosphere release valve
- Main steam release valves in the main steam isolation valve compartment Rear piping rupture
- The environmental condition of the main steam isolation valve compartment is deteriorated and the operation function of the main steam discharge valve is damaged.
- Reactor coolant system pressure control failure
- Isolation of broken steam generator (including main steam atmosphere release valve) required

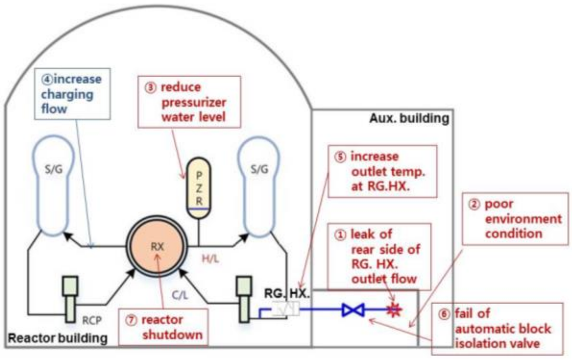

Fig.2 Scenario of mission M-11.

If an accident occurs, take measures to isolate the steam generator to prevent the radioactive reactor coolant from leaking through the steam generator and being continuously released into the atmosphere. If the leakage path from the damaged steam generator to the atmosphere can not be blocked, the pressure of the damaged steam generator will be approximately equal to the atmospheric pressure, and the pressure differential between the reactor coolant system and the damaged steam generator will increase resulting in leakage from the primary to the secondary It grows. In this case, cooling water in the recharge water storage tank for injecting cooling water into the reactor coolant system becomes depleted, and re-filling measures of the recharge water storage tank are required. This increases the possibility of damage to the core as additional operator action is required. Therefore, if the robot system can perform measures to isolate the main steam discharge valve of a broken steam generator in the condition of poor environmental condition of the main steam isolation valve compartment, it can greatly contribute to nuclear safety.

4.3 Prevent the release of nuclear fission products using water spray

The scenario of the M-18 mission is to prevent the fission product by spraying water using a fire hose when the fission product is discharged outside the reactor building as shown in Fig. 3.

- Significant Damage of Major Accidents and Core
- Emissions of fission products from the reactor coolant system into the reactor building
- Damage to the isolation valve of nuclear fuel conduit

The fission products in the reactor building are released into the nuclear fuel building through the nuclear fuel separator valve damages.

- Cleaning demand of fission products release.

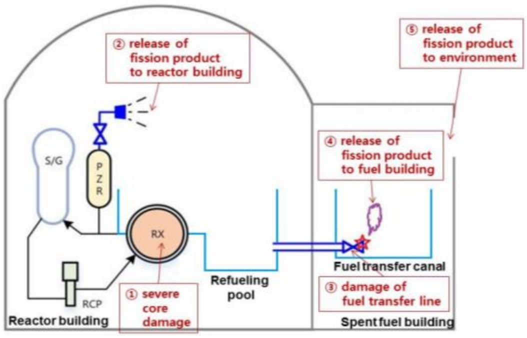

Fig.3 Scenario of mission M-18.

In the event of an accident, high-activity fluids are released into the fuel-handling area of the nuclear fuel building, and if there is no action to mitigate it, large quantities of fission products are released into the environment and uncontrolled, and the residence of the nuclear fuel building is lost . Therefore, it is required to prepare some fission products by spraying water with a fire hose or the like to the fissile product discharge part, and if the robot system can perform this, the risk of accident can be reduced.

5 Robot task

Based on the results of this review, we evaluated the importance of each measure and selected three basic missions that are highly applicable to robotic systems. The selected basic mission is to manually shut off the isolation valve at the low pressure boundary coolant loss event (downstream of the outflow channel), to manually shut off the main steam atmosphere release valve when the steam generator tube ruptures, and to remove the fission product release with a spray water.

The emergency action missions were reviewed in detail about the movement routes, obstacles in the route, countermeasures, and the physical structure of the facility. Robot task for performing the above 3 missions are as follows:

- Enter the building from the outside (open doors)
- Move staircase
- Move upstairs through ladder
- open main steam release valve actuator cover
- Operate valves using a wrench (hexagon),
- Operate the glove valve's handwheel
- Open the fire hydrant cover
- Operating the handwheel in the open state
- Carry fire hose to nuclear fuel transport canal
- Operate fire hose nozzle

6. Concluding Remarks

In order to develop robots capable of responding to nuclear accidents, it is necessary to determine the robot's mission that can contribute to the safety of the power plant. As a part of robotic mission deduction work, we reviewed the procedures and guidelines for accident prevention and mitigation. 20 missions are selected by the criteria of field work and harmful to human workers. The missions are to be used to develop the basic scenario for the application of the robot system. And the testbeds will be constructed for the verification of robot performance on the basis of the mission.

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