Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Establishment of Methodologies to Evaluate Fires in Nuclear Facilities

Background and Objective

To obtain conformity on the new regulatory requirements for nuclear power plants, it is necessary to prepare fire prevention methodology with high accountability in accordance with the fire impact assessment guide enacted in June 2013. In addition, in order to reduce the risk induced by internal fire needed for the periodic safety review after recommencement of operations, continuous improvement of the fire hazard assessment and the fire prevention methodology is necessary.

In this project, we aim to evaluate the fire prevent methodology (fire extinguishing system, etc.) for nuclear power plants based on the fundamental fire tests and confirm its validity. In addition, to improve the accuracy of fire behavior prediction in accordance with fire source (such as, cable fire, oil fire and high energy arcing fault fire), we aim to integrate the fire hazard evaluation method and contribute to the establishment of scientific and rational countermeasures for fire prevention.

Main results

1 Establishing a construction method of tube-type automatic fire extinguishing system for cable tray fire

Among the countermeasures to reduce the internal fire impacts of nuclear power plants, installation of the tube-type automatic fire extinguishing system (Fig. 1) may be applicable as an automatic fire extinguishing equipment for cable tray fires. In order to establish an effective construction method for such a system, fire extinguishing tests were carried out using a cable tray attached to the metal lid with actual maximum width (1.8 m), and subjecting the inflammable high-voltage power cables to an overcurrent of 2 kA class (Fig. 2) in vertical and horizontal orientations. As a result, fire extinction capability for the longest range of fire extinguishing equipment charged with the environmentally friendly halide fire extinguishing agent (50 m) was confirmed and a prospect of applicability for the actual installation obtained.

2 Clarification of limitations on the occurrence of High Energy Arcing Fault (HEAF) fires in high-voltage switchgear components

Successive fire due to a HEAF event in the high-voltage metal-clad switch gear*1 was identified at the Onagawa nuclear power plant at the time of the Great East Japan Earthquake. As such, we tested full scale high-voltage metal-enclosed switch gear components (6.4 kV and 8.0 kV), and confirmed that the arcing energy below 25 MJ did not induce the HEAF fire (Fig. 3), regardless of the arcing discharge position. Furthermore, we developed CFD (Computational Fluid Dynamics) code to predict damage to the metal enclosure and the zone of influence by pressure and gas emitted from a broken enclosure, thus confirming its applicability to the fire hazard assessment.

3 Establishment of an efficient methodology to predict air temperature in a compartment fire by the fire model FDS

In fire impact assessments for fire compartments, to establish the extent of fire impact and estimate the firing time or damage time of important safety equipment, the representative fire model FDS (Fire Dynamics Simulator)*2 is applicable for the detailed evaluation of compartment fires with complicated configurations however analysis accuracy is highly dependent on input conditions. As such, we evaluated the accuracy of a fire model, FDS, for a fire plume from combustible liquid and a natural convection from a high-temperature vertical wall, and found that the air temperature in a compartment fire could be reproduced accurately by appropriately setting the pyrolysis conditions of the fire source or computational grid-spacing condition (Fig. 4) (N13010).

*1 Installed in the metal enclosure with a protective relay (such as circuit breakers) and high-voltage bus to protect and control the power system.
*2 A CFD model developed by NIST (National Institute of Standards and Technology) in the US, which primarily simulates heat and substance transport in fire fields and enables evaluations of spatial distributions of physical quantities such as air temperature.

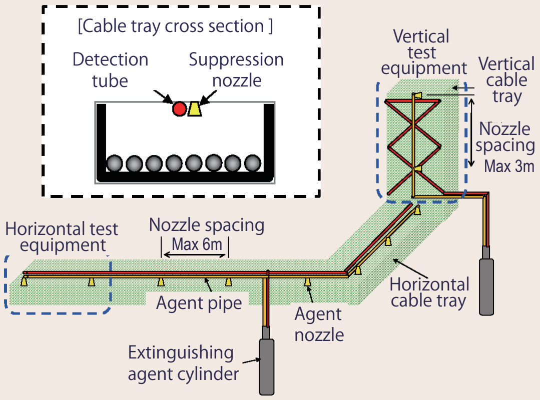

Fig. 1: Example of a tube-type automatic fire extinguishing system for cable tray fires

A tube-type automatic fire extinguishing system is composed of a fire extinguishing agent cylinder, detection tube, pipe and valve for agent injection, etc. Immediately after the burst of the polyamide detection tube containing pressurized nitrogen gas due to the heat of the flame (activation temperature: 180℃), the pneumatic cylinder valve for fire extinguishing agent (Novec1230: liquid at room temperature, boiling point 49℃) will be activated. The suppression agent will be injected through the nozzles into the designated fire area and induce a suppression effect over the combustion reaction and a cooling effect. Moreover, as this system can detect fires automatically without any power source, the capability of fire extinguishing even in the event of a power failure can be assured.

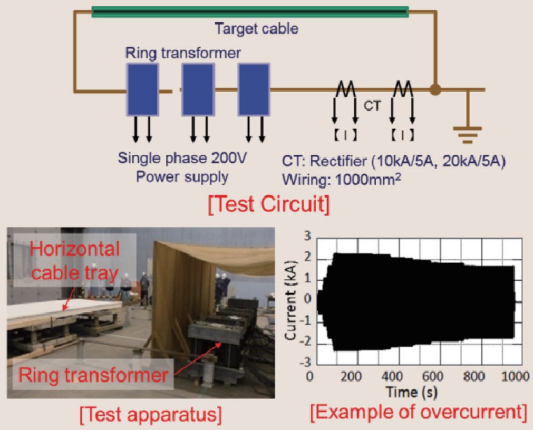

Fig. 2: Cable fire test apparatus with the overcurrent system

Using the overcurrent test equipment installed in high power short-circuit testing facility at the electric power engineering research laboratory (Yokosuka area), cable fire extinguishing tests subjected to six times the allowable current (2 kA) were carried out using flammable high-voltage power cable (6.6kV-CV-3C-150sq). In these tests, one target cable was continuously energized by ring transformers to reproduce the cable fire.

By using a cable tray attached to a metal lid of actual maximum width (1.8 m) covered with a heat resistance sheet, an ensemble which simulates the end of the extinguishing agent pipe system, we performed fire extinguishing tests in horizontal and vertical orientations and confirmed that use of 50 m of tube-type automatic fire extinguishing system was the longest possible coverage.

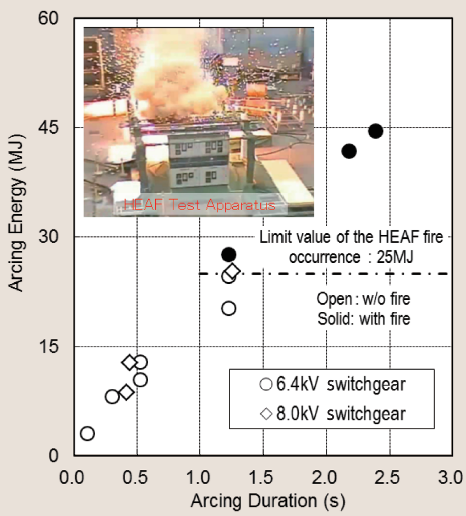

Fig. 3: Arcing energy measured in HEAF tests using high-voltage switchgears and the limitations of fire occurrence

We measured arcing energy* using two types of high-voltage switchgears (test voltage 6.4 kV and 8.0 kV, three-phase three-wire system, copper bus conductor) under a condition with short circuit current around 20 kA and durations from 0.1 to 2.2 sec. When the arcing energy did not exceed 25 MJ, a successive fire was not identified, regardless of the arcing discharge position (VCB room or bus-bar room).

*Hot gas heated in the metal enclosure due to arc flash will be emitted out of the enclosure or to adjacent enclosure, and has a potential to damage surrounding equipment.

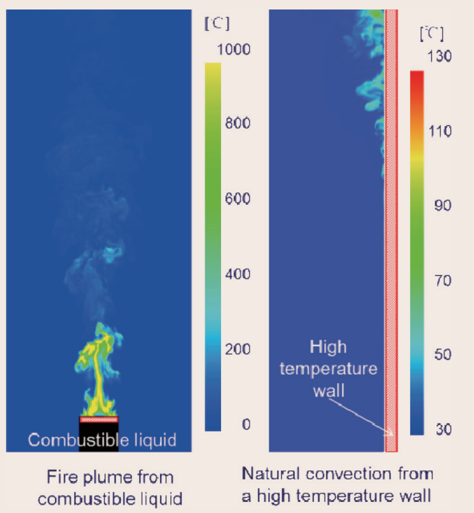

Fig. 4: Example of simulation of the fire plume using a fire model FDS

The FDS fire model gives spatial distributions of physical quantities, such as temperature, velocity, oxygen concentration, as well as their temporal variations. As shown in the figure on the left, concerning grid spacing for accurately predicting a fire plume from combustible liquid (Ethanol, pan diameter 30 cm), the condition of $\Delta < D^*/20$ (D^*: characteristic fire size, Δ: grid spacing) could be applied. Moreover, as shown in the figure on the right, for a natural convection from a high temperature wall, unsteady flows near walls were accurately predicted under the grid-spacing condition of $\Delta\eta <$ approximately 0.6 (η: similar variable for laminar boundary layer).