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. Furthermore, 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 prevention methodology (fire extinguishing system, etc.) for nuclear power plants based on fundamental fire tests and confirm the validity of such methodology. In addition, to improve the accuracy of fire behavior prediction in accordance with fire source (such as cable fire, oil fire and electrical cabinet), we aim to integrate the fire hazard evaluation method and contribute to the establishment of scientific and rational countermeasures for fire prevention and internal fire PRA.

Main results

1 Establishing a construction method of an automatic foam fire extinguishing system for cable tray fires

Among the countermeasures to reduce the internal fire impacts of nuclear power plants, installation of the wet-type automatic fire extinguishing system with foam fire extinguishing agent (Fig. 1) may be applicable as 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 ladder-type cable tray covered by the flame-proof sheet with 0.6 m width, and subjecting the inflammable high/low-voltage power cables to an overcurrent of 2 kA class (Fig. 2) in vertical and horizontal orientations. As a result, reliable fire extinction capability of the cooling and suffocation effect by foam fire extinguishing agent was confirmed and the prospect of applicability for actual installation obtained.

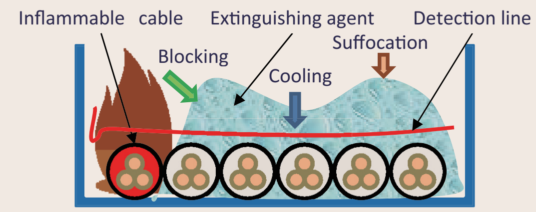
2 Clarification of limitations on the occurrence of High Energy Arcing Fault (HEAF) fires in low-voltage electric cabinets

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 a full scale low-voltage electric cabinet (power center) following high-voltage metal-enclosed switch gear, and confirmed that arcing energy above 19MJ induced the HEAF fire in the low-voltage electric cabinet with relatively content volume (Fig. 3). Based on these HEAF tests, we aim to reflect on the identification methodology of the zone of influence due to the HEAF fire and contribute to integration into the fire hazard evaluation.

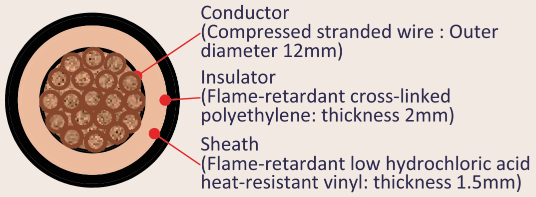
3 Establishment of an efficient methodology to predict air temperature in a compartment fire by the fire model

In fire hazard evaluation, in order to estimate the ignition time or damage time of important safety equipment, it is necessary to appropriately set the time change of heating power from heat source (heat release rates, HRRs). In the compartments of nuclear power plants, as the oxygen concentration around fire source may vary due to the air flow pattern by the ventilation system which may also be operated in the case of fire, HRRs may be highly dependent on the ventilation flow rate. In order to verify its dependency, fire tests in a single compartment were performed and the relationship between the oxygen concentration around fire sources and HRRs (Fig. 4) was clarified. In addition, through executing multiple compartment fire tests, we clarified the effect of the ventilation flow rate and the disposition of the air inlet/outlet duct on the air temperature and the heat balance in the compartments, and the heat transfer among compartments. Based on these test results, we aim to reflect on setting input conditions for fire models to reproduce the air temperature in the compartments and fire propagation scenarios, and finally contribute to the improvement of the fire PRA method.

*1 Installed in the metal enclosure with the protective relay (such as circuit breakers) and high-voltage bus to protect and control the power system.



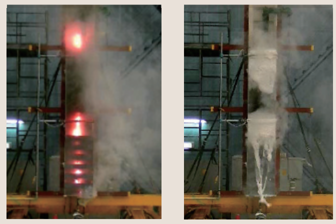
[Extinguishing principle]



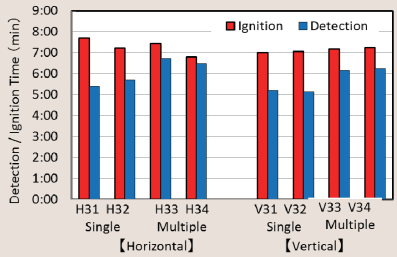
[Cross section of inflammable low voltage power cable]

Fig. 1: Example of an automatic foam fire extinguishing system for cable tray fires

An automatic foam fire extinguishing system is composed of a fire extinguishing agent cylinder, driving nitrogen cylinder, detection line, pipe and nozzle for agent injection, fire receiver etc. Foam suppression agent will be injected through the nozzles into the designated fire area and induce cooling and suffocation. Immediately after the short circuit of the detection cable at the activation temperature 90℃, the fire detection signal will be transferred to the fire receiver, and the fire extinguishing agent cylinder will be activated automatically. The allowable temperature is 90℃ for the continuous condition and 230℃ for the short-circuit condition for the inflammable low voltage power cable used in the fire tests (600 V, 100 mm^2, single core).



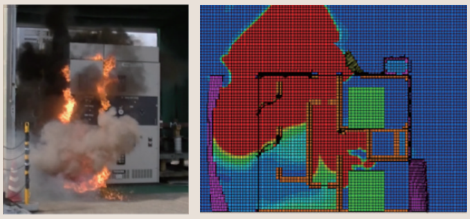
[Combustion after ignition and Operating conditions of foam fire extinguishing equipment]



[Comparison between ignition and detection time]

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

We confirmed that abnormal temperature conditions could be detected before the ignition in horizontal and vertical orientations by the S-shaped detection lines installed inside the cable tray. In addition, in the case of the horizontal cable tray, the foam suppression agent remained uniformly inside cable tray and succeeded in immediate suppression after injection. Similarly, in the case of the vertical cable tray, by the use of steel thin plates at intervals of 20 cm inside the steel cover attached to the cable tray, we verified the retention condition of the foam agent in the tray and its suppression capability.



[Examples of HEAF test with low voltage cabinet and simulation for zone of influence]

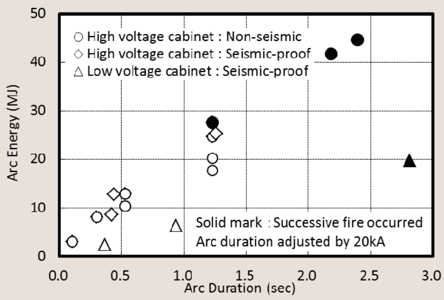
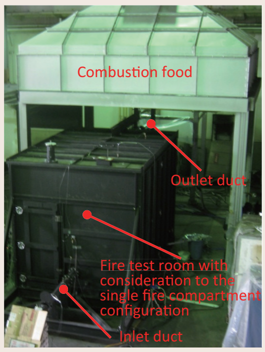
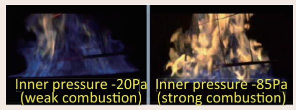


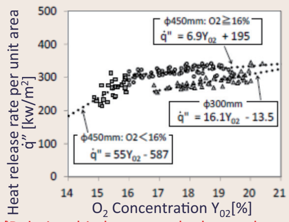
Fig. 3: Arcing energy measured in HEAF tests using low-voltage electric cabinets and the limitations of fire occurrence

We measured arcing energy* using 480 V class electric cabinets (three-phase three-wire system) under a condition with short circuit current around 20 kA and durations from 0.1 to 3.0 sec. When the arcing energy exceeded 19 MJ, a successive fire was identified on low-voltage electric cabinet with relatively low content volume rather than high-voltage metal-clad switch gear (executed in 2013).

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







[Relationship between the heat release rate and the amount of oxygen]

Fig. 4: Identification of heat release rate in a compartment under ventilation conditions

As the fire model gives spatial distributions of physical quantities, such as temperature, velocity, oxygen concentration, as well as their temporal variations, its output values are highly dependent on heat release rate and air ventilation rate. In order to clarify such a dependency, we executed pool fire tests with ethanol in a fire test room (width 2.4 m×Depth 3.6 m×height 2.4 m) with consideration to the single fire compartment configuration. As test parameters, various heat source areas (diameter 30, 45, 60 cm), locations (central), ventilation flows (0-100 m^3/h) and the disposition of the ducts were used. We measured room temperature, inner pressure, heat flux to wall or ceiling, ventilation flow rate, mass loss rate and gas species (O_2, CO_2, CO). Moreover, we analyzed the mechanism of the fire plume and clarified the relationship between the heat release rate and the amount of oxygen entrained by fresh air. In addition, as a result of the fire test analysis by the fire propagation code, it is found that the air temperature in the fire compartment was appropriately predicted.