Priority Subjects — **Establishment of Optimal Risk Management**

Development of Fire Modeling Methodology for Nuclear Power Plant Applications

Background and Objective

The Japanese government aims to revise the fire protection requirement for nuclear power plant applications, and also expects the early implementation of fire hazard evaluation. As the fire protection design code was based on demonstration fire tests conducted in the late eighties, it is necessary to establish a fire hazard analysis methodology which can withstand business licenses and is based on the analysis of overseas data from recent years.

In this project, we aim to integrate the fire modeling methodology for nuclear power plant applications based on the fundamental fire source tests, and demonstrate countermeasures for the anticipated key issues regarding fire protection, such as high energy arcing fault (HEAF) events, which were identified after severe seismic disasters.

Main results

1 Applicability evaluation of fire impact analysis using a fire model FDS

In fire hazard evaluation, it is necessary to estimate the ignition time or damage time of important safety equipment. One representative fire model, FDS (Fire Dynamics Simulator), is suitable for fire hazard evaluation in complicated geometry compartments and detailed evaluation of fire phenomena, although the results greatly depend on numerical conditions. Sensitivity analyses and simulations reproducing existing experiments of fire plumes, fires in a single room and multiple rooms were performed (Fig. 1), showing recommended grid resolutions and fire-source models (N12019). These results contribute to appropriate estimations of equipment ignition time in various fire scenarios and the development of practical and effective fire protection plans.

2 Heat source characteristics of liquid fuel in a compartment under ventilation conditions

An accurate understanding of heat source characteristics, including fire plume and fresh-air entrainment processes, are indispensable in appropriately setting heat release rates in fire simulations, which provide important information for the evaluation of temperature and smoke transport behavior in fire compartments. Fire tests were conducted to firmly grasp the heat source characteristics of liquid fuel (ethanol) in a compartment under ventilation conditions, which mimics a compartment of a nuclear power plant*1. In these tests, the experimental parameters were pool size and ventilation flow rate. The mechanics of heat release rate reduction due to a lack of oxygen in fresh-air was discussed in detail (Fig. 2).

3 Evaluation of HEAF fire using full scale high-voltage metal-enclosed switchgear components

Successive fire due to a HEAF event in a high-voltage metal-clad switch gear*2 was identified at the Onagawa nuclear power plant after the Great East Japan Earthquake. In light of this, we tested full scale high-voltage metal-enclosed switch gear components (non-seismic and non-arc proof type), and evaluated arcing energy and the possibility of successive fire occurrence (Fig. 3). Furthermore, we analyzed details of internal pressure, damage to a metal enclosure and gas emissions from a broken enclosure using CFD (Computational Fluid Dynamics code) code (Fig. 4).

*1 Fire tests were conducted under the cooperative research agreement with the Tokyo University of Science.
*2 Installed in a metal enclosure with a protective relay (circuit breakers, etc.) and a high-voltage bus to protect and control the power system

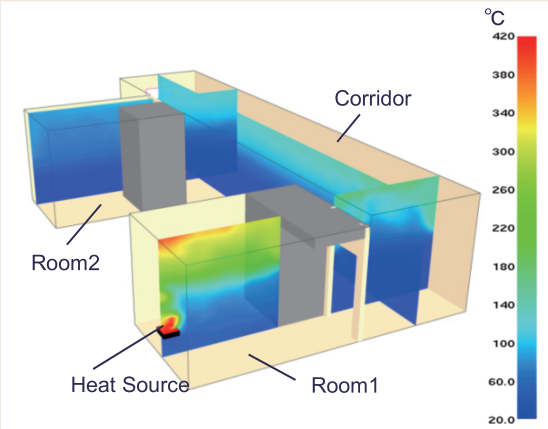

Fig. 1: Example of simulation of multi-room fires using a fire model FDS

In fire impact assessments for fire compartments, it is necessary to set the extent of fire impact and estimate the firing time or injury time of important safety equipment. This requires the rational application of fire models. The fire model "FDS*" gives spatial distributions of physical quantities, such as temperature, velocity, oxygen concentration and their temporal variations. Sensitivity analyses of grid resolution showed that the turbulence intensity of temperature in a fire plume is independent of grid spacing when the grid spacing is smaller than one-twentieth of the flame length scale based on heat release rate.

* A CFD model developed by the 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.

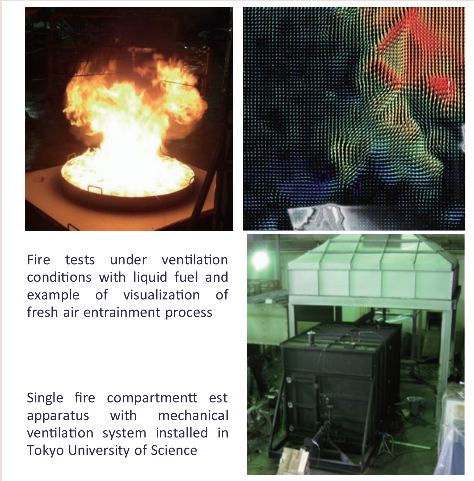

Fig. 2: Heat source characteristics of liquid fuel in a compartment under ventilation conditions

We installed a fire test room (width 2.4m × Depth 3.6m × height 2.4m) with a mechanical ventilation system with consideration to the single fire compartment configuration at the fire test facility located in Tokyo University of Science and initiated a liquid fuel fire with ethanol. As test parameters, various heat source areas (diameter 30, 45, 60cm), locations (central) and ventilation flows (0-100m^3/h) 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 the relationship between the reduced heat release rate and the amount of oxygen entrained by fresh air.

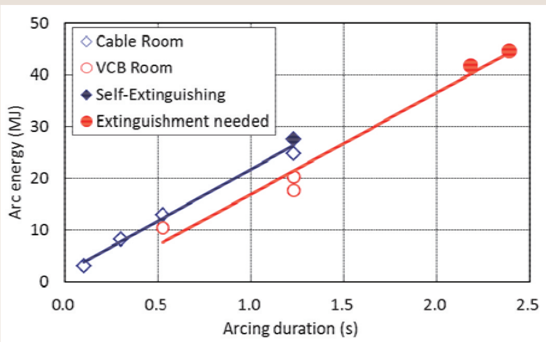

Fig. 3: Ignition conditions between arcing energy and duration measured in the HEAF tests using high-voltage metal-clad switchgears

We measured arcing energy* using a high-voltage metal-clad switchgear (test voltage 7.2kV, three-phase three-wire system, rated withstand current 40kA×2sec, copper bus conductor) in a short-circuit current with 18.9kA and durations of 0.1 to 2.2 sec. When the arcing energy exceeded 25MJ, successive fire was identified. Especially, in the case where the arc flash was discharged in the VCB room, a 2-second arcing duration caused successive fire which required extinguishment.

* 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 the surrounding equipment.

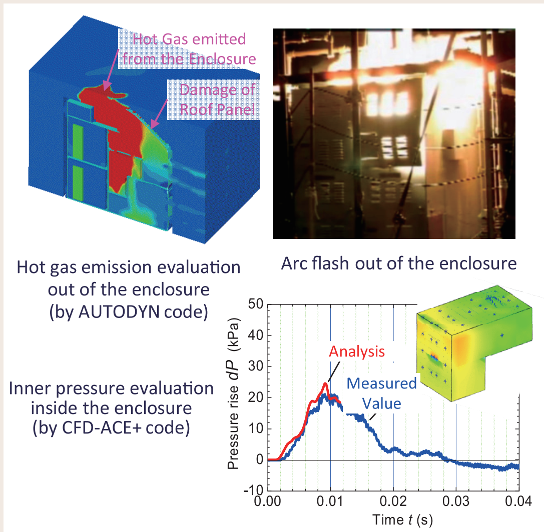

Fig. 4: Estimation of internal pressure and hot gas emission from the damaged enclosure

The arc flash in the upper cable room of the high-voltage metal switchgear heated the air in the enclosure and caused inner pressure. We calculated the pressure rise by using CFD code (CFD ACE+) on the assumption that 53% of measured arcing energy contributes to pressure rise. Results showed that the calculated pressure rise as in good agreement with the measured value. Furthermore, by impact analysis code AUTODYN, we were able to accurately represent propagation of hot gas and damage of the enclosure by modeling compressed gas as an arc flash source which has an energy equivalent energy to 53% measured arcing energy.