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Development of probabilistic risk assessment methodology against extreme snow for sodium-cooled fast reactor

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HIGHLIGHTS

- Snow PRA methodology was developed.
- Snow hazard category was defined as the combination of daily snowfall depth (speed) and snowfall duration.
- Failure probability models of snow removal action, manual operation of the air cooler dampers and the access route were developed.
- Snow PRA showed less than 10^{-6}/reactor-year of core damage frequency.

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ABSTRACT

This paper describes snow probabilistic risk assessment (PRA) methodology development through external hazard and event sequence evaluations mainly in terms of decay heat removal (DHR) function of a sodium-cooled fast reactor (SFR). Using recent 50-year weather data at a typical Japanese SFR site, snow hazard categories were set for the combination of daily snowfall depth (snowfall speed) and snowfall duration which can be calculated by dividing the snow depth by the snowfall speed. For each snow hazard category, the event sequence was evaluated by event trees which consist of several headings representing the loss of DHR. Snow removal action and manual operation of the air cooler dampers were introduced into the event trees as accident managements. Access route failure probability model was also developed for the quantification of the event tree. In this paper, the snow PRA showed less than 10^{-6}/reactor-year of core damage frequency. The dominant snow hazard category was the combination of 1–2 m/day of snowfall speed and 0.5–0.75 day of snowfall duration. Importance and sensitivity analyses indicated a high risk contribution of the securing of the access routes.

1. Introduction

External hazard risk is increasingly being recognized as important for nuclear power plant safety after the Fukushima Daiichi nuclear power station accident. To improve the nuclear plant safety, risk assessment methodologies such as a probabilistic risk assessment (PRA) methodology are necessary against various external hazards. In Japan, the PRA methodology against an earthquake has been developed as a priority because of the importance of consequences of an earthquake. Based on research and development (R&D) activities, the Atomic Energy Society of Japan (AESJ) published a seismic PRA standard (AESJ, 2007), and after the Fukushima Daiichi accident caused by tsunami, the AESJ vigorously developed a tsunami PRA standard (AESJ, 2012) as an important issue. Other than these two external hazards, there are no PRA standards against various external hazards in Japan. An alternative methodology different from the PRA, so called stress tests (ENSREG, 2012), was developed in Europe for complementary safety assessments, which is useful to evaluate a margin to core damage against earthquake and flood. Since challenging tasks in external PRA methodologies are quantitative external hazard evaluation, the stress test methodology would be useful and effective to suggest safety measures and accident managements that extend margins to core damage against the external hazards.

In response to the background, it is necessary for the Japanese electric utilities to verify the effectiveness of safety improvement measures for their light water reactors (LWRs) based on comprehensive risk assessments utilizing PRA and other methods. Safety measures would be implemented against natural disasters including large earthquakes, massive tsunamis and tornados as well as other events with low frequency, leading potentially to

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large consequences. In the interest of providing the R&D, the Nuclear Risk Research Center has been recently established in the Central Research Institute of Electric Power Industry (CRIEPI, 2014).

Before the establishment of this research center, a four-year research project has been started in Japan Atomic Energy Agency in 2012 in order to develop the margin assessment methodology against external hazards as well as PRA. In this project, only the decay heat removal (DHR) function was taken into account assuming no loss of reactor shutdown function such that the reactor trip was successful in the Fukushima Daiichi accident because a long-term cooling is important in case of accidents induced by external hazards. Although lessons learned from the Fukushima Daiichi accident suggest the importance of a spent fuel pool, this study focuses on event sequences resulting in core damage as a first step. The developed methodology is applied mainly to sodium-cooled fast reactors (SFRs), though it would be applicable basically for LWRs.

This study aims mainly at a contribution to the risk assessment and safety improvement of the DHR system of a typical SFR in Japan. Typical SFR heat sink is air, which is different from a heat sink in LWRs. Therefore, it is important external hazards that influence to air coolers (ACs) which are located at high elevation. Air is usually taken not only into the DHR system but also into ventilation and air-conditioning system, emergency power supply system, etc.

The external natural hazards are roughly categorized into three groups: underground, ground-surface, and above-ground hazards. One of the representative underground hazards is earthquake which would have a structural impact on the nuclear power plant. Since significant boundary/component failures might lead to core damage, seismic design with an appropriate design margin to component failure has been preferentially implemented (Yamano et al., 2012). The ground-surface hazards consist of tsunami (sea), flood (river), etc. The tsunami in the Fukushima Daiichi site in Japan and the flood in the Blayais site in France (Mattéi et al., 2001) have given full recognition to the significance of their hazard potential. From this background, nuclear regulatory authorities in many countries strongly require some actions and/or measures against their external hazards. The scope of external hazards in this study is above-ground hazards which might influence the DHR system of an SFR. In this project, the representative external hazards were selected through the screening process, in which a wide variety of external events were screened out in terms of site conditions, impact on plant, progression speed, envelope, frequency, natural hazards and above-ground hazards (Yamano et al., 2014). Consequently, this project selected extreme weathers (snow, tornado, wind and rainfall), volcanic phenomena and forest fire as representative hazards.

In this project, the methodologies of both PRA and margin assessment are developed against each external hazard through the external hazard and event sequence evaluations. It was scheduled to develop the methodologies against snow in the first year, tornado and wind in the second year, rainfall and volcanic eruption in the third year, and forest fire and combination events in the last year. The present paper is intended to develop the PRA methodology against extreme snow, which consists mainly of snow hazard evaluation and event sequence evaluation.

The Fukushima Daiichi accident triggered external events PRA studies. Compared to seismic and flooding PRA studies, however, snow-PRA-related studies are quite limited. One of previous studies focused on the maximum thickness of snow for a hazard intensity (Bareith et al., 2014a, 2014b). They pointed out air-intake blockages, snow removal actions, and so on, as unresolved issues. Such issues are taken into consideration in the present study, as well as two-parameters consisting of snowfall speed and duration for the snow hazard intensity, which will be described below.

2. Snow hazard evaluation

2.1. Collection of historical records of annual maximum data of snow

In Japan, snow data is recorded at representative local offices of the Japan Meteorological Agency (JMA). Near the typical SFR site, a local weather observatory measures and collects various weather data including snow at the Japan Sea side, central area in Japan. This study used snow data of 50 years from 1961 to 2010 based on the JMA database (JMA, 2011a). Historical records are plotted in terms of the annual maximum snow depth and the annual maximum daily snowfall depth in Fig. 1. At maximum, the annual maximum snow depth and the annual maximum daily snowfall depth are 1.96 m and 0.78 m/day, respectively. The snow depth has tended to decrease since 1980. As shown in Fig. 2, the heavier the daily snowfall is, the deeper the snow depth is. Scattering, however, is large in the deeper regions. In other words, duration of heavy daily snowfall is not always continuously long, so that the snowfall duration is important in the hazard evaluation.

2.2. Snow hazard evaluation methodology

In this study, a snow hazard evaluation methodology was developed as described in Fig. 3 based on a probabilistic precipitation estimation methodology proposed by the JMA (JMA, 2011b). A basic concept of this methodology is a generalized estimation

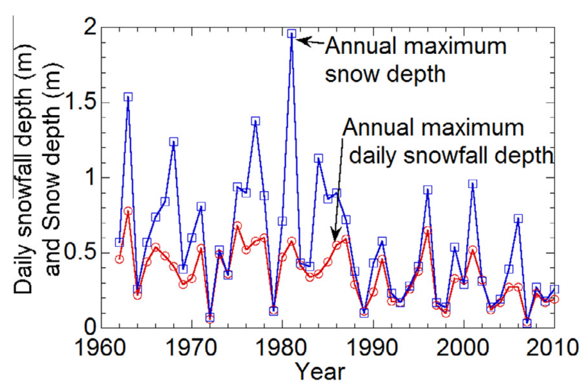

Fig. 1. Historical records of annual maximum data of daily snowfall depth and snow depth.

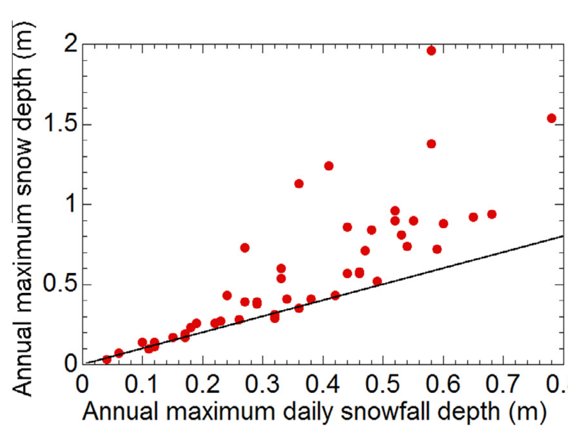

Fig. 2. Correlation of annual maximum data of daily snowfall depth and snow depth.