Case Studies in Fire Safety 4 (2015) 1–10

Contents lists available at ScienceDirect

Case Studies in Fire Safety

journal homepage: www.elsevier.com/locate/csfs

Short communication

Forest fire propagation simulations for a risk assessment methodology development for a nuclear power plant

Yasushi Okano *, Hidemasa Yamano

Japan Atomic Energy Agency, 4002, Narita, Oarai, Ibaraki 311-1393, Japan

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form 28 May 2015
Accepted 28 May 2015
Available online 29 June 2015

Keywords:
Forest fire
External hazard
Nuclear power plant
Risk assessment
Forest fire propagation simulation
FARSITE

ABSTRACT

After the Fukushima Daiichi nuclear power plant [NPP] accident, there has been an increased concern with the safety of NPPs in terms of external hazards, one of which is a forest fire which can create potential challenges to safety functions and the structural integrity of an NPP. As a part of the development of a risk assessment methodology for forest fires as an external hazard, forest fire propagation simulations have been performed by using the FARSITE simulator. These simulations have been used to evaluate two intensity parameters (i.e. fireline intensity and reaction intensity) and three other key parameters (i.e. flame length, rate-of-spread, and forest fire arrival time) which are related to "heat" and "flame" effects on an NPP. Sensitivity analyses for a wide range of weather conditions were performed in order to identify the variable ranges of the intensity and other key parameters. The location studied was selected from among areas with typical topographical and vegetation surrounding NPPs in Japan. The NPP is facing the sea and surrounded by hills, distanced from an urban area, with mostly broad leaf forests, several paddy fields and a few pasture areas.

Low-to-high frequency weather conditions have been utilized in this analysis; forest fire propagation simulations were performed "with/without prevailing wind" (i.e. 0–24 m/s wind speed) and "high/low values for ambient temperature and relative humidity" (−4.3 to 37 °C and 5–99%, respectively) according to the recorded data ranges for the typical NPP site. The maximum values of fireline intensity and rate-of-spread are 4.7×10^2 kW/m and 2.4 m/min and they depend very much on prevailing wind speed and relative humidity (around 2.3 and 1.8 times respectively) but less on ambient temperature (around 1.1 times). Reaction intensity and flame length change within relatively narrow ranges (around 1.7 and 1.5 times respectively) even for all the variation in weather parameters. The forest fire arrival time at the site is reduced by a factor of 5 with changing prevailing wind speed from the recorded-highest to zero. The arrival time increases some 3.4 times with the highest humidity compared to the recorded-lowest conditions, although it is changed little even by varying ambient temperature.

Given that this study shows that the maximum height of a flame on a canopy top is close to the range of power line height, a loss of offsite power is recognized as a possible subsequent event during a forest fire.

* Corresponding author.
E-mail addresses: okano.yasushi@jaea.go.jp (Y. Okano), yamano.hidemasa@jaea.go.jp (H. Yamano).

http://dx.doi.org/10.1016/j.csfs.2015.05.001

1. Introduction

The safety of a nuclear power plant [NPP] is ensured by continuous improvement in the safety approach through obtaining up-to-date operational experience and technical knowledge. After the Fukushima Daiichi NPP accident [1], there has been an increased concern with the safety and exposure of NPPs to external hazards [2], one of which is a forest fire. Conventional safety assessments of a forest fire have been performed in a conservative manner through application of typical deterministic envelope methods and boundary conditions. A new methodology for a risk assessment of a forest fire on an NPP is being developed [3] based on a probabilistic risk assessment methodology as an effective technique for qualitative evaluation of occurrence frequency and corresponding consequence analysis as a result of exposures of NPPs to various hazards.

The new methodology consists of two parts; the first one is a hazard assessment to obtain a "hazard curve" of fireline intensity and reaction intensity due a forest fire [4], and the second one is an event sequence analysis to obtain plant damage frequency due to the challenges by such a forest fire. For these assessments, it is necessary to clarify what phenomena of a forest fire might become challenges to an NPP and what intensities and parameters correspond to the challenges, which is the purpose of this paper. According to the existing deterministic assessments of effects on an NPP by an external fire [5] and by a wild fire [6], "fireline intensity" and "reaction intensity" are mainly considered as the important quantitative indexes.

In this study, physical phenomena related to a forest fire were analyzed in relation to the potential impacts on an NPP in order to identify "intensity" and key parameters especially related to "heat" and "flame" which may potentially have an effect on the NPP and to the external electrical power supply of the NPP. Forest fire simulations were performed for a range of typical NPP site conditions, and the strength values of the intensity and other key parameters were evaluated.

The FARSITE (Fire Area Simulator) software [7] was utilized for the forest fire propagation simulations in this study because of its wide applicability in relation to forest fire management and firefighting actions. However, the most applications of FARSITE have been related to vegetation, topographical and weather conditions of North America [8] and Europe [9,10]. These conditions are different to those in Japan (e.g. humid subtropical climate with rainy and typhoon seasons, wide areas of deciduous tree forest and paddy fields, and mountains/hills near to the seashore). As a result the database needed for FARSITE simulations was consolidated as part of this study.

The FARSITE simulations were performed on a reference condition of high ambient temperature [AT] and low relative humidity [RH] without a prevailing wind. A possible subsequent event important to NPP safety in relation to power line exposure was investigated as well. The sensitivity analysis was performed with changing weather parameters and forest fire breakout points in order to evaluate the range in variation of the forest fire intensity and the other key parameters of flame length, rate-of-fire spread [ROS] and forest fire arrival time.

2. General analysis of forest fire challenges to a power plant

2.1. Forest fire physical phenomena and potential challenges to a power plant

Physical phenomena during a forest fire spread [11] are raised by heat, flame, smoke and flying sparks (otherwise called embers or fire brands). The relation between the physical phenomena, forest fire intensity and these key parameters, resulting in possible consequential effects and potential challenges to an NPP are summarized in Fig. 1. This paper

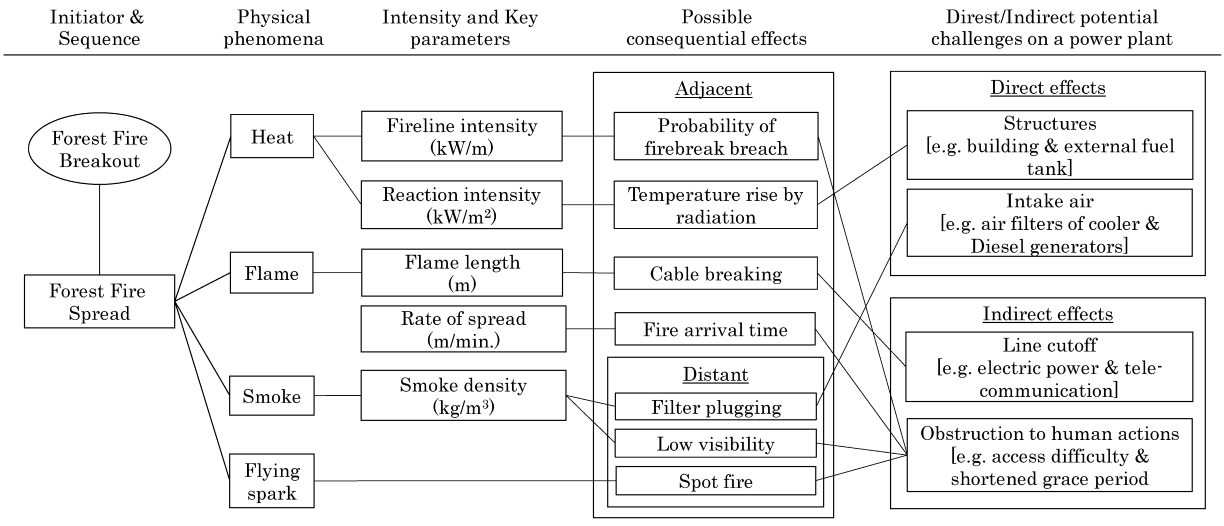

Fig. 1. Forest fire related physical phenomena, intensity and key parameters, possible consequences and potential challenges to a power plant.