Progress in Nuclear Energy 110 (2019) 34–40

Contents lists available at ScienceDirect

Progress in Nuclear Energy

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

Consequence analysis of a transportation accident of radioactive spent resin waste from a heavy water-cooled reactor to a the Gyeongju radioactive waste disposal facility

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ARTICLE INFO

Keywords:
Spent resin
Radiological accident
Dose assessment
Transportation
Radioactive waste

ABSTRACT

Radiological assessments of hypothetical accidents resulting in the dispersion of radioactive material are needed to ensure the safety of the public, especially during the transport of waste to disposal facilities. Therefore, a radiological impact assessment was conducted, assessing a hypothetical accident near the Wolsong receiving area during the transportation of radioactive spent resin waste from a heavy water-cooled reactor to the Gyeongju disposal facility. The HotSpot Health Physics code was used in this case study. It Because of the variability in transportation conditions, eight accident scenarios were considered based on waste type (cement solidification and dry spent resin), waste activity (low and intermediate level waste), and accident severity (1% or 10% radionuclide release). From the results, the form of the radioactive waste was the most important factor in determining the total effective dose equivalent (TEDE), because the aerosol fractions of dispersed radionuclides differed among the radioactive waste forms. Among the scenarios, the 10% release fraction and radioactive waste of dry spent resin scenario resulted in the highest TEDE of 1.4E-3 Sv within 10 min of exposure at a distance of 0.03 km, which was higher than the 1E-3 Sv/year dose limit for the public. A radiological impact assessment of spent resin waste transportation for the public was completed based on the specific scenarios.

1. Introduction

Radiological assessments of hypothetical accidents causing the dispersion of radioactive material are needed to support the safety of the public. A number of studies have performed radiological impact assessments of the dispersion of radioactive material from nuclear power plants (Birikorang et al., 2015; Cao et al., 2016; Muswema et al., 2014; Pirouzmand et al., 2015; Raza and Iqbal, 2005). In addition, assessments of the transportation of radioactive material are needed to analyze the safety of transportation (Bolat and Yongxing, 2013; Jeong et al., 2016). Because radioactive materials are dispersed through the environment in various matrixes, such as air, radionuclide dispersion can be calculated using a dispersion model, such as the Gaussian plume model used for short distances, which simulates radionuclides transport in the air using the Gaussian distribution for vertical and horizontal dispersion. The HotSpot code was used in this work to implement this plume model. It was developed by the Lawrence Livermore National Laboratory to estimate the radiation effects from the atmospheric release of radioactive materials (Hotmann and Fernando, 2013).

In South Korea, some radioactive waste are transported to the Gyeongju radioactive waste disposal facility via the sea. Such radioactive waste are loaded on cargo ships from nuclear facilities to the Wolsong receiving area, located at about 1.8 km from the Gyeongju radioactive waste disposal facility. From the Wolsong receiving area, the radioactive wastes reach their final destination (Fig. 1).

Large amounts of radioactive waste pass through the Wolsong receiving area. For example, 1000 drums can be transported per marine shipment and then 20 trucks with 50-drum capacities are needed for subsequent transport by land. In addition, various types of radioactive waste pass through this area, including all the wastes from different power plants within the country. Because of these activities, radiological assessment of radioactive waste transportation at the Wolsong receiving area to the Gyeongju radioactive waste disposal facility is needed. There are several codes for radiological risk assessment. In the case of RADTRAN, it is possible to set accident scenarios by fire accident as well as impact accident and to assess accident scenarios by effective dose to the human body rather than atmospheric dispersion (Jeong et al., 2016). INTERTRAN can set various accident scenarios

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https://doi.org/10.1016/j.pnucene.2018.09.007
Received 11 February 2018; Received in revised form 15 July 2018; Accepted 10 September 2018

Fig. 1. Transportation route and hypothetical accident point (Red and blue dotted lines: transportation routes by truck). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

such as shipment model, vehicle transportation model, accident classification model, material dispersion model, and population density model. RISKIND can be used to assess accident scenarios by exposure to neutrons and gamma rays (International Atomic Energy Agency, 2017a, 2017b). In the case of the HotSpot code, accident scenarios are set according to the type of atmospheric dispersion model rather than type of accident, and accident scenarios are assessed by the total effective dose equivalent according to distance. Therefore, as in this study, it is suitable for accident scenarios where the risk is assessed according to the TEDE at a certain distance. In this study, hypothetical accidents of various types of radioactive waste should be considered based on the atmospheric dispersion model of the HotSpot Health Physics code. HotSpot can set up various atmospheric dispersion models according to the type of accident.

The Wolsong nuclear power plant is a heavy water reactor that uses ion exchange resins to treat Spent resin is stored in a storage tank at the power plant, with a storage capacity of 354.9 m^3. However, disposal of spent resin will be necessary in the future, because the total storage amount is expected to be saturated within 10 years. Many radionuclides exist in spent resin, such as ^{14}C, ^{60}Co, and ^{137}Cs. In particular, ^{14}C is a long-lived nuclide with a half-life of 5730 years and exerts biological effects through carbon metabolism reactions from internal exposure via respiration and ingestion. Since these nuclides can affect human health over a long period of time, safety evaluations considering atmospheric diffusion are necessary.

In this study, a radiological assessment of transportation of radioactive spent resin waste from a heavy water-cooled reactor from the Wolsong receiving area to the Gyeongju disposal facility was performed under various scenarios. The radiological impact of the accident scenarios was estimated with the HotSpot code to determine the total effective doses equivalent (TEDE) based on the effective doses from ground shine, inhalation, and cloud shine.

2. Materials and methods

2.1. Dose calculation code

In the case of a radiological accident, radionuclides are dispersed and can affect anyone who is exposed. Radionuclides can be dispersed in the air and further deposited on the ground, and then can enter the body via inhalation. The HotSpot Health Physics code version 3.0.3, which implements the general Gaussian plume model, was used to perform the atmospheric dispersion modelling and dose calculations. The Following equation is the basis of the Gaussian plume equation (Hotmann and Fernando, 2013).

$$C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z L u} exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \left\{exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}\exp\left[-\frac{\lambda x}{u}\right]DF(x)$$

C = Time-integrated atmospheric concentration (Ci-s)/(m^3).
Q = Source term (Ci).
H = Effective release height (m).
λ = Radioactive decay constant (s^{-1}).
x = Downwind distance (m).
y = Crosswind distance (m).
z = Vertical axis distance (m).
σ_y = Standard deviation of the integrated concentration distribution in the crosswind direction (m).
σ_z = Standard deviation of the integrated concentration distribution in the vertical direction (m).
u = Average wind speed at the effective release height (m/s).
L = Inversion layer height (m).
DF(x) = Plume Depletion factor

By the Gaussian plume equation, the radionuclides are dispersed as in Fig. 2. Fig. 2 shows the HotSpot coordinate system according to the Gaussian plume equation (Hotmann and Fernando., 2013).

Based on this abovementioned equation, radionuclide concentrations can be calculated, from which it is possible to perform dose calculations. Three main exposure pathways can be derived based on the dispersion model, as shown in Fig. 3.

3. In this study, the cloud shine, inhalation, ground shine, and resuspension exposure pathways were considered for dose calculations. Standard terrain conditions were considered as the conservative option because the source location was the point between the Wolsong

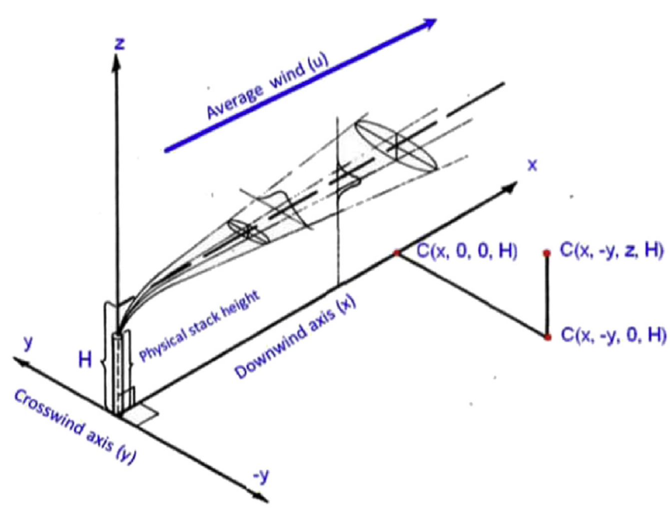

Fig. 2. The HotSpot coordinate system.