

Simulation and calculation of power plant accidents doses using HotSpot software

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Abstract

Various factors affect the release of radioactive materials in the power plant events including event types, wind speed, air temperature, and so on. In this study, a new model was developed using HotSpot software for calculating doses at different intervals from the site of the incident, and then, this model was simulated and validated using MCNPX simulator code. Moreover, effective intervals of the dose caused by each radioisotope were measured. The results showed that calculations for determination of doses at different intervals can be obtained using simulation, and as a result, components and other parameters such as buildings or facilities can be added to the simulator and the doses were calculated in those cases.

Keywords: HotSpot Software; MCNPX; nuclear power plant accidents; effective radius.

Introduction

When the damage to the heart of the reactor occurs, there may be different release scenarios that, in each of these scenarios, the release of radioactive material into a variety of environments will be different. In general, the types of events that lead to damage to the reactor's heart in power reactors include 1- Early release 2- Bypass of containment 3- Late release 4- No containment failure. It is assumed that the incidence is the first type as Chernobyl accident, and this accident could be the worst accident that resulted in the highest amount of radioactive material release and consequently the greatest

radiobiological consequences [1-5]. There are main and important factors that determine the rate and severity of release [6]. However, there are several numbers of radionucleotides contribute a great role in the possible incident. The frequency of different types of radioactive nucleotides in a reactor depends on various factors including the frequency of radio nucleotides in the heart, the release to the environment, the behavior of radio nucleotides in the environment, and the radiobiological effects of each radionucleotide. In the present research, the contents of a 1,000 Mega Watt reactor in the middle of a fuel cycle have been considered. For reactors with

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different power, the core inventory has a direct relation to the reactor's heat output [7-9].

HotSpot software

The HotSpot Health Physics codes were provided for the United States government and created to provide Health Physics personnel with a fast, field-portable calculational tool for evaluating accidents involving radioactive materials. There is no limit to use the HotSpot health physics code; the HotSpot program shows approximately the radiation effects of the released materials in space. This program is used to respond quickly to individuals and authorities in events of radioactive materials. Moreover, this program can be used to analyze the effects of radioactive materials. One of

the most important uses of HotSpot software is the calculation of dose distribution at various intervals using Gaussian distribution models based on particle size, release height, air stability, precipitation, and so on [10,11].

Experimental

This study was approved by our local ethics committee. There are various categories for calculating and evaluating the dose and their effects respectively. Classification of radioisotopes is also important because radioisotopes with close energies produce the same dose in the human body. The gamma energy of each radioactive material with the weight percentage of released gamma is shown in Figure 1.

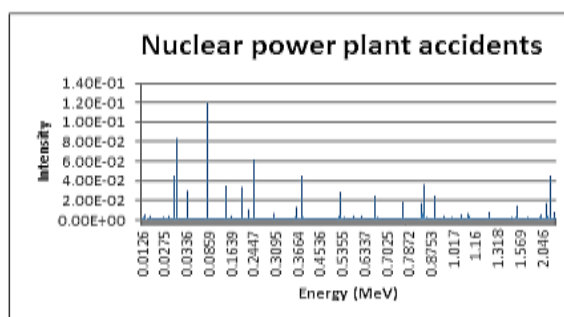


Figure 1. Gamma energy of output materials of a light water atomic power plant

Thus, the source term of a nuclear power plant can be written based on the radiation's percent of each energy in the MCNP code [12,13]. A regular framework based on the definitions of the ICRU dose calculation has been discussed for validation. Considering the problems of practical measurement for radioactive distribution and the elimination of contamination, different methods were evaluated and, particularly, the HotSpot standard software which is used in measurements and calculations of dose and distribution of radioactive substances and radioisotopes was proposed. The radioisotope energy is

the most important factor in determining the simulation radius. For each radioisotope at different intervals (in two ground deposition and suspended particles), the dose was calculated and the dose curve was validated according to the distance with HotSpot software. According to the validation of HotSpot software, the software was used in two stages. In this report, HotSpot 2.07.2 version (the latest version of this software) has been used to validate different sources in the first step, and to determine the distribution of radioisotopes at different distances in the next step [10]. As the distance is the most important method

of protection against radiation, the dosage of a radioactive substance is very small in very far distances. However, in calculating the volume of the radioisotope around the phantom, in addition to the exponential increase in

$$[S] = \text{Mev/g/cm}^{-2}$$

The purpose of determining the mass stopping power is to determine the distance in which the particle is stopped statistically. Different radioisotopes have different mass stopping coefficients depending on the energy and type of radioactive particles (alpha, beta, gamma) [19-21]. Therefore, the most important factor in determining the radius of simulation is the radioisotope energy and the type of particles. So, the dose should be calculated for each radioisotope at different intervals (in two different ground deposition and suspended particles), and the dose curve should be validated according to the distance with the HotSpot software [22,23].

To determine the radius of simulation, an effective radius and the concentration of radioactivity should be considered uniformly in the range of effective radius. The basic assumption used in determining the simulation radius was that the dose of radioisotopes outside the mass stopping power range as the maximum particle range would be approximately zero, and if the environment was uniformly assumed, this range would be equal to the mean distance of the particle. This average distance is different in the case of atomic loss and ground deposition. This method is completely new [24,25].

Suspended particles, as well as ground deposition caused by atomic loss, are dependent on various factors such as distance from explosion place

the calculation time, an error is generated with a third power of distance. The linear rate of energy loss divided by the adsorbent density equals with mass stopping power [14-18].

$$S = \frac{dE/dx}{\rho}$$

or accident place, wind speed, release height, air stability, rainfall, and solar radiation. Here, using HotSpot software at the determined intervals and in two different weather conditions, the activity rate was calculated and used to determine the source [26,27].

Results and discussion

The total mass attenuation coefficient for each element can be defined using the sum of the mass attenuation coefficients of all collisions caused by probabilities of the photon collision to the atom and can be obtained from the available tables for each energy. Collision coefficients in a substance composed of a mixture or a combination of several elements can be calculated using the coefficients of the collision of their constituent elements. The distance, which is statistically passed by the photons in the air to reach a complete stop, can be calculated using the mass stopping coefficient. Therefore, the dose of radioisotopes will be zero far away from an effective radius [28]. The effective radius of several radioisotopes has been calculated (Table 1) [29]. The theory of mass stopping power must be used to calculate the effective radius of the atomic loss. In the nuclear loss, calculations of the maximum range of particles in the air are a little more complex than before. Also, the effective radius was used to calculate the amounts obtained in the ground deposition mode. However, a

coefficient of 1.3 must be applied to correct the error caused by the particle range. In other words, the maximum range of particles will be divided into three to obtain the simulation radius. For this reason, these values were calculated for some radioisotopes in different energies and compared with the HotSpot software to confirm the accuracy of the dose obtained in the range of radioisotope energies provided by the presented scenarios and to be used for next steps (Table 2). As noted above, in the power plant events, we will have a dispersion of radioactive materials in the surrounding area. As the number of depositions and falls are different by changing the height of

material dispersion, in this project, it is assumed that the power plant starts to spread materials on the ground. In these incidents, a set of radioactive materials is a dispersion in space that calculation can be performed according to available data of radioisotopes activity (Table 3).

In this research, it was tried to present the results with acceptable accuracy. To do this target, many simulations were repeated several times or evaluated in a variety of ways [30]. One of the problems in this project was the long-time simulations and many answers for different situations that only the final answer was given in this study.

Table 1. Effective radiation dose due to several gamma radiation radionuclides

Radioisotope	$\frac{1}{\mu \cdot \rho} \text{ cm}$
Co-60	13545
Cu-60	11495

Table 2. Calculation of atomic loss in the range of effective radius

Radioisotope	Diameter Cm	Volume (cm ³)	Dose MCNP (Sv.m ² /BqSec)	Dose HotSpot (Sv.m ² /BqSec)	Error%
Co-60	4470	1.87e11	1.06e-13	1.26e-13	15.9
Tc-99m	1880	1.39e10	5.29e-15	5.89e-15	-10.2
I-131	2607	3.71e10	1.95e-14	1.82e-14	7.14
Cs-137	3330	7.73e4	3.26e-14	2.73e-14	19.6
I-133	3000	5.65e4	3.38e-14	2.94e-14	14.9

Table 3. Calculation of the dose resulting from power plant events at different intervals

Distance from the site of the accident (km)	Dose rate caused by the dispersion On a sunny day (Sv/Sec)	Dose rate caused by the ground deposition On a sunny day (Sv/Sec)	Dose rate caused by the dispersion at night (Sv/Sec)	Dose rate caused by the ground deposition at night (Sv/Sec)
1	6.11819E-05	5.29405E-05	0.000899684	0.000647722
2	1.27969E-05	9.55764E-06	8.17772E-05	5.97293E-05
4	2.44589E-06	1.72158E-06	5.24711E-06	4.80819E-06
6	8.51851E-07	6.92912E-07	7.5947E-07	9.37101E-07
8	3.99606E-07	3.53659E-07	2.53986E-07	3.15122E-07
10	2.21666E-07	2.10759E-07	1.00614E-07	1.38016E-07
20	3.64673E-08	4.81223E-08	6.9724E-10	1.1488E-09

40	7.57424E-09	1.20153E-08	3.21447E-13	6.62485E-13
60	3.26648E-09	5.48297E-09	3.2573E-16	7.00011E-16

The dose rate caused by the dispersion is about 10,000 times greater than the dose caused by the ground deposition. This issue must be discussed more. Moreover, the amount of doses in the weather conditions of the night is more than that of the sunny condition. Considering the presence of individuals and personnel or ordinary people at different distances, it seems that it is possible to determine the security boundaries for each category and the time of the presence of persons in these borders. However, in each incident, depending on the type and probability of leakage and the release of radioactive substances in the environment, the safe distance from the accident center can be calculated separately. As described in the introduction, HotSpot software considers different conditions and factors in computing dose and in fact provides a model for the distribution of activity and doses in the environment [31].

Conclusion

In this study, we simulated successfully this calculation and model with the MCNPX simulator. Therefore, we will be able to use it in any program whose purpose is to simulate and calculate the dose more accurately.

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Competing interest

The authors declare that they have no competing interests.

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