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2020 Tokyo Summer Olympic Games' Radiological Guard by Multiple-Barrier Extension Using Atmospheric Dispersions: Introduction of 'Natural-Barrier' Concept

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1. Introduction

It is very important to protect humans from the hazardous radiations that resulted, and are still a threat, from past severe nuclear accidents, such as the Fukushima and Chernobyl disasters. Especially in Fukushima, the Tokyo 2020 Olympic Games will be held in proximity to the site [1]. Even though most of the games will be held near Tokyo city, the Fukushima Azuma Baseball Stadium and the Miyagi Stadium (Fig. 1) are closer to the site of the accident, and will most certainly host baseball, softball, and football games [2]. The most common nuclear safety systems employ a multiple-barrier approach, where multiple protection shields are layered from the nuclear fuel to the reactor building. Therefore, it is highly necessary to investigate much more effective systems to block the exposure of contaminated material to the environment, including humans. To maintain the integrity of the environment around a NPP is a crucial matter after a nuclear accident, where the dispersion of radioactive material in the atmosphere can contaminate the facilities nearby, and cause direct lethal effects in humans by direct inhalation. In this study, it is investigated for an effective radiological protection system, inspired by the conventional multiple-barrier concept, and evaluated its efficacy in the case of a potential nuclear accident. In addition, it is applied to make use of atmospheric dispersions to protect against the leakage of radioactive materials. Fig. 2 shows a newly modified multiple-barrier system in this work for nuclear safety [3] where an additional barrier system is introduced in which atmospheric air flows are used. In this work, there are five characteristic protecting layers to block the radioactive materials that can potentially leak from the nuclear fuel. Additionally, it is introduced for an environment-dependent shield with different characteristics depending on whether the plant is near a seashore or in the inland. In the geosphere, the natural barrier provided by rocks can be employed as a defense layer against underground water flow or human intrusion [4]. So, it is imagined that the same concept of "natural-barrier" could be extended to the treatment of atmospheric dispersions. As a matter of fact, it has been proven that, in the case of the Fukushima NPP accident, the significant air flow around the plant contributed to the diffusion of leaked material [4-6]. However, there are also many other NPPs on seashores around the world, and the accurate consideration of the atmospheric dispersions in such environments following a leak is a crucial aspect when planning safety systems [4-10].

2. Methods

In the modeling, the natural conditions such as site geological aspect, season and its related wind direction are examined for the nuclear safety issues. So, two kinds of winds are analyzed for the different seasons. The potential accident is an explosion that causes the plant to collapse and the fission products to leak out of the reactor building, which is what had happened in the Fukushima and Chernobyl cases. It is also explained for the site position of the plant, evaluating the difference in the disaster caused by radiological dispersions if the plant is surrounded by land, or in proximity of an ocean. Fig. 3 shows the modelling of atmospheric dispersions inland and near a seashore, where the Chernobyl case is shown as the example of an inland incident, and the Fukushima case as an example of a seashore incident.

For the calculations, both the climate elements and other natural and anthropic factors that determine the concentration of radiological material in the atmosphere are shown in Table I [11]. In order to report the radioactive materials' concentrations, the Gaussian plume dispersion model is used [7], written as follows:

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}e^{-\frac{y^2}{2\sigma_y^2}}\left(e^{-\frac{(z+H)^2}{2\sigma_z^2}}+e^{-\frac{(z-H)^2}{2\sigma_z^2}}\right) \quad (1)$$

where Q (g s^{-1}) is a pollutant's emission rate, u (m s^{-1})is the average wind speed, σ_y and σ_z (m) are the y and z direction plume standard deviation, respectively, x, y and z represent the x, y and z position, respectively, and H (m) is the effective stack height. From this equation, the C is inversely proportional to wind speed and we notice that

$$C \propto \frac{1}{u} \quad (2)$$

The modeling of atmospheric divergent wind is in Fig. 4, in which the higher-pressure zone is located above the body of water. The mathematical form in the divergent case can be expressed as follows [12,13],

$$\frac{1}{\rho}\nabla_H P + f\hat{k}\times V - \frac{1}{\rho}\frac{\partial\tau}{\partial z} = 0 \quad (3)$$

where τ is the surface stress vector, f is the Coriolis parameter, P is the scalar pressure, ρ is the atmospheric density, V is the horizontal velocity vector. In addition, it is also possible to express the horizontal vector velocity as follows [12]:

$$V \propto \frac{1}{D} \quad (4)$$

where D is the depth of planetary boundary layer. Thus, implementing Equation 2, we obtain:

$$C \propto \rho \propto D \quad (5)$$

So, the radiation concentrations are proportional to the radiation dispersions and the depth of planetary boundary layer. Hence, it is analyzed for the Gaussian plume dispersion model and the analysis of divergent wind to obtain a simplified model for the behavior of atmospheric dispersion in the case of divergent wind. Fig. 5 shows the modeling of Rad-Dispersion which is the name of the graph.

In this modeling, it is used for the designed variables which are listed on Fig. 5. The simulations were carried out using the Vensim code system (PLE Windows version 7.2 Single Precision) [14], which is commonly used with regard to scientific and technological problems, as well as in the humanities, owing to its high reliability and optimal performance. The generated random numbers could be used for the variables in the interested systems and designs. Table I reports a list of climate and natural influencing factors that we selected to predict the behavior of an atmosphere containing radioactive materials. The main consideration is that, as the wind quantity is varied, the amount of radioactive materials diffused will vary as well. In cases of sampled quantity generated by random numbers as,

if then else (random 0 1 () < 0.3, 0, 1) (6)

This means that if the random number is lower than 0.3, the value is 0.0. Otherwise, it is 1.0. This is described as Wind1. In addition, the case

if then else (random 0 1 () < 0.7, 0, 1) (7)

is described as Wind2. That is, if the random number is lower than 0.7. the value is 0.0. Otherwise, it is 1.0. This means that the stronger winds are represented by the Wind2 case, because the comparison number, 0.7, is higher than 0.3.

3. Results

There are several simulation results regarding the natural condition consequences as the nuclear safety enhancements. Seasonal wind directions are variable in the Northern Hemisphere due to rotating of the Earth. This causes a new implication suggestion of another safety concept as the natural-barrier in the NPPs. The followings are the results of the simulation of Rad-Dispersion. Table II shows partial information regarding the wind quantity. Fig. 6(a) shows the concentration of the radioactive material, where the values have the highest one in 192^{nd} and then decrease gradually where the unit is dimensionless with the comparative quantity. In this modeling, the values are compared in the interested design for the numeric results. Radioactive dispersion is shown in Fig. 6(b). It can be seen that the two graphs are nearly similar, although the wind quantity is different in two cases. The values are stabilized around the 500.25^{th} day. If one uses the other kind of wind variable reflecting direction, quantity, or site condition, the results could be changeable. Fig. 7(a) shows the new concept of the multiple-barrier system incorporated with the natural-barrier system of season, geological site, Earth rotating, and wind. Fig. 7(b) describes the modeling of systematic symbol for wind motions for the simplified notifications. In winter, the northern wind is very frequent and stronger and otherwise, in summer, the higher air pressure is usually in the south. So, this fact can be used for the protection against radioactive materials. There are proposed three steps of a NPP in this paper which are the conventional multiple-barrier (in-plant), the region, and the shielding to humans. So, the multiple-barrier concept is extended from the conventional multiple-barrier (in-plant) to the shielding to humans.

4. Conclusions

It is very important to manage the dispersion of air contaminated by radioactive material. In the case of the Tokyo 2020 Olympics, due to the large influx of people expected, there is an urgency to ensure that Tokyo city and its vicinities are well shielded against the radiation contaminations that still flow in the air, considering the vast radioactive dispersion areas covered after the Fukushima accident. Therefore, the application of the concept of multiple-barriers, which includes the atmosphere as an additional barrier and also accounts for the characteristics of the environment, is a reasonable method for radiation protection; this is in contrast with only considering the radiation protection principles of distance, time, and shielding. In this study, the atmospheric barrier accounted for the dispersion of pollutants that were transported by the air flow in close proximity to the plant. It is challenged for the cases where the plant was located either near a seashore or on the inland. As it is shown above, the seashore NPP has an advantage to utilize the natural-barrier of atmospheric dispersions. Hence, if our method is applied considering the specific meteorological data in a certain region, the results could be different from the discussions in this study, especially in the Fukushima area. It is shown that the local contamination depends on air-filtering. Therefore, it is reasonable for the winter season when the northern wind is very frequent in the Northern Hemisphere nations. Otherwise, in summer, the higher pressure should be in the south. So, it is helpful for one to use the seasonal wind directions in the nuclear safety concepts. In this regard, natural conditions could contribute to radiological protection systems as part of the multiple-barrier systems in NPPs.

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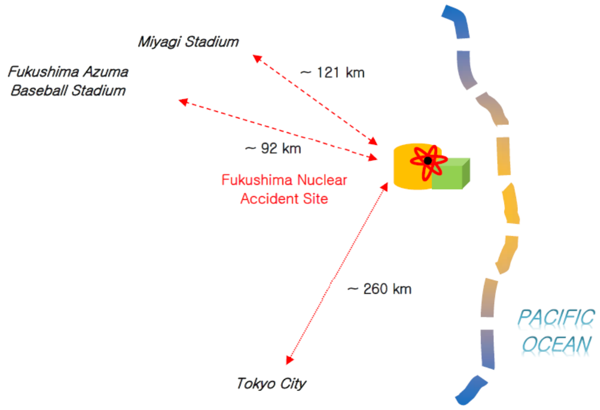


Fig. 1. Distance of two nearer stadiums to Fukushima accident site.

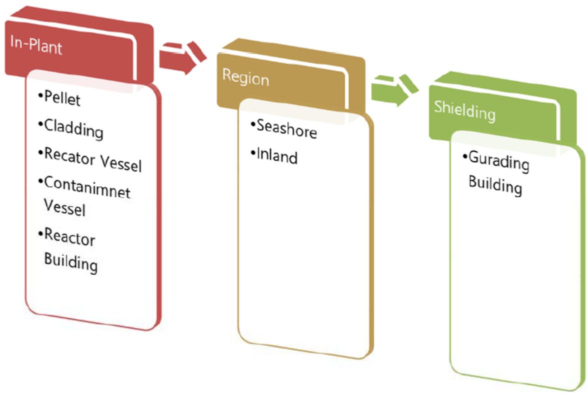


Fig. 2. Another barrier system for multiple-barrier in nuclear safety.

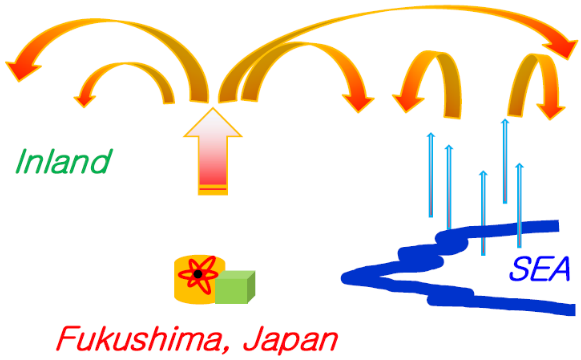


Fig. 3. Modeling of atmospheric dispersion on seashore.

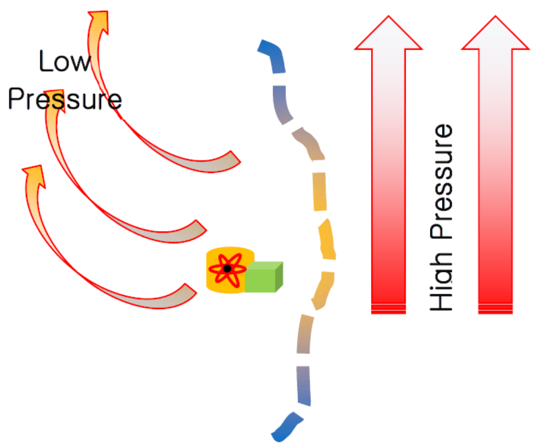


Fig. 4. Modeling of atmospheric divergent wind.

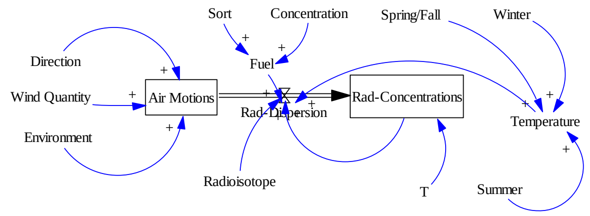
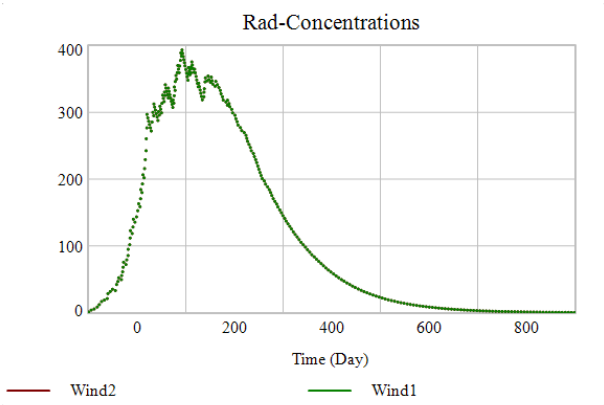
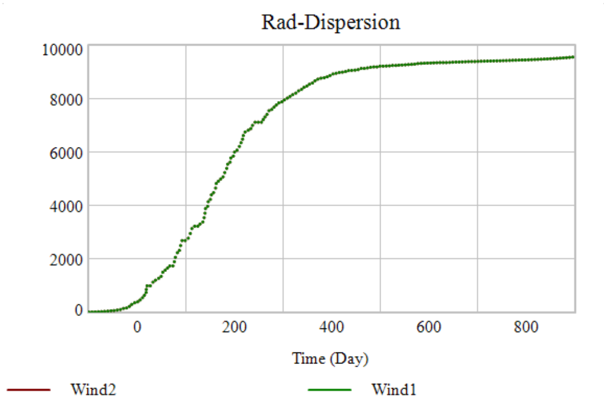


Fig. 5. Modeling of Rad-Dispersion.

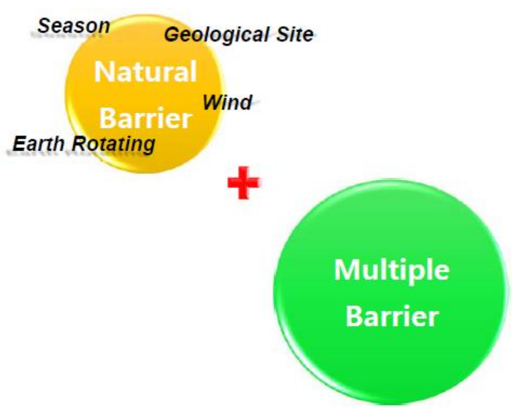


(a)

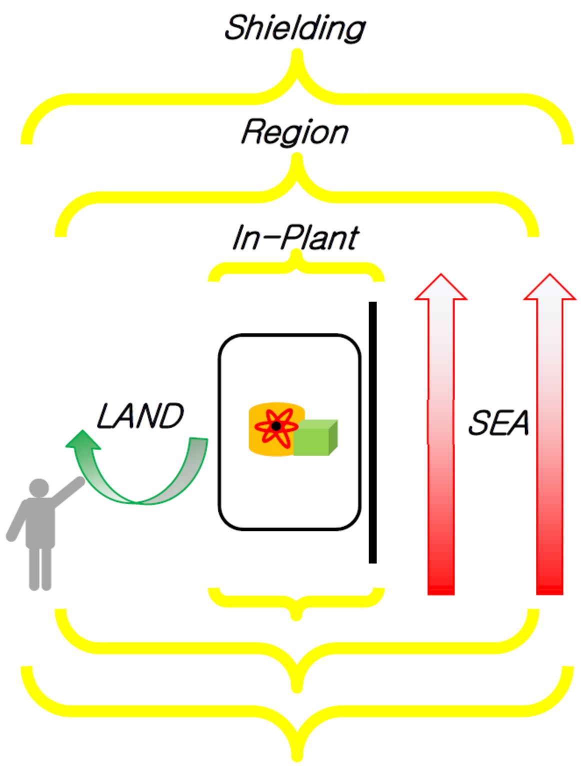


(b)

Fig. 6. Results for simulation of Rad-Dispersion (a) Concentration of radioactive material and (b) Radioactive dispersion.



(a)



(b)

Fig. 7. Configurations of the study (a) New concept of natural-barrier system and (b) Modeling of systematic symbol for wind motions in dispersion case.

Table I: Selected list of climate element

Element	Factor
Precipitation	Current, Geology
Temperature	Latitude, Altitude
Wind	Weather front, Base
Humidity	
Fog	

Table II: A piece of Wind Quantity

Time Step	Wind1	Wind2
0.0	0	0
0.25	1	0
…	…	…
0.75	1	0
1.00	1	1
…	…	…
1000	0	0