Proceedings of the Korean Nuclear Society Spring Meeting
Kori, Korea, May 2000

The Effects of Meteorological Data on Early Health Effects

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ABSTRACT

The influence of meteorological data on early health effects was examined. The meteorological data considered in this study are wind speed, rainfall rate, and atmospheric stability. The results showed that the values of early fatalities and early fatality risk show maximum value at the stable atmospheric condition with low wind speed and heavy rainfall rate. The information obtained through this research will be used in developing scenarios for the risk estimation in order to make strategies for reducing offsite health consequences.

1. Introduction

If a severe accident of nuclear power plant were to proceed to containment failure, radioactive materials would be released to the atmosphere. Should such an accidental release occur, the radioactive materials in the plume while dispersing in the atmosphere would be transported by the prevailing wind. Radioactive materials deposited from the plume would contaminate the environment and the population would be exposed to radiation. Consequences resulting from such an accidental release are early health effects, chronic health effects, and economic impacts.

The potential importance to offsite health and economic consequences of the accidental release from a nuclear power plant is a function of many factors such as source term, weather condition, emergency response scenarios, and so on. Although the unique accident sequence and source term release rate are considered in the consequence analysis, the resulting offsite health effects may be different if the source term release parameters and weather conditions are different. The relative influences of source term release parameters such as release height, heat content of the plume, release time, release duration, and warning time on offsite health consequences were investigated[1]. Also, the health consequences may be different if meteorological data such wind speed, rainfall rate, and atmospheric stability classes are different. Therefore, we examined the relative influence of meteorological data on health consequences. The information obtained through this research will be used in developing scenarios for the risk estimation in order to make strategies for reducing offsite health consequences.

2. Atmospheric Dispersion and Meteorological Data

If a severe nuclear power plant accident were to proceed to containment failure, a fraction of radionuclides in the form of noble gases, halogens, and aerosols would be released to the atmosphere. An assessment of the impact of such releases to the environment and the general public requires the calculation of airborne and ground concentrations of each radionuclide at various distances from the reactor. When released into the atmosphere, radioactive gases and aerosols will follow prevailing winds and be diffused due to atmospheric turbulence. Predictions of dispersion are most commonly made from the Gaussian plume model[2] due to its economy of computing time, simplified input requirements, and reasonable agreement with experimental data over flat terrain. It is also very useful for repetitive calculations and sensitivity studies.

As the plume of radioactive material travel downwind from the reactor, material is removed from the plume by radioactive decay and by deposition onto the ground. Deposition onto the ground is caused by two process: dry deposition due to gravitational settling onto, impaction on, and diffusion to surfaces, and wet deposition due to the scavenging of material by precipitation. Also, the basic dispersion model is usually modified to take account of a number of additional effects such as radioactive decay, the turbulent wake of the reactor building, the broadening of the time-averaged plume as a function of release duration to account for plume meander, mixing layer depth, surface roughness, and plume rise due to the thermal buoyancy of the plume.

Plume rise, dispersion, downwind transport, and deposition onto the ground depend on the prevailing weather conditions such as wind speed, rainfall rate, and atmospheric stability. In most consequence analysis codes, the meteorological data file of the site region is used. This file is usually composed of one year of hourly wind speed, rainfall rate, and atmospheric stability recorded at the site or nearby weather service station. The atmospheric transport models implemented in MACCS[3] require hourly readings of wind speed, rainfall rate, and atmospheric stability as input. For each weather sequence, 120 hours of weather data are required. In addition, four values of the mixing height, one for each season of the year, must also be specified.

The meteorological data of 1992 measured and recorded at the neighboring site tower of the YGN 3&4 nuclear power plants are assumed to be representative for the site. The constant weather conditions are selected among the five ways to specify the required 120 hours of weather data that constitute a weather sequence because it is possible to estimate the variation of health effects due to the change of values of meteorological data.

3. Modeling of Health Effects

The starting point of a consequence assessment is the postulated radionuclide release to the environment, which can be produced by the Level 2 PSA. The quantity and isotopic composition of released radionuclides, together with their physical and chemical characteristics, the heat content of the plume, the time profile of the release, and the release height are known as the source term. Generally, the source term also includes the frequency of the release. Among the various information needed to specify source term, the release height, the heat content of the plume, and time profile of the release are known as source term release parameters.

Source terms used for the calculation of health effects were derived from the Individual Plant Examination(IPE) results[4] and ORIGEN2 code[5]. Usually the source term release data is given as a fraction of the core inventory. Therefore, core inventory data for fission products was derived from ORIGEN2 evaluations. And the release fraction data were derived from the IPE results performed for the reference plants.

According to the study, 19 source term categories (STC) are defined after grouping similar containment failure modes into the same category. The simple parametric mass balance equation used in NUREG-1150 study[6] was applied to obtain source term release fraction rather than performing complicated plant-specific source term code calculation. The calculated source term release fractions are listed in Table 1, which are used to evaluate health effects in conjunction with the MACCS code.

Table 1. Source Term Release Fractions for YGN 3&4 NPPs

Nuclide Group	STC-3	STC-4	STC–6&10	STC-7&11	STC-8&12	STC-1&2&13
Noble Gases	1.0	1.0	1.0	1.0	1.0	0.
Iodine	6.77E-02	2.22E-01	8.01E-03	8.41E-03	2.58E-02	0.
Cesium	8.82E-02	2.23E-01	6.33E-03	1.14E-03	3.36E-02	0.
Tellurium	1.07E-02	3.49E-02	1.71E-03	6.12E-04	3.71E-02	0.
Barium	1.00E-03	3.29E-03	4.31E-03	1.08E-06	1.57E-02	0.
Strontium	7.71E-04	2.52E-03	3.22E-05	8.05E-07	3.87E-03	0.
Ruthenium	1.38E-03	4.51E-03	2.30E-08	5.75E-07	2.30E-05	0.
Lanthanum	4.87E-04	1.59E-03	5.04E-07	1.30E-08	5.04E-07	0.
Cerium	4.88E-04	1.60E-03	7.56E-07	1.90E-08	7.56E-07	0.

Nuclide Group	STC-14	STC-15	STC–16	STC-17	STC-18	STC-19
Noble Gases	1.0	1.0	1.0	1.0	1.0	7.41E-01
Iodine	6.95E-01	1.97E-01	5.02E-03	6.02E-02	3.59E-01	1.13E-01
Cesium	5.85E-01	1.29E-01	3.29E-03	3.95E-02	2.35E-01	9.24E-02
Tellurium	1.96E-01	3.59E-02	9.12E-04	1.09E-02	6.53E-02	9.27E-02
Barium	6.45E-03	1.18E-03	3.01E-05	3.61E-04	2.15E-03	1.46E-03
Strontium	4.02E-03	7.36E-04	1.87E-05	2.24E-04	1.34E-03	1.15E-03
Ruthenium	2.04E-03	3.74E-04	9.52E-06	1.14E-04	6.79E-04	8.21E-04
Lanthanum	1.00E-04	1.83E-05	4.66E-07	5.59E-06	3.33E-05	1.80E-05
Cerium	1.50E-04	2.75E-05	6.99E-07	8.39E-06	4.50E-05	2.55E-05

The MACCS code was used to evaluate health effects resulting from source terms of YGN 3&4 nuclear power plants outlined in Table 1. In MACCS, the dispersion and deposition of radionuclides released from containment building to the atmosphere were modeled with a straight-line Gaussian plume model. Plume rise and dry and wet deposition were taken into account in the code. Downwind concentrations of radionuclides up to 80 km were calculated for each directional sector around the site. Radiation doses to populations were calculated based on the radionuclide concentration which are predicted by the dispersion models. Exposure pathways considered in evaluating health consequences are exposure to the passing plume, exposure to radioactive materials deposited on the ground, exposures to deposited on skin, inhalation of radioactive materials directly from the passing plume, inhalation of radioactive materials resuspended from the ground by natural and mechanical processes, ingestion of contaminated foodstuffs, and ingestion of contaminated water.

The site was selected as the center of a polar grid and the grid was divided into 16 equally spaced sectors which is a fixed value built into MACCS with the outermost radius extending to 80 km. Each sector was divided further into 10 elements to reasonably account for the site specific population distribution. Population data of the year 1992 around the site was used in the calculation of health effects. Meteorological data such as hourly wind speed, wind direction, atmospheric stability, and rainfall rate measured and recorded at the neighboring site tower are assumed to be representative for the site. The weather data of the year 1992 was used in the calculation. A weather file consisting of 24 samples per day and 365 days of meteorological information was considered adequate in conjunction with stratified random sampling of four samples per day.

Evacuation and temporary relocation are considered as emergency response actions. These actions are to mitigate the effects of a release of radioactivity during a severe accident and are designed to reduce radiation exposures, public health effects, and economic impacts from an accident. Individuals evacuating are assumed to move to safety zone, i.e., beyond 16 km from the site at a speed of 1.8 m/sec which is a standard assumption used in NUREG-1150 studies. Relocation of individuals is allowed in three ways, i.e., hot-spot relocation, normal relocation, and long-term relocation, which are assumptions based on guidance given from default values suggested in MACCS, and also used in NUREG-1150 studies. Other parameters that enter the calculational process, such as protection factors for inhalation or skin exposure, resuspension, cloud and other shielding factors, and specific input required for deriving chronic effects, are assumed to be the default values recommended in the MACCS User's Guide.

4. Results and Discussion

The health effects modeled in MACCS are calculated from doses to specific organs, that are calculated using dose conversion factors. The early health effects such as fatalities and injuries are estimated using nonlinear dose response models that are described in detail in NUREG/CR-4214[7]. According to the model, total cases of a specific health effect are calculated by multiplying the average individual risk of experiencing an effect by the number of people who receive similar dose that leads to the risk. And average individual risks have been estimated using the individual risk models.

First of all, sample calculations were made based on the assumptions and parameter values mentioned above. Core inventory data for fission products used in health effect calculations was calculated from ORIGEN2 at end-of-cycle for the conservative estimation because fission product buildup is greatest at end-of-cycle conditions. According to the results, early fatality and total latent cancer fatality values are small fraction of the total number of individuals. The total latent cancer fatalities are larger than the early fatalities. This is due to the time span for calculation, i.e., the calculated latent cancer fatalities occurring over several decades. The individual early fatality risk and individual latent cancer fatality risk are 7.52×10^{-8} per year and 2.45×10^{-7} per year, respectively. These values are below the safety goal of the USNRC. However, these values are one or two order of magnitudes larger than the results of Surry, Zion, and Sequoyah plants calculated in the NUREG-1150 studies. This is due to the weather patterns at the Yonggwang site. According to the analysis of the meteorological data of the year 1992 at the site, the most frequent wind direction is west-north-west. The western part of the site is a marine area and the eastern part of the site is a populated region. Therefore, many individuals may be in the direct pathway of the radioactive plume.

Among the several cases of health effects, early fatalities, early injuries, and average individual early fatality risk are selected in order to investigate their variation resulting from the change of meteorological data. The early fatalities are caused by impaired functioning of red bone marrow, the lungs, and the gastrointestinal tract, and early injuries are caused by impaired functioning of stomach, lungs, skin, and thyroid. The typical phenomena of early injuries are prodromal vomit, diarrhea, pneumonitis, skin erythema, transepidermal, thyroiditis, and hypothyroidism. The individual risk for early fatality and early injury is modeled using a two parameter Weibull function as a hazard function. The average individual early fatality risk is obtained by taking the sum of the risk values in all sectors at a given distance and dividing it by the number of sectors.

The variation of early health effects resulting from the change of wind speed is shown in figures 1 through 3. As can be seen from the figures, three early health effects decrease as wind speed increases. This is due to the fact that as the wind speed increases, atmospheric turbulence influences atmospheric dispersion of radioactive material significantly. As a result, radionuclide concentrations decrease and the area influenced by radioactive plume is broader.

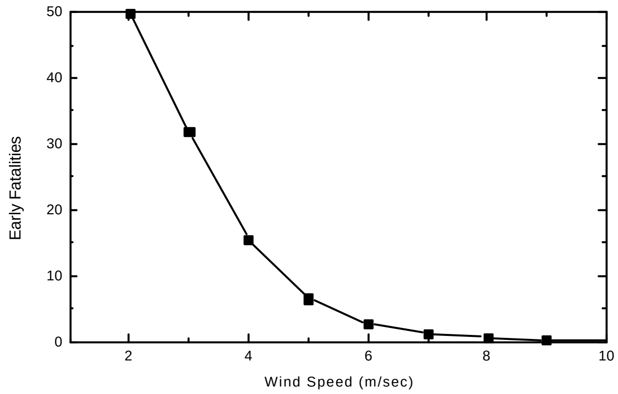

Fig. 1 Influence of Wind Speed on Early Fatalities

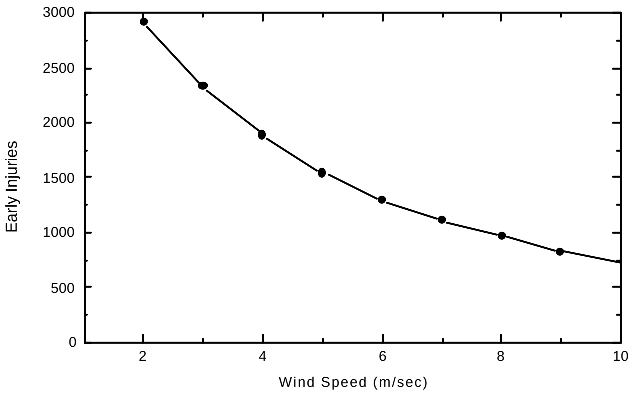

Fig. 2 Influence of Wind Speed on Early Injuries

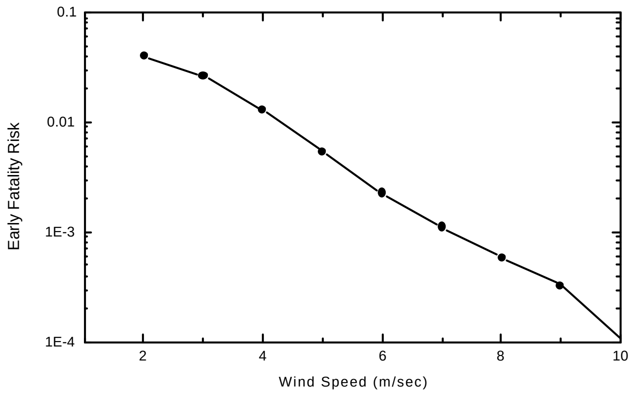

Fig. 3 Influence of Wind Speed on Early Fatality Risk

The influence of rainfall rate on the early health effects is shown in figures 4 through 6. As can be seen from figure 4, the early fatalities increase up to 50 mm/hr, and then decrease slightly. Also, as the rainfall rate increase up to 10 mm/hr, the average individual early fatality risk increases rapidly, and afterwards increase slightly. However, the early injuries decrease as the rainfall rate increase. This is due to the fact that the area influenced by the radioactive plume becomes narrow due to the wet deposition as the rainfall rate increase.

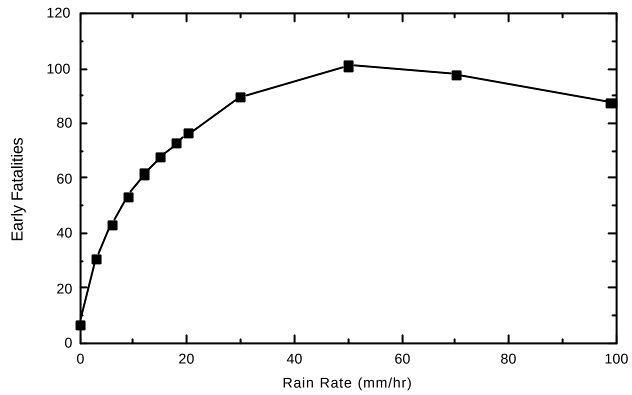

Fig. 4 Influence of Rainfall Rate on Early Fatalities

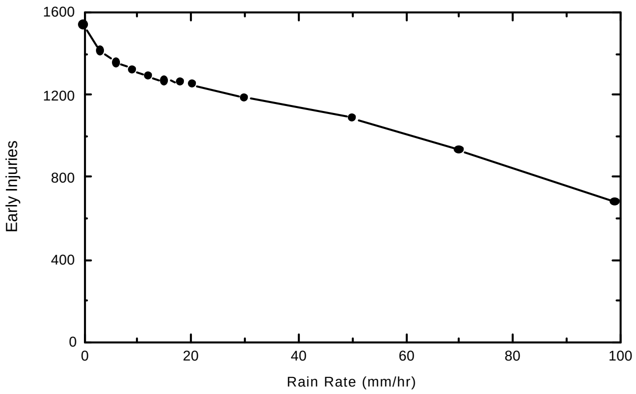

Fig. 5 Influence of Rainfall Rate on Early Injuries

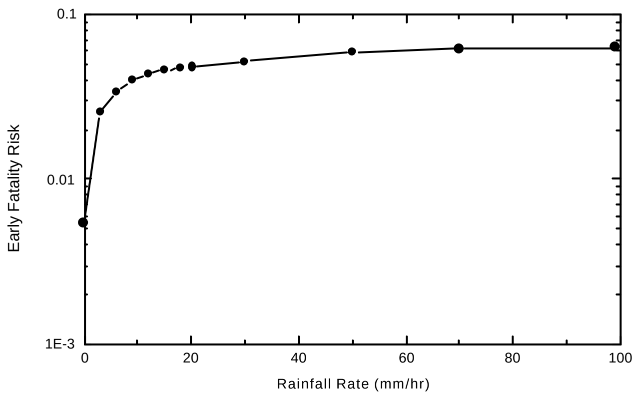

Fig. 6 Influence of Rainfall Rate on Early Fatality Risk

Figures 7 through 9 show the variation of health consequences resulting from the change of atmospheric stability classes. The three health consequences considered in this study show maximum values at stable conditions such as the atmospheric stability class E or F. This phenomenon can be attributed to the variation of dispersion characteristics due to the change of atmospheric stability. That is, the plume expansion is larger at unstable conditions than at stable conditions. Therefore, the area influenced by the radioactive plume increases, however, radionuclide concentration decreases at unstable conditions.

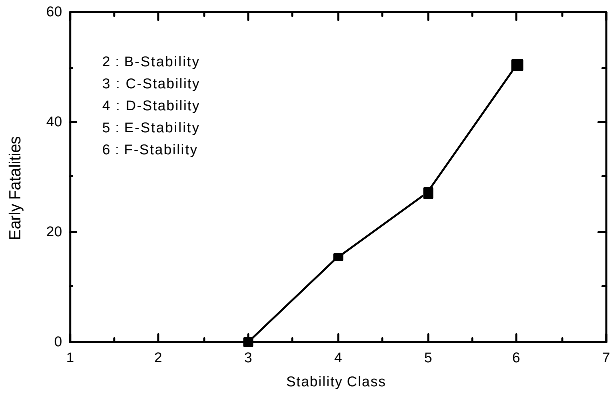

Fig. 7 Influence of Atmospheric Stability on Early Fatalities

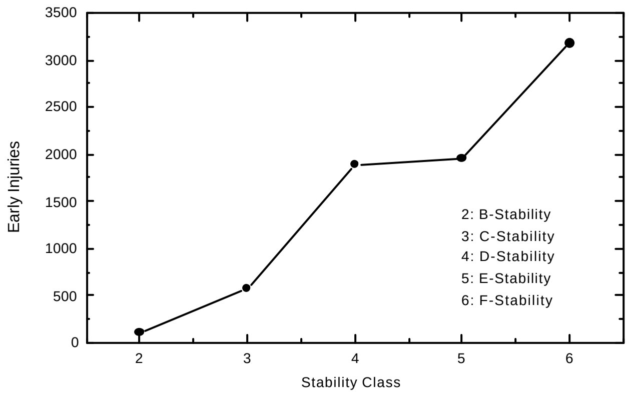

Fig. 8 Influence of Atmospheric Stability on Early Injuries

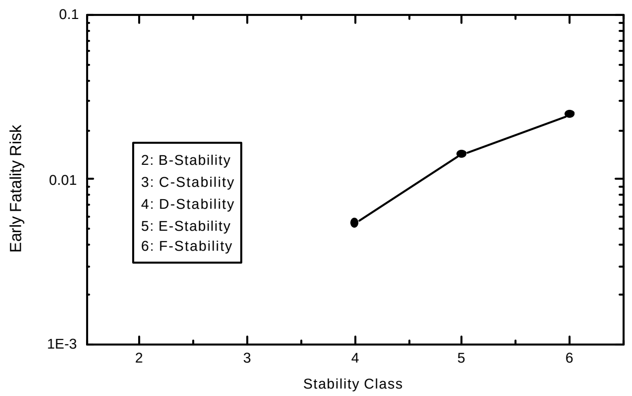

Fig. 9 Influence of Atmospheric Stability on Early Fatality Risk

5. Conclusions

The influence of meteorological data on the early health effects was investigated for the YGN 3&4 nuclear power plants using the MACCS code in order to identify their relative importance. The meteorological considered in this study in order to investigate their influence on the early health effects are wind speed, rainfall rate, and atmospheric stability class. The early fatalities, early injuries, and average individual early fatality risk are selected in order to investigate their variation resulting from the change of meteorological data. As wind speed increases, the values of health consequences considered in this study decrease, and early fatalities decrease more rapidly than any other health effect cases. As rainfall rate increases up to 10 mm/hr, the early fatalities increase rapidly and then increase slightly. And the early fatality risk increases as rainfall rate increases. However, early injuries decrease as rainfall rate increases. According to the results by the change of atmospheric stability, the values of health consequences considered in this study show maximum values at stable conditions such as stability class E or F. The information obtained through this research will be used in developing scenarios for the risk estimation in order to make strategies for reducing offsite consequences.

Acknowledgement

This project has been carried out under the Nuclear R&D Program by MOST.

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