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The Evaluation of Early Health Effects by YGN 3&4 Severe Accidents

Jongtae Jeong and Jaejoo Ha
Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

ABSTRACT

The influence of source term release parameters on early health effects was examined for the YGN 3&4 nuclear power plants. The release parameters considered in this study are release height, heat content, and release time. The early health effects by the change of release parameters are fatalities, injuries, and early fatality distance. The information obtained through this research can be very useful in developing strategies for reducing offsite consequences when combined with the influence of weather conditions on offsite risks.

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. Among them, source term is very important because the description of source term is a starting point of consequence assessment. The source term or source term spectrum is described by the release of radioactive material to the environment in case of a specific accident scenario at a nuclear power plant. Along with the radionuclides that will be released to the environment and the associated release rate, release parameters such as release height, heat content of the plume, and time profile of the release should be specified to fully define the source term.

The objective of this paper is to identify the relative importance of source term release parameters on early health effects. This relative importance provides an indication of the relative precision needed to adequately quantify the source term release parameters. The information obtained through this research is very useful in developing strategies for reducing offsite consequences in viewpoint of the offsite accident management.

2. Source Term Data

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[1] and ORIGEN2 code[2]. 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[3] 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[4].

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 source term release parameters selected in this study in order to investigate their influence on the early health effects are release height, heat content of the plume, and release time. The release height relative to the surrounding area, plays an important role in atmospheric dispersion. Therefore, information concerning the release point is necessary for the analysis of atmospheric dispersion and the influence of the buildings to the dispersion. Plume segments that contain appreciable sensible heat and thus buoyant may rise to heights much greater than their initial release height. If the temperature of a release from the ventilation stack is greater than the surrounding air temperature, the resulting plume rise can be calculated by a simple equation. Only when the release contains a significant amount of heat, the plume or a part of it shall rise. The release time, which is a parameter calculated in physical process model, is the interval between the start of the accident and the predicted start of the release of radionuclides to the atmosphere. In some consequence modeling codes, this interval is used to attenuate the source term by the process of radioactive decay.

3. Modeling of Health Effects

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 early 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[5]. 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 north-west-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[6, 7].

Among the several cases of health effects, early fatalities, early injuries, and early fatality distance are selected in order to investigate their variation resulting from the change of release parameter values. 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 early fatality distance is a radius from the site at which early fatalities are predicted to occur. This result is very useful in determining the emergency response action in order to reduce offsite risks.

The variation of early health effects resulting from the change of release height is shown in figures 1 through 3. As can be seen from the figures, the early fatalities and early fatality distance decrease rapidly as release height increases. However, the early injuries show little variation as release height changes. This is due to the fact that as release height 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. Therefore, the assumption of ground release in order to obtain conservative results for health consequences seems to be appropriate.

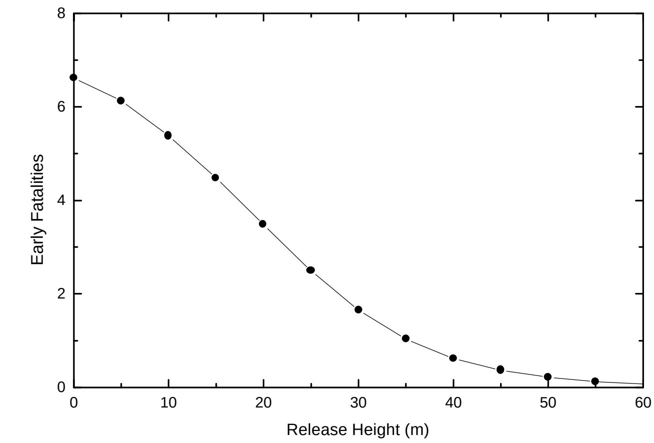

Fig. 1 Influence of Release Height on Early Fatalities

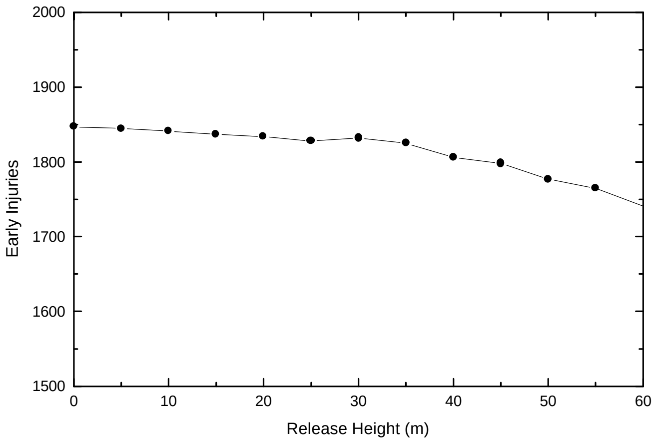

Fig. 2 Influence of Release Height on Early Injuries

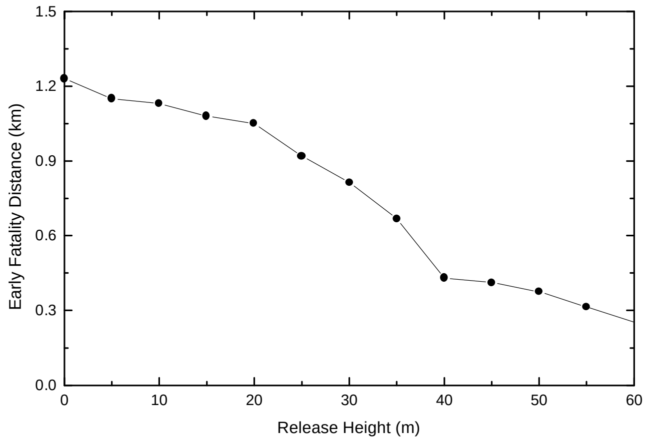

Fig. 3 Influence of Release Height on Early Fatality Distance

The influence of heat content of the release on the early health effects is shown in figures 4 through 6. As heat content of the release increases, the health effects decrease for three cases considered in this study. These results are due to the plume rise. In general, plume rise occurs due to thermal buoyancy if the effluent gases contain considerable amount of heat. As heat content of the release increases, plume rise also increases. As a result, the concentrations in the plume are lower at locations near to the release point.

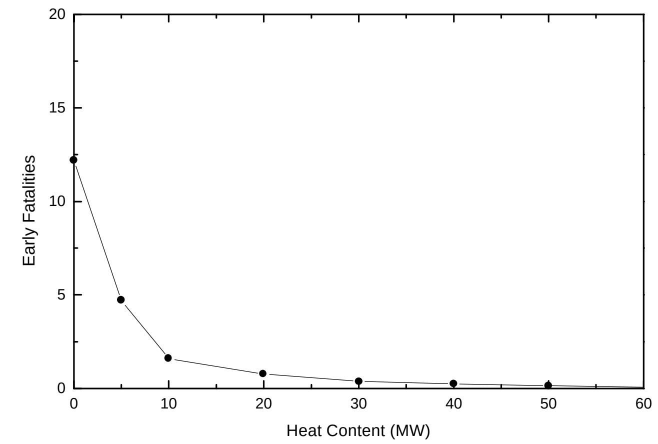

Fig. 4 Influence of Heat Content on Early Fatalities

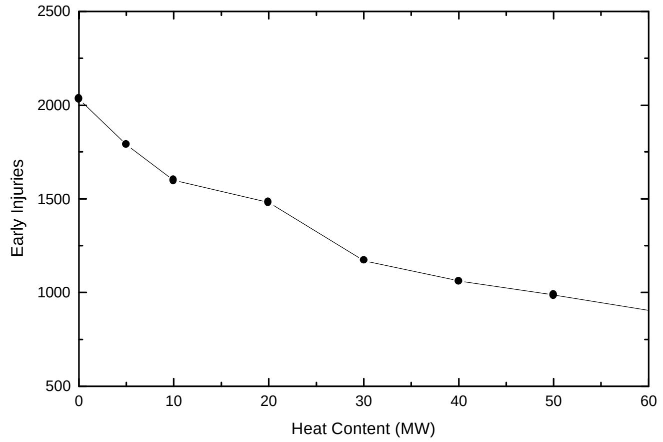

Fig. 5 Influence of Heat Content on Early Injuries

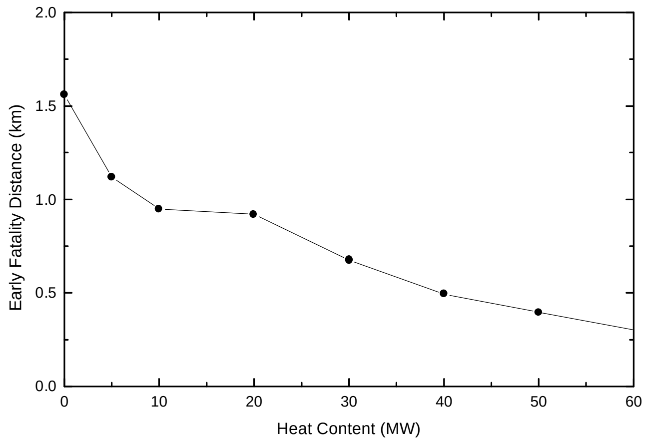

Fig. 6 Influence of Heat Content on Early Fatality Distance

Figures 7 through 9 show the variation of health consequences resulting from the change of release time. As can be seen form the figures, the influence of release time on health effects considered in this study shows very similar trend. The values of health consequences show maximum value at 2 hours of release time and then decrease rapidly. This is due to the fact the quantity of radionuclides decreases due to radioactive decay during the time between reactor shutdown and the start of the release.

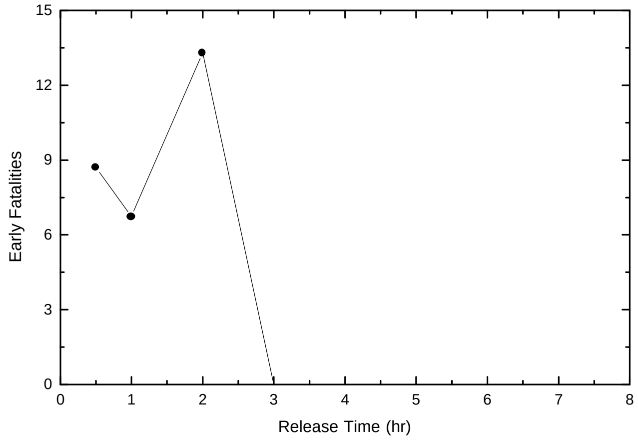

Fig. 7 Influence of Release Time on Early Fatalities

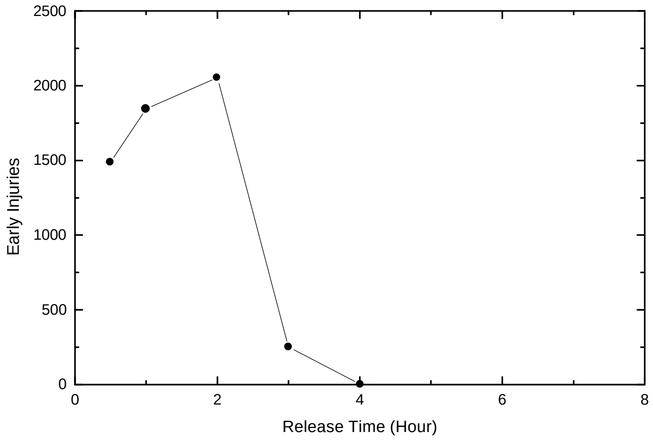

Fig. 8 Influence of Release Time on Early Injuries

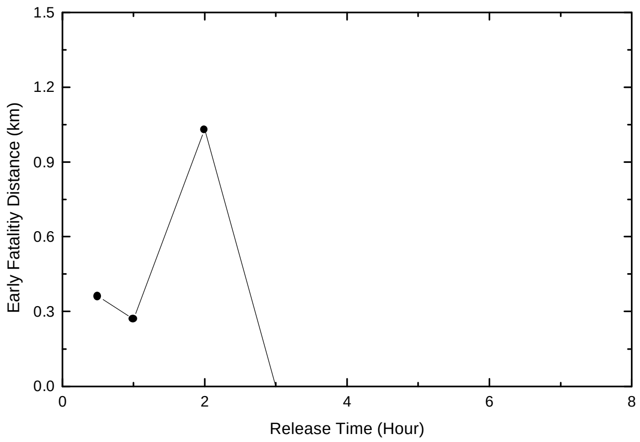

Fig. 9 Influence of Release Time on Early Fatality Distance

5. Conclusions

The influence of source term release parameters 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. This relative importance of the source term release parameters provides an indication of the relative precision needed to adequately quantify the source term release parameters. The source term release parameters selected in this study in order to investigate their influence on the early health effects are release height, heat content of the plume, and release time. The early fatalities, early injuries, and early fatality disance are selected in order to investigate their variation resulting from the change of release parameter values. As release height increases, the early fatalities and early fatality distance decrease rapidly, however, the early injuries show little variation. These results are attributed to the influence of atmospheric turbulence. As heat content of the release increases, the early health effects decrease for three cases considered in this study as a result of the plume rise due to thermal buoyancy. As release time increases, the values of health consequences considered in this study show maximum value at 2 hours of release time and then decrease rapidly. This is due to the decrease of quantity of radionuclides resulting from radioactive decay during the time between reactor shutdown and the start of the release. The information obtained through this research is very useful in developing strategies for reducing offsite consequences in viewpoint of the offsite accident management if they are combined with the influence of weather conditions on offsite risks.

Acknowledgement

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