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The Influence of Source Term Release Parameters on Health Effects

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Abstract

The influence of source term release parameters on offsite 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 effects of core inventory change as a function of fuel burnup was also examined. The health effects by the change of release parameters are early fatalities, cancer fatalities, and early fatality distance. The results showed that early fatalities and early fatality distance decrease as release height increases, although it does not have significant influence on cancer fatalities. The values of both early and late health effects decrease as heat content increases. As release time increases, health consequence shows maximum value in 2 hours of release time and then decreases rapidly. As fuel burnup increases, early fatalities decrease rapidly, while cancer fatalities increase rapidly. Both cases show little variation afterward. Early fatality distance is almost same in all fuel burnup history. The information obtained through this research is very useful in developing strategies for reducing offsite consequences when combined with the influence of weather conditions on offsite risks.
Key Words:

Key Words : source term, health effects, risk, release height, heat content, fuel burnup, release time

1. Introduction

If a severe accident of a 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 a prevailing wind. In result, the radioactive materials would contaminate the environment, and finally population would be exposed to radiation. Consequences resulting from such an accidental release are (1) early health effects, (2) chronic health effects, and (3) economic impacts. These consequences are estimated by a sequence of mathematical and statistical models that represent radioactive materials immediately after release from containment, the movement of the materials as they disperse downwind of the plant, the deposition of the material onto the ground, and the effects of airborne and the deposited materials on humans and the environment.

The potential importance to offsite health and economic consequences of an accidental release from a nuclear power plant is a function of many factors such as source term, weather condition, emergency response plan, and so on. Among them, the source term is very important because the description of the source term is a starting point of a consequence assessment. The source term or source term spectrum is a description of the release of radioactive material to the environment, and refers to the release from a specific accident scenario at a nuclear power plant. Based upon the core meltdown scenarios, a level 2 PSA determines the probability of the containment failure and the characteristics of the associated release of radioactive material. Along with the radionuclides 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 offsite health consequences. 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 for a consequence assessment is the postulated radionuclide release to the environment. 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. Also, the source term includes the frequency of the release.

Source terms used for the calculation of health effects were derived from the result of Individual Plant Examination (IPE) of YGN 3&4[1] and ORIGEN2 code[2]. According to the IPE, 19 source term categories (STC) are defined by categorizing similar containment failure modes. The simple parametric mass balance equation used in NUREG-1150 study[3] and reviewed by other paper[4] was applied to obtain source term release fraction. The calculated source term release fractions are listed in Table 1, which are used to evaluate health effects in MACCS code[5]. The core inventory data for fission products were derived from ORIGEN2 evaluations as a function of fuel burnup.

The source term release parameters selected in this study in order to investigate their influence on the offsite health consequences are (1) release height, (2) heat content of the plume, and (3) release time. The influence of core inventory change for fission products as a function of fuel burnup on health effects was also investigated. The release height, in relation to the surrounding area, plays an important role in atmospheric dispersion. Therefore, information concerning the release point is necessary to analyze the atmospheric dispersion and the influence of the buildings on the dispersion. Plume segments that contain appreciable sensible heat may rise to a height much greater than their initial release height. In such a case, the resulting plume rise is accounted for with a simple equation. The release time, which is a parameter calculated in the

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

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

modeling of physical processes, 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. Evaluation of Health Effects

3.1. Modeling and Assumptions

The MACCS code is 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 reactor containment to the atmosphere were modeled with a straight-line Gaussian plume model. Radiation doses to population were calculated based on the radionuclide concentration which is predicted by the dispersion models. Exposure pathways considered in the evaluation of health effects are: (1) exposure due to the passing plume, (2) exposure due to radioactive materials deposited on the ground, (3) exposures to due deposits on skin, (4) inhalation of radioactive materials directly from the passing plume, (5) inhalation of radioactive materials resuspended from the ground by natural and mechanical processes, (6) ingestion of contaminated foodstuffs, and (7) 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 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. The population and weather data of the year 1992 around the site are used in the calculation of health effects. A weather file consisting of 24 samples per day and 365 days of meteorological information is 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 are assumed to evacuate 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.

3.2. Sample Calculation of Health Effects

The health effects modeled in MACCS are classified as early and chronic health effects. Both health effects are calculated from doses to specific organs using dose conversion factors. Early health effects such as fatalities and injuries are estimated using nonlinear dose response models, and chronic health effects such as mortality and injuries resulting from radiation induced cancers are estimated using a linear-quadratic, zero threshold, dose response model[1]. MACCS models the early fatalities and cancer fatalities that would be caused by the radiation exposure in the population using models that are described in detail in NUREG/CR-4214[6]. According to the model, total cases of a specific health effect are calculated by multiplying the average individual risk by the number of people who receive similar dose that leads to the risk.

To evaluate health effects, sample calculations were made based on the assumptions and parameter values mentioned above. Core inventory data for fission products used for health effect calculations was derived from ORIGEN2 calculations using end-of-cycle inventory of fission products for the conservative evaluation because fission product buildup is greatest at end-of-cycle conditions. According to the results, the values of early fatality and total latent cancer fatality are small relative to the total number of individuals, and 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 occur 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. The safety goals of the USNRC for early fatality risk and cancer fatality risk are 5.0×10^{-7} per year and 2.0×10^{-6} per year, respectively. 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 can be due to the weather patterns and population at the Yonggwang site. According to the analysis of the meteorological

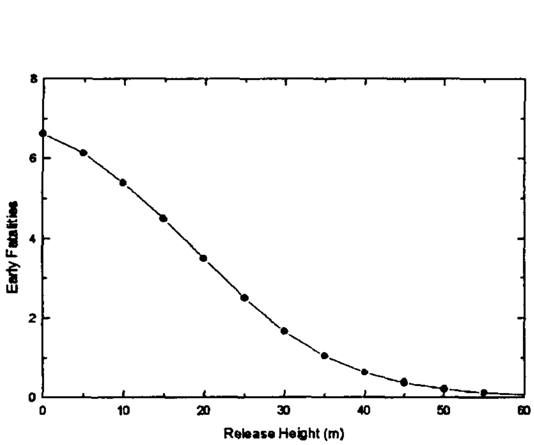

Fig. 1. Influence of Release Height on Early Fatalities.

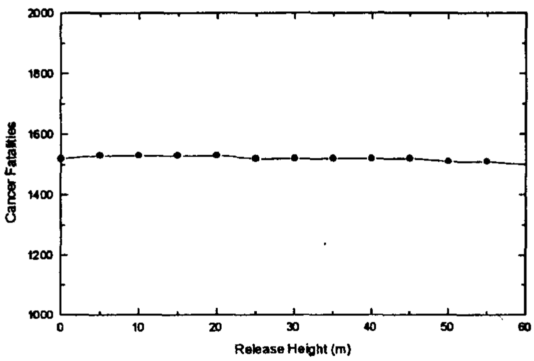

Fig. 2. Influence of Release Height on Cancer Fatalities.

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[7, 8].

Among the several cases of health effects, early fatalities, early fatality distance, and cancer fatalities are selected in order to investigate their variations resulting from the change of release parameter values and core

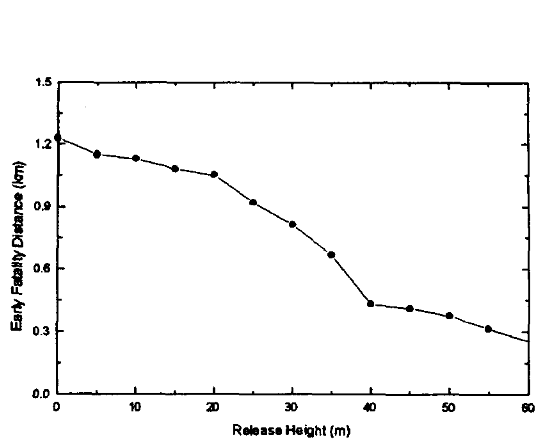

Fig. 3. Influence of Release Height on Early Fatality Distance.

inventories for fission products. Early fatalities are caused by impaired functioning of red bone marrow, the lungs, and the gastrointestinal tract. The individual risk for early fatality is modeled using a two parameter Weibull function as a hazard function. Cancer risk is modeled in three different ways, i.e., linear-quadratic relationship for low and medium dose levels, upper bound limit relationship for high dose levels, and linear term of the dose response function for chronic dose. The early fatality distance is a radius from the site at which early fatalities are predicted to occur, which is very useful in determining the emergency response action in order to reduce offsite risks.

4. Results and Discussion

4.1. Release Height

The variation of health consequences 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 as the release height increases.

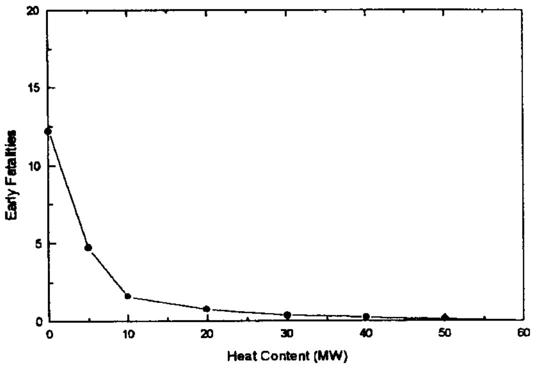

Fig. 4. Influence of Heat Content on Early Fatalities.

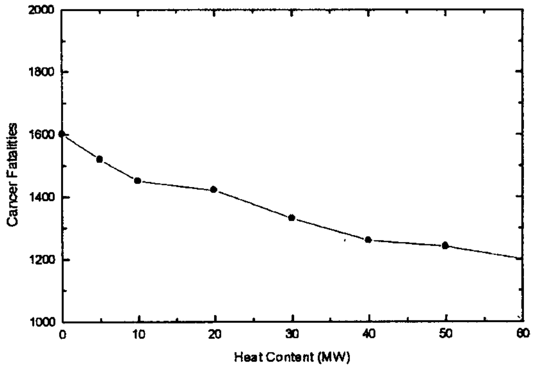

Fig. 5. Influence of Heat Content on Cancer Fatalities.

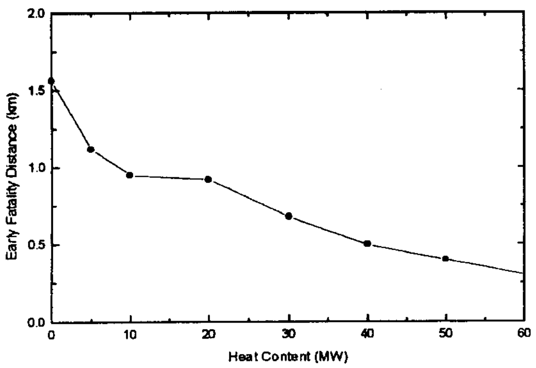

Fig. 6. Influence of Release Time on Early Fatalities.

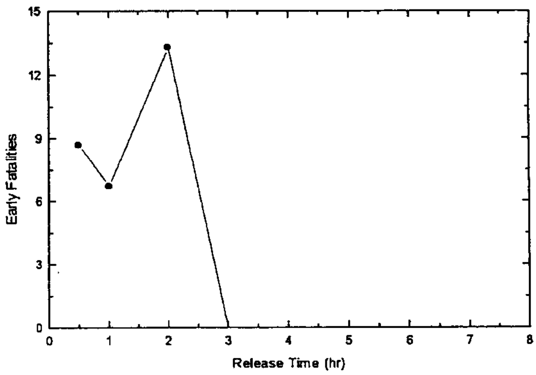

Fig. 7. Influence of Release Time on Early Fatalities.

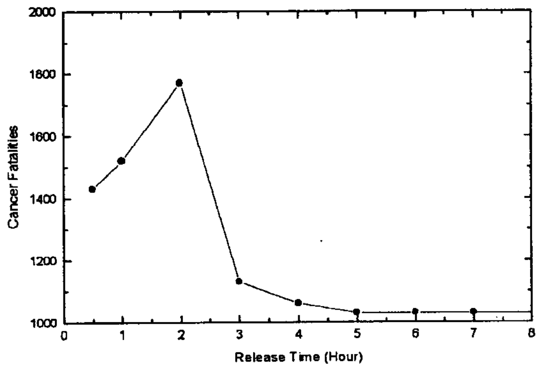

Fig. 8. Influence of Release Time on Cancer Fatalities.

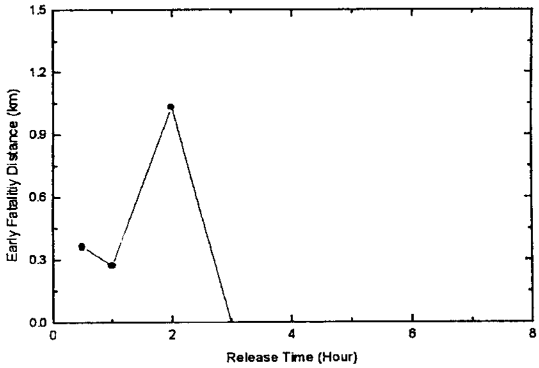

Fig. 9. Influence of Release Time on Early Fatality Distance.

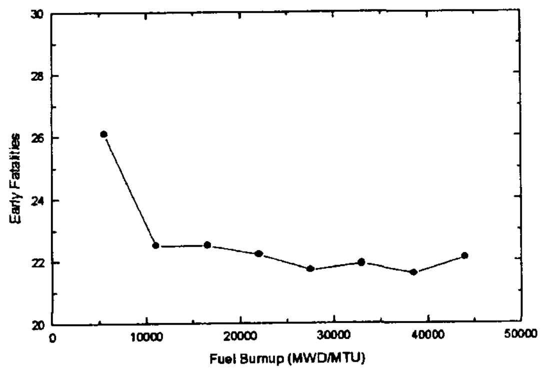

Fig. 10. Influence of Fuel Burnup on Early Fatalities.

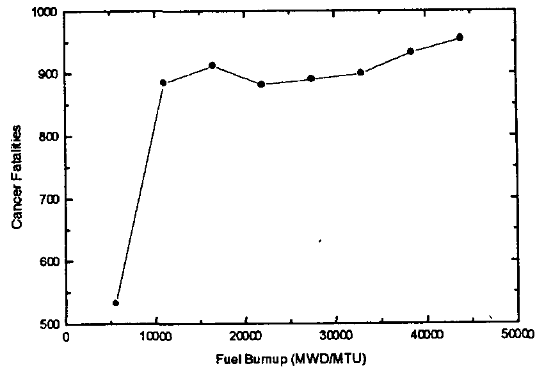

Fig. 11. Influence of Fuel Burnup on Cancer Fatalities.

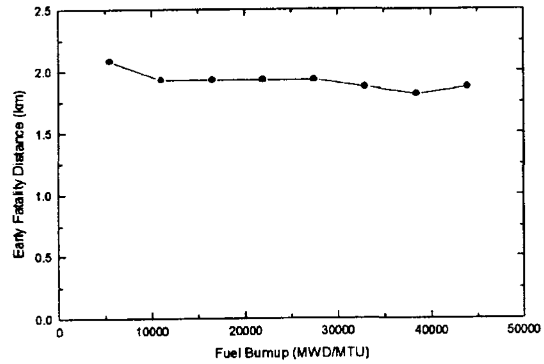

Fig. 12. Influence of Fuel Burnup on Early Fatality Distance.

However, the cancer fatalities show little variation as the release height changes. This is due to the fact that as the release height increases, atmospheric turbulence influences the atmospheric dispersion of radioactive materials significantly. As a result, radionuclide concentrations decrease and the area influenced by the radioactive plume is broader. Therefore, the assumption of ground release in order to obtain conservative results for health consequences is considered appropriate.

4.2. Heat Content

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

4.3. Release Time

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

4.4. Fuel Burnup

The change of fuel burnup means the change of core inventories for fission products, and also means the release rates in the case of same release fractions. As can be seen from figures 10 through 12, early fatalities decrease rapidly, but cancer fatalities increase rapidly. Both cases show little variation afterward. And early fatality distance is almost the same for all fuel burnup history. This is due to the fact that as fuel burnup increases, the increase rate for short-lived and long-lived nuclides is different. As concluded in WASH-1400[9] and NUREG/CR-4467[10], the short-lived nuclides such as iodine and tellurium dominate early doses, and elements with long-lived nuclides such as cesium are most important for long term consequences. According to the analysis of core inventories, the increase rate for long-lived nuclides is greater than that of short-lived nuclides.

5. Conclusions

The influence of source term release parameters on 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 offsite health consequences are release height, heat content of the plume, and release time. And the influence of core inventory change for fission products as a function of fuel burnup on health effects was also investigated. The early fatalities, early fatality distance, and cancer fatalities are selected in order to investigate their variations resulting from the change of release parameter values. The major findings are:

- As the release height increases, the early fatalities and early fatality distance decrease, but cancer fatalities show little variation as release height changes due to the influence of atmospheric turbulence.
- As the heat content of the release increases, the health consequences decrease for three cases considered in this study as a result of the plume rise due to thermal buoyancy.
- As the 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.
- As the fuel burnup increases, early fatalities decrease rapidly and then show little variation, on the contrary, cancer fatalities increase rapidly and then show little variation. And early fatality distance is almost the same for all fuel burnup history.

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.

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