Effect Analysis on the Radiation Dose Rate of Nagasaki Atomic Bomb Survivors by Atmospheric Condition

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1. Introduction

The Dosimetry System 2002 (DS02) had been established to evaluate the radiation doses for the atomic bomb survivors in Hiroshima and Nagasaki [1]. The radiation effects of neutrons and gamma-rays emitted from the atomic bombs detonated at both cities were analyzed, and two types of radiation transport codes (i.e., MCNP4C and DORT) were employed in their studies. It was specifically investigated for contribution of each type of radiations to total dose. However, it is insufficient to examine the effects by various environmental factors such as weather conditions, because their calculations were only performed under certain condition at the times of the bombings. In addition, the scope of them does not include acute radiation injury of the atomic bomb survivors in spite of important information for investigating hazard of unexpected radiation accident.

Therefore, this study analyzed the contribution of primary and secondary effects (i.e., skyshine and groundshine) of neutrons emitted from the Nagasaki atomic bomb. These analyses were performed through a series of radiation transport calculations by using MCNPX 2.6.0 code [2] with variations of atmospheric density. The acute radiation injury by prompt neutrons was also evaluated as a function of distance from the hypocenter, where hypocenter is the point on the ground directly beneath the epicenter which is the burst point of the bomb in air.

2. Methodology

The DS02 system had been developed by making more precise calculations based on the previous DS86 system; a major change is that the gamma-ray dose was increased from 7% to 10% for both cities, while the neutron dose had different aspects in each region. These results were also validated through the benchmark calculations of which uncertainties are relatively small. However, they focused on the evaluation for total dose, irradiated to the atomic bomb survivors, and soil activation only. Hence, additional researches are needed to understand other effects untreated with existing ones, such as environmental and biological effects. Accordingly, this study performed several calculations for analysis on the contribution of direct, skyshine, and groundshine effects to the total prompt neutron dose according to the change of atmospheric density.

The radiation transport calculations were performed by using the ENDF/B-VII.0 with the same data applied in the DS02 for the neutron leakage spectra, the air-over-ground geometry, and compositions for Nagasaki. The air-over-ground environment was modeled in the cylindrical geometry that the radius of the geometry extended out to 3,000m and the Z-axis was extended from 0.5m below the ground surface to 2,000m above it (**Fig. 1**).

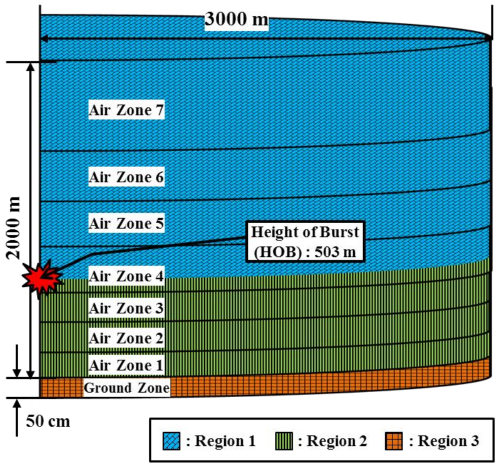

Fig. 1. Schematic of the Air-over-ground Model

The neutron source was located on the axis of the cylinder at a height of burst (HOB) of 503 m for the Nagasaki bomb. The air was divided into 7 axial zones with the altitude dependent atmospheric densities for moist air, dry air, and water vapor content are given as listed in **Table 1**.

Table 1: Nagasaki Atmospheric Density

Air Zone	Height (m)	Atmospheric Density (g/cm^3)		
		Moist Air	Dry Air	Water Vapor
1	0-125	1.152E-3	1.132E-3	1.961E-5
2	125-275	1.139E-3	1.121E-3	1.842E-5
3	275-449	1.124E-3	1.107E-3	1.709E-5
4	449-635	1.107E-3	1.091E-3	1.571E-5
5	635-835	1.089E-3	1.075E-3	1.434E-5
6	835-1095	1.068E-3	1.055E-3	1.285E-5
7	1095-2000	1.038E-3	1.027E-3	1.092E-5

As shown in Figure 1, there are 3 regions to obtain the direct and groundshine effects on the total prompt neutron dose. As an example, the groundshine dose was evaluated by using the region 1 replaced by a void and setting the surface source on the ground (SSW and SSR card). The neutron fluxes were estimated using the surface flux tallies (F2 tally) at 1m above the ground. The calculations were performed for the moist air, dry air and water vapor by changing in the atmospheric density, respectively. The acute radiation injury from the atomic bomb survivors was also evaluated through these calculations.

3. Results and Discussion

The radiation doses were calculated at 1m above the ground, as a function of distance from the hypocenter. The comparison on the results calculated in this study on dry air and in the DS02 is shown in **Figure 2**. The acceptable agreement between the total prompt neutron doses in both studies can be seen with relatively statistical uncertainties of below 10% within about 1,800m from the hypocenter. **Figure 2** shows that the groundshine dose is below the direct and skyshine dose at all the ranges, while the skyshine effect becomes greater than the direct effect at specific range. This trend appears the results of calculation used moist air. Whereas, when atmospheric density highly decreases, such as water vapor, the direct effect is greater than the skyshine effect within 2,500m.

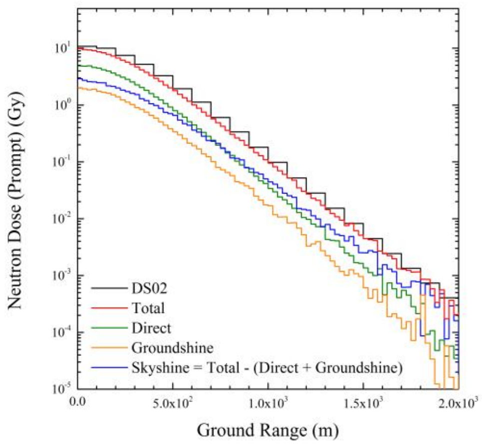

Fig. 2. Results of the DS02 and MCNP Calculations (Dry Air)

The points of intersection for direct and skyshine dose graph are given in **Table 2** with respect to dry and moist air. The point of intersection becomes closer to the hypocenter by about 150 m if the mean atmospheric density is increased by about 0.018×10^{-3} g/cm^3.

Table 2: Point of Intersection for Moist Air and Dry Air

	Mean Atmospheric Density (g/cm^3)	Point of Intersection (m)
Dry Air	1.116E-3	750
Moist Air	1.134E-3	600

The analysis on the acute radiation injury from total prompt neutron dose with variations of atmospheric density is shown in **Figure 3**. The LD 50/60 is the lethal dose at which 50% of those exposed to that dose will die within 60 days. It is estimated that the death from radiation effect of total prompt neutrons can be observed within about 525m in dry or moist air and within about 2,000m in water vapor.

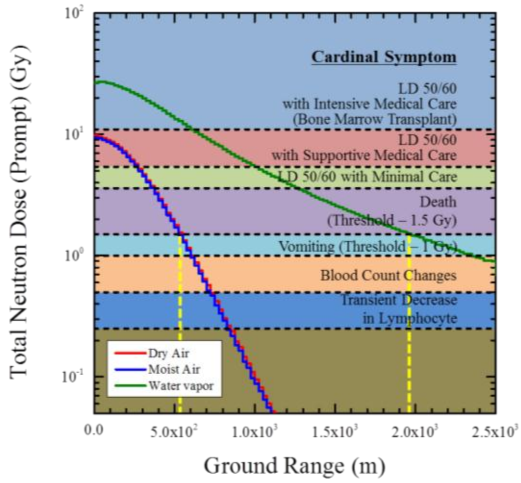

Fig. 3. Acute Radiation Injury from Total Neutron Dose

4. Conclusion

In this study, it is confirmed that the order of contribution to total prompt neutron dose is the direct, skyshine, and groundshine effect at the hypocenter. The order of direct and skyshine effect is inverted by increasing the distance from the hypocenter. It is also founded that the point of intersection for direct and skyshine effect to total prompt neutron dose moves towards the hypocenter with increasing the atmospheric density. This paper can be referenced to come up with an effective plan for dealing with a similar accident. The estimation of these effects can be used to prepare the counterplan for radiation accident by reference data.

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