Public Dose and Risk Evaluation for the Accident Transport of Naturally Occurring Radioactive Materials and Associated Consumer Products

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1. Introduction

Naturally occurring radioactive materials (NORMs) are natural substances containing long-lived radioactive element, specifically uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K) [1]. These radionuclides have also been incorporated in products or items which are available for various public consumptions [2]. Monazite and necklace are examples of NORM and consumer products containing NORM respectively. However, NORMs and consumer products are normally transported in bulk amount and large numbers in the public domain, and exposing the public along the routes to the radiological risks during normal (incident free) transport and accident [3]. Therefore, risk assessment have to be conducted during transportation. This helps to identify and reduce the likelihood of an accident to occur and setting appropriate measures for mitigating the consequences of its occurrence [4]. However, there is a backlog of information regarding radiological impact of transporting NORMs and consumer products in Korea, whereby, several studies conducted have focused of transport of artificial low and intermediate radioactive materials from nuclear, medical, and industrial facilities [5-6]. This study was conducted to assess the radiation dose and risk to public during an accident involving monazite and necklace shipments using RADTRAN computer code.

2. Materials and Methods

2.1 Accidents scenario

The public dose and risk was assessed along 12 route segments (links) of expressway between Seoul and Gyeongju during accident transport of Monazite and necklace consignments as shown in Fig.1. The shipment was carried in a container made of iron materials with dimensions of 12× 2.4 × 2.5 m and a maximum loading capacity of 21 tons. The containers was damaged by fire after vehicles collisions along the road routes. ^{238}U, ^{232}Th, and ^{40}K were assumed to be released, aerosolized, respired for conservatism with fractions rate of 0.1%, 1.0, and 1.0 respectively. The ground deposition velocity of the released radionuclide was also set to 0.01 m/s. Moreover, inhalation, ground shine, cloud shine, ingestion, and resuspension pathways were considered as sources of internal and external exposures to the public during an accident. Seoul was the point of accident for the worst-case scenario owing to its high population density, and is dominated by stability class F with a wind speed of 2.4 m/s. The collective dose and risks were estimated using the RADTRAN code.

2.2. Input data

Radiological and physical data for this study were obtained from nuclear security and safety commission (NSSC) and previous literatures respectively. Statistical analysis was conducted for consumer product (necklace) by selecting median values of radioactivity concentration and maximum value was also applied to NORM (monazite) data, which serve as an input. MicroShield code was employed to calculate an external dose rate from a transported radioactive shipment and RADTRAN code was used to estimate the total effective dose and risk based on developed transport accident scenarios.

Table I. Radiological input data used in RADTRAN code

Items	^{238}U (Bq)	^{232}Th (Bq)	^{40}K (Bq)	Dose rate at 1m (Sv/hr)
Monazite	3.41×10^{7}	3.41×10^{9}	3.04×10^{5}	1.36×10^{-13}
Necklace	9.66×10^{6}	7.22×10^{7}	8.50×10^{5}	3.79×10^{-13}

Table II. Route segments and physical input data [5]

Link name	Length (km)	Speed (km/hr)	Population density (Persons/ km^2)	Rate of fire accident (occurrence /km-car)	Road type
Link_1	16.6	110	22,6654	6.58x10^{-14}	Highway
Link_2	48.7	110	6,906	9.39x10^{-14}	Highway
Link_3	30.9	110	328	2.39x10^{-13}	Highway
Link_4	46.5	110	4,345	2.30x10^{-13}	Highway
Link_5	22.9	110	4,345	1.12x10^{-13}	Highway
Link_6	32.5	110	3,024	4.32x10^{-14}	Highway
Link_7	35.7	110	100	6.14x10^{-14}	Highway
Link_8	30.3	110	136	5.28 10^{-14}	Highway
Link_9	32.4	110	686	1.10x10^{-13}	Highway
Link_10	37.3	110	4,813	7.89x10^{-14}	Highway
Link_11	45	110	614	1.00x10^{-13}	Highway
Link_12	37	80	204	3.03x10^{-12}	Secondary road

2.3. Description of RADTAN and MicroShield Codes

RADTRAN is an internationally recognized computer code for the assessment of the risk and doses (dose risks) of transporting radioactive materials during incident-free transport and accident. The code was developed at Sandia National Laboratory and has since been expanded and developed to improve its analytical capability. The code also employs the Gaussian dispersion puff model for radionuclide atmospheric dispersion during an accident scenario, where the concentrations of radionuclides are assumed to change with time [7]. The governing mathematical equation for atmospheric dispersion is as follows:

$$\frac{CHI}{Q} = \frac{1}{2\pi\pi u_y \sigma_z}\left[exp\left\{-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right\}\right]\left[exp\left\{\frac{-(z-H)^2}{2\sigma_z^2}\right\} + \alpha exp\left\{\frac{-(z+H)^2}{2\sigma_z^2}\right\}\right] \quad (1)$$

Where:
CHI = the concentration of dispersed substance (Bq/m^3)
Q = the rate of release of dispersed substance (Bq/sec)
U = wind speed (m/sec)
σ_y = the crosswind meteorological constant (m)
σ_z = the vertical meteorological constant (m)
H = the release height (m)
α = the reflection term

MicroShield is a computer code that among other applications, can also be used to assess radiation exposure to people and materials. In the estimation of gamma-ray shielding, the code employs the point-kernel approach, in which the source region is partitioned into patches of smaller volume where the doses are integrated in terms of space and energy in the analysis [8]. The mathematical equation that governs the estimation of the total dose rate based on the point-kernel isotropic point source is as follows:

$$D = \int dE \times \frac{e^{-\mu r}}{4\pi r^2} \times C(E) \times S(E) \times B(\mu r, E$$
(2)

Where:
D = the total external dose rate
E = the energy of the photons
S = the intensity of the source (specific activity)
C = the density of gamma flux
r = the distance between the source and detector
μ = the attenuation coefficient
B = the buildup factor

3. Results and Discussion

RADTRAN was employed to estimate the dose and risks to public during accident scenario. Figures 2 and 3 reveals that, the highest collective dose occurred in link_4 during transport accident involving monazite and necklace shipments. The accident probability along with other factors, such as activity concentration, accident severity, package response, and dispersion environment, affect the public exposure (collective dose) dose and risk during accident. The population or collective dose is also direct proportional to the number of population or population density. However, the rate of accident probability for Link_3 and 12 is higher than link_4 but their respective population densities are much lower than population density for link_4, resulting to lower collective dose than link_4.

Moreover, the population exposure dose was far below the annual dose limits of 1 man-Sv (1000 man-mSv) recommended by International Atomic Energy Agency (IAEA). This results implied that, we can secure risk during accidents transport of NORMs and consumer product. Furthermore, Figures 4 and 5 presented the results of sensitivity analysis conducted by changing the value of release, aerosol, and respirable fraction by 0.1%, 1%, 10%, and 100%. The results have also indicated insignificant collective dose compared to 1 man-Sv/year (1000 man-mSv/year).

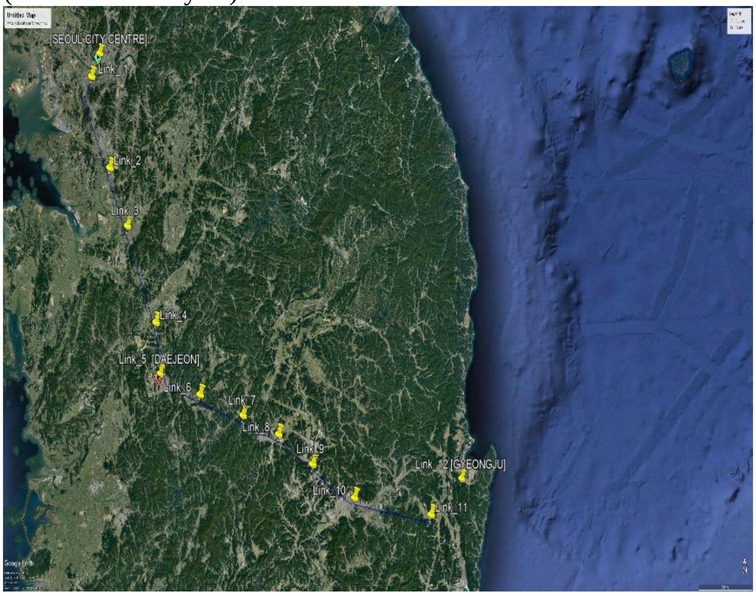

Figure 1: Route segments between Seoul to Gyeongju

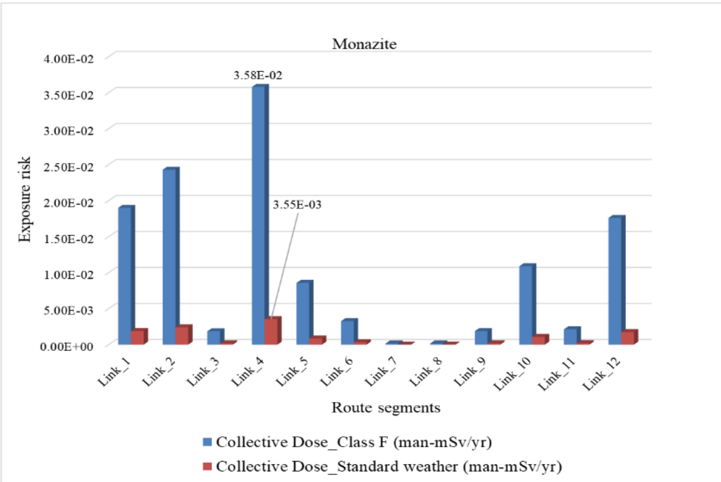

Figure 2: Accident transport result of Monazite

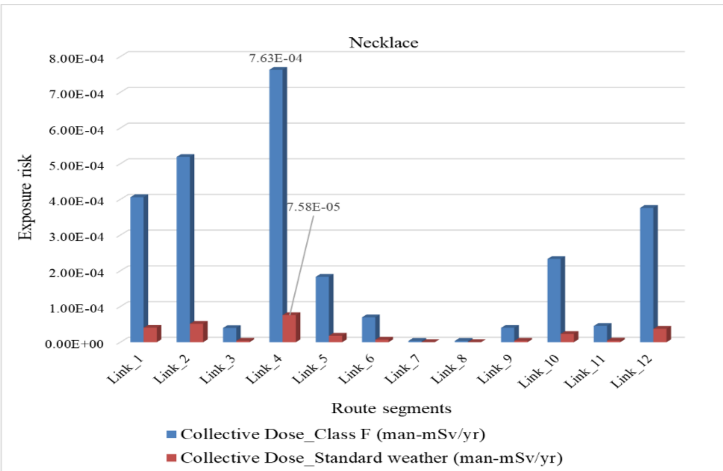

Figure 3: Accident transport result of necklace

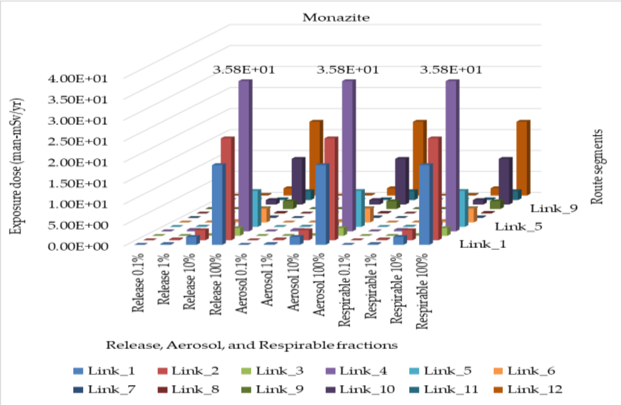

Figure 4: Sensitivity analysis result of monazite

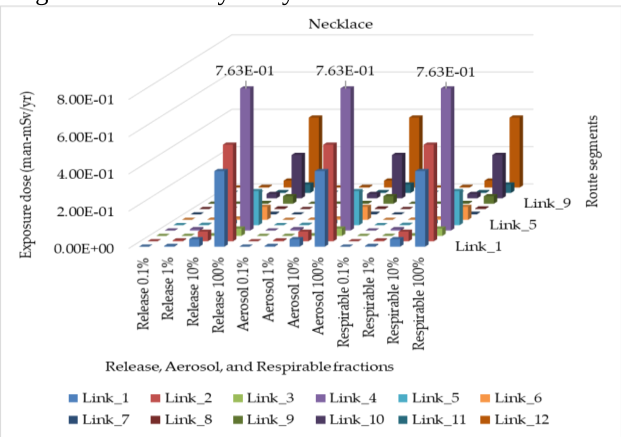

Figure 5: Sensitivity analysis result of necklace

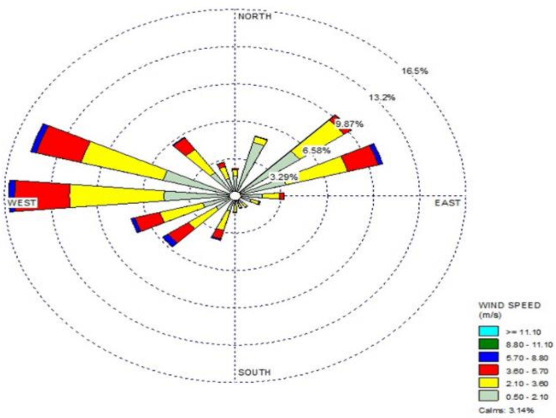

Figure 6: Windrose diagram showing wind speed and direction for Seoul

WRPLOT view freeware 8.0.2 was employed to analyze the data for a period of 10 years, from 2010 to 2020, as presented in Figures 6 [9]. The dominant wind direction with an average speed of 2.4 m/s is from the West (W) to East (E) direction and the West North West (WNW) to East South East (ESE) direction. Therefore, people who live in the direction of wind are more likely to be exposed to the released radionuclides during an accident.

4. Conclusion

RADTRAN was employed to evaluate radiation dose and risk to public during accident transport of monazite (NORM) and necklace (consumer product). Microshield was also used to estimate the external dose at 1m from the shipments container which is also used as input parameter in RADTRAN computer code. The results of public exposure dose and risk were insignificantly far below the annual regulatory limits of 1man-Sv or 1000 man-mSv, recommended by IAEA. Moreover, the sensitivity analysis results also indicated insignificant population exposure dose below the recommended dose limit. Therefore, safety can be secured during accident transport involving NORM and associated consumer products. However, the plotted wind rose indicated that wing speed direction shows the dominant dispersion towards East (E) and East South East (ESE) directions. Therefore, dwellers in the direction of the E and ESE are likely to be more exposed to radionuclides which were released during the accident scenario.

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