Radiological Dose Assessment using RESRAD Code: Case Study, Fukushima Accident for Soil and Public

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ABSTRACT

Estimation of radionuclides fallout as a result of routine atmosphere emission from Fukushima accident as estimate of the radionuclides doses of exposure human is one of parameter for a safety analysis to assess the doses received by an individual or population group by using theoretical model. A tremendous amount of radionuclides discharged because of the damage to cooling systems of nuclear reactors in the Fukushima No. 1 in March 2011. Fukushima and its adjacent prefectures were contaminated with fission products from the accident. The present study is estimates radiological doses and health risk to general public from deposition of radionuclides such as (110mAg, 129mTe, 134Cs, and 137Cs) on soil surface in south, north and central Miyagi Prefecture due to Fukushima accident by using RESRSD (version 6.5) computer code. In this assessment the exposure source parameters were adjusted over period of 100 years over an area of 7285 Km² and depth of 0.01 m. The predicted maximum total effective dose equivalent received by general public from deposited radionuclides on soil surface in south, north and central Miyagi Prefecture were found to be (3.36, 0.79 and 0.21 mSv/yr). Also the annual total cancer risk for public were estimated to be (2.25 x10⁻⁴, 1.0 x10⁻⁴, 4.0 x10⁻⁵) respectively.

Keywords: Fukushima Dai-ichi nuclear power plant accident, Miyagi Prefecture, Radioactivity, Cesium, Surface

INTRODUCTION

The Fukushima Dai-ichi nuclear power plant (37°25′17″ N, 141°01′57″ E) incurred seriously damage because of the Tohoku Earthquake and tsunami that occurred off the Pacific coast on March 11, 2011 (magnitude 9.0; JMA, 2011). Consequently, large quantities of artificial radionuclides were released from the plant (1, 2, 3). Until the earthquake occurred, units 1, 2, and 3 in the Fukushima No. 1 nuclear power plant, located in Futaba, Fukushima, Japan, had been supplying electric power under normal commercial operations. However, cooling functions for the reactors were lost because of damage by the earthquake. As a result of water decomposition by contact with hot fuel rods, hydrogen gas was evolved and accumulated in a reactor building. The resulting hydrogen explosion caused the collapse of outer walls of reactor buildings for units 1, 2, and 3. In addition, on March 12 exhaust ventilation from a nuclear reactor container was carried out to decrease pressure. The majority of the airborne fission product releases are reported to have been released through hydrogen explosions, venting, and leakage over March 2011. Consequently, high volatility fission products including 129mTe, 131I, 134Cs, 136Cs, and 137Cs were discharged into the environment. These radioactive elements were carried together with the air parcel, and subsequent wet and dry depositions caused accumulation of them on the ground. The measured deposited radionuclides in soils throughout the study area was Miyagi Prefecture in the south close the border with Fukushima prefecture including the central and northern parts beyond a 100-km radius from the power plant, as shown in Figure (1).
Fig. (1): Location of the study area (Miyagi Prefecture) and the Fukushima Dai-ichi Nuclear Power Plant (NPP)

RESRAD MODEL

The RESRAD computer code was used to calculate the total effective dose equivalent for external exposure pathway of deposited radionuclides $^{110m}$Ag (t$_{1/2}$ = 249.9 d), $^{129m}$Te (t$_{1/2}$ = 33.6d), $^{134}$Cs (t$_{1/2}$ = 2.062 y), and $^{137}$Cs (t$_{1/2}$ = 30.0 y) on soil surface in Miyagi Prefecture and excess cancer risk to occupancy exposed to Miyagi soil surface which Caesium-134 and Caesium-137 are generally responsible for radiation exposure. $^{137}$Cs is mainly a beta-emitter radionuclide, but its decay product Barium-137m also produces gamma-radiation. Radioactive sources used in RESRAD calculations were values of radionuclides concentration of ($^{110m}$Ag, $^{129m}$Te, $^{134}$Cs, and $^{137}$Cs) deposited on soil surface in Miyagi Prefecture. The expected estimation of amount effective doses of external gamma radiation due to ($^{110m}$Ag, $^{129m}$Te, $^{134}$Cs, and $^{137}$Cs) is calculated according to the following equation (1) \(^{(4)}\):

\[
M(t) = \sum_i S_i(0)/G_i(t) \leq 1 \quad \ldots\ldots(1)
\]

\[
= HE(t)/HEL \quad tr \leq t \leq th
\]

Where:

- $M(t)$ = fraction of the basic dose limit received by an average a member of the critical population group at time $t$ following the radiological survey (dimensionless),
- $S_i(0)$ = initial concentration of the $i^{th}$ principal radionuclide averaged, and
- $G_i(t)$ = single-radionuclide soil concentration guideline for the $i^{th}$ principal radionuclide in a uniformly contaminated zone at time $t$ (Bq/g [pCi/g])
- $HE(t)$ = average annual TEDE received by a member of the critical population group at time $t$ following the radiological survey of the site (mSv/yr [mrem/yr]),
- $HEL$ = basic dose limit (0.25 mSv/yr [25 mrem/yr]),
- $tr$ = time at which the site is released for use without radiological restrictions following the radiological survey (1 yr), and
- $th$ = time horizon (1,000 yr).
RESRAD Input Parameters

To estimate radiation doses by using RESRAD model from deposited radionuclides on surface soil in Miyagi Prefecture (northeastern Japan), caused from the Fukushima Dai-ichi nuclear power plant accident after the earthquake the activity concentrations of $^{110m}$Ag, $^{129m}$Te, $^{134}$Cs, and $^{137}$Cs were measured from the collected samples from 60–190 km north of the power plant and at depths of 0–0.01 m in the period April 16–29, 2011. The measured activity concentrations of ($^{110m}$Ag, $^{129m}$Te, $^{134}$Cs, and $^{137}$Cs) of surface soil samples south Miyagi was found 27,600 Bq/kg dry soil and average activity concentrations (4600 Bq/Kg) were also found in the northern part of Miyagi Prefecture but relatively low average concentrations (1250 Bq/Kg) were found in central Miyagi Prefecture$^5$. The Miyagi studied area were 7285 Km$^2$ $^6$ and 0.01 m depth. Duration of scenario is estimated at total exposure time of public at deposited radionuclides soil about 8 hour outdoor $^7$.

RESULT AND DISCUSSION

Total effective dose equivalent TEDE from deposited radionuclides such as ($^{110m}$Ag, $^{129m}$Te, $^{134}$Cs, and $^{137}$Cs) in south, central and north in soil surface Miyagi Prefecture for external exposure of public using RESRAD program for (1, 3, 6, 9, 10, 15 and 30) years which were estimated according to equation (1) are represented in Figures (2, 3, 4).

**Fig. (2): TEDE of south Miyagi Prefecture deposited soil**

**Fig. (3): TEDE of north Miyagi Prefecture deposited soil**
The maximum values of TEDE of deposited radionuclides on south, central and north Miyagi Prefecture soil surface according to Figures (2, 3, 4) are shown in table (1). It is noticed that significant variation of TEDE with surface Miyagi Prefecture location which larger in south than central and north. It is attributed to the amount of radionuclides deposition in each location of surface Miyagi Prefecture.

Table (1): Total effective dose equivalent TEDE (mSv/yr) of south, central and north of soil surface Miyagi Prefecture

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>10</th>
<th>15</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>South External exposure mSv/yr</td>
<td>4.812</td>
<td>3.365</td>
<td>1.786</td>
<td>0.665</td>
<td>0.0782</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>North External exposure mSv/yr</td>
<td>0.7934</td>
<td>0.5547</td>
<td>0.2976</td>
<td>0.1108</td>
<td>0.0130</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>central External exposure mSv/yr</td>
<td>0.2156</td>
<td>0.1507</td>
<td>0.0808</td>
<td>0.0030</td>
<td>0.0003</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**RISK ASSESSMENT**

The estimated doses and associated annual total cancer risk for public -exposed to deposited radionuclides on south, north and central Miyagi Prefecture soil surface are shown in figures (5, 6 and 7).
The values of annual total cancer risk of deposited radionuclides on south, north and central Miyagi Prefecture soil surface are (2.25 x10^{-4}, 1.0 x10^{-4}, 4.0 x10^{-5}) respectively.

Comparison between measured data and results from RESRAD program

The environmental measurement data used as primary input to the dose assessment depends on environmental monitoring data for Japan which include measurements of radionuclides in air, soil, foodstuffs, drinking-water and fresh water. Measured levels of deposited radionuclides are available for all 47 Japanese prefectures, and levels in Fukushima prefecture show significant variation with location. External doses can be significantly lower indoors than outdoors due to the shielding effects of the building. The dose assessment in Fukushima prefecture and neighboring prefecture was shown the estimated effective doses which was below the international agreed reference level for public exposure. The internationally agreed reference level of 300 Bq/m3 of radon concentration in air of residential dwellings represents approximately an annual effective dose of 10 mSv^{(8, 9)}. The expected dose value during the first year for the neighboring prefectures (Miyagi, Ibaraki, Tochgi and Gunna) are 3 mSv which agreement with measured data by using RESRAD Model^{(10)}. Also annual effective dose of about 10 mSv expected in two locations in the most effect part of Fukushima prefecture where the effective doses were estimated to be within a dose band of 10- 50 mSv^{(11)}. 
CONCLUSION AND RECOMMENDATION

According to the IAEA 1996 (12) (BSS) safety series publication No. 115, the currently accepted dose limit recommended is 1 msv/yr (100 mrem/yr) which is the main aim to achieve (ALARA) optimization for general public to decrease radiological hazard.

The calculated annual total effective doses equivalent received by general public from south, central and north Miyagi Prefecture soil surface are (3.36, 0.790 and 0.210 mSv/yr) respectively. Also its annual total cancer risk are estimated to be (2.25 x10⁻⁴, 1.0 x10⁻⁴, 4.0 x10⁻⁵) respectively. Radiation doses were converted to carcinogenic risks by using risk of the studied area factors recommended by the International Commission on Radiological Protection (ICPR 1990) (13). The ICPR risk factor is 1.25 x10⁻⁹ per mSv (5.0 x10⁻⁵ mSv⁻¹) for the public. Risks are expressed as the increased probability of fatal cancer over a lifetime. Generally the calculated doses and risks of the studied area were found to be lower than International limits except in the south Mayigi which are slightly higher than recommended limits. So a number of rational actions have to be taken by the government of Japan, municipal authorities and residents to lower radiation exposure.

REFERENCES

(3) nerh (nuclear emergency response headquarters, government of japan) (2011) report of japanese government to the iaea ministerial conference on nuclear safety—the accident at tepco’s fukushima nuclear power stations
(6) geography of miyagi prefecture (2011)
(7) federal ministry for the environmental nature conservation and nuclear safety radiological protection march (2012)
(8) radiation protection and safety of radiation sources: international basic safety standards (bss), interim edition. Vienna, international atomic energy agency, (2011)
(9) handbook on indoor radon: a public health perspective. Geneva, world health organization, (2009)
(11) preliminary dose estimation from the nuclear accident after the 2011 great east japan earthquake and tsunami (world health organization)
(13) icpr (1990): recommendation of the international commission on radiological protection, pergaman press, oxford, uk, 1991: publication 60