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Modeling Radiation Doses for a Hypothetical Contaminated Site Using RESRAD-OFFSITE Code Faisalabad, Pakistan

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ABSTRACT

Naturally Occurring Radioactive Materials (NORMs) are one of the main sources of radiation exposure to humans and environment. To assess the impact of NORMs on human health and environment, different approaches (Deterministic & Probabilistic) are used globally. The radiological doses to the public from NORMs depend on the level of radioactivity, type of usage of the site, nature of the deposition and the location of the population with respect to the contaminated site. Different international organizations like International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have established international safety standards regarding protection from man-made and natural sources of ionizing radiations. In the current research work, the radiological doses to public, off-site, from the soil of a hypnotically contaminated area with radionuclides (^{40}K, ^{137}Cs, ^{226}Ra and ^{232}Th) at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan has been estimated using (RESRAD-OFF) code.The radiation doses due to different exposure pathways have also been estimated. The relation of different exposure pathways with the doses has also been analyzed.

1. Introduction

Building materials surrounds high levels of radionuclides especially 226-Ra, 232-Ra, 40-K and 137-Cs.These four collectively produce a considerable amount of radioactivity. In Australia, activity concentration from stone is 4000 (Bq/kg), in clay bricks and concrete is 1600 (Bq/kg). The total dose received due to building materials is 0.5 (mSv/year) in Australia [1].

Over the years, it is also well known that coal power-stations release more radioactivity to the environment. By burning and different useful activities of coal high levels of radioactivity of about 1400 (Bq/kg) have been measured in some areas of the world [3]. Production of coal through mining gives rise to radon levels and higher levels of radium and potassium. Residues of radionuclides which have settled in waste water and have risen up to the environment have been measured with activities of 55,000 (Bq/kg) of Ra-226 and 15,000 (Bq/kg) of Ra-228 in earlier studies [1].

Mining and processing of metals ores from the earth, other than uranium also generate large quantity of NORM's wastes. Radon exposure is a prevalent problem in metals mines. A survey of 25 underground mines in china yielded six radon concentration having activity concentration of about 1000 (Bq/m³). In all the metals mines, the annual dose rate of (7.75 mSv/year) was found as quoted in literature [1-2].

In china, 44 coal mines (40 of which were underground and 15% above ground) showed that the radon concentration was 1000 (Bq/kg) in ground level mines. Public dose rate of exposure from uranium mining is about 1mSv/year, as quoted in literature [3].

Oil and gas production wells have shown that long lived uranium and thorium isotopes are not organized in a manner, from the rocks that contain them. However, 226-Ra, 224-Ra, 228-Ra and 210-Poare organized. It is well documented that total mean annual dose equivalent from oil and gas production industry is 1.72 (mSv) [4].

Phosphate rocks which are used in producing fertilizers are also a source of NORMs (uranium and thorium). Phosphate is a common constituent of fertilizers. The annual dose received from phosphate and fertilizers in Iran, outdoors, is found to be (0.07-0.09) mSv/year in soil samples containing fertilizers, whereas outdoors in infertile soil sample it is (0.06mSv/year) [5-12].

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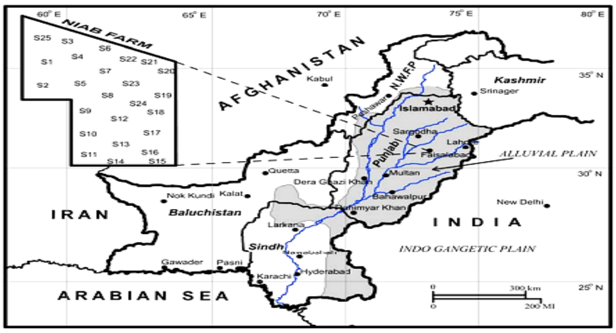

Fig. 1: Map of Pakistan showing location of area under study [13]

The region under analysis involved 100 hectors of productive soil at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan. The coordinates of the area as seen from Fig.1 is 31°24´ N and 73°05´ E [13].

2. Research Methodology

2.1 Computational Technique

RESRAD-OFFSITE code was developed by Environmental Science Division, Argonne National Laboratory, Department of Energy (DOE), U.S.A for the evaluation of radiation dose and assess cancer risks to an individual who directly spends his/her time on the primary contaminated area (onsite) or in the vicinity, of the primary contaminated area (offsite). For the execution of RESRAD-OFFSITE code, input data is required from the onsite contaminated zone (the zone in which radionuclides are present), for its modeling. For the modeling of RESRAD-OFFSITE code [14] different site specific parameters are required.

- Radionuclide concentration in the soil
- Agricultural areas and their contribution to dose
- Pastures, dwelling areas
- Well, and surface water body

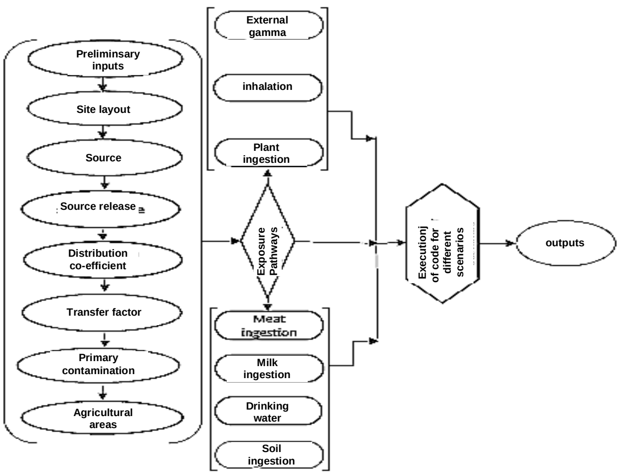

Fig. 2: RESRAD-OFFSITE model description

For the modeling of RESRAD-OFFSITE, there are three release models which are considered from the contaminated zone. Also considered is the radionuclide distribution and concentration from the contaminated zone. First model calculates the atmospheric release of the particulates due to suspension and diffusion by evapotranspiration processes. Secondly erosion by run-off water and groundwater release due to leaching by infiltrating water is taken into account. The release rates are used by the code to compute the transportation of the contaminants and the exposure at the offsite due to the onsite contamination. Another feature of the RESRAD-OFFSITE code (Ground water transport-model) is that it modulates the transfer factors of the parent nuclides as well as the daughter nuclides (process of decay and growth of radionuclides). In the RESRAD-OFFSITE model a feature of source release mechanism is also considered. For this feature two types of contaminated materials are considered, the first one is capable of decaying and the other is incapable of decaying. Therefore, two times-delay periods are required, the first is when the material is not decaying or is growing and the other is when the radionuclide is decaying or growing. Another feature of the RESRAD-OFFSITE code is the Area factor for offsite exposure scenario, which is defined as the ratio of calculated dose from the large primary contaminated area to the elevated area (hot spot) in the primary contamination.

In the exposure scenario, the area factor can be calculated by site specific parameters and probabilistic features of the code. Interface of the map of the code automatically calculates radiological dose and risk, for air and ground water transport distances. It also calculates the exposure scenario for a number of areas from a contaminated area, according to the number of user's specified conditions.

2.2 Initial Conditions and Assumptions

For the calculation of radiological doses, the geometry of the radiation source term, exposure distance between the source and the individuals and the reporting time are also considered [13].

2.2.1 Source term

The source term for the estimation of radiological dose was taken from published data [13], a source term, four radionuclide (40-K, 137-Cs, 226-Ra, and 232-Th) were considered. It is assumed that the concentrations of the radionuclides are uniform over the primary contamination. Three different soil layers up to 25cm were considered to be contaminated with the radionuclides by considering that the source was released from clean cover to the saturated zone through a depth of 0-25cm. The soil layers were categorized as, primary contamination, un-saturated zone and saturated zone.

2.2.2 Reporting time

The reporting time for the estimation of radiological dose for individuals residing off-site was taken as 8, 16, 24, 32, 40, 48, 56, 64, 72, and 80 years, in the RESRAD-OFFSITE code.

2.2.3 On-site and Off-site areas

The on-site area around the source term is 100 hectors (1000000m²), which is divided into co-ordinates, x-axis (1000m) and y-axis (1000m) [13]. The total area occupied by the off-site location is 100 hectors (1000000m²). This off-site area is divided into the co-ordinates-axis (1000m) and y-axis (1000m). The physical features of the off-site area e.g. the receiver spends zero time on the primary contamination in indoors and outdoors. Time spent by the receptor on the off-site dwelling area (indoor is 50% and outdoor is 10%).The receptors spend 10% time on farmed areas (which may lie on the primary and the secondary area) in fruit, grain, and no-leafy field and leafy vegetables fields and pasture and silage fields and livestock grain fields [13].

2.3 Exposure Pathways

In the exposure pathways five different exposure scenarios were considered. In the first scenario, radiological doses were calculated by taking into account all pathways (external gamma, inhalation, plant ingestion, meat ingestion, milk ingestion, drinking water and soil ingestion), using default inputs as defined by the RESRAD-OFFSITE code. In the second scenario, the radiological doses were calculated by considering all pathways (external gamma, inhalation, plant ingestion, meat ingestion, milk ingestion, drinking water and soil ingestion) using the model input parameters as used in literature [14]. In the third scenario, the radiological doses were calculated by considering all pathways (external gamma, inhalation, plant ingestion, meat ingestion, milk ingestion, drinking water and soil ingestion) using site specific data from literature [1-13]. In the fourth scenario, the radiological doses were calculated from scenario-1, scenario-2 and scenario-3 were compared with literature [13] for finding the maximum and the minimum dose for different locations and for the site soil parameters of different sites. In the last case, the radiological dose was calculated using default input and for each exposure pathway to identify the contribution of each pathway to the cumulative dose to the individual.

2.4 Assumptions

Following assumption were made for the processing of the site soil specific data

i. Some of the parameters such as irrigation applied per year, weather conditions were not available on annual basis, so these conditions were taken as constant.

ii. For the weathering conditions, agricultural, livestock, feed growing area and off site dwelling area parameters were considered to be the same each year.

iii. The radionuclide concentration in the soil was considered to be uniform over the specified area.

iv. The ground water transport radionuclide parameters were considered to be uniform from the primary contamination to the un-saturated and saturated zones.

v. The distribution and release rate of the radionuclides over the three layers was considered the same.

vi. The parameters (aquifer flow, irrigation, rain-fall factor, dry bulk density cover and management factor) values specified for the contaminated zone was the same for all radionuclide in the primary contamination zone.

vii. The reporting time for all radionuclides was the 8-80 yearssame.

2.5 Calculation Duration

To identify the severe effects of the radiological dose at the place on the offsite location, the zones where the radiological effects are most affective and common the calculations were performed for duration of 72 years.

3. Results and Discussions

3.1 Scenario I

In this scenario, the mean total dose equivalent to an individual for seventy two years, using default inputs, as defined by the RESRAD-OFFSITE code was estimated and is presented in Fig. 3 and Table 1 for, all exposure pathways (external gamma, inhalation of dust particles, plant ingestion, meat ingestion, milk ingestion, drinking water and soil ingestion). From data analysis, the maximum total effective dose of 1.606E-01(mSv) was obtained. The cumulative dose fluctuated with time.

3.2 Scenario II

In this scenario, the mean total dose equivalent to an individual for seventy two years, using model input parameters as used in literature [13] has been estimated and is presented in Fig. 3 and Table 2, for all pathways (external gamma, inhalation of dust particles, plant ingestion, meat ingestion, milk ingestion, drinking water and soil ingestion). From dose inclination analysis, the maximum total effective dose of 6.939E-01(mSv) was obtained. The cumulative dose fluctuated with time.

3.3 Scenario III

In this scenario, the mean total dose equivalent to an individual for seventy two years, for all pathways using site specific data from literature [1-14] at NIAB was estimated and is presented in Fig. 3 and Table 3, for all pathways (external gamma, inhalation of dust particles, plant ingestion, meat ingestion milk ingestion, drinking water and soil ingestion). From dose inclination analysis, the maximum total effective dose of 9.120E-02(mSv) was obtained. The cumulative dose fluctuated with time.

3.4 Scenario IV

In this scenario, the results from all 3 scenarios for the mean total dose equivalent to an individual for seventy two years were used. From the data analysis, a maximum dose of 6.939E-01 (mSv) was recorded at 72 years, and a minimum dose of 0.00005E-5 (mSv) was recorded at (0-7) years, from comparison of all output results of scenario-1, scenario-2 and scenario-3. This overall result for maximum dose was compared with literature [13] value of 0.23 (mSv) on annual basis. The dose fluctuated with time.

3.5 Scenario V

In last scenario, the mean total dose equivalent was estimated for all pathways for cumulative doses to the individual and are presented in Fig. 3.The maximum dose for scenario-1, scenario-2, scenario-3 and literature [13] data were 1.606E-01(mSv), 6.939E-01(mSv), 9.120E-02(mSv) at 72 years, 0.23(mSv) on annual basis respectively. Similarly the minimum dose for the scenario-1, scenario-2 and scenario-3, were 1.207E-01(mSv), 5.000E-05(mSv) and 5.23E-02(mSv) respectively at (0-7) years.

In Fig. 3, it can be seen that scenario-2 has a fluctuating trend, because initially the dose rate decreases with time. Radiological dose increases with time, due to the leaching of the radionuclides to ground water and increase in the growth of the progeny of the parent radionuclides. Moreover the distribution factors and erosion rates and the removal of clean cover from the primary contamination also cause variable dose rate. So after passage of time, radiological dose decreases by decay of parent and daughter radionuclides.

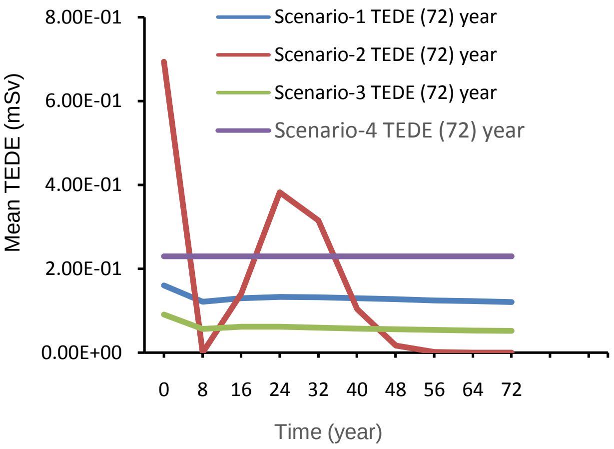

Fig. 3: Cumulative Results (Scenario-1, Scenario-2, Scenario-3 and, Scenario-4 [Mean TEDE with all Pathways (72hrs)]

4. Conclusions

From the data analysis presented in Fig. 3, the total mean effective dose were estimated, using site specific data as input parameters(aquifer flow, irrigation, rain-fall factor, dry bulk density cover and management factor),for the site of NIAB, Faisalabad. Based on the data analysis, the execution of RESRAD-OFFSITE code, a maximum dose of 9.120E-02 (mSv) was observed, for 72 years for scenario III. This dose limit is low as compared with the literature value of (0.23mSv) and the world average basic radiation dose limit of 1 mSv. Minimum dose of 1.207E-01mSv was obtained at seventy two years.

Table 1: Output Results of Scenario-1 (TEDE for all nuclides in 72 years)

Time ‘t’ (years)	TDOSE(t) (mSv/y)
0	1.606E-01
8	1.218E-01
16	1.299E-01
24	1.331E-01
32	1.322E-01
40	1.299E-01
48	1.274E-01
56	1.249E-01
64	1.227E-01
72	1.207E-01

Table 2: output Results of Scenario-2(TEDE for all nuclides in 72 years)

Time ‘t’ (years)	TDOSE(t) (mSv/y)
0	6.939E-01
8	2.584E-04
16	1.410E-01
24	3.822E-01
32	3.150E-01
40	1.041E-01
48	1.655E-02
56	1.699E-03
64	1.917E-04
72	5.000E-05

Table 3: Output Results of Scenario-3(TEDE for all nuclides in 72 years)

Time ‘t’ (years)	TDOSE(t) (mSv/y)
0	9.120E-02
8	5.707E-02
16	6.235E-02
24	6.185E-02
32	5.974E-02
40	5.763E-02
48	5.589E-02
56	5.454E-02
64	5.352E-02
72	5.275E-02

Table 4: Output Results of Scenario-4 (TEDE for all nuclides in 1 year)

Time ‘t’ (year)	TDOSE(t) (mSv/y)
01	0.23

The total mean effective dose was estimated, using model input parameters as given in literature [14]. Based on the data analysis, used for the execution of RESRAD-OFFSITE code a maximum dose of 2.34E-01(mSv), for 72 year, was observed. This dose limit is much lower as compared to the annual dose limit (0.23mSv)[13].The maximum dose in this scenario is lower than the world average dose rate of 1 (mSv).A minimum dose of 3.5E-04(mSv) was also obtained at seventy two year. The difference in doses is due to differences in site specific parameters in both scenarios (2 and 3).

Through analysis of total mean effective dose, using site specific parameters of NIAB site, Faisalabad, using RESRAD-OFFCODE maximum dose of 9.120E-02 (mSv) was obtained at (0-7) years. This dose limit is much lower as compared with dose values cited in literature [13].The maximum dose in this scenario 4 is less than the world average dose rate of 1 (mSv).

Through analysis, it can be seen that, the maximum dose received by an individual using site specific parameters at the NIAB site, is lower as compared to the literature values [1-13 & 13 14].

From the estimated results, it is concluded that the RESRAD-OFFSITE code is a very convenient code for the estimation of radiological doses. However, accuracy in estimation could be increased by using site specific input parameters accurately on an annual basis.

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