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Cancer Risk Assessment Due to Natural and Fallout Activity in Some Cities of Pakistan

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Abstract – The measured mean activities of ^{226}Ra, ^{232}Th, ^{40}K and^{137}Cs in the soil of Bahawalpur, Bahawalnagar and Rahimyar Khan Districts were 32.9, 53.6, 647.4 and 1.8 Bq kg^{-1}. The average absorbed dose rate calculated from these activities was 74.3 nGy h^{-1} and the mean annual effective dose rate was found to be 0.46 mSv y $^{-1}$. Absorbed doses to different body organs were derived from annual effective doses using tissue weighting factors. Radiation induced fatal cancer risks were assessed by using ICRP 60 Model. Estimations incurred 184deaths per year due to cancer.

Key words : Absorbed dose rate, annual equivalent dose, tissue weighting factors.

INTRODUCTION

The estimation of exposures of human populations from the various sources of radiation is an important and continuing goal of research. Many radionuclides occur naturally in terrestrial soils, rocks and building materials derived from them. Upon decay, these radionuclides produce an external radiation field to which all human beings are exposed. In terms of dose, the principal primordial radionuclides are ^{40}K, ^{232}Th and ^{238}U. Both ^{232}Th and ^{238}U series of radionuclidesproduce significant human exposures [1]. In addition to these naturally occurring nuclides, the fallout ^{137}Cs is also present in soil. The decay of radionuclides in soil produces a v-β radiation field in soil that also crosses the soil-air interface to produce exposures to humans.

Radioactive materials that decay spontaneously produce ionizing radiation, which has sufficient energy to strip away electrons from atoms creating ions or to break some chemical bonds. Any living tissue in the human body can be damaged by ionizing radiation. The body attempts to repair the damage, but sometimes the damage is too severe or widespread to repair. The long-life health effect of ionizing radiations is cancer. The estimated fatal cancer cases in the U.S.A. are 500 per 10,000 persons per sievert per year [2]. Other effects include nausea, weakness, and hair loss or diminished organ function. Fetus in the womb is also affected by radiation. These effects include smaller head or brain size, poorly formed eyes, abnormally slow growth, and mental retardation [3]. Studies indicate that fetuses are most sensitive between about eight to fifteen weeks after conception. They remain somewhat less sensitive between sixteen and twenty-five weeks old.

The study was carried out in southern part of Punjab, Pakistan, where the soil activity is higher than the world average which may cause the enhanced cases of cancer in this area. Some measures may be adopted to decrease the activity.

MATERIALS AND METHODS

The area under study extends three districts namely Bahawalnagar, Bahawalpur and Rahimyar Khan. The area lies between 27° 40′ - 30° 22′ North latitudes and 60º 45′-73º 58′ East longitudes. The areas of Bahawalnagar, Bahawalpur and Rahimyar Khan District are 8878, 24542 and 11880 sq. km, respectively. According to 1998 census [4-6] the population of this area was 7635500 persons.

Two methods of evaluating external exposures from radionuclides have been used. The first one is simply to summarize directly measured external γ dose rates in air outdoors and indoors, subtracting the dose rate due to cosmic rays. The other is to calculate the external gamma dose rates in air from measurements of the concentrations of the relevant radionuclides in soil. The two methods have provided generally consistent estimates of exposure. Surveys to determine the concentrations of radionuclides in soil have also been made. These results can be related to exposures by using estimates of the dose rates in air per unit concentration of radionuclides in soil. In this study the later method is adopted. In order to calculate the external dose rate, the knowledge of the specific gamma activities in soil is essential. The samples were collected during August, 2003 and the activity of soil was measured using standard methods of sampling and HPGe γ-spectrometer present in Pakistan Institute of Science and Technology, Nilore, Islamabad, Pakistan [7].

RESULTS AND DISCUSSION

The activities of soil samples taken from different towns of the areas under study are represented in Table 1.

The ^{226}Ra concentration is normally used instead of ^{238}U since there may not be equilibrium between them. The highest activity of ^{226}Ra, ^{232}Th and ^{40}K is found in Minchinabad and minimum in Derawer Fort, Fort Abbas and Liaqatpur, respectively. ^{40}K is the only nuclide

Table 1. Ativity of different nuclides in the different towns.

Towns	Mean activity (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Fort Abbas	29.9	52.3	669.1	3.0
Minchinabad	36.5	58.4	696.1	2.3
Hasilpur	30.9	49.9	651.2	1.3
Bahawalpur	35.1	57.0	633.9	0.8
Liaqatpur	36.0	58.4	584.8	0.8
Derawer Fort	28.8	51.2	677.9	2.0
R.Y.Khan	31.6	49.4	657.6	0.6
Sadiqabad	34.2	52.4	608.2	0.8
Mean	32.9	53.6	647.4	1.5

representing appreciable activity. ^{137}Cs has been found minimum in Bahawalpur while maximum in Rahimyar Khan.

When ionizing radiation passes through matter, including tissue, it deposits some of its energy in the traversed material as a result of electrical interactions. The resulting ionization of body tissue causes chemical changes in the irradiated cells that can potentially lead to biological damage.

The fundamental dosimetric measure of this energy transfer is the absorbed dose, which is defined as the amount of energy in Joules deposited by the radiation in 1kg of tissues and organs of the body. It is the result of the physical interactions of the ionizing radiation within the volume of material. An absorbed dose can be delivered by any type or combination of types of radiation in any type of material. The absorbed dose rate in air was measured by Eq.1. [8]

$$D = (0.604A_{Th} + 0.462A_{Ra} + 0.0417A_{K} + .001A_{Cs}) \text{ nGy h}^{-1} \quad (1)$$

Where A_{Th}, A_{Ra}, A_K and A_{Cs} are the activities of ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs respectively. The calculated absorbed dose rates are given in Table 2. Brazil, China, France, India, Iran and Italy have the highest absorbed dose rates with average ranging from 340 to 2800 nGy h^{-1} [1].

Table 2. The absorbed dose rates in the soil in different towns of southern Punjab, Pakistan.

Towns	D (nGy h^{-1})
Fort Abbas	73.3
Minchinabad	81.2
Hasilpur	71.6
Bahawalpur	77.1
Liaqatpur	76.3
Derawer Fort	72.5
Rahimyar Khan	69.8
Sadiqabad	72.8
Mean	74.3

Table 3. The equivalent dose rates of different towns.

Towns	Annual effective dose (mSv Y^{-1})
Fort Abbas	0.44
Minchinabad	0.50
Hasilpur	0.44
Bahawalpur	0.48
Liaqatpur	0.47
Derawer Fort	0.44
Rahimyar Khan	0.44
Sadiqabad	0.45
Mean	0.46

The absorbed dose is independent of the type and energy of the radiation; however, it was soon discovered that similar doses of radiation from different particles produced different amounts of biologic damage. For this reason, the concept of equivalent dose was established for purposes of radiation protection. Equivalent dose (H_T) in a tissue or organ, T, is the product of absorbed dose averaged within a tissue (D_T) and a radiation weighting factor (w_R), and thus [2]

$$H_T = D_T \cdot w_R \quad (2)$$

Radioactive radiation consists of α, β and V particles; among which α particles are stopped by the upper dead layer of our skin. The value of radiation weighting factor (w_R) for β and V particles is 1. Therefore, in our study the values of absorbed dose rates in Table1 also represent equivalent dose rates in nSv. This equivalent dose per hour can be converted to annual equivalent dose in air by multiplying it with 8760 hours of a year. Q is the factor which converts the dose in air to the effective dose harmful for the body. Its value is 0.7, 0.8 and 0.9 Sv Gy^{-1} y^{-1} for adults, children and infants, respectively in case of environmental exposure to gamma rays of moderate energy [1]. For simplicity the value of 0.7 is used in this study. The annual effective dose with occupancy factor 1 can be calculated as [9]:

$$H_T = T\ Q\ D \times 10^{-6} \quad (3)$$

Where H_T is annual equivalent dose, 10^{-6} is the factor converting nano into milli and D is the absorbed dose rate in air in nGy h^{-1}. T is time in hours in one year. From Eq. 3 the annual effective dose in the area under study has been calculated (Table 3).

From Table 3 it is obvious that the mean annual effective dose rate in the area under study is 0.46 mSv Y^{-1} ranging from 0.44 to 0.50 mSv Y^{-1} whereas the world average terrestrial annual effective dose is 0.48 mSv $y^{-1}$with range of 0.3-0.6 mSv Y^{-1} [1]. This effective dose rate is for whole body. However, the harm induced by radiation exposure has also been found to depend on the specific organ or tissue irradiated. The risk of induced cancer or hereditary disorders varies between organs for the same equivalent dose. To account for the various susceptibilities of the organs and tissues, a set of tissue weighting factors has been developed [2]. Effective dose is a measure of dose designed to reflect the amount of radiation detriment likely to result from the dose. Values of effective dose from any type of radiation and mode of exposure can be compared directly. The effective dose delivered to each organ can be calculated as [2]

$$E = \sum_T w_T \cdot H_T \quad (4)$$

Where, H_T is the equivalent dose in tissue T and w_T is the tissue weighting factor for tissue Table 4 represents the tissue weighting factors

Table 4. Tissue weighting factors for different organs and their measured values for the area under study.

Tissue or organ	Tissue weighting factor (W_T)	Effective dose to organs in the areas under study ($mSvY^{-1}$)								
		Fort Abbas	Minchina bad	Hasilpur	Bahawal pur	Liaqatpur	Derawer Fort	Rahimyar Khan	Sadiqabad	Mean
Gonads (testes or ovaries)	0.20	0.088	0.100	0.088	0.096	0.094	0.088	0.088	0.090	0.092
Red bone marrow	0.12	0.053	0.06	0.053	0.0576	0.0564	0.053	0.053	0.054	0.055
Colon	0.12	0.053	0.06	0.053	0.0576	0.0564	0.053	0.053	0.054	0.055
Lung	0.12	0.053	0.06	0.053	0.0576	0.0564	0.053	0.053	0.054	0.055
Stomach	0.12	0.053	0.06	0.053	0.0576	0.0564	0.053	0.053	0.054	0.055
Bladder	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Breast	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Liver	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Esophagus	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Thyroid gland	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Skin	0.01	0.044	0.005	0.044	0.0048	0.0047	0.044	0.044	0.0045	0.005
Bone surfaces	0.01	0.044	0.005	0.044	0.0048	0.0047	0.044	0.044	0.0045	0.005
Remainder	0.05	0.022	0.025	0.022	0.024	0.0235	0.022	0.022	0.0225	0.023
Whole body	1.00	0.44	0.50	0.44	0.48	0.47	0.44	0.44	0.45	0.46

for different organs of the human body and the measured effective doses for different organs and tissues.

It is obvious that the average dose to different organs of the people in the area under study are 0.092 mSv y^{-1} for gonads; 0.023 mSv y^{-1} for bladder, breast, liver, esophagus and thyroid gland; 0.055 mSv y^{-1} for red bone marrow, colon, lung and stomach; 0.005 mSv y^{-1} for skin and bone surfaces; 0.023 mSv y^{-1} for remainder and 0.46 mSv y^{-1} for whole body. W_T for the remainder is divided equally between adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, and uterus.

Estimates of radiological cancer risk from natural and fallout radiation are based on epidemiological studies of human populations exposed to high doses of radiation. The main source of information on the risk of radiation-induced cancer following whole-body exposure to external radiation comes from the follow-up studies on the Japanese survivors of the 1945 atomic bombings of Hiroshima and Nagasaki. Other studied populations include miners exposed to high concentrations of radon and its decay products in air, early radium dial painters who inadvertently ingested appreciable amounts of radium, and patients treated with high doses of medical x-rays, or given radium-224, radium-226 or thorotrast (thorium oxide). Additional information has been derived from extensive experiments on animals and other organisms.

Problems associated with the use of data on excess cancers in Japanese bomb survivors to predict consequences at lower levels of dose and dose rate have been extensively discussed in BEIR, UNSCEAR and ICRP reports. One problem is how to extrapolate the data on increased numbers of cancer experienced by the bomb survivors in the first 40 years following exposure to predict the increase that will occur

Table 5. Estimated fatal cancer risk (except leukemia) in the population of the area under study.

Cancer si	Risk factor fatal Cancer per 10,000 persons (Sv^{-1})	Estimated total fatal risk (Y^{-1})								
		Fort Abbas	Minchin abad	Hasil pur	Bahawal pur	Liaqat pur	Derawer Fort	Rahimyar Khan	Sadiq abad	Mean
Ovary	10	3.52	4.00	3.52	3.84	3.76	3.52	3.52	3.60	3.68
Colon	85	29.92	34.00	29.92	32.64	31.96	29.92	29.92	30.60	31.28
Lung	85	29.92	34.00	29.92	32.64	31.96	29.92	29.92	30.60	31.28
Stomach	110	38.72	44.00	38.72	42.24	41.36	38.72	38.72	39.60	40.48
Bladder	30	10.56	12.00	10.56	11.52	11.28	10.56	10.56	10.8	11.04
Breast	20	7.04	8.00	7.04	7.68	7.52	7.04	7.04	7.20	7.36
Liver	15	5.28	6.00	5.28	5.76	5.64	5.28	5.28	5.40	5.52
Esophagus	30	10.56	12.00	10.56	11.52	11.28	10.56	10.56	10.8	11.04
Thyroid gland	8	2.82	3.20	2.82	3.07	3.01	2.82	2.82	2.88	2.95
Skin	2	0.704	0.800	0.704	0.768	0.752	0.704	0.704	0.720	0.736
Bone marrow	50	17.60	20.00	17.60	19.20	18.80	17.60	17.60	18.00	18.40
Bone surfaces	5	1.76	2.0	1.76	1.92	1.88	1.76	1.76	1.80	1.84
Remainder	50	17.60	20.00	17.60	19.20	18.80	17.60	17.60	18.00	18.40
Whole body	500	176	200	176	192	188	176	176	180	184

over the total lifespan of the population. Various models relating the increase of cancer with age after exposure have been used to obtain lifetime risk estimates.

A second problem is how to apply the lifetime risk of various cancers occurring in a Japanese population to other populations. Because of different cancer incidence patterns in Japan and other countries, extrapolation to other populations is difficult. The ICRP 60 estimates were obtained by averaging results from two different extrapolation models and applying them to the population of five countries.

A third problem is the extrapolation of data from populations exposed to various whole body dosesof external radiation at high dose rates, to predicted effects of radiation at low dose rates. Based on theoretical considerations, experimental animal studies, and some limited human data, ICRP 60 has adopted the convention of dividing the cancer risks observed at high doses and high dose rates of x- and V-rays by a dose and dose rate effectiveness factor of two in order to obtain cancer risk estimates for low doses of ionizing radiation at low dose rates. UNSCEAR, 1993 [10] defined low doses as less than 200 mSv and low dose rates as less than 0.1 mSv min^{-1} or 6 mSv h^{-1} it should be noted that these doses and dose rates are very high compared to typical public doses.

Despite these problems and the uncertainties involved, an estimate of the probability of radiation-induced cancers is needed for use in radiation protection. Based on extrapolations from high dose epidemiological studies, ICRP Publication 60 recommends lifetime fatal cancer risk estimates of 0.04 Sv^{-1} for the adult population, and 0.05 $Sv^{-1}$for the entire population including all age groups, following a protracted whole body exposure of low dose and low dose rate radiation. Table 5 shows the estimates of fatal cancer according to ICRP 60 risk model.

The activities of ^{226}Ra, ^{232}Th and ^{40}K in the soil of Bahawalnagar, Bahawalpur and Rahimyar

Khan were higher than the global average, which are 32, 30 and 400 Bq kg^{-1}, respectively [1]. This higher activity reflected in absorbed dose rates whose global average is 57 nGy h^{-1} and indicated more incidences of cancer. By applying risk model from ICRP 60 it was estimated that 500 persons per 10,000 per year might be died of cancer due to terrestrial exposure. According to the latest census [2-4] the population of the area under study is 7635500 persons. Multiplying the estimated incidences with the rounded figure as 8000000, a total of 184 cancer deaths each year is obtained.

Bahawalpur Institute of Nuclear Medicine and Oncology (BINO)registered 739 cancer patients of different organ sites in the year 2002. According to this report there is more number of cancer cases in females than males. Figure 1 shows the trends in cancer in different organs and tissues.

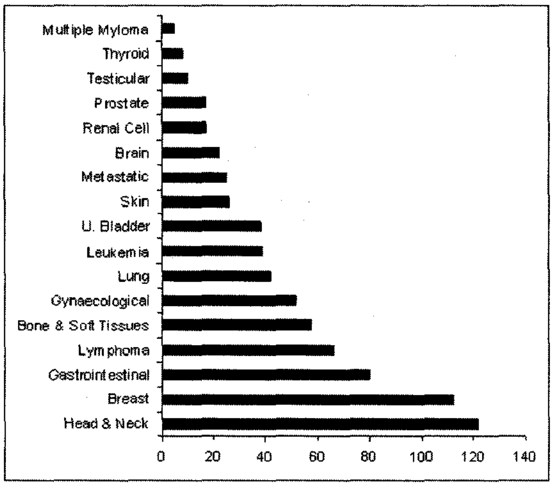

Fig. 1. Patients of different cancer sites coming to BINO in the year 2002.

CONCLUSIONS

Cancer risk due to natural and fallout radionuclides is of three fold; exposure, inhalation and ingestion. Risk due to exposure was estimated to be 184 cancer deaths per year with annual effective dose of 0.5 mSv Y^{-1}. A detailed estimate of cancer risk for each organ in different areas of the world (excluding Pakistan) can be seen in UNSCEAR, 2000 report. In the area under study risk due to inhalation of radon was estimated in a previous study and found to be 73 per million per year [11].The more cancer incidences in females is due to gynecologic tumor and breast tumor.

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