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- ***Review article***

Background radiation, people and the environment

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All living organisms are exposed to ionizing radiation comprising cosmic rays coming from outer space, terrestrial nuclides occurring in the earth's crust, building materials, air, water and foods and in the human body itself. The exposures are constant and uniform for all individuals everywhere including the dose from ingestion of ^{40}K in food. Cosmic rays are, more intense at higher altitudes, and the levels of uranium and thorium in soils are elevated in localized areas. Exposures also vary as a result of human activities and practices. In particular, building materials of houses and the design and ventilation systems strongly influences the indoor levels of the radioactive gas radon and its decay products, which contributes the doses through inhalation. Component of the sources of exposures to Indian population has been assessed based on the data generated. Total contribution from the natural sources to the Indian population works out to 2.3 mSv/y as against the global value of 2.4 mSv/y. Estimated modified source including mining of heavy metals, coal fired power plants, mining of phosphate rocks and its use as fertilizers, production of natural gas, gas mantles and luminescent dial and air travel contribution to the background radiation to the Indian population works out to be 1.2×10^{-3} mSv/y; atmospheric weapon tests contributes about 0.045 mSv/y, medical exposure contributes about 0.048 mSv/y and exposure due to nuclear power production contributes about 5.0×10^{-5} mSv/y to the background radiation. Brief review and comparison of the dose rates arising from natural and man made sources to the Indian population is given. **Iran. J. Radiat. Res., 2011; 9(2): 63-76**

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INTRODUCTION

Man is exposed to ionizing radiation spontaneously emitted by naturally occurring atomic species like ^{238}U and ^{232}Th ever since his existence on the earth. Three types of radiations, alpha, beta and gamma are emitted by different radioactive materials; which differ in their energy and penetrating power. One was exposed to radiation only from natural sources until recent times, when the growth of nuclear energy has created other sources of exposures, like fallout from weapon tests, radioactive releases from nuclear reactor operations and accidents, exposure due to radioactive waste deposals and industrial, medical and agricultural use of radioisotopes. Still, the major contribution to the average annual background radiation arises from natural sources. Exposures from natural sources are due to (a) external source of extra terrestrial origin (cosmic rays), (b) source of terrestrial origin (radioactive nuclides present in earth's crust, in atmosphere and in building materials), (c) internal exposure from radio nuclides taken in to the body through ingestion of food materials etc., and (d) indoor inhalation exposures due to radon (^{222}Rn), thoron (^{220}Rn) and their daughters. Some of these exposures are relatively constant and uniform to all individuals throughout the world; while others vary depending on the location and due to elevated levels of naturally occurring radioactive substances like uranium (^{238}U) and thorium (^{232}Th) in specific localized areas. All exposures except those from the direct cosmic radiation are produced by the radioactivity of the natural radionuclides present in the environment [1, 2].

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Table 1[3], table 2 [4-6] and table 3 [7, 8] respectively gives the reported cosmic ray dose rates at various altitudes, production rates and levels of cosmogenic radionuclides in the atmosphere and natural radionuclides produced by cosmic rays and terrestrial sources which are of interest present in the atmospheric environment respectively. Table 3 indicates the significance of ^{14}C and ^{7}B in terms of effective dose received by man annually. Values for ^{3}H and ^{14}C represent per nuclear explosion and can be marginally higher in locations where technologically induced activity prevails. Global average annual effective dose contribution from cosmogenic radionuclides through internal exposure is estimated to be about 0.015mSv/y [3].

Table 1. Cosmic Ray Dose Rates at Various Altitudes.

Elevation Above Sea level (m)	Equivalent Dose Rate ($\mu Sv.y^{-1}$)	Elevated Above Sea Level (m)	Equivalent Dose Rate ($\mu Sv.y^{-1}$)
0 – 150	260 – 270	1220 –1828	390 - 520
150 – 305	270 – 280	1828 – 2438	520 – 740
305 – 610	280 – 310	1438 – 3408	740 – 1070
610 – 1220	310 – 390	> 3408	1070

Table 2. Global Production Rates and Levels of Cosmogenic Radionuclides in the Atmosphere.

Nuclides	Global Production Rate		Global inventory (P.Bq)
	Per unit area (atoms. $m^{-2}.s^{-1}$)	(PBq $.y^{-1}$)	
^{3}H	2500	72	1275
^{7}B	810	1960	413
^{10}B	450	0.000064	230
^{14}C	25000	1.54	12750
^{22}Na	0.86	0.12	0.44
^{26}Al	1.4	0.000001	0.71
^{32}Si	1.6	0.00087	0.82
^{32}P	8.1	73	4.1
^{33}P	6.8	35	3.5
^{35}S	14	21	7.1
^{36}Cl	11	0.000013	5.6
^{37}Ar	8.3	31	4.2
^{39}Ar	56	0.074	.6
^{81}Kr	0.01	1.7×10^{-8}	0.005

Table 3. Natural Radionuclides in the Atmospheric Environment.

Isotope produced by cosmic rays			Isotopes produced from terrestrial sources		
Isotope	Half-life	Radiation emitted	Isotope	Half-life	Radiation emitted
^{14}C	5730 y	Beta	^{222}Rn(Radon)	3.82 d	Alpha
^{32}Si	650 y	Beta	^{218}Po(RaA)	3.05 m	Alpha
^{39}Ar	269 y	Beta	^{214}Pb(RaB)	26.8 m	Beta, gamma
^{3}H	12.3 y	Beta	^{214}Bi(RaC)	19.7 m	Alpha, beta, gamma
^{22}Na	2.6 y	Beta, gamma	^{210}Pb(RaD)	20.4 y	Beta
^{35}S	87 d	Beta	^{210}Bi(RaE)	5.0 d	Beta
^{7}Be	53 d	Gamma(EC)	^{210}Po(RaF)	138.4 d	Alpha
^{37}Ar	35 d	Gamma(EC)	^{220}Rn(Thoron)	55 s	Alpha
^{33}P	25 d	Beta	^{216}Po(ThA)	0.158 s	Alpha
^{32}P	14 d	Beta	^{212}Pb(ThB)	10.64 h	Beta, gamma
^{24}Na	15 hr	Beta, gamma	^{212}Bi(ThC)	60.6 m	Alpha, Beta, gamma

Natural radioactivity present on the earth's crust belongs to virgin and modified sources. Virgin sources are cosmogenic or primordial (terrestrial) and have existed on the earth since primordial times. Modified sources are from activities like uranium mining, usage of fossil fuel, production of fertilizers or naturally occurring radioactive materials used for building construction. Latter is known as technologically enhanced natural radioactive materials (TENORM). Sources of man made radiation include nuclear fuel cycle operation, nuclear weapon tests, medical and industrial applications of radionuclides. Extent of exposure to these sources depends on occupation, type of dwelling, location of habitation, life style and level of medical care one receives. Exposures due to natural radiation are of particular importance because it accounts for the largest contribution (nearly 53 %) to the total collective radiation dose to the world population [3].

Major contribution of doses from normal background regions arises from the inhalation of ^{222}Rn,^{220}Rn and their short lived progeny. ^{222}Rn and ^{220}Rn are ubiquitous, and are produced in the course of decay of ^{238}U and ^{232}Th series. Being inert gases, they escape to the atmosphere by diffusion and advection. They emanate from soil and walls of the buildings. Relatively constant exposure to population at a location is the distinctive characteristics of this mode of exposure. Virgin sources due to cosmic ray radiation consist of protons (85 %), alpha particles (14 %) and about 1 % from nuclei of atomic number between 4 and 26. These particles are highly penetrating and have high energy. Attenuation in the atmosphere decreases the flux of the cosmic rays on the earth's surface. As a result of this, the cosmic ray exposure becomes double for every 1500 meters above the earth's surface. Cosmic rays are the dominant source of ionization in the atmosphere from an altitude of 70 km down to around 1 km. Below this the ionization produced by cosmic ray is comparable to that of airborne and terrestrial radioactivity. At sea level nearly 80 % of ionization is caused by natural radioactivity, mainly by the emission of alpha particles from airborne radionuclides. Cosmic rays contribute mainly to the external exposure.

Attenuation of cosmic rays is also caused by buildings, which results in reduction up to 20 % in the cosmic ray exposure indoors. Number of radionuclides are produced by cosmic ray radiation through the interaction of the heavy charged particles coming from outer space, with the atmosphere, which contribute to the natural radiation exposures. Some of the significant cosmogenic nuclides thus produced are ^{3}H, ^{7}Be, ^{14}C and ^{22}Na which contribute mainly to internal exposure through inhalation. Concentration of a few cosmogenic radionuclides in various environmental matrices along with their annual intake and resulting average effective dose to man are presented in table 4 [9, 10]. Radiations from the widespread radioactive substances in rocks and soil, primarily those from the ^{238}U and ^{232}Th series, and from ^{40}K also contribute to ion production in the air, mainly by beta and gamma emission. In general, individual annual effective doses from cosmic ray radiation around the world ranges between 0.26 to 2.00 mSv/y with a mean value of 0.380 mSv/y. Average effective dose from cosmic ray radiation in India is estimated to be about 0.355 mSv/y [11]. Since the dose rate from cosmic radiation increases with altitudes, in high altitude locations like Gulmarg in India, the annual effective dose to residents is about 830 μSv/y [12].

Radionuclide existed on the earth's crust since its formation is referred as primordial radionuclide. They are isotopes of heavy elements. Main primordial nuclides are ^{40}K and ^{87}Rb and the isotopes of ^{238}U and ^{232}Th. ^{40}K is only 0.0118 % of natural potassium but is wide spread, and is important in the food chain. Natural radiation in environment is also caused by the isotopes of ^{238}U and ^{232}Th and their long-lived decay chains

as well as by ^{40}K, present in rocks and soil and gives rise to external exposure. Concentrations of these nuclides in various matrices are given in table 5 [13].

Levels of terrestrial radiation differ from place to place as the concentrations of these nuclides in earth's crust vary considerably. In India, regions of Maharashtra and South Gujarat covered by the Decan lava basalt are found to have low radioactivity content. Gangetic alluvial regions covering parts of Uttar Pradesh, Bihar and West Bengal have higher natural radioactivity, while the granite region of Andhra Pradesh exhibits higher levels of the primordial radioactivity [14]. Mean external dose rate from natural sources in high background regions of Kerala and Tamil Nadu, where ^{232}Th content is high in the monazite sand, is estimated to have a high value of 4.0 mSv/y and in some locations along the coastal strips, the annual external dose exceeds even 32.5 mSv/y [15,16]. ^{238}U and ^{232}Th isotopes being alpha emitters do not contribute significantly to the natural background radiation since the penetrating power of alpha radiation is very low. Their levels in the environment are too small to contribute significantly to the dose. But food and human tissues contain ^{238}U and ^{232}Th derived from soil and fertilizers, and this gives rise to internal dose of alpha radiation to our body. In India, based on a country-wide survey of outdoor natural gamma radiation using thermoluminescent dosimeters (TLD), covering more than 200 locations, spread over a period of two years, has yielded a national average value of 0.734 mSv/y as external terrestrial gamma background radiation consisting of contributions from cosmic ray component of 0.355 mSv/y and terrestrial component of 0.379 mSv/y [15]. Out of the total terrestrial component, 48.7 % is contributed by ^{40}K and the rest is from ^{232}Th (33.6 %) and ^{238}U series (17.7 %) [11, 14, 23].

Internal exposure is due to the ingestion of ^{238}U, ^{232}Th and the radionuclides produced by the decay of these as well as ^{40}K,

Table 4 . Annual Intake of cosmogenic radionuclides and the resulting effective dose.

Nuclide	Concentration ($Bq.m^{-3}$)	Intake ($Bq.y^{-1}$)	Effective dose ($\mu Sv.y^{-1}$)
^{3}H	Surface water : 400 Ocean water : 100	500	0.01
^{7}B	Air : 0.03 Rain water : 700	100	3.0
^{14}C	Specific activity : 227 (Bq/kgC)	20000	12
^{22}Na	Air : 3.0×10^{-7}	50	0.2

Table 5. Concentration of primordial radionuclides in various environmental matrices.

Environmental Matrix	^{238}U	^{226}Ra	^{40}K	^{87}Rb
Igneous rock (Bq/g)	0.04	0.048	1.2	-
Phosphate rock(Bq/g)	1.60	1.50	0.4	-
Lime stone (mBq/g)	16.0	5.0 – 20.0	30.0 – 150.0	-
Soil (mBq/g)	37.0	16.0	100.0	-
Air (µBq/m3)	1.2	1.5	22.0	-
Surface water (mBq/l)	0.18 – 62.9	0.4 – 111.0	$3.7\times 10^{2} – 2.4 \times 10^{5}$	0.9
Ocean surface water (mBq/l)	44.4	1.3 – 3.1	1.1×10^{4}	100.0
Ocean bottom water (mBq/l)	40.0	3.0 – 5.6	1.1×10^{4}	-
Human (Bq)	1.3 – 1.6	1.0 – 1.5	6300.0	455.0
Daily intake by human (mBq)	13.0	190.0 – 270.0	$1\times 10^{5} – 1.4 \times 10^{5}$	7000.0
Annual effective dose (µSv)	1.2	7.0	180.0	6.0

through dietary intake. It is estimated that on a global average the ingestion dose due to intake of food containing ^{238}U and ^{232}Th series nuclide works out to be 0.140 mSv/y and that due to ^{40}K is 0.170 mSv/y. Total dose received through ingestion pathway of dietary intake of long-lived radionuclide of ^{238}U and ^{232}Th series as well as ^{40}K works out to 0.310 mSv/y globally. Primordial radionuclides like ^{238}U and ^{232}Th series produce daughter nuclides by radioactive decay and contribute radiation dose due to the gamma emissions from ^{226}Ra and ^{224}Ra. Major contribution of doses from natural radiation arises from inhalation of ^{222}Rn and ^{220}Rn daughters [18]. ^{222}Rn and ^{220}Rn, are rare gases formed in the decay chain of ^{238}U and ^{232}Th series. It escape through the pores of the soil and diffuse to atmosphere in quantities depending up on the radioactive content and types of the soil and the prevailing atmospheric conditions, and give rise to inhalation exposures. Emanation over the sea is very small when compared to that over the land, due to its low radioactivity content. Typical worldwide outdoor levels of ^{222}Rn and ^{220}Rn are about 10 $Bq.m^{-3}$; while that of indoor radon and thoron are estimated to be 40 and 10 $Bq.m^{-3}$ respectively [3].

In India, based on a countrywide survey of indoor ^{222}Rn and ^{220}Rn , covering more than 2000 houses and more than 4000 quarterly measurements made out of different types of construction material spread over 130 locations at different parts of the country using solid state nuclear track detector (SSNTD) based twin chamber ^{222}Rn-^{220}Rn dosimeters for a period of three years has yielded a national average value for the inhalation dose due to ^{222}Rn, ^{220}Rn and their progenies equal to 1.235 mSv/y [19,20]. This estimate is based on the assumption that a person spends about two third of the day indoors and the remaining period outdoors. Contribution due to ^{220}Rn and its progeny works out to be nearly 15 % of the total inhalation dose. Above dose rate is comparable with the global value of 1.275 mSv/y. Total annual effective doses from natural radiation sources to the members of the Indian public works out to be 2.299 mSv/y; which can be compared with the global value of 2.455 mSv/y (table 6). Table 7 gives estimated natural background radiation levels in India major cities. Table 8 gives the estimated natural background radiation at some of the DAE installations in India (mSv/y) [21].

The houses where one leaves are made up of materials which contains natural radioactivity due to uranium, thorium and potassium. The gamma radiation arising from the walls, floors and ceilings, and radon and thoron and their progeny are the major sources of radiation exposures. Especially in closed rooms, radon is the significant dose contributing factor. Table 9

Table 6. Radiation exposures to Indian population from different natural sources and its comparison with the reported global value.

Radiation Sources	India		World	
	Annual Effective dose (mSv/y)	Percent contribution	Annual Effective dose (mSv/y)	Percent contribution
External:				
Cosmic radiation	0.355	15.44	0.380	16.14
Terrestrial	0.379	16.48	0.480	19.55
Internal:				
Cosmogenic nuclide (inhalation)	0.015	0.65	0.010	0.41
^{222}Rn and ^{220}Rn (inhalation)	1.235	53.72	1.275	51.94
Terrestrial	0.315	13.70	0.310	12.63
Total (ROUNDED OFF)	**2.30**	**100.0**	**2.5**	**100.0**

gives the natural radioactivity (Bq/kg) in commonly used building materials in India [22]. There are some locations around the world where the general public are exposed higher background radiation such as high background radiation areas where the gamma background radiation levels are high either due to uranium mining, high monazite deposits of water springs. The estimated radiation levels across these regions around the world are given in table 10.

Table 7. Estimated natural background radiation levels in Indian major cities.

City	Cosmic Ray component (mSv/y)	Terrestrial component (mSv/y)	Inhalation component (Rn +Tn) (mSv/y)	Cosmogenic component inhalation (mSv/y)	Ingestion through diet (mSv/y)	Total (mSv/y)
Bangalore	0.287	0.412	0.70	0.015	0.315	1.729
Chennai	0.287	0.536	0.55	0.015	0.315	1.703
Delhi	0.287	0.477	0.70	0.015	0.315	1.794
Hyderabad	0.287	0.875	1.09	0.015	0.315	2.582
Kolkatta	0.287	0.568	1.76	0.015	0.315	2.975
Mumbai	0.287	0.202	0.62	0.015	0.315	1.439
Nagpur	0.287	0.317	1.96	0.015	0.315	2.894
Trivandrum	0.287	0.412	0.70	0.015	0.315	1.729

Table 8. Natural background radiation levels at some of DAE installations in India (mSv/y).

Location	Background radiation dose (mSv/y)	Locations	Background radiation dose (mSv/y)
RAPS	0.60 – 1.01	NAPS	1.04 – 2.28
KAPS	0.63 – 0.91	UCIL, Jaduguda	0.99 – 2.22
TAPS	0.56 – 1.12	NFC, Hyderabad	1.63 – 2.79
BARC	0.45 – 0.70	MAPS	1.11 – 2.79
Kaiga	0.46 – 1.15		
IRE, Alwaye	0.56 – 1.12		

Table 9. Natural radioactivity content in commonly used building materials in India.

Material	Concentration (Bq/kg)			Material	Concentration (Bq/kg)		
	^{40}K	^{226}Ra	^{232}Th		^{40}K	^{226}Ra	^{232}Th
Cement	5 -385	16- 377	8 – 78	Clay	6 – 477	7 – 1621	4 – 311
Brick	130 – 1390	21 – 48	26 – 126	Fly ash	6 – 522	7 – 670	30 – 159
Stone	48 – 1479	6 – 155	5 – 412	Lime stone	6 – 518	1 – 26	1 – 33
Sand	5 – 1074	1- 5047	4 – 2971	Gypsum	70 -807	7 - 807	1 - 152
Granite	76-1380	4 - 98	103 - 240				

Table 10. Radioactivity content in coal and fly ash in India.

Radionuclide	Coal(Bq/kg)	Fly-ash(Bq/kg)
^{40}K	50 – 100	250 – 700
^{238}U series	16 – 27	200 - 150
^{232}Th series	8 – 27	50- 150

MODIFIED NATURAL SOURCES

Fossil fuels contain tracer quantity of cosmogenic radionuclides and large amount of primordial radionuclides ^{226}Ra, ^{224}Ra and ^{40}K come out into the environment on burning of these fuel and cause modified natural radiation dose to the population. Among the fossil fuels, coal contains the highest radioactivity and coal burning produces large amount of particulate emissions. Fly ash mass is less than that of coal and therefore, contains more radioactivity than coal itself. Major pathway for radiation exposure from coal-fired power plant is through inhalation. Table 10 gives the estimated radioactivity content in coal and fly ash samples in India [23]. Annual average release rates of radioactivity from various thermal power plants (TPS) in India using coal as a fuel are presented in table 11 [24,23].

Estimated annual per caput dose due to TPS operation using coal as fuel works out to be about 2.0 P × 10^{-4} mSv/y. Other technologically modified sources of radiation include mining operation of heavy metals (like lead, zinc, copper, manganese and gold), mining of phosphate rock and its use in consumer products. Table 12 gives the estimated effective collective dose equivalent to the population residing in 90 km radius area of 10000 MW(e) power generation plants for years plant operation [25].

The global nuclear industry with more than 430 operating nuclear reactors, having more than 8000 reactor years operational time, has produced just one serious accident with not a very large number of causalities immediately or even many years after the accident. Mean while, production and consumption of fossil fuel yields a constant flow of accidents and diseases, in addition to the green house gases. As per WHO report, about three million person die each year due to air pollution from the global energy production system dominated by fossil fuel. Table 13 gives the green house gas emission from electric production from various sources [21]. Table 14 gives the comparison between wastes from a nuclear reactor and a coal based thermal power plant of 1000 MW(e) capacity each [21]. Table 15 gives estimated per caput dose to Indian population from these modified sources of radiation. Total contribution from these works out to be 1.24 × 10^{-3} mSv/y.

Table 11. Annual Average Release Rate of Radioactivity From TPS in India.

Installed capacity (MWe)	Radioactivity released (GBq/y)		
	^{226}Ra	^{228}Th	^{40}K
200 – 400	0.16 – 0.84	0.22 – 1.70	0.37 – 11.2
400 – 600	0.48 – 3.70	1.22 – 2.01	3.04 – 19.5
600 – 800	0.45 – 1.90	0.70 – 4.00	2.24 – 5.90

Table 12. Estimated effective collective dose equivalent to the population residing with in 90 km radius of 10000 MW(e) power generating plants of years operation (man-Sv/y).

Organ	Dose excluding ingestion pathway	Dose including ingestion pathway	Organ	Dose excluding ingestion pathways	Dose including ingestion pathways
Whole body dose	4.7	40.0	Organ dose(bone, lung and thyroid)	73.0	206.0
Organ doses (all included)	83.0	235.0			

Table 13. Greenhouse gas emission from electricity production.

Source	Grams CO_2 equivalent/kWh	
	Indirect emission from life cycle	**Direct emission from burning**
Coal	289	1019
Gas	113	362
Hydro	236	…
Solar PV	280	…
Wind	21	…
Nuclear	10	…

Table 14. Comparison between wastes from a nuclear reactor and coal based thermal power plants each of 1000 MW(e) capacity.

Thermal Power Plant	Ash: 320,000 tonnes; CO_2: 6.5 million tones SO_2: 44,000 tonnes : NO_2: 22,000 tonnes
Nuclear Power Plant	High level waste : 27 tonnes of spend fuel or 3 Cu.m after reprocessing and vitrification Intermediate Level : 310 tonnes ; Low level: 460 Tonnes

Table 15. Radiation exposure from modified natural sources.

Source	Radio nuclides	Annual Effective dose (mSv/y)
Mining of heavy metal	Radon and daughters	0.69×10^{-3}
Coal fired power plant	^{226}Ra and ^{228Th}	0.20×10^{-3}
Mining of phosphate rock	$^{238}U$and ^{232}Th series and ^{40}K	0.012×10^{-3}
Natural gas	^{222}Rn and daughters	0.13×10^{-3}
Production of gas mantles	^{232}Th	4.54×10^{-5}
Luminescent dial production	^{3}H	3.8×10^{-5}
Air travel	Cosmic radiation	0.12×10^{-3}
Total		**1.24×10^{-3}**

Other man-made sources of radiation exposure include fallout from weapon tests; operation of nuclear power plants as well as medical and industrial applications of radionuclides. With the Trinity test of 1945, the era of nuclear weapon testing began and so did the global distribution of radioactive fallout from these tests. A total of 543 atmospheric weapon tests (including additional 39 safety tests carried out by United States, 12 carried out by United Kingdom and 5 carried out by France) are being carried during the period 1945 to 1980 giving a total yield of 440 Mt (comprising of 189 Mt due to fission and 251 Mt due to fusion) by all nuclear weapon countries all over the world. This gives a partitioned fission yield due to local and region (29 Mt), troposphere (16 Mt) and stratosphere (145Mt). These were carried out at different locations on and above the earth's surface, including mounting of towers, placemen on burgers on the ocean surfaces, suspension from balloons, drops from air planes and high altitude launching by rockets. Depending on the location of the detonation (altitude and latitude) the radioactive debris entered the local, regional, or global environment. A total of 25 tests of yield equal to or greater than 4 Mts were carried out giving a total fission yield of 106 Mt and fusion yield of 183 Mt [3]. These tests were of air, surface, barge, air drop type [3]. For tests conducted on the earth's surface, a portion of the radioactive debris is deposited at the site of the test (local fallout) and regionally up to several thousand kilometers down wind (intermediate fallout).

Fraction varies from test to test based on the meteorological conditions, height of the test, the type of surface and surrounding materials like water, soil, tower and balloon.

During the nuclear weapon detonation quite a large number of radioactive nuclides are released to the environment. Radionuclides released to the atmosphere following the nuclear weapon tests may reach the population either directly through inhalation or directly from deposited on the surface cause exposure to man either externally or internally through food chain. Table 16 gives the activity levels of some of the fallout radionuclides released to the atmosphere following the nuclear weapon tests during 1945 to 1999 [3]. Total release is derived from the estimated fission/fusion yields of the weapon tests with the atmospheric model. Measured results for ^{90}Sr and ^{137}Cs are for the period 1958 to 1965. Model values for ^{131}I, ^{144}Ba, ^{141}Ce, ^{103}Ru, ^{89}Sr, ^{91}Y and ^{95}Zr are normalized to total hemispheric deposition estimated from available measured values.

Table 17 gives the estimated external exposure due to radionuclides produced in atmosphere following nuclear weapon tests during 1945 to 1999 period [3]. Since most of the nuclear tests were carried out in the northern hemisphere the estimated external exposures were found to be high in this region as compared to southern hemisphere. Because of the preferential exchange of air between the stratosphere and troposphere in mid-latitudes, and the air circulation patterns in the troposphere, there has been enhanced deposition in the temperate regions, and lower deposition, by about a factor of two, in equatorial and polar regions. Table 18 gives the ingestion exposure to radionuclides produced in atmospheric nuclear testing during 1945 - 1999. Table 19 gives the population weighted cumulative deposition densities for fallout radionuclides over the period 1945 – 1999 other than ^{3}H and ^{14}C. From the measurements of ^{14}C content of stratospheric air using high flying aircraft and balloons, the total ^{14}C production from weapon tests is estimated to be about 3.6×10^{17} Bq [26], equivalent to about 250 years of natural production. Because of its long half life, bomb produced ^{14}C will persist in the environment for many thousands of years. Pattern of decrease can be estimated using the long term models for biogeochemical cycling of carbon that are being developed in the context of studies of global warming [27,28]. The annual average annual global effective doe from ^{14}C produced in atmospheric nuclear testing was at a maximum, 7.7 mSv in 1964 and has decreased by a factor of 4 since that time [3]. Annual per caput absorbed doses from the fallout radionuclides is estimated as 0.045 mSv/y based on 70 years average lifetime of a person. For fallout radionuclides, the contribution from ingestion route is found to be 4 times high as compared to that of external exposure while the external exposure itself is found to be 5 times greater than the doses which arise from inhalation of these radionuclides. Fallout of some of these radionuclides is being measured in India and the concentration levels of these nuclides in various environmental matrices are given in table 20 for India [29, 18].

Table 16. Radionuclides Released to the Atmosphere Following the Atmospheric Nuclear Weapon Tests Carried out During 1945 to 1999.

Nuclide	Activity Release (PBq/y)*	Nuclide	Activity Released (PBq/y)
^{131}I	5300	^{54}Mn	1299
^{140}Ba	9900	^{106}Ru	5890
^{141}Ce	7900	^{125}Sb	540
^{103}Ru	9900	^{55}Fe	907
^{89}Sr	5600	^{90}Sr	612
^{91}Y	7900	^{137}Cs	919
^{95}Zr	9900	^{144}Ce	11494

**Derived from estimated fission/fusion yields of nuclear tests with atmospheric models. Measured results used preferentially for ^{90}Sr and ^{137}Cs during 1958 – 1985. Model values for ^{131}I, ^{144}Ba, ^{103}Ru, ^{89}Sr, ^{91}Y and ^{95}Zr normalized to total hemispheric deposition estimated from available measurements.*

Table 17. Worldwide Average Annual External Exposure due to Radionuclides Released to the Atmosphere Following Nuclear Weapon Tests during 1945 – 1999.

Nuclide	Annual effective dose (μSv)	Contribution (%)	Nuclide	Annual effective dose (μSv)	Contribution (%)
^{131}I	1.58	0.34	^{54}Mn	19.2	4.14
^{140}Ba,^{140}La	26.7	5.76	^{106}Ru,^{106}Rh	24.5	5.28
^{141}Ce	1.09	0.24	^{125}Sb	12.2	2.63
^{103}Ru	12.0	2.59	^{137}Cs	166	35.80
^{95}Zr,^{95}Nb	81.7	17.62	^{90}Sr	110.7	23.88
^{144}Ce, ^{144}Pr	7.94	1.71	**Total: - 463.7 μSv :- 100.0 %**		

Table 18. Worldwide Average Annual Effective Dose by the Ingestion Exposure Root from Radionuclides Produced in Atmospheric Weapon Tests During 1945 – 1999.

Nuclide	Dose (μSv)	Total (μSv)
^{131}I	64.2	344
^{140} Ba, ^{140}La	0.51	
^{89}Sr	1.9	
^{55}Fe	6.6	
^{90}Sr	106	
^{137}Cs	165	
^{3}H	23.8	2517
^{14}C	2494	

Table 19. Population weighted cumulative deposition densities for fallout radionuclides around Northern Hemisphere (N.H) and Southern Hemisphere (S. H) during 1945 – 1999 other than ^{3}H and ^{14}C.

Cumulative Deposition Densities (Bq.m^{-2})							
Nuclide	**N.H**	**S.H**	**Total**	**Nuclide**	**N.H**	**S.H**	**Total**
^{131}I	510	273	482	^{144}Ce	50000	8120	45400
^{140}Ba	1520	808	1440	^{54}Mn	6560	714	5920
^{141}Ce	3080	1380	2900	^{106}Ru	33300	5470	30300
^{103}Ru	4660	2130	4380	^{125}Sb	8160	1380	7420
^{89}Sr	3440	1470	3220	^{55}Fe	14600	1630	13200
^{91}Y	5560	2490	5220	^{90}Sr	52900	12600	48440
^{95}Zr	7590	7130	7130	^{137}Cs	81000	19200	74100

Table 20. Measured concentration levels of fallout radionuclides in India.

Sample Matrix	Concentration of Fallout Radionuclides		
	^{90}Sr	^{137}Cs	^{239}Pu, ^{240}Pu
Air	140.0 – 191.0 (PBq/l)	10.0 – 30.0 (nBq/l)	2.1 – 2.3 (PBq/l)
Drinking water	1.1 (mBq/l)	< 2.0 (mBq/l)	39.2 (μBq/l)
Milk	< 0.005 – 0.35 (Bq/l)	< 0.007 – 0.442 (Bq/l)	…
Diet	< 0.005 – 0.205 (Bq/diet)	< 0.007 – 0.300 (Bq/diet)	0.17 – 0.18 (mBq)

^{3}H is produced in larger quantities in thermonuclear explosions. Its incorporation in precipitation caused the tritium content of surface waters of northern temperate zone to increase substantially, but there was only limited transfer of waters of southern hemisphere. Based on the estimated inputs of tritium to the atmosphere from northern and southern hemisphere, committed effective have been estimated as 0.051 mSv/y and 0.014 mSv/y in the northern and southern hemisphere respectively. From the measurements of ^{14}C content of stratospheric air using high flying aircraft and

balloons, the total production of ^{14}C from weapon tests has been estimated as 3.6×10^{17} Bq [26], equivalent to about 250 years of natural production.

NUCLEAR POWER PRODUCTION

Sources of radiation exposure from nuclear power production are also a contributor to the modified natural background radiation sources. Generation of electrical energy by nuclear means has grown steadily from the start of the industry in 1956. Relatively rapid rate of expansion which occurred during 1970 – 1985 period, an increase in energy generation of more than 20 % per year, slowed to a pace averaging just over 2 % per year from 1990 to 1996. At the end of 1997, there were about 437 nuclear reactors operating in about 31 countries across the world having a total installed capacity of 325 GW, and the energy generated in 1997 was 254 GWa. It has projected that the nuclear energy will continue to supply about 17 % of the total electrical energy generated in the world, as at present, or possibly a few percent less [3].Sources of radiation exposure from nuclear fuel cycle power production includes nuclear fuel cycle and which in turn contains the mining and milling of uranium ore and its conversion to nuclear fuel material; the fabrication of fuel elements; production of nuclear energy due to nuclear reactor operation; storage of irradiated fuel or its processing; with recycling of the fissile and fertile materials recovered; and the storage and disposal of radioactive wastes. For some types of reactors, enrichment of the isotopic content of ^{235}U in the fuel material is an additional step in the fuel cycle. Nuclear fuel cycle also includes the transport of radioactive materials between the various installations.

At various stages of nuclear fuel cycle, radionuclides are being released to the environment in small quantities resulting in radiation exposure to population. Important radionuclides released to the environment from ^{238}U milling along with their releases are given in table 21 [3]. ^{222}Rn in airborne stream and ^{238}U in liquid stream contributes major part of the radionuclides released to the environment during operation. Major radio nuclides released to the environment due to reactor operation are noble gases and particulates containing ^{90}Sr and ^{137}Cs. Table 22 gives the global normalized released to the environment due to reactor operation during the period 1970 to 1997 [3]. Tritium releases from heavy water reactors are found to be high since they use heavy water as moderator and primary heat transport system.

Table 21. Normalized release rates of radionuclides from uranium milling operation.

Release Rate (GBq/Gwa)					
Nuclide	**Concentration**	**Release**	**Nuclide**	**Concentration**	**Release**
^{222}Rn	3000	Airborne	^{210}Pb	0.02	Airborne
^{226}Ra	0.02	Airborne	^{210}Pb	0.01	Liquid
^{230Th}	0.02	Airborne	^{226}Ra	0.02	Liquid
^{238}U	0.40	Airborne	^{230}Th	0.01	Liquid
			^{238}U	0.30	Liquid

Table 22. Normalized releases of radionuclides from nuclear reactor operations.

Species	PWR (TBQ/Gwa)	HWR (TBq/Gwa)	Species	PWR (TBq/Gwa)	HWR (TBq/Gwa)
Noble gases	1301	7990	Particulates	0.027	0.00042
Tritium	26.5	3560	Tritium (Liquid)	142	2030
Carbon-14	1.13	25.3	Others(Liquid)	0.593	1.3

Normalized release rate of radionuclides from nuclear fuel processing plants are shown in table 23 for the period 1970 – 1997 [3]. It can be seen from this table that in the air borne stream, the release of ^{85}Kr is the highest followed by ^{3}H. In the liquid stream, ^{3}H and ^{106}Ru have higher release rates. Radiation dose to the population from operation of nuclear fuel cycle arise from the exposure due to the atmospheric discharges of fission product noble gases and ^{41}Ar and from internal exposures due to inhalation and ingestion of radionuclides like ^{3}H, ^{131}I, ^{90}Sr, ^{137}Cs, ^{222}Rn, ^{220}Rn and their progeny. Overall impact of nuclear power generation on total population exposure is negligible [18]. From the available data for Indian operating power plants, it is estimated that the percaput dose works out to be 1.5×10^{-5} mSv/y to the Indian population which is significantly lower than the dose received from natural radiation sources. Estimated annual per caput dose from other sources of power production in India works out to be 2.6×10^{-5} mSv/y from mining and milling operation; 1.4×10^{-6} mSv/y from fuel fabrication; 3.3×10^{-6} mSv/y from fuel waste management practice; and 4.8×10^{-6} mSv/y from other related activities [30]. Total per caput dose from complete nuclear fuel cycle works out to be 5.1×10^{-5} mSv/y of which 29.2 % is due to nuclear power plant operation. It is estimated that the world wide collective effective dose from nuclear power plant operation is 2 order of magnitude less than that from atmospheric weapon testing and this will generate a per caput effective dose of 0.1 µSv to the world population. This estimate represents only 5×10^{-3} percent of the average exposures to natural sources of radiation. Global average percentage contribution of each stage of nuclear fuel cycle to the total annual effective dose of 0.1 µSv is represented in table 24. Contribution from mining – milling and nuclear power plant releases are almost equal to the global average per caput dose from nuclear fuel cycle. In India, the contribution from the former is found to be double of that from the later.

Contribution from other man-made sources like application of radioisotope to industry and medical exposure are also a source of man-made radiation dose. Radiation dose due to the former is very small as compared to the dose due to medical exposure. Annual frequency of X-ray examination at present in the country is about 100 exposures per 1000 person and the total percaput dose from these 100

Table 23. Normalized releases from fuel reprocessing plants.

Nuclides	Airborne Effluents (TBq/Gwa)	Liquid Effluents (TBq/Gwa)
^{3}H	1986	1678
^{14}C	13.6	2.7
^{85}Kr	46073	….
^{129}I	0.018	0.18
^{131}I	0.15044	…..
^{137}Cs	0.13209	1280.6
^{90}Sr	……	186.3
^{106}Ru	…….	411.6

Table 24. Global average contribution of each stage of nuclear fuel cycle to the annual per caput dose of 0.1 µSv.

Stage	Contribution (%)	Stage	Contribution (%)
Mining	34.35	Reactor fabrication	37.22
Milling	2.86	Reactor release-airborne	1.15
Mile and mill tailings	14.31	Fuel processing	7.16
Fuel fabrication	0.07	Transportation	2.85

exposures of all types works out to be 0.021mSv/y. Similarly, the percaput dose due to nuclear medicine diagnostic and treatment procedures are about0.027 mSv/y. Thus, the total annual percaput dose from medical application to the Indian population is about 0.048 mSv/y against the world average value of 0.4 to 1.0 mSv/y. Table 25 gives the contribution of all the natural and man-made radiation sources to the dose received by a common man. It can be seen from this table that the contribution from all man-made sources works out to be about 3.93 % while that from the natural sources takes the major share of 96.07 % of the total. This pattern is similar to the one estimated globally.

Table 25. Total radiation exposure and percentage from natural, Modified and man-made sources to Indian population.

Sources	(mSv/y)	Percent (%)
Natural	2.299	96.07
Modified natural Sources	1.24×10^{-3}	0.052
Atmospheric weapon test	0.045	1.88
Nuclear Exposure	5.0×10^{-5}	2.09×10^{-3}
Medical Exposure	0.048	2.01
Total	**2.393**	**100.0**

CONCLUSION

Major contribution of the radiation exposure sources to the population are the natural background and medical exposures. In India, the total annual effective dose from man made and natural sources of radiation works out to be 2.393 mSv. Out of this 96.7 % of the radiation is caused by the natural background radiation sources. Modified sources contribute 0.052 %; atmospheric nuclear weapon tests 1.88 %; Medical exposures 2.01 % and exposure from nuclear power plant 2.09×10^{-3} %. It is important to note that despite so many technological activities, the additional increase in the dose is limited to 3.93 % of the total natural radiation dose, which anyway exists. It is made sure by the regulatory bodies that the common public does not get an additional dose of more than 1 mSv/y due to all the technological activities put together. This dose is a fraction of the natural radiation dose of about 2.4 mSv/y, which could be as high as 17 mSv/y in the coastal region of Kerala, Southern Part of India and over 30 mSv/y at localized spots in Kerala, while the average value of natural dose is 2.4 mSv/y, which is anyway unavoidable. It may be noted that this limit of 1 mSv/y is highly conservative, as the lowest threshold value of dose at which deterministic effect on human body can be observed. Per caput and collective dose values for the total population are based on the present status of the estimates of the individual exposure components. These values may change in the future depending up on the industrial and technological development of the country, the use of nuclear energy for electricity production, the improvement in health care techniques of the population and also the population growth rate. These may result in a decrease in the percentage contribution from natural sources to the total dose. We all are in the midst of a radiation environment, however low it may be, and it is not possible to avoid radiation exposure from natural sources altogether. All what is needed and is possible is to be conscious of this fact with a constant endeavor to control the radiation from man-made sources to levels as low as is reasonably achievable. Periodic review of the dose values reported in this note is very essential.

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