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K. K. Narayanan

D. Krishnan

M. C. Subba Ramu

Population Exposure to Ionising Radiation in India

Indian Society for Radiation Physics

Kalpakkam Chapter

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About ISRP and this Series

Ionising radiation is a powerful tool finding increasing applications in almost all walks of life, be it agriculture, medicine, industry or basic research. By the very nature of its diverse applications, the study of ionising radiations and their interaction with matter has diffused into various other scientific disciplines. It is with the primary objective of providing a common forum for the scientists and engineers working on different basic as well as applied aspects of Ionising radiation that the Indian Society for Radiation Physics (ISRP) was formed in 1976. Its membership consists of professional from national laboratories, universities and institutions of higher education, industry etc. In line with its basic objective, ISRP has been organising periodic national and regional seminars, topical meetings etc.

It is recognised that for an optimum utilization of any technology, a comprehensive appreciation of its problems and potentials must prevail not only amongst the scientists and engineers associated with the technology but amongst the general public also. In the case of ionising radiations while its hazard aspects seem to have been over played for historial or other reasons, its full potential in the service of mankind does not seem to have drawn the deserved attention of the general public. It is to fill up this gap and to develop an overall perspective, ISRP (Kalpakkam Chapter) has launched this series of semi-popular brochures and technical reviews on various facets of ionising radiation.

We feel that for any programme to be relevant and successful, a strong user-feed back is essential We earnestly solicit suggestions with regard to the content and level of these brochures, topics to be included etc. The suggestions may please be sent to :

Secretary
ISRP - Kalpakkam Chapter
Reactor Physics Division
Indira Gandhi Centre for Atomic Research
Kalpakkam - 603 102, Tamil Nadu.

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POPULATION EXPOSURE TO IONISING RADIATION IN INDIA

K.K. NARAYANAN
D. KRISHNAN
M.C. SUBBA RAMU

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FOREWORD

The developments in the fields of atomic energy and ionising radiations have shown that they can provide immense benefit to mankind. Their use in different facets of our life is rapidly increasing. However, these technologies are also facing a serious problem; a problem of perception. On the one hand, the scientists and technologists who have studied the subject and who have been working in these areas firmly believe that nuclear energy and ionising radiations can be very gainfully harnessed with least harm to the safety of the people or sanctity of the environment. On the other hand, there is also a growing fear in the minds of the public about the harmful effects of ionising radiation. The fear could be due to incomplete knowledge and may not have any scientific basis. In any case, if the utilisation of atomic energy and ionising radiations is to gain public acceptance, it is essential that all the information about these subjects is made amply available to the common man, in a language he understands. It is necessary that we generate literature in the form of monographs, books, reports or whatsoever, which, while retaining the scientific objectivity, is intelligible to the general public. This important task of no small magnitude calls for efforts from all concerned, governmental organisations, educational institutions and professional societies. It is in this context that the series publication of monographs on specific themes in radiation physics by the Kalpakkam Chapter of the Indian Society of Radiation Physics is to be welcomed. The earlier publications by the Society on topics such as radiation environment, food irradiation and nondestructive testing have been quite successful in increasing the awareness regarding the status and potential in the respective areas. The present monograph, fourth in the series, addresses itself to a subject of very wide interest. The authors have had many years of experience in assessment as well as measurement of radiation exposure levels from a variety of sources and are, therefore, eminently qualified to write about the subject.

Contrary to the belief prevailing in certain sections of the society that ionising radiations are harmful at any level, mankind has always been exposed to ionising radiations prevalent in nature and it has evolved in this natural radiation environment. The concern is, or should be, whether our technological endeavours have altered the total radiation exposure to any significant degree. This calls for an integrated perspective; what are the radiation exposures and their variations due to natural sources and what are the contributions from manmade sources. While international bodies such as United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have been collating relevant information on a global scale, such efforts are wanting in the case of Indian population. The authors' attempt to fulfill this need is a very timely and commendable one.

(D.V. GOPINATH)
Director
Health, Safety and Environment Group
Bhabha Atomic Research Centre

POPULATION EXPOSURE TO IONISING RADIATION IN INDIA

1.0 INTRODUCTION

Henri Becquerel, the French scientist, in 1896 discovered the phenomenon of radioactivity, though Marie Curie, the Polish-born chemist, was the first to coin the word "radioactivity". Both Becquerel's and Curie's work was greatly assisted by an earlier scientific breakthrough when in 1895 Wilhelm Roentgen, a German physicist, discovered X- rays.

Both radioactivity and the ionising radiation associated with it have existed on earth long before life emerged. Indeed, they were present in space before the earth itself appeared. Radioactive materials became part of the earth at its very formation. There is radioactivity in the air we breathe, the food we eat and the house we live in. Even man himself is slightly radioactive since all living tissues contain traces of radioactive substances. To this ubiquitous natural radiation, man has started adding his own, arising out of his technological activities. The interaction between humans and the environment has resulted in variations in the quality and quantity of the background ionising radiations to which a human being is exposed. Some are more exposed than others because of the type of their dwelling, location of habitation, their life styles and the level of medical care they receive. It is virtually impossible for people to avoid radiation from their living environment. Therefore, it is necessary to keep a constant vigil on the changes caused in the various sources of ionising radiation exposures.

The two sources of radiation, natural and man-made, are further sub-divided into different sub-groups according to their origin as shown in figure 1. This book presents estimates of the exposures to different sections of population in India and elsewhere from the various radiation sources listed in the figure. An estimate of the per caput exposure is also provided for each practice involving a source of ionising radiation. The per caput exposure is defined as the ratio of the collective exposure of the particular sections of population to the total population of the country. The per caput exposure serves

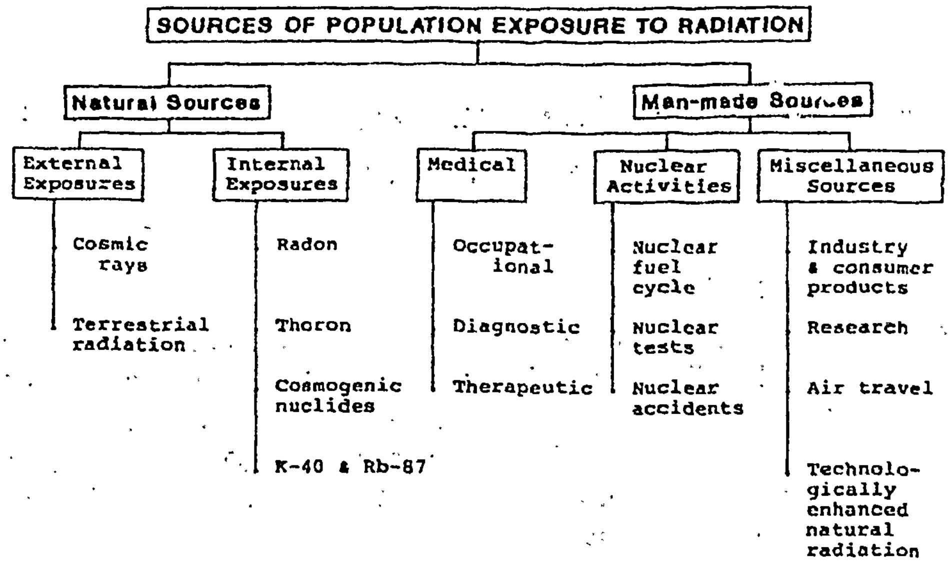

Fig.1 Sources of radiation

as a measure of the importance of different practices. Scientists employ a host of units to quantify the exposure to ionising radiation received by a person. The more commonly used units are explained in the glossary section of this book.

In considering doses to large populations, it is generally the statistical effect on the population which is of concern rather than the possible effects in individuals. This is especially true at low doses. The relationship between risks and ionising radiation was studied among the atomic bomb survivors in Japan and other irradiated populations who received doses above 1 gray. For estimating risks from low doses a linear relationship between dose and risk is assumed. i.e. the risk increases steadily in direct proportion to the dose. In effect the estimate of risk at low doses is extrapolated from what we know about the risk at high doses. The collective dose to population given in this book is based on this approach.

Estimation of per caput dose from different identified sources of radiation had been made by many national and international organisations. Two important reports often quoted in literature are by the National Radiological Protection Board (NRPB-1989) of United Kingdom and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR-1988). Values from these reports along with per caput dose in Japan and USA are compared with the Indian value.

2.0 NATURAL SOURCES OF RADIATION

The exposure to ionising radiation can be conveniently classified into : (a) external exposure resulting from sources external to the body and (b) internal exposure, resulting from radioactivity residual in the body. The cosmic radiation and radiation arising out of earth's crust and the building materials used for construction of houses and buildings give rise to the external exposure. The radioactivity naturally present in the body as well as that which enters it through inhalation and ingestion and is retained in the body contributes to internal exposure.

2.1 EXTERNAL EXPOSURES

2.1.1 Cosmic radiation

The high energy radiation that enters the earth's atmosphere from outer space is known as primary cosmic rays. The interaction of these rays with atoms present in air produces neutrons, protons and pions and a variety of reaction products known as cosmogenic radionuclides. At the ground level, the population exposure to the cosmic component arises out of minute fluxes of neutrons and protons and secondary radiation arising out of interaction with pions. The poles receive cosmic radiation more than the equatorial regions. Also the level increases with altitude. The radiation level nearly doubles for every 1500 meters. Most people live at or close to sea level, so there is little variation around the average dose from cosmic radiation of 355 μSv per year, which is applicable to India also. However, in high altitude cities, such as Gulmarg, the annual cosmic ray doses to residents may be as much as 830 μSv per year [1].

2.1.2 Terrestrial or primordial radiation

The important radioactive materials in rocks are potassium-40, rubidium-87 and the two series of radioactive elements arising from the decay of uranium-238 and thorium- 232, the long lived radionuclides that have remained on earth since its origin. The radon gas (radon-222) formed by decay product of uranium-238 and thoron gas (radon-220) produced during the decay series of thorium-232, seep out of the earth and cause internal exposures. This is dealt in more detail elsewhere in the book. Other radionuclides, such as those in the uranium-235 decay series, have little effect on the external exposure. The levels of terrestrial radiation differ from place to place around the world, as the concentrations of these materials in the earth's crust vary.

Recent surveys of outdoor external radiation levels in 23 countries, representing more than half of the world's population suggest that about 95 per cent of the people receive an average annual dose of 400 μSv from the terrestrial sources of natural background radiation [2].

In the Indian subcontinent, the regions of Maharashtra and south Gujarat are covered by the Deccan lava basalt with very low radioactivity; the Gangetic alluvial regions covering parts of Uttar Pradesh, Bihar and West Bengal have somewhat higher radioactivity; the granite region of Andhra Pradesh exhibits quite high levels of the primordial radioactivity. In the coastal areas of Kerala and Tamil Nadu, thorium rich monazite sands result in dose rates as high as 32,500 μSv per year in some locations [3].

From a countrywide survey of the out-door natural background gamma radiation levels using thermoluminescent dosimeters, covering 214 locations scattered all over India, the mean external dose in India has been estimated as 690 μSv per year [4]. The population weighted mean estimate for 1991 is 734 μSv per year. This includes the external dose from terrestrial radiation and cosmic radiation. The cosmic component is 355 μSv per year and the terrestrial component is 379 μSv per year. It has been estimated that 48.7% of the external terrestrial dose rate is due to potassium-40 and the rest due to uranium and thorium series [5]. In other words, 185 μSv is due to potassium-40 and 194 μSv due to uranium-238 and thorium-232 series. UNSCEAR - 1988 value for external dose due to terrestrial radiation is 150 μSv from potassium-40 and 260 μSv from uranium and thorium series. UNSCEAR - 1988 gives the external component of natural radiation exposure as 765 μSv per year.

2.2 INTERNAL EXPOSURE

Scientific observations so far show that major part of the internal dose that people *receive from natural sources is derived from* terrestrial sources: from the decay of uranium-238 and to a lesser extent, from the decay of thorium-232, potassium-40 and rubidium-87. Of these, the dose arising out of inhalation of radon and thoron, the gaseous daughter products occuring in the uranium-238 and thorium-232 decay series, constitutes the most important component of the natural background radiation dose to the population.

2.2.1. Radon and thoron inhalation dose

Radon gas seeps out of the earth all over the world. The dose from the inhalation of indoor short lived radon decay products varies significantly with the seasons. It also depends on the building design, the materials used for construction and the ventilation system. Natural ventilation in Indian houses can be expected to reduce indoor radon and its progeny levels. However, if the emanation rates are high, radon and its progeny levels in homes can be expected to be higher depending also on the building materials used, geographical location and the geological conditions of the soil.

Preliminary measurements by a group in Bhabha Atomic Research Centre give an estimate of the annual dose from indoor and outdoor radon and its short lived decay product concentrations to be 1160 μSv and 50 μSv respectively, making a total of 1210 μSv per year [6]. Randomly selected houses of different types such as huts, flats, bungalows, etc. situated in 24 states in the country were surveyed for radon and progeny levels indoors. The measurements were carried out over a period of two years. The total dose from indoor and outdoor short lived thoron and its decay products is taken as 160 μSv per year on the basis of the UNSCEAR data for the global average. These dose values are estimated taking into consideration that two-third of the day is spent indoors by an individual, on an average.

The total annual dose to an individual due to breathing of radon and thoron and their short lived daughter products present indoor and outdoor works out to be 1370μSv. UNSCEAR 1988 gives a value of 1260 μSv per year for the global average [2].

2.2.2 Dose due to potassium-40 and rubidium-87

Potassium is an essential element for the body and potassium-40 is absorbed in the body along with non- radioactive potassium. From data given in reference 7, the body content of potassium in Indian adults amounts to 3.06 g per kg body weight [7]. This will result in an annual dose of 189 μSv to an average Indian. As per UNSCEAR- 1988 report an average person receives about 180 μSv a year from potassium-40.

Very little is known about the behavior of rubidium in the environment. The UNSCEAR- 1988 value of annual dose from rubidium-87 is 6 μSv and is assumed to apply for Indian population also.

2.2.3 Inhalation dose from cosmogenic radionuclides

A large number of cosmogenic radionuclides are present in the stratosphere and troposphere. Only four cosmogenic nuclides (tritium, carbon-14, beryllium-7 and sodium-22) are of importance from the point of view of radiation dose to man. The annual doses are estimated to be 0.01 µSv for tritium-3, 3 µSv for beryllium-7, 12 µSv for carbon-14 and 0.2 µSv for sodium-22. Because of the relative homogeneity of the cosmic ray flux over the earth's surface, the variability of the annual doses due to cosmogenic radionuclides is expected to be low. 15 µSv per year estimated by UNSCEAR-1988 as the contribution from cosmogenic radionuclides to the internal dose from natural sources has been considered to be applicable for Indian population also.

2.3 TOTAL EXPOSURE FROM NATURAL SOURCES

Figure 2 gives the component of per caput dose in India from natural sources. It also gives the comparative values for India and world population. The total annual individual dose from natural sources to an Indian works out to 2433 µSv, out of which 734 µSv (30%) is from external exposure and 1699 µSv (70%) is from internal exposure. Of the latter, 1370 µSv is from radon and thoron and 15 µSv and 195 µSv are from cosmogenic and terrestrial radio-

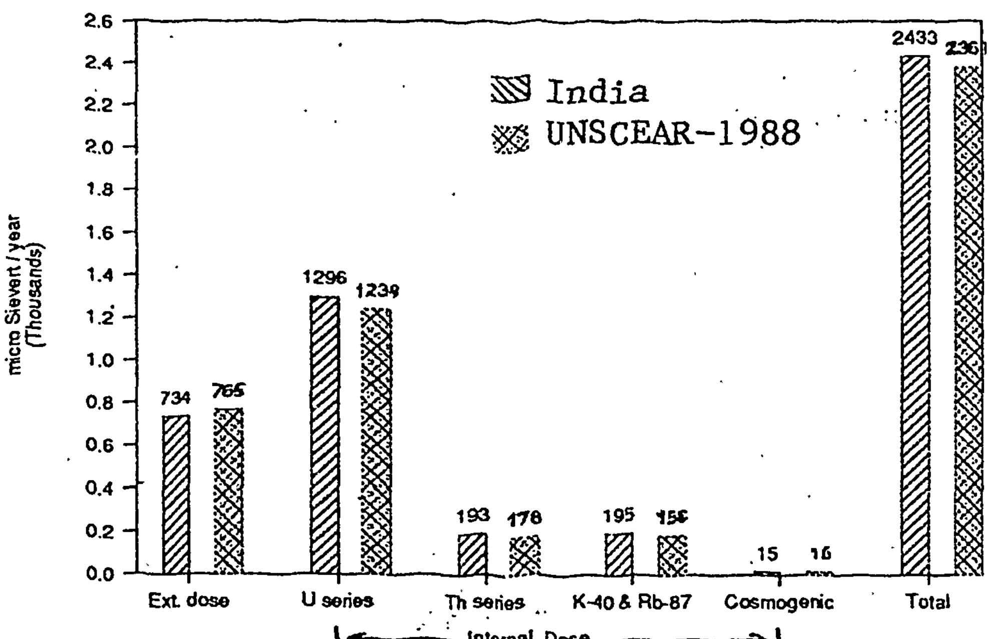

Fig.2 Components of per caput dose from natural sources of radiation

nuclides, respectively. UNSCEAR - 1988 value for total natural radiation is 2381 μSv per year out of which 765 μSv per year is due to external and 1616 μSv per year due to internal sources.

The collective dose to Indian population from natural sources is 2.07 Million person-Sv per year for a population of 851 millions (Mid 1991 population in India).

2.3.1 High natural background radiation area

Any discussion on natural background radiation in India will be incomplete without mention of the high background radiation in the coastal strips of Kerala and Tamil Nadu where, due to thorium content in monazite sand, the average external radiation level is 4000 μSv per year with peak values of 32,500 μSv per year in some locations in these areas [3].

The internal dose due to radon and thoron for this high background natural radiation is 3075 μSv per year [8]. The total of external and internal is around 7075 μSv per year. The break-up of the external and internal components is given in figure 3.

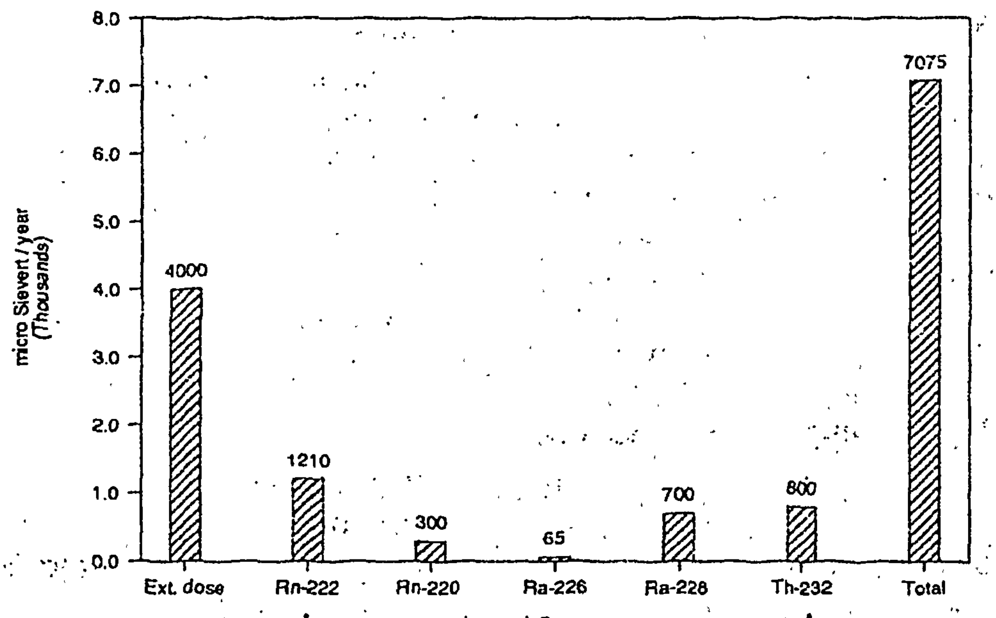

Fig.3 Components of per caput dose in high background areas in Kerala

3.0 MAN MADE SOURCES OF RADIATION

Over the last few decades man has artificially produced several hundred radionuclides for a variety of purposes such as medical diagnosis, radiotherapy, luminous displays, smoke alarm, etc. These applications contribute to additional radiation dose to man. Unlike the natural background radiation exposures which affect the entire population, the man-made applications affect directly only the population groups using them. Most of the man- made sources are controllable and the dose to people has direct correlation with the economic and industrial development of the country.

The man-made sources of radiation, as shown in Fig. 1 fall into 3 major groups: (1) Medical sources (2) Nuclear activities and (3) Miscellaneous sources. Let us see the contribution from each of them to the population dose in India.

3.1 MEDICAL SOURCES

Among the man-made sources of radiation, medical source is the most important, in view of its large contribution to population exposure, second only to natural radiation sources. There are two distinct classes of exposure to medical sources: i) occupational exposure to professionals in the medical field ii) exposure to patients during diagnostic procedures or investigations.

3.1.1 Medical occupational exposures

Personnel radiation monitoring in medical institutions in India is done by the Division of Radiological Protection, Bhabha Atomic Research Centre, Bombay. There are about 90,000 radiation workers in diagnostic radiology, out of whom only 13,000 are covered by the personnel monitoring services, and another 2000 in therapy facilities. The estimated collective dose to these 92,000 workers is 75 person-Sv per year. This will yield an average annual dose of 815 μSv per worker and a per caput annual dose of 0.09 μSv to Indian population [9].

3.1.2 Diagnostic exposures

The estimated annual frequency of X-ray examination at present in the country, is 100 exposures per 1000 persons. The total dose from 100 X-ray procedures of all types is estimated as 20,887 μSv [10]. Thus collective dose from these procedures will be 1.777×10^4 persons-Sv per year. This will result in the per caput dose of 21 μSv per year to the Indian population.

Radionuclides are used for both diagnosis and therapy.

Therapeutic doses are not included in the estimation of population dose because, these doses are administered to patients already afflicted with cancer and therefore cannot add further to cancer or gentic risk of the population. However, the treatment doses of thyrotoxicosis is considered as population exposure for the following reasons:

1) The administration of the nuclear medicine is at low activity levels.

2) The number of investigations/treatment for thyrotoxicosis is very large.

3) Patients are generally not hospitalised for long time after the administration of the radionuclides.

Table 1 gives the calculated annual collective dose from nuclear medicine procedures. The total collective dose from diagnostic procedures and treatment of thyrotoxicosis works out to 23,180 person-Sv per year and the per caput dose to population 27 μSv per year [11].

Table - 1

Annual collective dose from nuclear medicine procedure

Nulcear medicine procedure	No. of procedures per year	Dose per MBq administered (mSv)	Acivity administered per patient (MBq)	Annual collective dose (person-Sv)
Diagnosis				
- I-131	130,058	Variable 0.54 - 11.14	Variable 0.93 - 123	2046
- Tc-99m	80,360	12.33×10^{-3}	Variable 296 - 629	433
- Others	705	Variable 0.12 - 2.2	Variable 111 - 130	126
Treatment				
	5100	21.5	Variable 93-241	20,576

Total collective dose from nuclear medicine	:	23,181 person-Sv per year
Per caput dose to population	:	27 μSv per year

Figure 4 gives the distribution of per caput dose per year from various medical sources. The collective dose from medical sources works out to 4.10×10^4 person-Sv per year and the per caput dose to population 48 μSv per year. Almost 50% of the population dose results from the treatment of thyrotoxicosis. Diagnostic X-ray procedures contribute 44%. UNSCEAR-1988 gives annual average dose between 400-1000 μSv for world population.

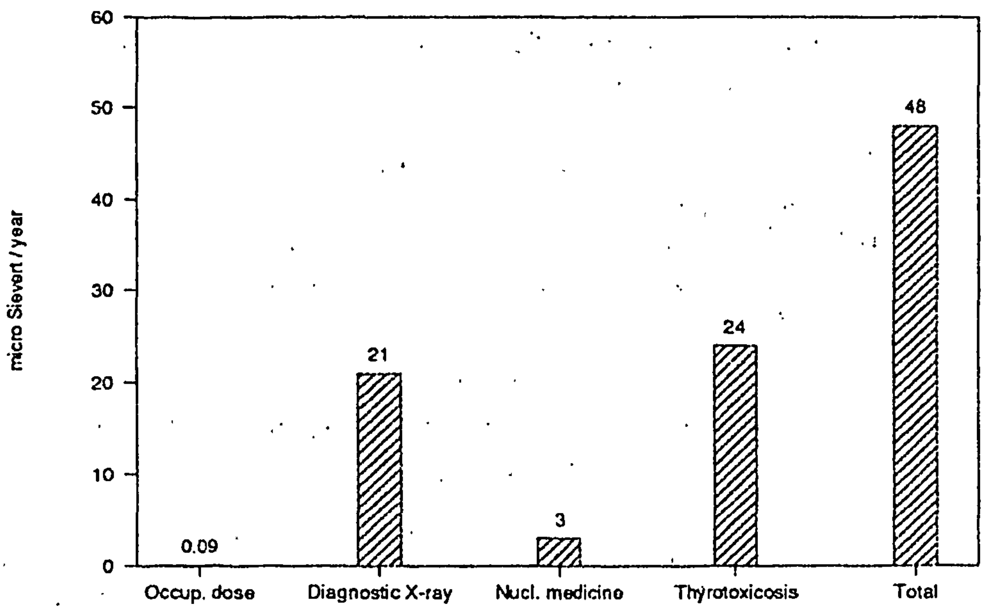

Fig.4 Components of per caput dose in India from medical sources

3.2 NUCLEAR ACTIVITIES

Of the man-made sources of radiation exposure, the nuclear activity related ones attract public concern all over the world. Medical sources, though they contribute the largest dose from man-made sources are prudently welcomed for their benefits. There is even less worry about natural sources of radiation which are ubiquitous and least controlled source of exposure.

Radiation sources relating to the nuclear industry originate from: 1) Nuclear fuel cycle, 2) Nuclear tests and 3) Nuclear accidents involving large scale release of radioactivity, such as Chernobyl accident.

3.2.1 Nuclear fuel cycle operations

Uranium mining and milling, fuel fabrication, reactor operation, reprocessing of spent fuel and radioactive waste management and disposal are the various stages of fuel cycle operations. Exposure occurs at all stages of the fuel cycle. While the radiation workers receive it during their work time in the fuel cycle facilities, members of the public receive from environmental discharges. The dose to workers will be mostly external due to working in radioactive areas. Internal dose to workers is due to inhalation of radionuclides in the work place. In India, the internal dose to workers in Pressurised Heavy Water Reactors (PHWRs) is almost fully contributed by tritium in the working environment (about 15 to 25% of the total dose). About 75% of workers engaged in nuclear fuel cycle operations get radiation dose. The dose to members of the public from effluent discharges could be from: 1) external dose due to atmospheric discharges of fission product noble gases and argon-41, and 2) internal dose due to inhalation and ingestion of radionuclides like tritium, iodine-131, strontium-90, cesium-137 etc.

Table 2. gives the collective dose, number of workers and average dose of a worker, at various stages of nuclear fuel cycle[12]. The total collective occupational dose is 82.6 person-Sv, giving an average dose of 4700 µSv per year to radiation workers and 0.1 µSv per year for the Indian population.

Table - 2

Distribution of Occupational Exposure among Various Stages of Nucear Fuel Cycle

Fuel cycle stage	No. of workers	Collective dose (person-Sv/yr)	Average dose per worker (mSv/yr)	Percentage of collective dose
Mining , milling and purification of U & Th	2107	20.50	9.70	24.8
Fuel fabrication	434	1.1	1.50	1.3
Power reactors	8944	53.5	6.00	64.8
Fuel reprocessing	1111	2.6	2.30	3.2
Waste management	616	1.1	1.80	1.3
Research reactors	1546	2.5	1.60	3.0
Other R&D	2361	0.8	0.30	1.00
Isotope production	521	0.5	1.00	0.6
Total (DAE)	17,640	82.6	4.70	100.0

Per caput dose to Indian population is 0.1 µSv/year.

Tables 3(a) and 3(b) give the collective dose per unit release of radionuclides from operating Nuclear Power Plants (NPPs) in India. Using the annual release values, the doses to the public from gaseous and liquid effluents have been calculated [13]. The regional collective dose from gaseous and liquid effluents released from NPPs is 0.011 μSv per year and to this an equal amount can be added to account for effluent releases at other stages of nuclear fuel cycle. The per caput dose to Indian population due to nuclear fuel cycle operations is 0.122 μSv per year. UNSCEAR-1988 value for global population from nuclear power generation is 0.2 μSv per year.

Table - 3(a)

Population Dose from Indian NPPs due to Gaseous Effluent Releases

(Average for operating years)

Radionuclides	Gaseous releases			
	Collective dose factor (person-Sv/TBq)	Release (TBq/yr)	Collective dose (person-Sv/yr)	Per caput dose (μSv/yr)
TAPS				
Fission-product Noble gases	2.96×10^{-5}	4.8×10^{4}	1.42	1.67×10^{-3}
Iodine & particulates	0.1	0.11	1.11×10^{-2}	1.30×10^{-5}
RAPS				
Ar-41	5.71×10^{-4}	3.7×10^{3}	2.11	2.48×10^{-3}
Tritium	3.05×10^{-3}	9.00×10^{2}	2.75	3.23×10^{-3}
C-14	0.53	0.90	0.48	5.64×10^{-4}
MAPS				
Ar-41	2.19×10^{-5}	1.04×10^{4}	0.23	2.70×10^{-4}
Tritium	9.90×10^{-4}	6.30×10^{2}	0.62	7.29×10^{-4}
C-14	0.17	1.5	0.26	3.06×10^{-4}
Total			7.88	9.30×10^{-3}

Table - 3(b)

Population Dose from Indian NPPs due to Liquid Effluent Releases

(Average for operating years)

	Liquid releases			
Radionuclides	Collective dose factor (person-Sv/TBq)	Release (TBq/yr)	Collective dose (person-Sv/yr)	Per caput dose (µSv/yr)
TAPS				
Gross beta	0.11	9.0	0.99	1.16×10^{-3}
RAPS				
Tritium	3.4×10^{-3}	14.2	4.83×10^{-2}	5.68×10^{-5}
Gross beta	0.75	3.7×10^{-3}	2.78×10^{-3}	3.27×10^{-6}
MAPS				
Tritium	2.30×10^{-6}	51.8	1.19×10^{-4}	1.40×10^{-7}
Gross beta	0.12	2.6×10^{-2}	3.12×10^{-3}	3.67×10^{-6}
Total			1.04	1.22×10^{-3}

Total Per caput dose due to gaseous and liquid discharges from NPPs	: 0.011 µSv per year
From other stages of nuclear fuel cycle	: 0.011 µSv per year
Total from nuclear fuel cycle	: 0.022 µSv per year

3.2.2. Nuclear tests

For the last 40-45 years there have been a number of atmospheric nuclear tests conducted by nuclear weapon countries. Most of the radioactive debris from atmospheric tests settle close by to the site of testing. Some remain in the troposphere (the lowest layer of the atmosphere) and are carried by the wind around the world at much the same latitude. As it travels, the radionuclides deposit on the surface of the earth, remaining on an average about a month in the air. But most of the radioactivity is pushed into the stratosphere (10 to 50 km up), where it stays for many months, and slowly descends all over the earth, exposing the people to ionising radiation.

Though fall-out contains several hundreds of radionuclides, only a few contribute to human exposure as most are produced in very small amounts or decay quickly. The four radionuclides which contribute more than one percent to the collective dose to the world population are carbon-14, cesium-137, zirconium-95 and strontium-90, in declining order of importance.

Because of their varying half-lives, dose from the fall-out radionuclides is delivered over different periods. Zirconium- 95, with a half life of 64 days, has already delivered practically all its doses. Cesium-137 and strontium-90 (both have half- lives of about 30 years) will have deposited most of the doses by the end of this century. Only carbon-14 (half-life 5730 years) will stay active into the far future, though at low dose rates and by the year 2000 will have delivered only seven percent of its eventual contribution.

In 1963, when atmospheric tests were at their peak, the average annual collective dose to world population amounted to about 7 percent of the equivalent exposure to natural radiation, decreasing to 2 percent by 1966 and one percent by early 1980. If no more atmospheric tests take place, future doses will get smaller and smaller.

The radiation doses due to fall-out radionuclides arise mostly from the ingestion of these radionuclides and their incorporation in food and from external irradiation from ground deposition. Exposures to populations are highest in the temperate regions and in the northern hemisphere, where most of the testing occurred. The dose for the southern temperate zone is about 70 percent of that for the northern temperate zone.

UNSCEAR-1988 assigns a per caput dose of 10 μSv per year to world population resulting from fall-out caused by past nuclear tests. Based on 10 years of environmental sampling carried out in India during and after the test periods, it is estimated that a per caput dose of 5.8 μSv per year results from dietary intakes of fall-out radionuclides (4.6 and 1.2 μSv per year from strontium-90 and cesium-137 respectively) [14].

3.2.3. Nuclear accidents involving large release of radioactivities

As detailed in earlier section on nuclear fuel cycle, the radiological impact from the routine operation of NPPs is very small. But concern remains about the consequences of potential accidents. The concern has increased many fold after the accident at the unit 4 of the Chernobyl NPS in USSR on 26 April 1986. The Three Mile Island reactor accident in USA in 1979 had not resulted in any significant dose to public.

In Chernobyl accident radioactive gases and dust particles were released: 25% the first day and the rest over the next few days. The initial releases of radioactive materials spread with winds in a northerly direction; subsequent releases dispersed towards the west and the south west and in other directions as well. Long-range atmospheric transport spread the released radioactivity throughout the northern hemisphere. Fall-out of airborne radioactivity was governed mainly by sporadic rainfall. Iodine- 131, cesium-134, cesium-137, tellurium-132, barium-140 and ruthenium-103 were the important radionuclides deposited, giving rise to radiation exposure externally from ground contamination and internally from the ingestion of contaminated food.

The above mentioned radionuclides were detected at Indian monitoring stations from middle May 1986. The levels reached their maximum in early fourth week of May and started decreasing thereafter. Iodine-131 could be detected in goat thyroid as well as in milk, grass and leafy vegetables [15].

Based on the measured radioactivity levels, the total dose to an average Indian was reported as 0.95 μSv per year [15]. UNSCEAR - 1988 does not give global average value for dose resulting from Chernobyl accident because of the large variations in the dose estimates in different countries.

Figure 5 summarises the distribution of population dose from the different nuclear related sources. The total collective dose is 5846 person-Sv per year and the per caput dose to Indian population works out to 6.87 μSv per year.

3.3 MISCELLANEOUS SOURCES OF RADIATION

Other sources of radiation to be considered arise from:

i) Industrial applications and consumer products incorporating radioisotopes
ii) Research activities
iii) Commercial air-travel
iv) Technologically enhanced natural radiation

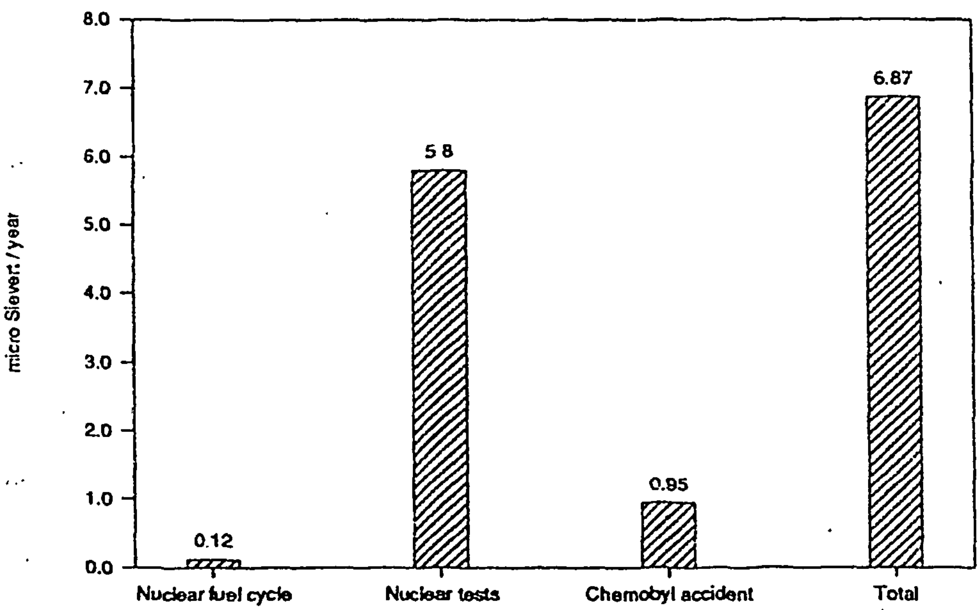

Fig.5 Components of per caput dose in India from nuclear activities

3.3.1 Industrial application and consumer products

Table 4 lists a number of radiation generating equipments as well as equipment and devices containing radioactive materials used in industry.

Workers who are engaged in using these equipment or fabricating the devices receive radiation exposure. Members of the public also receive some exposure because of proximity to the source of radiation. The collective dose to the population is the sum of the exposure to occupational workers and members of the public. Occupational doses in many cases are directly available from monitoring data and in other cases they are estimated from assessment of radionuclide concentration in air or radiation dose rate in the working area. Doses to members of the public are invariably estimated from environmental releases.

Table 5 gives the collective dose to occupational workers and to the general public from industrial applications. Maximum population collective dose of 500 person-Sv per year is estimated from television viewing (29.2 million TV sets, each viewed by 6 persons, average 4 hours per day, 350 days per year, at dose rate of

Table - 4

Industrial Applications of Radiation Sources

Source of radiation	Application
X-ray machines	- Detection of defects in welds and castings - Baggage check in airports
Picture tubes, that generate X-rays	- TV receivers - Video display units
Radioisotopes: cobalt-60, cesium-137, americium-241	- Measurement of liquid level in tanks, density of fluids, thickness of coatings
tritium; promethium-147; radium-226	- Luminous dial of watches, compasses and instruments
plutonium-238	- Power source in heart pacemakers
americium-241	- Fire detection devices
thorium-232	- Gas mantles of petromax lanterns

Table - 5

Summary of Exposure from Industrial Application and Consumer Products

	Industry/product	Collective Dose (person-Sv per year) Occupational	Public	Total	Per caput dose (µSv/year)
1.	Industrial radiography (6000 workers, 3/4 monitored)	32.1	-	32.1	3.77×10^{-2}
2.	Nucleonic gauging: (1600 gauges estimated)	0.29	-	0.29	3.41×10^{-4}
3.	Luminous dial production: (partly monitored)	0.12	15.31	15.43	1.81×10^{-2}
4.	Production of gas-mantles (1140 workers - estimated)	3.86	-	3.86	4.54×10^{-3}
5.	Tritium light-sources (estimated)	0.023	-	0.023	2.70×10^{-5}
6.	Cargo handling (monitored)	0.020	0.1	0.12	1.41×10^{-4}
7.	Television viewing (estimated)	-	500.00	500.00	0.59
	Total	36.41	515.41	551.82	0.65

0.002 μSv/hr at 2 meter away from TV sets) [16]. The total collective dose from industrial applications and consumer products work out to be 552 person-Sv per year yielding a per caput dose of 0.65 μSv per year to Indian population.

3.3.2 Research activities

There are about 228 institutions in the country using radiation sources for research activities. These are in addition to the other three categories viz., Department of Atomic Energy, industry and medicine and consist of various universities, research institutions, etc. There are 2363 radiation workers availing the personnel monitoring services and their annual collective dose is 0.83 person-Sv (mean dose is 0.35 mSv per year). From unpublished data the per caput dose to Indian population from research activities works out to 1×10^{-3} μSv per year.

3.3.3 Commercial air travel

Air travel exposes passengers and crew members to higher dose rates, albeit for short periods at a time. The source of radiation is cosmic rays. At 12,000 meters altitude the levels associated with intercontinental flights, exposure rate due to cosmic radiation is about 5 μSv per hour. Between 12,000 and 20,000 meters, where supersonic flights operate, the dose rate is 13 μSv per hour. At subsonic altitudes, the dose rate is 7 μSv per hour [17].

Indian Airlines carries around 11 million passengers annually [18]. The average sector distance is 1033 km and 560 km, respectively for Air Bus and Boeing passenger aircrafts and the average flight duration is 1.2 hours per sector [18]. The collective dose for air passengers is around 100 person-Sv which results in a per caput dose of 0.12 μSv per year.

3.3.4 Technologically enhanced natural sources of radiation (TENSR)

Some industrial activities, like the mining operations, bring to the surface of the earth, materials containing more than normal concentrations of natural radioactivity and also concentrate them in one or more products or by-products [19]. Mining operations for metals, coal, gas and rock phosphate, living in the vicinity of coal and gas-fired power plants, use of phosphate fertilizers and use of cooking gas lead to enhanced occupational and public exposures [20,21,22].

Table 6 gives the details on occupational and public exposure due to technologically enhanced natural sources of radiation. TENSR results in an annual occupational collective dose of 592.87 person-Sv and a population collective dose of 282.4 person-Sv, giving a total collective dose of 876 person-Sv per year. The per caput dose to Indian population is 1.03 µSv per year.

Table - 6

Exposure from Technologically Enhanced Natural Sources of Radiation (TENSR)

TENSR	Radionuclides	Collective dose, occupational/ public (person Sv/year)	Total Collective dose (person Sv/year)	Per caput dose (µSv/year)
1. Mining (Lead, Zinc, Copper, Manganese, Gold)	Radon and daugher products	585.56 (occupational)	585.56	0.69
2. Coal-fired power stations	Ra-226 and Th-228	168 (public)	168	0.20
3. Mining of phosphate rock and its use as fertilizer	U-238 and daughter products, Th-232 K-40	7.31 (occupational) 3.28 (public)	10.59	0.0124
4. Natural gas	Radon	111.6 (public)	111.6	0.13

Total occupational collective dose	- 592.87 person-Sv/year
Total public collective dose	- 282.9 person-Sv/year
Total collective dose	- 875.8 person-Sv/year
Per caput dose to Indian population	- 1.03 µSv/year

The contribution of all the miscellaneous sources of radiation taken together works out to 1529 person-Sv per year yielding a per caput dose of 1.8 µSv per year. 36% of the dose results from industrial application and consumer products and 57% from the technologically enhanced natural sources of radiation. Figure 6 gives the distribution of population dose in India from these sources.

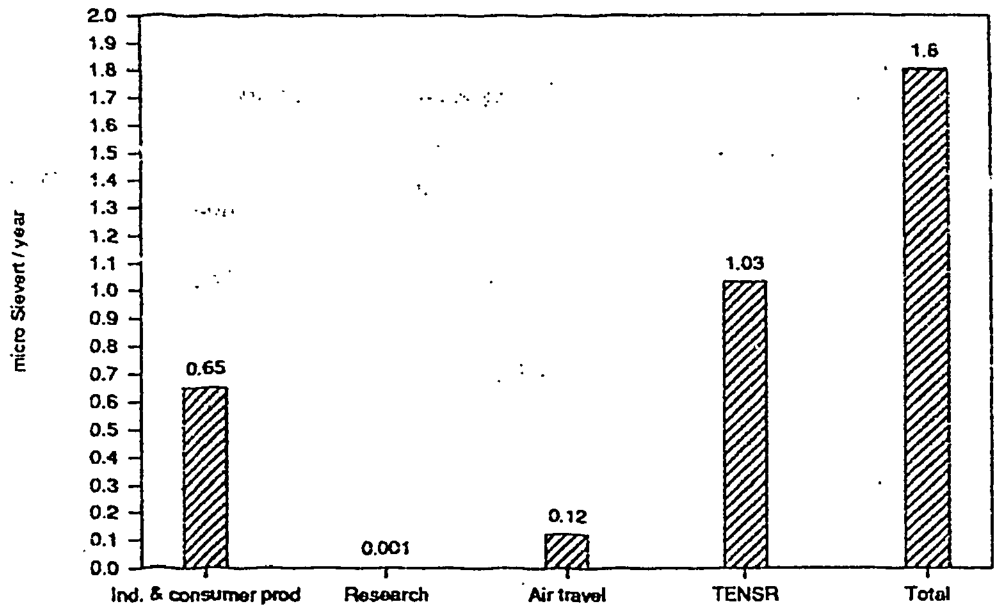

Fig.6 Components of per caput dose in India from miscellaneous sources

4.0 CONCLUSION

Fig. 7 gives the distribution of population exposure in India from all the identifiable sources, both natural and man-made. The total collective dose to Indian population is 2.119×10^6 person-Sv per year which will result in a per caput dose of 2490 µSv per year to the current population in India. 97.7% of the dose is contributed by natural sources, 1.93% by medical sources, 0.07% by miscellaneous sources and 0.3% by nuclear activities. The contribution from nuclear fuel cycle alone is 0.005%, which is equivalent to the dose resulting from 30 minutes exposure to average natural background or 10 minutes exposure to the high background areas in Kerala.

Table 7 gives the comparative values of per caput dose from ionising radiations for population of United Kingdom [23], United States of America [24], Japan [25] and the average for world population [2] along with the Indian values.

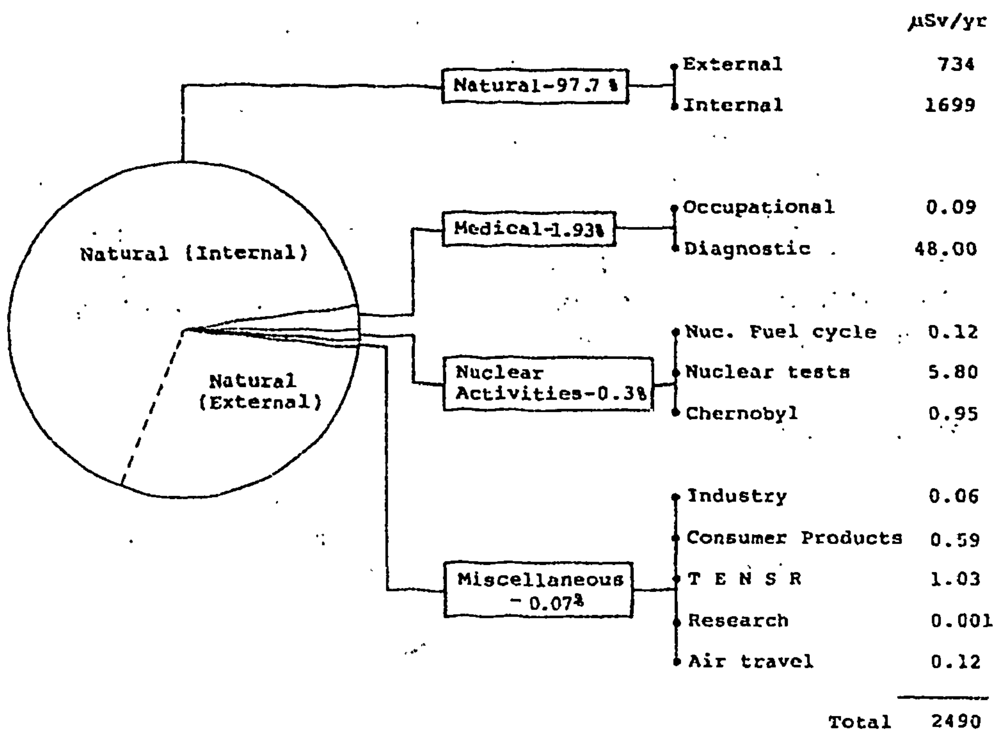

Fig.7 Per caput radiation dose to Indian population from all sources

Table - 7

Comparison of average radiation dose in India, UK, USA, Japan and world average (microsievert/year)

Sources	UK	U.S.A.	Japan	World average (UNSCEAR-1988)	India
Natural	2200	2950	1644	2400	2433
Medical	300	530	1602	400 - 1000	.48
Nuclear fuel cycle	2	20	0.4	0.2	0.122
All others	20	100	28.2	29.8	8.55
Total	2522	3600	3274.6	2830 - 3430	2490

The per caput and the collective dose values for the population are based on the present status of the estimates of the exposures. These values may change in the future depending upon the industrial and technological development of the country, the use of nuclear energy for electricity generation, 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. Therefore, periodic review of the dose values presented in this report is essential.

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GLOSSARY OF RADIATION UNITS

Becquerel (Bq)

It is the unit of radioactivity. One becquerel corresponds to one disintegration per second of any radionuclide.

1 MBq = 10^6 Bq

1 TBq = 10^{12} Bq

- Radioactivity of one litre of sea water is about 15 Bq.

- The amount of radioactivity in human body is about 3000 Bq due to potassium in the body.

Absorbed dose

Energy deposited by radiation per unit mass of tissue. Its unit is gray (Gy)

Dose equivalent

Absorbed dose weighted to take into account the type of radiation. Its unit is Sievert (Sv)

Effective dose equivalent

The dose equivalent weighted to express the equivalent sensitivity of different human organs to radiation exposure. Since it is a modified dose equivalent, it is also expressed in Sievert. In this brochure the word 'dose' is used with the same meaning as effective dose equivalent.

Collective effective dose equivalent

Effective dose-equivalent to a group of people from a source of radiation. In this brochure the phrase "collective dose" is used with the same meaning as collective dose equivalent. Its unit is person-Sievert (person-Sv).

Gray (Gy)

The special name for the unit of absorbed dose. It is the quantity of the energy of ionising radiation absorbed in unit mass of matter, such as body tissue. One gray corresponds to one joule per kilogram.

Sievert (Sv)

The special name of unit of dose- equivalent. This is the absorbed dose multiplied by a quality factor which takes into account the damage potential of the given type and energy of the radiation. In the case of betas, x-rays and gamma rays one sievert also corresponds to 1 joule per kilogram. One thousandth of one Sv is called millisievert (mSv) and one millionth of a sievert is called microsievert (µSv). Per caput dose given in this brochure is the average effective dose equivalent per person.

- Television viewing gives about 3 µSv in a year to a viewer.

- To and fro air travel between Bombay and Delhi will result in a radiation dose of about 30 µSv.

- An x-ray examination results in a radiation dose of about 200 µSv to the patient.

About the Authors

K. K. Narayanan

K. K. Narayanan is a Scientific Officer working in Health Physics Division of Bhabha Atomic Research Centre, Bombay for the last 26 years. He is a post-graduate in Physics from Bombay University. His field of interest includes operational health physics, environmental dose assessment and effluent discharge limits. He had served in the Working Group formed by World Health Organisation for developing guide line values for derived intervention levels for radionuclides in food.

D. Krishnan

D. Krishnan is a Scientific Officer Working in Division of Radiological Protection, BARC for the last 30 years. He got his M.Sc. in Nuclear Physics from Madras University and Ph.D. in Biophysics from University of California, Berkelly. His field of interest includes radiation protection aspects in medical, industrial, agricultural & research applications. Special areas of interest are : radiation biology, radiation protection, sensitization and dosimetry of internal radioactivity. Currently he is the editor of Bulletion of Radiation Protection.

M. C. Subba Ramu

M. C. Subba Ramu is a Scientific Officer working in BARC which he joined in 1957. He has a Ph D. in Science from Bombay university. He has 34 years of experience in the fields of background radioactivity, formation and characterisation of aerosols, aerosol inhalation and the behaviour of aerosol particles in the human respiratory tracts and measurements of radon and its daughters in dwellings.