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OCCUPATIONAL RADIATION DOSES OF WORKERS AT PAKISTAN RESEARCH REACTOR-I (PARR-I) AND AT RADIOISOTOPE PRODUCTION PLANT (RIPP) DURING 1995 TO 1999

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Radiation doses of workers working at Pakistan Research Reactor –I (PARR-I) and Radioisotope Production Plant (RIPP) during the period of 1995 to 1999 have been analysed. It is observed that annual average effective dose values per worker during this period are quite low and well under the limit of 20 mSv/y averaged over a period of five consecutive years. The highest annual dose received by any worker during this period was 13.2 mSv at PARR-I and 31.4 mSv at RIPP. Both are below the maximum dose limit of 50 mSv/worker during any single year over a period of five years. The highest accumulated dose received by any worker in the reported period was 30 mSv and 56.1 mSv at PARR-I and RIPP respectively. These values are less than the limit of 100 mSv that should not be exceeded during five years. None of the workers at both places exceeded any relevant dose limit. The probability of excess cancer risk due to annual average dose values lies in the range of 15 to 151 cancers in a population of one million, which is relatively very low as compared to actual deaths per million that lie in the range of 373 to 994 in various industries. Thus, it is concluded that the PARR-I and RIPP operation is radiologically safe and the workers are well trained and aware of the radiation protection procedures.

Keywords: Occupational radiation doses, PARR-I and RIPP, TLD, Excess cancer risk

1. Introduction

Use of radiation in various fields has increased tremendously during the last few decades. To get benefit out of their use the recommendations and dose limits laid down by the relevant international radiation protection agencies are required to be followed in order to ensure health and safety of radiation workers [1,2]. To achieve this, the workers are monitored for occupational radiation doses they receive and their dose record is maintained. Analysis of the dose record not only provides information about effectiveness of the radiological protection procedures but also helps to identify any underlying shortcomings in these procedures.

The Pakistan Research Reactor-I (PARR-I), which is 10MW Thermal, Low Enriched Uranium (LEU) fuel, swimming pool type reactor, is used for production of radioisotopes meant for medical and agricultural uses, training of manpower and for basic research [3]. The workers engaged in work at PARR-I are monitored for occupational radiation doses by the Radiation Dosimetry Laboratory, Health Physics Division of Pakistan Institute of Nuclear Science and Technology (PINSTECH), which is the only laboratory in the country providing personnel monitoring services for assessment of external and internal absorbed doses nationwide [4]. Thermoluminescent Dosimeters (TLD), having LiF (TLD-600 & TLD-700) as active chips, are issued to the workers at PARR-I on monthly basis and the relevant dose record is maintained by a locally developed versatile and specific data base handling software [5]. TLD-600 is ^{6}Li enriched whereas TLD-700 is ^{7}Li enriched. ^{6}Li registers dose due to gammas as well as thermal neutrons whereas ^{7}Li only records dose due to gammas. The difference in the response of two chips indicates the neutron dose. Therefore, dosimeters with this specific combination of chips are issued to the reactor workers. The RIPP workers, engaged in work with beta/gamma emitting isotopes, are issued TLD-100 i.e. LiF having Li with its natural abundance. These cards are meant for beta/gamma fields only. TLDs are one of the best dosimeters available to assess the absorbed radiation dose and are widely used in the world [3,6-8]. LiF is reusable and has comparatively

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better tissue equivalence and linear dose response over a wide range of photon energies, the features that favour its choice among contemporary TLD materials [9].

In the present paper occupational radiation doses as received by the workers at PARR-I and RIPP during 1995 to 1999 are presented. Consecutive five years have been chosen to check compliance with the annual average effective dose limit of 20 mSv averaged over a period of 5 years for any worker with the condition that the dose limit of 50 mSv during any single year and a total of 100 mSv in consecutive 5 years is not exceeded [2].

2. Experimental Procedure

Thermoluminescent dosimeters from HARSHAW (now BICRON) containing TLD-600 & TLD-700 chips (NG67 type) were issued to the workers at PARR-I and TLD-100 (G-1 type) to the workers at RIPP. The dosimeters were issued for a calendar month and the absorbed dose was assessed by reading them at the end of the month. The dosimeters were read by a fully automatic and computerized TLD system Model 8800 from HARSHAW. Reading of dosimeters was actually a controlled heating, which resulted in emission of light. Plot of light intensity versus heating temperature called glow curve, is shown in Fig. 1. Intensity of the emitted light was proportional to the absorbed dose. The reading procedure of dosimeters was optimised in such a way that the irrelevant low temperature peaks in the glow curve of LiF were automatically excluded as well as effective annealing was achieved in one complete readout cycle. The Thermoluminescent light signal used for dose assessment was collected between 110 °C and 280 °C. The system computer determined the dose by using calibration parameters that were obtained by careful calibration at the Institute's Secondary Standard Dosimetry Laboratory (SSDL) exposure facilities. The calibration exposure was given to the TLDs on a standard water phantom. The chip-to-chip inherent variations in the TLDs were normalized by employing element sensitivity correction factors that were pre-determined before issuing a dosimeter to a worker. All the workers were advised to wear TLDs at waist level during their job. Direct Reading Dosimeters (DRD) were also worn by the workers for quick exposure information, specially when work involved high radiation levels such as demineralizer unit or sample transfer to hot cell. The dose record was maintained by a computer-based data-handling programme, File Manager Software (FMS), that was retrievable in different formats.

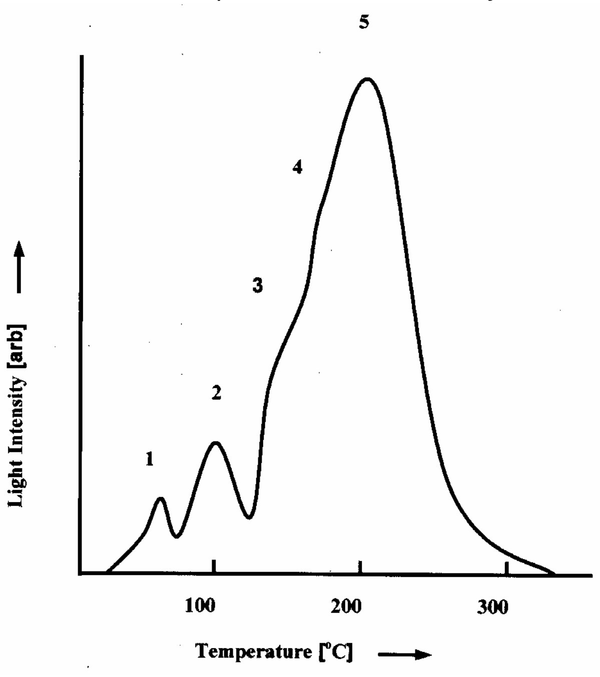

Figure 1. Glow curve of LiF TLD-100.

3. Results and Discussion

The workers at PARR-I are engaged in various kinds of jobs that include reactor operation, maintenance of pool water quality by regeneration at demineralizer unit, irradiation of encapsulated samples for isotope production and research purpose and routine maintenance etc. The RIPP workers transfer irradiated samples from the reactor building to the Radioisotope Production Plant, process these samples and prepare them in the dispensable form. The dose values given in this paper satisfy the trumpet curve accuracy criterion that is adopted internationally [10-12]. It dictates that the ratio of the measured dose value H_m to the conventional true dose value H_t should fulfil the following condition:

$$\left[\frac{H_m}{H_t}\right]_{\text{UpperLimit}} = 1.5\left[1+\frac{H_0}{2H_0+H_t}\right]$$

and

$$\left[\frac{H_m}{H_t}\right]_{\text{LowerLimit}} = \frac{1}{1.5}\left[1-\frac{2H_0+H_t}{H_0}\right]$$

or more explicitly

Table 1. Number of PARR-I workers and their annual gamma doses during 1995 to 1999.

Year	Number of monitored workers	Annual average effective dose (mSv)	Annual collective effective dose (man Sv)	Probability of excess cancer risk per year	Number of fatal cancers per year per million
1995	36	1.23	4.4×10^{-2}	1.54×10^{-5}	15
1996	40	2.28	9.13×10^{-2}	2.85×10^{-5}	28
1997	41	2.67	1.09×10^{-1}	3.34×10^{-5}	33
1998	46	4.12	1.90×10^{-1}	5.15×10^{-5}	51
1999	45	4.64	2.09×10^{-1}	5.80×10^{-5}	58

Table 2. Number of RIPP workers and their annual gamma doses during 1995 to 1999.

Year	Number of monitored workers	Annual average effective dose (mSv)	Annual collective effective dose (man Sv)	Probability of excess fatal cancer risk per year	Number of fatal cancers per year per million
1995	23	1.65	4.0×10^{-2}	2.06×10^{-5}	21
1996	21	2.63	6.0×10^{-2}	3.29×10^{-5}	33
1997	26	7.54	2.0×10^{-1}	9.43×10^{-5}	94
1998	28	12.06	3.4×10^{-1}	1.51×10^{-4}	151
1999	29	6.72	1.9×10^{-1}	8.40×10^{-5}	84

$$\frac{1}{1.5}\left[1-\frac{2H_0}{H_0+H_t}\right] \le \frac{H_m}{H_t} \le 1.5\left[1+\frac{H_0}{2H_0+H_t}\right]$$

where

$$1.5 \ge H_m/H_t \ge 1/1.5 \qquad \text{for} \qquad H_t \approx H_a$$

$$\left(\overline{H_a} = 20\text{mSv}\right)$$

$$2.0 \ge H_m/H_t \ge 0 \text{ for } H_t = H_r, \; H_r \ge 0.085\text{mSv} .$$

H_0 The lowest dose for which trumpet curve can be used, taken as 0.085 mSv.

H_a Dose limit for the period of one year.

H_r Recording level for the period of one month.

The doses measured by the TLD system in our laboratory fall within the trumpet curves as has been checked by the IAEA through an international intercomparison in 1999 [13].

Table 1 shows the number of PARR-I workers on yearly basis and doses they received. The number of workers during 1995 to 1999 (calendar years) remained fairly constant from 36 to 46 at PARR-I. The number of RIPP workers remained in the range of 21 to 29 during this period as shown in Table 2. The annual average effective dose is an indicator that depicts an overall trend of occupational radiation dose during a year. It is worth mentioning here that only gamma doses are shown in Tables 1, 2, 4 and 5, since none of the workers received any neutron dose during this period. Table 1 shows that although the values of annual average effective dose per worker at PARR-I during all the five years are not very high, there is an increasing trend in its value. In 1995 annual average effective dose per worker was 1.23 mSv whereas in 1999 it was 4.64 mSv. A similar behaviour is followed by the annual collective effective dose, which is obvious. In spite of the

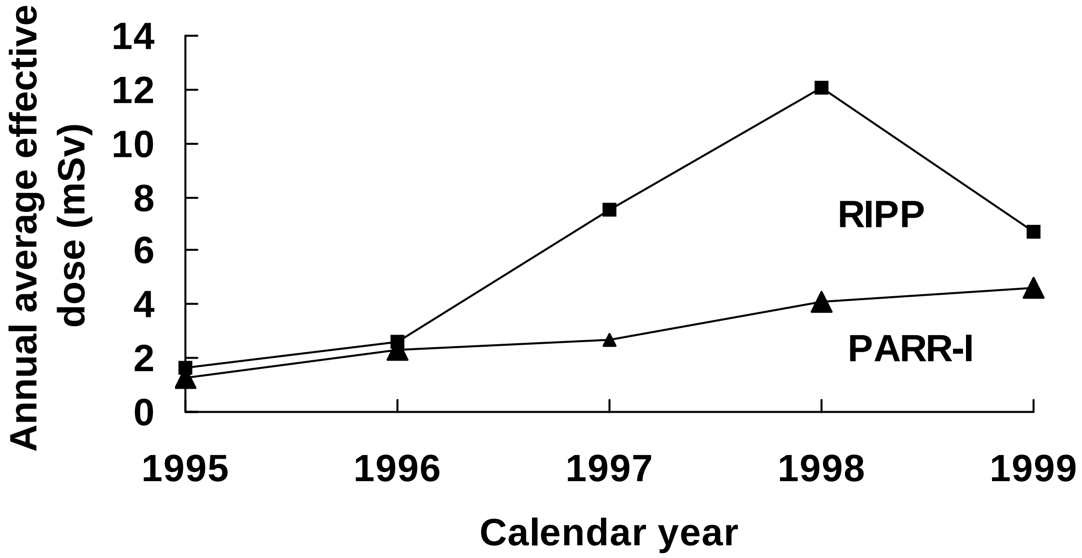

Fig. 2. Plot of annual average effective doses of PARR-I and RIPP workers during 1995 to 1999.

increasing trend, the annual average doses are well below the annual limit of 20 mSv/y. The average effective dose of PARR-I workers, averaged over all the five years, is 3.09 mSv, which is almost 6.5 times lower than the dose limit of 20 mSv/y averaged over five consecutive years. The increasing trend in the annual average dose is because of increase in the reactor operation hours during that period, from 264 hours in 1995 to 948 hours in 1999 [14]. The maximum annual dose of any single worker at PARR-I throughout 1995 to 1999 was 13.2 mSv that occurred in 1998. This value is 26.4% of the maximum dose limit of 50 mSv/worker during any single year over a period of five years. The accumulated dose of any single worker during consecutive five years should not exceed the limit of 100 mSv. The maximum accumulated dose received by any worker at PARR-I during 1995 to 1999 was 30 mSv. This value is less than one third of the limit of 100 mSv. The annual average dose per worker of the RIPP workers during this period is shown in Table 2. All the annual dose values during this period were below the relevant limit of 20 mSv/y. However, these values are relatively higher as compared with the annual average doses of the PARR-I workers during the same period. There is also an increasing trend in the annual average effective dose values of RIPP workers, like that of PARR-I workers. However, there is a peak in annual average effective dose occurring in 1998 for the RIPP workers that does not exist in the case of PARR-I workers as shown in Fig. 2. This is because of addition of a dry distillation plant in the RIPP Lab during 1998. The average effective dose of RIPP workers during these five years is 7.1 mSv as compared to 3.09 mSv for the PARR-I workers, however it is below the limit of 20 mSv/y. The maximum annual dose received by any worker at RIPP was 31.4 mSv (compared to 13.2 mSv for PARR-I workers) that occurred during 1995. This value is 62.8% of the relevant limit of 50 mSv. The five-year accumulated dose of any single worker during this period was 56.1 mSv, which is almost double of that for PARR-I workers, nevertheless, it is less than the relevant limit of 100 mSv. The reason that all the doses in case of RIPP workers are relatively on the higher side as compared with the PARR-I workers is that the RIPP workers work relatively at close proximity with the irradiated samples.

The probability of excess fatal cancer risk due to the annual average effective dose has also been calculated as shown in Tables 1 and 2. These calculations are based upon a probability of induction of fatal cancer of 1.25×10^{-2} per Sv of absorbed radiation dose [15,16] that translates into 125 cancer deaths in a population of ten thousand. It is seen in Tables 1 and 2 that the annual probability of excess fatal cancer risk lies in the range of 1.54×10^{-5} to 1.51×10^{-4} that translates into probability of 15 to 151 annual cancer deaths in a population of one million. To put this figure in proper perspective the mean annual fatal accident rates and fatalities in various industries in United

Table 3. Occupational mean fatal accident rates per year in the United States from various industries.

Sr. No.	Name of industry	Mean fatal accident rate per year	Fatal accidents per year per million
1.	Transport and public utilities	3.73×10^{-4}	373
2.	Agriculture	6.13×10^{-4}	613
3.	Construction	7.17×10^{-4}	717
4.	Mining and quarrying	9.94×10^{-4}	994

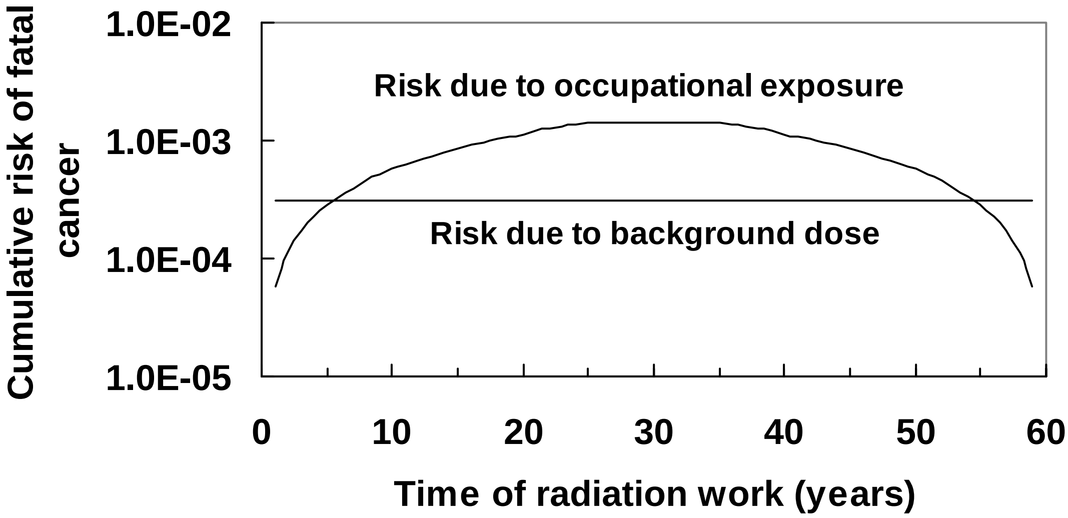

Fig. 3. Life time cumulative risk of fatal cancer due to occupational exposure and due to natural background radiation dose.

States during 1955 to 1975 are given in Table 3 [16]. It can be seen that these values are comparatively very high; 373 to 994 actual annual deaths per million as compared to the mere probability of 15 to 151 cancer deaths per million. The five years average dose of PARR-I and RIPP workers is 4.4 mSv/y. Assuming that a worker is exposed at this annual average radiation dose throughout his job, the lifetime cancer risk has been calculated and graphically shown in Figure 3. In this calculation it is assumed that the worker starts the radiation work as soon as he is employed and retires after a service of 35 years. These calculations are done following the model adopted by P. S. Iyer and R. V. Dhond [17]. There are three main assumptions that are made in the model; (i) the cancer risk varies linearly with the dose, (ii) the risk persists for twenty five years after the dose is received and reduces to zero after crossing twenty five years and (iii) the appearance of cancer is independent of time during twenty five years. Thus as soon as the worker enters into twenty sixth year the risk due to dose received during first year of service reduces to zero. This is why the life time risk flattens after twenty fifth year of service and remains constant upto the retirement, the 35th year of service. After retirement there is no occupational risk, thus the curve falls down. The risk due to mean background radiation dose of 1 mSv/y has also been plotted in Figure 3. This value of background dose is an average of two years background that has practically been measured in the Radiation Dosimetry Laboratory, PINSTECH. If assumed that the general public is exposed at the background dose level of 1 mSv/y then the flat line indicates the risk to the general public.

Table 4. Number of PARR-I workers distributed in various effective dose intervals during 1995 to 1999.

Year / Dose	0-0.99 (mSv)	1.0-4.99 (mSv)	5.0-9.99 (mSv)	10-14.9 (mSv)	15-19.9 (mSv)	20-29.9 (mSv)	>30 (mSv)
1995	9	27	-	-	-	-	-
1996	1	39	-	-	-	-	-
1997	-	40	1	-	-	-	-
1998	4	32	9	1	-	-	-
1999	-	30	15	-	-	-	-

Table 5. Number of RIPP workers distributed in various effective dose intervals during 1995 to 1999.

Year / Dose	0-0.99 (mSv)	1.0-4.99 (mSv)	5.0-9.99 (mSv)	10-14.9 (mSv)	15-19.9 (mSv)	20-29.9 (mSv)	>30 (mSv)
1995	7	16	-	-	-	-	-
1996	2	19	-	-	-	-	-
1997	1	5	10	10	-	-	-
1998	-	1	8	12	5	1	1
1999	1	7	17	4	-	-	-

To see the dose distribution in a more explicit way the number of workers at PARR-I and RIPP has been divided in various dose intervals as shown in Tables 4 and 5 respectively. The data in Table 4 shows that 67% to 98% of all the PARR-I workers received dose in the range of 1.0 to 4.99 mSv. Also it can be seen that all the workers received doses below 10 mSv with one exception of a worker who received a dose of 13.2 mSv during 1998. The number of workers lying in the range of 5.0 to 9.99 mSv progressively increased during 1997 to 1999. This might be due to increased work at demineralizer unit or irradiated sample transfer. During 1995 and 1996 all the RIPP workers received doses in the first two ranges of 0-0.99 mSv and 1.0 to 4.99 mSv. During 1997 to 1999 the maximum number of workers received doses in the dose ranges of 5.0-9.99 mSv and 10-14.9 mSv. There is only one worker at RIPP who received an annual dose of more than 30 mSv in the reported period.

The annual average dose values compare well, rather are relatively on the lower side when compared with other workers in the nuclear industry. For example the occupational radiation exposure in Italian TRINO ENEL Nuclear Power Plant lie in the range of 0.5 mSv to 8.3 mSv for the staff [18]. In Japan, during 1992, the workers received radiation dose in the range of 15-30 mSv in the power generation sector whereas averaged over all 33,000 workers in all types of radiation work the mean dose was 0.4 mSv [19]. The annual average effective dose world over averaged over 380000 or more workers during 1985 to 1989 have been given by the UNSCEAR in the range of 0.5 mSv to 2.9 mSv [20]. These values are lower as compared with ours. This is because the dose has been averaged over a very large number of workers in the case of UNSCEAR. In our case this number is comparatively insignificant. For a better comparison, annual average whole body doses of reactor operation workers at Organic Cooled

Table 6. Annual average whole body dose of reactor operation workers at organic cooled research reactor WR-1 in Canada and Karlsruhe Nuclear Research Centre in Germany.

Year	Annual average dose per worker (mSv)	
	Canada	Germany
1973	6.9	3.0
1974	8.3	3.17
1975	9.3	2.6
1976	8.2	2.67
1977	7.6	2.2
1978	5.7	2.27

Research Reactor WR-1 in Canada [21] and Karlsruhe Nuclear Research Centre in Germany [22], two similar research reactor facilities, for the period from 1973 to 1978, have been given in Table 6.

These values lie in the range of 2.2 mSv/year to 3.17mSv/year for Germany and 5.7mSv/year to 9.3mSv/year in Canada. These values compare well with annual average dose values in our case. Thus our research facilities are as radiologically safe as in developed countries.

4. Conclusion

Our analysis of the data during 1995 to 1999 shows that all the workers received doses well below the relevant dose limits thus conforming to the principle of As Low As Reasonably Achievable (ALARA). Hence we can conclude that the PARR-I and RIPP operation is radiologically safe as well as the workers are well trained in the procedures of radiation protection and follow the code of practice issued from time to time [23].

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