An analysis of cancer mortality among atomic energy employees in Bombay and Tarapur

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We present a status report on radiogenic cancer risk estimates for atomic energy employees living in Bombay and Tarapur in comparison with natural cancer risk levels recorded in the Bombay city general population. In spite of their being the oldest cohorts among the Indian nuclear reactor communities, the inadequacy of the present databases do not permit statistically significant conclusions. When all the data (of employees and their families in both places) are combined to create an adequate database, the age-specific cancer death rates obtained match those for the Bombay city general population. However, it is well known that cancer deaths in the general population are always under-registered, and, in view of this, it is likely that cancer risks for the Department of Atomic Energy community are lower than those actually present in the city population.

Of the communities associated with Indian atomic energy establishments located at various places in the country, the employee communities belonging to those at Bombay and Tarapur are the oldest cohorts with data on collective radiation doses (see Figure 1). Recognizing the carcinogenic potential of even low levels of ionizing radiation received by nuclear workers, an attempt is being made to assess the cancer mortality status of these two cohorts. The availability of reliable base-line cancer mortality data for the general population of Bombay city[1] has also been a major consideration in choosing these two cohorts for the study. (Base-line cancer mortality data are almost non-existent for other places in the country.) Both the study populations are covered by centralized medical services. Death records were extracted from the centralized medical records of the Department of Atomic Energy (DAE). The cancer diagnoses were invariably done at the Tata Memorial Hospital in Bombay, a constituent unit of DAE and a leading institute for cancer diagnosis and therapy. Details of the age- and site-specific analyses of the standardized mortality ratios (SMRs) are being published elsewhere[2,3]; these reports do not however consider the radiation workers as a separate population group among the employees. Here we briefly outline the method, summarize the previous results with specific reference to the radiation workers, and estimate the collective radiogenic risk factors for the radiation workers and compare them with values reported for nuclear establishments in the UK and the USA[4-6].

Standardized mortality ratios

Method of analysis

SMRs were computed using the person-years-at-risk (PYAR) method, commonly known as 'subject-year method'[7]. The study covers members of the DAE communities, who, in the case of Tarapur, were resident at Tarapur as on 1 January 1971, or, in the case of Bombay, as on 1 January 1975, and takes into account all persons joining/leaving these places later. The closing dates for the study are 31 December 1988 for Tarapur and 31 December 1987 for Bombay. Each person contributes one person-year (PY) to the database corresponding to his/her age in a given calendar year, if he/she had been present in the respective place for at least six months during that year. For each year, the available sexwise database was divided into five-year age-at-risk intervals, viz. 0–4, 5–9, . . ., 70–74, 75+ years. The 'expected' numbers (E) of cancer as well as deaths due to all causes for a given population were calculated by using the age-specific death rates obtained from the Bombay cancer registry[1] and Bombay Municipality[8]. (This procedure automatically takes into account the ageing of the study cohort.) From the corresponding observed deaths (O) taken from the medical records, SMRs were calculated as $(O/E) \times 100$. The observed numbers of deaths are assumed to be Poisson variables for testing the statistical significances of the SMRs against a null hypothesis value of 100, as well as for calculating their 95% confidence limits[9]. There has been a gradual increase in the study populations during the study period (Figure 1) and therefore these are not strictly cohorts. However, this does not introduce any error in the SMR calculations based on the PYAR method, wherein each person's contribution to risk is explicitly included.

Results

The basic data and the SMRs with 95% confidence intervals (CIs) for the population groups are given in Table 1. An apparently higher cancer risk (i.e. $SMR > 100$, compared to Bombay city population) is indicated only for the case of Tarapur radiation workers; as these are predominantly males in the middle age group, similar analysis was done[3] on the

Table 1. Analysis of cancer risk for DAE population groups.

DAE complex	Study period	Population category	Database: Person-years	Database: Person-sieverts	Observed cancer deaths	SMR (95% CIs)*
Bombay	1975–87	Radiation workers	55,254	153.29	9	55 (25,104)
		Non-radiation workers	147,624	0.0	41	94 (67,128)
		Families	498,873	0.0	104	68** (55,83)
		DAE community	701,751	—	154	72** (61,84)
Tarapur	1971–88	Radiation workers	22,972	351.55	10	215 (103,395)
		Non-radiation workers	9153	0.0	1	56 (2,311)
		Families	91,416	0.0	30	53** (36,76)
		DAE community	123,541	—	41	66** (47,90)
Bombay + Tarapur		Radiation workers	78,226	504.84	19	91 (55,142)
		Non-radiation workers	156,777	0.0	42	92 (67,125)
		Families	590,289	0.0	134	64** (54,76)
		DAE community	825,292	—	195	71** (62,82)

*Standardized mortality ratios with reference to Bombay city population, and 95% confidence intervals.
**Significantly less than 100, $P<0.01$.

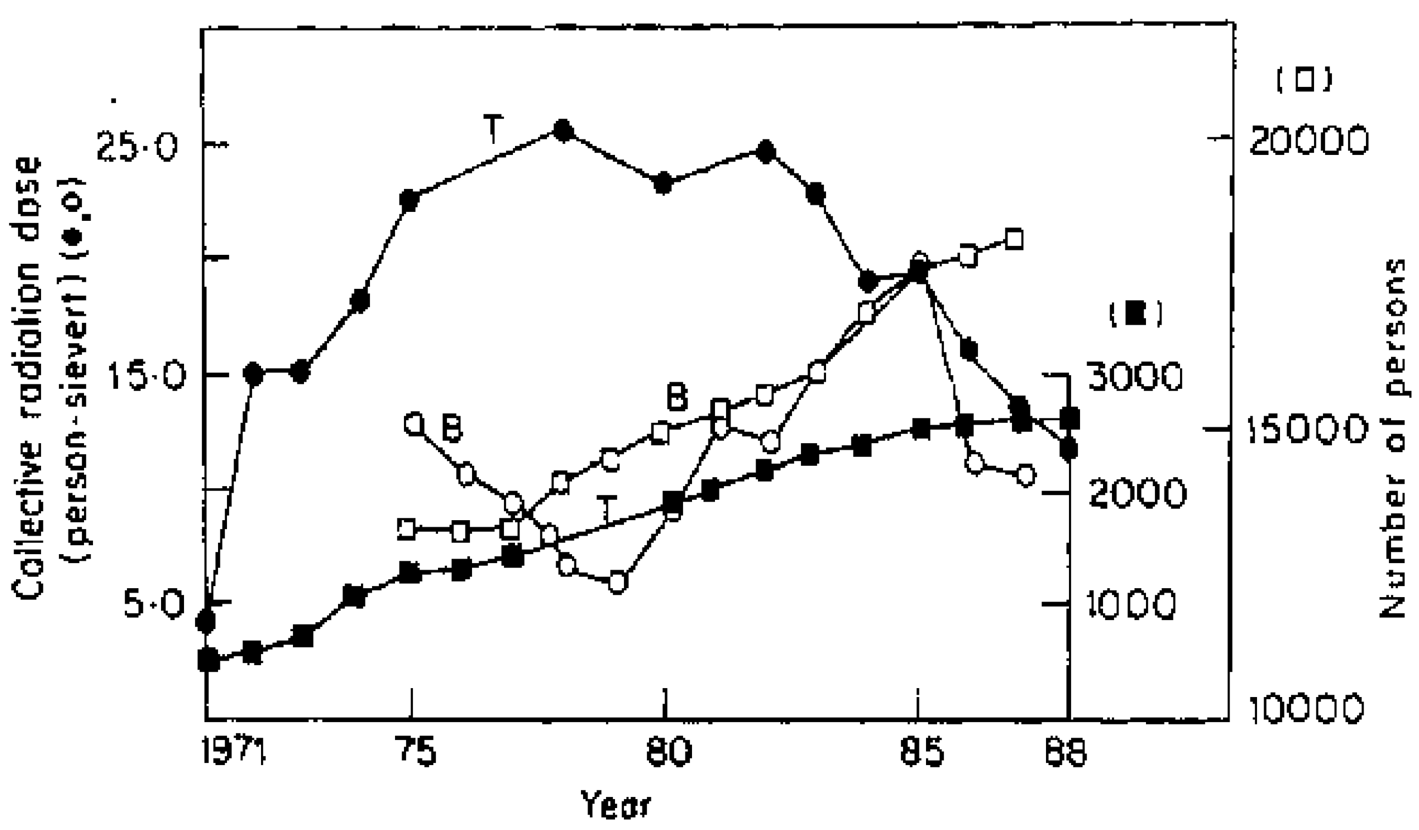

Figure 1. Growth of atomic energy establishment employee populations at Bombay (□, B, 1975–87) and Tarapur (■, T, 1971–88), and their collective annual radiation doses (B, ○; T, ●).

same age group for males in the family population (not exposed to any occupational radiation). This yields equally high SMR (data not shown), thereby suggesting that the base-line cancer risk itself might be higher for males at Tarapur. Besides, the SMR for Tarapur radiation workers lacks statistical significance and the 95% CI values indicate that the data are also commensurate with a situation of there being no excess risk. The only situations having statistically significant SMRs and reasonably small spreads in their 95% CIs are when the SMRs are considerably lower than 100. Such situations are indeed seen for the families of the employees, both in Bombay and Tarapur. Similarly, when the data for the employees and their families are combined under the label 'DAE Community', to yield adequate database in each sex, SMRs significantly less than 100 are obtained (Table 1). An important point emerges when we compare the SMR for the Tarapur DAE community with that for the combined (Bombay and Tarapur) non-radiation-worker population: the SMR for the former alone has statistical significance, even though the databases as well as the observed deaths are comparable for the two population groups. This is because the worker population does not have an adequate database in the older age groups, which alone contribute significantly to cancer risks.

The inadequacy of database for the worker population and the consequent wide 95% CIs are not peculiar to India alone. Even in the USA and the UK, where nuclear plants have been in operation for longer periods than in India, similar drawbacks continue to exist[4, 5]. This situation is graphically presented in Figure 2. For various observed deaths and ranges of SMR values three domains of significance are shown at 1% probability level for the null hypothesis (SMR = 100) to be true for the study population[10]. The three domains refer to: (i) SMR being significantly not different from 100 (no extra risk), (ii) SMR being signifi-

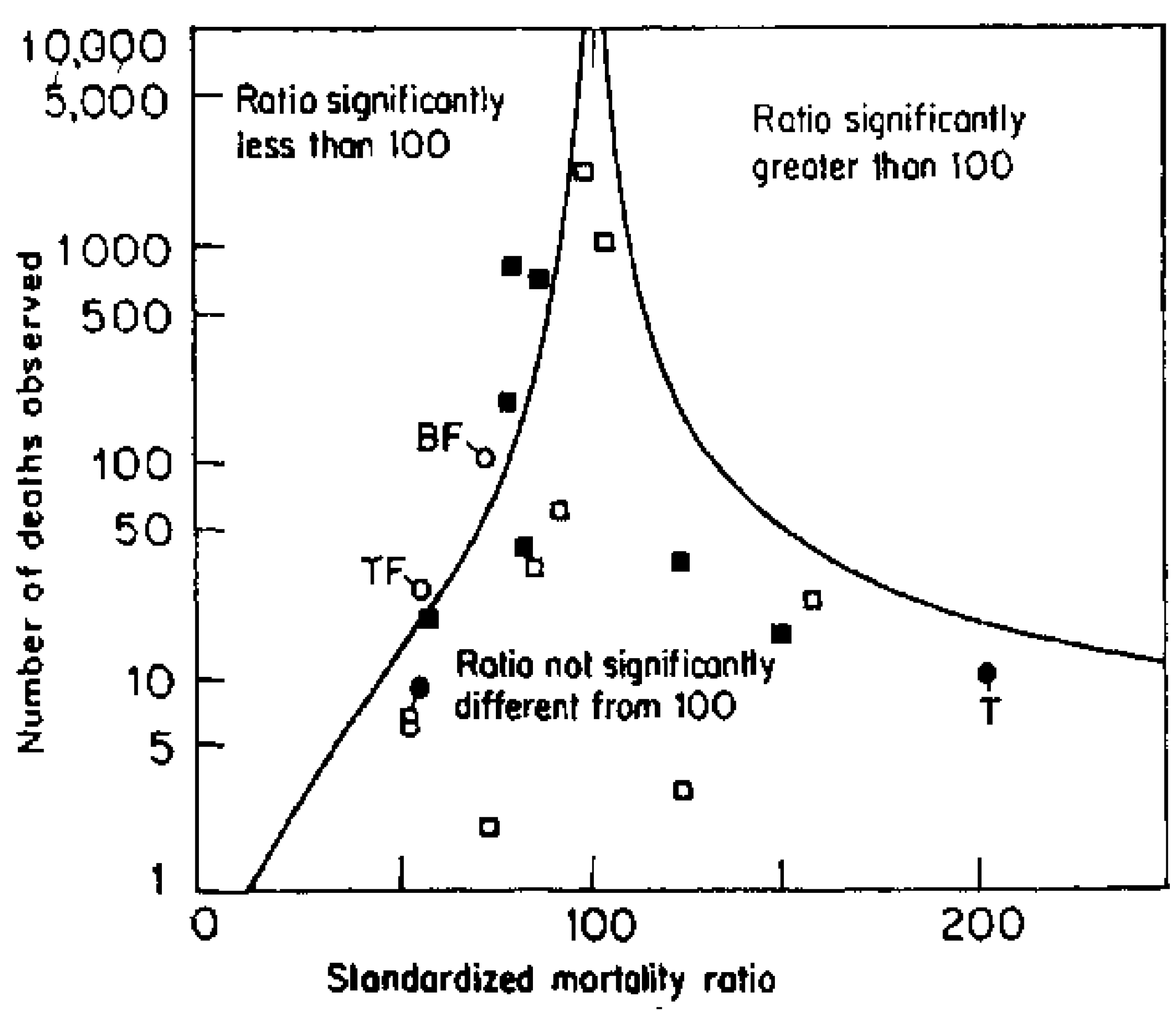

Figure 2. Domains of significance of standardized mortality ratio with respect to a no-risk hypothesis (SMR = 100) for a significance level of $P<0.01$. Epodemiological data on cancers: ○, families of DAE employees at Bombay (BF) and Tarapur (TF), present study; ●, radiation workers at Bombay (B) and Tarapur (T), present study; □, populations near nuclear installations in the UK; ■, radiation workers in UK AEA.

cantly higher than 100 (excess risk), and (iii) SMR being significantly less than 100 (less risk). It is seen that a majority of the SMR estimates, including our own, fall in the domain of 'not significantly different from 100'. The results for the families of the nuclear reactor workers in Bombay and Tarapur lie in the domain of 'less risk' referred to above; this points to a healthier status of the study population, which is not surprising as the community is well cared for by a centralized medical scheme. Statistically significant SMRs (<100) could be obtained only for the family populations, mainly because these are adequate databases.

Age-specific cancer mortality rates

The family data could not, however, be used as reference to evaluate occupational risks for the employees; the age structures and sex ratios of these two databases are nearly complementary to each other and cannot be compared at all. (The employees are predominantly adult males while the families are predominantly children and adult females.) The combined database of the DAE community, at least up to the retirement age of 60 years, reveals an age structure and a sex ratio that are comparable to those available for any urban general population. The age-specific cancer death rates for males and females in the combined DAE community have been compared with those for the Bombay city population (Figure 3). While the male cancer-risk curves more or less match, there seems to be much less cancer risk for females in the DAE community. Both the Bombay-city and the DAE-population groups are highly cosmopolitan, with persons from various states of the country. However, the overall economic and health conditions are obviously not similar. Besides, while the registration system in the DAE community

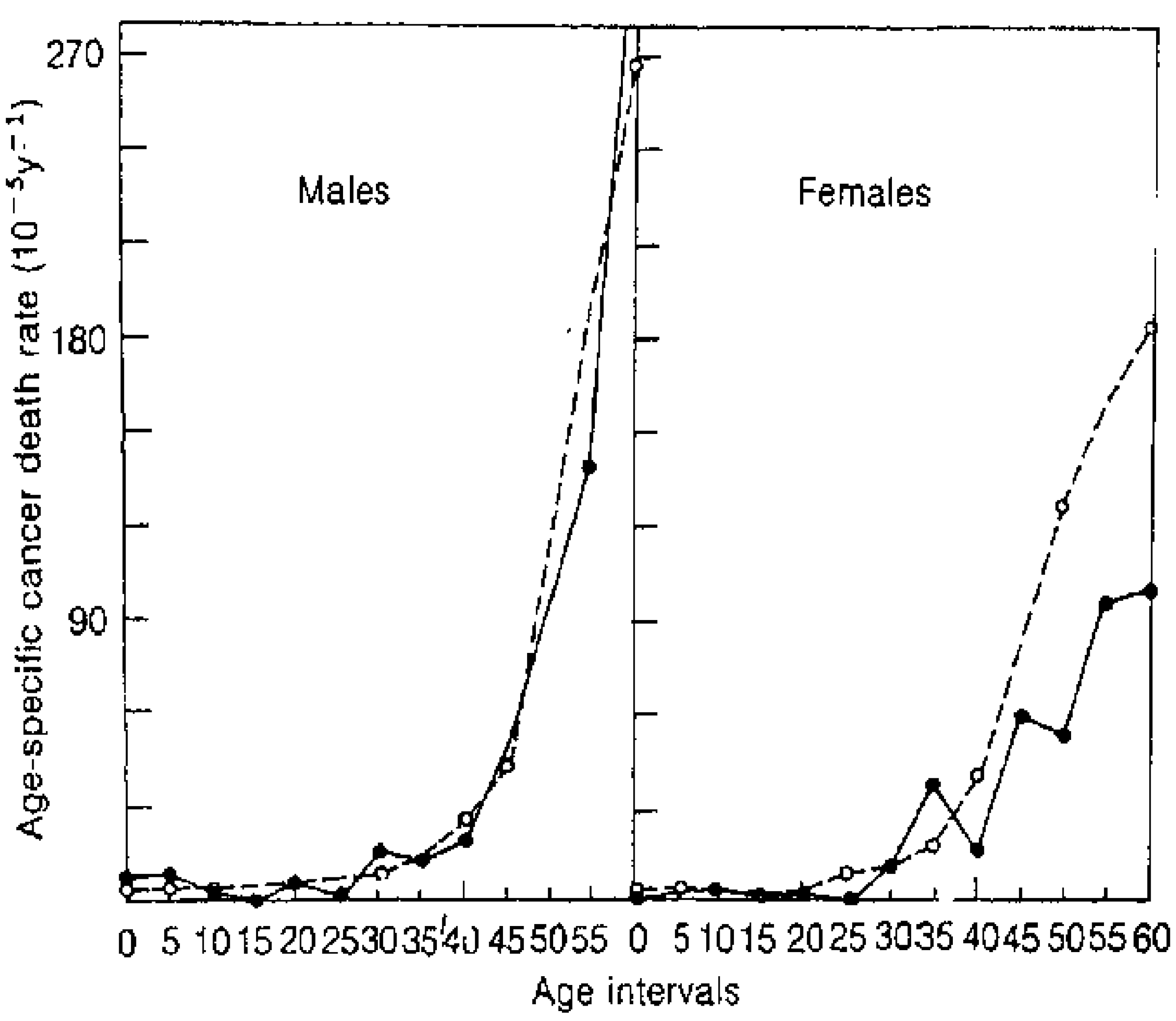

Figure 3. Age-specific cancer mortality rates for males and females of the Bombay city population (○) and the DAE community (●).

may be deemed almost complete (as all the people are covered by a central medical surveillance), the same is not true of the general city population, for which cancer mortalities are likely to be underestimated. The US Committee on Biological Effects of Ionizing Radiations—popularly known as BEIR III—estimates the extent of under-registration to be about 23% in the advanced countries; in India, this is likely to be even higher. In view of this, the presently obtained SMRs could be overestimates and the cancer risks for the DAE community could actually be lower than those present in the Bombay city general population.

Radiogenic cancer risk factor

In the absence of any unambiguous evidence for cancer risks relating to occupational exposure for the DAE community, we tend to regard the data presented in Figure 3 as rather reliable base-line cancer mortality data for a typical Indian urban industrial settlement. (It is important to realize that, in India, such epidemiological data are not readily available.) Nevertheless, for the sake of considering all possibilities, an analysis is made here *assuming* the observed cancer deaths among the radiation workers to have been associated with radiation exposure. In such an analysis, it is customary to evaluate an annual excess cancer risk factor per 10^6 person-years (PY) of the database per 10 millisieverts (mSv) of the cumulated dose. For the present, it is only a gross estimate because the study population is not strictly a cohort; besides, mortality status of retired radiation workers has not been monitored (the percentage of retired workers is, however, very small). The excess cancer mortalities in our case were calculated in comparison to the Bombay city population, after normalizing for the age structure of the radiation-worker population. The collective dose of the study cohort in any year is assumed to contribute to annual risks in the following years throughout the study period. In view of the 'initiator-promoter' hypothesis of radiation carcinogenesis, it is considered prudent not to disregard the risks accrued through the latent period. Thus the risk factor can be expressed as:

$$R = [(\text{observed} - \text{expected})\ \text{cancer deaths}] / \sum_{j=1}^{T} (T+1-j)\, D_j,$$

where R is the risk factor, T the total period of exposure (1969–88 for Tarapur and 1965–87 for Bombay) and D_j the collective dose for the jth year (parts of these profiles, for the study period only, are shown in Figure 1). As leukaemia is the most serious of all the radiation-induced cancers (with a distinctly different latent period from those for others), the annual risk factors are calculated separately for leukaemia and

Table 2. Comparison of estimated annual excess radiogenic risk factors for all malignant neoplasms and leukaemia for various cohorts.

Country	Community	Excess risk/10 mSv/10^6PY (95% CIs)	
		All malignant neoplasms	Leukaemia
USA[6]	Rocky Flats	−37 (−140,60)	—
	Portsmouth	1 (−110,111)	15 (−17,47)
	Hanford	−15 (−66,37)	−2 (neg., 4)
UK[6]	AEA	17 (−22,62)	0 (−3,10)
	Sellafield	17 (−30,70)	1.5 (neg., 4)
India	DAE, Bombay	−21 (−35,2)	−1 (−4,14)
	DAE, Tarapur	17 (0.6,43)	5 (−0.5,21)
ICRP-26 (ref. 11)	Typical worker population in nuclear industry	5*	0.8*
UNSCEAR-88 (ref. 12)	A-bomb survivors	~28*	~3.0*
RERF-88 (ref. 13)	Projected for Japanese population life-table of 1985	~46*	~3.0*

*Extrapolated from the life-time risk factors given in respective reports.

for all malignant neoplasms combined (Table 2). It is readilly seen that the values obtained for the Indian nuclear reactor establishments at Bombay and at Tarapur are in the same range as those reported[6] for similar establishments in the UK and the USA. Obviously, these values cannot reflect true radiogenic cancer risks because any estimate of the cancer risk can be complete only when the study cohort is followed through the complete life-table; moreover, any radiogenic risk can be proved only through establishing a proportional-risk curve with respect to increasing dose intervals. Unfortunately, this also could not be done as the available cancer cases are too few to be subdivided into various dose categories. Nevertheless, the estimates do serve as indices of the level of radiation safety achieved in work practice. Although the risk factors for Tarapur appear to be somewhat on the higher side compared to the values traceable to the International Commission on Radiological Protection (ICRP[6, 11], the uncertainties indicated also include situations of there being much lower cancer risk factors operative on the study population. Moreover, this excess risk may also be an artefact, arising out of our comparing the DAE community with the Bombay city population instead of with a true reference population from Tarapur, which is not available. At the same time, it is worth mentioning here that the ICRP risk factors are being debated in various forums, and an upward revision is sought. Based on revised dose estimates for Hiroshima and Nagasaki A-bomb survivors, the United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR-88 report[12] arrives at a seven-fold increase, and the Radiation Effects Research Foundation, Hiroshima, (RERF) report[13] predicts a ten-fold increase in life-time risk factors. The annual risk factors linearly extrapolated from these estimates are also indicated in Table 2.

Concluding remarks

The overall picture that emerges is that there is no evidence of any statistically significant excess cancer risk for the Indian atomic energy establishment's employees. Nevertheless, the present analysis highlights a need for accumulating more data by a close follow-up study of these cohorts over long periods. Sufficient numbers of observed deaths in different dose categories for employee population groups would have to be accumulated before a statistically meaningful analysis of mortality with respect to radiation exposure can be attempted.

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