EFFECTS OF LOW-DOSE IONIZING RADIATION AMONG THE EMPLOYEES AT THE MADRAS ATOMIC POWER STATION: A CROSS-SECTIONAL STUDY

Tata Memorial Centre

Tata Memorial Hospital
Dr. E. Borges Marg, Parel
Mumbai - 400 012

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A Report
Prepared
Under the Consultancy Service Contract of NPCIL
with
Tata Memorial Centre
by
The Epidemiological Studies Cell
Tata Memorial Hospital
Mumbai

March 2001

TATA MEMORIAL CENTRE

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PREFACE

In January 1992, the Nuclear Power Corporation of India Ltd. (NPCIL) entered into a Consultancy Service Contract (No.CSC-92-1-TMC) with the Tata Memorial Centre (TMC) to carry out epidemiological studies in the employees and their families. The aim of the study was to investigate whether any health hazards were associated with exposure, if any, to low-dose ionizing radiation. The contract was to undertake the studies at 6 power stations or project sites. These were located at Tarapur, Maharashtra; Rawatbhata, Rajasthan; Kalpakam, Tamilnadu; Narora, Uttar Pradesh; Kakrapar, Gujarat and Kaiga, Karnataka.

NPCIL also set up a Corporate Committee for Epidemiological Studies (COCES). The first meeting of COCES was held on 6th April 1992. Two additional committees were also constituted viz. Senior Technical Advisory Group (STAG) and Planning and Implementation Supervisory Committee for Epidemiological Studies (PISCES), and their functions and terms of references were laid down. Member-Secretary PISCES was designated to be officer in-charge of Epidemiological Surveys. These committees met periodically. In the initial phase of the study, several issues were debated and decisions taken regarding the target population, the controls, the types of health indicators to be studied, the instrument for data collection and several technical issues.

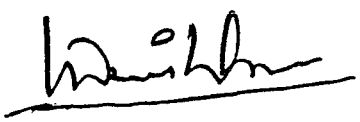
Tarapur Atomic Power Station was the first site selected for the survey, because of its proximity to Tata Memorial Hospital (TMH), which allowed enumerators, statistician and doctors from TMH to visit the site regularly to carry

out the work. This was followed by Kakrapar Atomic Power Station. Besides these two power stations, the data at other power stations were collected by the local academic/medical institutes as per the guidelines provided by TMH and the data transported to the Epidemiological Studies Cell at TMH for processing and analysis.

To-date the reports of surveys carried out at Atomic Power Stations located at Tarapur, Kakrapar, Rawatbhata, Narora, Kaiga and now Kalpakkam have been prepared. The AAM Cancer Research Institute, Kanchipuram (Tamilnadu) was responsible for collection of data at MAPS.

One of the important results yielded by these surveys revealed no increase in the prevalence of malignancies in the radiation workers as compared to non-radiation workers; nor was there any difference in the prevalence of malignancies in spouses and offspring of employees as compared to relevant control groups. The study has provided useful indicators and generated reliable baseline data for carrying out further work.

The Tata Memorial Centre has been privileged to undertake this research project to address a problem which is not only scientifically important but also socially relevant. This report, I am sure, will be of interest to a wide range of readers from epidemiologists, scientists, physicians as well as physicists concerned with these issues.



- Dr.K.A.Dinshaw
Director, TMC

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SUMMARY:

The potential effect of ionizing radiation on human population has been a concern to the scientific community and to the public at large, for a long time. The Nuclear Power Corporation of India Limited (NPCIL) recognised the need for more precise information on the biological effects of low dose radiation on human population. In response to this concern NPCIL awarded a Consultancy Service Contract to the Tata Memorial Centre (TMC), to carry out epidemiological studies in radiation occupational workers and their families at various power station/project sites. At Tarapur and Kakrapar Power Stations TMC undertook the survey. The surveys at other sites have been conducted by local academic/medical institutions as per the procedures standardized by TMC, and the data were transported for processing and analysis to its Epidemiological Studies Cell especially set up for this purpose.

The present document reports the results of the cross-sectional survey carried out at Madras Atomic Power Station (MAPS), during the period Jan.1997 to February 1998 by Arinagar Anna Memorial Cancer Research Institute (AAMCRI), Kanchipuram (Tamilnadu). Subsequently all the medical records were scrutinized to obtain information on the group that could not participate in the survey, and this work was completed by February 1999. The present report is based on the data of 5462 employees, 3969 spouses of employees and 5589 offspring of employees. The prevalence of malignancies in

these three groups has been studied and congenital anomalies in the offspring of employees has also been reported on.

There was no statistically significant difference in the prevalence of malignancies in radiation workers as compared to that of non-radiation workers of MAPS. The observed (O) to expected (E) ratio of prevalent cancer cases in males was 1.19 (2/1.68) with 95% confidence limit (CI) of 0.14 to 4.29. Similarly no significant difference in the prevalence of malignancies was observed between the radiation workers of MAPS and non-radiation workers of Bhabha Atomic Research Centre (BARC, Mumbai), [O/E = 0.29 (2/6.82), 95% CI = 0.04 – 1.05]. The female employee group was very small and there was no case of cancer among the female workers. Furthermore, cancer is known to increase with age and there is no specific pathology related to radiation induced cancer. Numerous studies have demonstrated that a cohort of workers is healthier than the general population cohort (healthy worker effect), and they experience lower risks for cancer and other diseases. To avoid this bias, general population controls were not utilized.

There is no exposure to radiation of nuclear installation origin, to the spouses of employees. All the cancer cases were seen in female spouses only. The prevalence of malignancies in the spouses has been compared with that seen in the spouses of BARC (Mumbai) employees, yielding an observed to expected ratio of 0.43 with 95% CI = 0.16 - 0.94.

As in the case of the spouses, in the offspring also there is no direct exposure to radiation of power plant origin. There were 4 cancer cases reported in the offspring group, 3 in males and one in females. The prevalence of

malignancies in the male offspring of radiation workers has been compared with that of non-radiation workers. There was no statistically significant excess in the prevalence of malignancies in male offspring of radiation workers as compared to that of non-radiation workers of MAPS [O/E = 2.53 (2/0.79), 95% CI = 0.31 - 9.13]. The comparison of prevalence of malignancies in female offspring of radiation workers with that of non-radiation workers could not be undertaken because there were no cancer cases in the female offspring of non-radiation workers to compare with the one case in female offspring of radiation workers.

There were 58 cases of congenital anomalies (major and minor) among 5589 offspring of employees, giving prevalence of 1.04% (1.49% in males and 0.58% in females). The prevalence of congenital anomalies in the offspring does not seem high. An earlier exhaustive study at large maternity home in Mumbai had reported the prevalence of congenital anomalies among the new born children to be 1.4%. The question regarding effects of in-utero medical exposure is not addressed to as this information was not available.

In conclusion, no increase in cancer prevalence was observed in the radiation workers of MAPS as compared to the non-radiation workers. This finding has been consistently observed at all the power stations where surveys have been carried out viz. Tarapur Atomic Power Station, Rajasthan Atomic Power Station and Narora Atomic Power Station. There were no cancer cases seen in the small group of employees of Kakrapar and Kaiga Atomic Power Stations. Furthermore there was no excess of cancer prevalence in the spouses and offspring of the employees as well, as compared to the corresponding control groups.

EFFECTS OF LOW-DOSE IONIZING RADIATION AMONG THE EMPLOYEES AT THE MADRAS ATOMIC POWER STATION : A CROSS-SECTIONAL STUDY

1. INTRODUCTION

The potential effect of ionizing radiation on human population has been a concern to the scientific community and the public at large, for a long time. The Nuclear Power Corporation of India Limited (NPCIL) recognized the need for more precise information on the biological effects of low dose radiation on human population. In response to this concern the NPCIL awarded a Consultancy Service Contract to Tata Memorial Centre (TMC) to undertake epidemiological survey in the employees and their families at various project sites. NPCIL also constituted various committees (composition given in Appendix G) to monitor the progress of the project. TMC conducted the survey at two sites viz. Tarapur DAE Centre and Kakrapar Atomic Power Station. For surveys at other stations TMC provided guidelines regarding the format for data collection, the questionnaire, and the software for data entry. This data was then transferred to TMC for processing and analysis at its Epidemiological Studies Cell especially set up for the purpose.

This report deals with data collected at Madras Atomic Power Station.

2. OBJECTIVES

The general aim of the project was to conduct health survey in employees and their families residing with them and assess morbidity due to various diseases and evaluate the impact, if any, of low-dose radiation.

Specific aims, for this report, are to compute morbidity (prevalence) of cancer and compare with suitable controls, for 3 groups viz. the employee group, their spouses and their offspring. Additionally, for the offspring group prevalence of congenital anomalies is also to be studied.

3. OPERATIONAL METHODOLOGY

Arinagar Anna Memorial Cancer Research Institute (AAMCRI), Kanchipuram (Tamilnadu) collected the data for this survey at MAPS. The actual data collection was initiated in January 1997 and was concluded by February 1998. The survey involved filling a questionnaire with respect to demographic and medical data and other relevant details as well as carrying out medical examination. Health information on the group that could not participate in the survey was obtained from the medical records maintained at the DAE Hospital, Kalpakkam, and the data collection work was completed by February 1999.

3.1 Questionnaire

A detailed questionnaire was designed for collection of information on demographic characteristics and medical and health history and radiation exposure history. Besides, data were also obtained on lifestyle factors like tobacco use, alcohol consumption, dietary intake and other occupational exposures. This was necessary, since environmental/lifestyle factors determine a large fraction of cancer rates. Thus, the confounding/modifying effects of these factors could be taken into account, if required. Occupational history including the type of occupational radiation exposure and period of exposure prior to and after joining the power station was obtained. Medical history giving

details of past and/or present illness, if any, and details of clinical examinations, reproductive history of women employees/spouses and for the offspring history of congenital anomalies, if any, were also recorded.

The questionnaire was field-tested earlier at Tarapur Atomic Power Station, and was used in the present survey also.

3.2 Field Survey, Data Collection and Processing

The employees and their families were invited by the local authorities of the MAPS to participate in the survey and to come to the DAE Hospital at Kalpakkam, where investigations were conducted and data collected. For this survey, a team from AAM Cancer Research Institute, Kanchipuram, visited DAE Hospital at Kalpakkam every week. Doctors from AAM Cancer Research Institute examined each and every participant as they presented themselves and filled the medical part of the proforma. The investigations that were carried out included testing of complete blood count (C.B.C.), chest x-ray and cytological investigations.

Following criteria were set for carrying out these investigations :-

1. All adults above the age of 40 years and smokers 35 years and above had to undergo chest x-ray.
2. All females above the age of 35 years had to undergo pap-smear test.
3. All children had to undergo blood test (C.B.C.).
4. Adults had to undergo blood test (C.B.C.) only if it was not done for the past one year.

The database was created from the completed proformas, with the software installed at DAE Hospital, Kalpakkam by the Epidemiological Studies Cell of TMH. The floppies containing the database were then transported to this cell for processing and analysis.

4. POPULATION COVERAGE

This report is based on information on 5462 employees, 3969 spouses of employees and 5589 offspring of employees i.e. a total of 15,020 individuals from all the units of DAE located at Kalpakkam. The details of the population covered are given in Table 1 below. Of these 11303 members were individually examined and interviewed. For 3717 individuals i.e. 25% of the study population, information on health status with respect to malignancies and congenital anomalies in the offspring, if any, was obtained by reviewing the medical records maintained at DAE Hospital. Both these conditions are such that they would be brought to the notice of the doctor and recorded and hence there was little likelihood of missing these cases.

Table 1 : Population Covered i.e. Employees, Their Spouses and Offspring (1997-1998)

Groups	Covered in the Survey			Information obtained from the medical records of Kalpakkam DAE Hospital			Total
	Males	Females	Total	Males	Females	Total	
Employees	3952	356	4308	1012	142	1154(21%)	5462(100%)
Spouses	85	2969	3054	51	864	915(23%)	3969(100%)
Offspring	1985	1956	3941	826	822	1648(29%)	5589(100%)
Total			11303(75%)			3717(25%)	15020(100%)

5. HEALTH OUTCOMES FOR STUDY

The basic study design was cross-sectional type with no follow-up. It was simply a one time survey, so that only prevalence of various conditions could be assessed. Neither the incidence nor mortality were studied. The health outcomes reported on here are

1. Malignant disease in three groups viz. employees, their spouses and their offspring.
2. Congenital anomalies in the offspring

Members of the surveyed group were given a thorough medical check-up. However for the purpose of this report only the above two conditions have been considered.

6. SELECTION OF COMPARISON GROUP

Several options were available for selection of the comparison group. One was to have internal comparison group i.e. compare radiation workers with non-radiation workers of MAPS. The other was to have external comparison group, such as the general population. A third suggestion made by the STAG/PISCES committee members was to obtain comparison group from Bhabha Atomic Research Centre (BARC), Mumbai employees and their family members. Each of these groups carries both useful and restrictive elements.

6.1 Comparison Group for Evaluating Cancer Prevalence in Employees

General population groups are not ideal in studies evaluating occupational exposures, because workers are usually healthier than the general population

(the healthy worker effect) - healthier people are more likely to get jobs and continue at work. Hence the workers are generally expected to experience lower risks for cancer and for other diseases than the general population. Furthermore, there are no cancer prevalence data available for the general population and prevalence estimated from available incidence rates by a fixed multiplier (1.5, 2 or 3) as an estimate of average duration, would not be strictly proper.

The second alternative of comparing with BARC(Mumbai) employees and their families, may also be questionable because in the perception of the lay public, these employees also come under the umbrella of radiation workers.

The better alternative is to have an internal comparison group i.e. compare prevalence of cancer among those exposed to radiation with those who were not exposed, within the same study group.

We have therefore made the following comparisons for prevalence of cancer in the employees :

1. Radiation Workers of MAPS vs. Non-Radiation Workers of MAPS
2. Radiation Workers of MAPS vs. Non-Radiation Workers of BARC (Mumbai)

6.2 Comparison Groups for Evaluating Cancer Prevalence in Spouses of Employees

As regards spouses of employees, comparing this group with the general population does not pose a problem if the prevalence data were to be available, because the question of `healthy worker effect' does not arise. However, one expects the study group to be socio-economically somewhat better off than

the general population and comparison with the spouses of employees of BARC (Mumbai), would perhaps be more relevant though not the ideal. Therefore, cancer prevalence in the spouses has been compared with the available prevalence data in the spouses of BARC (Mumbai) employees.

6.3 Comparison Group for Evaluating Cancer Prevalence in Offspring of Employees

Cancer prevalence in the offspring has been studied by comparing

1. Offspring of Radiation Workers of MAPS vs. Offspring of Non- Radiation Workers of MAPS.
2. Offspring of Radiation Workers of MAPS vs. Offspring of Non-Radiation Workers of BARC (Mumbai).
3. Offspring of employees of MAPS vs. Offspring of employees of BARC (Mumbai)

6.4 Comparison Group for Evaluating Congenital Anomalies in Offspring of Employees

It has not been possible to obtain the prevalence of congenital anomalies in a comparable cross-section of the population independent of radiation-occupational groups. The only data available from the country deals with prevalence of congenital anomalies in the new born (Master-Notani et al;1968, Agarwal et al;1991) and hence are not comparable with the present data. We have therefore attempted to compare the prevalence of congenital anomalies in the offspring of employees of MAPS with those of BARC (Mumbai) employees. Internal comparison i.e. comparing offspring of radiation workers versus those of non-radiation workers, though undertaken, is of limited value. That is because such a comparison does not answer the question of in-utero exposure

that is not work-related, as there is no reliable information available on such an exposure for spouses of male employees. In-utero work-related exposure of female employees is restricted to not more than 2 mSv during the pregnancy period as per the recommendation of AERB/ICRP. There were 117 female radiation workers and they have received mean cumulative radiation dose of only 1.84 mSv.

7. RADIATION EXPOSURE : DEFINITION AND MEASUREMENT

The details of annual radiation dose received by employees was provided by MAPS. An employee who has been given a TLD number for measuring radiation exposure is defined for the purposes of this study as a radiation worker. The radiation exposure to an employee at a nuclear installation can either be external and/or internal and is mainly due to gamma and beta radiation.

External exposure is caused due to radioactive source external to the body and is measured by means of personal dosimeters. These dosimeters can either be thermoluminescent dosimeters (TLD) or film badge type dosimeters. For day-to-day dose management direct reading type dosimeters (DRD) are also employed. For special applications, some other types of dosimetry devices are used.

Internal exposure is caused due to radioactive materials entering the human body through inhalation, ingestion and injection. This type of exposure is monitored by bioassay and whole body counting techniques.

The external radiation exposure received by an employee is controlled by suitable adjustment of distance, time and shielding, while the internal exposure is controlled by protective equipment and clothing.

The dose received by the personnel is controlled and is kept well below the stipulated exposure limits recommended by International Commission on Radiological Protection (ICRP) and Atomic Energy Regulatory Board (AERB), from time to time.

The distribution of cumulative radiation dose in mSv (external cum internal), received by radiation workers of MAPS is given in Appendix A. The cumulative dose of an employee is measured by adding annual doses from initial employment upto end-1998, when the survey ended. The mean cumulative radiation dose per worker was 37.94 ± 1.37 mSv in males. There were 117 female radiation workers and the mean cumulative radiation dose per worker was 1.84 ± 1.30 mSv. Furthermore, not a single annual radiation dose exceeded 250 mSv or more, which is considered to be a radiation incident of medical significance for the United States population (Fry,1980). In fact, almost all the annual radiation doses for 2328 male radiation workers were below 50 mSv/year; except 4 employees who were exposed to annual doses between 50 mSv and 60 mSv/year.

8. CHARACTERIZATION OF EMPLOYEE POPULATION : UNIVARIATE DESCRIPTION

Table 2 describes the age and sex distribution of the radiation and non-radiation workers. It is seen that almost 40% of male employees are below the

age of 40, about a third are between 40 and 50 years and the rest are 50 years of age or above. Age distribution by 5 year age categories is given in appendix B.

Table 2 : Age Distribution of Employees of MAPS by Radiation Status (1997-1998)

	Males		Females	
Age	Radiation Workers No.(%)	Non-Radiation Workers No.(%)	Radiation Workers No.(%)	Non-Radiation Workers No.(%)
Upto 39	1036(45)	1021(39)	81(69)	237(62)
40 - 49	813(35)	957(36)	29(25)	116(31)
50+	479(20)	658(25)	7(6)	28(7)
Total	2328(100)	2636(100)	117(100)	381(100)

For age distribution by 5-year age interval see appendix B.

Besides age and sex differences, which have been adjusted for in all comparisons, it is of importance to see the profile of the radiation and non-radiation workers with respect to other characteristics which could influence, exposure-cancer prevalence relationship. This information was available for 4308 (3952 males and 356 females) interviewed employees. The distributions of these characteristics are shown in Table 3 for male employees only, because there were very few female employees. The radiation and non-radiation workers were found to be similar with respect to marital status (over 85% were married), community distribution (almost 90% belonged, as expected, to the majority community), educational level (31% had studied upto undergraduate level or above) and also the habit pattern (74% had no habit). There was however a higher proportion of scientific/technical staff in the group of radiation workers (87%) than non-radiation workers (73%).

Table 3 : Profile of Male Employees (interviewed) of MAPS by Radiation Status (1997-1998)

Group	Radiation Workers No. (n=1904)	%	Non-Radiation Workers No. (n=2048)	%	Total No. (n=3952)	%
• **Marital Status**						
Unmarried	252	13.2	220	10.7	472	11.9
Married	1645	86.4	1823	89.0	3468	87.8
Widowed/Divorced/ Separated	7	0.6	5	0.2	12	0.3
• **Community**						
Hindu	1731	90.9	1876	91.6	3607	91.3
Muslims	38	2.0	34	1.7	72	1.8
Christians	132	6.9	132	6.4	264	6.7
Others	3	0.2	6	0.3	9	0.2
• **Education***						
Upto primary	79	4.1	180	8.8	259	6.6
Middle (V-VII std)	190	10.0	322	15.8	512	13.0
Secondary and Technical after SSC (VII-XII Std)	1041	54.7	914	44.8	1955	49.6
Undergraduate and above	594	31.2	623	30.6	1217	30.8
• **Habits**						
No habit	1402	73.6	1506	73.5	2908	73.6
Chewers only	29	1.5	39	1.9	68	1.7
Smokers only	183	9.6	197	9.6	380	9.6
Alcohol consumers only	112	5.9	117	5.7	229	5.8
Combination of Habits	178	9.3	189	9.2	367	9.3
• **Cadre of Work***						
Administration	100	5.3	177	9.0	277	7.2
Scientific	719	37.8	641	32.5	1360	35.1
Technical	937	49.2	791	40.2	1728	44.6
Security	36	1.9	31	1.6	67	1.7
Labour	112	5.9	279	14.2	391	10.1
School teacher	0	0	51	2.6	51	1.3

* Among the 2048 non-radiation workers; information was not available, regarding education on 9 employees and on designation of 78 employees.

9. STATISTICAL METHODS

This is a cross-sectional survey with no follow-up, so that only the prevalence of conditions of interest can be studied. The primary interest is to study the prevalence of malignancies, particularly in the radiation workers and compare with that in adequate control groups of non-radiation workers.

While comparing prevalence of malignancies in different groups, it is essential to control for confounding factors, since a large fraction of cancer rates of a population are affected by local environmental/life style factors (Higginson and Muir, 1979; Doll and Peto, 1981). Since most of the factors looked at in Table 3, particularly the life style factors which could affect cancer pattern, are similarly distributed between radiation and non-radiation workers, their confounding effect is likely to be minimal, even though it has not been possible to control for them because of small number of cancer cases in the employees.

All comparisons, however, have been controlled for age and sex differences. The observed (O) number of cases in the 'study' group is compared with the expected (E) number, arrived at from the corresponding control group. This has been calculated under the assumption that the age-specific prevalence, in 5-year age intervals in the study group is the same as that in the corresponding control group and is obtained by summing the products of the age-specific prevalence of the control group with the age distribution of the 'study' group. This has been done individually for males and females. The observed number of cases is considered to follow a Poisson distribution with mean E and under the null hypothesis, the ratio O/E is unity. The confidence intervals are read from the tables prepared by Bailar and Ederer

(1964) for the ratio of an observed value of a Poisson variable to its expectation. For interpretation, if the 95% confidence interval covers the null value of unity, then there is no significant difference between the observed and expected values, at the 5% level of significance. If this interval does not cover unity, then the observed value is significantly higher or lower than the expected value depending on whether the interval covers values that are higher or lower than unity.

This methodology is followed for all comparisons that have been undertaken in this document.

10. OBSERVATIONS AND DISCUSSION

The core question of the study concerns whether the employees of the Nuclear Power Plants, if exposed to low doses of ionizing radiation, are at higher risk for any disease condition; in particular cancer. The query is also extended to the family members i.e. their spouses and offspring. The interest is focused on cancer induction, since it is considered to be the most important long-term somatic effect of radiation exposure. However, it is not possible to distinguish between malignancies caused by ionizing radiation from those caused by other factors. There is no radiation specific tumor pathobiology. In general, only the frequency of an already prevalent tumor is expected to be elevated by radiation exposure. The age-adjusted incidence rate of cancer of different sites reported from 6 population based Indian cancer registries is attached in Appendix D, for reference (ICMR, Biennial Report, 1992).

In this survey, which is a cross-sectional type, the question is being addressed by assessing prevalence of cancer in the study population comprising

of a) employees, b) spouses and c) offspring and comparing these with the prevalence in relevant control groups; to see if there is any excess in disease prevalence.

Besides malignant conditions, prevalence of congenital anomalies in the offspring have also been studied to see the effect of low-dose radiation in the unborn child.

10.1 Cancer Prevalence in Employees.

There were four prevalent cancer cases in the male employee group; and none in female employees. The distribution of cases by radiation status is shown in Table 4.

Table 4 : Prevalent Cancer Cases in Employees of MAPS by Sex and Radiation Status (1997-1998)

		Males	Females	Total
Radiation Workers	No.	2328	117	2445
	Cases	2	0	2
Non-Radiation Workers	No.	2636	381	3017
	Cases	2	0	2
Total	No.	4964	498	5462
	Cases	4	0	4

The description of cases giving details of age, sex, year of diagnosis and employee's designation at the time of the survey, year of joining DAE and radiation status is given in Table 5. Among the male employees there was one

case of cancer at each of the following sites: stomach, parotid gland, thyroid and one case of Hodgkin's disease.

Table 5: Details of Prevalent Cancer Cases in Employees of MAPS (1997-1998)

Cancer Site (ICD-9TH)	Age	Sex	Year of Diag.	Year of joining DAE	Designation at survey time	Cumulative dose in mSv upto the year of diagnosis	Habits
Stomach (151)	58	M	1996	1971	Tradesman	91.4 mSv	No habits
Parotid Gland(142)	59	M	1994	1968	Tradesman	127.6 mSv	No habits
Thyroid (154)	47	M	1990	1979	Driver	Non-Radiation Worker	No habits
Hodgkin's Disease (201)	42	M	1995	1975	Tradesman	Non-Radiation Worker	No habits

M - Male, F - Female

The two radiation workers who developed cancer of the stomach and parotid gland have received very low cumulative radiation doses of 91.4 mSv and 127.6 mSv respectively over a period of 25 to 26 years which cannot possibly have caused the disease. The remaining 2 cancer cases viz. Cancer of the thyroid and Hodgkin's Disease occurred in non-radiation workers and therefore are not attributable to radiation exposure.

The prevalence of the cancers of all-sites together in the radiation workers (males-2 cases, females - none) was compared with that in non-radiation workers (males - 2 cases, females - none) of the MAPS, after adjusting for differences in age distribution.

In males, the observed to expected ratio was 1.19 with 95% confidence interval of 0.14 to 4.29 as given in Table 6. In females there was no case of cancer in either group.

Table 6 : Comparison of Cancer Prevalence in Radiation Workers of MAPS with Non-Radiation Workers of 1) MAPS and 2) BARC, Mumbai

Groups Compared	Males			Females		
	Observed cases O	Expected cases E	O/E (95%CI)	Observed cases O	Expected Cases E	O/E (95%CI)
Radiation Workers (MAPS) vs. Non-Radiation Workers (MAPS)	2	1.68	1.19 (0.14-4.29)	0	-	-
Radiation Workers (MAPS) vs. Non-Radiation Workers (BARC, Mumbai)	2	6.82	0.29 (0.04-1.05)	0	-	-

E =Expected based on the corresponding comparison group, adjusted for age
CI=Confidence Interval.

Thus, there was no statistically significant excess of prevalent cancer cases (all-sites) in the radiation workers as compared to non-radiation workers of MAPS.

This observation is in line with the results reported by Nambi and Mayya (1997). In their study of cancer mortality of employees of five units of DAE (India), no excess was observed in radiation workers compared to non-radiation workers.

Furthermore, the cancer prevalence in the radiation workers of MAPS has also been compared with the prevalence in non-radiation workers of BARC (Mumbai), adjusting for sex and age differences. Details of the prevalent cancer cases in BARC (Mumbai) employees are given in Appendix C Table 2.

Thus, even when radiation workers of MAPS were compared with non-radiation workers of BARC (Mumbai), there was no significant difference in cancer prevalence and the observed to expected ratio for males was only 0.29 with 95% of confidence interval of 0.04 to 1.05 (Table 6). It needs to be emphasized however, that the most relevant comparison is the internal one, where the radiation and non-radiation workers of the same plant have been compared.

10.2 Cancer Prevalence in Spouses

There were six cancer cases in the spouses of employees MAPS and all were females as seen in Table 7. The two cases of cancer of the buccal mucosa and the one of lung cancer, both are known to be associated with tobacco use. Cigarette smoking as a cause of lung cancer has been established since long (Doll and Hill, 1950; Wynder and Graham, 1950), and so also the association of bidi smoking and lung cancer (Notani and Sanghvi, 1974). Tobacco chewing and smoking are also important risk factors in the development of oral cancer (Jussawalla and Jain, 1979). In the present study, the 54 year old spouse with buccal mucosa (BM) was a tobacco chewer though the other case of BM was not. Information on tobacco habit was not available for the case of lung cancer and the information on the diagnosis was obtained from the medical records.

Table 7 : Prevalent Cancer Cases in Spouses of Employees of MAPS (1997-1998)

Spouses	Males	Females	Total
Number	136	3833	3969
Cases	0	6	6

Of the remaining 3 cases one was cancer of the cervix, where infection with human papilloma virus is a causative agent along with life style risk factors, viz. early age at marriage and circumcision status of partner (possibly) [Ponten et al,1995]. Cancer of the skin and cancer of the stomach were the other two reported malignancies. Cancer of the skin is a rare malignancy in Indian population; while incidence of cancer of the stomach is reported to be higher in cancer registry areas of southern parts of the country compared to other registry areas (ICMR, Biennial Report, 1992).

However, none of the malignancies in the spouses can be attributed to radiation, since none of them was an employee.

Table 8 : Details of Prevalent Cancer Cases in Spouses of Employees of MAPS (1997-1998)

				Employee's Details		
Cancer Site (ICD-9TH)	Age	Sex	Year of Diag.	Year of joining DAE	Designation	Radiation Status
Cheek (145)	40	F	1997	1975	Tradesman	NR
Cheek (145)	54	F	1997	1975	Tradesman	R
Stomach (151)	44	F	1996	1972	Asst.Admn.Officer	NR
Cervix (180)	45	F	?	1974	Sci. Officer	NR
Skin (173)	37	F	1994	1984	Sci. Officer	NR
Lung (162)	50	F	1990	1994	LDC	NR

R - Radiation Worker, NR - Non-Radiation Worker, F - Female

As discussed in the earlier section (6.2), the cancer prevalence, in the spouses of employees, has been compared with the prevalence in the spouses of BARC(Mumbai) employees, which is a fairly large group and is expected to be from a similar socio-economic strata. The prevalent number of cancer cases in spouses of BARC(Mumbai) employees is given in Appendix C Table 3.

Table 9 : Comparison of Cancer Prevalence in Spouses of Employees of MAPS vs. Spouses of Employees of BARC, Mumbai

Groups Compared	Observed cases O	Expected cases E	O/E (95%CI)
Spouses of Employees of MAPS Vs Spouses of Employees of BARC (Mumbai)	6	13.93	0.43 (0.16-0.94)

E = Expected based on the corresponding comparison group, adjusted for age
CI= Confidence Interval.

Table 9 shows the results of comparison and it is seen that there is a significantly lower prevalence of cancer in the spouses of employees of MAPS as compared to that of BARC (Mumbai) employees. The observed to expected ratio was 0.43 with 95% confidence interval of 0.16 to 0.94.

The spouses of female employees was a very small group comprising of 136 individuals and no cases of cancer were seen.

10.3 Offspring : Cancer Prevalence

We have considered cancer prevalence in the offspring and not restricted to childhood cancers only. Conventionally, childhood cancers imply cancers in children 14 years of age and under. However, the age-group considered for analysing cancer pattern in offspring seems to vary from study to study. In fact,

in the Dounreay study of childhood leukemia in Northern Scotland, the age group considered was 0 to 24 years (Darby and Doll,1987). We have taken 19 years as the cut-off point, because one of the 4 cancer cases was over the age of 14. Besides, almost 84% of the offspring were 19 years of age and under (Appendix B).

Table 10 : Prevalent Cancer Cases in the Offspring (<=19 years) of Employees of MAPS (1997-1998)

Offspring of		Males	Females	Total
Radiation Workers	No.	1024	1047	2071
	Cases	2	1	3
Non-Radiation Workers	No.	1323	1293	2616
	Cases	1	0	1
Total	No.	2347	2340	4687
	Cases	3	1	4

There were four cancer cases among 4687 offspring who were 19 years of age and under as seen from Table 10. Three were males and one was a female. The female offspring was a year old when diagnosed as presacral teratoma with bilateral inguinal node metastasis. In-utero exposure to radiation if any was unknown.

Of the 3 male cases, two were offspring of radiation workers as seen from Table 11. One was a case of Ewing's sarcoma which was diagnosed at age 11. Radiation in high doses is the only environmental agent known to produce bone cancer, particularly osteogenic sarcoma. It is unlikely that the case of Ewing's sarcoma could have been exposed to high doses of radiation in his life time. The second case of ganglioneuroblastoma was diagnosed at age 8. Neuroblastoma generally arise in the adrenal medulla and some in the sympathetic nervous

tissue in the chest, pelvis and other sites. It is not possible to assess the cause of this childhood malignancy. The third case of acute lymphoblastic leukemia was diagnosed at the age of 3 years. The occupation of the parent (employee) was 'Tradesman' and he was a non-radiation worker. Information on in-utero exposure, if any, for medical purposes, is not known.

Table 11: Details of Prevalent Cancer Cases in the Offspring of Employees of MAPS (1997-1998)

				Employee's Details		
Diagnosis (ICD-9TH)	Age	Sex	Year of Diag.	Year of joining DAE	Designation at survey time	Radiation Status
Ewing's Sarcoma (170.9)	15	M	1994	1972	Sci. Officer	R
Ganglioneurobla-Stoma (M9490/3)	8	M	1998	1980	Sci. Officer	R
Acute Lymphoblastic Leukemia (204)	5	M	1995	1984	Tradesman	NR
Presacral teratoma With bilateral Inguinal node Metastasis (195.3)	5	F	1994	1985	Sci. Officer	R

R - Radiation Worker, NR - Non-Radiation Worker, M - Male, F – Female

The cancer prevalence in male offspring of radiation workers was compared with those of non-radiation workers of MAPS (Table 12). The observed to expected ratio was 2.53 with a fairly wide 95% confidence interval (0.31 to 9.13) because of small sample size. Thus, no significant difference in cancer prevalence between the 2 groups was observed. There were no cases of

cancer seen in the female offspring (<=19 years) of non-radiation workers, either of MAPS (Table 10) or of BARC (Mumbai) (Appendix C, Table 4), to compare with the lone cancer case in the offspring of radiation workers.

Table 12: Comparison of Cancer Prevale: :e in Offspring of Radiation Workers vs. Offspring of Non-F :diation Workers of MAPS

Groups Compared	MALES			FEMALES		
	Observed cases O	Expected cases E	O/E (95%CI)	Observed cases O	Expected Cases E	O/E (95%CI)
Offspring of Radiation Workers (MAPS) vs. Offspring of Non-Radiation Workers (MAPS)	2	0.79	2.53 (0 1-9.13)	0	-	-

E =Expected based on the corresponding co: parison group, adjusted for age.
CI= Confidence Interval.

Thus, there was no statistically sig: ficant excess of prevalent cancer cases in the offspring of radiation workers : compared to that of non-radiation workers of MAPS.

Overall comparison of prevalent car er cases in the male offspring of employees of MAPS with those of BAR((Mumbai) employees showed no significant difference. The observed to e pected ratio was 2.03 with 95% confidence interval of 0.42 to 5.94. There w re no cases of cancer in the female offspring (<=19 years) of BARC (Mumbai) employees to compare with one case seen in the offspring of MAPS.

Prenatal exposure (obstetric x-rays) and occurrence of cancer in children

has been extensively studied ever since the association was first reported in the Oxford survey of childhood cancers in 1958. A 40% higher risk was reported of leukemia and solid tumors in children who were exposed to diagnostic x-rays as fetuses compared to those who were not exposed (Bithell and Stewart 1975, Muirhead and Kneale 1989). We are in no position to study this effect, as history of in-utero exposure for medical purposes is not available.

10.4 Prevalence of Congenital Anomalies in the Offspring

Among the somatic effects of radiation, other than cancer, developmental effects in the unborn child are of great concern. Exposure to high doses of radiation can cause death, anomaly, growth retardation and functional impairment depending on the foetal stage at which exposures occur.

Several abnormalities have been reported in humans after in-utero irradiation. The commonly reported ones are microcephaly, often combined with mental retardation, some central nervous system defects and growth retardation.

Because of large environmental and genetic variables encountered in human populations, it is very difficult to measure any effect that might be produced by low-dose radiation, on the developing foetus.

Table 13 gives the number of congenital anomalies both major and minor observed in the offspring of the employees with details of anomalies given in Table 14. The information on anomalies that might have occurred in the stillborn fetuses or in neonatal deaths was not available.

Table 13 : Prevalence of Congenital Anomalies (Major and Minor) in Offspring of Employees of MAPS (1997-1998)

		Males	Females	Total
Offspring of Radiation Workers	No.	1224	1239	2463
	Cases(%)	18(1.47)	4(0.32)	22(0.89)
Offspring of Non-Radiation Workers	No.	1587	1539	3126
	Cases(%)	24(1.51)	12(0.78)	36(1.15)
Total	No.	2811	2778	5589
	Cases(%)	42(1.49)	16(0.58)	58(1.04)

Total number of congenital anomalies (major and minor) recorded were 58 in number, of which 42 were in male offspring and 16 in female offspring; giving an overall prevalence of 1.04%. The prevalence of congenital anomalies in a comparable cross-section of the population is not available with which the present data could be compared. An earlier exhaustive study at a large maternity hospital in Mumbai, has reported the prevalence of congenital anomalies after clinical examination of new born to be 1.4% (Master-Notani et al, 1968).

There are certain anomalies, indicated in Table 14 which fall outside the range of anomalies classified as congenital by the International Classification of Diseases (ICD) codes; 740 to 759. For example, inguinal hernia (ICD 550), though outside the range was considered in UNSCEAR reports as congenital. Therefore, for the time being we have considered all the observed anomalies for the analysis.

Table 14: List of Prevalent Congenital Anomalies(Major and Minor) in Offspring of Employees of MAPS(1997-1998)

CONG.ANOMALIES (ICD 9TH :740-759)	Males		Females		Total
	No.(age)	(Parent/employee Radiation Status)	No.(age)	(Parent/employee Radiation Status)	
1.Central Nervous System (740-742)					
Anencephalus	1(4)+	(NR)	-		1
Spina Bifida with Hydrocephalus	1(14)+	(R)	-		1
Encephalocele	-		2(10,13)	(NR,NR)	2
Microcephalus	-		2(1,5)+	(NR,NR)	2
Cong. Hydrocephalus	1(15)+	(NR)			1
Anomalies of nervous System	-		1(9)+	(R)	1
Total	3		5		8
2.Cardiovascular System (745-747)					
Common Truncus	1(22)+	(R)			1
Tetralogy of Fallot's			1(5)	(NR)	1
Ventricular Septal Defect	-		2(5,23)	(NR,NR)	2
Anomalies of Heart	3(6,10,10)+	(R,NR,NR)	3(6,7,15)+	(NR,R,NR)	6
Total	4		6		10
3.Musculo-Skeletal System (754-756)					
Anomalies of Skull and Face and Jaws	1(3)+	(NR)	1(5)+	(NR)	2
Nasal Septal Deviation	1(11)	(NR)	-		1
Talipes Equinovarus	-		1(12)	(R)	1
Polydactyly	1(10)	(R)	-		1
Club Feet	1(13)	(NR)			1
Anomalies of Skull and Face Bones			1(7)+	(NR)	1
Total	4		3		7
4.Gastro-intestinal System (749-751)					
Cleft Palate	1(12)+	(R)	-		1
Cleft Palate with Cleft Lip	1(10)	(NR)	-		1
Tongue Tie	1(26)+	(R)	-		1
Meckel's Diverticulum	1(21)+	(R)	-		1
*Rt. Inguinal Hernia	1(9)	(NR)	-		1
Hirschsprung's Disease and Other Congenital Functional Disorders of Colon	1(9)+	(NR)	-		1
Total	6		0		6

CONG.ANOMALIES (ICD 9TH :740-759)	Males		Females		Total
	No.(age)	(Parent/employee Radiation Status)	No.(age)	(Parent/employee Radiation Status)	
5.Genito-Urinary System (752-753)					
Undescended Testis	3(8,12,10) 5(14,26,20,5, 14)+	(R,R,NR) (NR,NR,R,R, NR)	-		8
Hypospadias and Epispadias	1(2)+	(NR)	-		1
Renal Agenesis and Dysgenesis	1(26)+	(R)	-		1
Total	10		0		10
6.Anomalies of Eye (743)					
Anophthalmos	1(2)+	(NR)	-		1
Cong. Cataract	1(11)	(R)	-		1
Total	2		0		2
7.Anomalies of Ear , Face and Neck (744)					
Deformity Ear	1(9)	(R)	-		1
Anomalies of Face & Neck	-		1(5)	(NR)	1
Total	1		1		2
8.Anomalies of Respiratory system (748)					
Choanal Atresia	1(1)+	(NR)	0		1
9.Other Congenital Anomalies (759)					
Anomalies of Spleen	2(5,17)+	(NR,NR)	-		2
Endocrine Glands excluding Adrenal Gland	1(11)+	(NR)	-		1
Total	3		0		3
10.Syndrome					
Down's Syndrome (758)	2(1,16)+	(NR,R)	-		2
Marfan's Syndrome (759)	1(11)	(R)	-		1
Total	3		0		3
11.*Mental Retardation (319)					
?Cause	3(8,21,24)	(R,NR,R)	1(10)	(R)	4
12.*Growth Retardation (783)					
?Cause	2(5,6)	(NR,NR)	0		2
TOTAL	42(1.49%)		16(0.58%)		58(1.04%)
Total Number of Offspring	2811		2778		5589

* These anomalies fall outside the range of ICD-9th 740-759

R : Radiation Worker, NR : Non-Radiation Worker

+Only ICD codes were provided, and the details of description have been taken from the International Classification of Diseases, 9th revision, Vol.I & II, 1977.

Attempt was made to compare the prevalence in the offspring of employees of MAPS with the prevalence in the offspring of BARC (Mumbai) employees. On closer scrutiny of BARC (Mumbai) data (Appendix C, Table 5) it was obvious that not all congenital anomalies (major and minor) have been recorded. From Table 15 it is seen that the prevalence of these anomalies is well below 0.5%; a definite underestimate, naturally yielding significantly different results when compared with Kalpakkam data. The classification of congenital anomalies followed by the two centres may not be identical. Thus comparison with BARC (Mumbai) data does not seem feasible.

Table 15 : Prevalence of Congenital Anomalies in Offspring of Employees of BARC(Mumbai) : 1994

	Males	Females	Total
No. of Offspring	14,446	12,645	27,091
No. of Congenital Anomalies	55	42	97
Prevalence (%)	0.38	0.33	0.36

Internal comparison i.e. comparing offspring of radiation workers of MAPS with those of non-radiation workers, as mentioned earlier, is of limited value, since that would not answer the question of in-utero exposure. However, the results of comparison are shown in Table 16. The prevalence of congenital anomalies is not significantly different in the male or the female offspring of radiation workers as compared to the prevalence in the corresponding male/female offspring groups of non-radiation workers of MAPS.

Questions of classificatory nature, nonetheless, still remain to be answered. Whether one should include anomalies falling outside the ICD range like mental retardation where sometimes the cause is given as due to birth injury

Table 16: Comparison of Prevalence of Congenital Anomalies in Offspring of Radiation Workers vs. Offspring of Non-Radiation Workers of MAPS

Groups Compared	MALES			FEMALES		
	Observed cases O	Expected cases E	O/E (95%CI)	Observed cases O	Expected Cases E	O/E (95%CI)
Offspring of Radiation Workers (MAPS) vs. Offspring of Non-Radiation Workers (MAPS)	18	18.39	0.98 (0.58-1.55)	4	9.72	0.41 (0.11-1.05)

E = Expected based on the corresponding comparison group, adjusted for age.
CI= Confidence Interval.

while at times no information on cause is provided. Overall, the prevalence of congenital anomalies seen in the offspring of employees is 1.04% (1.5% in males and 0.6% in females). An earlier exhaustive study at a large maternity hospital in Mumbai, has reported the prevalence of congenital anomalies after clinical examination of new borns to be 1.4% (Master-Notani et al, 1968).

11. CONCLUSION

This survey was carried out among the employees of the MAPS and their spouses and offspring. The study end points were prevalence of malignancies in the above three groups as well as prevalence of congenital anomalies in the offspring. Prevalence, no doubt, is not such a desirable study end-point for evaluating etiological associations, and a cohort follow-up study would be the method of choice. *Nonetheless, the survey has provided important indicators. It*

has demonstrated that cancer prevalence in radiation workers was not different from the prevalence seen in non-radiation workers both of MAPS as well as of BARC.

Efforts were made to ensure comparability of exposed and unexposed groups. We have adjusted for the effects of age and sex differences. The distributions of other possible confounding factors were compared for the radiation and non-radiation workers of MAPS and no major differences were observed. Thus, the possibility of biased results is minimized to the extent possible. Such a comparison of radiation workers of MAPS with non-radiation workers of BARC (Mumbai) could not be undertaken, because the information on confounding factors, other than age and sex, was not available on the employees of BARC (Mumbai).

The cumulative dose distribution in the radiation workers provided by MAPS has been shown in Appendix A. Furthermore, because of small numbers involved, no attempt was made to see the dose-response relationship. The employees were classified as radiation workers and non-radiation workers on the basis of whether they were using personal dosimeters or not. Most of the radiation workers do not receive any significant dose. Even the dose received is generally kept well within the maximum annual permissible dose as stipulated by International Commission on Radiological Protection (ICRP) and Atomic Energy Regulatory Board (AERB) and is thus not likely to cause any health effects.

Furthermore the annual dose received by the family members or the members of the general population residing near MAPS is a small fraction

(0.5%) of the dose permitted (1 mSv) by AERB/ICRP for the public. Thus there is no direct exposure to radiation of power plant origin and therefore none of the malignancies in spouses as well as the offspring of employees can be attributed to radiation. Furthermore, there was no statistically significant difference in the prevalence of malignancies in male offspring of radiation workers as compared to that of non-radiation workers of MAPS. The comparison of prevalence of malignancies in female offspring of radiation workers with that of non-radiation workers could not be undertaken because there were no cancer cases in female offspring of non-radiation workers to compare with the lone case in female offspring of radiation workers.

As regards congenital anomalies in the offspring of employees, the prevalence in a comparable cross-section of the population was not available with which the data of the present survey could be compared. Internal comparison i.e. comparison of offspring of radiation and non-radiation workers of MAPS, though of limited value, also yielded no significant difference. However, an earlier exhaustive study at large maternity home in Mumbai had reported the prevalence of congenital anomalies among the new born children to be 1.4%.

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APPENDIX A

Radiation Exposure Data of MAPS Employees

DOSE DISTRIBUTION OF MAPS EMPLOYEES

Table 1: Cumulative Radiation Dose in mSv from initial employment upto 1998 in Radiation Workers of MAPS, by Age and Sex

A) MALES

Exposure (in mSv)	No. of Persons in Different Age Groups					
	18-	30-	40-	50+	Total	%
0-	252	400	389	199	1240	53.3
1-	30	53	124	78	285	12.2
10-	20	10	22	30	82	3.5
20-	25	21	31	44	121	5.2
50-	4	77	75	43	199	8.5
100-	2	114	121	62	299	12.8
200-	0	28	51	23	102	4.4
Total	333	703	813	479	2328	100.0

Mean Cumulative Radiation dose per worker = 37.94 ± 1.37 mSv

B) FEMALES

Exposure (in mSv)	No. of Persons in Different Age Groups					
	18-	30-	40-	50+	Total	%
0-	27	44	27	5	103	88.0
1-	4	4	2	2	12	10.2
10-	0	0	0	0	0	0
20-	0	1	0	0	1	0.9
50-	0	0	0	0	0	0
100-	0	1	0	0	1	0.9
Total	31	50	29	7	117	100.0

Mean Cumulative Radiation dose per worker = 1.84 ± 1.30 mSv

APPENDIX B

Kalpakkam Study Population Distribution By Age, Sex And Radiation Status

Table 1: Distribution by Age, Sex and Radiation status of MAPS Study Population (1997-1998)

A] Employees :

Sex / Radiation status	Age <20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
Males											
Radiation Workers	0	72	261	304	399	325	488	333	132	14	2328
Non-Radiation Workers	6	33	197	348	437	424	533	421	219	18	2636
Total	6	105	458	652	836	749	1021	754	351	32	4964
Females											
Radiation Workers	0	8	23	37	13	14	15	7	0	0	117
Non-Radiation Workers	5	10	49	96	77	58	58	21	7	0	381
Total	5	18	72	133	90	72	73	28	7	0	498

B] Spouses of Employees :

Sex	Age 15-	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
Males	0	7	9	21	36	26	18	9	4	6	136
Females	13	165	582	812	810	822	471	139	16	3	3833
Total	13	172	591	833	846	848	489	148	20	9	3969

C] Offspring of Employees :

i) Offspring of Radiation Workers

Sex	Age 0-4	5-9	10-14	15-19	20-24	25-29	30-34	Total
Males	121	276	331	296	160	36	4	1224
Females	119	288	339	301	162	29	1	1239
Total	240	564	670	597	322	65	5	2463

ii) Offspring of Non-Radiation Workers

Sex	Age 0-4	5-9	10-14	15-19	20-24	25-29	30-34	Total
Males	150	350	455	368	212	52	0	1587
Females	133	361	403	396	204	38	4	1539
Total	283	711	858	764	416	90	4	3126

APPENDIX C

BARC (Mumbai) Data

APPENDIX C

Table 1: Distribution of BARC (Mumbai) study population by Age, Sex and Radiation Status (1994).

A] Employees :

Sex / Radiation status	Age <20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
Males											
Radiation Workers	0	6	58	214	288	325	519	573	417	16	2416
Non-Radiation Workers	9	497	1826	2204	1896	1787	1926	2011	1479	101	13736
Total	9	503	1884	2418	2184	2112	2445	2584	1896	117	16152
Females											
Radiation Workers	0	0	12	19	13	20	20	21	8	1	114
Non-Radiation Workers	2	163	616	522	268	328	333	243	110	5	2590
Total	2	163	628	541	281	348	353	264	118	6	2704

B] Spouses of Employees :

Sex	Age 15-	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
Males	0	3	48	139	142	141	166	168	145	95	1047
Females	70	851	2135	2196	1992	2443	2287	1142	169	13	13298
Total	70	854	2183	2335	2134	2584	2453	1310	314	108	14345

C] Offspring of Employees :

Sex / Radiation status	Age <1	1-4	5-9	10-14	15-19	20-24	25+	Total
Males								
Rad. Workers Children	24	171	324	430	552	546	200	2247
Non-Rad. Workers Children	313	1649	2293	2281	2462	2188	1013	12199
Total	337	1820	2617	2711	3014	2734	1213	14446
Females								
Rad. Workers Children	33	174	324	385	474	441	131	1962
Non-Rad. Workers Children	299	1578	2210	2075	2163	1717	641	10683
Total	332	1752	2534	2460	2637	2158	772	12645

Table 2: Prevalent Cases of Cancer in Employees of BARC(Mumbai) by Age, Sex, Radiation status and Site (ICD 9th), 1994

A] Radiation Workers (Males) :

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
152	SMALL INTESTINE								1			1
154	COLON								1	2		3
162	LUNG							1	1			2
202	NON.HODGKIN'S LYMPHOMA								1			1
205	LEUKEMIA MYELOID							1				1
TOTAL		0	0	0	0	0	0	2	4	2	0	8

B] Radiation Workers (Females) :

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
180	CERVIX							1				1
202	NON.HODGKIN'S LYMPHOMA							1				1
TOTAL		0	0	0	0	0	0	2	0	0	0	2

C] Non-Radiation Workers (Males) :

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
143	ALVEOLUS		1									1
145	PALATE								1			1
150	ESOPHAGUS						1					1
151	STOMACH						1		3	2		6
154	RECTUM							1				1
155	LIVER									1		1
157	PANCREAS							1		1		2
160	ETHMOID						1	1				2
161	LARYNX								1			1
162	LUNG								2			2
162	TRACHEA					1						1
170	BONE							1				1
171	CONNECTIVE TISSUE							1				1
172	MELANOMA						1					1
185	PROSTATE					1						1
188	BLADDER							2		1		3
189	URETER							1		1		2
191	BRAIN								1			1
193	THYROID						2		1			3
195	ILL DEFINED SITES				1				1			2
201	HODGKIN'S LYMPHOMA		1									1
202	OTHER LYMPHOMA								1	1		2
204	LEUKEMIA LYMPHOID				1					1		2
205	LEUKEMIA MYELOID						1					1
TOTAL		0	2	0	2	2	7	8	11	8	0	40

D] Non-Radiation Workers (Females) :

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
174	BREAST						2	1	1	1		5
183	OVARY					1						1
TOTAL						1	2	1	1	1		6

Table 3: Prevalent cases of cancer in Spouses of Employees of BARC(Mumbai) by age, sex and site (ICD 9th), 1994

A) MALES

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
191	BRAIN				1							1
TOTAL					1							1

B) FEMALES

		AGE GROUPS										
ICD 9TH	SITE	<20	20-	25-	30-	35-	40-	45-	50-	55-	60+	Total
151	STOMACH							1				1
153	COLON				1	1	1					3
154	RECTUM					1				1		2
162	LUNG						1					1
171	CONNECTIVE/ SOFT TISSUE					1						1
174	BREAST				2	3	6	11	7	1		30
179	UTERUS					1			1			2
180	CERVIX						1			1		2
183	OVARY						2	2	1			5
184	VAGINA						1					1
191	BRAIN				1							1
193	THYROID						1	1	1			3
205	LEUKEMIA MYELOID			1	1							2
TOTAL		0	0	1	5	7	13	15	10	3	0	54

Table 4: Prevalent Cases of Cancer in Offspring of Employees of BARC(Mumbai)+ by Age, Sex and Site (ICD 9th), 1994

A) MALES

		AGE GROUPS						
ICD 9TH	SITE	<5	5-	10-	15-	20-	25-	Total
171	CONNECTIVE/ SOFT TISSUE				1	1		2
173	SKIN OTHER			1				1
186	TESTIS				1			1
191	BRAIN		1	1				2
202	NON.HODGKIN'S LYMPHOMA						1	1
205	LEUKEMIA MYELOID				1			1
	TOTAL	0	1	2	3	1	1	8

B) FEMALES

		AGE GROUPS						
ICD 9TH	SITE	<5	5-	10-	15-	20-	25-	Total
191	BRAIN						1	1
	TOTAL	0	0	0	0	0	1	1

+Note: All cases were in offspring of the Non-Radiation Workers.

Table 5: CONGENITAL ANOMALIES OBSERVED IN OFFSPRING OF EMPLOYEES OF BARC(Mumbai) (1994)

CONG.ANOMALIES (ICD 9TH : 740-759)	Males No.(Age)(Parent/Employee's Rad.Status)	Females No.(Age)(Parent/Employee's Rad. Status)	Total
1.Central Nervous System (740-742)			
Microcephalus	1(12) (NR)	3(2,7,14) (NR,NR,R)	4
Hydrocephalus	5(1,2,5,14,15)(NR,NR,NR,NR,NR)	1(8) (NR)	6
Meningomyelocele	1(4) (NR)	2(4,15) (NR,NR)	3
total	7	6	13
2.Cardio-Vascular System (745-747)			
Pulm.Valvotomy	1(1) (NR)	-	1
Atrial Septal Defect(ASD)	6(2,2,4,6,16,19) (NR,NR,NR,NR,NR,NR)	11(1,2,4,46,12,15,20,29,22,25) (NR,NR,NR,NR,NR,NR,NR,NR,NR,R,R)	17
Ventricular Septal Defect(VSD)	9(1,9,12,12,17,18,24,27,20) (NR,NR,NR,NR,NR,NR,NR,NR,R)	7(1,2,5,19,8,12,17) (NR,NR,NR,NR,R,R,R)	16
ASD + VSD	1(11) (NR)	-	1
Fallot's Tetrology	3(3,14,16) (NR,NR,NR)	-	3
Cong.Heart	5(3,4,13,20,4)(NR,NR,NR,NR,R)	2(10,10) (NR,NR)	7
Patent Ductus Arteriosus	3(8,13,16) (NR,NR,NR)	3(0,6,18) (NR,NR,NR)	6
total	28	23	51
3.Musculo-skeletal System (754-756)			
Talipes	2(3,26) (NR,NR)	-	2
Talipes equinovarus	1(9) (NR)	-	1
Polydactyly	-	1(4) (NR)	1
total	3	1	4
4.Digestive System (749-751)			
Cleft Lip + Palate	1(1) (NR)	2(21,26) (NR,NR)	3
Cleft Palate	1(8) (NR)	4(3,5,7,7) (NR,NR,NR,R)	5
total	2	6	8
5.Genito-Urinary System (752-753)			
Hypospadias	1(19) (NR)	-	1
Undescended Testis	1(20) (NR)	-	1
Cong.Hydronephrosis	-	1(4) (NR)	1
total	2	1	3
6.Syndrome			
Down's Syndrome (758)	10(2,3,7,8,10,14,18,19,20,21) (NR,NR,NR,NR,NR,NR,NR,NR,NR,R)	3(11,20,2) (NR,NR,R)	13
7.Hereditary Condition			
*Thalassemia (282)	3(1,8,10) (NR,NR,NR)	2(11,26) (NR,NR)	5
Total	55(0.4%)	42(0.3%)	97(0.4%)
Total no. of offspring	14446	12645	27091

* This anomaly falls outside the range of ICD-9th 740-759

APPENDIX D

Annual Age-Adjusted Cancer Incidence Rate Per 100,000 Population From 6 Population-Based Indian Registries, 1989

APPENDIX D

Table :Annual Age-Adjusted (World Population) Cancer Incidence Rate per 100,000 persons, India. **Males; 1989**

ICD9th	SITE	REGISTRY					
		BANGALORE	BOMBAY	MADRAS	DELHI	BHOPAL	BARSHI
140	LIP	0.4	0.3	0.6	0.5	0.2	0.0
141	TONGUE	4.7	6.5	5.3	7.7	13.2	2.1
142	SALIVARY GLAND	0.8	0.4	0.4	0.8	0.5	0.5
143	GUM	0.6	1.5	0.9	1.1	1.3	1.4
144	FLOOR OF MOUTH	0.3	0.6	0.1	0.2	1.0	0.0
145	OTHER MOUTH	2.1	3.7	6.3	2.4	8.1	2.0
146	OROPHARYNX	1.9	3.2	1.9	3.2	3.8	0.0
147	NASOPHARYNX	0.6	0.6	0.6	0.6	0.0	0.0
148	HYPOPHARYNX	5.9	8.2	6.5	2.3	8.4	3.5
149	PHARYNX	0.2	1.8	1.0	0.6	2.3	1.3
150	OESOPHAGUS	9.4	11.5	10.2	6.4	7.7	6.7
151	STOMACH	9.5	7.0	16.5	3.4	3.7	1.2
152	SMALL INTESTINE	0.0	0.5	0.1	0.2	0.0	0.0
153	COLON	2.7	4.0	2.0	2.0	1.4	2.0
154	RECTUM	4.3	3.9	4.5	3.0	5.5	4.0
155	LIVER	3.2	3.5	1.9	2.2	2.1	2.6
156	GALLBLADDER	0.5	1.6	0.3	1.9	2.6	0.0
157	PANCREAS	1.7	2.5	1.4	2.3	2.4	0.0
158	RETROPERITONEUM	0.9	0.3	0.1	0.3	0.0	2.1
159	OTHER DIGESTIVE	0.8	0.7	0.0	0.6	0.0	0.0
160	NASAL CAVITY	0.3	1.4	0.6	0.5	1.6	0.0
161	LARYNX	4.1	8.8	5.5	8.6	2.9	1.3
162	LUNG	8.6	14.6	11.1	11.9	14.1	2.0
163	PLEURA	0.6	0.2	0.2	0.2	0.4	0.0
164	THYMUS	0.1	0.1	0.2	0.1	0.0	0.0
165	OTHER RESPIRATORY	0.0	0.0	0.0	0.0	0.0	0.0
170	BONE	1.3	0.8	0.9	1.2	0.6	0.0
171	CONNECTIVE TISSUE	0.6	1.5	1.0	1.5	0.8	1.0
172	SKIN MELANOMA	0.1	0.3	0.3	0.2	0.0	0.0
173	SKIN OTHER	2.0	1.3	2.2	1.4	0.7	2.7
175	BREAST MALE	0.2	0.3	0.7	0.7	0.0	0.0
185	PROSTATE	7.1	6.9	3.6	6.3	5.6	1.9
186	TESTIS	0.6	0.9	1.1	0.7	0.1	0.8
187	PENIS	1.8	1.6	2.8	1.7	0.6	5.1
188	URINARY BLADDER	2.7	4.2	3.8	5.6	0.6	0.8
189	KIDNEY	1.1	1.4	0.9	1.8	0.7	0.4
190	EYE	0.2	0.4	0.3	0.2	0.2	0.0
191	BRAIN	3.8	3.0	1.8	3.4	3.2	0.0
192	NERVOUS SYSTEM	0.2	0.1	0.0	0.1	0.0	0.0
193	THYROID	0.9	0.7	0.9	0.8	0.3	0.5
194	OTHER ENDOCRINE	0.1	0.2	0.1	0.3	0.0	0.0
195	ILL DEFINED	1.1	0.3	0.9	1.8	0.0	0.7
196	SECONDARY LYMPH	1.9	3.5	2.0	0.0	1.3	1.9
197	SECONDARY RESPI	1.7	2.6	3.3	0.4	2.8	1.4
198	SECONDARY OTHER	0.7	1.5	0.9	0.1	0.7	0.0
199	PRIM UNKNOWM	9.0	1.1	3.3	11.6	0.0	2.1
200	LYMPHOSARCOMA	0.4	1.3	0.6	0.0	0.0	0.7
201	HODGKINS	2.4	1.2	1.7	1.6	1.5	1.0
202	OTHER LYMPHOID	2.7	2.7	3.3	5.1	0.5	1.2
203	MULTIPLE MYELOMA	0.6	1.3	0.5	2.7	0.3	0.0
204	LEUKEMIA LYMPHOID	1.6	1.6	1.5	2.5	1.5	0.8
205	LEUKEMIA MYELOID	2.3	1.9	1.4	2.5	0.7	1.9
206	LEUKEMIA MONOCYTIC	0.1	0.0	0.2	0.0	0.0	0.0
207	LEUKEMIA OTHER	0.0	0.2	0.0	0.0	0.0	0.0
208	LEUK UNSPECIFIED	0.7	0.3	0.3	1.3	0.2	0.0
	ALL SITES	112.2	130.4	118.5	118.8	106.2	57.6

APPENDIX D

Table :Annual Age-Adjusted (World Population) Cancer Incidence Rate per 100,000 persons, India. **Females; 1989**

		Registry					
ICD9TH	SITE	BANGALORE	BOMBAY	MADRAS	DELHI	BHOPAL	BARSHI
140	LIP	0.1	0.2	0.3	0.3	0.0	0.0
141	TONGUE	1.0	1.9	2.1	1.3	1.4	0.0
142	SALIVARY GLAND	0.5	0.3	0.2	0.5	0.0	0.0
143	GUM	2.8	1.0	1.5	1.1	1.5	0.0
144	FLOOR OF MOUTH	0.4	0.1	0.2	0.0	0.0	0.0
145	OTHER MOUTH	7.9	2.8	6.5	1.4	5.3	0.6
146	OROPHARYNX	0.5	0.6	0.4	1.0	0.5	0.0
147	NASOPHARYNX	0.4	0.2	0.3	0.2	0.5	0.0
148	HYPOPHARYNX	1.2	1.5	2.7	0.6	0.8	0.5
149	PHARYNX	0.1	0.9	0.5	0.0	0.4	0.0
150	OESOPHAGUS	10.2	8.2	7.7	4.6	5.2	1.4
151	STOMACH	4.3	3.4	7.1	2.4	1.1	1.3
152	SMALL INTESTINE	0.0	0.3	0.0	0.2	0.0	0.0
153	COLON	2.3	2.4	0.8	2.0	2.1	0.5
154	RECTUM	2.2	2.6	2.6	1.8	0.0	1.7
155	LIVER	1.0	1.8	0.6	1.1	1.1	0.0
156	GALLBLADDER	0.8	2.3	0.6	6.6	5.2	0.0
157	PANCREAS	1.0	1.8	0.7	1.3	0.6	0.6
158	RETROPERITONEUM	0.5	0.6	0.1	0.3	0.0	0.0
159	OTHER DIGESTIVE	0.5	0.5	0.0	0.3	0.0	0.0
160	NASAL CAVITY	0.4	1.0	0.8	0.4	0.4	0.0
161	LARYNX	0.7	1.3	0.3	1.8	0.5	0.0
162	LUNG	1.6	3.7	1.7	2.2	3.2	0.0
163	PLEURA	0.5	0.2	0.0	0.2	0.5	0.0
164	THYMUS	0.1	0.1	0.0	0.0	0.0	0.0
165	OTHER RESPIRATORY	0.0	0.0	0.0	0.0	0.0	0.0
170	BONE	0.9	0.7	0.6	1.2	1.1	2.4
171	CONNECTIVE TISSUE	0.3	0.9	0.7	1.7	0.5	0.6
172	SKIN MELANOMA	0.1	0.3	0.2	0.2	0.0	0.0
173	SKIN OTHER	1.6	1.2	0.7	1.6	0.7	2.3
174	BREAST FEMALE	22.3	26.1	24.6	28.3	21.9	6.8
179	UTERINE	0.6	1.5	0.4	1.2	0.5	0.0
180	CERVIX UTERI	26.4	19.4	43.5	30.1	24.3	26.2
181	PLACENTA	0.0	0.1	0.2	0.2	0.3	0.0
182	BODY UTERUS	2.0	2.2	1.9	2.5	4.2	0.0
183	OVARY	4.7	7.0	6.0	8.7	6.2	0.9
184	VAGINA	1.4	1.7	2.0	1.5	0.5	1.3
188	URINARY BLADDER	0.8	1.3	1.1	1.0	0.0	0.0
189	KIDNEY	0.4	0.8	0.7	1.4	0.0	0.0
190	EYE	0.0	0.2	0.6	0.4	0.0	0.0
191	BRAIN	1.7	2.2	0.8	2.6	1.6	0.0
192	NERVOUS SYSTEM	0.0	0.1	0.0	0.1	0.0	0.0
193	THYROID	3.2	2.0	1.1	2.2	2.1	0.0
194	OTHER ENDOCRINE	0.1	0.1	0.1	0.1	0.0	0.0
195	ILL DEFINED	0.7	0.5	0.4	1.5	0.0	1.3
196	SECONDARY LYMPH	0.6	1.3	0.6	0.0	0.2	0.7
197	SECONDARY RESPI	0.8	1.9	2.4	0.5	2.2	0.0
198	SECONDARY OTHER	0.5	1.2	0.5	0.0	1.0	0.0
199	PRIM UNKNOWN	7.4	0.7	3.8	12.1	0.0	1.1
200	LYMPHOSARCOMA	0.2	0.9	0.3	0.0	0.0	0.6
201	HODGKINS	0.7	0.7	0.7	1.0	0.2	0.0
202	OTHER LYMPHOID	1.9	2.1	1.5	2.4	0.5	1.4
203	MULTIPLE MYELOMA	0.7	0.6	0.2	2.1	0.5	0.0
204	LEUKEMIA LYMPHOID	0.6	1.1	0.5	1.4	0.6	0.0
205	LEUKEMIA MYELOID	2.0	1.3	0.9	2.0	0.5	0.0
206	LEUKEMIA MONOCYTIC	0.0	0.0	0.2	0.1		0.0
207	LEUKEMIA OTHER	0.0	0.1	0.0	0.0	0.0	0.0
208	LEUK UNSPECIFIED	0.9	0.4	0.2	1.1	0.0	0.0
	ALL SITES	124.7	120.4	135.0	140.7	100.1	52.2

APPENDIX E

Glossary of Terms Used

APPENDIX F

Abbreviations

GLOSSARY OF TERMS USED

Cross-sectional Study	:	One of the observational analytical epidemiological methods to examine relationship between disease and other variables of interest as they exist in a defined population at a particular time. (The other two well-known methods in this category are Cohort studies and Case-Control studies).
Incidence Rate	:	The rate of occurrence of a disease within a specified period; expressed as number of cases per unit of population per unit of time. In particular, cancer incidence rate is conventionally expressed per 100,000 population, per year.
Ionizing Radiation	:	Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.
Morbidity	:	1. The condition of being diseased. 2. The incidence, or prevalence, of illness in a group.
Mortality Rate	:	Is analogous to incidence rate but refers to the occurrence of death rather than the occurrence of disease and is expressed as number of deaths per unit of population per unit of time.
Prevalence	:	The number of cases of a disease in existence at a given time per unit of population.
Relative Risk	:	Expression of risk due to exposure, as a ratio of the risk among the exposed to that among those not exposed.
Sievert (Sv)	:	SI unit of radiation dose equivalent. It is equal to absorbed dose in Gray, times a quality factor, times other modifying factors.
TLD	:	Thermoluminescent Dosimeter.

ABBREVIATIONS

AERB	:	Atomic Energy Regulatory Board
BARC	:	Bhabha Atomic Research Centre
COCES	:	Corporate Committee for the Epidemiological Studies (Constituted by NPCIL)
DAE	:	Department of Atomic Energy
ICRP	:	International Commission on Radiological Protection
NPCIL	:	Nuclear Power Corporation of India Limited
PISCES	:	Planning and Implementation Supervisory Committee for Epidemiological Studies (Constituted by NPCIL)
STAG	:	Senior Technical Advisory Group (Constituted by NPCIL)
TMC	:	Tata Memorial Centre
TMH	:	Tata Memorial Hospital

APPENDIX G

Composition of Committees (COCES, STAG, PISCES)

APPENDIX G

COMPOSITION OF COMMITTEES

CORPORATE COMMITTEE FOR THE EPIDEMIOLOGICAL STUDIES (COCES) (1992-)

1. C.M.D., NPCIL	- Chairman
Mr. S.L. Kati	
Mr. S.K. Chattarjee	
Dr. Y.S.R.Prasad	
Mr. V.K.Chaturvedi	
2. ED (F), NPCIL	- Member
Mr. C.K.Koshy	
Mr. R.C. Joshi	
Mr. S.B. Kulkarni	
3. ED (O), NPCIL	- Member
Mr. K. Nanjundeswaran	
Mr. Ch. Surendar	
Mr. B. K. Bhasin.	
4. Director, NIOH, Ahmedabad	- Member
Dr. S.K. Kashyap	
Dr. H.N. Saiyed	
5. Director,(HSEG) BARC, Mumbai	-Member
Dr. D.V. Gopinath	
Dr. U.C. Mishra	
Dr. V. Vekat Raj	
6. Director, TMC	- Member
Dr. P.B. Desai	
Dr. K.A. Dinshaw	
7. Director,Biomedical Group, BARC, Mumbai	- Member
Dr. C.R. Bhatia	
Dr. P.C. Kesavan	
Dr.(Mrs) A.M. Samuel	
8. Director (E & PA), NPCIL	- Member
Mr. B.N. Jayram	
Mr. M.L. Mittra	
9. Director (Health & Safety), NPCIL	- Member Secretary
Dr. L.G.K. Murthy	
Mr. G.R. Srinivasan	
Mr. B.K.Bhasin	
Mr. S. Krishnan,ED(CPHSE)	
Mr.P.M. Wagh	
Late Mr. M. Das, Associate Director	
10. Director, TMH	- Member
Dr. R.S. Rao	
Dr. K.A. Dinshaw	
11. Director, CRI	- Member
Dr. M.G. Deo	
Dr. A.N. Bhise	

INVITEES TO CORPORATE COMMITTEE FOR THE EPIDEMIOLOGICAL STUDIES (COCES) (1992-)

1. Dr. K.A. Dinshaw, Head, Radiation Oncology, TMH
2. Dr. L.D. Sanghvi, Consultant, TMH
3. Mr. K. Muthuswamy, CAO, TMC
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5. Mr. B.M.L. Sah, Head, Health Physics Group, NPCIL
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11. Dr.P.K.Sinha, Medical Supdt, KAPS Hospital, Kakrapar.
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APPENDIX G

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