BNL-NUREG-46742

A Survey of Doses to Worker Groups in the Nuclear Industry*

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(Invited paper presented at the Westinghouse REM Seminar, Pittsburgh, Pennsylvania, October 1991)

1. Introduction

The nuclear industry has long prided itself as among the safest of industries. In fact the dose limits in most countries have been based on that philosophy. Recent reevaluation of data, particularly for the survivors of Hiroshima and Nagasaki, has indicated, however that the risk for cancer and severe genetic defects may be up to 4 times greater than previously estimated[1,2]. At the same time the safe industries, such as trade, manufacture and service, have improved their record of safety[3]. These industries have historically been used as yard-sticks for what is safe byy hhe organizations that make recommendations on dose limits, the U.S. National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). The combination of these two factors has lead to a reexamination of radiation dose limits. The NCRP has suggested[4] "...as guidance for radiation programs that cumulative exposure not exceed the age of the individual in years x 10 mSv (years x 1 rem)." The ICRP has recommended a dose limit of 10 rem averaged over 5 years[5].

With these developments in mind, the U.S. Nuclear Regulatory Commission (NRC) requested the ALARA Center of the Brookhaven National Laboratory to undertake two parallel studies. One study, which is still ongoing, is to examine the impact of the newly recommended dose limits on the nuclear industry as a whole; the other study was intended to assist in this larger project by looking more closely at the nuclear power industry. Preliminary data had indicated that the critical industry as far as the impact of new regulatory limits were concerned would be the nuclear power industry, because, it was conjectured, there existed a core of highly skilled workers in some groups which routinely get higher than average exposures. The objectives of the second study were to get a better understanding of the situation vis à vis the nuclear power industry, by identifying the high-dose worker groups, quantifying the annual and lifetime doses to these groups to see the extent of the problem if there was one, and finally to determine if there were any dose-reduction techniques which were particularly suited to reducing doses to these groups.

In this presentation we describe some of the things learned during our work on the two projects. For more detailed information on the project on dose-reduction techniques for high-dose worker groups in the nuclear power industry, see NUREG/CR-5139[6]. An industry advisory committee has been set up which is in the process of evaluating the data from the larger project on the impact of new dose limits and will shortly produce its report.

*This work was carried out under the auspices of the Office of Nuclear Regulatory Research, United States Nuclear Regulatory Commission.

2. One Year's Detailed Picture For The U.S. Nuclear Industry

The U.S. nuclear industry is spread over many diverse sectors. It is therefore very difficult to get a complete and comprehensive picture of the state of radiation exposure of all the radiation workers in every sector of the industry. Fortunately there exists a study carried out by the Environmental Protection Agency (EPA) which provides quantitative data on nearly all sectors[7]. We have relied on this data for our analysis of the industry as a whole.

2.1. Male And Female Workers In The Nuclear Industry

Figure 2.1 shows the number of male and female workers employed in radiation related work. Figures 2.2 and 2.3 give the proportion of male and female workers in various sectors of the nuclear industry, such as medicine, industry, the nuclear fuel cycle, government, and miscellaneous fields. These sectors encompass all radiation workers in the U.S., including those in nuclear power operations. The data has been separated into male and female subgroups. It will be seen below that such a breakdown leads to some interesting correlations.

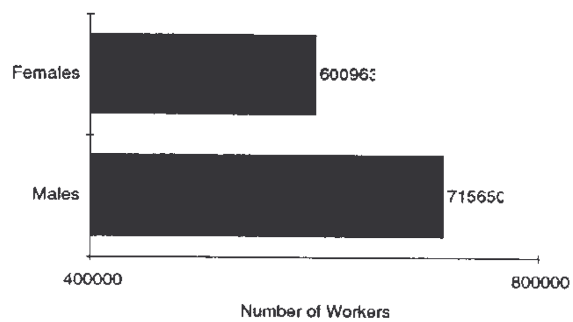


Fig. 2.1: U.S. Radiation Workers

Figure 2.1 shows that contrary to expectation, the number of women employed in radiation work is nearly the same as the number of men. However, an examination of Figures 2.2 and 2.3 shows that they are carrying out very different kinds of tasks. The great majority of women are employed in medicine and dentistry whereas the men are fairly evenly split in all the various sectors, with industry being the largest sector. Further analysis indicated that the males employed in medicine are apparently being used in a somewhat different manner than the females. It also worth noting that the mean age of male radiation workers is higher (36 years) than of female radiation workers (31 years).

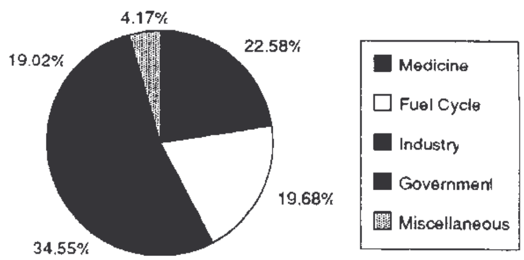


Fig. 2.2: Proportion of male radiation workers in various sectors

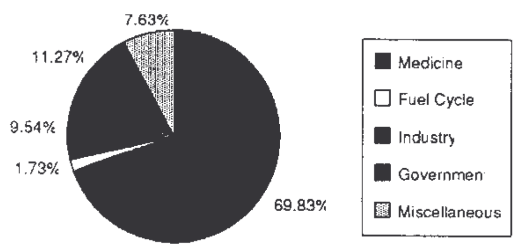


Fig. 2.3: Proportion of female radiation workers in various sectors

2.2. Correlation Of Radiation Dose With Age

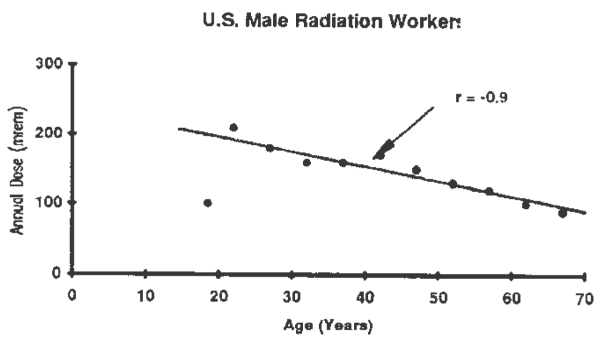
As stated above, the NCRP has suggested a lifetime limit on radiation dose for occupational workers. Questions have been raised about this approach since it was thought by some experts that the older radiation workers, because of their greater experience, may be indispensable for tasks which expose workers to high dose. This would imply that the older workers would have higher annual doses. To assess this view it was decided to check for a correlation between age and radiation dose for occupational workers. To do so the age groups were transformed to mean ages for each group and the mean annual dose to each group was used. The data were suitably weighted by the number of workers in each group. Table 2.1 shows the mean annual dose equivalent for all U.S. radiation workers by sex and age.

Table 2.1: Mean Annual Dose Equivalent for U.S. Radiation Workers

Age	Males		Females	
	Mean Annual Dose	Number of Workers	Mean Annual Dose	Number of Workers
19	100	8,035	40	25,090
22	210	84,336	50	168,534
27	180	147,742	50	158,986
32	160	157,869	60	94,237
37	160	104,636	60	57,865
42	170	69,220	60	38,649
47	150	52,934	60	24,760
52	130	39,650	60	17,608
57	130	30,781	60	12,360
62	100	14,489	50	5,389
67	90	5,958	60	1,485

2.2.1. Males

It was found that the dose of male radiation workers showed a significant *inverse* correlation with age (see Figure 2.4). Further analysis showed that this negative correlation was

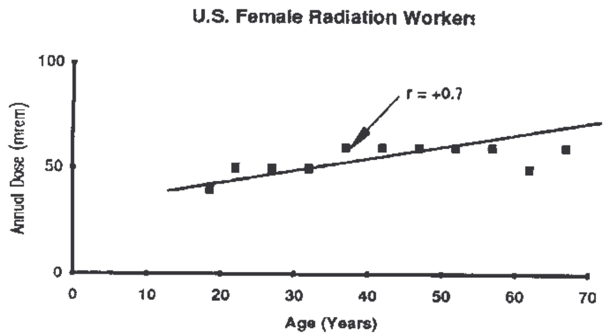


strongest in the sectors of the nuclear fuel cycle, of industry (including radiography), and manufacturing and distributing, which are included in the miscellaneous sector in Figure 2.2. There appeared to be no correlation between age and dose in the sector of medicine and dentistry for males.

Fig. 2.4: Correlation of Radiation Dose with Age

2.2.2. Females

When one examines the female age and dose data for correlation one sees a different picture. The female data show a weaker *direct* correlation with age (Fig. 2.5). That is, as women radiation workers grow older they seem to be exposed to more radiation. In examining this further, one sees that the vast majority of female radiation workers are employed in the medicine and dentistry sector. It is indeed in this sector that there is a strong direct correla-



tion with age for women. In all other sectors there seems to be virtually no correlation of radiation dose with age for women.

Fig. 2.5: Correlation of Radiation Dose with Age

2.2.3. Discussion Of The Above Results

The correlations observed in the above data have a strong statistical significance, since very large numbers are involved (approximately 700,000 men and 600,000 women). The data show that males as a rule are getting less and less radiation dose as they age. This is true not only for the nuclear industry as a whole but also in each one of the major sectors, including the nuclear fuel cycle.

For females the situation is quite the contrary. As women get older and more experienced they are exposed to greater doses of radiation. A closer look at the data shows that this is primarily due to the preponderance of women in the medical sector where there is a strong direct correlation with age. The only sector where there is any slight inverse correlation of dose with age for females is in the sector of the nuclear fuel cycle. However only 2% of females are employed in this sector (see Figure 2.3).

The weak direct correlation of radiation dose with age for females would suggest that an age related does limit may have an adverse impact on females in the higher age group. However, the mean annual dose equivalent is only about 0.5 mSv (50 mrem) for women compared with 1.6 mSv (160 mrem) for men. These numbers indicate that an age related annual dose limit of say 10 mSV (1,000 mrem) per year, over the age of the individual, as proposed by the NCRP, would not affect a female's right to pursue employment in her chosen profession. Moreover, our inquiries could not find any women who were close to exceeding the age x 1 rem criterion.

It should be emphasized that the above analysis considers only aggregate data and does not take into account the availability of skilled workers in critical sectors. The approach should therefore be regarded as looking at the overall philosophy of an age related dose limit, as proposed by the NCRP, when it is compared to actual numbers from the nuclear industry. The next section looks in more detail at the data from one of the critical sectors of the nuclear industry, the nuclear power industry, to examine some of the other implications.

3. Closer Examination Of Data From One Sector Of The Nuclear Industry

The data for the nuclear industry as a whole suggested that the average annual dose equivalent to workers was considerably below the present dose limits. Moreover, as we have seen, there appeared to be a downward correlation with age for male workers, whose average annual dose equivalents were a factor of 3 higher than that for females. However, there are other questions which require closer examination. To do so we decided to examine one sector of the nuclear industry, the nuclear power industry, more closely. It was indeed the critical sector, since data and feedback indicated that the impact of revised dose limits on other sectors of the nuclear industry would be much smaller in comparison.

We wanted to know:

a) what proportion of workers were getting higher than average dose

b) what was the extent of these doses

c) whether there were any special, highly skilled work groups that were chronically getting the higher doses

d) whether there was a shortage of skilled workers who were receiving higher than average doses

e) if there were any job-specific or task-specific techniques that would ameliorate doses to any high-dose groups.

In order to carry out this study we solicited the support of the nuclear power industry. The industry responded very well to our request for information. Twenty-two domestic nuclear plants and 6 contractors provided information and data for this study. Among these were 13 PWR plants and 9 BWR plants, some of them containing more than one reactor unit. There were no special criteria for the selection of these plants; we passed out a questionnaire during the International Workshop on Occupational Dose Control and ALARA that was held at the Brookhaven National Laboratory in September 1989. The plants on whom the study is based were the ones that voluntarily provided us information. Thus, in a sense, this can be called a random selection. Data, advice and suggestions were also provided by the international nuclear community (see NUREG/CR-5139[6] for details).

Table 3.1 shows the data on whole-body dose for 1988 for the PWR plants; table 3.2 shows the data for BWR plants. The tables show data on the total number of persons monitored at the plants, including data on contractors.

One sees from both tables that the average dose per worker is only a small fraction of the present annual whole-body dose limit. In addition, one can see that only a small proportion of workers are getting doses greater than 20 mSv (2 rem) annually. The percentage of workers getting more than 20 mSv (2 rem) ranges from 0.1 to 5 %, except at one BWR plant where 8% of the workers get more than 20 mSv (2 rem) annually.

Table 3.1: Whole-body dose data for PWR plants for 1988

Plant	Number Monitored	With annual whole-body dose > 2 rem		Average Dose per worker
		Number	%	
PWR-1	3,841	24	0.6	0.11
PWR-2	4,446	164	3.7	0.24
PWR-3	2,234	0	0	0.06
PWR-4	2,519	2	0.1	0.26
PWR-5	2,942	6	0.2	0.19
PWR-6	759	0	0	0.1
PWR-7	3,290	80	2.4	0.33
PWR-8	3,736	10	0.3	0.11
PWR-9	1,446	5	0.3	0.32
PWR-10	1,975	60	3	0.5
PWR-12	1,984	18	0.9	0.23
PWR-13	1,279	1	0.1	0.21

Table 3.2: Whole-body dose data for BWR plants for 1988

Plant	Number Monitored	With annual whole-body dose > 2 rem		Average Dose per worker
		Number	%	
BWR-1	1,684	5	0.3	0.33
BWR-3	4,887	7	0.1	0.19
BWR-4	2,265	63	2.8	0.51
BWR-5	2,616	22	0.8	0.28
BWR-6	3,957	326	8.2	0.45
BWR-7	3,727	69	1.9	0.29
BWR-8	10,322	201	1.9	0.28
BWR-9	3,215	148	4.6	0.52

Table 3.3: Whole-body dose data for Various Worker Groups at PWR plants for 1988

Work Group	Number with dose	
	Annual > 2 rem	Lifetime (rem) > age
Maintenance Technicians	23	20
Boiler Makers	5	2
Welders	24	0
Health Physics Technicians	10	6
Pipe Fitters	11	0
Riggers	61	5
Millwrights	49	2
Fuel Handlers	11	0
Decon Workers	7	0
Other Contract Personnel	85	41
Total	286	76

Table 3.4: Whole-body dose data for Various Worker Groups at BWR plants for 1988

Work Group	Number with dose	
	Annual > 2 rem	Lifetime (rem) > age
Pipe Fitters	23	0
Health Physics Technicians	8	7
Millwrights	418	1
Boiler Makers	2	0
Riggers	1	0
Maintenance Technicians	18	54
I & C Technicians	13	0
Quality Assurance	2	2
Radwaste Handlers	3	1
Other Contract Personnel	100	2
Total	588	67

Tables 3.3 and 3.4 show which work groups are getting the higher doses. Table 3.3 displays the PWR data; table 3.4 the BWR results. The PWR data indicate that out of a total of 30,451 persons monitored 296 (about 1%) have doses above 20 mSv (2 rem) and 82 (0.3%) have lifetime doses in rem greater than their age. For BWRs, out of a total of 32,673 moni-

tored the number of workers getting annual doses above 20 mSv (2 rem) is 602 (about 2%). The number of persons whose lifetime dose is greater than their age is 68 (0.2%). Thus, far fewer workers exceed the "lifetime dose greater than age" limit than those that exceed 2 rem/year.

A closer examination of the data shows that the main groups receiving doses of greater than 20 mSv (2 rem) per year are millwrights, maintenance technicians, riggers, welders, and "other" contract personnel, belonging to various groups. Further inquiries indicated that although the numbers are small, some of these workers are in short supply.

For both PWR and BWR plants, most workers with lifetime dose greater than age are in the maintenance technician group. It may be worth looking more closely at this group to see what kind of tasks are giving them the elevated doses, and whether there are any techniques that could help ameliorate doses to this group of workers. We again rely on information and suggestions from the plants that were a part of this survey.

3.1. High-Dose Tasks For Maintenance Technicians

3.1.1. PWR Plants

The PWR plants identified the following tasks that lead to high doses for maintenance technicians:

- Reactor head work:
  - Disassembly / reassembly
- Steam generator work:
  - Maintenance
  - Nozzle dam installation
  - Channel head entry for loop seals
  - Eddy current testing
  - Mechanical plugging
  - Work on scaffolding and manways
- Maintenance of reactor coolant system:
  - Seal leak repair on pump
  - Repacking of valves in loop room
  - Maintenance of system flow and temperature gauges
  - Unplugging of lines in high radiation areas
  - Pump maintenance and repair
  - Valve maintenance, repair and replacement, e.g. loop stop valves
- Accumulator pressurizer transmitter replacement
- Snubber maintenance

- Refueling activities

3.1.2. BWR *Plants*

The BWR plants identified the following tasks:

- In-core cable repair:
  - Low and intermediate power range monitors
  - Source range monitors
- Control rod drives:
  - Maintenance, replacement and service
- Valve maintenance and repair
- Refueling activities

3.2. Techniques For Reducing Doses For Maintenance Technicians

The responding plants also provided us with a number of techniques that they had found effective in reducing dose to the various high-dose groups. Some of these techniques were job-specific and others were task-specific. From these we list here those techniques appropriate to maintenance technicians:

3.2.1. Job-Specific Techniques

a) Provide steam generator primary manway shields

b) Use lift devices for manways

c) Ensure secondary side of steam generators are full to afford shielding in cubicles

d) Provide portable man-lift devices to reduce the need for scaffolding

e) Utilize multiple-stud tensioners for manways

f) Use an "O-ring" replacement tool for Grinne valve work

g) Make extensive use of mock-ups

h) Consider modification of the conoseal

i) Use a cleaner for the steam generator manway bolt-hole

j) Consider decontamination for high exposure maintenance

k) Flush the primary system with hydrogen peroxide

l) Use a mobile, remotely operated camera, e.g. for reactor head inspections

m) Provide job-specific shielding

n) Remove equipment or component to low-dose area if more extensive work is required

o) Ensure reactor coolant activity is low by using precoat filters and demineralizers

p) Provide and clear pre-job briefing

q) Use live-load valve packings to reduce the need for repacking

r) Improve the design of the pump seal to minimize leakage

s) Use valve designs of nearly zero leakage and high reliability

t) Assign a radiation protection technician to the maintenance group to improve job planning and communication

3.2.2. Task-Specific Techniques

- <u>Refueling:</u>
  - Use reactor vessel head shield
- <u>Steam generator channel head entry for loop seals:</u>
  - Practice on realistic mock-up to reduce time
  - Check equipment and eliminate defects before use
  - Use quick-installation seal platforms
  - Use lead blankets for shielding
- <u>Installation of robot arm in channel head:</u>
  - Utilize remotely operated arm
  - Chemically decontaminate the channel head
  - Practice on realistic mock-ups
  - Use quick-installation lead blanket
- <u>Steam generator eddy current testing or mechanical plugging:</u>
  - Increase use of zero entry robots
- <u>Robot maintenance:</u>
  - Use nearly maintenance-free and/or modular robots

4. Other Dose-Reduction Techniques

Other dose-reduction techniques which were of a more general nature were suggested in our discussions with the health physicists, plant engineers and contractors that provided us information. For example, it was suggested that plants maintain a set of high-dose group data sheets which may be periodically updated. The sheets would identify the worker groups that needed watching and show how the doses to the workers were developing over the years. They would identify the jobs that expose the groups to higher doses and maintain a running account of the dose accrued while carrying out these tasks. Finally there would be two sets of successful dose-reduction techniques identified: one set would consist of techniques which require little cost and may be readily implemented; the other would list those techniques that would require more planning, plant-wide cooperation and/or more outlay.

Table 4.1: Sample data sheet for in-service inspectors and quality assurance technicians

High-Dose Group Data Sheet In-Service Inspectors / Quality Assurance Technicians	1989	1990	1991
Annual Dose (mrem)			
Annual dose to group			
Average annual dose to individuals			
Doses from High-dose Tasks			
Ultrasonic inspection of primary piping			
Cleanliness inspection of steam generators			
Radiography			
Eddy current testing			
Removal and replacement of insulation			
Successful Low-cost Dose-reduction Techniques			
Use photography			
Mark insulation panels to ease retrieval			
Keep pipes and tanks filled with water			
Provide low-dose wait areas for NDT technicians			
Use quick-action fasteners			
Flush or hydrolaze			
Chemically decontaminate			
Successful Higher Cost Dose-reduction Techniques			
Use modular insulation design			
Provide permanent platforms for repetitive work			
Provide quick-disconnect insulation for easy dismantling and installation			
Provide automated NDT equipment			

By examining these sheets, plant health physicists would be able to rapidly decide whether any special measures were called for and if so what level of measures were necessary. This seems a very worthwhile way to monitor and reduce doses to high-dose groups.

5. References

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