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ALARA - PROGRESS AND PROSPECTS

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1. INTRODUCTION

This paper has two main topics. The first part describes the establishment and work of the ALARA Center; the second part presents some results of our studies at the Center with international data on doses at PWR plants. This data then is used to reach a preliminary understanding of some of the factors that are causing high doses at PWRs. Our approach should help in reducing occupational exposures in a more effective manner.

2. REASONS FOR THE ESTABLISHMENT OF THE ALARA CENTER

Although occupational radiation exposures (ORE) to individuals generally have been kept well below the regulatory limits in the United States, the collective occupational dose equivalents show large increases over time (Ref.1).

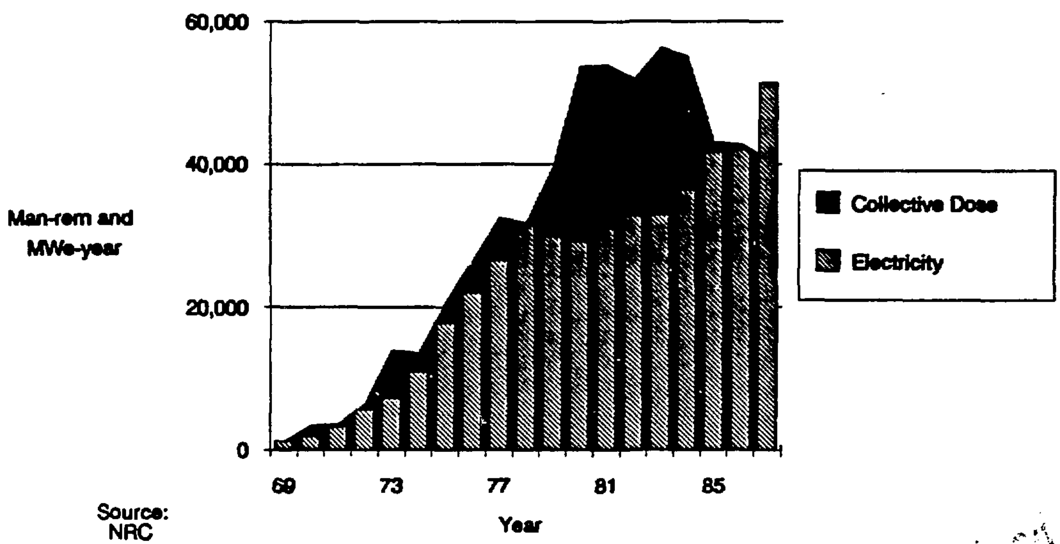


Fig.1: Collective Dose and Gross Electricity versus Year

MASTER

Between 1969 and 1978 the annual collective dose rose gradually, at roughly the same rate as the total amount of electricity produced by nuclear power plants. After 1978, however, the electricity generated was nearly constant for several years, but collective occupational dose increased steeply (Fig.1).

The rise in ORE raised questions about ALARA :Are doses as low as reasonably achievable? Compared to other countries with considerable nuclear power generation, the collective occupational exposures were significantly higher in the United States. Figure 2 shows the averaged collective dose equivalents at power reactors for several countries (Ref.2). The dose equivalents have been normalized to per unit of electricity produced.

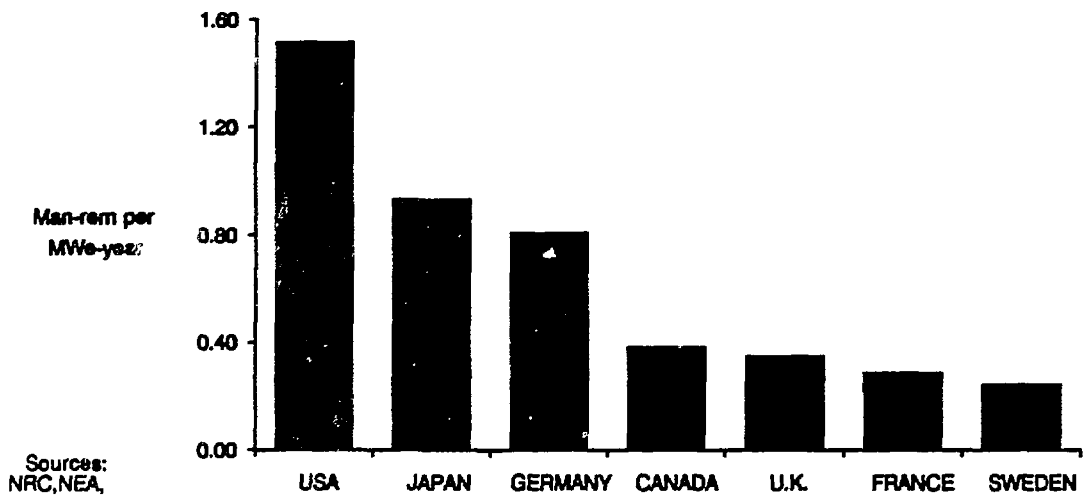


Fig.2: Collective Dose Equivalents at Power Reactors--Five year average (1981-85)

A part of the increase in ORE could be attributed to the multiplant actions that were mandated after the Three Mile Island 2 accident (Ref.3). Nevertheless, the Nuclear Regulatory Commission (NRC) wanted to ascertain that appropriate efforts to reduce ORE in accordance with the ALARA principle were being made.

In compliance with its congressional mandate to oversee the radiation safety of workers at nuclear power plants, the NRC asked the Brookhaven National Laboratory to create a center to help monitor efforts that were likely to reduce occupational radiation exposure. The NRC project required the ALARA Center to evaluate dose reduction research and ALARA-related programs, and to note any areas where additional effort may be fruitful. The Center also was directed to inform the NRC on promising research and developments related to ALARA that were being carried out abroad, and to examine areas where international collaboration may be valuable.

3. FUNCTIONS OF THE ALARA CENTER

Once the planning to set up an ALARA Center was underway, it was necessary to examine what its appropriate functions should be. The planners had to bear in mind limitations on the availability of qualified man-power and funds. With these constraints, it was decided to concentrate in the first phase on the following objectives:

(a) *Monitor dose-reduction efforts* in the United States and abroad.
(b) Carry out studies on dose reduction.
(c) Inform the NRC on aspects of dose reduction.
(d) Inform the nuclear industry on dose reduction efforts.
(e) Act as a center where information related to ALARA can be deposited, circulated and retrieved by the nuclear industry.

4. RESEARCH PROGRAM OF THE ALARA CENTER

4.1 Past Research

4.1.1 Comparative Assessment of Foreign and U.S. Nuclear Power Plant Dose

One of the first projects the center undertook was a comparative assessment of dose experience at U.S. and foreign nuclear power plants. Occupational dose data and experience from nuclear power plants throughout the world were to be compared with similar data and experience in the *United States, and the reasons for the reduced doses* in other countries were to be examined. To aid in this study, an international workshop on historical dose experience and dose reduction was held at Brookhaven in 1984. The proceedings are available as NUREG/CP-0066 (Ref.4),and the main conclusions are outlined in the summary report NUREG/CR-4381 (Ref.5).

	WEIGHTS
Water Chemistry	1.7
Water Purification	1.6
Reduced Cobalt	1.6
Remote Tools, Robotics	1.5
Decontamination	1.5
Backfits	1.4
Worker Motivation	1.3
Permanent vs Transient Work Force	1.3
Management Commitment	1.3
Multiple Reactors per Site	1.3
Reliable Design	1.3
Passivation	1.2
Quality Assurance	1.2
Standard Plant Design	1.2
Shielding, Segregation of Active Components	1.2
Product of weights	106.

Fig.3: Factors that affect dose at nuclear power plants

One outcome of this study was a list of the most significant factors that affect occupational exposure at water reactor power plants (Fig.3). A weight was assigned to each factor, based on nuclear plant and literature studies. The assigned weight is the ratio of the dose expected at a plant where that factor is poorly controlled to one where the control is good. The product of the weights is around 100. Thus, the doses at a power plant with optimum performance in all these factors, compared to a plant with poor control on all of them, should differ by a factor of about 100. No plant of either category exists, but one can see why doses between different power plants can vary by factors of up to ten or more.

4.1.2 Cost-effectiveness of Engineering Modifications at Nuclear Power Plants

Another part of the research program of the ALARA Center was a study of a large number of engineering modifications to water reactor plants, using a cost-benefit methodology developed at the center. The detailed results and the analytical techniques are discussed in NUREG/CR-4373 (Ref.6). Figure 4 shows a sampling of the results of the most cost-effective modifications for PWR plants. The first column describes the modification, the next shows the likely savings in dose over the life of the project in person-rem per year: this is followed by the capital cost for installing the modification, and finally, the total benefits expected over the project's lifetime if the worth of one person-rem is equated to $1,000.

Modification	Dose Savings Man-rem/Y	Capital Cost $	Total $ Saved (@ $1,000/rem)
Refueling Machine	3	225,000	32,000,000
RV Head Multistud Tensioner	53	940,000	29,000,000
Integrated Head Assembly	4	75,000	13,000,000
SG Channel Head Decontamination	3,790*	2,000,000	8,000,000
Cavity Decontamination (WEPA system)	3	90,000	4,000,000
Photographic Technique for SG Tube Plugging Inspections	53	5,000	1,000,000
Robotic Inspection of Ice Condenser Area	5	80,000	600,000

*Dose savings during subsequent work in man-rem (not man-rem/y)

Fig. 4: Cost-effectiveness of Engineering Modifications at NPPs

4.1.3 High-dose jobs and related techniques of dose reduction

Simultaneously we carried out another project visiting 18 reactors to gather data on typical high-dose jobs and related techniques for dose reduction. The results of this work are summarized in NUREG/CR-4254 (Ref.7). Figures 5 and 6 illustrate the kind of information obtained from this work.

	Collective Dose (man-rem)		
Job Title	Minimum	Maximum	Average
Snubber, Hanger, and Anchor Bolt Inspection and Repair	0.30	580	110
Steam Generator Eddy Current Testing	12	140	50
Reactor Disassembly/Assembly	12	120	48
Steam Generator Tube Plugging	3.4	180	47
In-Service Inspection	1.0	130	46
Plant Decontamination	5.0	67	45
Primary Valve Maintenance and Repair	1.4	120	30
Scaffold Installation/Removal	0.50	62	30
Insulation Removal/Replacement	1.2	37	18
Reactor Coolant Pump Seal Replacement	1.1	44	17
Steam Generator Manway Removal/Replacement	4.4	51	16
Instrumentation Repair and Calibration	1.1	31	12
Chemical, Volume, and Control System Repair and Maintenance	0.80	37	11
Secondary Side of the Steam Generator Inspection and Repair	2.3	41	11
Fuel Shuffle/Sipping and Inspections	3.6	16	9.2
Operations - Surveillance, Routines, and Valve Lineups	3.0	18	7.4
Cavity Decontamination	1.1	16	5.9
Pressurizer Valve Inspection, Testing, and Repair	0.30	21	5.5

Fig.5: Collective Dose Summaries for High-Dose Jobs at Westinghouse PWRs

To make the comparisons between different plants meaningful, it is necessary first to carefully define the job itself, outlining what is to be included and what is to be excluded. Figure 6 illustrates the definition for one job, and gives the maximum, minimum and average dose for this job based on the sample of reactors. The figure also shows some techniques that were effective in reducing occupational exposure. The techniques were grouped into those related to reducing dose rates, to reducing exposure time and to reducing contamination.

JOB TITLE: **Cavity Decontamination**

JOB DESCRIPTION:

Decontamination of the reactor cavity floor and walls during refueling. Can include wet mop, maslin, hydrolasing, hand scrub, wall-washing machines, electropolishing, glass bead blasting, and strippable paint. Excludes tool decon, equipment decon, decontamination in the cavity associated with major modifications, and processing and shipment of any of the cavity decontamination waste.

OUTAGE COLLECTIVE DOSE:

REACTOR SUPPLIER	MINIMUM man-rem	MAXIMUM man-rem	AVERAGE man-rem
Westinghouse	1.1	16	5.9
Combustion Engineering	.8	11	5.3
Babcock & Wilcox	-	-	-

DOSE-REDUCTION TECHNIQUES:

Dose-Rate-Reduction Techniques:

- Perform as much decontamination from above as possible
- Change mop heads on charging floor
- Continuously monitor mop heads, vacuum cleaners, and maslin
- Maintain distance from vessel opening and transfer canal
- Use underwater vacuum on floor during draindown
- Place lead on skiff or bucket walls and bottom
- Use remote cleaning equipment e.g. robotic hydrolaser

Timesaving Techniques:

- Provide highly polished stainless steel walls
- Provide wall-and floor-washing machines
- Use strippable decontamination coating
- Perform electropolishing or wet glass bead blasting
- Preplan method and logistics of cavity decontamination
- Employ experienced decontamination technicians

Contamination-Reduction Techniques:

- Hose down walls and brush crud (bathtub) ring from the charging floor during draindown
- Use strippable decontamination coating
- Keep walls wet prior to decontaminating

Fig.6: PWR High Dose Job Dose-reduction Information Sheet

4.1.4 Optimization of the Control of Contamination at Nuclear Power Plants

In another project we examined the problem of optimal control of contamination at nuclear power plants. A methodology was developed (Fig.7), which enables one to compare the existing "do nothing" situation with different options to remove contamination. The methodology uses personal computer spreadsheet programs, and analysis of cost-effectiveness and cost-benefit. This work is summarized in NUREG/CR-5038 (Ref.8).

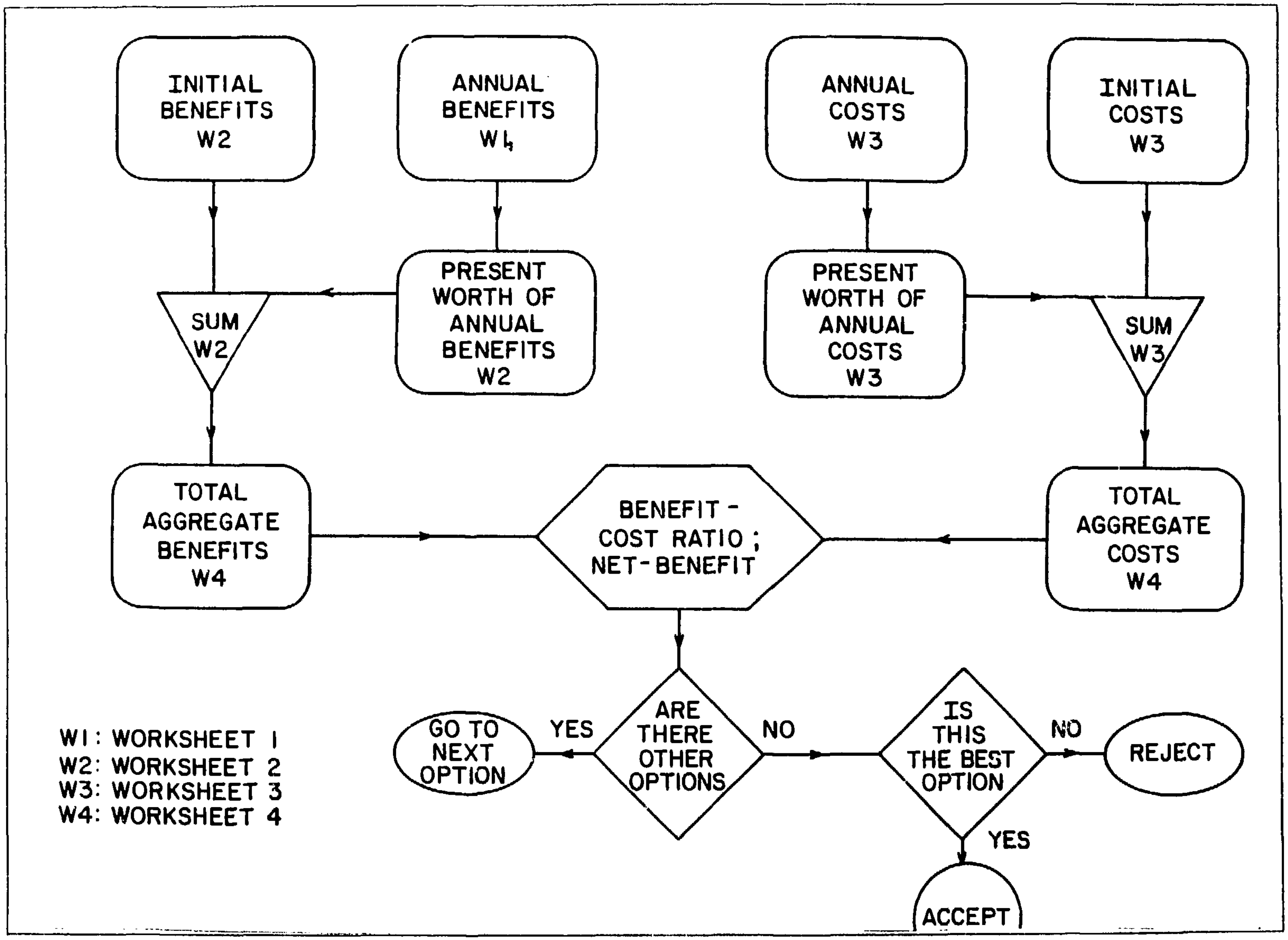


Fig. 7: Model Schematic

Some interesting features of this work are: (1) It proposes a simple and flexible method to develop the monetary worth of a unit of collective dose. (2) It can take into account the skin and extremity dose if desired. (3) It attempts to quantify the degradation imposed by a contaminated environment on the efficiency of workers. (4) It proposes guidelines for the use of protective apparel, for radiation surveys and for monitoring contamination. Table 1, taken from the study, shows the apparel factors for various items of protective apparel. These factors, which are related to worker efficiencies in protective apparel, are based on experiments carried out in Canada by Ontario Hydro (Ref.9) and were utilized with their permission.

Table 1: Effect of protective apparel on efficiency*

Item of Apparel	Type	Apparel Factor u
Gloves	Cloth	0.90
	Rubber	0.80
	Heavy Rubber	0.50
Hood	Cloth	1.00
	Disposable	1.00
	Wet Suit	0.98
Coverall	Cloth	1.00
	Disposable	0.99
	Wet Suit	0.98
	Supplied-air	0.97
Shoe Covers	Disposable	0.97
	Rubber	0.96
Respirator	Air Purifying	0.97
	Air Supplied	0.96

Gross Apparel Factor **U** given by

$U = u_{gloves} \times u_{hood} \times u_{coveralls} \times u_{shoe\ covers} \times u_{respirator}$

* Courtesy of Ontario Hydro (Ref.9)

4.2 Present Studies

4.2.1 Correlation of Radiation Fields and Plant Collective Doses with Measures to Reduce Exposures

One current project is to correlate the radiation fields in nuclear power plants and the collective doses with features of the plant or measures which may reduce radiation exposure. This is a difficult task, but we hope to express quantitatively the expected dose reduction that would follow the introduction of such measures.

4.2.2 Data Base on Dose Reduction Research and Health Physics Technology

An international data base that covers research on dose reduction and projects in health physics technology has been developed.

The objectives of this NRC-sponsored project are :-

* To monitor the status of research on dose reduction and to inform the NRC about its efficacy.
* To make such information available to researchers and organizations.
* To exchange information on dose reduction with appropriate organizations abroad.

The staff of the ALARA Center, therefore, developed a computerized, international data-base of information on dose-reduction research and technological projects in health physics. The information on the data base is continually updated and monthly summaries are provided to the NRC and to contributors to the data base either upon phone request or by periodic (approximately annual) mailings. Presently there are 250 research and 135 projects on health physics technology in the data base, that are described in two annual reports, NUREG/CR-4409 Volumes 1 and 2 (Ref.10,11). Another volume is scheduled to come out this year. In addition, bibliographies of selected readings in radiation protection and ALARA are periodically published, NUREG/CR-3469 Volumes 1, 2 and 3 (Ref.12,13,14). Volume 4 of the bibliography also is scheduled for publication this year.

Recently the data base was made available to users through an on-line link, using a personal computer and a modem. An electronic bulletin board service will be provided where users can deposit and retrieve information and exchange ideas and experiences.

4.3 Future Plans

4.3.1 Hot Particles

We have started work on a project which addresses the problem of hot particles. We plan to carry out the following tasks: (a) define the source term for hot particles, (b) define methods of prevention and mitigation, (c) assess the pathways to the human body, and (d) design and conduct animal experiments.

4.3.2 International Workshop

We plan to hold periodic international workshops (about every four years) of the type described above. The next one is scheduled for 1989, the week after the Westinghouse REM Seminar. It will be jointly sponsored by the NRC, the DOE and the ALARA Center, in co-operation with the Nuclear Energy Agency of the OECD.

4.3.3 Collaboration with the Nuclear Energy Agency

On a wider scale,the need for the kinds of activities that the ALARA center is carrying out, led the Nuclear Energy Agency of the Organization for Economic Cooperation and Development to propose an extension of this program, encompassing Western Europe, Japan, Canada and the United States. They are considering having three regional centers, which would collect dose-related information from member countries, analyze the information and make it available to interested parties including the nuclear industry and national regulatory organizations. The ALARA Center is collaborating with the NEA in this program.

4.3.4 Feasibility of Worker Self-monitoring in the United States

We also plan to explore the feasibility of introducing self-monitoring for workers in U.S. nuclear power plants. The concept was developed in Canada and appears to have been successful. However, circumstances are different in the United States. It would be worth exploring whether any aspects of the approach can be transplanted in the United States and whether new approaches appropriate to U.S. conditions can be developed. Since we proposed the concept we have learned that at least one U.S. utility is already evaluating this approach.

5. WORLDWIDE COMPARISON OF PWR EXPOSURES

The second part of the paper presents the preliminary results from a study of radiation exposures of approximately 100 PWRs from several countries. The scope of the paper only permits the inclusion of certain areas which appear to be especially interesting.

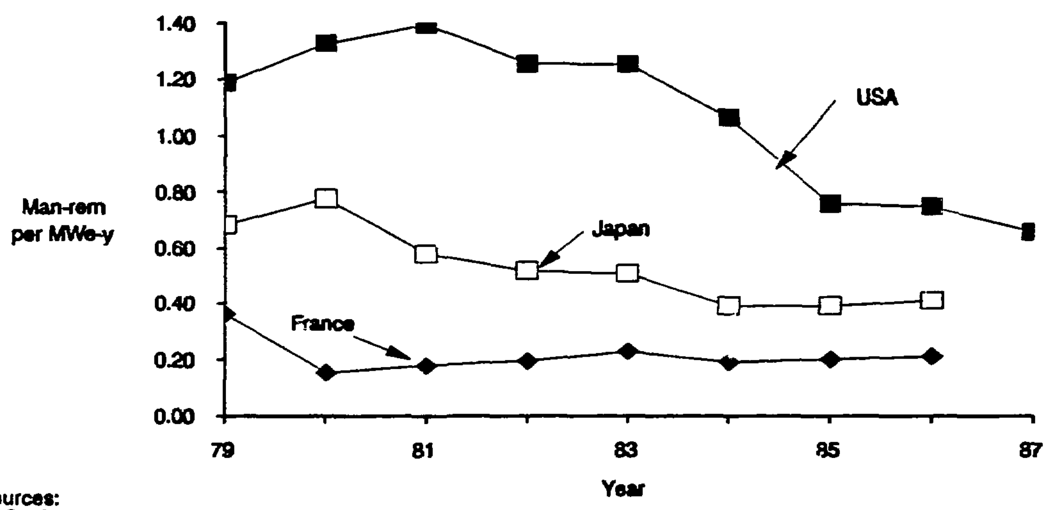
Table 2 shows the countries that we considered, the number of PWRs operating in each country, and the reactor operating years up to 1984. The United States has the largest and longest-running program. Japan and France have approximately the same number of years of operating experience. However, the Japanese experience is based on half the number of reactors in France, which means that the Japanese reactors are much older on the average.

Table 2: Operating Experience of Selected PWR Countries*

Country	Number of PWRs	Reactor operating years
Belgium	4	29
France	22	72
Finland	2	9
F.R. Germany	7	35
Holland	1	10
Japan	11	88
Sweden	3	13
Switzerland	1	5
United States	47	366

* Till 1983; > 400MWe gross output

Figure 8 shows the data on annual collective dose from Japanese and French PWRs. The U.S. data is also given for comparison. Several points are noteworthy: (a) the U.S. doses are the highest, but they are continuing to decrease, (b) the Japanese and French doses are tending to flatten out and perhaps even increase slightly since 1984, and (c) the French doses are the lowest. Most French plants are of modern design and have been operating for considerably less time than the average U.S. or Japanese plants. From Canadian experience, we know that one of the most effective ways to reduce dose is at the design stage. In some instances, a single improvement such as a change in materials can eliminate a major source of cobalt and consequently reduce dose.



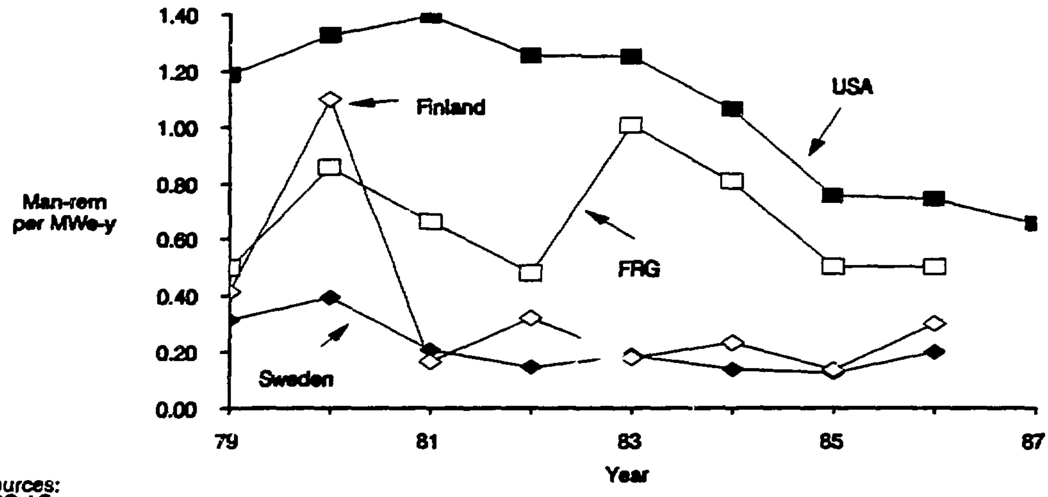
Sources: NRC,AC

Fig. 8: PWR Annual Collective Dose Equivalent. United States, Japan, and France

Figure 9 compares the U.S. PWR dose data with that from West Germany, Sweden and Finland. The Swedish and Finnish doses are remarkably low, partly as the result of excellent dose-control practices used in those countries. In Sweden low doses are partly due to the innovative chemistry that is being utilized.

In the case of Finland, the low doses are also partly attributable to the particular plant design of the Loviisa PWRs. These plants, which differ in design from western PWRs in a number of respects, have some strong points. For example, they seem to be free of serious problems of corrosion, their primary circuits are free of stellite, a major contributor to cobalt activity, and the 12 horizontal steam generators of the two Loviisa plants have required little maintenance. Of the 66,000 tubes only one had to be plugged.

Table 3 gives the main conclusions of the study, which shows the annual collective doses averaged over plant life as functions of plant age and size. The influence of plant size on occupational exposure is often concealed by the fact that larger plants have generally been operating for shorter periods. However, when all the data is analyzed in this manner the effect of the plants' size and age becomes obvious.



Sources:
NRC,AC

Fig. 9: PWR Annual Collective Dose Equivalent. United States, FRG, Sweden, Finland

Table 3: Lifetime average annual collective doses
as a function of PWR size and age.

Plant age (y)	Annual collective dose (man-rem)			
	Small (400-600MWe)	Medium (750-1000MWe)	Large (>1000MWe)	All
New (1-5)	119 (3)	147 (28)	332 (6)	175
Intermediate (6-10)	178 (8)	314 (25)	427 (8)	310
Old (11-16)	376 (13)	769 (9)		537
All ages	278	305	386	

Further analysis suggests that the PWRs in this study fall into four groups: (a) 400-600 MWe U.S., Japanese and European PWRs, with two coolant loops and ages of 9 years or more. Their lifetime average annual collective doses are around 300 man-rem, (b) 750-1000 MWe two- or three-loop plants with lifetime average annual collective doses of 300 - 600 man-rem. These plants were designed before attention was seriously focused on reducing occupational exposures. A number had problems with their steam generators, (c) Newer three loop-reactors with 750-1000 MWe gross output, built outside the United States and generally operating for less than 5 - 6 years. Their lifetime average annual collective dose is around 200 man-rem,and (d) Four-loop plants of between 1000 and 1300 MWe gross output. These plants have various ages and their annual collective doses averaged over their lifetime also vary widely, from 200 to 1100 man-rem for individual reactors.

7. CONCLUSIONS

Despite the vicissitudes that the nuclear industry is going through in the United States and abroad, its research and development profile remains in a healthy state. The doldrums that supposedly afflict the nuclear industry are not perceptible in R & D as evidenced by the vigorous research program in the area of dose-reduction that already is producing significant results.

Ultimately it may be possible to achieve doses so low that they become an insignificant factor in the workers' health and welfare. Apart from making the plants much more efficient and economical to operate, this achievement would improve the public's perception of nuclear power by making work in power plants more nearly conventional.

The targets for radiation dose for the advanced light water reactors now being designed are approaching this objective. By their efficient low-dose operation, some power plants in the United States and abroad are showing that it is a realistic goal. However, only with major efforts at dose-reduction can the older high-dose power plants, be improved. Thus, the achievement of this goal may only be possible sometime in the next century.

To ensure that doses are ALARA, plant-wide ALARA plans should be developed and adopted. Each action or modification for potential dose reduction should be carefully considered in accordance with the general principles of ALARA and given a priority for implementation. Thus, there is an important need for carefully targeted ALARA evaluations and studies.

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