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THE PROGRAM OF THE ALARA CENTER AT BROOKHAVEN NATIONAL LABORATORY*

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ABSTRACT

In 1984 the Brookhaven National Laboratory was asked by the Nuclear Regulatory Commission to set up a Center to monitor dose-reduction efforts in the US and abroad and to focus the industry's attention on ALARA. The paper summarizes the main work of the ALARA Center between 1984 and 1992. The Center maintains nine data bases for the NRC and the Nuclear Power Industry. These databases are constantly updated and access to them is provided through a personal computer and a modem and by periodic publications in the form of a newsletter and NUREG reports.

Also described briefly are eight other projects related to dose-reduction at nuclear power plants that the Center has carried out for the NRC. Among these are projects that analyze the cost-effectiveness of engineering modifications, look at worldwide activities at dose reduction and compare US and foreign dose experience, examine high-dose worker groups and high-dose jobs, develop optimum techniques to control contamination at nuclear plants, and look at the doses being received by men and women in all sectors of the nuclear industry.

Items presented in the paper include summary tables of the most cost-effective modifications for nuclear plants, collective dose summaries of plant high-dose jobs, illustrations of dose-reduction techniques, a table quantifying the effect of protective apparel on worker efficiency, some of the more popular dose reduction methods used at US plants and the authors' evaluation of the potential impact and effectiveness of various dose-reduction techniques. The paper also presents data on doses to various worker groups at US plants. In analyzing the doses to various sectors of the nuclear industry as a whole, it is shown that there is a strong downward linear correlation between dose and age for male workers in all sectors of the nuclear industry except that of medicine. References are provided to publications where additional information is available.

INTRODUCTION

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

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

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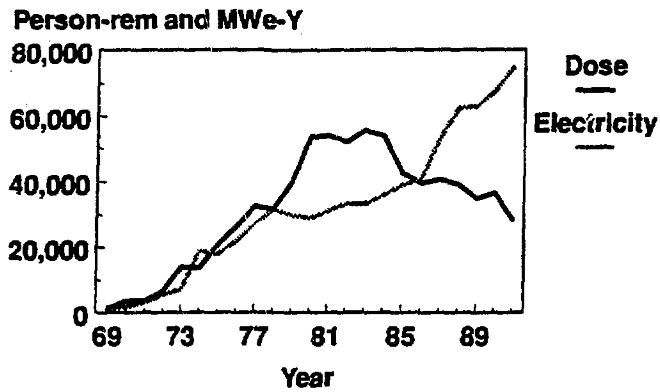
Figure 1. Radiation Exposure and Power Generation: US Nuclear Plants



The rise in occupational radiation exposures raised questions about ALARA: Are doses as low as reasonably achievable? Moreover, compared to other countries with considerable nuclear power generation, the collective occupational exposures were significantly higher in the United States. A part of the increase in occupational radiation exposures could be attributed to the multi-plant actions that were mandated after the Three Mile Island 2 accident.

The US Nuclear Regulatory Commission (NRC) wanted to ascertain that appropriate efforts to reduce occupational radiation exposures 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 Brookhaven National Laboratory (BNL) 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 the 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.

Since then, remarkable progress has been made by the ALARA community in reducing occupational exposures at US nuclear power plants (Figure 2). However, advances have also been made abroad. Figure 3 shows the averaged collective dose per reactor in 1989 (the last year for which comparative data is available) for several countries. One sees that we still have some way to go. In 1991 the US average collective dose per reactor was 257 person-rem.

Figure 2. US Collective Radiation Exposure per Light Water Reactor, 1973-1991

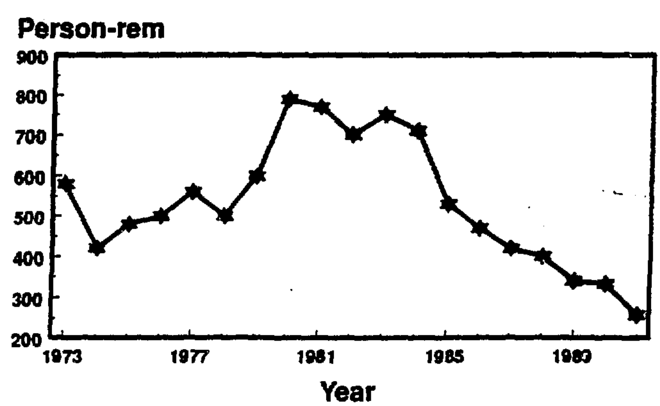
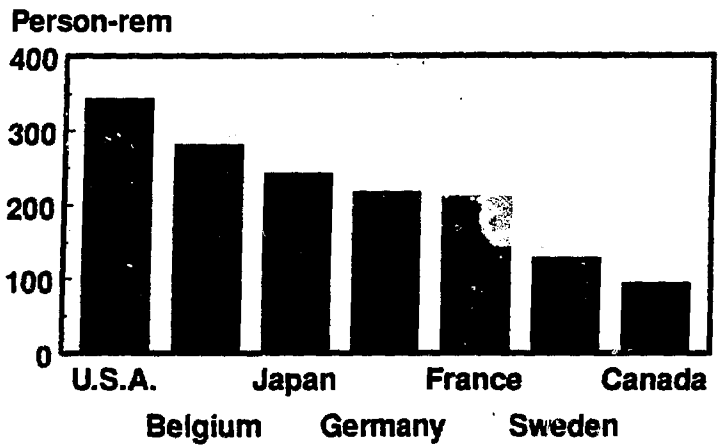


Figure 3. Comparison of Collective Radiation Exposure per Reactor, 1989



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 the limitations on the availability of qualified manpower and funds. With these constraints, it was decided to concentrate 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.

RESEARCH PROGRAM OF THE ALARA CENTER

Past Research

Comparative Assessment of Foreign and US Nuclear Power Plant Dose Experience

One of the first projects the ALARA Center undertook was a comparative assessment of dose experience at US 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, periodic international workshops on historical dose experience and dose reduction are held at Brookhaven National Laboratory. The proceedings of the 1984 workshop are available as NUREG/CP-0066,[1] and of the 1989 workshop as NUREG/CP-0110.[2] Our next workshop is to be held on May 8-11, 1994. Some of the subjects we plan to discuss during the workshop are:

a) Work Planning, Prioritization, and High-dose Jobs

b) Cobalt Replacement, Chemistry, and Decontamination

c) ALARA during Operations and Backfits

d) New Reactors and ALARA

e) Robotics, Remote Tooling, and Remote Surveillance

f) Economics and Optimization

g) Dissemination of Information

h) Recent Recommendations on Dose Limitation

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.[3] Table 1 shows a sampling of the results of the most cost-effective modifications. 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.

Table 1. Cost-Effectiveness of Engineering Modifications at Nuclear Power Plants

Modification	Dose Savings Person-rem/y	Capital Cost** $	Total $ Saved (@ $1,000/rem)
Refueling machine	3	225,000	32,000,000
Reactor vessel head multistud tensioner	53	940,000	29,000,000
Integrated head assembly	4	75,000	13,000,000
Steam generator (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
Robotics inspection of ice condenser area	5	80,000	600,000

*Dose savings during subsequent work in person-rem (not person-rem/y).
**All costs are in 1984 dollars.

Recently we have been participating in a small project with the nuclear industry to update this information. Fifteen utilities are providing data and are partaking in that project.

High-dose Jobs and Related Techniques of Dose Reduction

Another project we carried out was to gather data on typical high-dose jobs and related techniques for dose reduction. During this study 18 reactor sites were visited. The results of this work are summarized in NUREG/CR-4254.[4] Tables 2 and 3 illustrate the kind of information obtained from this work. To illustrate some of the findings of this study a few of the high-dose jobs for boiling water reactors are displayed in Table 2. The table also shows the minimum, maximum and average doses for these jobs. Since this study remarkable improvements have been made and the radiation doses for these jobs have decreased very significantly.

Table 2. BWR Collective Dose Summaries for Outage High-Dose Jobs

Job Title	Collective Dose (person-rem)			Population Size
	Minimum	Maximum	Average	
Snubber inspection and repair	3	1400	290	15
Taurus repair, modification	100	600	280	14
In-service inspection	32	380	150	15
CRD remove, rebuild, replace	6	230	60	15
Primary valve maintenance	7	150	57	6
Reactor disassembly, assembly	8	51	24	15
Fuel shuffle, sipping, inspection	4	58	19	15
Refueling pool decontamination	3	6	4	12

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. Table 3 illustrates the definition for one job. Also shown are techniques that were effective in reducing occupational exposure for this job. The techniques were grouped into those related to reducing dose rates, to reducing exposure time, and to reducing contamination. About 20 such dose-reduction data sheets were developed for BWR-type plants and 20 for PWR plants. These sheets have proved very useful in job-planning activities.

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 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 the cost-effectiveness and cost-benefit. This work is summarized in NUREG/CR-5038.[5]

Important features of this work are: (1) a simple and flexible method to develop the monetary worth of a unit of collective dose; (2) description of a method for taking into account the skin and extremity dose, if desired; (3) a method for quantifying the degradation imposed by a contaminated environment on the efficiency of workers; and (4) guidelines for the use of protective apparel, for radiation surveys, and for monitoring contamination. Table 4, 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 and were utilized with their permission.

Relative Importance of Processes and Practices in the Control of Radiation Exposure

In another project, we were required to evaluate processes important to dose control at nuclear plants. We sent out a questionnaire to several US utilities, asking them to assess the importance of certain processes in dose reduction. Using their responses, we divided the processes into high, medium, and low levels of efficacy. Figure 4 displays the results for some processes which were classified as having a medium impact on dose reduction.

Table 3: A Typical BWR High-Dose Job Dose-Reduction Data Sheet

Recirculation Pump Seal Replacement

DESCRIPTION:

Outage or forced outage recirculation pump seal replacement. Includes surface and equipment decontamination; auxiliary piping removal; grating removal; flange spool piece removal; rigging installation; lower coupling removal; seal removal; seal surface cleaning; seal testing, replacement and inspection; replacement of auxiliary piping; set thrust bearing; replacements of spool piece and grating. Excludes work associated with vibration measurements; in-service inspection; pump modification, reinsulation, painting; and motor inspection and repairs.

DOSE-REDUCTION TECHNIQUES:

Dose-rate-reduction Techniques:

- Flush seals and seal-cooling lines
- Evaluate shielding of local 'hot spots'
- Provide shield around grating and inside bowl
- Decontaminate seal surface and bowl and shield with plastic

Timesaving Techniques:

- Erect scaffolding and install temporary lighting
- Use recirculation pump seal replacement video tape
- Use hydraulic jacks and strongbacks to couple shaft
- Split leak-off collar to improve shaft coupling and facilitate thermocouple connection
- Modify shaft shroud to facilitate its removal

Contamination-reduction Techniques:

- Mop plastic-covered grating periodically
- Erect plastic walls around change area and contaminated parts storage area
- Wrap old seals in plastic or transport in sealed transfer cart
- Decontaminate highly contaminated parts in ultrasonic sink or dip tank
- Rebuild seals underwater or in a ventilated doghouse

Table 4. 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
	Air Supplied	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: $U = u_{gloves} \times u_{hood} \times u_{overalls} \times u_{shoe\ covers} \times u_{respirator}$

Assessment of Worldwide Activities on Dose Reduction

In this project, we were asked to examine the main areas of research and development related to dose reduction and the potential impact of this work on plant doses. The results of this work are summarized in NUREG/CR-5158[6]. Tables 5 and 6 display our main conclusions.

Dose-reduction Techniques for High-dose Worker Groups in Nuclear Power Plants

This study is based on the experience of 25 US plants, 6 contractors, and various European, Asian, and Canadian utilities. The study:

a) Identifies the high-dose work groups.

b) Quantifies the number of workers in these groups and compares this to the total radiation workers in the plant.

c) Compares the average dose to these groups with average dose to all plant workers.

d) Identifies the jobs that lead to high dose.

e) Describes techniques found effective in reducing doses to these groups.

The work is reported in NUREG/CR-5139. Some of the findings are summarized in Table 7.[7]

Figure 4: Processes with Medium Impact on Radiation Dose

- A. Automatic control rod drive handling machines
- B. Cavity wall decontamination equipment
- C. O_2 in feedwater and reactor water
- D. Passivation of new piping
- E. Permanent platforms

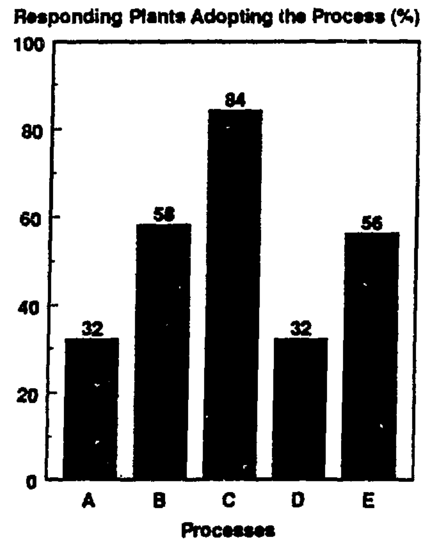


Table 5. Potential Impact of Radioactive Source Reduction Techniques on Nuclear Power Plant Collective Occupational Exposures

	Potential Impact on Collective Dose*			
Technique	Short term**	Intermediate term**	Long term**	Remarks
Cobalt reduction	low	medium	high	Largest impact on new plants
Preconditioning	low	medium	medium	For new plants and replaced components
Water chemistry	medium	medium	medium	Cost-effective technique
Component decontamination	medium	low	low	More effective for older plants
Full system decontamination	-	medium	low	Critical-path savings
Low waste decontamination processes	-	medium	low	Low waste-handling costs
Advanced reactor designs	-	medium	high	Very large source reductions possible

*Relative to the annual collective dose at the beginning of the appropriate period.
**Short (<7 years), intermediate term (7-20 years), long term (>20 years).

Table 6. Potential Impact of Exposure Time Reduction Techniques on Nuclear Power Plant Collective Occupational Exposures

Technique	Potential Impact on Collective Dose*			Remarks
	Short term**	Intermediate term**	Long term**	
Improved materials	low	medium	medium	Significant for component replacement and new plants
Control of intergranular stress corrosion cracking of BWR piping	medium	medium	low	Important for present BWRs
Control of PWR steam generator tube corrosion	medium	medium	low	Important for present PWRs
Remote tools	low	low	medium	Significant for new and standardized plants
Robotics	low	medium	medium	Need rugged, reasonably priced devices
Operational and maintenance techniques	low	medium	medium	Very cost-effective for dose reduction
Advanced reactor designs	-	medium	high	Offer new possibilities for remote tools, robotics, etc.

*Relative to the annual collective dose at the beginning of the appropriate period.
**Short (<7 years), intermediate term (7-20 years), long term (>20 years).

Present Work

Doses to Worker Groups in the Nuclear Industry

We were asked by the NRC to examine the nuclear industry as a whole, to look at the doses to groups of workers in various sectors, doses to men and women, examine any correlations, analyze the data and to provide them with our conclusions. To comply with this request we have carried out a review of the literature, analyzed the data and published some of our findings in an article in the November - December 1992 issue of the journal *Radiation Protection Management*.[8] We were fortunate to receive the Editors' Award as best paper of 1992 for this publication. Some interesting findings are summarized here:

a) There are approximately 715,000 men and 600,000 women in the nuclear industry.

b) The proportion of men and women in various sectors of the industry are shown in Figure 5.

c) The average annual dose for men is about 160 mrem; for women it is 50 mrem.

d) There is a straight line downward correlation between age and dose for men (see Figure 6); no such correlation is seen for women.

Table 7. Whole-Body Dose Data from Contributing BWR Plants, 1988*

Work Group	Number with		
	annual dose > 1 rem	annual dose > 2 rem	Lifetime dose > age
Pipe Fitters	83	23	0
Health Physics Technicians	188	8	7
Millwrights	1,154	418	1
Boiler Makers	15	2	0
Riggers	19	1	0
*Maintenance Technicians	277	18	54
Radwaste handlers	18	3	1
Instrumentation and Control Technicians	85	13	0
Quality Assurance Technicians	28	2	2
Electrical Technicians	83	0	0
Auxiliary Operators	63	12	1
Reactor Operators	28	2	0
Other Contract Personnel	277	100	2
Total	2,318	602	68

*Total Number of BWR workers monitored by plant sites that participated was 32,673.

Figure 5. Proportion of Male and Female Radiation Workers in Various Sectors

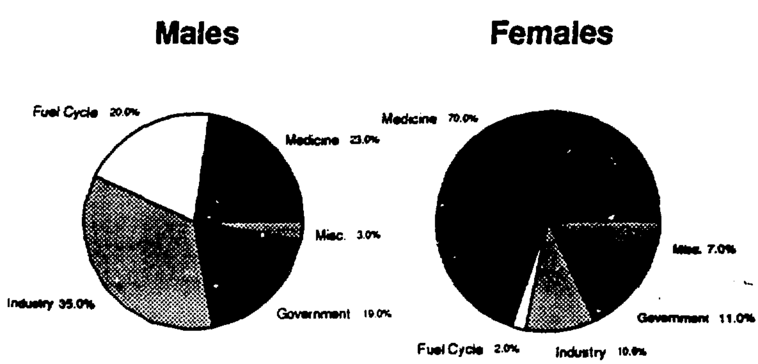
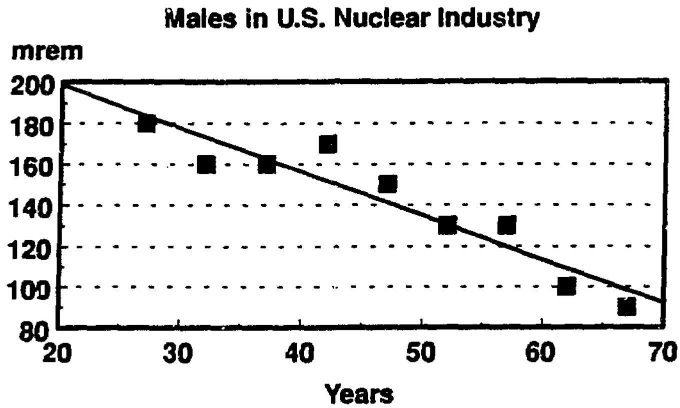


Figure 6. Mean Annual Dose versus Age



An ALARA Handbook

Another project is the production of an ALARA Handbook. This handbook is primarily intended for front-line radiation workers, although it will be useful to others involved with ALARA program implementation, such as Radiation Protection Managers, ALARA Coordinators and inspectors. Its purpose is first, to provide assistance in day-to-day ALARA-related decisions and second, to assist in the implementing radiation protection programs. The hand book contains information on many subjects, including limits and regulations, exposure control, conversion of units, useful formulae, radiation work, and elements of an ALARA program. Figures 7 and 8 summarize some advice on work planning that is included in the handbook.

Figure 7. Elements of Work Planning

- Identify the Hazards
- Assess the Hazards
- Control the Hazards
- Determine the Dosimetry Required for Radiation Work
- Determine the Protective Clothing Required
- Determine the Equipment Required
- Decide on Appropriate Dose Check Points before Work Commences
- Obtain the Necessary Authorizations
- Document where appropriate

Figure 8. Identifying the Hazards

A. Break down the job into steps and examine each step to determine possible hazards.

B. Ask these questions:

1) What work will the people be doing?
2) What other work is going on?
3) What systems are in the work area?
4) What hazards are to be expected?
5) Will the work itself create or change hazards?

Information System on Dose-reduction Research and Health Physics Technology

In order to comply with another task assigned to us by the NRC, which is to gather and disseminate information on ALARA, a multifaceted information system has been developed that covers research on dose control and projects in health physics technology. The objectives of this NRC-sponsored project is to monitor the status of research on dose reduction and to inform the NRC about its efficacy.

The staff of the ALARA Center have developed computerized data bases of information on various aspects of dose reduction. The information in the data bases is continually updated and provided to users of the system either upon phone request or by periodic mailings. Monthly summaries are sent to the NRC.

Some of the data bases are based on information collected by the ALARA Center through literature searches, visits to conferences, and discussions with experts in various fields. Other information has been provided by nuclear power plants for the use of other power plants and the ALARA Center.

The information in the various data bases is available on-line to users by means of a personal computer, a modem, and a password. The users may search for desired information on-line, print it to their own printers, or capture the information electronically on their fixed disks for later off-line playback and printing. The on-line information system is called ACE, for ALARA Center Exchange.

Alternately, most of the information on ACE may be obtained through fax machines using our fax-on-demand system, ACEFAX. One dials the telephone number from a regular fax machine and a voice prompts one on how to obtain specific documents, charts and photographs, including the list of documents on the system. This simple approach has become fairly popular with our users. The fax-on-demand system has the as yet unpublished and most up-to-date material in our databases, including the latest unpublished draft of our news letter, *ALARA Notes*.

The information available at the ALARA Center is of varying kinds: the RESEARCH data base describes worldwide ongoing ALARA-related research; the Health Physics database describes innovative approaches being used to reduce dose at world nuclear power plants; the NEWS database provides a summary of the most topical happenings in the world of ALARA and forms the basis for *ALARA Notes*, which now is distributed to about 1,000 readers worldwide. We also have databases on plant processes and practices, a bibliography of ALARA publications with about 2,000 entries, and a database on plant experiences with difficult jobs.

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 research and development 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.

We may be halfway there already with some of the new German and Japanese plants and even bigger gains are expected with some of the new American designs. For example, the targets for radiation dose for the advanced light water reactors now being designed are approaching this objective. Moreover, 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 are the older high-dose power plants being 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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