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OVERVIEW, WHAT IS ALARA? ARE WE THERE?

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ABSTRACT

As low as reasonably achievable (ALARA) in radiation protection at nuclear power plants is a complex criterion involving decisions requiring both professional judgement and quantitation. The former has been emphasized in most plants to date, however, unless quantitative studies are made it will be difficult to judge if doses at U.S. plants are ALARA. An ALARA assessment for each plant is suggested, which would include evaluations of both qualitative (e.g. organizational) and quantitative (e.g. cost-benefit or cost-effectiveness) efforts.

INTRODUCTION

The as low as reasonably achievable (ALARA) concept is not new. In subsequent papers in this meeting, Webb (1) and Peterson (2) will review historical developments of the concept in the International community and the U.S. respectively. Lombard (3) will describe quantitative decision aiding techniques and other speakers will illustrate practical implementation. In this paper, I will present my views on the concept and will review data gathered at the BNL ALARA Center; data which may help answer the question - are we there?

WHAT IS ALARA?

The ALARA concept has undergone a number of changes in terminology and emphasis over the past 30 or 40 years (4). The words praticable, lowest possible, practical, readily achievable, reasonably achievable, and optimization have been used somewhat interchangeably. The ICRP uses optimization as synonomous with ALARA and indicates social and economic factors are to be considered. Thus ALARA includes both qualitative and quantitative aspects. This is probably the most generally accepted version of the ALARA concept at the present time.

The methods employed to arrive at the optimum balance between social and economic costs and avoided doses are still variable and in a state of changing emphasis. For example, quantitation may be employed by regulatory groups to arrive at levels deemed "de minimis" or "below regulatory concern", (5,6), thereby reducing the need for quantitation at doses below 0.01 mSv for example. Quantitation may also be required to determine whether ALARA objectives are being met in the design and operation of major facilities such as nuclear power plants (7). However, the level of effort required has been specified in only general terms. The value of $100,000/person-Sv ($1,000/person-rem) has been employed in design and planning for avoiding public exposures from nuclear plant effluents (8). No comparable value has been recommended by the NRC for avoiding occupational exposures.

One point which needs emphasis in discussing ALARA is that the dose response relation is assumed linear, even at doses far below the exposure limits. For this reason, ALARA efforts tend to focus on collective dose. However, dose distribution becomes important in a cost-benefit analysis as dose limits are approached. This is usually handled by assigning progressively higher values to the value of detriment ($/person-Sv) for those groups or individuals receiving higher doses. Thus, the value assigned to detriment may vary from that assigned for health effects, which is the α term defined in ICRP 37, to a value (the β term) which is typically up to 100 times that value. The higher values reflect additional detriments such as the cost of hiring and training additional workers. These higher values are somewhat confusing since they reflect conditions that vary from plant to plant, job to job, and with time. Thus, a particular plant may have a β value for welders that is different from the β value for electricians, etc. Values of β may depend on average dose per person in a particular group. Typically, however, a common average or "effective" value is applied uniformly at a specific plant.

The second point which needs emphasis is that ALARA includes both qualitative and quantitative inputs to the optimization process. At the design or major modification stage, or when large collective doses are involved, a greater degree of quantitation is justified and usually needed. It is often true that quantitation is not needed at the operational level on a day-to-day basis. However, I would encourage a quantitative thinking process even for day-to-day decisions. For example, a properly trained technician can easily be taught to think in terms of $/person-Sv (or $/person-rem) using a nominal plant average value, e.g. $100/person-mSv ($1/person-mrem). A technician who surveys an operation can readily make a mental calculation of costs being incurred using the product of persons x dose rate x $/rem. It then becomes much easier to make consistent decisions on the worth of making minor changes in order to reduce what may be considered an "acceptable" but not ALARA exposure. Of course, if the change affects outage-time, the calculation needs to include incremental outage costs. This simple type of quantitation can be of great help in deciding practical questions of "where to draw the line?" in small collective exposure situations. The alternative is to accept doses or dose rates low in comparison to exposure limits. This leads to decisions to accept small doses which can <u>easily</u> be avoided and this is not ALARA.

There is a limit to how much quantitation is justified. Obviously, the costs in time, job delay, etc. should not exceed the likely detriment saving. Thus the analyst, health physicist, engineer or technician should not usually spend an hour to save 0.01 Sv (1 millirem), but may well justify a few minutes time if no other costs are incurred.

Finally, it should be emphasized that usually one needs only to consider the changes in costs and benefits and need not be concerned with evaluating total costs and benefits. These incremental costs include production costs (such as outage time). When they are much greater than protection costs, they may well govern the decision. Similarly, other qualitative factors such as perception of risk may need to be considered, especially when the general public is affected.

The quantitative part of the optimization process needs to be supplemented by qualitative considerations. When significant costs are involved, and uncertainties in the quantitative evaluations are large, management may choose an option with less expected net benefit but greater assurance of success. In order to make the importance of uncertainties clear, it is generally helpful to provide management with a sensitivity analysis that reflects the probable range of uncertainty in the final cost-benefit or cost-effectiveness result, and that also reflects the sensitivity of the result to minor changes in important parameters or assumptions in the evaluation.

ARE WE THERE?

In attempting to answer the question - "Are the U.S. nuclear power plants operating in an ALARA manner?" comparisons with other countries are helpful. When we made them in 1984 (9) we found that the average collective occupational dose per reactor per year during the five year period 1978-1982 varied from about 6.8 Sv/yr for U.S. plants to about 0.5 Sv/yr for Finnish plants. Approximate collective doses for other countries were: Japan 6 Sv/yr, F.R. Germany 5.6 Sv/yr, the Netherlands 3.1 Sv/yr, Switzerland 2.5 Sv/yr, Canada 1.8 Sv/yr, France and Sweden each 1.2 Sv/yr, and the United Kingdom 1.8 Sv/yr. This comparison seems to indicate that either the collective doses at the U.S. plants were not ALARA or some other countries may have spent resources beyond those which would have been justified to achieve the ALARA objective. It is also possible that other factors, such as safety precautions to prevent major accidents, a more dose intensive regulatory climate, or differences in plant selections and design philosophy may have had major impacts. For example, recent studies indicate that NRC-initiated multi-plant actions (safety related precautions) accounted for 40% of typical U.S. plant doses during the period 1979-1983 (10). Since 1983 U.S. collective doses have been reduced by about 40% to about 4.8 Sv/yr per plant as these backfits have been completed.

Decisions made at the design stage can be especially important and cost effective. For example, the standardized plant designs in France (which has a government owned electric generating system) have permitted greater emphasis on the design and use of remote tooling, automation in refueling, and intensive training of highly specialized maintenance and refueling crews. Also, Swedish plants have many more shielded compartments for pumps, valves and other equipment likely to be highly radioactive. This design philosophy leads to lower dose rates during maintenance and less need for use of temporary shielding and the dose required for its installation and removal. This and other design features lead observers to class the Swedish plants as "gold plated". However, a comparison of capital costs for plants in various countries shows that U.S. capital costs in the 1970 to 1980 period increased from 1.4 times to 3.5 times the costs for Swedish plants of comparable size. Thus, any additional cost for dose control in them seems to have been relatively small. However, since U.S. plants may be handicapped with less effective plant lay-out or design, comparisons with other countries is not sufficient to judge if the present mix of plants in the U.S. are operating ALARA. Each plant must be considered in light of its present configuration, shielding, space limitations, cobalt and nickel content of primary system components, provisions for remote operations, etc. Until this is done, an unequivocal answer to the question cannot be given.

ASSESSING ALARA

Most plants have implemented the basic elements of an ALARA program (11). These elements have been clearly spelled out in NRC Regulatory Guides 8.8 (7), 8.10 (12) and NUREG-0761 (13), and were recently discussed by Dionne (14). He suggests the following be emphasized: a policy statement, definition of responsibilities, an ALARA Committee, suggestion system, job reviews, design audits, procedure and facility reviews, reports to management, special equipment, and training. The effort that is justified for each element depends on collective dose at the plant and other factors, such as plant design, operational problems, and worker qualifications.

In order to ensure that a plant is at or near the ALARA optimum, I believe a detailed ALARA study is needed. It should include: (a) an appraisal of the plant in terms of the elements of an effective ALARA program and, (b) a detailed listing and evaluation of the cost effectiveness of various possible engineering, design, and major operational changes that could be made to reduce doses.

With reference to job reviews and planning, an inventory of high-dose jobs based on data collected at 19 U.S. plants has been given (11). Tables 1 and 2 list jobs involving greater than 0.01 Sv/yr collective dose for PWR and BWR plants, respectively. These jobs have been defined and effective dose-control techniques applicable to each have been listed in related dose-reduction data sheets (11). Data sheets such as these should be a part of the work package typically used in planning high-dose jobs. When appropriate, simple cost-benefit calculations should be used to optimize these jobs during job planning.

The suggested listing of engineering, design, and major operational changes which could be made to reduce doses could be developed using items in the publication "Compendium of Cost-Effectiveness Evaluations of Modifications for Dose Reduction at Nuclear Power Plants" (15). A few of the over 150 evaluations presented in that publication are shown in Table 3. These were considered exceptionally cost effective, since savings in both costs and dose were expected. Many other modifications with cost-effectiveness <\$100,000/person-Sv (<\$1,000/person-rem) were also identified (e.g. see Table 4 which is discussed below). However, a plant-specific list should be developed for each plant which would be expected to include many items not included in the BNL study. For example, optimum use of shielding, mock-up training, primary system chemistry, filter change-out, use of remote monitoring and surveillance and full system decontamination need additional study. These studies should lead to a list of possible actions which could be prioritized in terms of cost-effectiveness (\$/person-Sv), benefit/cost ratio, net benefit, and total possible dose savings. The list would be a dynamic one which would need continued updating as new possibilities become available or as plant conditions change.

COMMENTS ON QUANTITATION

Both collective doses and costs of dose control are sufficiently large at most U.S. nuclear power plants so that quantitative cost-benefit or cost-effectiveness evaluations can be justified. Cost-benefit calculations differ from cost-effectiveness in that a monetary value for collective dose is required to complete a cost-benefit calculation, whereas in cost-effectiveness calculations the ratio of net capital and operational costs (the numerator) compared to the value of net collective dose savings (the denominator) can be used to obtain cost-effectiveness in terms of net costs per unit dose saved.

The latter value can then be used to rank or prioritize items as well as to compare results to the monetary values of detriment considered appropriate at the plant, or to values appropriate for the crews most likely affected.

Once a list of prioritized dose-reduction modifications has been established, it can be used to aid in decisions on design or modification. However, it usually is not the only factor to be considered. For example, Table 4 shows additional examples of results of cost-effectiveness evaluations which were given in Reference 15. These results have been arranged in order of decreasing cost-effectiveness, based on results of the "Present Worth D" model (column 2 in Table 4). This was only one of five econometric models used in the study and the results for the other models are also given in Reference 15. The ranking turns out to be rather insensitive to which cost-effectiveness model is used. However, cost-effectiveness values differ by approximately an order of magnitude from low values for the "Basic Model" to high values for the "Revenue Requirements Model B", with results shown here intermediate between them. Each model has its use. However, the Present Worth D model is generally preferred and includes discounting of both future costs and doses.

Other criteria which may be used to rank options include net dollars saved per dollar invested (column 3 in Table 4), net dose saved per dollar invested (column 6 in Table 4), and net benefit in $1000s (column 7 in Table 4). The two criteria which are based on dollars invested would be important if decisions were being made on capital budgets or expenditures. The plant manager may tend to be more concerned with dollars saved, whereas, the radiation protection manager would be more interested in dose savings. Although the two criteria give very similar rankings for the items listed, this need not be the case. For example, if outage costs or savings are involved, the dollars saved could change markedly while dose saved would likely be affected much less or not at all. The last criterion, net-benefit, which is listed in column 7 of Table 4, is least useful since it does not reveal anything about amount invested.

If the cost-effectiveness value is less than the valuation of detriment ($/person-Sv) for the plant, the item is justifiable from an ALARA criterion, provided no other more cost-effective option is possible. However, even when highly cost-effective options have been identified, their immediate implementation may not be possible due to budget limitations or other constraints. In these cases, attempts should be made to remove these limitations in the future.

SUMMARY

The ALARA concept in radiation protection includes both qualitative and quantitative considerations. In order to assess the adequacy of ALARA efforts one needs to review organizational, operational and design aspects of a nuclear power plant. While the organizational and operational aspects of the ALARA program tend to be qualitative, the design and some operational aspects are necessarily quantitative. The quantitative efforts which are justified depend on collective doses involved and the costs involved in their control or reduction. To assess the appropriateness of the ALARA efforts, detailed and quantitative studies of possible design and operational changes are needed to provide management with a periodically updated listing of possible improvements, their estimated costs, potential dose savings, cost effectiveness and benefit/cost ratios as well as periodic re-evaluations of the valuation of detriment that is appropriate at the plant.

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Table 1 PWR Repetitive High-Dose Jobs

Rank	Job Title	Average man-rem/yr (Westinghouse Plants)
1	Snubbers, Hangers, and Anchor Bolts Inspection, and Repair	110
2	Steam Generator Eddy Current Testing	50
3	Reactor Assembly/Disassembly	48
4	Steam Generator Tube Plugging/Sleeving	47
5	In-Service Inspection	46
6	Plant Decontamination	45
7	Primary Valve Maintenance and Repair	30
8	Scaffold Installation/Removal	30
9	Insulation Removal/Replacement	18
10	Reactor Coolant Pump Seal Replacement	17
11	Steam Generator Manway Removal/Replacement	16
12	Instrumentation Repair and Calibration	12
13	Secondary Side of Steam Generator Inspection and Repair	11
14	Chemical, Volume, and Control System Repair and Maintenance	11
15	Fuel Shuffle, Sipping, and Inspections	9.2
16	Operations-Surveillance, Routines, and Valve Lineups	7.4
17	Cavity Decontamination	5.9
18	Pressurizer Valve Inspection, Testing, and Repair	5.5
19	Radwaste System Repair, Operation, and Maintenance	4.9
20	Residual Heat Removal System Repair and Maintenance	2.7

Table 2 BWR Repetitive High-Dose Jobs

Rank	Job Title	Average man-rem/yr
1	Snubber Inspection and Repair	290
2	Torus Repair, Inspection, and Modifications	260
3	In-Service Inspection	150
4	CRD Removal/Rebuild and Replacement	60
5	Primary Valve Maintenance and Repair	57
6	Scaffold Installation/Removal	57
7	Jet Pump Inspection and Repair	46
8	Insulation Removal and Replacement	44
9	Safety Valve Repair and Inspection	39
10	Plant Decontamination	37
11	Residual Heat Removal System Repair and Maintenance	34
12	Reactor Assembly/Disassembly	24
13	Operations-Surveillance, Routines, and Valve Lineups	24
14	Main Steam Isolation Valve Repair and Inspection	20
15	Fuel Shuffle, Sipping, and Inspection	19
16	Radwaste System Repair, Operation, and Maintenance	16
17	Instrumentation Repair and Calibration	15
18	TIP/SRM/IRM Calibration, Repair and, Maintenance	11
19	Recirculation Pump Seal Replacement	7.8
20	Turbine Overhaul and Repair	6.2
21	Refueling Pool Decontamination	4.4

Table 3 Exceptionally Cost Effective Modifications

PWR	Δ rem/yr	Cap. Cost	Lifetime Savings**
*Improved Refueling Machine	3	$225,000	$30,000,000
*Multi-Stud Tensioner	26	940,000	14,000,000
*Integrated Head Assembly (new plant)	4	75,000	13,000,000
SG Channel Head Decon	158	2,145,000	8,300,000
WEPA Cavity Decon System	2.4	89,000	4,300,000
Shredder - Compactor	10.5	450,000	3,000,000
*Quick Opening Hatch (new plant)	0.5	15,000	1,800,000
Remote Readout Near Seal Table	2	12,000	1,700,000
*Steam Generator Manway Tensioner	16.5	500,000	1,200,000
Photographic Technique for SG Tube Plugging Inspection	52	5,000	960,000
Robotic Inspection of PWR Ice Cond. Area	5.2	76,800	630,000
Solid Waste High Integrity Containers	1.7	150,000	570,000
Robotic Smoke Detector Inspection	1.6	20,000	28,000

BWR			
*WEPA Cavity Decon System	2.4	$ 89,000	$ 4,300,000
*Control Rod Drive Handling Tool	32	325,000	4,200,000
Shredder-Compactor	10.5	450,000	3,000,000
Solid Waste High Integrity Containers	1.7	150,000	570,000
Robotics Inspection of Moisture Separator & Feedwater Areas	23.3	65,900	550,000
Robotics Surveillance of High Pressure Feedwater Heater Rooms	1.3	20,800	78,000

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* Evaluation for these modifications included costs for replacement power.

** Based on present worth values discounted at 4%/year. $saved calculated using $100,000/person-Sv ($1,000/person-rem).

Table 4 Modifications with Positive Costs and Positive Dose Savings (15)

Project	Cost-Effectiveness* $/Person-Rem	Benefit/cost $Saved* / $Invested	K$ Invested	REM Saved (DISC.)	D.REM Saved* / K$Invested	K$* SAVED
BWR-CRD Hydrolazing	35	27	5.9	300(170)	29	$160
SG Head, Portable Shield	86	22	35	1,500(850)	24	$780
CVCS Shields	100	9.0	1.8	30(17)	9.4	$16
Clean Seal Water	110	9.2	33	600(340)	10	$300
PWR Level Monitor, N-16	120	7.4	16	240(140)	8.8	$120
Low Cobalt Coolant Pumps	120	7.5	35	560(300)	8.6	$260
Low Cobalt CRD Mechanism	140	6.3	59	810(430)	7.3	$370
Low Cobalt SG	140	6.3	349	4,700(2,500)	7.2	$2,200
Reactor Head Shield	180	24	1.9	88(55)	29	$45
Low Cobalt Fuel Nozzles	190	-	-	93(53)		$44
Low Cobalt Coolant Pump	200	4.0	35	320(170)	4.9	$140
Robotic Insp.of Ice Cond.	210	5.8	21	270(160)	7.6	$120
Manway Cover Equipment	230	3.4	6.5	45(28)	4.3	$22
Mock-Up Training, SG Jobs	270	19	63	2,900(1,700)	27	$1,200
Viewing Windows in BWRs	290	2.5	36	200(130)	3.6	$91
PWR Laydown Head Shield	310	2.2	16	90(52)	3.3	$36
CRD Decon. Tank	330	1.9	53	270(150)	2.8	$100
PWR Head Shield	330	2.0	185	890(560)	3.0	$370
CRD Electropolish Tank	340	1.9	58	300(170)	2.9	$110

* Based on present worth values discounted at 4%/year. $saved calculated using $100,000/person-Sv ($1,000/person-rem).