NUREG/CR-3665
SAIC-84/1317
Executive Summary

Optimization of Public and Occupational Radiation Protection at Nuclear Power Plants

Prepared by J. J. Cohen

Science Applications, Inc.

Prepared for
U.S. Nuclear Regulatory Commission

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Until recently decision makers on the Nuclear Regulatory Commission staff have had to evaluate proposals for new maintenance and inspection requirements at nuclear power plants without the benefit of quantitative comparisons between the risk potential averted by the new requirement and the occupational risk created at the same time. While it was fully recognized that the generation of quantitative information of high precision would not be possible, it was also recognized that improved analytical techniques for quantitative comparisons could contribute substantially to the decision making process. Therefore funding was requested for a research project to develop an appropriate technique, to document it, and to provide comprehensive supporting material which would enable users to understand its strenths and weakness and to evaluate the rationale on which it is based. The project was awarded to SAI, Inc., and it has, I believe, been very ably carried out by the SAI staff.

R E Alexander

Robert E. Alexander, Chief
Occupational Radiation Protection Branch
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OPTIMIZATION OF PUBLIC AND OCCUPATIONAL RADIATION PROTECTION AT NUCLEAR POWER PLANTS

Executive Summary

An area of growing concern in recent years has been the apparent increase in levels of collective radiation dose to workers at nuclear power plants in the USA. U.S. Nuclear Regulatory Commission (NRC) decisions and rulings related to in-service inspection, retrofits, and plant upgrades have been primarily intended to reduce the risk of public radiation exposure resulting from either routine release of radioactivity or potential accident situations. However, implementation of the required control measures and procedures can often result in increased levels of occupational radiation exposure. Recognizing the need to incorporate occupational dose into probabilistic risk assessments (PRA), value-impact, and cost-benefit analyses, the NRC has sponsored this study with the objective of developing an appropriate methodology to factor potential worker exposures into safety assessments. This report on the study is presented in three volumes. These are:

Volume 1 - "A Review of Occupational Dose Assessment Considerations in Current Probabilistic Risk Assessments and Cost-Benefit Analyses" by Peter R. Lobner,

Volume 2 - "Considerations in Factoring Occupational Dose into Value-Impact and Cost-Benefit Analyses" by Jerry J. Cohen, and

Volume 3 - "A Methodology for the Optimization of Occupational and Public Radiation Exposure for Nuclear Power Plants" by William H. Horton.

Volume 1 reviews value-impact analysis and probabilistic risk assessment methods, and discusses the manner and degree to which these methods consider potential occupational radiation exposure resulting from a variety of in-plant activities, including: normal operation and maintenance, repair, retrofit, minor incidents, major accidents, cleanup, and plant decommissioning. Value-impact analysis methods which include occupational exposure as an element of the value-impact equation have previously been suggested; however, no standard approach for analysis has been adopted. Comparison of the results of value-impact analyses must, therefore, be made with caution because different value-laden assumptions made by the analyst can have strong effects on the outcome. Such assumptions include the monetary equivalent of a person-rem, and the relative value of occupational and public exposure.

Probabilistic methods have been used in value-impact evaluations to quantify incremental or averted occupational exposure from reactor accidents; however, occupational exposure has not been addressed in probabilistic risk assessments (PRAs) of nuclear power plants to date. Consideration of occupational exposure in a PRA could greatly increase the complexity of the plant model, and the benefits from such an analysis are uncertain. In lieu of expanding the scope of PRAs to address occupational risk, the separate, limited-scope probabilistic evaluations developed for value-impact analysis would provide a practical analytical capability to determine the optimization of occupational and public radiation exposure.

ALARA guidance for optimization of radiation exposures to the general public also requires consideration of relevant social and economic factors. Clearly, any resultant increase in occupational dose should be included in such assessments. However, since review of previous PRA's and cost-benefit analyses indicates that this has not generally been the case in the past, a consistent methodology is required. Even in those cases where occupational dose has been considered, it has seldom been done in a quantitative and analytical manner. Examples are noted where the implementation of decisions intended for reduction of public dose actually results in collective occupational dose levels exceeding the averted public collective dose.

Volume 2 reviews considerations for factoring occupational radiation dose into risk assessment and derives a methodology for factoring occupational dose into cost benefit analyses. The related issues include: evaluation of occupational vs. public radiation exposure, stochastic vs. non-stochastic effects, probabilistic risk considerations, uncertainty, and de minimis dose levels.

A suggested formulation for determination of total or net detriment (CD_n) for input to cost-benefit analysis is:

$$CD_n = \left[(p \cdot CD_p^{\alpha}) + q(p \cdot CD_o^{\alpha}) \right] i,j....$$

where:

CD_p = Public collective dose (man-rem)

CD_o = Occupational collective dose (man-rem)

p = Probability of occurrence

α = Risk aversion factor

i,j = Alternative states

q = Equivalence factor

and:

$$q = \frac{\text{Value per unit of occupational collective dose averted}}{\text{Value per unit of public collective dose averted}}$$

The risk aversion factor (α), as suggested by previous NRC safety goals studies, provides a means of scaling societal aversion to high consequence risks and incorporating such aversion into calculational models. The occupational dose equivalence factor (q) relates the value of occupational to that of public dose. Various arguments for setting the value of q equal to, greater than, or less than unity are reviewed and discussed. The imputed values of the risk aversion and occupational dose equivalence factors must, to a large extent, be determined on a subjective basis and require the judgment of regulatory authorities.

Certain other factors required for cost-benefit analyses involving optimization of radiation exposures also involve subjective evaluation. These include: a possible "discount" factor (i) for determination of present value of future radiation dose; an equivalence factor (f) relating the relative value of averting stochastic and non-stochastic effects; and finally, the cost effectiveness guideline (Cg) which establishes a monetary equivalent for collective dose aversion. Those factors requiring subjective evaluation are discussed and previous efforts to establish their values are reviewed. A summary of the range of previous recommendations and suggested first approximations is given in Table 1.

Table 1

COST-BENEFIT ANALYSIS FACTORS REQUIRING SUBJECTIVE DETERMINATION

Factor	Definition	Range of Previous Recommendations	Suggested First Approximation
α	Risk Aversion Factor	1 - 3	1.2
q	Occupational Dose Equivalence Factor	0 - 10	1.0
i	Discount Factor	0 - 0.1	0
f	Collective Dose (man-rem) Equivalent for Non-Stochastic Effects (Early Deaths)	$5 \times 10^3 - 1.5 \times 10^5$	2.5×10^4
Cg	Cost Effectiveness Guideline (\$/man-rem)	\$10 - \$1000	\$100

The methodology presented in Volume 3 of the report provides a tool for the assessment of candidate NRC guidance and licensing decisions. For purposes of explanation, simplifying assumptions for measurement of detriment for inclusion in cost-benefit analysis are made. The measure is in terms of dollars and includes occupational and public dose detriment as well as monetary costs. The methodology incorporates many previously developed dose and risk analysis methods. In the current study, detailed methods are developed for assessing the impact of inspection and testing on safety system availability. An example application of the methods is performed which deals with steam generator tubing inspection frequency.

The methods incorporate closed-form solutions to detailed Markov models of a system composed of two redundant legs with some common piping, and of a component which undergoes a sequential failure process. The system model can also be used to evaluate simple serial and redundant systems. The models also provide a detailed treatment of possible operator errors. Expansion of the model to cover maintenance activities could be accomplished with minimum effort. The sequential failure Markov model evaluates components which have observable degraded states prior to failure. This would cover degradations like piping leakage prior to rupture and pump vibration prior to seizure.

The steam generator inspection example is presented to illustrate the impact of tube inspection on the likelihood of tube rupture using the sequential failure Markov model. This example evaluates the optimum inspection intervals for tubing which would yield the minimum cost and the minimum total dose to the public and plant personnel. Results in the example indicate that a five year inspection interval would minimize total dose (assuming equivalent value for occupational and public dose aversion) and that a two year inspection interval would minimize the total cost including dose detriment. Optimization is controlled by the costs and doses associated with steam generator inspection and repair but not by initial accident costs and doses. The evaluation also does not consider tube leakage prior to rupture.

In applying the methods presented in Volume 3 it is important to realize that the information obtained in the process is only one input into a decision process. These models and the required data bases are not intended to represent reality beyond what is necessary for decision making. The cost values obtained for a specific evaluation are not intended to represent actual costs. The objective of the analysis is to come as close to reality as is practical. However, the methodology is developed to provide a comparative tool for measuring alternatives. It is the comparative nature of the methodology that allows for simplification and utilization of an incomplete data base.

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An area of growing concern in recent years has been the apparent increase in levels of collective radiation dose to workers at nuclear power plants in the USA. U.S. Nuclear Regulatory Commission (NRC) decisions and rulings related to in-service inspection, retrofits, and plant upgrades have been primarily intended to reduce the risk of public radiation exposure resulting from either routine release of radioactivity or potential accident situations. However, implementation of the required control measures and procedures can often result in increased levels of occupational radiation exposure. Recognizing the need to incorporate occupational dose into probabilistic risk assessments (PRA), value-impact, and cost-benefit analyses, the NRC has sponsored this study with the objective of developing an appropriate methodology to factor potential worker exposures into safety assessments. This report on the study is presented in three volumes. The following are subtitles for Volumes 1-3: Volume 1, "A Review of Occupational Dose Assessment Considerations in Current Probabilistic Risk Assessments and Cost-Benefit Analyses," Volume 2, "Considerations in Factoring Occupational Dose into Value-Impact and Cost-Benefit Analyses," and Volume 3, "A Calculation Method."

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