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Compendium of Cost-Effectiveness Evaluations of Modifications for Dose Reduction at Nuclear Power Plants

Prepared by J.W. Baum, G. R. Matthews

Brookhaven National Laboratory

**Prepared for
U.S. Nuclear Regulatory
Commission**

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ABSTRACT

This report summarizes available information on cost effectiveness of engineering modifications potentially valuable for dose reduction at nuclear power plants. Data were gathered from several U.S. utilities, published literature, equipment and service suppliers, and recent technical meetings.

Five simplified econometric models were employed to evaluate data and arrive at a value for cost effectiveness expressed in either (a) dollars/rem, or (b) total dollar savings calculated using a nominal value of $1,000/rem. Models employed were: a basic model with no consideration given to the time value of money; two models in which discounting was used to evaluate costs and savings in terms of present values; and two models in which income taxes and revenue requirements were considered. Results from different models varied by as much as a factor of 10, and were generally lowest for the basic model and highest for the before-tax revenue requirements model.

Results for 151 evaluations employing different assumptions concerning number of plants per site and outage impacts were tabulated in order of decreasing cost effectiveness. Twenty-five evaluations were identified as exceptionally cost effective since both costs and dose were saved. Forty evaluations indicated highly cost-effective changes based on costs below $1,000/rem saved using results of the present-worth model that included discounting of future dose savings.

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PREFACE

This report is the result of research performed for the United States Nuclear Regulatory Commission, under NRC FIN A-3708, to identify potentially cost-effective methods of dose reduction at nuclear power plants, gather data on promising techniques, and evaluate their cost effectiveness.

Data for this report were gathered from published literature, visits to several U.S. nuclear power plants, information presented at recent technical meetings, and vendors of nuclear equipment and services.

Since each plant is unique in terms of radioactive contamination levels in systems, amount of shielding, equipment layout, capital formation, organization, and various operational costs, it should be clear that the results presented here are illustrative only; i.e., plant-specific evaluations are needed to judge effectiveness at any specific site. Sample calculations have been provided to demonstrate cost-effectiveness evaluation methods and to facilitate plant-specific evaluations.

This study shows that many modifications with high potential for being cost effective have been proposed or implemented at some plants. It is hoped that this compendium will draw attention to these and stimulate their further study, evaluation, and, in some cases, implementation. It is also hoped that users of this document will comment on it and provide new data on modifications mentioned, as well as data on other modifications so that the compendium may be updated and expanded in the future. A form that may be copied and used for this purpose is provided on the next page.

DOSE-REDUCTION MODIFICATION DESCRIPTION

Title: ____________________

Contributed by: ____________ Affiliation: ____________
Address: ____________ Phone: ____________

Description: ____________________

Capital Costs Including Materials and Installation: $( )
in 19__ dollars.

Annual labor savings (or costs)* = ______
Annual materials savings (or costs)* = ______
Annual maintenance savings (or costs)* = ______
Annual replacement power savings (or costs)* = ______
Annual waste disposal savings (or costs)* = ______
Other savings (or costs)* = ______
Dose to install = ______
Annual dose saved = ______
Useful life = ______

*Use negative sign or parentheses for costs

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Raymond Crandal (James McHugh)	Northeast Utilities Service Co.
Bruce Dionne	Brookhaven National Laboratory
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Chris Wood	Electric Power Research Institute

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Compendium of Cost-Effectiveness
Evaluations of Modifications for
Dose Reduction at Nuclear Power Plants

SUMMARY

Data were gathered on 151 variations of modifications (not all applicable to any one plant) having potential for dose reduction in nuclear power plants. These data were evaluated for cost effectiveness expressed in $/rem using five simplified econometric models: (1) a basic model in which no account was taken of taxes, inflation, or the costs of borrowing money; (2) a present-worth model in which "real" interest and discount rates were used to arrive at capital and future operational costs expressed in 1984 dollars; (3) a discounted rem present-worth model D, similar to the present-worth model, but in which values of future rem savings were also discounted; (4) an after-tax revenue-requirements model A, which reflected after-tax cash flows; and (5) a before-tax revenue-requirements model B, which reflects before-tax cash flows.

Results of these analyses are summarized in Tables 3.1 through 3.3, which list those results that are exceptionally cost effective, effective, and not cost effective, respectively. In the first two tables, results are listed in order of decreasing cost effectiveness based on evaluations using the discounted rem present-worth model D.

Twenty-five evaluations were found to be exceptionally cost effective in that both costs and collective dose (rem) were saved. These items are listed below and in Table 3.1. Several of these were for similar modifications at different sites. Using a nominal value of $1,000 as the value of a rem saved, the predicted values for total dollars that should be saved over the expected useful life of the modification were:

EXCEPTIONALLY COST-EFFECTIVE MODIFICATIONS

PROJECT NAME	PROJECT DESCRIPTION	DISCOUNTED REM PRESENT-WORTH MODEL D TOTAL $ SAVED (@ $1,000/REM)
DU-82-13*	PWR Refueling Machine (New Plant, on Critical Path)	$32,000,000
LO-83-03B*	PWR Reactor Vessel Head Multi-Stud Tensioner/Detensioner (Two Reactor Site, on Critical Path)	$29,000,000
LO-83-03A*	PWR Reactor Vessel Head Multi-Stud Tensioner/Detensioner (Single Reactor Site, on Critical Path)	$14,000,000
DU-82-12*	PWR Integrated Head Assembly (New Plant, on Critical Path)	$13,000,000
DU-82-11*	Multi-Stud Tensioners/Detensioners for PWR Reactor Pressure Vessel (on Critical Path)	$13,000,000

IJ-83-01	PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)	$9,400,000
PD-83-01A	Steam Generator Channel Head Decontamination (Not on Critical Path)	$8,300,000
WA-84-02*	Reactor Cavity Decontamination Using the WEPA Cleaning System	$4,300,000
AI-80-04B*	BWR Control-Rod-Drive-Handling Tool (on Critical Path 25% of Time)	$4,200,000
PI-83-01*	PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)	$4,100,000
PH-83-01*	PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)	$3,500,000
DU-83-01	Shredder-Compactor for Dry Active Waste	$3,000,000
WH-84-06A	Robotics System for Remote Inspections of BWR Moisture Separator and Feedwater Pump Areas (Three Reactor Site)	$1,800,000
DU-82-06*	PWR Quick Opening Fuel Transfer Tube Closure (New Plant, on Critical Path)	$1,800,000
WH-84-02	Remote Readout Near PWR Seal Table	$1,700,000
PF-83-01B*	PWR Steam Generator Manway Tensioner/Detensioner and Handling Device (on Critical Path 25% of Time)	$1,200,000
PA-77-01	Photographic Technique for PWR Steam Generator Tube Plugging Inspections	$960,000
PG-83-01*	PWR Steam Generator Manway Tensioner/Detensioner	$820,000
WH-84-01	Robotic Inspection of PWR Ice Condenser Area	$630,000
PB-82-01	Solid Radioactive Waste Handling Using High Integrity Containers	$570,000
WH-84-06B	Robotics System for Inspections in BWR Moisture Separator and Feedwater Areas (Single Reactor Site)	$550,000
WH-84-07A	Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Three Reactor Site)	$280,000
WH-84-05B	Portable Robotic System for Smoke Detector Inspection (Three Reactor Site)	$200,000
WH-84-07B	Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Single Reactor Site)	$78,000

WH-84-05A	Portable Robotics System for Smoke Detector Inspection (Single-Reactor Site)	$28,000

*Evaluations for these modifications included costs for replacement power.

All other items considered had positive costs. For those with net costs and positive values of expected dose savings, a $/rem value of cost effectiveness is employed to permit easier selection of items above or below the $/rem value which may apply at a given plant. If all personnel are well below their annual dose limits, one might, for example, wish to identify all items having cost-effectiveness values below a few hundred 1984 dollars/rem (see Reference 2 in Section 1.4); whereas, if the item affects individuals who are near their annual dose limits, hiring and training new workers may cost several thousands of dollars per additional rem predicted, leading to a proportionately higher $/rem cut off.

Forty items with cost-effectiveness values at or below $1,000/rem based on the discounted rem present-worth model were identified. These were:

COST-EFFECTIVE MODIFICATIONS

PROJECT NAME	PROJECT DESCRIPTION	DISCOUNTED REM PRESENT-WORTH MODEL D $/REM
AI-80-02	BWR-CRD Scram Discharge Line Flange for Hydrolazing the Header	35
AI-80-21	Portable Shielding System for the PWR Steam Generator Channel Heads	86
LO-83-01B	Shielding for CVCS Demineralizers (Option B)	100
AI-80-07	Clean Seal Cooling Water Supply for BWR Recirculation Pump	110
DU-82-08	PWR Power Level Monitor Using ^{16}N Detectors	120
BE-82-01E	Cobalt Replacement in PWR Reactor Coolant Pumps (Three-Loop Operating Plant, Pumps Replaced for Other Reasons)	120
LO-83-01A	Shielding for CVCS Demineralizers (Option A)	120
YO-82-01A	Replacement of PWR Steam Generators with Low-Cobalt (<0.03%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	120
BE-82-02E	Replacement of PWR Control-Rod-Drive Mechanisms with Low-Cobalt Parts (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	140

BE-82-06E	Replacement of PWR Steam Generators with Those Having Low-Cobalt (0.015%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	140
BE-82-02F	Replacement of PWR Control-Rod-Drive Mechanisms with Low-Cobalt Parts (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	140
YO-82-01B	Replacement of PWR Steam Generators Using Low-Cobalt (<0.03%) Tubing (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	150
BE-82-06F	Replacement of PWR Steam Generators with Those Having Low-Cobalt (0.015%) Tubing (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	170
EG-84-02A	Temporary Shielding for PWR Reactor Vessel Head	180
DU-85-01	Low-Cobalt Specifications for PWR Fuel Assembly Nozzles (New Plant)	190
BE-82-01F	Cobalt Replacement in PWR Reactor Coolant Pumps (Four-Loop Plant, Pumps Replaced for Other Reasons)	200
WH-84-03	TV Robot Inspection of PWR Vessel Head (Single-Reactor Site)	210
DU-82-01	Reduce Cobalt Impurity in New PWR Steam Generator Tubing (Sizewell 'B' Plant)	230
EG-84-04	Handling Equipment for PWR Steam Generator Manway Covers	230
JA-83-01	Mock-Up Training for PWR Steam Generator Jobs	270
AI-80-15	Installation of Viewing Windows in BWR Plants	290
DU-82-03	PWR Reactor Pressure-Vessel Head Laydown Shield	310
AI-80-05	BWR Control Rod Drive Disassembly and Decontamination Tank	330
EG-84-02B	Permanent Shield for PWR Reactor Vessel Head (Three-Reactor Site)	330
AI-80-06	Electropolishing Tank for BWR Control Rod Drives	340
EG-84-07	Relocation of Instrument Readout at PWR Spent-Fuel Pit Heat Exchanger	350
AI-80-19	Helium Leak Detection for BWR Condenser Tubes	350
AI-80-16	Relocation of Fuel Sipping Cans	420

EG-84-03B	Shielding for PWR Reactor Upper Internals (Two-Reactor Site)	570
EG-84-06	Ultrasonic Testing of PWR Pressurizer Surge Line (Three-Reactor Site)	610
PL-84-01B	PWR Reactor Vessel Head Shielding (No Critical Path Expense)	620
DU-82-05	PWR Steam Generator Tube Inspection and Repair Robot	630
AI-80-12	BWR Pipe Insulation Improvements for In-Service Inspections	650
PC-82-01	TV Monitor for BWR Cleanup Heat Exchanger Room	670
AI-80-04A	BWR Control Rod Drive Handling Tool	780
PL-84-01A	PWR Reactor Vessel Head Shielding (On Critical Path)	860
AI-80-11	Acoustic Emission Instrumentation for ISI of the Reactor Vessel and Reactor Coolant Piping	900
PE-83-01	Decontamination of a BWR Recirculation System	910
AI-80-01	Air-Cooled Anticontamination Suit, Radio Dosimetry, and Radio Communications	950
EG-84-03A	Shielding for PWR Reactor Upper Internals (Single-Reactor Site)	1,000

Thirty-five items were identified with cost-effectiveness values between \$1,100/rem and \$5,000/rem based on present-worth model D evaluations. These are probably cost effective for many plants. Thirty-eight items were of questionable cost effectiveness with \$/rem values >\$5,000/rem. Finally, 13 items were not considered effective since predicted costs and doses were both increased. These items are listed in Table 3.3.

Those modifications with greatest potential for dose savings were:

- chemical decontamination of BWR primary systems, 4,400 to 6,200 predicted rem savings during plant life depending on whether fuel is in place or not;
- steam generator replacement with generators having < 0.015% cobalt in tubes, 1,600 to 5,500 predicted rem savings during plant life depending on operating or new plant;
- decontamination of steam generators, 100 to 3,600 predicted rem savings per decontamination depending on initial dose rates;
- magnetic filtration of primary system water, 3,300 predicted rem savings during plant life;
- mock-up training for steam generator jobs, 2,900 predicted rem savings during plant life; and

- steam generator tube inspection and repair robot, 2,200 predicted rem savings during plant life.

A comparison of results shown for different models in Tables 3.1 through 3.3 reveals a factor of 5 to 10 difference between $/rem values for the basic model (usually the lowest values) and the before-tax revenue requirements model (highest values). Results for the discounted rem present-worth model, which is used for priority rankings (and includes discounting of both future costs and future rem savings), were generally larger than those for the basic model by a factor of about 1 to 2 and lower by a factor of about 5 than results for the before-tax revenue requirements model. For purposes of radiation protection, the discounted rem present-worth model seems most appropriate since in this model the present value of money is considered for both operational costs and the value of future rem savings, but taxes and interest on borrowed money are not included.

1. INTRODUCTION

The National Council on Radiation Protection and Measurements (NCRP) (1), the International Commission on Radiological Protection (ICRP) (2,3), and the Nuclear Regulatory Commission (NRC) (4-9) have all urged a policy of radiation protection relying not only on dose limits but also on keeping doses "as low as reasonably achievable" (ALARA). The degree of dose reduction which is reasonably achievable depends on benefits, costs, and optimization of expenditures for dose reduction (2,3,10). Thus, an effective ALARA program at nuclear power plants should include consideration of both costs and achievable dose reductions. A number of high-dose maintenance tasks known to contribute significantly to plant collective doses (11) these include steam generator manway cover removal and replacement, eddy current testing and repairs of steam generator tubing, reactor refueling operations, and maintenance on reactor coolant pumps and valves. New equipment is being designed for new plants and retrofitted to some existing plants. These changes are expected to yield large reductions in collective dose. However, additional data and analysis are needed to demonstrate the cost effectiveness of many of the available options.

1.1. Objectives

The objectives of this program were to gather data on recently proposed or implemented modifications with potential for dose reduction, to examine analytical models currently being employed for cost-effectiveness evaluations, to perform evaluations of proposed modifications, and to rank the results according to priorities.

1.2 Approach

Data on costs and effectiveness of engineering modifications were obtained from published reports, plant visits, and other sources cited in Section 5. Cost-effectiveness evaluations methods employed at utilities and proposed by various authors (12-15) were examined and simplified to arrive at models described in Section 2. These models were then used with an IBM PC computer and spread-sheet program (Symphony from Lotus) to develop cost-effectiveness values for each modification.

The economic models employed here are in some cases unique (or, to the authors' knowledge, not currently employed in their exact form). However, they are based on commonly employed models and principles. Since conclusions regarding cost effectiveness are influenced by the $/rem value used in any analysis, results are expressed as a ratio of cost in 1984 dollars to collective dose saved (in rem). This permits easy comparison to any $/rem value which happens to be employed at a given time and by a given organization.

The $/rem ranking of the cost-effective modifications is not correct for the projects with negative values. Negative values result when either the numerator of the ratio is negative, because operational savings exceed capital costs, or when the denominator is negative because net dose savings are negative. If the ratio is negative because the numerator (total cost) is negative, a highly desirable and exceptionally cost-effective case is indicated. However, when the denominator is negative, there is not only no dose savings but the modification would cause an increase in dose and thus would be very undesirable from a cost-effectiveness point of view. For this reason, the exceptionally cost-effective modifications and those with negative dose savings have been rank ordered in terms of total dollars saved instead of $/rem.

It is interesting to note, however, that if both the numerator and denominator are negative, the ratio is an acceptable measure of cost ef ectiveness. Thus, even though doses are increased for negative denominators, the dollar savings may be sufficient to justify the increase. However, no examples of this were found.

It was also considered important to compare the results from several models to illustrate the range of possible outcomes and to aid in understanding the importance of various parameters and assumptions.

At the present time, there seems to be no consensus on the best model for evaluating modifications for purposes of dose control at ALARA levels. Mann (14) has recently reviewed the principles of cost effectiveness and optimization in radiation protection. His work and the ICRP document on optimization (15) are recommended for more detailed discussions of methodologies, their applications, and limitations.

1.3 Organization of Report

Since a large number of modifications and variations were studied, the material has been organized in Sections 3 and 4 by author or source of information. Each evaluation has a three-part alpha-numeric designation. The first two letters are determined by the author's last name or plant code (PA, PB, etc. for plant A, plant B, etc.). The next two numbers indicate the year the original data were published or produced, and the last set of characters identifies the item for correlation with results expressed in the summary table and for purposes of indexing. Thus, BE-82-04B is based on data in a report by Bergman published in 1982. The number 4 refers to a fourth modification considered from his data, and B refers to an alternative (in this case 4-loop vs 3-loop plant) of that modification.

The project names have PWR or BWR in the title to facilitate identification of dose-reduction modifications for each reactor type. Dose-reduction modifications applicable to both reactor types have no such designation in their titles.

Results of the cost-effectiveness evaluations (expressed to two significant places) are listed in Tables 3.1 through 3.3.

Authors and sources of information used in Section 4 are identified in Section 5. In the subject index, items are referred to by the alpha-numeric index, since this facilitates indexing of future additions to the compendium.

1.4 REFERENCES FOR SECTION 1

1. National Bureau of Standards Handbook 59, Recommendations of the National Committee on Radiation Protection, Permissible Dose From External Sources of Ionizing Radiation, September 1954. ICRP 2

2. ICRP Publication 22, A Report of ICRP Committee 4, Implications of Commission Recommendations that Doses be kept as Low as Readily Achievable. Adopted by the Commission in April 1973.

3. ICRP Publication 26, Annals of the ICRP, Recommendations of the International Commission on Radiological Protection, Pergamon Press, New York 1977.

4. U.S. Nuclear Regulatory Commission Regulatory Guide 8.8, Revision 3, Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be as Low as Is Reasonably Achievable, June 1978.

5. U.S. Nuclear Regulatory Commission Regulatory Guide 8.10, Revision 1-R, Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as is Reasonably Achievable, September 1975.

6. U.S. Nuclear Regulatory Commission Regulatory Guide 8.18, Revision 1, Information Relevant to Ensuring That Occupational Radiation Exposures at Medical Institutions Will Be as Low as Reasonably Achievable, 1982.

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14. Mann, Bruce J., Cost-Benefit Analysis as a Decision Tool for Occupational Radiation Protection, Radiation Protection Management, Jan. 1984, pp.51-64.

15. ICRP Publication 37, Cost-Benefit Analysis in the Optimization of Radiation Protection, Annals of the ICRP Vol.10, No.2/3, Pergamon Press, 1983.

2. COST-EFFECTIVENESS MODELS

Five mathematical models were developed for evaluation of cost effectiveness of engineering modifications intended for dose reduction. These models were developed to illustrate the sensitivity of results to different assumptions frequently employed, and to yield results of interest to different users.

2.1 ASSUMPTIONS

In each model, capital and operational costs in 1984 were estimated from original data by increasing estimated costs by 8%/yr compounded from base year costs employed in the original studies. For most studies, the base year costs were estimated for years 1979 through 1984. During this time, inflation decreased from about 8%/yr to about 4%/yr during 1983 and 1984. However, a constant inflation factor of 8%/yr was employed in these studies to reflect an inflation in nuclear costs during the past few years perceived to be greater than that of the consumer price index. Additional adjustments for inflation may be needed if these results are to be applied in future years.

In the economic analyses, data on capital, labor, material, training, maintenance, overhead, replacement power, waste disposal, and tax costs were sought. Also, information on dose to install, annual dose saved, and amortization period were obtained when possible. When data were not available, cost values were usually set to zero and 30 years was used for the amortization period. In some cases, values for maintenance costs were estimated here even though they were neglected in the original analysis. This was done in an attempt to put all evaluations on a nearly comparable basis. All costs included in an analysis have been stated, thus allowing comparisons with original analyses.

Since dose rates and collective doses increase as plants age, estimated dose savings are generally based on averages over the amortization period assumed for the modification. All results are affected by the assumed amortization period and must be adjusted if other periods are more appropriate.

2.2 BASIC MODEL

A basic model, containing the elements commonly used in most analyses, is often employed in which capital costs, annual operating costs, dose to install, and annual dose savings are considered. However, no consideration is given to the time value of money, interest on capital costs, or taxes. Cost effectiveness is calculated in terms of net cost in dollars per net savings in collective dose equivalent (rem).* The results from this model are obtained from Eq. (1):

$$\text{Basic} = F(C - A_o\, n) \;/\; (nD_2 - D_1), \text{ dollars/rem} \qquad (1)$$

$$F = (1 + I)^Y,$$

*Collective dose equivalent has been defined in ICRP Pub. 26 and has units of Sieverts (1 Sv = 100 rem). While common practice in the U.S. is to express collective dose equivalent in units of man-rem, rem (the less redundant and more nearly correct unit) will be employed in this report.

where

- F is inflation factor (to convert to 1984 dollars);
- C is capital cost in base year (year of original estimate);
- A_o is the sum of annual savings due to the sum of labor, material, training, maintenance, overhead, waste disposal, and replacement power costs (in base year);
- n is number of years over which equipment will be amortized and annual savings will be summed;
- D_1 is dose to install in rem;
- D_2 is annual dose savings in rem per year;
- I is assumed inflation rate (estimated at 8%) between base year and 1984; and
- Y is number of intervening years between base year and 1984.

Values for the factors for various inflation rates and years are listed in Appendix A. The inflation factor is often neglected in making a preliminary estimate using the basic model.

Example: Consider modification DU-83-01 Shredder-Compactor for Dry Active Waste on page 81. Capital cost C was $450,000 in 1983. Inflation factor F = 1.08 from Appendix A for 1 year inflation at 8%.

Annual operating savings A_o:

Labor savings	=	$39,000/yr
Disposal Savings	=	$177,600/yr
Maintenance (cost)	=	-$22,500/yr

A_o = Net operational savings = $194,100/yr
For n = 25 yr, D_2 = 10.5 rem/yr and D_1 = 0 rem

$$\text{Basic} = \frac{1.08\ (\$450{,}000 - \$194{,}100/\text{yr} \times 25\ \text{yr})}{(25\ \text{yr} \times 10.5\ \text{rem/yr} - 0\ \text{rem})}$$

$$= \frac{-\$4{,}754{,}700}{262.5\ \text{rem}} = -\$18{,}000/\text{rem (rounded to two significant places)}$$

Note that the numerator was negative since operational savings exceeded capital costs. Thus, this result indicates an exceptionally cost-effective modification since both costs and collective dose are reduced.

At $1,000/rem, total dollars saved = $4,754,700 + $1,000/rem x 262.5 rem ≈ $5,000,000.

2.3 PRESENT-WORTH MODEL, NO DISCOUNT OF REM VALUES

A present-worth model is frequently employed to reflect the time value of money. In this model all future operating costs are converted to equivalent worth in 1984 dollars using a discount rate d which reflects the real value of money (inflation and taxes are neglected). The equation used in this model is:

$$\text{Present-Worth} = F(C - A_o K_2)/(nD_2 - D_1), \text{ dollars/rem} \quad (2)$$

$$K_2 = \frac{(1 + d)^n - 1}{d(1 + d)^n}, \text{ yr}, \quad (3)$$

where d is a discount rate assumed to be 4% for this analysis. The annuity factor K_2 represents the present value of payments of one dollar per year for n years. Values of K_2 for various amortization periods and discount rates are listed in Appendix B. Multiplying this by the annual operating savings gives a present worth of those savings which can be subtracted from the original capital costs. The result represents the present value of the money required to pay for capital equipment and changes in operating costs (but not return on investment or taxes) for the life of the project (n years).

This model is an improvement over the basic model since it applies the same economic value or weight to both capital and operating expenses. In it, bias due to the changing value of money caused by inflation is avoided. Also, tax costs, which are recovered indirectly through the social use to which they are put, are not included. However, discounting operating savings in the numerator without comparable discounting of the future value of dose reductions (the denominator) leads to a bias of debatable justification. Therefore, a discounted rem present-worth model D (see Section 2.4) was also employed.

Example: Considering the same modification as above, for the present-worth model with a 25 year amortization period, and 4% discount rate:

$$K_2 = \frac{(1 + 0.04)^{25} - 1}{0.04\ (1 + 0.04)^{25}} = \frac{2.67 - 1}{0.04\ (2.67)} = 15.6 \text{ yr}$$

$$\text{Present-Worth} = \frac{1.08 \times (\$450{,}000 - \$194{,}100/\text{yr} \times 15.6 \text{ yr})}{262.5 \text{ rem}}$$

$$= \frac{-\$2{,}784{,}200}{262.5 \text{ rem}} \approx -\$11{,}000/\text{rem} \text{ (rounded to two significant places).}$$

At \$1,000/rem, total dollars saved = \$2,784,200 + \$1,000/rem x 262.5 rem $\approx$\$3,000,000. (Note: the slight difference between this value and from that given in Table 3.1 is due to rounding K_2 to 15.6 in the above.)

2.4 DISCOUNTED REM PRESENT-WORTH MODEL (PRESENT-WORTH MODEL D)

None of the econometric models studied to date have employed discounting of future rem savings. The rationale for not doing so is based on the ethical question of valuing a future risk or health effect differently from one incurred at present. Cohn (1) has considered this question in some detail. However, since the value of a rem in nuclear power plant operation is usually governed by costs of manpower replacement, training, and other factors, rather than the health effects costs which are usually much smaller, it seems appropriate to discount future rem savings at the same rate as that used for operational savings in the numerator of Eq. (2). The equation for this model is:

$$\text{Present-Worth } D = F(C - A_0 K_2)/(K_2 D_2 - D_1), \text{ dollars/rem,} \tag{4}$$

where K_2 is the annuity factor given by Eq. (3), and d is discount rate, assumed to be 4% for this analysis.

Example: Consider again the modification described in DU-83-01. Discounting future rem savings by 4% yields:

K_2 = 15.6 yr (as above)

$$\text{Present-Worth } D = \frac{1.08 \times (450{,}000 - \$194{,}100/\text{yr} \times 15.6 \text{ yr})}{(15.6 \text{ yr} \times 10.5 \text{ rem/yr} - 0 \text{ rem})}$$

$$= \frac{-\$2{,}784{,}200}{163.8 \text{ rem}} \approx -\$17{,}000/\text{rem}.$$

At \$1,000/rem, total dollars saved = \$2,784,200 + \$1,000/rem x 163.8 rem \$2,900,000. (Note: The difference between this value and that given in Table 3.1 and the Summary is due to rounding of K_2 to 15.6 in the above).

2.5 AFTER-TAX REVENUE REQUIREMENTS MODEL (REV. REQ. MODEL A)

A revenue requirements model that reflects the revenue requirements based on effective (after-tax) interest rates is also of some interest. This approach reflects the Board of Directors' or treasurer's point of view. For this model present worth, as calculated above, is converted to uniform annualized payments, which can be secured for n years from a present investment, using "effective" interest rate i, which reflects tax deductions on interest payments, and annuity factors K_1 given by Eq. (6) below (or taken from Appendix C). Typical values for effective interest rates are about 10% at present, based on capital cost of money of about 13.5% and income tax deductions of about 35%. In addition, taxes on revenues, which typically average 5% per year, are accounted for by the factor 0.95 in the denominator of Eq. (5), used for this model.

$$\text{Rev. Req. A} = \frac{nK_1 F(C - K_2 A_t)}{0.95 (nD_2 - D_1)}, \text{ dollars/rem} \tag{5}$$

$$K_1 = \frac{i (1 + i)^n}{(1 + i)^n - 1}, \text{ yr}^{-1}, \tag{6}$$

where A_t is the annual operating savings, A_o above, less the annual federal and state taxes on capital investments (assumed to be 2% of capital costs unless otherwise stated by sources of information); and i is effective interest rate (10%). For this model, d is assumed to be 4% as for the present-worth models above.

Example: Consider again modification DU-83-01. Using effective interest rate i = 10% yields:

$$K_1 = \frac{0.1\ (1 + 0.1)^{25}}{(1 + 0.1)^{25} - 1} = \frac{1.08}{10.8 - 1} = 0.11\ yr^{-1}$$

K_2 = 15.6 yr (as above)

$$A_t = A_o - (0.02 \times \$450{,}000)/yr$$

$$= A_o - \$9{,}000/yr = \$185{,}100/yr$$

$$\text{Rev. Req. A} = \frac{25\ yr \times 0.11\ yr^{-1} \times 1.08\ (\$450{,}000 - 15.6\ yr \times \$185{,}160/yr)}{0.95\ (25\ yr \times 10.5\ rem/yr - 0\ rem)}$$

$$= \frac{-\$7{,}239{,}553}{0.95 \times 262.5\ rem}$$

$$= \frac{-\$7{,}239{,}553}{0.95 \times 262.5\ rem} = \frac{-\$7{,}620{,}582}{262.5\ rem} \approx \$29{,}000/rem$$

At \$1,000/rem, total dollars saved = \$7,620,582 + \$1,000/rem x 262.5 rem ≈\$7,900,000.

2.6 BEFORE-TAX REVENUE REQUIREMENTS MODEL (REV. REQ. MODEL B)

A second revenue requirements model in which effective interest rate is increased to 20% is more frequently employed. This model reflects before-tax revenue requirements or costs to utility customers. In other respects the model is equivalent to revenue requirements model A above. The equation for this model is as follows:

$$\text{Rev. Req. B} = \frac{nK_1\ F(C - K_2\ A_t)}{0.95\ (nD_2 - D_1)}\text{, dollars/rem.} \qquad (7)$$

The revenue requirements models, or variations of them, are often employed by utilities since they reflect cash flow requirements and related needs for rate increases. Often, the capital costs are escalated, but no discount is applied to operational savings. This tends to distort actual impacts on rate structures and therefore has been avoided here. Similarly, the economic value of a rem should be escalated to properly reflect the time value of money, the changing costs of all factors included in operational savings, and the changing cost of health effects. Since the major economic factor in the current estimates of the value of a rem is labor cost, incurred by needs to hire additional workers if dose limits are approached, the value of dose saved should be changed in the same proportion as used for capital costs and operational costs in the numerator of Eqs. (5) and (7). Doing this would give results similar to those of the present-worth model (the only difference being inclusion of tax effects in the revenue requirements models). Therefore, rem values were not discounted in the revenue requirements models to better reflect current practice and to provide results for comparisons with the other models.

Example: For the same modification as considered above, C, K_2 and A_t are as above and using 20% as effective interest rate:

$$K_1 = \frac{0.2\ (1 + 0.2)^{25}}{(1+ 0.2\ )^{25} - 1} = \frac{0.2 \times 95.4}{95.4 - 1} = 0.202\ \ yr^{-1}.$$

$$\text{Rev. Req. B} = \frac{25\ yr \times 0.202/yr \times 1.08\ (\$450{,}000 - 15.6\ yr \times \$185{,}100/yr)}{0.95\ (25\ yr \times 10.5\ rem/yr - 0\ rem)}$$

$$= \frac{-\$13{,}294{,}452}{262.5\ rem} \approx -\$51{,}000/rem.$$

At \$1,000/rem, total dollar saved = \$13,294,452 + \$1,000/rem x 262.5 rem $\approx$\$14,000,000.

2.7 DISCUSSION OF MODELS

Of the five models presented here, the basic model with costs adjusted to estimated year of installation is perhaps best for initial scoping analyses. If the results from this model suggest that a modification is probably cost effective, a more complete evaluation using a model which reflects the present value of total savings, or the cost effectiveness in \$/rem, is appropriate. For present-value evaluations, the discounted rem present-worth model has merit since in it the time value of money required to compensate for higher future doses is valued in the same manner as similar costs for other expenses in the cost-effectiveness equation.

The revenue requirements models reflect additional costs due to taxes and inflation. Since inflation costs are primarily a reflection of the changing value of money, they are not considered "real" costs and are best avoided if possible. Since taxes are both a societal cost and a societal benefit, they cancel in terms of total impact on society and are best avoided in cost-effectiveness evaluations (at least at the national level). However, federal taxes are a local cost and a national benefit. Thus, the choice of scale (local or national) for balancing costs and benefits becomes important. Since the utility manager operates on a local scale (must increase local rates to pay federal taxes), he will be concerned with taxes and revenue requirements. However, the before-tax revenue requirements do not properly reflect the allowed tax deductions, and thus the after-tax revenue requirements model A would seem more appropriate for the local level.

Note from the above that there is a federal disincentive to making dose-reduction modifications since their cost is increased by federal taxes. A tax credit for dose-reduction modifications could be used to alleviate this problem.

It should also be noted that the ratio of costs/rem saved can be negative if operational cost savings exceed capital costs. These modifications are thus exceptionally cost effective since both costs and dose are saved. On the other hand, the ratio can also be negative if costs are positive and dose saved is negative. This would result if collective dose were increased by the modification. This result would not be cost effective.

2.8 REFERENCES FOR SECTION 2

1. Cohn, Bernard L., Discounting in Assessment of Future Radiation Effects, Health Physics 45, pp. 687-697, 1983.

3. RESULTS OF COST-EFFECTIVENESS EVALUATIONS

Results of the above cost-effectiveness evaluations are summarized in Tables 3.1 through 3.3. Details on these modifications are given in Section 4.

The 25 items listed in Table 3.1 were exceptionally cost effective in that net costs were negative and dose savings were positive. To rank these for cost effectiveness, a criterion other than simply the ratio of costs to dose saved was used, since this ratio loses its meaning when costs are negative. For the ranking of these options, total savings were calculated using $1,000/rem as the value of collective dose savings. Rankings are based on results from the present-worth model D.

Total dollars saved based on other assumed values for the monetary value of a rem saved may easily be calculated as follows. Use the dollar saved data in Table 3.1 and add the value calculated using the product of the rem saved (discounted rem saved for present-worth model D) and the difference in value between the desired value for dollars/rem and the $1,000/rem value employed to obtain the results in Table 3.1.

For example, to estimate total dollars saved for the first item in Table 3.1 using the basic model and $3,000/rem as the assumed monetary value for a rem saved, one adds $180,000 [($3,000/rem - $1,000/rem) x 90 rem] to the $55,000,000 shown to obtain a total of $55,180,000. This change would not be considered significant since all results are rounded to two significant places.

For the last item in Table 3.1, however, using $3,000/rem and the basic model one obtains $161,000 for total dollars saved, an increase of nearly a factor of 2.5.

Table 3.2 contains results for 113 items which had both positive costs and positive dose savings. For these, the ratio of net dollar costs to net rem saved is employed as the cost-effectiveness criterion. Results are listed in order of increasing costs per rem saved and vary from $35/rem to $120,000/rem based on the discounted rem present-worth model D.

Total dollars saved, based on a nominal value of $1,000/rem saved, is given in the last column for results from the present-worth model D (using discounted rem). Similar savings may be calculated for any of the five models and for other assumed monetary values for dose savings using the data in Table 3.2 and the equation:

$$\text{Total dollars saved} = (D - CER) \times R,$$

where

- D is the monetary value assumed for one rem saved,
- CER is the cost-effectiveness ratio from Table 3.2, and
- R is rem saved (or discounted rem saved for present-worth model D).

Positive values for this total would be considered cost effective.

For example, the first item in Table 3.2, AI-80-2, yielded $20/rem as the cost-effectiveness ratio for the basic model. At $1,000/rem, the total dollars saved as predicted by this model are:

Total dollars saved = ($1,000/rem - $20/rem) x 300 rem = $294,000

Note that this value is considerably larger than the result shown in the last column for results from the present-worth model D. The difference is due mainly to the difference between rem saved and discounted rem saved.

Table 3.3 contains results for 13 items with negative predicted discounted rem savings and positive predicted costs. The results indicate that these items were not effective. However, for five of these modifications, values for rem saved (not discounted) were positive and therefore a different conclusion might be reached for other models. The results provided after the descriptions of these modifications (in Section 4) reveal that very large values (> $20,000/rem) of the ratio $/rem saved were obtained for the other four models considered.

TABLE 3.1: EXCEPTIONALLY COST-EFFECTIVE MODIFICATIONS

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED
	total $ saved (assuming $1,000/rem)						
DU-82-13*	55,000,000	32,000,000	32,000,000	110,000,000	200,000,000	90	52
LO-83-03B*	52,000,000	30,000,000	29,000,000	95,000,000	180,000,000	1,600	900
LO-83-03A*	24,000,000	14,000,000	14,000,000	43,000,000	81,000,000	790	450
DU-82-12*	23,000,000	14,000,000	13,000,000	44,000,000	85,000,000	120	69
DU-82-11*	23,000,000	13,000,000	13,000,000	43,000,000	81,000,000	240	140
PJ-83-01*	17,000,000	9,600,000	9,400,000	31,000,000	58,000,000	360	210
PD-83-01A	8,300,000	8,300,000	8,300,000	21,000,000	35,000,000	3,700	3,700
WA-84-02*	6,300,000	4,300,000	4,300,000	10,000,000	18,000,000	48	33
AI-80-04B*	7,600,000	4,600,000	4,200,000	13,000,000	23,000,000	940	530
PI-83-01*	7,600,000	4,200,000	4,100,000	13,000,000	24,000,000	420	240
PH-83-01*	6,300,000	3,900,000	3,500,000	10,000,000	19,000,000	960	550
DU-83-01	5,000,000	3,100,000	3,000,000	7,900,000	14,000,000	260	160
WH-84-06A	3,200,000	2,700,000	1,800,000	4,000,000	5,600,000	2,100	1,200
DU-82-06*	3,000,000	1,800,000	1,800,000	5,800,000	11,000,000	15	8.6
WH-84-02	3,000,000	1,800,000	1,700,000	5,700,000	11,000,000	59	34
PF-83-01B*	2,500,000	1,400,000	1,200,000	3,400,000	6,100,000	440	230
PA-77-01	1,700,000	1,600,000	960,000	1,700,000	1,900,000	1,600	900
PG-83-01*	1,500,000	860,000	820,000	2,600,000	4,900,000	90	52
WH-84-01	1,200,000	700,000	630,000	1,900,000	3,400,000	150	89
PB-82-01	1,100,000	590,000	570,000	1,800,000	3,300,000	51	29
WH-84-06B	1,000,000	840,000	550,000	1,100,000	1,500,000	700	400
WH-84-07A	510,000	330,000	280,000	810,000	1,400,000	120	68
WH-84-05B	370,000	260,000	200,000	520,000	860,000	140	83
WH-84-07B	150,000	95,000	78,000	200,000	340,000	39	22
WH-84-05A	65,000	49,000	28,000	26,000	5,800	48	28

*Replacement power costs were used in model calculations.

TABLE 3.2: MODIFICATIONS WITH POSITIVE COSTS AND POSITIVE DOSE SAVINGS

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED	TOTAL $ SAVED BASED ON PWD (@ $1,000/REM)
	dollars/rem							
AI-80-02	20	20	35	90	170	300	170	$160,000
AI-80-21	49	49	86	220	420	1,500	850	$780,000
LO-83-01B	59	59	100	270	500	30	17	$16,000
AI-80-07	62	62	110	280	530	600	340	$300,000
DU-82-08	68	68	120	300	580	240	140	$120,000
BE-82-01E	62	62	120	330	630	560	300	$260,000
LO-83-01A	69	69	120	310	590	51	29	$26,000
YO-82-01A	66	66	120	350	670	3,500	1,900	$1,600,000
BE-82-02E	72	72	140	380	730	810	430	$370,000
BE-82-06E	75	75	140	390	760	4,700	2,500	$2,200,000
BE-82-02F	76	76	140	400	770	770	410	$350,000
YO-82-01B	82	82	150	430	830	3,700	2,000	$1,700,000
BE-82-06F	93	93	170	490	940	5,000	2,700	$2,200,000
EG-84-02A	170	110	180	340	630	88	55	$45,000
DU-85-01	186	110	190	360	680	93	53	$44,000
BE-82-01F	110	110	200	570	1,100	320	170	$140,000
WH-84-03	150	120	210	490	930	270	160	$120,000
DU-82-01	130	130	230	600	1,100	2,700	1,600	$1,200,000
EG-84-04	150	150	230	550	1,000	45	28	$22,000
JA-83-01	260	160	270	550	1,000	2,900	1,700	$1,200,000
AI-80-15	160	160	290	740	1,400	220	130	$91,000
DU-82-03	180	180	310	810	1,500	90	52	$36,000
AI-80-05	190	190	330	870	1,600	270	150	$100,000
EG-84-02B	210	210	330	790	1,400	890	560	$370,000
AI-80-06	200	200	340	890	1,700	300	170	$110,000
EG-84-07	220	220	350	820	1,500	13	7.8	$5,100
AI-80-19	200	200	350	920	1,700	180	100	$67,000
AI-80-16	240	240	420	1,100	2,100	30	17	$9,900
EG-84-03B	380	360	570	1,300	2,400	84	52	$22,000
EG-84-06	510	510	610	920	1,300	17	14	$5,500

TABLE 3.2 (continued): MODIFICATIONS WITH POSITIVE COSTS AND POSITIVE DOSE SAVINGS**

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED	TOTAL $ SAVED BASED ON PWD (@ $1,000/REM)
	dollars/rem							
PL-84-01B	420	390	620	1,400	2,600	200	120	$47,000
DU-82-05	480	370	630	1,500	2,800	2,300	1,300	$470,000
AI-80-12	380	380	650	1,700	3,200	390	220	$78,000
PC-82-01	560	520	670	950	1,400	25	19	$6,400
AI-80-04A	400	440	780	2,100	3,900	940	530	$120,000
PL-84-01A	570	540	860	2,000	3,600	200	120	$17,000
AI-80-11	500	500	900	2,300	4,300	1,300	740	$77,000
PE-83-01	910	910	910	1,100	1,200	900	900	$85,000
AI-80-01	550	550	950	2,500	4,700	150	86	$4,200
EG-84-03A	640	640	1,000	2,400	4,500	41	25	($750)
WH-84-04B	590	590	1,100	2,600	5,000	55	30	($2,600)
EG-84-05A	690	690	1,100	2,600	4,800	770	480	($47,000)
WA-84-01	1,100	1,100	1,100	1,300	1,400	99	95	($13,[illegible])
PK-83-01	540	690	1,200	2,900	5,600	69	40	$7,800
AI-80-09	760	760	1,400	3,400	6,500	58	33	($11,000)
AI-80-18	700	700	1,400	3,200	6,000	210	110	($39,000)
EG-84-01	820	820	1,500	3,700	7,000	28	16	($7,700)
AI-80-08	850	850	1,500	3,900	7,300	43	24	($13,000)
PF-83-01A	620	880	1,700	3,300	6,300	440	230	($160,000)
AI-80-03	980	980	1,700	4,400	8,400	90	52	($36,000)
BE-82-03S	870	870	1,800	5,300	10,000	220	110	($82,000)
AI-80-13	810	810	1,900	3,700	7,000	45	20	($17,000)
BE-82-03K	1,000	1,000	2,000	5,300	10,000	190	95	($95,000)
WH-84-04A	1,100	1,100	2,000	4,900	9,200	28	15	($15,000)
AI-80-10	1,200	1,200	2,100	5,300	10,000	620	350	($380,000)
AI-80-20	1,200	1,200	2,100	5,500	10,000	60	35	($39,000)
AI-80-22	1,200	1,200	2,200	5,200	9,900	190	100	($120,000)

**Dollar values in parentheses are negative.

TABLE 3.2 (continued): MODIFICATIONS WITH POSITIVE COSTS AND POSITIVE DOSE SAVINGS**

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED	TOTAL $ SAVED BASED ON PWD (@ $1,000/REM)
	dollars/rem							
EG-84-05B	1,400	1,400	2,200	5,200	9,600	260	160	($190,000)
MI-83-03B	2,100	1,300	2,300	4,800	9,200	6,000	3,500	($4,500,000)
BE-82-03T	1,300	1,300	2,700	7,900	16,000	170	83	($140,000)
BE-82-01C	1,400	1,400	2,900	8,500	17,000	640	320	($590,000)
LO-83-02	2,200	1,700	2,900	6,800	13,000	63	36	($70,000)
LO-83-05	2,300	1,700	3,000	6,700	13,000	66	38	($74,000)
DU-82-04	1,800	1,800	3,100	8,100	15,000	45	26	($55,000)
BE-82-03L	1,600	1,600	3,200	8,300	16,000	140	70	($150,000)
AI-80-17	1,800	1,800	3,200	8,300	16,000	120	69	($150,000)
PM-84-01	2,100	2,200	3,800	8,600	16,000	11	6.6	($18,000)
MI-83-02B	3,400	2,200	3,800	8,000	15,000	4,400	2,600	($7,200,000)
DU-82-10	2,200	2,200	3,900	10,000	19,000	290	170	($480,000)
LO-83-04	2,100	2,400	4,100	11,000	21,000	57	33	($100,000)
BE-82-01A	1,900	1,900	4,400	10,000	20,000	470	210	($700,000)
BE-82-02C	2,300	2,300	4,600	14,000	27,000	920	460	($1,600,000)
MI-83-01B	3,700	2,700	4,700	11,000	20,000	6,300	3,600	($14,000,000)
BE-82-03O	2,400	2,400	4,800	14,000	28,000	140	67	($250,000)
BE-82-04M	2,500	2,500	5,000	15,000	29,000	320	160	($620,000)
BE-82-02D	2,600	2,600	5,300	16,000	31,000	840	420	($1,800,000)
BE-82-04N	2,600	2,600	5,300	16,000	31,000	140	69	($290,000)
DU-82-07	4,100	3,100	5,400	13,000	24,000	110	61	($270,000)
BE-82-03P	3,000	3,000	6,200	18,000	36,000	180	87	($450,000)
AI-80-14	3,400	3,400	6,600	15,000	29,000	650	330	($1,900,000)
BE-82-01D	3,400	3,400	6,900	20,000	40,000	360	180	($1,000,000)
BE-82-03C	3,800	3,800	7,700	23,000	45,000	520	260	($1,700,000)
BE-82-03G	3,500	3,500	9,100	18,000	35,000	93	35	($290,000)
BE-82-04C	4,700	4,700	9,400	28,000	55,000	400	200	($1,700,000)
BE-82-04G	3,600	3,600	9,600	19,000	37,000	210	81	($690,000)

**Dollar values in parentheses are negative.

TABLE 3.2 (continued): MODIFICATIONS WITH POSITIVE COSTS AND POSITIVE DOSE SAVINGS**

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED	TOTAL $ SAVED BASED ON PWD (@ $1,000/REM)
	dollars/rem							
BE-82-03D	4,900	4,900	9,800	29,000	57,000	480	240	($2,100,000)
DU-82-02	6,300	6,200	11,000	28,000	52,000	3,400	1,900	($19,000,000)
BE-82-02A	3,700	3,700	11,000	19,000	38,000	570	180	($1,900,000)
BE-82-04H	4,000	4,000	11,000	21,000	41,000	91	32	($330,000)
BE-82-03M	5,900	5,900	12,000	36,000	70,000	140	71	($780,000)
BE-82-03H	4,800	4,800	15,000	25,000	49,000	110	36	($500,000)
BE-82-02B	4,400	4,400	15,000	23,000	44,000	510	150	($2,100,000)
BE-82-05C	7,800	7,800	16,000	47,000	92,000	580	290	($4,300,000)
BE-82-04D	8,500	8,500	17,000	51,000	100,000	230	110	($1,900,000)
MI-83-02A*	18,000	11,000	19,000	37,000	70,000	4,400	2,600	($46,000,000)
BE-82-03N	10,000	10,000	20,000	60,000	120,000	100	51	($990,000)
BE-82-05D	10,000	10,000	20,000	61,000	120,000	600	300	($5,800,000)
BE-82-04K	10,000	10,000	21,000	62,000	120,000	60	30	($590,000)
BE-82-01B	6,000	6,000	23,000	32,000	61,000	200	52	($1,200,000)
BE-82-04L	12,000	12,000	24,000	71,000	140,000	76	38	($860,000)
BE-82-05A	11,000	11,000	28,000	59,000	110,000	410	160	($4,400,000)
BE-82-06C	15,000	15,000	30,000	89,000	170,000	5,200	2,600	($74,000,000)
MI-83-03A*	36,000	21,000	36,000	70,000	130,000	6,000	3,500	($120,000,000)
BE-82-06D	19,000	19,000	38,000	110,000	220,000	5,500	2,700	($100,000,000)
MI-83-01A*	37,000	22,000	38,000	75,000	140,000	6,300	3,600	($130,000,000)
BE-82-03Q	20,000	20,000	41,000	120,000	240,000	29	14	($560,000)
BE-82-03R	21,000	21,000	43,000	130,000	250,000	27	13	($560,000)
BE-82-04O	23,000	23,000	46,000	140,000	270,000	20	9.9	($450,000)
BE-82-05B	16,000	16,000	47,000	83,000	160,000	380	130	($5,900,000)
BE-82-04P	26,000	26,000	53,000	160,000	310,000	17	8.5	($440,000)
DU-82-09	36,000	36,000	62,000	160,000	310,000	45	26	($1,600,000)
BE-82-03A	8,200	8,200	110,000	43,000	83,000	240	19	($2,000,000)
PD-83-01B*	180,000	120,000	120,000	340,000	620,000	3,700	3,700	($430,000,000)

*Replacement power costs were used in model calculations.
**Dollar values in parentheses are negative.

TABLE 3.3: MODIFICATIONS WITH NEGATIVE DISCOUNTED REM SAVINGS**

PROJECT NAME	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B	REM SAVED	DISC. REM SAVED
	total $ saved (assuming $1,000/rem)						
BE-82-04J	(510,000)	(510,000)	(520,000)	(2,400,000)	(4,600,000)	-65	-72
BE-82-04I	(540,000)	(540,000)	(550,000)	(2,200,000)	(4,700,000)	-88	-96
BE-82-03J	(650,000)	(650,000)	(670,000)	(3,100,000)	(5,900,000)	-81	-92
BE-82-03I	(660,000)	(660,000)	(670,000)	(3,100,000)	(5,900,000)	-79	-91
BE-82-04E	(670,000)	(670,000)	(700,000)	(3,300,000)	(6,300,000)	-53	-77
BE-82-03E	810,000	810,000	(870,000)	4,400,000	8,600,000	40	-21*
BE-82-04F	(970,000)	(970,000)	(1,000,000)	(4,800,000)	(9,200,000)	-75	-110
BE-82-03F	(1,100,000)	(1,100,000)	(1,100,000)	(5,500,000)	(11,000,000)	-10	-55
BE-82-04A	1,800,000	1,800,000	(2,000,000)	9,700,000	19,000,000	70	-93*
BE-82-04B	(2,000,000)	(2,000,000)	(2,100,000)	(10,000,000)	(20,000,000)	-50	-150
BE-82-03B	2,200,000	2,200,000	(2,400,000)	12,000,000	23,000,000	170	-29*
BE-82-06A	75,000,000	75,000,000	(77,000,000)	400,000,000	780,000,000	1,700	-500*
BE-82-06B	100,000,000	100,000,000	(100,000,000)	540,000,000	1,000,000,000	2,300	-640*

*Note that the value for discounted rem saved, which is obtained from the denominator of equation (4) in Section 2.4, can be negative even though rem saved is positive, since K_2 operates only on annual dose savings (D_2) and not on dose to install (D_1).

**Dollar values in parentheses are negative.

4. DESCRIPTIONS OF MODIFICATIONS

AI-80-01: Air-Cooled Anticontamination Suit, Radio Dosimetry, and Radio Communications

In the study on engineering techniques for reducing occupational radiation exposure at operating nuclear power plants, the Atomic Industrial Forum Subcommittee considered improved radio communications and radio telemetry of dosimetry information as well as the addition of air conditioning to air-supplied suits to improve worker efficiency. It was estimated appropriate improvements could reduce the dose to workers performing general maintenance (now 10 to 180 rem collective dose per plant) by approximately 5 rem/yr. Total costs were estimated at $56,000 including $6,250 research and development costs. No dose would be incurred during implementation, and amortization was assumed to be over 30 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital costs for equipment, research and development = $56,000
- Dose to install = 0 rem
- Annual dose savings = 5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	550	550	950	2,500	4,700

AI-80-02: BWR-CRD Scram Discharge Line Flange for Hydrolazing the Header

Considerable crud accumulates in scram discharge lines. Considerable exposure could be saved if these lines were flushed out before maintenance and inspection activities. It was proposed in the AIF Study that holes be cut in the end of each header to allow them to be hydrolazed, thus, flushing the radioactive material out. Bolted flanges would be installed on the end of each header to allow the procedure to be repeated during subsequent outages. Resulting reduction in general area dose rate and local dose near the header and scram discharge line was estimated at 10 rem/yr. Approximately 5 rem collective dose would be required to implement this modification. Total cost for implementation including $250 for research and development was estimated at $4,000. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979

- Capital cost of modification including research and development = $4,000
- Dose to install = 5 rem
- Annual dose savings = 10 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	20	20	35	90	170

AI-80-03: Shielded Forklift Truck for Radwaste Handling

In most plants, drums containing radioactive waste are moved into and out of storage and loaded for shipment using a forklift truck. Several rem per year collective dose are typically incurred during this operation. It was estimated that use of a shielded fork-lift truck would reduce the collective dose by 3 rem/yr. Total capital cost for such a truck was estimated at $60,000. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment and installation = $60,000
- Dose to install = 0 rem
- Annual dose savings = 3 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	980	980	1,700	4,400	8,400

AI-80-04A: BWR Control-Rod-Drive Handling Tool

Hydraulically operated control rod drives on BWR plants are overhauled about once every five years. Approximately 40 drives are typically overhauled during a refueling shutdown, requiring about one full week of work. Removal and replacement of the drives entails work beneath the reactor vessel where radiation levels are high. A newly designed handling tool was developed for BWR-6 plants which provides a semiremote means of raising and lowering the control rod drive, torquing the bolts, and transferring the control rod drive outside the vessel pedestal area. This tool can be operated by one man, and requires about one hour per control rod drive. Thus, a single person could remove the control rod drives in half the time formerly required for a crew of four. Labor savings of 120 man-hour/yr at $20/hr would therefore equal $2,400/yr. Estimated average exposure reduction using the automated equipment would be 32 rem/yr collective dose, and capital cost would be $325,000, including 25% of the research and development cost ($300,000). A collective dose of 20 rem was estimated for installation of this equipment. No credit was taken for possible replacement power cost savings. Had it been included, this modification would have been exceptionally cost effective since both dose and costs would be reduced (see AI-80-04B below). No credit was taken for a reduced crew size (4 to 1) and a 50% reduction in removal and replacement time. Input data for the cost-effectivenss evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost including research and development = $325,000
- Labor Savings = $2,400/yr
- Dose to install = 20 rem
- Annual dose savings = 32 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	400	440	780	2,100	3,900

AI-80-04B: BWR Control-Rod-Drive-Handling Tool (on Critical Path 25% of Time)

This modification is identical with AI-80-04A except credit is taken for reduction in replacement power costs of 8 hr per outage. Assuming an outage each 18 months and $30,000/hr replacement power cost, savings would be $160,000/yr. Input data for the cost-effectiveness evaluations for this modification were therefore:

- Base year for capital costs = 1979
- Capital cost = $325,000
- Labor Savings = $2,400/yr
- Dose to install = 20 rem
- Annual replacement power savings = $160,000/yr

- Annual dose savings = 32 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-7,100	-3,900	-6,800	-12,000	-24,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

AI-80-05: BWR Control Rod Drive Disassembly and Decontamination Tank

Disassembly of control rod drives on a bench in open air typically contributes about 20 rem collective dose per year at BWR plants. In addition to external exposure, inhalation and contamination control are also problems. A shielded water filled tank was proposed for disassembly and initial decontamination of these drives. The tank, approximately twice as long as the flush tank currently being used, would require a circulating water supply and shielded filter. Total cost for the equipment plus installation was estimated at $35,000. Approximately 2 man-rem would be required for installation and approximately 9 rem/yr collective dose would be saved assuming 20 control rod rebuilds per year and recent experience with these units at two facilities (BE-84). Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment plus installation = $35,000
- Dose to install = 2 rem
- Annual dose savings = 9 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	190	190	340	870	1,600

AI-80-06: Electropolishing Tank for BWR Control Rod Drives

Electropolishing the spud end of the control rod drive before starting maintenance could reduce dose rates by 50 to 75%. It would also reduce the potential for airborne contamination and spread of contamination and a possibility of beta-radiation exposures. After the spud end is electropolished, the drive may be disassembled and some parts further electropolished. The tank would be 15 ft long and contain a solution of phosphoric acid, which would be pumped through a shielded filter. Estimated cost for the tank plus installation was \$40,000. Estimated dose during installation and learning to operate the equipment was 1 rem. Annual dose savings were 10 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost of equipment plus installation = \$40,000
- Dose for installation plus training = 1 rem
- Annual dose savings = 10 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	200	200	340	870	1,600

AI-80-07: Clean Seal Cooling Water Supply for BWR Recirculation Pump

Maintenance of BWR recirculation pumps typically results in 16 to 30 rem collective dose per year. Ninety percent of this exposure is received during pump seal replacement. It was estimated that the frequency of pump seal maintenance could be reduced by approximately a factor of 6 by installation of a clean water supply to purge the recirculation pump seals. This estimate is based upon experience at some plants which have implemented this modification. The seal purge system consists of a connection to the control rod drive cooling water supply, a constant flow control valve, a flow meter, a relief valve, and the necessary isolation valves. Total estimated cost for the modification including \$10,000 engineering cost was \$25,000, assuming about 100 ft of piping at \$100 per linear foot installed and about \$5,000 for valves and instrumentation. An estimated 5 rem would be required for installation and an annual savings of 20 rem collective dose would be achieved. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost of equipment, engineering and installation = \$25,000
- Dose to install = 5 rem
- Annual dose savings = 20 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	62	62	110	280	530

AI-80-08: Remote Oil Sampling and Replacement for BWR Recirculating Pumps

Recirculation pump oil sampling and replacement contribute about 2 rem collective dose per year to a typical BWR plant. Temporary hoses and a transfer pump could be attached to the pump motor using quick disconnects to allow oil sampling and replacement from outside the drywell. Estimated cost for this modification was $25,000 and approximately 2 rem would be required to install the quick disconnect joints on the pumps. It was estimated that 1 1/2 rem/yr collective exposure could be reduced with this modification. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost of equipment plus installation = $25,000
- Dose to install = 2 rem
- Annual dose savings = 1.5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	850	850	1,500	3,900	7,300

AI-80-09: BWR Recirculation Pump Maintenance Work Platform

An additional approach to those in AI-80-07 and AI-80-08 would be the installation of a permanent work platform around the pumps for annual maintenance work. Total cost as estimated by the AIF Subcommittee was $30,000, including $6,250 research and development. Estimated exposure to implement was 2 rem and estimated annual exposure reduction was 2 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment, installation, research, and development = $30,000

- Dose to install = 2 rem

- Annual dose savings = 2 rem/yr

- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	760	760	1,400	3,400	6,500

AI-80-10: BWR Main Steam Isolation Valve Leakage Control System

The main steam isolation valves in BWRs must be routinely tested to determine that the leakage limits are not exceeded. Aproximately one third of the valves fail the 11.5-scf/hr requirement when tested. This is normally not a critical-path activity, however, repeated failures to meet the leakage limits at some plants have led to critical-path delays. The cost of replacement power for these incidents is not included in the present analysis. One proposal for reducing the amount of work that must be performed on the valves is to increase the allowable leakage rate by, for example, installing a leakage control system. The system would be pressure controlled and consist of compressors, blowers, valves, etc. of proven technology. Estimated cost for this modification would be $500,000, including about $25,000 for research and development. The estimated exposure to implement the modification was 10 rem and it was estimated that a 21-rem/yr exposure reduction could be achieved. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979

- Capital cost for equipment, installation and research and development = $500,000

- Dose to install = 10 rem

- Annual dose savings = 21 rem/yr

- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,200	1,200	2,100	5,300	10,000

AI-80-11: Acoustic Emission Instrumentation for ISI of the Reactor Vessel and Reactor Coolant Piping

An estimated 80-rem collective dose per outage is incurred during in-service inspections on the vessel and reactor coolant piping. Removal and replacement of insulation accounts for approximately half this exposure. The total number of locations requiring ultrasonic testing during this inspection could be reduced by installing acoustic emission instrumention on the reactor vessel and reactor coolant loop to determine locations of discontinuities in the metal. The technology for this type of acoustic inspection has not received full acceptance since false positive indications are possible. An estimated $500,000 of research and development are needed to complete the development of this methodology. Total capital investment for equipment installation and 25% of this research and development cost was estimated at $450,000. It was also estimated that approximately 40 rem collective dose would be required for the initial installation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for captial cost = 1979
- Capital cost including research, development, equipment, and installation = $450,000
- Dose to install = 40 rem
- Annual dose savings = 45 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	510	510	900	2,300	4,300

AI-80-12: BWR Pipe Insulation Improvements for In-Service Inspection

As indicated in AI-80-11 above, removal and reinstallation of insulation to allow inspection of pipe welds accounts for approximately 40 rem collective dose per year at BWR plants. The AIF Subcommittee suggested that improved, clearly identified, and easily removed and replaced sections of insulation could reduce exposures by about 13 rem/yr, assuming 10 years to replace the insulation and a 50% saving in dose accumulation during the next 20 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for captital cost = 1979
- Capital cost of materials plus installation = $100,000
- Dose to install = 0 rem

- Annual dose savings = 13 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	380	380	650	1,700	3,200

AI-80-13: Permanent Hoist to Remove and Replace BWR Safety Relief Valves

Several safety relief valves are removed, tested, and replaced each refueling outage in BWR plants. Removal and installation of these valves are responsible for an estimated 9 rem/yr collective dose. In those plants where space is available in the drywell, installation of a permanent hoisting system was proposed to aid in removal and installation of the safety relief valves. Estimated cost for equipment plus installation was $25,000. Estimated exposure to install this modification was 15 rem, assuming 200 man-hours to install at an average exposure rate in the drywell of 75 mrem/hr. A 25% reduction in time required to move valves within the drywell was assumed for an estimated savings of 2 rem/yr collective dose. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment plus installation = $25,000
- Dose to install = 15 rem
- Annual dose savings = 2 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	820	820	1,900	3,700	7,000

AI-80-14: Replace Hydraulic Snubbers in BWR Drywell with Mechanical Snubbers

Inspection of safety-related hydraulic snubbers and periodic removal for testing account for approximately 36 rem collective dose per year in BWR plants. The AIF Subcommittee suggested replacing one third of all safety-related hydraulic snubbers in the drywell with mechanical-type snubbers during each of three outages. Total cost estimate for replacement of 150 snubbers over three years was $1,500,000. Assuming that the exposure to install mechanical snubbers would be approximately equal to that for removal and installation of the present hydraulic snubbers, an estimated 100 rem collective dose for implementation of this modification was given. Expected annual exposure reduction was 25 rem/yr consisting of 10 rem/yr on staging, 10 rem/yr on removal and replacement of snubbers, and 5 rem/yr on inspection. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment plus installation = $1,500,000
- Dose to install = 100 rem
- Annual dose savings = 25 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,400	3,400	6,600	15,000	29,000

AI-80-15: Installation of Viewing Windows in BWR Plants

Periodic visual observation of operating equipment for adequate lubrication and proper operation causes an estimated 18-rem/yr collective dose in BWR plants. Installation of five inexpensive water-filled viewing windows was proposed in shield walls, where this will avoid direct entry for a total cost of $25,000, including installation. Approximately 1-1/2 rem would be required for installation and an estimated 7.5-rem/yr dose reduction would be achieved. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Costs for installation of 5 windows = $25,000
- Dose to install 5 windows = 1.5 rem
- Annual dose savings = 7.5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	160	160	290	740	1,400

AI-80-16: Relocation of Fuel Sipping Cans

During refueling the integrity of selected fuel rods is determined by sipping water in the vicinity of the fuel. An estimated 1 rem/yr collective dose could be saved if fuel sipping cans were located near the reactor cavity, thereby reducing the transit time of fuel assemblies to and from the reactor and thus exposure to fuel-handling personnel on the fuel bridge. Estimated costs for relocation of the sipping cans would be $5,000. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital costs for equipment plus installation = $5,000
- Dose to install = 0 rem
- Annual dose savings = 1 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	250	250	430	1,100	2,100

AI-80-17: Automated Sampling for Sipping BWR Fuel Elements

An automated sampling system for sipping fuel elements in a BWR could be employed to reduce annual collective dose by about 4 rem/yr. Using the automated equipment, sipping cans would be located deeper in the spent-fuel pool for better shielding. Demineralized water would be circulated through the cans, a sample drawn, and the lids closed. all from a remote-control panel. Time required for the job and perhaps even critical-path time would be saved with this method. However, no credit has been taken for either. Total cost to implement this modification, including research and development, was estimated at $150,000. This includes $60,000 for the sampling system and control panel and $15,000 for each sipping can. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital costs for equipment plus installation = $150,000
- Dose to install = 0 rem
- Annual dose savings = 4 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	1,800	1,800	3,200	8,300	16,000

AI-80-18: Provide Expansion Loops and Cooled Seal Water for BWR Reactor Water Cleanup Pumps

The reactor water cleanup water pumps in BWR plants require periodic maintenance to replace shaft seals because of excessive wear or failure. An estimated 8 rem/yr collective dose could be saved by providing expansion loops for seal water cooling on the reactor cleanup pumps to reduce loading on the pump casing due to thermal changes and thereby reduce shaft and seal damage. Estimated cost, including about \$5,000 for research and development, is \$100,000. Estimated dose to implement is 30 rem. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital costs for equipment plus installation = \$100,000
- Dose to install = 30 rem
- Annual dose savings = 8 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	700	700	1,400	3,200	6,000

AI-80-19: Helium Leak Detection for BWR Condenser Tubes

Condenser leak detection and repair in BWR plants are frequently accomplished with plant at reduced power level and, as a consequence, maintenance crews are exposed to radiation from ^{16}N and ^{15}O. An average 12 rem/yr collective dose attributable to this exposure could be reduced by 50% if an improved helium leak detection technique developed by EPRI were employed. With this technique, helium gas is delivered to a specific number of tubes. A leaky tube is rapidly indicated by a helium leak detector located downstream of the steam-jet air ejector. Once a leak is detected, the helium is delivered to successively lower numbers of tubes until the leak is precisely located. This technique offers significant savings because of its speed and sensitivity. Total cost of equipment plus installation was estimated at \$25,000. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979

* Capital costs for equipment plus installation = $25,000
* Dose to install = 0 rem
* Annual dose savings = 6 rem/yr
* Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	200	200	350	920	1,700

AI-80-20: Remote Cable Cutting and Disposal Tools for Repair of BWR Transversing In-core Probe

Repair to the cabling and drives to the transversing incore probe have caused an estimated 3 rem/yr to the average BWR plant. The detector and cabling become activated and their repair must be accomplished under the reactor vessel in an area of higher-than-average radiation fields. New designs for this type of equipment have reduced the mechanical problems associated with earlier designs. Remote cable cutting and disposal techniques have been adapted for the BWR-6 design. This new equipment could be back-fitted for approximately $50,000 per plant. Expected dose savings would be 2 rem/yr and no dose would be incurred during installation. Input data for the cost-effectiveness evaluations for this modification were:

* Base year for capital cost = 1979
* Capital cost for equipment plus installation = $50,000
* Dose to install = 0 rem
* Annual dose savings = 2 rem/yr
* Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,200	1,200	2,100	5,500	10,000

AI-80-21: Portable Shielding System for the PWR Steam Generator Channel Heads

Dose rates in the primary heads of PWR steam generators are typically from 4 to 50 rem/hr. Annual collective doses due to maintenance of steam generators including steam generator tube plugging have typically been 20 to 1,000 rem/yr, with an average estimated at 100 rem/yr, which could be reduced to 50 rem/yr by use of a portable shielding system for the steam generator channel heads. Estimated total cost including approximately $12,500 for research and development was $50,000. Estimated dose for installation and removal of the special shield was 10 rem. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost of equipment including research, development and installation = $50,000
- Dose to install = 10 rem
- Annual dose savings = 50 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	49	49	86	220	420

AI-80-22: Shielding and Remote Tools for Filter Cartridge Replacement in PWR Plants

Cartridge-type filters in the reactor auxiliary system of a PWR plant require periodic replacement as a result of buildup of solid materials on the filter medium. Replacement involves isolating the filter housing, opening the housing, removing the cartridge, inserting a fresh cartridge, and transporting the expended cartridge to a shielded container. These operations cost an estimated 14-rem/yr collective dose in an average PWR plant. Installation of additional shielding around the filter housing; the use of remote tools for opening the filter housing, and removing the filter cartridge; and shielding the filter cartridges after removal has been proposed. These changes could be implemented during scheduled outages at a total cost of approximately $150,000 and an expenditure of 20 rem. Expected exposure reductions were estimated at 7 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1979
- Capital cost for equipment plus installation = $150,000
- Dose o install = 20 rem
- Annual dose savings = 7 rem/yr

- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,200	1,200	2,200	5,200	9,900

BE-82-01A: Cobalt Replacement in PWR Reactor Coolant Pumps (Operating Three-Loop Plants)

Bergman et al. have evaluated the cobalt sources in Westinghouse-designed three- and four-loop plants. Their evaluations indicate that journals, bushings, and radial bearings, all containing stellite, are principal contributors to the cobalt released to the primary system. To replace the cobalt in the main coolant pumps, one would have to replace the shaft and bearing cartridge. From plant experience, this would require an estimated expenditure of 30 rem per pump. The cost to change out and install three parts in a pump would be approximately $260,000. For three-loop plants, averaging five years of operation, the estimated dose savings from elimination of stellite in the main coolant pumps would be 16 rem/yr. These authors assume a useful life of 35 years which is therefore used as the amortization period in these cost-effectiveness evaluations. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Cost of three pumps including installation = $780,000
- Dose to install three pumps = 90 rem
- Annual dose savings = 16 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,900	1,900	4,400	10,000	20,000

BE-82-01B: Cobalt Replacement in PWR Reactor Coolant Pumps (Operating Four-Loop Plants)

Data similar to those of Bergman et al. for a four-loop plant indicate similar costs per pump and dose to install but smaller annual dose savings, namely, 9.2 rem/yr. Input data for the cost-effectiveness evaluations for this modification were therefore:

- Base year for capital costs = 1982
- Capital costs for four pumps including installation - $1,040,000
- Dose to install four pumps = 120 rem
- Annual dose savings = 9.2 rem/yr
- Amortization period = 35 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	6,000	6,000	23,000	32,000	61,000

BE-82-01C: Cobalt Replacement in PWR Reactor Coolant Pumps (Three-Loop Plant Under Construction)

For a three-loop PWR plant under construction, capital cost for installation of three pumps having low-cobalt parts replacing those formerly containing stellite would be approximately $780,000 as for the previous 3-loop example (BE-82-01A), since we assume construction is far enough along to require removal, dismantling, and rebuilding of the pumps. Since the plants have not operated, no dose would be incurred during installation. Also, the assumed amortization in this case is over 40 years. Thus, input data for the cost-effectiveness evaluations for this modification were:

- Base year for captial costs = 1982
- Capital costs for replacing three coolant pumps = $780,000
- Annual dose savings = 16 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,400	1,400	2,900	8,500	17,000

BE-82-01D: Cobalt Replacement in PWR Reactor Coolant Pumps (Four-Loop Plants Under Construction)

This option is similiar to BE-82-01B except that the annual dose savings are estimated at 8.9 rem/yr and the amortization period is over 40 years of plant life. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Cost of installing four coolant pumps = $1,040,000
- Dose to install = 0 rem
- Annual dose savings = 8.9 rem/yr
- Amortization period = 40 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,400	3,400	6,900	20,000	40,000

BE-82-01E: Cobalt Replacement in PWR Reactor Coolant Pumps (Three-Loop Operating Plant, Pumps Replaced for Other Reasons)

If main coolant pumps are being replaced for other reasons, the incremental costs of replacing stellite-containing materials with low-cobalt materials is estimated at $30,000 for three pumps. Since the pumps are being replaced for other reasons, no dose for installation is charged to the cobalt replacement. As for modification BE-82-01A, it is assumed that the plant has operated five years and has a remaining lifetime of 35 years. Input data for the cost-effectiveness evaluations for this modification were therefore:

- Base year for capital cost = 1982
- Development and material costs = $30,000
- Dose to install = 0 rem
- Annual dose savings = 16 rem/yr
- Amortization periods = 35 years

Results for the cost-effectiveness evaluations for this modification were as follows:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	62	62	120	330	630

BE-82-01F: Cobalt Replacement in PWR Reactor Coolant Pumps (Four-Loop Operating Plant, Pumps Replaced for Other Reasons)

This modification is similar to BE-82-01E above; however, annual dose savings are assumed to be 9.2 rem/yr based on operating plant data for existing four-loop plants. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for development and material = $30,000
- Dose to install = 0 rem
- Annual dose savings = 9.2 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	110	110	200	570	1,100

BE-82-02A: Replacement of PWR Control-Rod-Drive Mechanisms with Low Cobalt Parts (Operating Three-Loop PWR Plant)

Control-rod-drive mechanisms in Westinghouse-designed PWR plants have a number of stellite (high cobalt) wear-resistant parts. In their analyses, Bergman et al. indicate release of about 4 to 6 g/yr of cobalt for both three- and four-loop plants. Most of this cobalt is released to the primary coolant loop. It subsequently circulates and deposits as crud throughout the entire primary system. This crud constitutes the major source of radiation exposure from these plants. The cost for replacing the complete latch assembly, using low cobalt parts where applicable, is estimated as $1,800,000 for a three-loop plant. On the basis of field data, it is estimated that collective dose attributable to replacement of the control-rod-drive mechanisms would be 240 rem for the Beaver Valley plant. Annual dose savings attributable to reduced cobalt activation, however, are also proportionately large and result in an estimated annual dose reduction of 23 rem. The operating plant is assumed on average to have five years' operation and therefore a remaining 35-year lifetime. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs of equipment including cost of installation = $1,800,000
- Dose to install = 240 rem
- Annual dose savings = 23 rem/yr

* Amortization period = 35 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,700	3,700	11,000	19,000	38,000

BE-82-02B: Replacement of PWR Control-Rod-Drive Mechanisms with Low-Cobalt Parts (Operating Four-Loop Plant)

This modification is similar to BE-82-02A above, except that it applied to an operating four-loop Westinghouse plant. Dose estimates are based on field experience, which indicates a possible savings of 22 rem/yr. Input data for the cost-effectiveness evaluations were:

* Base year for capital costs = 1982
* Capital cost of hardware and installation = $1,900,000
* Dose to install = 265 rem
* Annual dose savings = 22 rem/yr
* Amortization period = 35 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,400	4,400	15,000	23,000	44,000

BE-82-02C: Replacement of PWR Control-Rod-Drive Mechanisms with Low Cobalt Parts (Three-Loop Plant Under Construction)

This modification is similar to BE-82-02A; however, since the plant is under construction, no dose is incurred during installation. Also, the amortization is the lifetime of the plant, estimated at 40 years. Input data for the cost-effectiveness evaluations for this modification were:

* Base year for capital costs = 1982
* Cost for hardware and installation = $1,800,000
* Annual dose savings = 23 rem/yr
* Dose to install = 0 rem

- Amortization period = 40 years

Results of cost-effectiveness evaluations for this modifi-ation were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	2,300	2,300	4,600	14,000	27,000

BE-82-02D: Replacement of PWR Control-Rod-Drive Mechanisms with Low Cobalt Parts (Four-Loop Plant Under Construction)

This modification is similar to BE-82-02B; however, since the plant is under construction, no dose is attributed to installation. Also the amortization period is the full 40-year assumed lifetime of the plant. Input data for the cost-effectiveness evaluations were:

- Base year for capital cost = 1982
- Capital costs for hardware and installation = \$1,900,000
- Dose to install = 0 rem
- Annual dose savings = 21 rem/yr
- Amortization period = 40 years

Results for the cost-effectiveness evaluations on this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	2,600	2,600	5,300	16,000	31,000

BE-82-02E: Replacement of PWR Control-Rod-Drive Mechanisms with Low-Cobalt Parts (Three-Loop Operating Plant, Replacement Needed for Other Reasons)

This modification is similar to BE-82-02A; however, it is assumed that control-rod-drive mechanisms are being replaced for other reasons and therefore the incremental costs of employing low-cobalt parts in the drive mechanisms is only \$50,000 for material and developmental costs. Since the control-rod-drive mechanisms are being replaced for other reasons, additional dose to install low-cobalt components is 0. Input data for the cost-effectiveness evaluations were:

- Base year for capital costs = 1982
- Capital costs for development and material = \$50,000
- Dose to install = 0 rem

- Annual dose savings = 23 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	72	72	134	380	730

BE-82-02F: Replacement of PWR Control-Rod-Drive Mechanisms with Low Cobalt Parts (Four-Loop Operating Plant, Replacement Needed for Other Reasons)

This modification is similar to BE-82-02B; however, since mechanisms are being replaced for other reasons, capital cost for development and material is only $50,000. Also, no dose is charged to installation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for development and material = $50,000
- Dose to install = 0 rem
- Annual dose savings = 22 rem/yr
- Amortization period = 35 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	76	76	140	400	770

BE-82-03A: Replacement of All Valves in PWR Reactor Coolant System with Low-Cobalt Valves (Three-Loop Operating Plant)

There are a total of 38 valves in the reactor coolant system of a three loop Westinghouse PWR plant. Bergman et al. estimated total cobalt input to the primary system as 2 to 3.2 g/yr from reactor coolant system valves. Bergman et al. considered a high-cobalt alloy area exposed to primary coolant and percent of this area in contact with wear surfaces for gate, globe, check, butterfly, and spray valves. For their analyses, it was assumed that all valves in the reactor coolant system will be replaced with low-cobalt valves. In items BE-82-03E through -03L below, replacement of specific types of valves will be considered for three- and four-loop plants. The total costs for replacement of all valves in a three-loop PWR plant is estimated at $1,700,000, including cost of installation. Dose to install was estimated on the assumption of 5 rem per valve for valves less than five inches and 10 rem for valves greater than five inches. These data were based on plant experience. Estimated annual dose savings were based on consideration of grams/per year cobalt contributed by valve wear in comparison to total grams from all components and total dose per year for the plant. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for equipment and installation = $1,700,000
- Dose to install = 235 rem
- Annual dose savings = 13.6 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	8,200	8,200	110,000	43,000	83,000

BE-82-03B: Replacement of All Valves in PWR Reactor Coolant System with Low-Cobalt Valves (Four-Loop Operating Plant)

This modification is similar to BE-82-03A above; however, four-loop Westinghouse PWRs have a somewhat different valve complement consisting of a total of 46 valves in the entire system. Dose estimates for this modification were based on data obtained from the Trojan plant. Input data for the cost-effectiveness analyses for this modification were:

- Base year for capital costs = 1982
- Capital costs for hardware and installation = $2,000,000
- Dose to install = 260 rem
- Annual dose savings = 12.4 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	13,000	13,000	-82,000	70,000	131,000

Note that the result obtained using present-worth model D is negative, whereas those from the other models are positive. This is due to a change in sign of rem saved from +170 for undiscounted to -29 for discounted.

BE-82-03C: Replacement of All Valves in PWR Reactor Coolant System with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-03A; however, since the plant is under construction, no dose is incurred during installation and the amortization period is 40 years rather than 35. The annual dose savings is estimated as 13 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for captial cost = 1982
- Capital costs for hardware and installation = $1,700,000
- Dose to install = 0 rem
- Annual dose savings = 13 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,800	3,800	7,700	23,000	45,000

BE-82-03D: Replacement of All Valves in PWR Reactor Coolant System with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This modification is similar to BE-82-03B; however, since the plant is under construction, no dose is incurred in the installation. Also, the amortization period is assumed to be 40 years. Input data for the cost-effective evaluations for this modification were:

- Base year for capital costs = 1982
- Capital cost for hardward and installation = $2,000,000
- Dose to install = 0 rem
- Annual dose savings = 12 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,900	4,900	9,800	29,000	57,000

BE-82-03E: Replacement of PWR Reactor Coolant System Check Valves with Low-Cobalt Valves (Three-Loop Operating Plant)

Three-loop Westinghouse PWR plants have nine check valves in the reactor coolant system with significant stellite surfaces which contribute cobalt to the primary system through corrosion and wear. Approximately 3% of the high-cobalt alloyed surface area which is exposed to primary coolant would actually be in contact with another surface so that wear could occur. For this analysis, we estimated the fraction of total cobalt due to valve wear which can be specifically attributed to check valves on the basis of their relative surface areas and percent of area in contact with another surface such that wear could occur. There are six 6-in. check valves and three 12-in. check valves in a typical three-loop plant. It is assumed that 10 rem per valve would be required for replacement. Input data for the cost- effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for valves plus installation = $732,000
- Dose to install = 90 rem
- Annual dose savings = 3.7 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	22,000	22,000	-41,000	110,000	220,000

Note that the result obtained using present-worth model D is negative, whereas those from the other models are positive. This is due to a change in sign of rem saved from +40 for undiscounted to -21 for discounted.

BE-82-03F: Replacement of PWR Reactor Coolant System Check Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

This modification is similar to BE-82-03E; however, in a four-loop plant there are four 10-in., four 6-in., one 2-in., and four 1-1/2-in. check valves. It was assumed that 10 rem per valve was required for installation of the large valves and 5 rem per valve for the five small valves. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs of valves plus installation = $893,000
- Dose to install = 105 rem
- Annual dose savings = 2.7 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
-99,000	-99,000	-19,000	-520,000	-1,000,000

This modification is not recommended since net dose savings are negative and net costs are positive.

BE-82-03G: Replacement of Reactor Coolant System Pump Gate Valves With Low-Cobalt Valves (Three-Loop Operating PWR Plant)

There are six 3-in. gate valves of concern in a reactor coolant system of a typical three-loop Westinghouse PWR plant. Since the high-cobalt parts of the valves are not all in contact with wear surfaces during operation, it is assumed that 12% of the high-cobalt area is effectively in contact and that 5 rem will be incurred for replacement of each valve. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital cost of valves plus installation = $276,000
- Dose to install valves = 30 rem
- Annual dose savings = 3.5 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness analyses for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,500	3,500	9,100	18,000	35,000

BE-82-03H: Replacement of PWR Reactor Coolant System Gate Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

This option is similar to BE-82-03G above; however, the four-loop plants have ten 3-in. gate valves, costing $19,000 plus $27,000 each for installation. Estimated dose to install is 5 rem per valve. Thus, the input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for valves plus installation = $460,000
- Dose to install = 50 rem
- Annual dose savings = 4.6 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,800	4,800	15,000	25,000	49,000

BE-82-03I: Replacement of PWR Reactor Coolant System Globe Valves with Low-Cobalt Valves (Three-Loop Operating Plant)

Three-loop Westinghouse PWR Plants have three 1-1/2-in., fifteen 2-in., and three 3-in. globe valves with significant amounts of high-cobalt stellite. The wear surface only contacts the plug over a small area in these valves, thus the area in contact with a wear surface was estimated at only 1%. It was estimated that about 5-1/2% of the cobalt from all valves in the reactor coolant pump system is due to wear and corrosion of the globe valves in a three-loop plant. Estimated dose to install was 5 rem per valve. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs of valves plus installation = $496,000
- Dose to install = 105 rem
- Annual dose savings = 0.74 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-7,300	-7,300	-6,300	-38,000	-74,000

This modification is not recommended since net dose savings are negative and net costs are positive.

BE-82-03J: Replacement of PWR Reactor Coolant System Globe Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

This analysis is similar to that above for BE-82-03I. The four-loop PWR system has twenty 2-in. globe valves and one 3-in. globe valve with significant amounts of high-cobalt stellite. Capital costs for these valves is $5,000 each and installation is $18,000 per valve for the 2-in. valves and $27,000 per valve for the 3-in. valves. Input data, therefore, for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital cost of valves plus installation = $492,000
- Dose to install = 105 rem
- Annual dose savings = 0.69 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-7,100	-7,100	-6,200	-37,000	-72,000

This modification is not recommended since net dose savings are negative and net costs are positive.

BE-82-03K: Replacement of PWR Reactor Coolant System Spray Valves with Low-Cobalt Valves (Three-Loop Operationg Plant)

There are two 4-in. spray valves with significant amounts of stellite in a typical three-loop Westinghouse PWR plant. These valves cost $45,000 plus $36,000 each for installation with an estimated 5-rem-per-valve installation dose. Spray valves have somewhat greater area of stellite than other valves and the percent of the area in contact with a wear surface is also greater. Consequently, the contribution to cobalt input from these spray valves is significant. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $162,000.
- Dose to install = 10 rem
- Annual dose savings = 5.6 rem/yr
- Amortization period = 35 years

Results for the cost-effectiveness evaluations of this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,000	1,000	2,000	5,300	10,000

BE-82-03L: Replacement of PWR Reactor Coolant System Spray Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

This modification is similar to BE-82-03K above; however, in the four-loop plant the valves cost less ($5,000 each), and installation costs are greater, ($90,000 per valve). Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $190,000
- Dose to install = 10 rem
- Annual dose savings = 4.3 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,600	1,600	3,200	8,300	16,000

BE-82-03M: Replacement of PWR Reactor Coolant System Check Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-03E; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed was 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Captial cost for valves plus installation = $732,000
- Dose to install = 0 rem
- Annual dose savings = 3.6 rem/yr
- Amortization period = 40 years

Results of cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	5,900	5,900	12,000	36,000	70,000

BE-82-03N: Replacement of PWR Reactor Coolant System Check Valves with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This option is similar to BE-82-03F; however, since this plant is under construction, no dose is attributable to installation and the amortization period assumed was 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $893,000
- Dose to install = 0 rem
- Annual dose savings = 2.6 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	10,000	10,000	20,000	60,000	120,000

BE-82-03O: Replacement of PWR Reactor Coolant System Gate Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-03G; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $276,000
- Dose to install = 0 rem
- Annual dose savings = 3.4 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,400	2,400	4,800	14,000	28,000

BE-82-03P: Replacement of PWR Reactor Coolant System Gate Valves with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This option is similar to BE-82-03H, however, since this plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effective-ness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $460,000
- Dose to install = 0 rem
- Annual dose savings = 4.4 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,000	3,000	6,200	18,000	36,000

BE-82-03Q: Replacement of PWR Reactor Coolant System Globe Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-03I; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $496,000
- Dose to install = 0 rem
- Annual dose savings = 0.72 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	20,000	20,000	41,000	120,000	240,000

BE-82-03R: Replacement of PWR Reactor Coolant System Globe Valves with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This option is similar to BE-82-03J; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $492,000
- Dose to install = 0 rem
- Annual dose savings = 0.67 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	21,000	21,000	43,000	130,000	250,000

BE-82-03S: Replacement of PWR Reactor Coolant System Spray Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This option is similar to BE-82-03K; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaulations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $162,000
- Dose to install = 0 rem
- Annual dose savings = 5.4 rem/yr
- Amortization period = 40 year

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	880	880	1,800	5,200	10,000

BE-82-03T: Replacement of PWR Reactor Coolant System Spray Valves with Low-Cobalt Valve (Four-Loop Plant Under Construction)

This modification is similar to BE-82-03L; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $190,000
- Dose to install = 0 rem
- Annual dose savings = 4.2 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,300	1,300	2,700	7,900	16,000

BE-82-04A: Replacement of All Valves in PWR Chemical Volume and Control System with Low-Cobalt Valves (Three-Loop Operating Plant)

There are a total of 54 valves in the chemical volume and control system in a typical three-loop Westinghouse PWR plant. These valves are thought to contribute between 1-1/2 and 2-1/2 grams of cobalt per year to the primary system. In the present analyses, we consider all 54 valves will be replaced. In items BE-82-04E, -04G, and -04I, we consider separately the cost-effectiveness of replacing all check valves, gate valves, and globe valves in the CVCS system, respectively. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital cost for hardware and installation = $1,600,000
- Dose to install = 280 rem

- Annual dose savings = 10 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	27,000	27,000	-20,000	140,000	270,000

Note that the result obtained using present-worth model D is negative, whereas those from the other models are positive. This is due to a change in sign of rem saved from +70 for undiscounted to -93 for discounted.

BE-82-04B: Replacement of All Valves in PWR Chemical Volume and Control System with Low-Cobalt Valves (Four-Loop Operating Plant)

A modification similar to that above for a four-loop plant reveals that replacement of all valves in the CVCS system is not cost effective since there is a net rem cost rather than savings. However, the data will be analyzed for purposes of comparison. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for hardware and installation = $1,700,000
- Dose to install = 260 rem
- Annual dose savings = 6 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-40,000	-40,000	-13,000	-210,000	-400,000

This modification is not recommended since net dose savings are negative and net costs are positive.

BE-82-04C: Replacement of All Valves in PWR Chemical Volume and Control System with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This analysis is similar to BE-82-04A; however, for plants under construction no dose would be incurred during installation, and the amortization period would be 40 years rather than 35. As a result, input data for the cost-effectiveness evaluations for this option were:

- Base year for capital costs = 1982
- Costs of hardware and installation = $1,600,000
- Dose to install = 0 rem
- Annual dose savings = 10 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,700	4,600	9,400	28,000	55,000

BE-82-04D: Replacement of All Valves in PWR Chemical Volume and Control System with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This modification is similar to BE-82-04B; however, since the plant is under construction no dose is incurred during installation of the modification, and the amortization period assumed is 40 years. Therefore, input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for hardware and installation = $1,700,000
- Dose to install = 0 rem
- Annual dose savings = 5.8 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	8,500	8,500	17,000	51,000	100,000

BE-82-04E: Replacement of Check Valves in the PWR Chemical Volume and Control System with Low-Cobalt Valves (Three-Loop Operating Plant)

There are 21 check valves in the CVCS system of a three-loop Westinghouse PWR plant, which contain significant amounts of high-cobalt stellite. These check valves contribute about half as much cobalt to the primary system as the reactor coolant check valves since they are much smaller. It was assumed that

5 rem were required for installation of each valve. Cost of each valve varied from $5,000 to $7,500 and cost to install from $6,750 to $3,600. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $531,000
- Dose to install = 105 rem
- Annual dose savings = 1.5 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-12,000	-12,000	-8,000	-62,000	-120,000

This modification is not recommended since <u>net dose savings are negative</u> and net costs are positive.

<u>BE-82-04F: Replacement of Check Valves in the PWR Chemical Volume and Control System with Low-Cobalt Valves (Four-Loop Operating Plant)</u>

This modification is similar to BE-82-04E above; however, in the four-loop plant there is a total of 30 check valves, all four inches or less in size. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $768,000
- Dose to install = 145 rem
- Annual dose savings = 2.0 rem/yr
- Amortization period = 35 years

Results for the cost-effectiveness evaluations of this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-12,000	-12,000	-8,300	-63,000	-120,000

This modification is not recommended since <u>net dose savings are negative</u> and net costs are positive.

BE-82-04G: Replacement of PWR CVCS Gate Valves with Low-Cobalt Valves (Three-Loop Operating Plant)

There is a total of 13 gate valves in the CVCS system of a three-loop Westinghouse PWR plant that have significant amounts of high-cobalt stellite. Since the high-cobalt parts in the valves are not all in contact with wear surfaces during operation, it is assumed that 12% of the stellite surface area is effectively in contact with wear surfaces. It was assumed that the 6-in. gate valves required 10-rem dose for installation and the other 12 smaller gate valves each required 5 rem. Input data for the cost-effectiveness evaluations for this modification were:

- Base year fo capital cost = 1982
- Capital cost for valves plus installation = $665,000
- Dose to install = 70 rem
- Annual dose savings = 8.1 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,600	3,600	9,600	19,000	37,000

BE-82-04H: Replacement of PWR CVCS Gate Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

There are four 4-in. and two 3-in. gate valves in the CVCS system of a four-loop PWR plant that have significant amounts of high-cobalt stellite. It is estimated that a dose of 5 rem per valve would be incurred during installation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $312,000
- Dose to install = 35 rem
- Annual dose savings = 3.6 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,000	4,000	11,000	21,000	41,000

BE-82-04I: Replacement of PWR CVCS Globe Valves with Low-Cobalt Valves (Three-Loop Operating Plant)

There is a total of 21 globe valves with significant amounts of stellite in the CVCS system of a three-loop Westinghouse PWR plant. Since these valves are all rather small (less than three inches) and only about 1% of the stellite contacts a wear surface, they contribute only small amounts of cobalt to the primary circuits. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $391,000
- Dose to install = 105 rem
- Annual dose savings = 0.5 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-5,200	-5,200	-4,800	-27,000	-53,000

This modification is not recommended since net dose savings are negative and net costs are positive.

BE-82-04J: Replacement of PWR CVCS Globe Valves with Low-Cobalt Valves (Four-Loop Operating Plant)

There is a total of 16 globe valves with significant amounts of stellite in the CVCS system of a four-loop Westinghouse PWR plant. Since these valves are all less than three inches in size, and only about 1% of the stellite surface area is in contact with a wear surface, their cobalt contribution to the primary system is rather nominal. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $384,000
- Dose to install = 80 rem

- Annual dose savings = 0.43 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-6,900	-6,900	-6,200	-36,000	-70,000

This modification is not recommended since <u>net dose savings are negative</u> and net costs are positive.

BE-82-04K: Replacement of PWR CVCS Check Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-04E; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $531,000
- Dose to install = 0 rem
- Annual dose savings = 1.5 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	10,000	10,000	21,000	62,000	120,000

BE-82-04L: Replacement of PWR CVCS Check Valves with Low-Cobalt Valves (Four-Loop Plant under Construction)

This modification is similar to BE-82-04F; however, since the plant is under construction, no dose is attributable to installation and the amortization period is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982

- Capital cost of valves plus installation = $768,000
- Dose to install = 0 rem
- Annual dose savings = 1.9 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	12,000	12,000	24,000	71,000	140,000

BE-82-04M: Replacement of PWR CVCS Gate Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

There are 13 gate valves with significant amounts of stellite in the CVCS system of a three-loop Westinghouse PWR plant. One of these is a 6-in. valve, the others are all four inches or less. These valves contibute significantly to the cobalt content in the primary system. This modification is similar to BE-82-04G; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $665,000
- Dose to install = 0 rem
- Annual dose savings = 7.9 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,500	2,500	5,000	15,000	29,000

BE-82-04N: Replacement of PWR CVCS Gate Valves with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This modification is similar to BE-82-04H; however, since the plant is under construction, no dose is attributable to installation and the amortization period assumed is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $312,000
- Dose to install = 0 rem
- Annual dose savings = 3.5 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,600	2,600	5,300	16,000	31,000

BE-82-04O: Replacement of PWR CVCS Globe Valves with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar BE-82-04I; however, since the plant is under construction, no dose is attributable to installation and the assumed amortization period is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost for valves plus installation = $391,000
- Dose to install = 0 rem
- Annual dose savings = 0.5 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	23,000	23,000	46,000	140,000	270,000

BE-82-04P: Replacement of PWR CVCS Globe Valves with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This modification is similar to BE-82-04J; however, since the plant is under construction, no dose is attributable to installation and the amortization period is 40 years. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital cost of valves plus installation = $384,000
- Dose to install = 0 rem
- Annual dose savings = 0.43 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	26,000	26,000	53,000	160,000	310,000

BE-82-05A: Replacement of All PWR Loop Stop Valves in RCS System with Low-Cobalt Valves (Three-Loop Operating Plant)

Bergman et al. indicate that the loop stop valves in a typical three-loop Westinghouse PWR plant are contributors to cobalt input to the primary system. This input is due almost entirely to corrosion input, and contributes approximately 30% to the total cobalt input from all valves in the primary system. However, capital costs for these valves and their installation are high and thus the cost-effectiveness for their replacement is not as great as for some other valves in the primary system. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for hardware and installation = $3,900,000
- Dose to install = 120 rem
- Annual dose savings = 15 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	11,000	11,000	28,000	59,000	110,000

BE-82-05B: Replacement of All PWR Loop Stop Valves in RCS System with Low-Cobalt Valves (Four-Loop Operating Plant)

This analysis is similar to BE-82-05A; however, it applies for a four-loop

Westinghouse PWR plant. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for hardware and installation = $5,200,000
- Dose to install = 160 rem
- Annual dose savings = 15.5 rem/yr
- Amortization peri d = 35 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	16,000	16,000	47,000	83,000	160,000

BE-82-05C: Replacement of All PWR Loop Stop Valves in RCS System with Low-Cobalt Valves (Three-Loop Plant Under Construction)

This modification is similar to BE-82-05A; however, since the plant is under construction, the dose incurred by installation is zero, and the amortization period assumed is 40 years. Therefore, input data for the cost-effectiveness evaluation for this modification were:

- Base year for capital costs = 1982
- Capital costs for equipment and installation = $3,900,000
- Dose to install = 0 rem
- Annual dose savings = 14.5 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	7,800	7,800	16,000	47,000	92,000

BE-82-05D: Replacement of All PWR Loop Stop Valves in RCS System with Low-Cobalt Valves (Four-Loop Plant Under Construction)

This modification is similar to that of BE-82-05B, except that it is for a four-loop PWR plant which is under construction; therefore, installation dose is zero, and the amortization period is 40 years. Input data for the cost-effectiveness evaluation for this modification are, therefore:

- Base year for capital costs = 1982
- Capital costs of equipment and installation = $5,200,000
- Dose to install = 0 rem
- Annual dose savings = 15 rem/yr
- Amortization period = 40 years

Results for cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	10,000	10,000	20,000	61,000	120,000

BE-82-06A: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Three-Loop Operating Plant)

In this option, it is assumed that all three steam generators in the three-loop Westinghouse PWR plant are being replaced in order to reduce cobalt contributions to the primary system. As a result, the entire capital cost is attributable to the replacement. A major limitation of the analysis for this option is that no account has been taken of replacement power costs. We assume that waste disposal costs are included in the $66,000,000 capital cost of installation. The analyses are based on data in the report of Bergman et al. Dose estimates are based on field data.

Input data for the cost-effectiveness evaluations for this modification were:

- Base year capit l costs = 1982
- Capital costs of equipment plus installation = $66,000,000
- Dose to install = 3,000 rem
- Annual dose savings = 134 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	46,000	46,000	-150,000	240,000	460,000

Note that the result obtained using present-worth model D is negative, whereas those from the other models are positive. This is due to a change in sign of rem saved from +1700 for undiscounted to -500 for discounted.

BE-82-06B: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Four-Loop Operating Plant)

This modification is similar to BE-82-06A, except that it applies to a four-loop Westinghouse PWR Plant. Input data for the cost-effectiveness evaluations were:

- Base year for capital costs = 1982
- Capital costs of equipment plus installation = $88,000,000
- Dose to install = 4,000 rem
- Annual dose savings = 180 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	45,000	45,000	-160,000	230,000	450,000

Note that the result obtained using present-worth model D is negative, whereas those from the other models are positive. This is due to a change in sign of rem saved from +2,300 for undiscounted to -640 for discounted.

BE-82-06C: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Three-Loop Plant Under Construction)

This modification is similar to BE-82-06A; however, since the plant is under construction, dose attributable to installation is equal to zero, and the amortization period assumed is 40 years. Thus, input data for the cost-effectiveness evaluation for this modification were:

- Base year for capital costs = 1982
- Capital cost for equipment plus installation = $66,000,000
- Dose to install = 0 rem
- Annual dose savings = 130 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	15,000	15,000	30,000	89,000	170,000

BE-82-06D: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Four-Loop Plant Under Construction)

This option is similar to BE-82-06B; however, since this plant is under construction, the dose to install is zero and the assumed amortization period is 40 years. Input data for the cost-effectiveness evaluation for this modification were:

- Base year for capital costs = 1982
- Capital costs of equipment plus installation = $88,000,000
- Dose to install = 0 rem
- Annual dose savings = 138 rem/yr
- Amortization period = 40 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	19,000	19,000	39,000	110,000	220,000

BE-82-06E: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)

For some plants, steam generators have deteriorated to the point that replacement is necessary. In this case, it is of interest to evaluate the cost effectiveness of additional costs incurred by specification of low-cobalt tubing for the replacement steam generators. From the data of Bergman et al., it is estimated that low-cobalt tubing costs an additional $100,000 per steam generator. Since only this cost is attributable to the capital costs of the low-cobalt option, this option becomes highly cost effective relative to that in which the entire cost of the steam generator must be attributable to the replacement. Thus, this modification is similar to BE-82-06A, except for a lower capital cost. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982

- Capital costs for low-cobalt specification = $300,000
- Additional dose attributable to installation = 0 rem
- Annual dose savings = 134 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	75	75	140	390	760

BE-82-06F: Replacement of PWR Steam Generators with Those Containing Low-Cobalt (<0.015%) Tubing (Four-Loop Operating Plant, Replacement Needed for Other Reasons)

This modification is similar to BE-82-06B; however, for this option it is assumed that steam generators were being replaced for other reasons. Consequently, the only incremental costs attributable to the low-cobalt is approximately $100,000 per steam generator. In addition, since the steam generators were being replaced anyway, the incremental dose attributable to the low-cobalt specification is zero. Input data for the cost-effectiveness evaluations for this modification were:

- Base data for capital costs = 1982
- Capital costs of low-cobalt specification = $400,000
- Additional dose for installation = 0 rem
- Annual dose savings = 143 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	93	93	180	490	950

DU-82-01: Reduce Cobalt Impurity in New PWR Steam Generator Tubing (Sizewell 'B' Plant)

This modification is similar to BE-82-06E; however, the estimated annual dose savings are somewhat less since the evaluation was made for the Sizewell 'B' Plant, which has a number of modifications that limit total annual doses. The authors of this report estimated that a reduction in the cobalt impurity level of the tubing to 0.015% would reduce the release rate of cobalt into the primary coolant by a factor of approximately 2. It was further estimated that, on the basis of U.S. experience, cobalt-60 contributes about 75% of the total dose after the first two years of station life. Considerations of the dose savings due to low-cobalt impurity in the steam generator were based on a Sizewell 'B' nominal plant experiencing 230 rem/yr. Therefore, with the above factors of 0.75 x 0.5, the net savings are equivalent to about 90 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of employing low cobalt in steam generator tubing = $330,000
- Dose to install = 0 rem
- Annual dose savings = 90 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	130	130	230	600	1,100

DU-82-02: Magnetic Filtration in New PWR Plant

Use of magnetic filtration was considered in the design of the Sizewell 'B' Plant in order to reduce the corrosion product inventory and therefore deposition in the primary system. This type of filtration has the advantage that it can operate at high flow rates and high temperatures; however, it is still in the research and development phase for application in power reactors. Uncertainties remain regarding efficiency versus particle size and possible contribution of the filter to soluble corrosion products. Costs for a magnetic filtration installation in the Sizewell 'B' Plant were based on needs of a major redesign in one of the most critical areas of the plant. For a filter capable of handling 0.5% of full power flow, the filter system cost was estimated at $18,750,000 (U.S.).

As a result of the additional number of welds and valves in the system, the in-service inspection and maintenance dose for the plant is estimated to be increased by about 10 rem/yr. The dose and costs of the associated waste arising from the filtration unit will depend on the disposal concept which is adopted. A reasonable estimate of waste disposal cost for 75 drums per year using an estimated disposal cost of $360 per drum is $27,000/yr waste. Input for the cost-effectiveness evaluations for this modification were:

- Base year for Capital Cost = 1983

- Capital costs of equipment + installation = $18,750,000
- Dose to install = 0 rem
- Annual dose savings = 112 rem/yr (for Sizewell 'B' Plant)
- Amortization period = 30 years
- Additional waste disposal costs = $27,000/yr

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	6,300	6,200	11,000	28,000	52,000

DU-82-03: PWR Reactor Pressure-Vessel-Head Laydown Shield

A reactor pressure-vessel-head laydown shield protects the workers while changing the head O-rings. Dose rates of up to several rem/hr are typical from crud deposited inside the head dome. It was estimated that such a shield would save approximately 3 rem/yr collective dose at the Sizewell 'B' Plant. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of equipment and installation = $15,000
- Annual dose savings = 3 rem/yr
- Dose to install = 0 rem
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	180	180	310	810	1,500

DU-82-04: PWR Reactor Pressure-Vessel-Head Laydown Area Shield

Normally, the reactor pressure-vessel-head must be parked in the general area of the operating floor and contributes to high dose rates throughout the general area. Some French and German plants segregate the reactor pressure-vessel-head from the general area by means of a parking area shield. This has also proved effective at the Kewaunee and Prairie Island Plants in the U.S. It is important that a special parking area for the pressure-vessel-head be planned in the early stages of plant design. For the Sizewell 'B' Plant, it was estimated that design and installation costs for this provision would be about $75,000, and that the reduced exposures would be approximately 1 to 2 rem/yr, assuming the use of a SIGMA refueling machine. Thus, other plants not employing this refueling machine would have even larger savings. Input data for the cost-effectiveness evaluation of this modification for a plant such as the Sizewell 'B' Plant were:

- Base year for capital cost = 1983
- Additional design engineering and installation cost = $75,000
- Dose to install = 0 rem
- Annual dose savings = 1.5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,800	1,800	3,100	8,100	15,000

DU-82-05: PWR Steam Generator Tube Inspection and Repair Robot

One of the most effective methods of reducing collective dose in a PWR plant is to perform eddy-current testing, inspection, tube repairs, and ultrasonic inspection of the channel head welds remotely using a specially designed robotic device. A number of such systems are currently being developed (see EG-84-05A and EG-84-05B, below). The remotely operated service arm (ROSA) developed by Westinghouse is typical. ROSA is a highly sophisticated device with a number of different control modes. A variety of special tools can be attached to the service arm to do several different maintenance operations inside steam generators. Operators are required to install the arm in the channel head but it is not necessary for a man to enter the channel head. Once installed, the device is operated from a trailer containing the control center which is positioned outside the containment. Estimated cost for this device is approximately $450,000. For this evaluation, we assume maintenance costs to be 4% of capital cost, or $18,000/yr. Estimated savings are approximately 75 rem/yr on a typical four-loop Westinghouse plant in the U.S. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of equipment = $450,000
- Maintenance cost = $18,000/yr

- Dose to install = 0 rem
- Net annual dose savings = 75 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	480	370	630	1,500	2,800

DU-82-06: PWR Quick-Opening Fuel Transfer Tube Closure (New Plant, on Critical Path)

The fuel transfer system in a typical Westinghouse PWR plant employs a blind flange closure on the refueling cavity end of the fuel transfer tube. This flange is attached to the tube by 20 bolts, which must be manually removed and reinstalled at each refueling. Normally, it takes two men up to one hour to remove the flange and about two hours to install it. For a new plant such as Sizewell 'B', an estimated annual dose savings of approximately 0.5 rem/yr would be achieved. Critical-path time saving was estimated at 3 hours per refueling. Replacement power costs were not stated but are assumed to be \$31,250/hr in these evaluations. One refueling operation per year is also assumed. Annual labor cost will be reduced by approximately \$120 per year on the basis six man-hours per year saved. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Cost for capital equipment plus installation = \$15,000
- Annual labor savings = \$120/yr
- Dose to install = 0 rem
- Annual replacement power savings = \$94,000/yr
- Annual dose savings = 0.5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	-200,000	-120,000	-200,000	-390,000	-730,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

DU-82-07: Multi-Stud Tensioner/Detensioner and Handling Device for PWR Steam Generator Manway Covers

Manual removal of one manway cover from the steam generator typically results in a dose of about 0.6 rem on U.S. PWR plants. Multi-stud tensioning and detensioning devices are available for removing the bolts from the steam generator manway cover. The manway cover is removed with a related handling device. These are used in a number of European plants and cost approximately $90,000. For the Sizewell 'B' Plant, it was anticipated that two units would be required, thus providing one unit for a pair of steam generators. The dose savings on such a four-loop plant would be about 3 to 4 rem/yr. This analysis is based on a new plant design in which adequate space and arrangements have been provided for use of such devices. Annual maintenance costs are estimated at 4% of capital cost. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for two complete units = $180,000
- Dose to install = 0 rem
- Annual dose savings = 3.5 rem/yr
- Annual maintenance cost = $7,200
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	4,100	3,100	5,400	13,000	24,000

DU-82-08: PWR Power Level Monitor Using ^{16}N Detectors

Instead of monitoring reactor power levels using temperatures derived from a flow through the dedicated RTD (reactor temperature detectors) bypass manifolds, one can measure reactor power by monitoring ^{16}N activity of the coolant. The RTD manifolds and valves tend to trap crud and thus contribute shutdown radiation levels near the coolant loops, particularly near the steam generator channel head. Also, the RTD bypass system has proved to be troublesome and requires extensive maintenance on operating plants. Nitrogen-16 power monitors are available from Westinghouse for approximately $15,000. For the Sizewell 'B' station, it was estimated that use of these monitors would save approximately 8 rem/yr collective dose. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983

- Capital cost of equipment plus installation = $15,000
- Dose to install on a new plant = 0 rem
- Annual dose savings = 8 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	68	68	120	300	580

DU-82-09: PWR Dedicated Refueling Pool Filter/Demineralizer System

Dose rates above the refueling pool can be reduced by improving the cleanup system. In the Sizewell 'B' Plant reference design, a separate system for purefying the refueling pool during refueling was considered. The system contained one centrifugal pump, four filters in parallel, two mixed-bed demineralizers each with a strainer, and two float-type skimmers. The pump was designed for 100% of the system capacity and the demineralizers were each designed for 50% of the system capacity. During refueling when the refueling cavity is full, the refueling pool cleanup pump removes water from the pool and transfers it through the cleanup filters and demineralizers and back to the pool. In addition, the cleanup can be augmented by the chemical and volume control system via the residual heat removal system. These operations are continued during the entire refueling process to maintain water quality. Average dose savings were expected to be 1 or 2 rem per refueling. Also, some benefit was expected from reduced fuel shuffling time due to improved water clarity. Since this would be critical-path time, it constitutes the major cost savings to be expected from this modification. It is therefore important that a value be determined for expected refueling time savings; however, no estimate was made in the Sizewell 'B' analysis and, therefore, none is included in this cost-effectiveness evaluation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital costs of equipment plus installation = $1,500,000
- Dose to install = 0 rem
- Annual dose savings = 1.5 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness benefit analyses for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	36,000	36,000	62,000	160,000	310,000

DU-82-10: Shielding of PWR Reactor Coolant Pump Motor Compartment and Provision of Permanent Access Features in Primary Loop Cells

Exposure in typical plants during maintenance of reactor coolant pumps could be reduced by shielding the pump motor and the seal change areas from the reactor coolant pump itself. This can be achieved by incorporating shielding into the floor above the pump bowl and erecting a shield above this floor between the reactor coolant pump and the steam generator in each loop. Another possible way of reducing exposure is to incorporate additional permanent man-access features that eliminate the need to erect temporary scaffolding in the relatively high-radiation areas of primary loop cells. These modifications, however, affect other safety aspects of the plant such as ventilation and structural loading on the floors. Thus, careful engineering design and planning are required. For the Sizewell 'B' Plant, costs and dose savings were estimated for provision of a 5-cm-thick steel shield floor in the pump cell, a 10-cm-thick solid shield wall between the pump and the steam generator, and permanent platforms within the loop cells. Costs were estimated to be $75,000, $300,000 and $225,000, respectively. Estimated dose savings were 9.7 rem/yr. Thus, the input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital costs of engineering design, equipment and construction = $600,000
- Dose to install in new plant = 0 rem
- Annual dose savings = 9.7 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,200	2,200	3,900	10,000	19,000

DU-82-11: Multi-Stud Tensioners/Detensioners for PWR Reactor Pressure Vessel (on Critical Path)

Commercially available multi-stud tensioners/detensioners are capable of both tensioning and detensioning reactor vessel closure studs, removing and inserting the studs from the flange, and handling the full complement of studs, nuts and washers from or to the reactor pressure vessel. Most of these operations are carried out with a remote-control panel on the operating floor. For the Sizewell 'B' Plant, the cost differential of using a multi-stud tensioning device rather than three single-stud tensioners, two stud-removal devices, three storage racks for studs, nuts, and washers, and associated hydraulic/-electrical power units and handling equipment is approximately \$600,000. It was estimated that use of this equipment would reduce dose to operators by about 8 rem per refueling outage compared to the system of single-stud tensioning and removal. In addition, the short operating time required when using the multi-stud tensioning devices reduces the time for refueling outages and unscheduled shutdowns, which require removal of the reactor pressure-vessel-head, by approximately one day. No value was given for the cost of replacement power for the 1200-MWe Sizewell 'B' Plant; however, the estimate for a typical 750-MWe U.S. plant is approximately \$750,000/day. Annual maintenance costs are estimated here at 4% of capital cost. Assuming the reactor pressure-vessel-head is removed annually, the input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital costs of equipment plus installation = \$600,000
- Dose to install = 0 (for a new plant)
- Annual dose savings = 8 rem/yr
- Annual replacement power savings = \$750,000/yr
- Annual maintenance cost = \$24,000
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	-95,000	-54,000	-93,000	-180,000	-340,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

DU-82-12: PWR Integrated Head Assembly (New Plant, on Critical Path)

The integrated head assembly being considered for the Sizewell "B" PWR Plant will eliminate many of the operations normally required for removal and replacement of the lifting rig, the concrete missile shield, and the cooling system and cables for the control rod drive mechanism. It was estimated that this would save one day of refueling time, 100 man-hours labor, and 4 rem collective dose each refueling. Assuming \$30,000/hr replacement power cost, \$20/hr labor cost, and \$75,000 capital cost, the input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = $1983
- Capital cost for equipment and installation = $75,000
- Dose to install = 0 rem
- Annual replacement power savings = $720,000
- Annual labor savings = $2,000/yr
- Annual dose savings = 4 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-190,000	-110,000	-190,000	-370,000	-710,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

DU-82-13: PWR Refueling Machine (New Plant, on Critical Path)

A manipulator crane with automatic x-y position control was considered for refueling of the Sizewell "B" PWR Plant. The machine handles thimble plugs and rod cluster control assemblies as well as fuel assemblies. The refueling machine has an underwater TV system. This machine could save an estimated 57 hours of refueling time and approximately 2 to 5 rem per year collective dose. Additional cost over a standard refueling machine is estimated at $225,000. Using $30,000/hr as replacement power cost, and assuming annual maintenance costs equal 4% of capital cost, the input data for this modification were:

- Base year for capital cost = 1983
- Capital cost for equipment = $225,000
- Dose to install = 0 rem
- Annual replacement power savings = $1,710,000/yr
- Annual dose savings = 3 rem/yr
- Maintenance cost = $9,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	-610,000	-350,000	-610,000	-1,200,000	-2,200,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

DU-83-01: Shredder-Compactor for Dry Active Waste

Dry active waste consisting of paper, rags, wood, sheet metal, tools, and other miscellaneous materials are typically compacted with either a drum or box compactor. Typically, 5,000 to 30,000 ft^3/yr of dry active waste are generated per plant. EDS Nuclear has evaluated the cost effectiveness of a combination shredder-compactor, which could achieve a volume reduction factor of 1.7 over use of a compactor alone. A Saturn Model 52-32 shredder was employed in the evaluation. This unit is capable of shredding wood, plastics, rubber, cloth, paper, and nonferrous metals. Steel with cross sections up to 1/4-in. may also be shredded. Using a 200-horsepower drive system and 1-1/2-in. cutting blades, the shredder can process 50 to 75 ft^3/min of compacted waste. The shredder can also process compacted waste including 55-gallon drums containing paper, plastic, rubber, and small amounts of wood and metal. The shredder assembly can be mated with virtually any type of compacter. Large box compactors, for example, 5 x 5 x 5 ft, are desirable since fewer drums will then need handling. Cost-effectiveness evaluations for this modification were based on an assumed annual disposal volume of 18,000 ft^3 using a typical drum-box compactor, distance to burial site of a 1,000 miles, cost of transportation and disposal of \$25/ft^3, and a volume reduction factor of 1.7. Installed cost of a shredder-compactor was estimated at \$450,000, assuming no additional cost for space for the equipment. Annual labor requirements were reduced from 2,380 to 430 man-hours, using the combination shredder-compactor with a savings of \$39,000/yr based on \$20/hr labor cost. Estimated radiation exposure would be reduced from 11.3 rem/yr to 0.8 rem/yr. Costs for tranportation would be reduced from \$118,800 to \$70,000/yr and for disposal from \$313,200 to \$184,400/yr. Maintenance cost was not included, which we assume here would be 5% of capital cost or \$22,500/yr. For this analysis, we also assume additional annual taxes of \$9,000/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of equipment plus installation = \$450,000
- Labor cost savings = \$39,000/yr
- Transportation and disposal cost savings = \$177,600/yr
- Additional annual taxes = \$9,000/yr

- Maintenance cost = $22,500/yr
- Dose to install = 0 rem
- Annual dose savings = 10.5 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-18,000	-11,000	-17,000	-29,000	-53,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

DU-85-01: Low-Cobalt Specifications for PWR Fuel Assembly Nozzles (New Plant)

Typically, fuel assembly nozzles are made from material with a cobalt specification of <0.12%. In practice, values of 0.07% are obtained. Recent quotes have been received indicating a cost of $6.00 to $12.00 per assembly for units with a cobalt specification of <0.015%. Currently, approximately 4 rem/yr collective dose is attributed to nozzle exposure, and thus an estimated saving of 3.1 rem/yr (4 - 4 x 0.015/0.07) could be achieved using the lower cobalt nozzles. Assuming 64 nozzle assemblies are changed per year, the additional annual cost would be $384 to $768 per year. The input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1984
- Annual material costs = $576/yr
- Dose to install = 0 rem
- Annual dose savings = 3.1 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	190	110	190	360	680

EG-84-01: PWR Quick-Opening Hatch for Fuel Transfer Tube (Not on Critical Path)

In PWR plants, fuel is transferred from the containment to the fuel-handling building by a fuel transfer tube. This tube historically has been covered with a blind flange held in place by about 20 bolts. More recently, quick-opening hatches have been designed and are now available for installation in new plants (as described in DU-82-06 above). During the 1982 outage, a submarine-type quick-opening hatch was installed in one of the Swedish plants at a cost of $20,000 (U.S.) and an installation exposure of 1.7 rem. Estimated savings of about 1 rem per refueling, based on the contamination levels at that time, would be achieved with the new installation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Cost of capital equipment = $20,000
- Dose to install = 1.7 rem
- Annual dose savings = 1 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	820	820	1,500	3,700	7,000

EC-84-02A: Temporary Shielding for PWR Reactor Vessel Head

To reduce the exposure during preparation for lift of the reactor vessel head and the reinstallation of the head, temporary lead sheet shielding has been used at the Ringhals 2 Plant. Cost of the lead sheet is about $1,500 (U.S.). Annual dose savings from this shielding are approximately 3.5 rem/yr net. No data were given on labor costs to install and remove the shielding. Twenty man-hours at $20/hr is assumed here. Input data for the cost effectiveness evalations for this modification were as follows:

- Base year for capital costs = 1981
- Cost of capital equipment = $1,500
- Annual labor costs = $400/yr
- Annual dose savings = 3.5 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	170	110	180	340	630

EG-84-02B: Permanent Shield for PWR Reactor Vessel Head (Three-Reactor Site)

Permanent and more effective shields for the reactor vessel heads at the Ringhals 2, 3 and 4 plants have been designed. These shields will have a capital cost of approximately $185,000 (U.S.). Annual labor costs to install are assumed negligible. The permanent shield is expected to save an additional 8.4 rem/yr per reactor over that of temporary shielding (3.5 rem/yr) for a total savings of 11.9 rem/yr per reactor or 35.7 rem/yr for the three reactor sites. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1984
- Capital cost of equipment = $185,000
- Dose to install = 0 rem
- Annual dose savings (estimated) = 35.7 rem/yr
- Amortization period = 25 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	210	210	330	790	1,400

EG-84-03A: Shielding for PWR Reactor Upper Internals (Single-Reactor Site)

The reactor vessel flange and its bolt holes and sealed surfaces require cleaning and inspection each year. To lower the exposures at the three Swedish PWR plants, a shield costing $19,500 (U.S.) was purchased which can be installed on top of the upper internals of this reactor to reduce exposures during these jobs. This evaluation is based on its use at Ringhals 2 where the average dose before the modification was 2.75 rem and afterwards 1.1 rem. Although the unit can be used at three plants, its entire cost is apportioned to a single plant for this evaluation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980
- Cost of capital equipment = $19,500

- Annual dose savings = 1.65 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	640	640	1,000	2,400	4,500

EG-84-03B: Shielding for PWR Reactor Upper Internals (Two-Reactor Site)

For this analysis we assume that the shield described in EG-84-03A can be used at a second reactor at the same site. We also assume that it requires 8 man-hours of labor at $20/hr to move the shield from one reactor plant to the other. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980
- Cost of capital equipment = $19,500
- Labor costs = $160/yr
- Annual dose savings = 3.35 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	380	360	570	1,300	2,400

EG-84-04: Handling Equipment for PWR Steam Generator Manway Covers

Egner has reported on steam generator manway covers designed and built by the maintenance department at the Ringhals Nuclear Power Plant. Capital cost was only $5,600 (U.S.). The average collective dose for dismantling and reinstallation of the manway covers on three steam generators in Ringhals 2 was reduced from 3.1 rem to 2.2 rem for a dose reduction of 0.9 rem per steam generator overhaul. It is anticipated that the steam generator will have to be opened for maintenance approximately twice per year. Average dose savings are therefore estimated at 1.8 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982

- Capital cost of equipment = $5,600
- Annual dose savings = 1.8 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluation for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	150	150	230	550	1,000

EG-84-05A: Manipulator for PWR Steam Generator Tube Inspection and Repair (Three-Reactor Site)

A special manipulator originally designed for eddy-current testing in steam generators at the Ringhals plants has in fact not yet been used for that purpose; however, it has been used for tube pulling and steam generator sleeving (a similar modification is described in DU-82-05 above). During tube pulling in 1983, 15 tubes were pulled at a cost of 36 rem instead of the expected 90 to 105 using standard methods. To achieve this success it was also necessary to provide extensive training in mock-ups.

For the three PWR plants on the Ringhals site, dose savings are expected to be as high as 25 rem/yr for eddy-current testing alone. The estimated cost of a commercial manipulator is $175,000. Since it is desirable to work on two generators simultaneously, two manipulators would normally be needed at a single-unit site. Since there are three units at Ringhals, it was decided to keep a third manipulator as a spare. Total investment cost for this site, therefore, is estimated at $525,000. Dose savings at the Ringhals station were conservatively estimated to be 685 rem over a 25 year period or 30.6 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1984
- Cost of three manipulators = $525,000
- Annual dose savings = 30.6 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	690	690	1,100	2,600	4,800

EG-84-05B: Manipulator for PWR Steam Generator Tube Inspection and Repair (Single-Reactor Site)

Assuming the above manipulator for steam generator work was employed at a site with a single reactor, it is likely that only two manipulators would be purchased for a total capital investment of $350,000. For this analysis we will also make the conservative assumption that the annual dose savings is primarily due to eddy-current testing and is equal to 10.2 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1984
- Capital cost for equipment = $350,000
- Annual dose savings = 10.2 rem/yr
- Amortization period = 25 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,400	1,400	2,200	5,200	9,600

EG-84-06: Ultrasonic Testing of PWR Pressurizer Surge Line (Three-Reactor Site)

Dose rates around the primary system dimineralizers and spent resin tank in Swedish PWRs are high enough that some inspections have been temporarily suspended. In 1983, a special tool for in-service inspection was tried for ultrasonic testing of the pressurizer surge line which has a dose rate of about 15 rem/hr at the test point. On the basis of the current testing frequency, an estimated 17 rem could be saved by inspection of the three PWRs in the next eight years. The investment for this equipment is about $8,000 (U.S.). Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital cost for equipment = $8,000
- Annual dose savings = approximately 2.1 rem/yr
- Amortization period = 8 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	510	510	610	920	1,300

EG-84-07: Relocation of Instrument Readout at PWR Spent-Fuel Pit Heat Exchanger

It is the practice at Swedish plants to limit inspections in areas where dose rates are above 100 mrem/hr or airborne activity is over 10 MPC or surface contamination is greater than 10^{-2} uCi/cm^2. To avoid unnecessary exposure, some instruments have been relocated. One example is the relocation of instruments from the spent-fuel pit heat-exchanger room. The collective dose saved was estimated as between 0.01 and 1.0 rem/yr, depending on the amount of damaged fuel. For this evaluation, we assume a dose saving of 0.5 rem/yr on the average. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital cost of equipment = $2,500
- Annual dose savings = 0.5 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	220	220	350	820	1,500

JA-83-01: Mock-Up Training for PWR Steam Generator Jobs

An estimate of the value of mock-up training for steam generator workers was made by James in 1983 (see also LO-83-05). He considers the following steam generator jobs:

- Set up of equipment (three persons outside; one hour)
- Opening manway (three persons outside; three hours)
- Installing primarly nozzle dam (one person inside, two outside; 40 minutes)
- Finding and marking leakers (one person inside; 30 minutes)
- Fitting and welding plug (one person inside, two outside; 20 minutes)
- Inspecting and pressure testing (one person inside, two outside; 20 minutes)
- Removing nozzle dam (one person inside, two outside; 40 minutes)
- Replacing manway (three persons outside; three hours)
- Testing and cleanup (two persons outside; 1-1/2 hours).

Typical tube repair for the two channel heads for the steam generator would require five man hours inside the channel head and 56 outside. Typical dose rates inside the channel head are approximately 12-1/2 rem/hr, and outside approximately 55 mrem/hr for an estimated collective dose of 65.6 rem. Also, inspection activities alone result in approximately 57 rem per steam generator. Assuming a tube failure probability of .25 per steam generator per year and a required annual inspection on each generator, the expected dose from steam generator tube maintenance in a four-loop pressurized water reactor is about 294 rem/yr.

Using the realistic model channel-head mock-up, reductions of one third to one half can be achieved. Assuming one third, this results in a dose reduction of 93 rem/yr inside the channel head and about 5 rem/yr outside. The cost of this dose reduction is composed of the capital costs of the training mock-up plus the annual cost of training. Capital cost is estimated at $60,000. An estimated 60 inside-channel-head workers and 30 helpers can each have 8 hours of mock-up training at an instruction cost of $9,600 per year for the inside channel-head-workers ($20/hr x 480 man-hours) and $3,600 for the helpers ($15/hr x 240 man-hours). For this analysis, we have assumed an additional $9,600 for of the training instructors.

An annual labor cost savings due to the increased worker efficiency of the trained workers is also expected. The productivity increase is worth an estimated $150/yr for the inside-channel-head workers ($20/hr x 7.5 man-hours/yr saved), and $1,390 for the helpers ($15/hr x 92.7 man-hours/yr saved). Other savings due to fewer required crew changes, less use of protective equipment, and other factors have been neglected in the present analysis. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Cost of captial equipment = $60,000
- Dose to install = 0 rem
- Dose savings = 98 rem/yr
- Training cost = $22,800/yr
- Labor savings = $1,540/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	260	160	270	560	1,000

LO-83-01A: Shielding for CVCS Demineralizers (Option A)

Lochard et al. (LO-83) have provided data on cost effectiveness of a number of engineering-type options used in existing French pressurized water reactors. Their basic data on cost and dose savings are converted to costs in terms of

1984 U.S. dollars. Demineralizer operation is controlled from a valve remote control room. A 50-cm-thick concrete wall would be sufficient for nonradioactive demineralizers. Any extra thickness beyond 50 cm is considered a biological shielding. For Option A considered here, a 40-cm extra thickness is evaluated.

Estimates of dose rates in the working area were based on the surface dose rates on demineralizers as measured over a three-year period in the Tihange plant. Dose rates at the surface of demineralizers were 450 rem/hr. A 50-cm-thick wall would reduce this dose rate to 200 mrem/hr in the valve control room. An additional 40-cm thickness of concrete wall will reduce the dose rate in the working area in the control room to approximately 2 mrem/hr. Working time in the area is 8.5 man-hr/yr. Assuming cost of concrete = $\$215/m^3$ (1980 U.S. dollars), input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980
- Dose savings = 1.7 rem/yr
- Capital cost = $2,600
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	69	69	120	310	590

LO-83-01B: Shielding for CVCS Demineralizers (Option B)

This option is similar to Option A above except a 20-cm-thick biological shield is considered for use in the valve room which is located under the valve control room considered in LO-83-01A above. Dose rates in the working area of the valve room are consequently reduced from 200 to 20 mrem/hr by the additional shielding for an annual dose savings of (180 mrem/hr for 5.6 hours) approximately 1 rem/yr. Input values for the cost-effectiveness evaluations for this modification were:

- Year for initial analysis = 1980
- Initial capital costs = $1,300
- Annual dose savings = 1 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	59	59	100	270	500

LO-83-02: Remote Control of Filter and Demineralizer Valves

Collective dose from exposure to the filter and demineralizer valves can also be reduced by locating the valve controls remotely in the room above the valve room. Dose rates in the valve control room on the upper level are considered negligible because of the separation distance and the thickness of the concrete floor (50 cm). The ambient dose rate in the valve room was 250 mrem/hr and a total job time was 8.5 man-hours/yr. Input data for cost-effectiveness evaluations for this modification were:

- Base year for data = 1980
- Capital equipment costs = $46,000
- Dose savings = 2.1 rem/yr
- Assumed annual operation and maintenance costs = $1,840/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,200	1,700	2,900	6,800	13,000

LO-83-03A: PWR Reactor Vessel Head Multi-Stud Tensioner/Detensioner (Single-Reactor Site, on Critical Path)

This machine simultaneously loosens or tightens the 58 vessel head studs that fasten the reactor head to the reactor vessel (see index for five similar evaluations). The main advantage of using this machine is a reduction in critical-path time since opening and closing the reactor vessel lie on the critical path. A substantial dose savings is also achieved since these operations take place on the bottom of the reactor pool where dose rates are on the order of 100 mrem/hr.

In Option A we assume the machine will service a site with a single reactor. Annual savings of 43 hours critical-path time and 196 man-hours labor are assumed. Replacement power costs are assumed to be $15,000 per hour and labor costs $15 per hour. Annual maintenance costs are assumed to be 4% of capital costs. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980

- Capital equipment costs = $940,000
- Annual replacement power savings = $645,000/yr
- Annual maintenance costs = $37,600/yr
- Annual labor savings = $2,940/yr
- Annual dose savings = 26.3 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-30,000	-17,000	-29,000	-54,000	-100,000

This modification is exceptionally cost-effective since net dose savings are positive and net costs are negative.

LO-83-03B: PWR Reactor Vessel Head Multi-Stud Tensioner/Detensioner (Two-Reactor Site, on Critical Path)

This option is identical to LO-83-03A, except that capital costs are shared between two units and labor savings are muliplied by 1.8 (90% of 2X) because of the need for moving the head from one facility to another. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980
- Capital equipment costs = $940,000
- Annual replacement power savings = $1,290,000/yr
- Annual maintenance costs = $37,600/yr
- Annual labor savings = $5,292/yr
- Annual dose savings = 52.6 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-32,000	-18,000	-31,000	-59,000	-110,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

LO-83-04: PWR Steam Generator Manway Cover Multi-Stud Tensioner/Detensioner Machine

This machine is used to automatically open and close the two man-hole covers of each steam generator (see index for five similar evaluations). The assumed frequency for steam generator inspection is once per outage and one supplementary generator is visited every two years on the average. Two machines are purchased to service each unit and the cost is $57,000 per machine. Estimated labor savings of 54 man-hours/yr valued at $15/hr are based on four workers taking five hours without the machine and two workers using one hour with the machine. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1980
- Capital costs = $114,000
- Annual labor cost savings = $810/yr
- Annual dose savings = 1.9 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,100	2,400	4,100	11,000	21,000

LO-83-05: Mock-up Training for PWR Steam Generator Jobs

In France, mock-up training is done in a life-size model of a lower part of a steam generator (see JA-83-01 for similar evaluations). This model is used for intensive training of personnel and testing of tools before each job is done on the steam generator in order to reduce working times in the chambers, where the dose rates are about 15 rem/hr. Training reduces the time required for removing primary pipe covers (nozzle dams) from 12 minutes to 6.6 minutes and for removing the manway covers from 3 hours to 2 hours. These jobs are performed an average of 1.5 times per year. Two workers are required for the latter job and one for the former. Dose rates are approximately 70 mrem/hr during removal of the manway cover and approximately 15 rem/hr during removal of the primary pipe covers. Training also reduces time spent on other aspects of the job but this is neglected in the present analysis, thus leading to a conservative estimate of the mock-up's effectiveness. Total investment cost for the mock-up is $41,000. The time spent on training and the cost of training supervision were not estimated. For this evaluation, we have assumed that 6 workers would need training for 20 hours each by an instructor who would spend a total of 40 hours in training activities. Total training costs, based on 160 man-hours at $15/hr, are therefore $2,400. Input data for cost-effectiveness evaluations for this modification are therefore:

- Base year for capital cost = 1980
- Capital cost = $41,000
- Estimated dose savings = 2.2 rem/yr
- Estimated training cost = $2,400/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,300	1,700	3,000	6,[illegible]	13,000

MI-83-01A: Concentrated Chemical Decontamination of BWR Primary System (Without Fuels, on Critical Path)

Miyamura et al. of Tokyo Electric Power have done cost-benefit studies of chemical decontamination of entire BWR primary systems. One system studied employs a concentrated chemical process of the type used in the Dresden Reactor, with a decontamination factor of about 100.

Special liquid waste treatment facilities are needed when the concentrated chemical process is used. A building measuring 43 x 23 x 32 m high, which contains a liquid waste storage tank, decontamination reagent storage tank, storage tanks for liquid wastes, decontamination reagent, rinsing water, and facilities for the concentration, demineralization, and solidification of liquid wastes were included in the cost evaluation for this modification. Total costs for these facilities were $30,520,000. Since the radwaste treatment facility for the concentrated process can be used for other aspects of station operation, only 25% of the facility cost was attributed to the decontamination process. The solidified waste generated by a typical decontamination operation would require about 600 storage drums and would take some 2,300 man-days processing time. The estimated time for decontamination was 58 days of which 33 days would incur additional replacement power costs. The optimum interval for carrying out the decontamination procedure with the fuel removed is between two and three times during eight effective full power years. Data for these analyses were based on decontamination twice during eight years. On the basis of a decontamination factor of 100, estimated collective dose which would be saved during the 8-yr period was 1,830 rem less 80 rem per decontamination (or 160 rem for the two decontaminations), leaving a net 1,670 rem saved in eight years. Thus, the annual dose savings was estimated at 209 rem/yr. Operational costs during the 8-yr period were $3,270,000 or about $409,000/yr. Cost of the replacement power required was estimated at $6,000,000/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $7,630,000.
- Annual dose savings = 209 rem/yr
- Amortization period = 30 years
- Labor and waste disposal costs = $409,000/yr
- Replacement power costs = $6 million/yr

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	37,000	22,000	38,000	75,000	140,000

MI-83-01B: Concentrated Chemical Decontamination of BWR Primary System (Without Fuel, Not on Critical Path)

This modification is similar to MI-83-01A above; however, in this case we assume that decontamination can be performed while the plant is shut down for other reasons and, therefore, replacement power costs were not incurred. This makes a substantial difference in the costs and cost effectiveness for this modification. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $7,630,000.
- Annual dose savings = 209 rem/yr
- Labor and waste disposal costs = $409,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,700	2,700	4,800	11,000	20,000

MI-83-02A: Dilute Chemical Decontamination of BWR Primary System (Fuel in Place, on Critical Path)

This modification was also evaluated by Meamura et al. and is based on use of the Candecon-type decontamination process and an assumed decontamination factor of 5. For this process the optimum decontamination frequency with the fuel in place was approximately once every eight years. Waste generated consists of spent resins and filters which can be handled by existing facilities. The volume of waste generated would be about 2,300 drums and would require about 3,400 man-days of labor. The liquid waste processing equipment is temporarily installed during the work period. The decontamination work would require extending the normal inspection period by approximately 21 days. The decontamination operation would cause a collective dose of approximately 90 rem and would save a collective dose of approximately 1,270 rem during the 8-yr intervening period for a net savings of 1,180 rem or approximately 148 rem/yr. Capital cost of equipment plus installation for decontamination facilities was estimated at $2,100,000. Annual operating costs including costs of waste disposal were estimated at $363,000 per year and replacement power costs would average $1,906,000/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $2,100,000.
- Replacement power costs = $1,906,000/yr
- Annual dose savings = 148 rem/yr
- Labor and waste disposal costs = $363,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	18,000	11,000	19,000	37,000	70,000

MI-83-02B: Dilute Chemical Decontamination of BWR Primary System (Fuel in Place, Not on Critical Path)

This item is similar to MI-83-02A above; however, in this case it is assumed that decontamination can take place while the plant is shut down for other purposes. Therefore, replacement power costs are not included in the analyses. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982

- Cap tal costs for equipment plus installation = $2,100,000.
- Annual dose savings = 148 rem/yr
- Labor and waste disposal costs = $363,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modificacion were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	3,400	2,200	3,800	8,000	15,000

MI-83-03A: Dilute Chemical Decontamination of BWR Primary System (Without Fuel, on Critical Path)

This item is similar to MI-83-02A; however, removal of the fuel prior to decontamination reduces the requirements for decontamination equipment and volumes of decontamination solutions which must be handled. However, optimum decontamination frequency is now twice per eight years instead of once, which results in somewhat larger cumulative dose savings but also somewhat larger replacement power costs if the decontamination operation must be done on critical-path time. Dose incurred during decontamination was estimated at 50 rem per campaign or 100 rem per 8-yr period. Collective dose reduction due to the decontamination was estimated at 1,690 rem per 8-yr period, for a net saving of 1,590 rem or approximately 200 rem/yr. Capital cost of equipment in this case was $1,690,000. Estimated annual costs for labor and waste disposal were $298,000/yr and $5,810,000/yr for replacement power. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $1,690,000.
- Annual dose savings = 200 rem/yr
- Labor and waste disposal costs = $298,000/yr
- Replacement power costs = $5,810,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	36,000	21,000	36,000	70,000	130,000

MI-83-03B: Dilute Chemical Decontamination of BWR Primary System (Without Fuel, Not on Critical Path)

This item is similar to MI-83-03A; however, in this case it was assumed that the decontamination could take place while the plant was shut down for other purposes and therefore no costs were incurred for replacement power. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $1,690,000.
- Annual dose savings = 200 rem/yr
- Labor and waste disposal costs = $298,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,100	1,300	2,300	4,800	9,200

PA-77-01: Photographic Technique for PWR Steam Generator Tube Plugging Inspections

Many PWR plants have had problems with steam generator tube denting. To prevent further deterioration of dented tubes, these tubes are frequently plugged. After the tube plugging operation, inspections are needed to verify the proper completion of plugging and to periodically verify the continued integrity of the steam generator tube plugs. A photographic technique to inspect for tube plugging integrity was developed by a quality control inspector at one U.S. power plant and later employed at a second plant. Previously, visual inspections were performed with considerable difficulty due to the high radiation fields, necessitating short stay times. In addition, wearing of an airfit plastic suit, poor lighting, and high ambient temperature (about 130°F) made accurate inspections difficult.

The photographic technique involves taking of four pictures per tube sheet. Pictures are subsequently developed and enlarged and are of sufficiently high quality to be the basis for the tube plugging inspection. Using the old technique, inspectors would incur approximately 300- to 400-mrem dose and four assistants would incur approximately 2.7-rem collective dose per steam generator inspected. With the photographic technique, doses were cut to 20 mrem for inspectors and to 130 mrem for assistant personnel. Total man-hours required for the inspection were reduced from 16 to 3 per generator. Assuming a labor cost of $20/hr, this gives a $4,680/yr labor cost savings for 18 steam generator inspections per year. Annual dose savings of 2.9 rem/yr for a steam generator were multiplied by 18 steam generator inspections per year for an annual savings of 52.2 rem/yr. No data were given for the capital equipment costs for photographic equipment and any special devices needed for holding cameras or developmental purposes. Therefore, in this analysis, capital equipment costs were assumed to be $5,000. Costs of materials were also not given, and for this evaluation were assumed to be $2,000/yr. Maintenance costs were also arbitrarily assumed to be 10% of capital costs or $500/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1977
- Capital costs for equipment plus installation = $5,000
- Labor savings = $4,680/yr
- Additional materials costs = $2,000/yr
- Maintenance costs = $500/yr
- Dose to install = 0 rem
- Annual dose savings = 52.2 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-66	-36	-62	-110	-220

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PB-82-01: Solid Radioactive Waste Handling Using High Integrity Containers

This analysis compares the cost of radioactive waste handling using an existing system which employs 55-gallon drums and a new system employing high-integrity containers. Based on historical data from 1979 through 1981, the average collective dose caused by the solid waste handling operation was 1.7 rem/yr. The waste consists primarily of 80 radioactive filters processed per year. Annual cost of packaging, transportation, and burial for these filters was approximately $54,400. Using high-integrity containers, estimated cost reduction would be $16,580/yr based on the same 80 filters per year. Thus, the new system would save $37,800/yr. Property taxes for the proposed alternative were estimated at $1,300/yr. It was assumed that no property taxes are paid on the present system. The proposed system eliminates nearly all exposure associated with barrel handling without introducing any new exposure as a result of handling the high-integrity containers. Thus, the expected annual dose saving is 1.7 rem/yr. Detailed engineering cost studies were not done for the proposed new system. However, costs were assumed to be between $75,000 and $225,000 in order to put financial bounds on the investment. For these analyses we will assume an investment cost of $150,000, which includes the cost of engineering design, installation, shielding, and removal of any existing equipment. The salvage value of the existing equipment is assumed near zero. Thus, input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital costs of equipment plus installation = $150,000
- Annual waste disposal costs savings = $37,800/yr
- Additional annual taxes = $1,300/yr
- Annual dose savings = 1.7 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-21,000	-11,000	-19,000	-34,000	-65,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PC-82-01: TV Monitor for BWR Cleanup Heat Exchanger Room

A closed-circuit television system was considered for routine inspection in the cleanup heat exchanger room. A commercial unit with one camera and a turnable mount, both verticle and azimuthal, was considered. Dose rates in the general working area were about 100 mrem/hr with hot spots well in excess of 1 rem/hr. Daily visual inspection of the cleanup heat exchanger room resulted in collective annual doses of approximately 3 rem. These inspections require approximately 30.4 man-hours per year. The closed-circuit television system's cost was estimated at $5,000 including camera and lens, turnable mount, and remote monitoring controls. The useful life of the system was estimated at 10 years. Approximately 100 man-hours would be required to install the system of which 50 man-hours would be in the cleanup heat exhanger room in 100-mr/hr areas. Thus, the estimated dose to install the system is 5.0 rem. Labor costs were estimated at $20/hr, yielding an installation cost of $2,000. Property taxes were assumed to be $100/yr. Annual maintenance costs were assumed to be $500/yr. Thus, input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1982
- Capital costs for equipment plus installation = $7,000

- Dose to install = 5 rem
- Annual dose savings = 3 rem/yr
- Additional Property taxes = $100/yr
- Maintenance costs = $500/yr
- Amortization period = 10 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	560	520	670	950	1,400

PD-83-01A: Steam Generator Channel Head Decontamination (Not on Critical Path)

Maintenance, inspection, and repair of steam generators are principal causes of collective dose in PWR reactors. Because extensive maintenance was needed, it was decided to chemically decontaminate the inlet and outlet channel heads on both steam generators. Initial primary channel head radiation levels ranged from 20 to 25 R/hr. Approximately 30,000 tubes were eddy-current tested, 2,000 sleeves were installed, 384 tubes were plugged, 10 plug welds were repaired, and 3 tubes were pulled. The predicted collective dose equivalent for these jobs, without decontamination, was approximately 4,800 rem.

A process for decontaminating the steam generator channel head was selected for testing and field demonstration. The program was carried out in three major phases: Phase 1 involved extensive laboratory testing, Phase 2 involved major off-site activities essential for the smooth transition and readiness for full field decontamination, and Phase 3 involved the actual field application of the process to decontaminate both steam generator channel heads. Overall dose reduction factors achieved were approximately 7 and 6 for the cold legs of steam generators 1 and 2, respectively. Because of hydrolaser equipment problems, only the cold legs of steam generators 1 and 2 were hydrolased. Thus, the additional reduction in dose rate (DF=3) due to hydrolasing was not available for the hot legs.

Labor costs were reduced because fewer boilermaker and labor jumpers were required at the lower doses. It was assumed that the number of each type of jumper was proportional to the collective dose. Since $1,129,950 was spent on jumpers, this implies that 6.7 times (the effective decontamination factor) this value would have been spent on jumpers if decontamination had not been carried out. Thus, the jumpers' wages saved by decontamination were $6,440,715. Since jumpers' wages were a capital expenditure, their cost could be capitalized and we have also treated decontamination costs of $2,145,191 as a capital cost. The net dose savings was the difference between the gross savings of 3,790 rem and the dose due to decontamination of 130 rem, or a net savings of 3,660 rem. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Decontamination costs = $2,145,191
- Labor savings (a capital gain) = $6,440,715
- Dose to decontaminate = 130 rem
- Dose savings during subsequent work = 3,790 rem
- Amortization period = 24 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-1,300	-1,300	-1,300	-4,700	-8,500

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PD-83-01B: PWR Steam Generator Channel Head Decontamination (on Critical Path)

The steam generator channel head decontamination described in PD-83-01A incurred no costs for replacement power since it occurred during a refueling outage. The decontamination operation took a total of 28 days. Had this time been on critical path, the cost of replacement power could well have been in the range of 25 to 30 million dollars. Thus, the cost effectiveness of decontamination is dependent on the critical path time required. To test the importance of this, analysis was made using $25,000,000 as replacement power cost and treating this as part of the capital cost for this project. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Decontamination costs = $2,145,191
- Labor savings (a capital gain) = $6,440,715
- Dose to decontaminate = 130 rem
- Dose saved during subsequent work = 3,790 rem
- Replacement power costs = $25,000,000
- Amortization period = 24 years

Results of the cost-effectiveness evaluations for this project were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	6,100	6,100	6,100	22,000	40,000

PE-83-01: Decontamination of a BWR Recirculation System

Decontamination of the recirculation system in BWR plants is an important method of reducing exposures for major maintenance operations during typical refueling outages. For example, in a scheduled outage for a BWR plant, the following work was planned in the primary containment (drywell): in-service inspection, induction heating stress improvement, hanger modifications, limitorque MOV replacement, and weld overlay repair. The cost effectiveness of decontamination for these jobs is considered in this analysis. Effective dose rate for work in the drywell was estimated at 0.5 rem/hr. One hundred five welds were to be inspected before induction heating stress improvement and 87 welds afterward. The estimated ISI inspection time was 80 man-minutes per weld for 173 welds and 240 man-minutes per weld for 10 welds, for an estimated dose of 135 rem. It was also estimated that 78 of the welds would require stress improvement and take 12 man-hours per weld causing 468-rem collective dose. Work on the two motor-operated valves was to require 125 man-hours per valve, causing 125-rem collective dose. The weld overlay repair work was expected on 10% of 192 welds and was expected to take 6 man-hours per weld, causing 58-rem collective dose. It was also estimated that 130-rem collective dose would be received removing insulation in preparation for the weld work and 20 rem during shield-block removal and replacement. Total expected collective dose without decontamination was therefore 936 rem. It was assumed that no hanger modifications would be done in the drywell if decontamination was not performed, and thus no credit was taken for decontamination rem savings from that phase of the project. Decontamination would use an estimated 50 rem of exposure. A dose-reduction factor of 10 was assumed, giving a dose savings of 842 rem. Miscellaneous other work was specifically identified to have dose savings of 103 rem, for a total savings of 945 rem, from which must be subtracted 50 rem due to decontamination operations. Net rem saved, therefore, was 895 rem. Total cost for decontamination was \$300,000 vendor cost plus \$450,000 utility support. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Cost for modification (assumed to be capital) = \$750,000
- Dose to decontaminate = 50 rem
- Dose savings during subsequent work = 945 rem
- Amortization period = 1 year

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	910	910	910	1,100	1,200

PF-83-01A: PWR Steam Generator Manway Tensioning/Detensioning Handling Device (Not on Critical Path)

This analysis is based on proposed procurement of a steam generator primary manway tensioning/detensioning and handling unit (see also DU-82-07 and EG-84-04). Cost of this equipment was approximately $200,000 plus approximately $64,000 for auxiliary equipment and other installation costs, bringing the total capital costs to $500,000. Manual removal and replacement of the manway cover require 100 man-hours and 5 rem. Automated cover removal and replacement was predicted to require 4 man-hours and 0.2 rem. The unit has two steam generators, each having two manway covers. Assuming 0.86 outages per year and labor costs of $25/hr, total present labor costs are approximately $8,600/yr. The automated system would require 4 man-hours per manway versus 100 with the present system. Thus, labor costs with the automated system would be $344/yr. Annual dose savings were estimated at 16.5 rem/yr. Dose to install, based on 500 man-hours at an average dose rate of 0.11 rem/hr, is estimated at 55 rem. For the present analysis, removal of the manways was not considered a critical-path activity, although if the plant experiences significant steam generator problems in the future, this may change. The impact of critical-path time and related outage costs will be considered in PF-83-01B below. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital cost for equipment and installation = $500,000
- Labor savings = $8,256/yr
- Additional annual property taxes = $2,700/yr
- Annual dose savings = 16.5 rem/yr
- Dose to install = 55 rem
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	620	880	1,700	3,300	6,300

PF-83-01B: PWR Steam Generator Manway Tensioner/Detensioner and Handling Device (on Critical-Path 25% of Time)

This modification is identical to that covered in PF-83-01A, except here we assume that the manway cover handling will be a critical-path job for 25% of the time. Replacement power costs were assumed as $550,000 per day. Manual removal of the manway cover typically requires 12 to 14 hours, whereas the automated equipment should require only 1 hour. Thus, the critical-path time saved is assumed to be 25% of 12 hours or three hours/yr. This has a value of $68,750 for savings of replacement power costs. Input data for the cost-effectiveness evaluations for this modification were therefore:

- Base year for capital costs = 1983
- Capital costs of equipment plus installation = $500,000
- Labor savings = $8,256/yr
- Annual replacement power savings = $68,750/yr
- Annual property taxes = $2,700/yr
- Annual dose savings = 16.5 rem/yr
- Dose to install = 55 rem
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-4,400	-2,000	-3,900	-6,500	-12,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PG-83-01: PWR Steam Generator Manway Tensioner/Detensioner

This modification is similar to DU-82-07, EG-84-04, PF-83-01A, and PF-83-01B. Removal of the steam generator manways is required each outage to allow access. The covers weigh approximately 700 lb. and the work must be done in a high-radiation area. Removal and installation each require approximately 100 man-hours exposure in areas which have effective dose rates of 40 mrem/hr. Removal typically requires two hours of critical-path time at replacement power costs of $700,000 per day. Refueling occurs every 15 months; therefore, there are approximately 0.8 outages per year. Savings for replacement power costs using the special handling system will therefore be $46,667/yr. Since there will be no critical-path savings during the first year, an additional $47,000 is included in the original installation costs. New studs and nuts which are expense items will cost $30,000 the first year only. Property tax on the $56,000 capital investment was $740/yr. A service life of 30 years was assumed for the tool. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital costs = $133,000
- Additional annual taxes = $740/yr
- Annual labor savings = $2,410/yr
- Annual dose savings = 3 rem/yr
- Annual replacement power savings = $46,667/yr
- Amortization period = 30 years

Results for the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-16,000	-8,600	-15,000	-28,000	-53,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PH-83-01: PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)

The tensioning and detensioning operations on the reactor vessel head studs are time consuming and costly in terms not only of dose to workers but also in terms of man-hours and critical-path time. This analysis is based on consideration of a multi-stud tensioning device (see index for five similar evaluations). This system would require modification of the existing studs, and thus this cost was included in the analysis. On the basis of the manufacturers' claim, it was estimated that five men would require six hours to complete the tensioning-detensioning operation for a total of 30 man-hours. Labor costs were estimated at $20/hr for the tensioner crew. Based on historical experience, approximately 746 man-hours were required using the manual method, thus a projected labor savings of $14,300/yr is anticipated. Collective dose to remove and replace the studs historically amounted to 33 rem/yr, whereas the estimated dose using the automated system would be 1.3 rem/yr for an annual savings of 31.7 rem/yr. Time required for tensioning and detensioning would be reduced by 62 hr/yr. It was assumed that 25% of the time this operation would be on critical-path and that replacement power costs for this plant were $250,000 per day. Thus, annual savings for replacement power would be approximately $161,500/yr. Capital cost for equipment plus stud modification was estimated at $349,000. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of equipment plus installation = $349,000
- Labor savings = $14,300/yr
- Annual replacement power savings = $161,500/yr
- Annual dose savings = 31.7 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-5,600	-3,100	-5,300	-9,800	-19,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PI-83-01: PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)

This modification is similar to PH-83-01 above; however, labor costs and collective doses are considerably smaller since the tensioning and detensioning operation takes only half as long at this plant (see index for other similar evaluations). Use of the multi-stud tensioning system was expected to reduce collective doses from 15.5 to 1.4 rem/yr for a net savings of 14.1 rem/yr. Required labor charges would be reduced from 332.3 to only 30 man-hours/yr for a net labor cost savings of $6,000/yr. Time for tensioning and detensioning would be reduced from 36 to 6 hr/yr for a savings of 30 hr/yr. Assuming that operations were on critical path 25% of the time and that replacement power costs were $700,000 per day for this plant, the average annual critical-path costs saved would be $219,000/yr. Capital costs for equipment plus stud modifications for this plant would be $349,000/yr. Input data for the cost-effectiveness evaluations for this modification were therefore:

- Base year for capital cost = 1983
- Capital cost of equipment plus installation = $349,000
- Labor savings = $6,000/yr
- Annual replacement power savings = $219,000/yr

- Annual dose savings = 14.1 rem/yr

- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-16,000	-9,000	-16,000	-29,000	-55,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PJ-83-01: PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)

This modification is similar to PH-83-01 and PI-83-01 above; however, for this plant, replacment power costs are $900,000 per day and the automated equipment will save a total of 12 rem/yr compared to the manual method of tensioning and detensioning. Man-hours required for tensioning and detensioning have historically been about 400 hr/yr, whereas with the new system it is estimated that 30 hr/yr would be required, thus providing a labor cost savings of $7,400/yr. The tensioning and detensioning operations historically take 60 hours versus 6 hours using the proposed modification. Thus, the time required for the jobs would be 54 hours less with the automated equipment. Assuming this to be critical-path time 25% of the time and replacement power cost to be $900,000 per day for this plant, the average critical-path savings were estimated at $506,250/yr. Capital cost for equipment plus modification of existing studs was again $340,000 for this plant. Thus, input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983

- Cost of capital equipment plus installation = $340,000

- Labor savings = $7,400/yr

- Annual replacement power savings = $506,250/yr

- Annual dose savings = 12 rem/yr

- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modificaiton were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-45,000	-26,000	-44,000	-85,000	-160,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

PK-83-01: PWR Quick-Opening Hatch for Fuel Transfer Tube (Backfit)

This modification is similar to EG-84-01, DU-82-06, LA-83-06, and PM-84-01; however, the evaluation employs somewhat different cost assumptions. As part of refueling operations at PWR plants, the fuel transfer tube flange must be removed and reinstalled. This takes place in a high-radiation and heavily contaminated area and occasionally leads to external contamination of personnel as well as the accumulation of 3- to 4-rem collective dose for the entire operation. The average time to remove, clean, and reinstall the existing flange is 55 hours. Cost for the quick-opening transfer tube hatch was estimated at $57,000. Dose rates in the work area prior to fuel shuffle were approximately 100 mr/hr, and post-fuel-shuffle dose rates were 2 rem/hr. An estimated 16 man-hours at $20/hr would be required to install the closure assembly. This cost was added to the initial capital costs. Seven man-hours' labor would be required for operation of the proposed flange as contrasted to 55 man-hours for the existing flange. Assuming 0.8 outages per year, the net labor cost savings would average $768/yr. Estimated exposure for operation of the existing flange is 3.2 rem per outage as compared to 0.35 rem per outage for the proposed flange. Again, assuming 0.8 outages per year, the net collective dose savings would be 2.3 rem per year. Estimated property taxes for the proposed system were $700 per year. The number of workers required to remove and reinstall the flange would be reduced from 2 to 1. The probability of airborne contamination and personnel contamination is reduced, but no credit has been taken for this. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital costs of equipment plus installation = $57,320
- Labor savings = $768/yr
- Dose to install = 0 rem
- Annual dose savings = 2.3 rem/yr
- Additional Property taxes = $700/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	540	690	1,200	2,900	5,600

PL-84-01A: PWR Reactor Vessel Head Shielding (on Critical Path)

Historically, the removal and replacement of the reactor head has caused a collective dose of approximately 20 rem per outage at one U.S. PWR plant. Use of lead blankets hung around the thermal shroud in the 1982 refueling utage resulted in a 25% reduction during the head removal process. Specially designed reactor pressure-vessel-head shielding is available from commercial sources. In these analyses, the cost effectiveness of one commercial system was considered. This system consists of 42 flexible vertical lead panels 7 ft long. These panels contain lead wood encased in Herculite and have a 3/4-in. lead equivalency. The lead panels are suspended from a permanently mounted track system which is pressure fitted to the reactor vessel head. A personnel exposure of approximately 0.5 rem would be required to permanently affix the track system to the reactor head. Thereafter, the total collective dose expenditure for installation and removal of the lead shielding would be approximately 0.4 rem. It was estimated that use of the special shield system would reduce the collective dose for this job by 50% for a 10-rem-per-outage saving. On the assumption of a 15-month refueling cycle, an estimated 8 rem per year, on average, would be saved by this special shield system. Cost of the special shielding is $56,821. Other capital cost expenditures include $2,500 for engineering costs, $30,000 for 1-1/2 hours of critical-path time to install the new shield support system, $5,000 for seismic analyses, and $1,000 for initial training of shield-handling workers. Total capital expenditures were therefore estimated at $95,321. Annual costs assumed were $250 maintenance costs, $75 crane operator costs, $300 for retraining of workers, and $125 for installation and removal costs, for a total of $750/yr. Capital costs include the cost of 3 steel storage containers for the shielding. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1984
- Capital costs of equipment, installation & critical-path time = $95,321
- Dose to install = 0.5 rem
- Labor costs = $200/yr
- Training costs = $300/yr
- Maintenance costs = $250/yr
- Annual dose savings = 8 rem/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	570	540	860	2,000	3,600

PL-84-01B: PWR Reactor Vessel Head Shielding (No Critical-Path Expense)

This modification is similar to PL-84-01A above; however, in this case it was assumed the plant was down for other purposes and installation of the shield support would not be a critical-path job. As a result, capital costs were $65,321, or $30,000 less than for the above example. All other costs and savings were the same. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1984
- Capital costs of equipment, installation & training = $65,321
- Dose to install = 0.5 rem
- Labor costs = $200/yr
- Training costs = $300/yr
- Annual Dose Savings = 8 rem/yr
- Maintenance costs = $250/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	420	390	620	1,400	2,600

PM-84-01: PWR Quick-Opening Hatch for Fuel Transfer Tube (Operating U.S. PWR Plant)

This modification is similar to DU-82-06, EG-84-01, and PK-83-01; however, costs are based on a recent evaluation at a U.S. PWR plant. Capital cost for the equipment plus installation was estimated at $25,000 in 1983 dollars. For this plant, installation dose would be 1.2 rem, assuming an average of 50 mrem/hr in the work area and a job duration of 24 man-hours. For this evaluation, we have also assumed a 6-man-hours/yr savings due to the reduced time for opening this tube compared to the existing flange with 20 bolts. At $20/hr, this saves approximately $120/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital costs of equipment plus installation = $25,000
- Dose to install = 1.2 rem

- Annual dose savings = 0.5 rem/yr
- Labor savings = $120/yr
- Amortization period = 25 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	2,100	2,200	3,800	8,600	16,000

WA-84-01: PWR Steam Generator Decontamination

The Lovissa Plant in Finland is a Soviet-VVER-440-designed plant with eight horizontally oriented steam generators. Here, dose rates in the working areas within the steam generator were 250 to 450 mr/hr as measured at a height of a half-meter above the tubes, and with the secondary side water at its maximum level. Temporary shielding installed above the tubes dropped the dose rates by a factor of about 10, which is the radiation field in which the work would have been carried out if decontamination of the steam generators had not been undertaken. Decontamination was scheduled during a prolonged shutdown, so that critical-path time was not affected. Total costs of decontamination did not exceed $100,000. Since the initial dose rates were relatively low in this plant, the collective dose saved was only 100 rem. It should be pointed out that recontamination subsequent to further plant operation caused the dose rates above the two bundles inside the two decontaminated steam generators to rise to about five times the level found inside the other four steam generators of the same unit, which were not decontaminated. This points to the need for a passivation or reoxidation process following the decontamination operation, which should be carried out prior to power operation. This increased dose rate is neglected in the following analyses since it is assumed it would be avoided in future applications. Of course, some additional costs will be incurred for the passivation process. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital cost = $100,000
- Dose to decontaminate = 1 rem
- Dose savings after decontamination = 100 rem
- Amortization period = 1 year

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1100	1100	1100	1300	1400

WA-84-02: PWR Reactor Cavity Decontamination Using the WEPA Cleaning System

Post-refueling reactor cavity pool decontamination requires significant manpower, may be on the critical path, and typically contributes several rem committed dose. Hydrolasing, hand scrubbing, strippable paint, and special scrubbing machines have been used with increasing success. A commercial system consisting of a crane-supported wall scrubber, a person-operated floor scrubber, and a hand-held scrubber has been successfully employed at Calvert Cliffs and results in an estimated exposure reduction of about 3.6 rem per refueling or 2.4 rem/yr (18-month cycle). Estimated costs for the three units, including $4,000 for spare parts and pads in 1984, were $89,000. Annual waste disposal cost savings of $3,100/yr were estimated over hand scrubbing. Cost of materials was estimated at $5,000/yr, primarily for new brushes. Watson et al. indicate that "it is difficult to determine whether the system actually improved the outage schedule (by shortening the normal amount of crane time needed for decontamination)," but the system may have reduced crane time by as much as 2-1/2 days. Other users of this equipment estimated critical-path savings of 1/2 to 2-1/2 days. In addition to being faster than manual cleaning, hydrolaser cleaning, or use of strippable coatings, the reduced airborne contamination levels, which result from using the special scrubbing machine, also contributed to shorter outage times. For this analysis, we have conservatively assumed a critical-path savings of 24 hours per refueling or 16 hours per year, with $20,000/hr replacement power cost. Since the units are used only a day or two per year, their useful life was estimated at 20 years in this analysis (the authors assumed 10 years). Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1984
- Capital costs = $89,000
- Waste disposal cost savings = $3,100/yr
- Material costs = $5,000/yr
- Annual replacement power savings = $320,000/yr
- Annual dose savings = 2.4 rem/yr
- Amortization period = 20 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-18,000	-12,000	-17,000	-28,000	-49,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-01: Robotic Inspection of PWR Ice Condenser Area

Ice condensers in PWRs are generally entered daily to inspect for frost and ice buildup, and to verify that their handling units are functioning properly. Dose rates in the room are 2 to 5 mrem/hr and inspections require approximately 30 minutes' time on the part of two individuals. At the two PWR plants at the Sequoyah site, 5.2 rem collective dose was received in 1983 during these operations.

The proposed modification is to use a robotic inspection device attached to existing bridge crane rails and power busbars in the ice condenser rooms. A color TV camera with lights and a zoom lense would be mounted on the carriage. A control console located in an auxiliary building would be used for control of robots in both ice condenser rooms.

Using the robotic system, a single person can make an inspection in approximately 1 hour, whereas 3 people are required by the present system for approximately 1 hour including time for changing in and out of decontamination clothing. Thus, a savings of 2 person-hours per inspection can be expected with a robotic system. This yields an annual labor savings of 1,460 man-hours at an estimated cost of $20/hr. For this analysis, we assume annual maintenance costs will be 4% of the total capital investment.

Equipment procurement and installation cost estimates for two robots and one control console for use in the two Sequoyah Plant ice condensers are:

- Base year for capital costs = 1983
- Capital cost of equipment including testing and installation = $76,800
- Maintenance cost = $3,072/yr
- Labor savings (1,460 man-hours/year) = $29,200/yr
- Protective clothing reduction (1,460 sets/yr) = $7,300/yr
- Exposure to install = 1.4 rem
- Annual dose savings = 5.2 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-6,500	-3,500	-6,100	-11,000	-21,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-02: Remote Readout Near PWR Seal Table

The seal table areas in a typical PWR plant must be entered once each shift to inspect the glycol temperature board, test the RHR sump alarm, and check the back draft damper alarm panel as needed. Three workers are usually required, including two who make the initial entry wearing contamination-zone clothing. Each entry takes about 50 minutes, including 30 minutes for clothing changes. The background in these areas is about 2 to 5 mr/hr. The need for entry to these areas could be eliminated by relocating the control and temperature panels immediately outside the seal table area. The probes and sensory components would remain inside the area, and a single unsuited operator could perform an inspection in about 15 minutes' total time. Estimated installation costs for this modification include 400 man-hours of labor at $20/hr = $8,000, plus $4,000 cost for installation material, and a collective dose of approximately 1 rem. Approximately 3,500 man-hours per year labor would be saved after the installation, and annual dose savings of approximately 2 rem/yr would be expected. In addition, 4,380 fewer contamination-zone clothing changeouts per year would be required with an estimated savings of $5 per changeout or $21,900 per year. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital costs for equipment plus installation = $12,000
- Dose to install = 1 rem
- Labor savings = $70,000/yr
- Annual dose savings = 2 rem/yr
- Material costs savings = $21,900/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-50,000	-29,000	-51,000	-96,000	-180,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-03: TV Robot Inspection of PWR Vessel Head (Single Reactor Site)

Visual inspection by two fully suited workers with respirators is required under the reactor vessel head during removal and reinstallation. Dose rates from 5 to 15 rem/hr cause collective doses of approximately 9 rem/yr from this operation. This inspection could be done with a remotely controlled television robot. A camera would be installed on a small trolley that mounts to the existing monorail encircling the reactor vessel head near the top. The TV camera assembly would be connected to the underside of the trolley using a stand-off bracket and a telescoping tube. The TV monitor and control panels would be located on a mobile cart that could be placed on the reactor refueling floor. After the reactor head has been raised, the operator would extend the telescoping tube to the desired level, using a remote pushbutton switch. A joy-stick control would activate the pan/tilt mechanism used to position the camera. Cost of equipment including procurement, assembly, and testing was estimated at $19,000. It would take approximately 1 man-hour to install and 1 man-hour to operate during each refueling outage. Use of the robotic system would save an estimated 3 man-hours per refueling outage worth $40/hr for a total of $120/yr. No impact on critical-path time is expected. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital costs including procurement, assembly & testing = $19,000
- Labor savings = $120/yr
- Maintenance costs = $760/yr
- Annual dose savings = 9 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	150	120	210	490	930

Note: Cost-effectiveness evaluations were based on a site with a single reactor. Costs per rem saved would be lower for multiple-reactor sites.

WH-84-04A: Remote Inspection of PWR Keyway (Single-Reactor Site)

The keyway of a PWR is entered for visual surveillance for water leaks under the reactor vessel and to check the water level in the sump during refueling operations. The radiation levels in the keyway range from 700 mrem/hr to 200 rem/hr and access to the area is difficult. White et al. proposed that a remote inspection device be used consisting of a flexible boroscope coupled to a computer-controlled TV camera. Guide tubes with inspection openings at predetermined points would be installed in the keyways. A boroscope attached to long cables would be fed through these guide tubes. As the boroscope is being fed through the guide tube, the operator actuates the articulating lens at each inspection port. When the boroscope reaches the end of the guide tube, it protrudes through the end and then is used to survey the area at this point. It is then pulled back into the guide tube and moved into another inspection port. After all the inspections are complete, the TV-boroscope assembly is bound to a cable reel and then can be transported and used wherever needed. The estimated cost for procurement, assembly, and testing of this equipment was $25,000. Approximately 100 man-hours at $24/hr would be required for installation, and a collective dose of 2.5 rem could be incurred. No saving in man-hours is expected with this equipment; however, exposure reduction of approximately 1 rem per refueling outage is estimated. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for installation, procurement & tesing = $27,400
- Dose to install = 2.5 rem
- Annual dose savings = 1 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	1,100	1,100	2,000	4,900	9,200

Note: Cost evaluations were based on a single-reactor site and cost per rem saved would be lower for multiple-reactor sites.

WH-84-04B: Remote Inspection of PWR Keyway (Two-Reactor Site)

This modification is similar to WH-84-04A above; however, we assume here that the same remote surveillance equipment can be used at two reactors at the same site. Installation at the second reactor will require another 100 man-hours at $24/hr and expected dose savings will be a total of 2 rem/yr and 5 rem for installation. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for materials plus installation = $29,800

- Dose to install at two reactors = 5 rem
- Annual dose savings = 2 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
\$/rem:	590	590	1,100	2,600	5,000

WH-84-05A: Portable Robotics System for Smoke Detector Inspection (Single-Reactor Site)

At the Browns Ferry Plant, manual inspection of over 200 smoke detectors is a three-week task performed twice a year by a team of two electricians and one health physics technician. The ceiling detectors require ladders and special scaffolds to reach up to 40-ft heights. Contamination-zone clothing is needed in many areas. White et al. proposed that a portable robotic system consisting of a push-pull floor cart with a 25-ft powered lift, an electrically operated telescoping tube that can extend to a height of 15 ft and collapse to a 1-1/2 ft-height, a remotely operated pressurized smoke canister and nozzle, a voltmeter with contact probes, and a motorized pan-tilt mechanism for aiming the nozzle and the voltmeter at the smoke detector. Holes would be drilled in the detector covers for insertion of the voltmeter probes. All tests could easily be performed by one worker who would control all motors using a switch box located on the cart. A reel on the cart carring 50 to 100 ft of cable would be used to connect the cart to a 110-volt power outlet. The same equipment could be modified for testing detectors in high-radiation areas using a motorized cart and adding a television camera. Cost of the equipment, assembly, and testing was estimated at \$20,000. Reduced man-hour requirements at each plant due to using the robotics equipment was estimated at 40 man-hours/yr of health physics technician time and 120 man-hours/yr of inspection worker time. These man-hours were valued at \$20/hr. Specific job dose data were not available for these jobs. Therefore, for this evaluation, an average exposure rate of 10 mrem/hr was assumed for the above 160 man-hours/yr work. The assumed annual dose savings is therefore 1.6 rem/yr per plant. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost of equipment plus installation & testing = \$20,000
- Labor savings = \$3,200/yr
- Dose to install = 0 rem
- Maintenance cost = \$2,000/yr

- Annual dose savings = 1.6 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-360	-17	-29	470	880

This modification is exceptionally cost effective since net dose savings are positive and <u>net costs are negative</u>.

WH-84-05B: Portable Robotic System for Smoke Detector Inspection (Three-Reactor Site)

This modification is similar to WH-84-05A; however, in this case it is assumed that three reactors exist on the same site and the robotic equipment can be shared between the three plants. Cost of equipment, installation, and testing is therefore the same; however, annual labor savings and dose savings would each be three times greater than above. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for equipment plus installation & testing = $20,000
- Labor savings = $9,600/yr
- Dose to install = 0 rem
- Annual dose savings = 4.8 rem/yr
- Maintenance cost = $2,000/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-1,600	-840	-1,500	-2,600	-5,000

This modification is exceptionally cost effective since net dose savings are positive and <u>net costs are negative</u>.

WH-84-06A: Robotics System for Remote Inspections of BWR Moisture Separator and Feedwater Pump Areas (Three-Reactor Site)

A floor-mounted robotics vehicle has been proposed for use at the Browns Ferry Plant, which includes three 1,000-MWe BWR reactors. Each reactor has one moisture separator room and three feedwater pump rooms. Sixty-four worker entries are made to each moisture separator room each year, and dose rates are approximately 2 rem/hr. Weekly entries by two individuals are made into the pump rooms (936 worker entries per year), which have dose rates from 20 to 125 mrem/hr. These entries are for purposes of visual inspection and radiation monitoring and require full contamination-zone clothing. Thus, there is a total of 1,128 individual worker entries per year for the three reactors at this site.

The vehicle proposed for this application would be a wheeled unit complete with sensors and controls for fixed-sequence motion following a floor tape. A telescoping tube assembly mounted on the cart would raise the sensing devices up to a 15-ft elevation. Sensors would include a color TV camera, directional microphone, and radiation monitors. The vehicle would be powered and controlled through a motorized cable reel with the vehicle's controls located outside the room being inspected. Contamination smearing capability is not included but could be added at a nominal cost. Estimated costs for equipment, assembly, testing, and installation of floor tapes were $66,700. Reduced health physics technician labor and operator labor costs were estimated at $19,600/yr. An estimated 1,128 sets per year of contamination-zone clothing with respirators would no longer be required, which would save $15,200/yr. Estimated installation dose was 1-rem, and annual dose savings would be approximately 70 rem/yr. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for equipment, installation, and testing = $66,700
- Labor cost savings = $19,600/yr
- Clothing and respirator savings = $15,200/yr
- Annual dose savings = 70 rem/yr
- Dose to install = 1 rem
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-500	-280	-480	-880	-1,700

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-06B: Robotics System for Inspections of BWR Moisture Separator and Feedwater Pump Areas (Single-Reactor Site)

This modification is similar to WH-84-06A; however, since the unit will be used at a single-reactor site, the capital cost would be reduced slightly because of reduced labor costs for installation of floor tapes. Labor requirements in future years, clothing and respirator requirements, dose to install, and annual dose will all be reduced to one third the above values. Input data for the cost-effectiveness evaluation for this modification were:

- Base year for capital cost = 1983
- Capital cost for equipment plus installation = $65,900
- Labor cost savings = $6,530/yr
- Clothing and respirator cost savings = $5,070/yr
- Dose to install = 0.3 rem/yr
- Annual dose savings = 23.3 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluations for this modificaiton were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-440	-210	-360	-580	-1100

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-07A: Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Three-Reactor Site)

Each reactor at the Browns Ferry Plant has three high pressure feedwater pump rooms. Each room is entered an average of twice per month by a three-worker team for a visual surveillance to locate steam leaks. Workers are fully suited and exposed to dose rates ranging from 10 to 20 mrem/hr. A portable robotic mechanism was proposed, which would be inserted through holes in the ceilings of these rooms. The mechanism would consist of an industrial hoist with a 35-ft extension, a color TV camera, a radiation monitor, and a directional microphone. A hand-held mechanism would provide precision positioning. Controls would be installed to a portable console located on a higher elevation. Costs of equipment, assembly, and testing were estimated at $20,000, and installation labor costs for drilling 18 holes at the three reactors were $2,400. It was further estimated that use of the robotic mechanism would reduce health physics technician labor requirements by 200 man-hours/yr and the cost of contamination-zone clothing by $8,800. The robotic system would be in use less than 500 hr/yr for surveillance in these rooms and therefore would be available for use elsewhere. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital cost = 1983
- Capital cost for equipment, testing, and installation = $22,400
- Labor savings = $4,000/yr
- Contamination clothing savings = $8,800/yr
- Dose to install = 1 rem
- Annual dose savings = 4 rem/yr
- Amortization period = 30 years

Results of the cost-effectiveness evaluation for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-3,300	-1,800	-3,200	-5,800	-11,000

This modification is exceptionally cost effective since net dose savings are positive and net costs are negative.

WH-84-07B: Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Single-Reactor Site)

This modification is similar to WH-84-07A, but here it is assumed that the equipment is being purchased for a site having a single reactor. Capital costs are reduced, therefore, by $1,600 because less labor is needed during installation. Also, future costs for labor and contamination clothing as well as estimated annual dose, and dose to install were all reduced to one third the values used in the previous example. Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1983
- Capital cost for equipment testing and installation = $20,800
- Labor savings = $1,300/yr
- Reduced contamination clothing costs = $2,900/yr
- Dose to install = 1/3 rem
- Annual dose savings = 1.3 rem/yr

Results of the cost-effectiveness evaluation for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	-2,900	-1,400	-2,500	-4,200	-7,900

This modification is exceptionally cost effective since net dose saving are positive and net costs are ne; tive.

YO-82-01A: Replacement of PWR Steam Generators with Low Cobalt (<0.03%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)

This modification is similar to BE-82-06E; however, cobalt specifications are less stringent by a factor of 2. Young et al. have examined the relative cost of specifying 0.03% and 0.015% cobalt in replacement steam generator tubing. They indicate a 35% increase in cost of a steam generator unit if Inconel-600 containing 0.03% cobalt is specified, and a 53% increase if 0.015% cobalt content is specified. Thus, changing the cobalt specification from 0.015% to 0.03% would reduce the additional capital cost of a steam generator from $100,000 to $66,000. For a three-loop plant, the incremental costs of specifying 0.03% cobalt would therefore be $198,000. The net cobalt input to the primary system would be reduced by an estimated 12% if 0.03% cobalt is specified and by 16% if 0.015% cobalt is specified. Therefore, the estimated annual dose savings for a plant with 0.03% cobalt specified would be 100 rem/yr (12/16 of 134 rem/yr used in BE-82-06E). Input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital costs for low cobalt specification = $198,000
- Additional dose attributable to installation = 0 rem
- Annual dose savings = 100 rem/yr
- Amortization period = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	66	66	120	350	670

YO-82-01B: Replacement of PWR Steam Generators with Low Cobalt (<0.03%) Tubing (Four-Loop Operating Plant, Replacement Need for Other Reasons)

This modification is similar to BE-82-06F; however, less stringent cobalt specifications are employed. As indicated in YO-82-01A above, capital costs would be reduced to $66,000 per steam generator or $264,000 for a four-loop plant. Also, for reduced cobalt input as indicated above, annual dose savings for the four-loop plant would be approximately 107 rem/yr. Thus, input data for the cost-effectiveness evaluations for this modification were:

- Base year for capital costs = 1982
- Capital cost for low cobalt specifications = $264,000
- Dose to install = 0 rem
- Annual dose savings = 107 rem/yr
- Amortization = 35 years

Results of the cost-effectiveness evaluations for this modification were:

	BASIC MODEL	PRESENT WORTH	PRESENT WORTH D	REV REQ MODEL A	REV REQ MODEL B
$/rem:	82	82	150	430	830

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APPENDIX A

VALUES OF CAPITAL ESCALATION FACTOR FOR VARIOUS INFLATION RATES

amorti-zation period (years)	INFLATION RATE					
	2%	4%	6%	8%	10%	12%
1	1.020	1.040	1.060	1.080	1.100	1.120
2	1.040	1.082	1.124	1.166	1.210	1.254
3	1.061	1.125	1.191	1.260	1.331	1.405
4	1.082	1.170	1.262	1.360	1.464	1.574
5	1.104	1.217	1.338	1.469	1.611	1.762
6	1.126	1.265	1.419	1.587	1.772	1.974
7	1.149	1.316	1.504	1.714	1.949	2.211
8	1.172	1.369	1.594	1.851	2.144	2.476
9	1.195	1.423	1.689	1.999	2.358	2.773
10	1.219	1.480	1.791	2.159	2.594	3.106
11	1.243	1.539	1.898	2.332	2.853	3.479
12	1.268	1.601	2.012	2.518	3.138	3.896
13	1.294	1.665	2.133	2.720	3.452	4.363
14	1.319	1.732	2.261	2.937	3.797	4.887
15	1.346	1.801	2.397	3.172	4.177	5.474
16	1.373	1.873	2.540	3.426	4.595	6.130
17	1.400	1.948	2.693	3.700	5.054	6.866
18	1.428	2.026	2.854	3.996	5.560	7.690
19	1.457	2.107	3.026	4.316	6.116	8.613
20	1.486	2.191	3.207	4.661	6.727	9.646
21	1.516	2.279	3.400	5.034	7.400	10.804
22	1.546	2.370	3.604	5.437	8.140	12.100
23	1.577	2.465	3.820	5.871	8.954	13.552
24	1.608	2.563	4.049	6.341	9.850	15.179
25	1.641	2.666	4.292	6.848	10.835	17.000
26	1.673	2.772	4.549	7.396	11.918	19.040
27	1.707	2.883	4.822	7.988	13.110	21.325
28	1.741	2.999	5.112	8.627	14.421	23.884
29	1.776	3.119	5.418	9.317	15.863	26.750
30	1.811	3.243	5.743	10.063	17.449	29.960
31	1.848	3.373	6.088	10.868	19.194	33.555
32	1.885	3.508	6.453	11.737	21.114	37.582
33	1.922	3.648	6.841	12.676	23.225	42.092
34	1.961	3.794	7.251	13.690	25.548	47.143
35	2.000	3.946	7.686	14.785	28.102	52.800
36	2.040	4.104	8.147	15.968	30.913	59.136
37	2.081	4.268	8.636	17.246	34.004	66.232
38	2.122	4.439	9.154	18.625	37.404	74.180
39	2.165	4.616	9.704	20.115	41.145	83.081
40	2.208	4.801	10.286	21.725	45.259	93.051

APPENDIX B

VALUES OF K2 FOR VARIOUS AMORTIZATION PERIODS AND DISCOUNT RATES

amortization period (years)	DISCOUNT RATE 2%	4%	6%	8%	10%	12%
1	0.980	0.962	0.943	0.926	0.909	0.893
2	1.942	1.886	1.833	1.783	1.736	1.690
3	2.884	2.775	2.673	2.577	2.487	2.402
4	3.808	3.630	3.465	3.312	3.170	3.037
5	4.713	4.452	4.212	3.993	3.791	3.605
6	5.601	5.242	4.917	4.623	4.355	4.111
7	6.472	6.002	5.582	5.206	4.868	4.564
8	7.325	6.733	6.210	5.747	5.335	4.968
9	8.162	7.435	6.802	6.247	5.759	5.328
10	8.983	8.111	7.360	6.710	6.145	5.650
11	9.787	8.760	7.887	7.139	6.495	5.938
12	10.575	9.385	8.384	7.536	6.814	6.194
13	11.348	9.986	8.853	7.904	7.103	6.424
14	12.106	10.563	9.295	8.244	7.367	6.628
15	12.849	11.118	9.712	8.559	7.606	6.811
16	13.578	11.652	10.106	8.851	7.824	6.974
17	14.292	12.166	10.477	9.122	8.022	7.120
18	14.992	12.659	10.828	9.372	8.201	7.250
19	15.678	13.134	11.158	9.604	8.365	7.366
20	16.351	13.590	11.470	9.818	8.514	7.469
21	17.011	14.029	11.764	10.017	8.649	7.562
22	17.658	14.451	12.042	10.201	8.772	7.645
23	18.292	14.857	12.303	10.371	8.883	7.718
24	18.914	15.247	12.550	10.529	8.985	7.784
25	19.523	15.622	12.783	10.675	9.077	7.843
26	20.121	15.983	13.003	10.810	9.161	7.896
27	20.707	16.330	13.211	10.935	9.237	7.943
28	21.281	16.663	13.406	11.051	9.307	7.984
29	21.844	16.984	13.591	11.158	9.370	8.022
30	22.396	17.292	13.765	11.258	9.427	8.055
31	22.938	17.588	13.929	11.350	9.479	8.085
32	23.468	17.874	14.084	11.435	9.526	8.112
33	23.989	18.148	14.230	11.514	9.569	8.135
34	24.499	18.411	14.368	11.587	9.609	8.157
35	24.999	18.665	14.498	11.655	9.644	8.176
36	25.489	18.908	14.621	11.717	9.677	8.192
37	25.969	19.143	14.737	11.775	9.706	8.208
38	26.441	19.368	14.846	11.829	9.733	8.221
39	26.903	19.584	14.949	11.879	9.757	8.233
40	27.355	19.793	15.046	11.925	9.779	8.244

APPENDIX C

VALUES OF K1 FOR VARIOUS AMORTIZATION PERIODS AND INTEREST RATES

amortization period (years)	INTEREST RATE 5%	10%	15%	20%	25%	30%
1	1.050	1.100	1.150	1.200	1.250	1.300
2	0.538	0.576	0.615	0.655	0.694	0.735
3	0.367	0.402	0.438	0.475	0.512	0.551
4	0.282	0.315	0.350	0.386	0.423	0.462
5	0.231	0.264	0.298	0.334	0.372	0.411
6	0.197	0.230	0.264	0.301	0.339	0.378
7	0.173	0.205	0.240	0.277	0.316	0.357
8	0.155	0.187	0.223	0.261	0.300	0.342
9	0.141	0.174	0.210	0.248	0.289	0.331
10	0.130	0.163	0.199	0.239	0.280	0.323
11	0.120	0.154	0.191	0.231	0.273	0.318
12	0.113	0.147	0.184	0.225	0.268	0.313
13	0.106	0.141	0.179	0.221	0.265	0.310
14	0.101	0.136	0.175	0.217	0.262	0.308
15	0.096	0.131	0.171	0.214	0.259	0.306
16	0.092	0.128	0.168	0.211	0.257	0.305
17	0.089	0.125	0.165	0.209	0.256	0.304
18	0.086	0.122	0.163	0.208	0.255	0.303
19	0.083	0.120	0.161	0.206	0.254	0.302
20	0.080	0.117	0.160	0.205	0.253	0.302
21	0.078	0.116	0.158	0.204	0.252	0.301
22	0.076	0.114	0.157	0.204	0.252	0.301
23	0.074	0.113	0.156	0.203	0.251	0.301
24	0.072	0.111	0.155	0.203	0.251	0.301
25	0.071	0.110	0.155	0.202	0.251	0.300
26	0.070	0.109	0.154	0.202	0.251	0.300
27	0.068	0.108	0.154	0.201	0.251	0.300
28	0.067	0.107	0.153	0.201	0.250	0.300
29	0.066	0.107	0.153	0.201	0.250	0.300
30	0.065	0.106	0.152	0.201	0.250	0.300
31	0.064	0.105	0.152	0.201	0.250	0.300
32	0.063	0.105	0.152	0.201	0.250	0.300
33	0.062	0.104	0.152	0.200	0.250	0.300
34	0.062	0.104	0.151	0.200	0.250	0.300
35	0.061	0.104	0.151	0.200	0.250	0.300
36	0.060	0.103	0.151	0.200	0.250	0.300
37	0.060	0.103	0.151	0.200	0.250	0.300
38	0.059	0.103	0.151	0.200	0.250	0.300
39	0.059	0.102	0.151	0.200	0.250	0.300
40	0.058	0.102	0.151	0.200	0.250	0.300

SUBJECT INDEX

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12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

This report summarizes available information on cost effectiveness of engineering modifications of potential value in dose reduction at nuclear power plants. Data was gathered from several U.S. utilities, published literature, equipment and service suppliers, and recent technical meetings.

Five simplified econometric models were employed to evaluate data and arrive at a value for cost effectiveness expressed in either (a) dollars/rem; or (b) total dollar savings calculated using a nominal value of $1,000/rem. Models employed were: a basic model with no consideration given to the time value of money; two models in which discounting was used to evaluate costs and savings in terms of present values; and two models in which income taxes and revenue requirements were considered. Results from different models varied by as much as a factor of 10, and were generally lowest for the basic model and highest for the before-tax revenue requirements model.

Results for 151 evaluations employing different assumptions concerning number of plants per site and outage impacts were tabulated in order of decreasing cost effectiveness. Twenty-five evaluations were identified as exceptionally cost effective since both costs and dose were saved. Forty evaluations indicated highly cost-effective changes based on costs of less than $1,000/rem saved using results of the present-worth model that included discounting of future dose savings.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
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