BNL-NUREG- 33809
CONF-8310143--53

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Dose Reduction at Nuclear Power Plants *

BNL-NUREG--33809

DE84 002870

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Presented at the Eleventh Water Reactor

Safety Research Information Meeting

Gaithersburg, Maryland

October 24-28, 1983

*This work was performed under the auspices of the U.S.Nuclear Regulatory Commission.

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Introduction

The Collective dose equivalent at nuclear power plants increased from approximately 1,250 rem in 1969 to nearly 54,000 rem in 1980 (8). This rise is attributable primarily to an increase over the same time period in nuclear generated power from 1,289 MW-yr to 29,155 MW-yr; and secondly, to increased average plant age. However, considerable variation in exposure occurs from plant to plant depending on plant type (BWR or PWR), refueling schedule, maintenance problems, etc. In order to understand the factors influencing these differences, the Nuclear Regulatory Commission has recently contracted with Brookhaven National Laboratory (BNL) to study dose-reduction techniques and effectiveness of as low as reasonably achievable (ALARA) planning at light water plants. These studies have the following objectives:

- Identify high-dose maintenance tasks and related dose-reduction techniques,
- Investigate utilization of high-reliability, low-maintenance equipment,
- Recommend improved radioactive waste handling equipment and procedures,
- Examine incentives for dose reduction, and
- Compile an ALARA handbook on data, engineering modifications, cost-effectiveness calculations, and other information of interest to ALARA practitioners.

High-Dose Maintenance Tasks

Maintenance work contributes about 79% to the annual collective dose at BWRs and about 70% at PWRs. These differences are attributable primarily to differences in plant design and layout. BWRs tend to have a greater number of contaminated components since their turbines are exposed to activity generated in the primary system. However, the steam generators which separate primary and secondary systems in PWRs get contaminated and, due to many recent steam generator tube failures, this system proves to be the largest source of exposure in PWR systems.

Data on nuclear power plant doses as a function of specific jobs was reported in 1974 by Pelletier et al. in a study done for the Atomic Industrial Forum (1). A more recent and more detailed study on doses for specific jobs, and related to specific components and systems was done by Warman et al. (2) for EPRI. Typical data from this study are shown in Table 1 for jobs exceeding 5 man-rem at a typical BWR plant. Data for this plant indicate the highest dose tasks relate to work on control rod drives, nozzles, work on piping insulation and welds in the drywell, wiring repairs on the nuclear instrumentation system, repair and inspections of various valves and pumps in the reactor water recirculation and radioactive waste management systems. In general, the reactor vessel and appurtenances, main steam system and torus system also contribute significantly to high doses at BWRs.

Typical PWR plant refueling doses are given in Table 2 for four successive refueling cycles. For this sytem, steam generator work has been the outstanding source of exposure, followed by work on the reactor vessel head and refueling operations. An increase in total dose is seen in successive refueling cycles (61,268,322 and 434 man-rem, respectively) mainly due to the increased doses received in steam generator work.

Lattanzi et al. (3) reported in 1981 on annual dose data from 67 U.S. and European plants. Data for 18 of the more important maintenance activities at PWR and BWR plants are summarized in Tables 3 and 4, respectively. For comparison, data from Pellitier's study (1) are also included in these Tables. Total doses for the listed activities changed less than 10% between Pellitier's earlier study (approx. 1973) and the 1981 compilation of Lattanzi et al. It is interesting to note the large differences between low and high exposures for various activities. This is frequently greater than a factor of 10. Also, high values are often two to four times the average for a given activity.

Dose-Reduction Techniques

Good health physics practices include many dose reduction techniques in addition to the basic three - time, distance and shielding. Data will be gathered on these as well as design, engineering and equipment techniques which are in use or under study.

Two previous studies of importance in terms of dose-reduction techniques are the AIF/NESP study on design features (4) and the AIF report on engineering techniques and modifications (5). The former report includes information on 119 subjects. It does not include cost information nor does it serve as a complete checklist during plant design. However, it does provide a useful summary of features which should be considered.

The AIF report on engineering techniques includes some cost estimates; but total costs, and benefits achievable are plant specific, therefore, appropriate cost-effectiveness calculations are not possible without further study. The data contained in the AIF assessment is summarized in order of decreasing cost per man-rem saved in Tables 5 and 6 for PWR and BWR Plants, respectively. These costs do not include health-effects costs nor costs or savings due to changes in critical-path times. The costs may also not adequately reflect savings due to reduced work times and reduced crew changes in future years. Since critical-path costs and manpower savings, in the cost/benefit equations, are generally as important or more important than health-effects costs, it is essential to evaluate them.

The results tabulated illustrate that, for some modifications, the cost per man-rem saved is less than the usually employed health-effects value of $1,000 per man-rem. This means these modifications are likely to be cost-effective provided critical-path time is not increased and even if no savings in future work or crew changes result. This is especially interesting since an effective interest rate of about 20% was used in the AIF study whereas "real" interest rate (ususally 3 to 7%) may be more appropriate. The real rate is corrected for inflation which influences both the cost of borrowing money and the cost of future health effects by about the same factor. The difference is highly significant since it results in cost estimates that are 3.94 times larger for 20% interest rates than they are for 3% interest rates.

Other hardware and procedural changes which are being considered are illustrated by those listed in the Westinghouse Electric 1980 edition of their Nuclear Digest. These modifications and likely dose reductions are shown in Table 7. Costs and dose savings typically associated with installation, operation and maintenance of these modifications will be evaluated and studied for cost-effectiveness.

In new PWR plant designs, a collective dose reduction of about 20% appears to be possible by using low cobalt steel (Inconel 600 with a maximum cobalt content of 0.015%) in the steam generator tubes. This can be obtained at comparatively little extra cost. Some foreign plants have recently been designed with predicted collective dose considerably below current U.S. experience. For example, the Sizewell "B" PWR plant to be built in England (6) has a design target of 0.2 rem/MW(e)-y collective dose. This may be compared to 0.5 rem/MW(e)-y for similar four-loop Westinghouse plants built in the U.S. since 1974. In addition, a design target of 1.0 rem maximum individual effective dose equivalent has been imposed. Several design features are included to meet the 1 rem/y criterion, even though these features may not be cost-effective (based on a sliding scale of $60 to $1,500/man-rem over the dose range 0 to 5 rem/y).

Equipment Reliability

The Nuclear Plant Reliability Data (NPRD) system is maintained by the Institute of Nuclear Power Operations (INPO). Knowing which components contribute to high worker dose, it should be possible to evaluate the value of reliability improvements to dose-reduction actions. Since routine and non-routine maintenance activities at nuclear power plants contribute about 70 to 80% of the total station exposure, reducing the amount of routine maintenance and repair via the use of higher reliability equipment may be important.

The objective of this task is to investigate the use of equipment reliability data, including dose received in component repair, and determine if this data is used by maintenance and engineering personnel. This will be accomplished by questioning the:

- Availability of NPRD data to station personnel,
- Availability of component repair exposure data,

- Application of NPRD and exposure data to preventative maintenance programs
- Application of NPRD and exposure data to equipment replacement,
- Methodology used to determine unreliable components, and
- Nature of the feedback loop on unreliable equipment from maintenance worker to architect-engineers.

Improved Radioactive Waste Handling Equipment and Procedures

Numerous studies have been reported on radioactive waste volume reduction. Although volume reduction leads to occupational dose reduction, this is only one of many areas to consider in dose reduction associated with radioactive waste handling. A study of the available literature reveals that a detailed review of radwaste dose-reduction techniques at nuclear power plants has not been performed. Numerous radwaste handling improvements have been implemented at each nuclear facility over the course of its operation. The objective of this task is to examine these improvements and recommend the most beneficial radwaste handling equipment and procedure changes which would reduce occupational exposure. Areas to be investigated via plant visits include:

- Administrative policy and practices,
- Radioactive waste management organization,
- Waste handling training and procedures,
- Equipment and facility modifications,
- Dose-reduction improvements, and
- Dose associated with radioactive waste handling operations.

Incentives for Dose Reduction

As health physicists we have strong incentives for reducing exposures since this is so basic to our profession. However, operators of an electric generating plant have very powerful monetary incentives, which at times are in competition with dose-reduction objectives.

Incentives which may aid in achieving dose reduction include:

- Monetary, resulting from related reduction in critical-path time, smaller required work forces, etc.,
- Desire for improved personnel relations which results from worker recognition that plant management is concerned with worker health and safety,
- Desire for reduced NRC and INPO surveillance and reporting,
- Minimizing insurance costs,
- Good public relations,
- Goals, such as annual reduction in dose per plant or per unit power generated, and
- Rewards for useful worker ALARA suggestions.

Available data on these and other incentives will be gathered and analyzed for their effectiveness.

ALARA Handbook

As information is gathered on this project, we are considering the development of a loose-leaf notebook type handbook which could conveniently be updated as needed. The types of information we hope to obtain may be organized into the following sections:

- Data on high-dose maintenance tasks,
- Data on dose-reduction techniques,
- Case histories of innovative ALARA techniques,
- Examples of cost-effectiveness calculations,
- Data on high reliability components,
- Information on robotics, and other futuristic techniques,
- Names and addresses of ALARA engineers and health physicists, and
- ALARA references.

Contributions to the ALARA Handbook will be solicited and authorship or source will be acknowledged if desired. Contributors would, of course, be on the mailing list for the Handbook and its updates. By this mechanism we hope to aid in documenting the growing body of ALARA knowledge and techniques, and facilitate exchange of useful information which will make the process even more effective.

The first publication coming out of this work will be an Annotated Bibliography on Selected Readings on Radiation Protection and ALARA (7).

References

1. C.A. Pelletier et al., National environmental studies project, compilation and analysis of data on occupational radiation exposure experienced at operating plants. Prepared for Atomic Industrial Forum, Inc. (1974).

2. E.A. Warman et al., Occupational radiation exposure reduction technology planning study, EPRI NP-1862, Technical planning study TPS 7961 (1981).

3. D.C. Lattanzi, C. Papa and S. Paribellli, Operating experience at nuclear power plants and its application to occupational radiation exposure reduction, in Proceedings of the International Symposium on the Application of the Dose Limitation System in the Nuclear Fuel Cycle Facilities and other Radiation Practices, pp. 191-204, IAEA, Vienna, 1982.

4. Compendium of design features to reduce occupational radiation exposure at nuclear power plants, edited by P.J. Pettit. Report for the National Environmental Studies Project of the Atomic Industrial Forum, Inc., AIF/NESP-020 (1981).

5. An assessment of engineering techniques for reducing occupational radiation exposure at operating nuclear power plants, prepared by the AIF Subcommittee on Engineering Techniques for Reducing Occupational Exposures (1980).

6. The application of the ALARA Principle to Sizewell "B", PWR/RX646, National Nuclear Corporation Limited, 1983.

7. J.W. Baum and D.A. Schult, Occupational Dose Reduction at Nuclear Power Plants, Annotated Bibliography on Selected Readings on Radiation Protection and ALARA, NUREG/CR-3469, BNL-NUREG-51708, in press.

8. B.G. Brooks, Occupational Radiation Exposure at Commercial Nuclear Power Reactors, Annual Report, NUREG-0713, Volume 2, 1980.

Table 1

BWR Plant B Summary of Doses Recorded Where Specific Job/Component/System Exceed 5 Man-Rem *

Job Description	Component Description	System	Man-Rem
Clean, Grind & Test	CRD Return Nozzles	Nuclear Boiler System	59
Insulation and Welds	Drywell	Undefined	45
Wiring	ACAD/CAM	Nuclear Boiler System	39
Rebuild	Spare CRDs	CRD Hydraulic	19
Repair	Valve-1201-72	RWCU Filter Demin.	17
Cleanup	Drywell & Refueling Flow	Undefined	16
Remove and Replace	CRDs	CRD Hydraulic	16
Inspect and Replace	Receive Pump Seal	Recirculation	14
Repair	Valve-1201-43	RWCU Filter Demon.	11
Repair	Condensate Pump	Reactor Protection System	10
Inspect and Repair	Snubbers	Undefined	9
Remove and Replace	Aux. Cleanup Pump	RWCU Filter Demin.	8
Replace Light Glass	"B" Receive Pump	Recirculation	8
Remove	CRD Return Nozzle Sleeve	Nuclear Boiler System	6
Inspection	Torus Area	Undefined	6
TOTAL			283
Overall Total			460
% of Overall Total			62%

*Data from Warman, et al, 1981. (Ref. 2)

Table 2

PWR Plant C Refueling Doses
By Job Description *

Job Function	Total Dose (Man-Rem) 1st Refueling	2nd Refueling	3rd Refueling	4th Refueling	Average
Steam Generator Work	-	-	92	183	138
General Entry and Miscellaneous Work	8	88	46	36	44
Reactor Vessel Head Removal and Replacement	32	42	28	20	31
Eddy Current Testing Steam Generator Tubes	-	28	26	26	27
Defueling/Refueling Operations	14	32	16	16	20
NSM Work	-	-	14	25	20
Inservice Inspection	-	11	20	25	19
Reactor Vessel Head Work on Storage Stand	8	8	3	51	18
Valve Repair or Replacement	-	27	26	20	18
Reactor Coolant Pump Seal and Motor Repair	-	22	19	8	16
Letdown Cooler Replacement	-	-	10	8	9
General Cleanup and Decontamination	-	8	6	10	8
Incore Instrument Work	-	1	16	6	8
Specimen Work	-	1	-	-	1
TOTAL	61	268	322	434	

*Data from E. Warman, et al, 1981. (Ref. 2)

TABLE 3 PRESSURIZED WATER REACTOR

AVERAGE MANREM EXPOSURE FOR 18 ACTIVITY CATEGORIES

Activity Category	US PWR Pellitier's[c] Ave.	High	Low	(N)[a]	US & European PWR Lattanzi's[d] Ave.	High	Low	(N)[a]
1. Liquid waste treatment	11.5	47.6	2.2	(8)	9.8	31.0	1.0	(24)
2. Solid waste handling	7.0	19.0	1.1	(10)				
3. Gaseous waste systems	1.1	-	-	(1)	Not included			
4. Head removal and installation	18.2	33.6	5.0	(8)	17.0	51.0	2.8	(36)
5. Fuel Handling	10.1	42.0	0.6	(10)	4.0	14.0	0.5	(31)
6. Instrumentation work, including calibration	3.6	7.8	0.8	(10)	6.0	13.8	7.0	(21)
7. Inservice inspection	15.7	23.2	1.7	(4)	28.0	115.0	2.0	(95)
8. Control rod drive work	minimal				4.5	17.7	4.0	(26)
9. Major equipment failures	Not included				Not included			
10. Recirculation pumps, including cleanup systems	Not applicable				Not applicable			
11. Steam generator inspection and repair	75.6	246.4	14.3	(14)	53.0	200.0	2.8	(56)
12. Reactor coolant pumps	7.8	15.4	1.7	(7)	67.0	82.0	57.0	(8)
13. Main coolant loops[b]	14.3	30.8	2.2	(7)	Not included			

(TABLE 3 continued)

Activity Category	US PWR Pellitier's[c] Ave.	High	Low	(N)[a]	US & European PWR Lattanzi's[d] Ave.	High	Low	(N)[a]
14. Charging pumps	3.9	11.8	0.6	(8)	Not included			
15. Valves	11.5	31.1	2.0	(5)	9.1	33.6	0.4	(25)
16. Turbine and auxiliary equip.	Minimal				Minimal			
17. Fuel pool including cleanup system	0.8	2.0	0.3	(6)	Not included			
18. Condensate demineralizers	Not applicable				Not applicable			
Total	181				198			

a. Number of annual fractions used to compute average.

b. Exposures from work on valves at Plant 12 have been subtracted and are included under "valve" category.

c. Pellitier's average fractions of annual plant exposure were multiplied by the average PWR Annual Exposure of 280 manrem to obtain the tabulated man-rem values; data from: Pellitier, Charles A. et al. "Compilation and Analysis of Data on Occupational Radiation Exposure Experienced at Operating Nuclear Power Plants", Science Applications, Inc., 1974.

d. Lattanzi, D. et al., "Operating Experience at Nuclear Power Plants and Its Application to Occupational Radiation Exposure Reduction", in Proceedings of the International Symposium on the Application of the Dose Limitation Systems in Nuclear Fuel Cycle Facilities and other Radiation Practices, pp. 191-204, IAEA, Vienna, 1982.

TABLE 4 BOILING WATER REACTOR

AVERAGE MANREM EXPOSURE FOR 18 ACTIVITY CATEGORIES

Activity Category	US BWR Pellitier's[c] Ave.	High	Low	(N)[a]	US & European BWR Lattanzi's[d] Ave.	High	Low	(N)[a]
1. Liquid waste treatment	14.0	27.5	4.75	(4)	11.0	35.0	0.2	(22)
2. Solid waste handling	5.75	22.5	1.75	(6)				
3. Gaseous waste systems	6.75	13.75	2.25	(3)	Not Done			
4. Head removal and installation	3.5	8.0	1.0	(12)	5.5	16.0	1.2	(36)
5. Fuel Handling	13.75	42.5	2.5	(12)	6.4	14.0	2.0	(19)
6. Instrumentation work, including calibration	7.5	27.5	1.5	(8)	7.1	24.0	0.8	(15)
7. Inservice inspection	12.25	24.0	3.5	(11)	23.0	106.8	3.3	(47)
8. Control rod drive work	8.0	23.5	1.25	(12)	7.5	32.0	6.0	(49)
9. Major equipment failures	Not included				Not included			
10. Recirculation pumps, including cleanup systems	19.5	72.5	1.5	(13)	58.0	88.0	51.0	(11)
11. Steam generator inspection and repair	Not applicable				Not applicable			
12. Reactor coolant pumps	Not applicable				Not applicable			
13. Main coolant loops[b]	Not applicable				Not applicable			

(TABLE 4 continued)

Activity Category	US BWR Pellitier's[c] Ave.	High	Low	(N)[a]	US &European BWR Lattanzi's[d] Ave.	High	Low	(N)[a]
14. Charging pumps	Not applicable				Not applicable			
15. Valves	13.0	40.0	1.25	(8)	4.1	29.0	2.0	(47)
16. Turbine and auxiliary equip.	6.75	25.0	1.5	(7)	3.3	11.0	0.6	(20)
17. Fuel pool including cleanup system	1.25	3.25	0.25	(6)	5.4	31.0	0.3	(39)
18. Condensate demineralizers	9.75	0.25	(4)		Not included			3.0
Total	122				131			

a. Number of annual fractions used to compute average.

b. Exposures from work on valves at Plant 12 have been subtracted and are included under "valve" category.

c. Pellitier's Average Fractions of annual plant exposure were multiplied by the average BWR annual exposure of 250 man-rem to obtain the tabulated man-rem values, data from Pelletier, Charles A, et al., "Compilation and Analysis of Data on Occupational Radiation Exposure Experienced at Operating Nuclear Power Plants", Science Applications, Inc., 1974.

d. Lattanzi, D., et al. "Operating Experience at Nuclear Power Plants and Its Application to Occupational Radiation Exposure Reduction", in Proceedings of the International Symposium on the Application of the Dose Limitation System in Nuclear Fuel Cycle Facilities and other Radiation Practices, pp. 191-204, IAEA, Vienna, 1982.

Table 5 - Summary of Engineering Modifications for BWR's *

BWR Tasks	Engineering Modifications	Estimated Annualized Cost ($)	Net Annual Man-rem Saved	Cost ($) Per man-rem Saved
Routine Visual Inspection	Install viewing windows in various areas of plant (5 windows)	1,000	7.5	130
General Maintenance	Scram discharge line modifications; cut holes in header to allow hydrolazing	800	5	160
Recirculation Pump Maintenance	Supply clean water to recirculating pump seals	5,000	20	250
Control Rod Drive Maintenance	Install electropolishing tank & electropolish the spud end of the CRD	8,000	10	800
Condenser Tube Maintenance	Improve helium leak detection	5,000	6	830
Refueling & Inspection	Locate fuel sipping cans near reactor cavity	1,000	1	1,000
Control Rod Drive Maintenance	Provide shielded water filled tank for disassembly & initial decontamination	7,000	6	1,200
Inservice Inspection--Primary System	Provide clearly identified & easily replaced section of insulation above weld	20,000	13	1,600
Inservice Inspection--Primary System	Install acoustic emission instrumentation on the vessel & primary coolant loop	90,000	43	2,100
Control Rod Drive Removal	Install semi-remote device for removing & replacing CRD's	65,000	31	2,100
General Maintenance	Improve working conditions, communications and radiation monitoring	11,000	5	2,200
RWCP Maintenance	Provide expansion loops and cooled seal water for RWCU pumps	20,000	7	2,900
Recirculating Pump Maintenance	Install permanent work platform around the pumps	6,000	2	3,000
Recirculating Pump Maintenance	Provide remote motor oil sampling and replacement capability	5,000	1.5	3,300

Table 5 - Summary of Engineering Modificatins for BWR's (cont'd.)

BWR Tasks	Engineering Modifications	Estimated Annualized Cost ($)	Net Annual Man-rem Saved	Cost ($) Per man-rem Saved
Safety Relief Valve Maintenance	Install a permanent hoisting device in drywell to remove and replace safety relief valves	5,000	1.5	3,300
Solid Waste Handling	Provide shielded fork-lift truck	12,000	3	4,000
TIP Repair Work	Provide remote cable cutting and disposal tools for TIP repair	10,000	2	5,000
MSIV Maintenance	Install a leakage control system	100,000	20	5,000
Primary Source Term Reduction	Magnetic filter in feed water	1,400,000	194	7,200
Refueling & Inspection	Use automatic sampling system for sipping fuel elements	30,000	4	7,500
Primary Source Term Reduction	High temperature filter in reactor coolant loop	750,000	97	7,700
Reactor Water Cleanup--Pump Maintenance	Reroute RWCU suction piping to downstream of heat exchanger	72,000	8	9,000
Reactor Vessel Open/Close--Stud Tension, Detensioning & Stud Removal	Provide remotely operated device	100,000	11	9,100
Snubber Inspection and Maintenance	Replace the hydraulic snubbers in drywell with mechanical snubbers	300,000	22	13,600
Solid Waste Handling	Install remote handling equipment	100,000	5	20,000
MSIV Maintenance	Replace y-pattern globe valve MSIV's with ball valves	800,000	18	44,000
Reactor Cavity Cleanup	Develop remote cleaning equipment	200,000	3	67,000
Radwaste Evap. Maintenance	Install multi-skid integral shielded units from improved material	400,000	5	80,000
Refueling & Inspection	Utilize improved BWR-6 refueling platform	300,000	1.8	167,000
MSIV Maintenance	Develop and apply automated lapping tools	700,000	4	175,000

*Data from report by AIF, Subcommittee on Engineering Techniques for Reducing Occupational

Table 6 - Summary of Engineering Modifications for PWR's *

PWR Tasks	Engineering Modifications	Estimated Annualized Cost ($)	Net Annual Man-rem Saved	Cost ($) Per man-rem Saved
Steam Generator Maintenance and Tube Plugging	Develop integrated portable shielding system	10,000	50	200
Steam Generator--Eddy Current Testing	Develop equipment to remotely install & remove the test devices	23,000	18	1,300
Steam Generator--Eddy Current Testing	Use method of completely remote installation & removal of "finger walker"	34,000	15	2,200
General Maintenance	Improve working conditions, communications and radiation monitoring	11,000	5	2,200
Steam Generator--Primary Head Access	Manway tensioning and handling device requiring only one operation	12,000	4	3,000
Primary Source Term Reduction	High temperature, coolant filter	750,000	225	3,300
Solid Waste Handling	Provide shielded fork-lift truck	12,000	3	4,000
Steam Generator Maintenance and Tube Plugging	Develop better tools & equipment for semi-remote inspection & plugging	100,000	20	5,000
Filter Cartridge Replacement	Install additional shielding plus use remote tools for opening & removing filter cartridge	30,000	6	5,000
Reactor Cavity Water Cleanup	Use high flow (250 gpm) clean-up system on skid mount	10,000	2	5,000
Steam Generator Maintenance and Tube Plugging	Develop fully remote equipment for tube plugging & automatic welding	680,000	90	7,500
Reactor Vessel Open/Close--Study Tension, Detensioning & Stud Removal	Provide remotely operated device	100,000	11	9,100
Primary Valve Maintenance	Perform a valve evaluation study	150,000	10	15,000
Residual Heat Removal Pump Maintenance	Use pumps with split couplings as replacement RHR pumps	70,000	4	17,500

Table 6 - Summary of Engineering Modifications for PWR's (cont'd.)

PWR Tasks	Engineering Modifications	Estimated Annualized Cost ($)	Net Annual Man-rem Saved	Cost ($) Per man-rem Saved
Solid Waste Handling	Install remote handling	100,000	5	20,000
Incore & Primary Instrumentation	Water vacuum incore detectors during withdrawal	25,000	1	25,000
Reactor Vessel Open/Close	Several separate improvements to handling equipment, tool design, personnel access, etc.	160,000	4	40,000
Reactor Vessel Open/Close	Replace head system with integrated design that combines lifting rig, seismic platform & cooling system, etc.	580,000	14	41,000
Filter Cartridge Replacement	Replace existing system with remotely operated back flushable filters	800,000	12	67,000
Reactor Cavity Cleanup	Develop remote cleaning equipment	200,000	3	67,000
Reactor Cavity Water Cleanup	Use high flow (600 gpm) cleanup system on skid mount	140,000	2	70,000
Radwaste Evap. Maintenance	Install multi-skid integral shielded units from improved material	400,000	5	80,000
Refueling Operations--Movement of Core Components & Fuel	Automated, higher speed refueling machine with improved fuel assembly gripper, automatic movement of bridge	250,000	2	125,000
Inservice Inspection Primary System--Containment Piping	Develop & implement automated inspection equipment	520,000	2	260,000
Reactor Coolant Pump Seal Maintenance	More efficient seal replacement system plus improved seal design	800,000	4	200,000

*Data from report by AIF Subcommittee on Engineering Techniques for Reducing Occupational Exposures, 1980. (Ref. 4)

Table 7 - Hardware and Procedural Techniques to Reduce Radiation Exposure in Nuclear Plants *

Item	Forward Fit	Backfit	Annual Man-rem Savings
Thermocouple Column Seal Clamp Redesign	●	●	2
Reactor Vessel Flange Cleanup Method	●	●	4
Reactor Vessel Head O-Ring Spring Clip	●	●	2
Permanent Reactor Cavity Seal Ring	●		3
Reactor Coolant Pump Seals Maintenance System	●	●	8
Optimized Valve Packing	●	●	10
Reactor Cavity Wall Cleanup System	●	●	1
Reactor Vessel Headstand Modification	●	●	1
S/G Primary Manway Cover Handling Fixture	●	●	4
Stud Spin-out Tool	●	●	6
Reactor Vessel Stud Tensioning/Detensioning Procedure	●	●	5
Integrated Reactor Vessel Head Package		●	5
Control Rod Change Fixture--Drive and Control System Upgrade	●	●	2
Reactor Coolant Pump Electrical Quick Disconnects	●	●	1
Control Rod Drive Mechanism Quick Disconnect Panel	●	●	2
Upper Head Electrical Test Box	●	●	1
Fuel Transfer Tube Quick Acting Hatch	●	●	4

*Data from Westinghouse Electric 1980 Edition of Nuclear Energy Digest.