
Some Aspects of Cost/Benefit Analysis for In-Service Inspection of PWR Steam Generators

Prepared by G. E. Zima, G. H. Lyon, P. G. Doctor,
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Pacific Northwest Laboratory
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ABSTRACT

This report discusses a number of aspects of cost/benefit (C/B) analysis for in-service inspection (ISI) of pressurized water reactor (PWR) steam generators (SGs) and identifies several problem areas that must be addressed prior to a full C/B analysis capability.

Following a brief review of the impact of SG problems on the productivity of PWR units and of the scope and variability of SG problems among U.S. PWRs, various occupational implications of SG ISI are considered, namely manpower, time, and rad exposure. The opportunities provided by refueling outages in respect to ISI frequency and work time windows are reviewed. Indices for characterizing the nondestructive testing (NDT) information, rad exposure, \$ impact, and manpower and time attributes of single ISIs and a series of ISIs over an arbitrary evaluation period are presented and calculated for a number of ISI cases using SG parameters for three typical PWR units.

A comparison of the \$ impact of unscheduled outages attributable to SG problems with the \$ cost of ambitious ISI strategies indicates that the \$ cost is virtually negligible for well-planned ISIs. Considering the ALARA constraint on occupational rad exposure, the skilled manpower pool for NDT work appears to be the principal factor limiting ISI scope and frequency. Analysis of the manpower and time requirements for inspection of a 40-unit PWR population indicates, however, that an ISI strategy embodying two campaigns per year and a total population inspection within a 2-year interval is not far beyond current capabilities.

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INTRODUCTION

There is ample incentive for improvement of the unit-wide performance of pressurized water reactor (PWR) steam generator (SG) tubing measured in terms of energy productivity loss and the occupational rad exposure attending SG inspection and requalification work.

Satisfactory resolution of the SG tubing degradation problem will require improvement both in tubing surveillance and in the material and environmental factors that affect tubing performance. The surveillance component of this improvement is the focus of this report. Nondestructive surveillance or in-service inspection (ISI) provides the principal measure of the tubing response to the working environment and, therefore, the principal guide to improvements in design, operation and maintenance practices that can optimize this response. Surveillance, in conjunction with degradation limits (e.g., plugging limits) on serviceability, also permits censoring of tubes that reach the "unacceptable" regime. Successive inspections provide a measure of the dynamics of the degradation processes and enable progressive refinement of censoring limits assuming reasonably steady-state working conditions.

The ability of an ISI program to satisfy the above functions is influenced by a number of factors: the overlap between the tubing sample of the inspection and the actual/potential problem zones within the SGs; the sensitivity of the nondestructive testing (NDT) technique to significant structural changes; the frequency of the inspections; the degradation limits used for censoring and the rate of the fastest degradation process; and the coordination of the ISI information with operation and maintenance details that could conceivably impact SG tubing performance, particularly those pertaining to management of the secondary water chemistry.

This report discusses a number of considerations that are preliminary to a full cost/benefit (C/B) analysis of SG ISI strategies and identifies some of the problem areas for further study toward development of a practicable C/B analysis technique.

SUMMARY

The fundamental relationship in SG ISI C/B analysis is that between the intensity (frequency, duration) of the unscheduled outages attributable to SG problems ($[USO_{sg}]$) and the intensity (information content on tubing integrity) of the ISI program ($[ISI]$). A satisfactory quantification of this relationship does not appear possible at present because of the sparsity of unit-wide tube performance information and the complex coupling among ISI information, unit design/operation/maintenance (D/O/M) practice that affects tubing behavior, and the tubing response to D/O/M changes. It is reasonable, however, to expect $[USO_{sg}]$ to decrease with more ISIs, assuming a conscientious effort to coordinate $[ISI]$ with unit D/O/M practice affecting the tubing. Without the latter effort, persistent adverse working conditions for the SG tubing could force $[USO_{sg}]$ to the point of periodic SG replacement and eventually to economic defeat of the unit irrespective of the level of $[ISI]$.

In the absence of predictable levels of $[USO_{sg}]$ as a guide for ISIs, it is expected that consideration of occupational rad exposure, ISI manpower availability, inspection time, and \$ costs of the ISI will be invoked to limit inspections to the "maximum feasible" level. This is a somewhat subjective criterion, but its $[USO_{sg}]$ basis would be expected to improve under careful and comprehensive observation of tubing performance and correlation with relevant unit D/O/M practice.

To assist in the latter effort, several indices and relationships are suggested in this report that attempt to quantify a number of aspects of SG ISI, including: occupational rad exposure, \$ impact, manpower and time requirements as a function of the ISI information index (Iisi). The information index given here considers scope (% of total tubes inspected), sample distribution (number of SGs involved in inspection), and frequency of inspections over an arbitrary evaluation period. This index does not take cognizance of the limitations of current NDT techniques in detecting significant changes in the tubing structure. While the information index would presumably be maximized by using state-of-the-art NDT techniques, the discrimination ability between nominal and unacceptable tubing structures represents an important and largely implicit

limitation on the significance of any ISI information index. Several composite indices (comprised of two or more single indices) are also suggested for assessment of ISI strategies. All of these indices are evaluated for 14 ISI cases and for three typical PWR units (2, 3, and 4 SGs per unit). The 14 ISI cases considered in this report range from the minimum inspection cases under Regulatory Guide 1.83 and ASTM Code XI rules to various arbitrary cases extending to 100% scope for each inspection over the evaluation period of 9 years. The inspection frequency over this period for all ISI cases was determined by average data for refueling outages of PWR units in the United States. Preliminary analysis of SG ISI requirements indicates that very conservative tubing inspection programs can be accomplished when the basis frequency and work time windows are controlled by the refueling outages. The refueling outage schedule is therefore considered to be a natural basis for evaluation of the indices. The 9-year evaluation period was chosen to accommodate up to a 3-year interval between inspections. Each of the indices considered in this report has both an individual inspection and an evaluation period counterpart. For illustration purposes, only the evaluation period index was computed although data for computation of indices for individual inspections are given.

For all the units considered, the C_1 composite index (information index divided by rad exposure index) exhibits a near monotonically increasing behavior with increase in the information index over the full range of the latter index. The somewhat more comprehensive composite index C_2 (information index divided by the product of the rad exposure and $\$$ impact indices) exhibits intermediate minima within the given information index range (see Figure 18, p. 49). The latter index shows some promise as an indicator of practicable ISI strategies, given input appropriate to individual units.

The manpower and time requirements for inspection of a 40-unit PWR population are analyzed in this report using values obtained from our NDT contractor consultants. Time and manpower estimates are given for various inspection scopes and for various inspection campaigns involving different numbers of units. Analysis of Nuclear Regulatory Commission (NRC) data revealed the expected bimodal characteristic of the histogram of fuel outage calendar dates. Our data suggest that an ISI strategy comprised of two campaigns per year and

a complete 40-unit population inspection within a 2-year period is not far removed from current or a reasonable extension of current SG NDT manpower capability under the ALARA (see Appendix A) constraint with respect to occupational rad exposure.

The \$ impact of USO_{sg} for a 1000-MW(e) unit is compared with the \$ impact index of the most ambitious ISI strategy considered in this report (100% scope for each inspection over the 9-year evaluation period) over a range of the lost power cost factor (mills/kWh). Even under a fairly pessimistic assumption as to the critical path interference of the SG ISI work, the cost of the ISI work is much less than the unit-wide cost of USO_{sg} based on 1976-1978 outage information for PWR units in the United States. The cost of well-planned (low-interference) ISI activity appears quite negligible compared to current or near-term projected USO_{sg} costs.

Some of the problems associated with a probabilistic analysis of SG tubing performance and calculation of the conditional failure probability that is related to specification of the interval between inspections are considered briefly. The prospects for a significant (probabilistic) tubing performance component in the SG ISI C/B analysis would be enhanced by increasing the NDT information content of inspections and better reporting of inspection findings.

An analysis of the costs and activities associated with the disposal of solid wastes derived from SG tubing leakage events indicates that this aspect of the SG tubing problem is negligible in respect of occupational exposure and \$ impact when compared to the SG inspection/requalification work and the downtime costs assignable to SG problems.

SG ISI C/B analysis will necessarily be a process of successive refinement due to current limitations on the knowledge of tubing behavior as a function of: (a) the as-installed state of the tubing; (b) the unit D/O/M practice pertinent to tubing performance. At the first level, a C/B analysis code should assist the unit manager in identifying his maximum feasible ISI intensity, based on the financial situation, ISI manpower availability, and rad exposure factors specific to his unit. This report has attempted to quantify some of these factors and to obtain some measure of their importance to SG ISI.

Successive levels of an SG ISI C/B code would represent progressive refinement of the maximum feasible concept based on $[USO_{sg}]$ experience. For well managed units, this refinement would be expected to result in some relaxation of the ISI intensity.

Practicable C/B analysis codes could be exercised by the individual unit managers at their discretion using local facilities or optionally a central agency serving a number of units for data banking and computation. It would appear feasible to incorporate many unit technical management functions within the purview of such a central agency in addition to the SG ISI service.

IMPACT OF STEAM GENERATOR PROBLEMS ON PRODUCTIVITY OF PWR UNITS

A number of criteria have been used and proposed to measure the impact of various unit problems and operational functions on power production. The capacity factor (CF, energy produced per year/maximum possible) has both simplicity and minimum ambiguity to recommend it as a criterion and it will suffice for the purposes of this report.

Recent Electric Power Research Institute (EPRI)-sponsored reports on the outage picture for light water reactor (LWR) units^(1,2) summarize the distribution of outage time between fuel and nonfuel outages as follows:

	<u>Total Outage Time, %</u>	<u>Capacity Factor Loss, %</u>
Refueling	41	11
Nonfuel (>100 hr)	40	11
Nonfuel (<100 hr)	19	5

From these studies, it was indicated that outages (fuel and nonfuel) account for a CF loss of about 27% with nonfuel outages accounting for about 16%. The outages attributable to SG problems generally fall within the >100-hour category as shown by the histogram of Figure 1. The modal value (corresponding to the highest frequency) is near 150 hours while the mean value is in excess of 500 hours. A measure of the contribution of SG problems to the CF loss attributable to nonfuel outages is obtainable from another recent EPRI-sponsored report that analyzed outages for both fossil and nuclear units. In this report,⁽³⁾ the CF loss attributable to SGs over the period from July 1976 to June 1978 is given below by the SG manufacturer:

Westinghouse (W)	3.9%
Babcock & Wilcox (B&W)	4.8%
Combustion Engineering (CE)	1.3%
Composite	3.6%

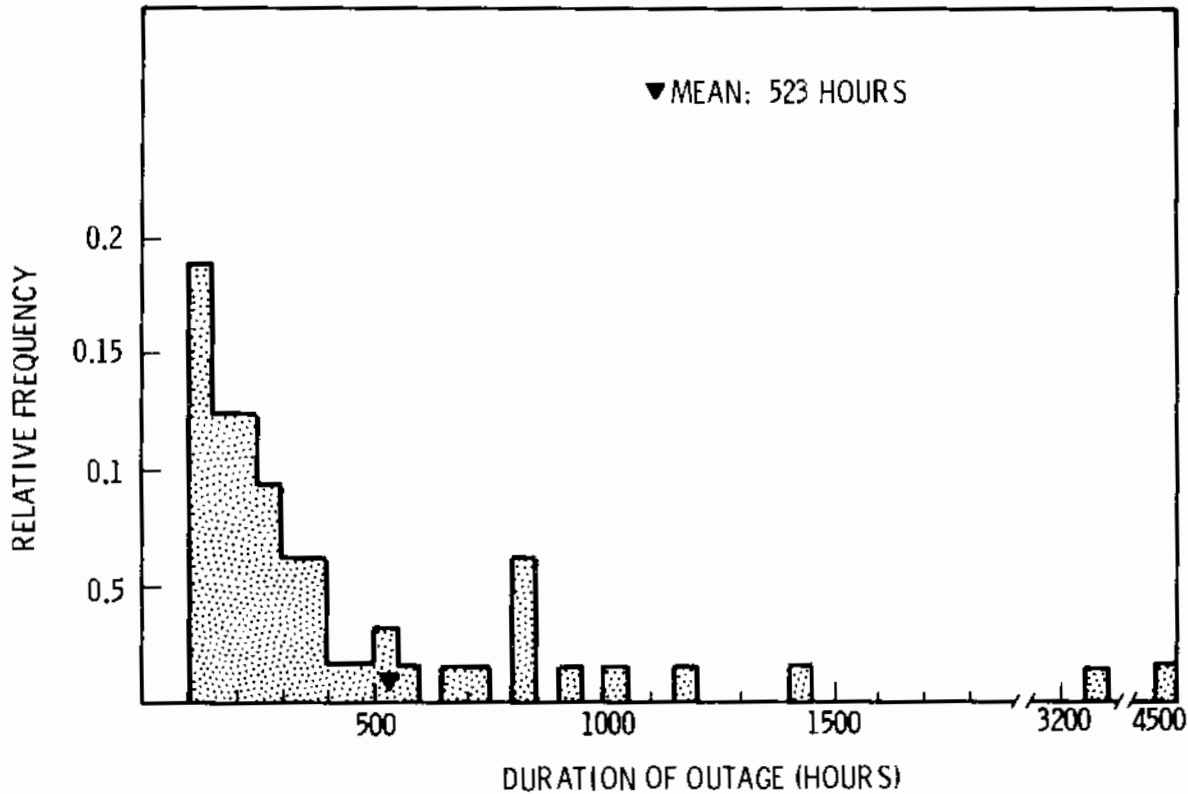


FIGURE 1. Histogram of Outages Involving Generators (>100 hr) (Reference 2)

Using the composite value of 3.6% for the SG impact on CF and the value of 16% CF loss due to nonfuel outages, it is seen that SG problems account for about 23% of the nonfuel outage time. From the relationship,⁽⁴⁾ 1000 MW(e) hr → 1500 barrels (bb1) oil, the barrel of oil equivalent of a change in CF can be estimated as follows:

$$\begin{aligned}
 \text{bb1/yr} &= \frac{\text{CF}(\%) \times [\text{MW}(\text{e})] \times 1500 \times 365 \times 24}{100 \times 1000} \\
 &= \Delta \text{CF}(\%) \times [\text{MW}(\text{e})] \times 1.31 \times 10^2
 \end{aligned}$$

where [MW(e)] is the unit rating and ΔCF is the incremental change in CF. For a 1000-MW(e) unit, a CF increment of 3.6% (given above as the composite value for the SG impact) would be equivalent to:

$$\text{bb1/yr} = 3.6 \times 1000 \times 1.31 \times 10^2 = 472,000$$

which is another rough measure of the impact of SG problems on nuclear units.

Detailed studies of the productivity of boiling water reactor (BWR) and PWR units have been made that help to quantify the impact of particular problem areas on unit productivity. Of the PWR units, reports have been issued on Turkey Point 3,⁽⁵⁾ Oconee 1,⁽⁶⁾ and Maine Yankee.⁽⁷⁾ The Turkey Point report gives the productivity loss attributable to various critical path items over the two years, 1975 and 1976. Using a base power level of 715 MW(e), the SG tube problems accounted for a loss of 544,323 MWh(e) over the observation period. In terms of CF loss this represents

$$\Delta\text{CF} = \frac{544,323 \times 100\%}{715 \times 2 \times 365 \times 24} = 4.3\%$$

In contrast, the Maine Yankee unit has reported no outage time attributable to SG problems throughout its history (from December 1972 to the present) although other heat exchangers (principally the main condenser) have been troublesome. From a corrosion perspective, the Maine Yankee unit is of particular interest inasmuch as brackish (chloride-containing) water is used as the condenser coolant.

As indicated above and in the following section there is a wide variation among the nuclear units with respect to SG reliability and any generic indices of SG performance must be so qualified. A somewhat more comprehensive indication of the various costs associated with SG tubing problems is given in the following sections.

While, as noted above, the downtime associated with SG tubing problems is a significant component of the CF loss for U.S. PWR units, it should be pointed out that to date there has been no public hazard associated with SG problems. This is indicated by the following data on the incidence of actual tube ruptures among the population of tubes plugged over the period 1975-1980.^(8,9,15)

<u>Plugged Tubes</u>	<u>Known Leakers</u>	<u>Ruptures</u>
10's of thousands	100's	5

Marsh⁽¹⁵⁾ defines a rupture as a leak that is greater than the normal charging flow capacity of the unit. None of the ruptures resulted in a significant off-site radiation dose.

SCOPE AND VARIABILITY OF STEAM GENERATOR TUBING PROBLEMS

In the readily accessible literature data on tubing performance are exceedingly sparse. We refer to the service time corresponding to a particular spectrum of tubing defect conditions for all the tubes of the unit. More specifically, we refer to the number of operable tubes, the number of unfailed plugged tubes and some measure of their residual life expectancy at time of plugging, and the number of failed tubes and their approximate failure time. In most instances, the performance information appears to present quite a limited perspective on the tubing behavior of the overall unit. Consequently, we are at this time limited to rather crude indices of tubing performance.

The majority of work to date on the statistical analysis of the outage data entailed investigating what data are available in what form. We talked with people at the Nuclear Regulatory Commission (NRC), EPRI, Southwest Research Institute (SWRI), and a local nuclear power utility, Washington Public Power Supply System (WPPSS).

The NRC Gray Book computerized data base SIOSR contains unscheduled outage data going back to 1974. One problem is that the cause of the outage is not always known at the time that the outage report is made so that there is a major source of error for a statistical analysis. There are also some inconsistencies in the definition of some of the unit performance indices. The advantage of this data base is that the raw data are made available for independent analyses.

The Nuclear Plant Reliability Data System (NPRDS) data base being developed by SWRI contains more detailed engineering data than the SIOSR data base. Since participation is voluntary, the completeness of the information and consistency of definition vary among the utilities. Combining data across plants for statistical analyses becomes problematical, and obtaining the raw data for our analyses appears to be a problem.

Another source of outage data is Nuclear Power Experience, Inc. This is perhaps the most complete and reliable source of outage data since incidence reports are generally followed up. The cause of an outage is more accurately

known than the one given in the Gray Book data base. However, unlike the Gray Book and NPRDS systems, the data are not computerized. Data are presented in narrative form so the quantification of information for statistical analyses is a sizable but not insurmountable task.

References 1, 2, and 3 are recent EPRI-sponsored analyses of outage trends in LWRs. The data source for these documents is the Gray Books.

Reference 1 analyzes the length of outage time due to refueling as a function of plant life. Refueling is the major cause of outage time except in the first year of reactor operation.

Reference 2 analyzes the causes of major (>100 hours) forced outages. SG problems are ranked second behind problems with the steam system based on arithmetic averages of outage times taken over plants with vastly different operating experience. The hours of downtime associated with SG problems may be rather imprecise due to the uncertainty in the cause of the outage, but the ranking is probably reasonably accurate.

Reference 3 compares the various measures of the unit performance that are provided in the Gray Books; examples are the Availability Factor (AF), Equivalent Availability Factor (EAF), and Capacity Factor (CF). The major problem in understanding the information contained in these data is that none of the measures, individually, describe the complexity of reactor performance. There is a good discussion of this in Section 2 of the cited report.⁽³⁾

From these reports we have the relative contribution of SG problems to outage time and a feel for the inaccuracies in the data. Based on the information described above, we obtained a data tape from NRC of all the unscheduled outage data contained in the SIOSR data base for use in statistical analysis of SG-caused outages.

Because of time constraints, the statistical analyses have been quite limited to date. Some of these are summarized in Figures 2 and 3. The data for plants with at least two calendar years of data were obtained from several reports.^(8,9) The breakdown by manufacturer for the computerized analysis is Westinghouse, 28; Combustion Engineering, 8; Babcock & Wilcox, 7; and

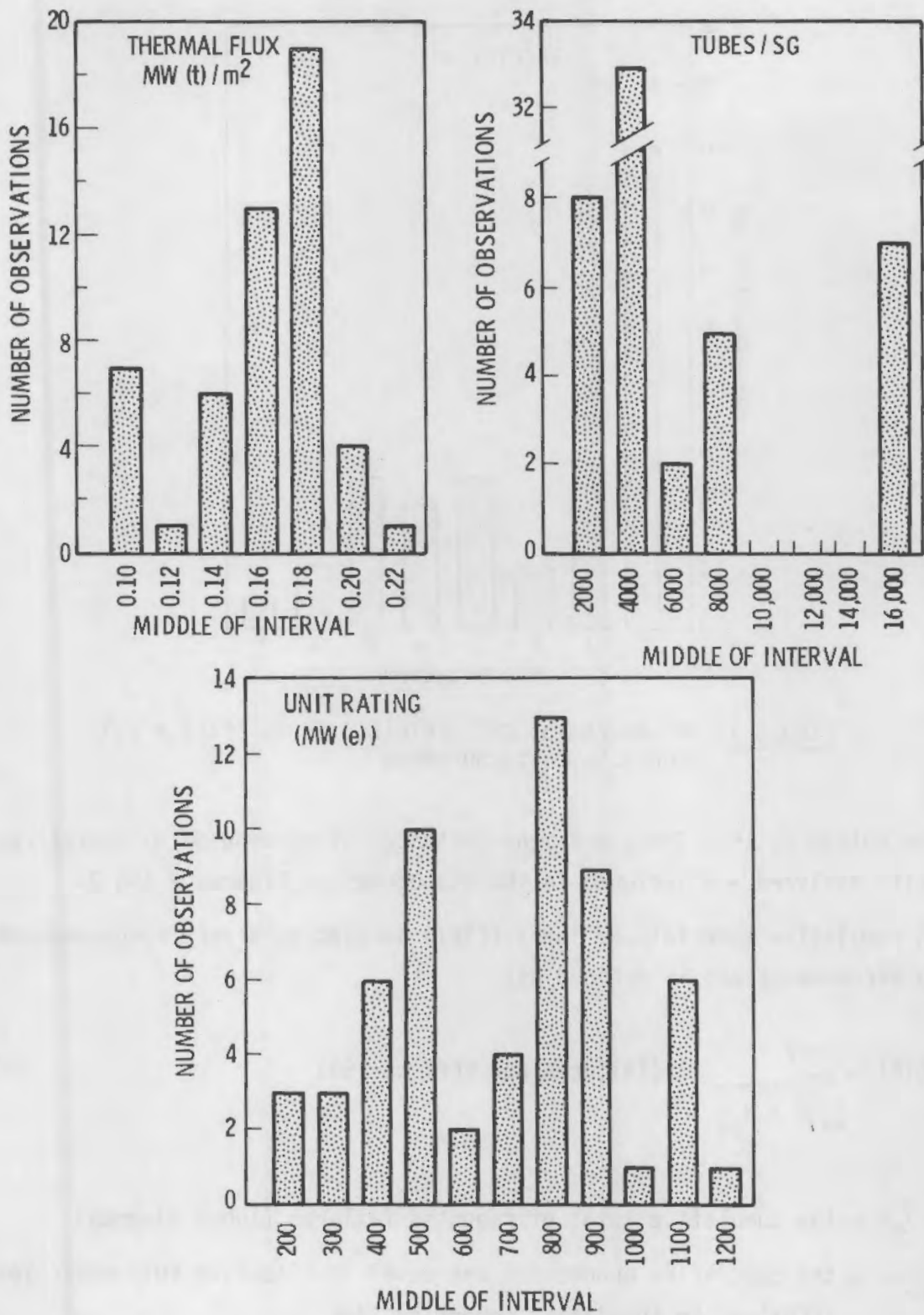


FIGURE 2. Histograms of Various Unit Steam Generator Parameters

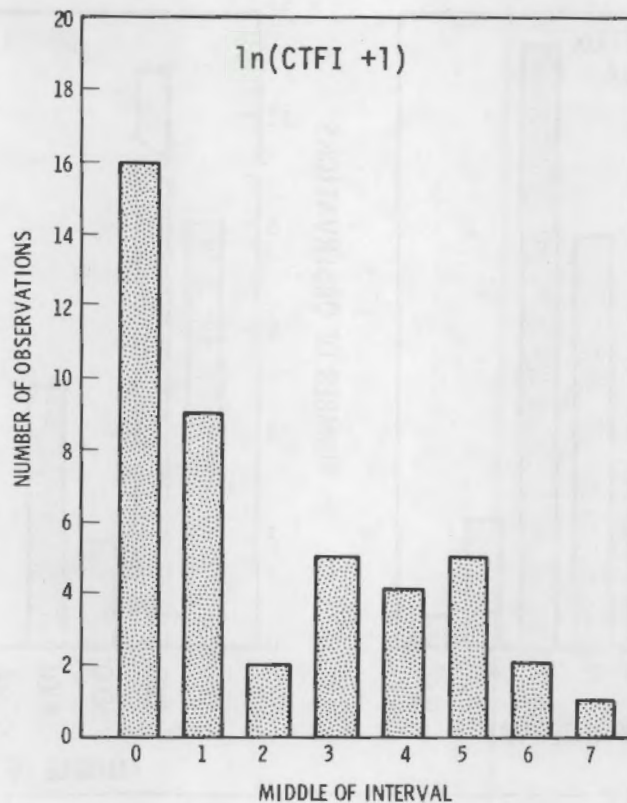


FIGURE 3. Histogram of CTFI [Plotted as $\ln(\text{CTFI} + 1)$] for U.S. Units Surveyed

foreign builders, 15. There are many instances of missing data; therefore, not all units analyzed are included in the histograms of Figures 2 and 3.

A cumulative tube failure index (CTFI) is used as a very rough measure of tubing performance and is defined as:

$$\text{CTFI} = \frac{\sum f}{\sum \theta \times N_{\text{sg}}} \quad (\text{failures per EFPY per SG}) \quad (1)$$

where $\sum f$ = the cumulative total of reported failures (tubes plugged)

$\sum \theta$ = the cumulative production expressed in effective full power years (EFPY) up to the latest reporting time

N_{sg} = the number of SGs in the unit.

Preliminary analyses were also done for several unit parameters that conceivably could influence tubing behavior, namely mean thermal power flux per SG [$MW(t)/m^2$], plant rating [$MW(e)$], and tubes per SG. Computer printer-plot histograms of the above variables for all plants are the basis for Figures 2 and 3.

Histograms provide an easy way to see the structure of the data, its variability, and possible erroneous values. More importantly, they provide a method for evaluating the behavior of indices that are devised to describe plant performance. For example, the histogram of $MW(e)$ is trimodal, which shows that reactors tend to cluster into three size groups. The histograms of number of tubes/generator and flux would show small variability if it were not for the Babcock & Wilcox plants, where the number of tubes/generator is very high (15,000-16,000) and the thermal flux is low (0.09- 0.125). However, one Westinghouse plant, Yankee Rowe, had a flux of 0.106.

The tube failure index ranged from 0 (no tube failures) to over 900 (Palisades). In order to get a meaningful histogram, the data were transformed to the following variable for Figure 3: $\ln [(tube\ failure\ index) + 1]$. The behavior is highly skewed, even exponential, which suggests that the mean is not a good representative average value. The mean is approximately 7.39 on the untransformed scale, and the median (the 50% point of the histogram) is about 2.12. Of the units reviewed whose data allowed some computation of the CTFI (not all such units were used in the statistical analysis or histograms):

- the CTFI ranged from 0 to 230 for 26 Westinghouse units with 7 units at 0
- the index ranged from 0 to 950 for 5 Combustion Engineering units with 2 units at 0
- the index ranged from 0 to 6.5 for 6 Babcock & Wilcox units with 1 unit at 0
- the index ranged from 0 to 46 for 9 foreign units with 2 units at 0.

It might be noted here that the yearly CTFI characteristics for these units also exhibit a wide variability and no correlation has been evident between the CTFI and the plant age. A cumulative plot of SG impact on CF versus plant age given in Reference 3 appears to support an "induction period" of roughly 4 years before tubing failures appear. Our preliminary findings do not support any induction period, certainly not on a generic basis. Furthermore, as noted above, the picture of the tubing defect state versus plant age or cumulative EFPY is far too diffuse to permit any identification of so subtle a feature as an induction period for tubing failure under a given plant's operating and maintenance history.

Of those units with some history of tubing failure, we have not acquired sufficient data to permit any failure rate analysis. The success of any prediction technique for tubing failure will depend on the degree to which cognizance can be taken of the internal (material) and external (environmental) factors affecting the tubing performance. Considering the complexity of such factors, the state of knowledge of the independent and synergistic action of these factors, and the unpredictable time displacement between cause and effect (which can range between weeks and years), we are not optimistic that tube failure prediction will enjoy much success in the near future. Such prediction will be aided by more comprehensive ISI and by more standardization of SG design, plant operation, and maintenance practice, particularly with respect to control of the secondary water system chemistry. Some additional comments on the problems of reliability analysis for SG tubes are given in a following section.

An ISI strategy receiving much current attention is a 100% inspection of one generator at a plant and then inferring the results to the other generators at the plant. This would be valid only if the failure rates do not differ significantly among the generators at the same plant. To test this hypothesis, separate tube plugging rates were obtained for the generators at six plants. The data and statistical results are given in Tables 1 and 2. The plugging rates within the same plant were compared by a χ^2 test for the equality of proportions. The value of the χ^2 statistic and the significance level are given in Table 2. The significance levels of only two of the plants are

TABLE 1. Distribution of Tubes Plugged Among Unit SGs

Unit	SG(A)	SG(B)	SG(C)	SG(D)	Period	Plant Parameters ^(b)
Robinson 2 (Westinghouse)	52 ^(a) 44%	32 28%	32 28%	--	'72-'77	700 MW(e) 3260 tubes/SG CCW: fresh
Palisades (Combustion Engineering)	1540 51%	1462 49%	--	--	'73-'77	700 MW(e) 8519 tubes/SG CCW: fresh
San Onofre (Westinghouse)	71 33%	40 19%	102 48%	--	to 6/79	430 MW(e) 3794 tubes/SG CCW: sea
Haddam Neck (Westinghouse)	1 3%	2 5%	14 36%	22 56%	to 2/79	575 MW(e) 3795 tubes/SG CCW: fresh
Oconee 1 (Babcock & Wilcox)	7 12%	54 88%	--	--	to 7/79	871 MW(e) 15,531 tubes/SG CCW: fresh
Point Beach 1 (Westinghouse)	294 53%	264 47%	--	--	to 10/79	497 MW(e) 3260 tubes/SG CCW: fresh

- (a) Top number is number of tubes plugged; bottom number is percent that this represents of tubes plugged for entire unit.
 (b) CCW = condenser cooling water.

TABLE 2. Test of Failure Uniformity Among SGs

Plant	Generator				χ^2	Sig Level
	A	B	C	D		
Robinson 2	0.0160 ^(a)	0.0098	0.0098		6.98	0.03
Palisades	0.1808	0.1716			2.46	0.12
San Onofre	0.0187	0.0105	0.0269		27.59	0
Haddam Neck	0.0003	0.0006	0.0037	0.0058	31.34	0
Oconee 1	0.0004	0.0035			36.28	0
Point Beach 1	0.0902	0.0810			1.76	0.18

- (a) Data under various SGs are fraction of tubes plugged for given SG.

greater than 0.10, which suggests that the equality of failure rates may not hold for a sizable number of plants. Plant records should yield further data on the failure distribution among SGs. Obviously these data are needed to characterize the course of ISI conservatism as the scope of the ISI is reduced on a regular or periodic basis.

The plans are to continue the statistical analyses using the data obtained from the SISO data base. In addition to the analyses needed for the C/B analysis, an outgrowth of the work will be an evaluation of the quality of the data being collected for the data base and possible suggestions on how to improve the information content in the unit performance indices and how to present the results to increase understanding.

FACTORS AFFECTING SCOPE AND FREQUENCY OF IN-SERVICE INSPECTION

The factors affecting the time, manpower, and radiation exposure components of an SG ISI have been analyzed by consulting various sources, including personal contacts with the following organizations: Conam Inspection Division of Nuclear Energy Systems; Zetec, Inc.; and the Inspection Division of the Babcock & Wilcox Co. A brief summary of the findings to date are presented in this section. A number of aspects of the various costs of SG ISI are developed in somewhat more detail in the following section.

Time, Manpower, and \$ Factors

Figures 4A and 4B present bar graphs of the various aspects of the SG ISI that account for the man-hour expenditure. The unit number refers to the coded identity of a particular unit. The figures give the man-hours attributable to four aspects of the ISI, namely preparation time, setup time, test time, and administrative delays.

- preparation time: transportation, instrument calibration, normal indoctrination of special crews (health, security)
- setup time: mockup training, actual instrumentation setup, and removal outside and within SG
- test time: NDT of the selected tube sample
- administrative delays: miscellaneous delays over and above nominally expected administrative items

The tube sample size is given with each bar graph in Figures 4A and 4B. Sample size ranges from 451 to 15,637 tubes. For this report, various average values obtained from the survey are of interest and are summarized in Table 3.

Figure 5 presents some preliminary information on the total cost of an ISI on a per-tube-inspected basis.

Table 4 presents some miscellaneous information on the tube plugging operation.

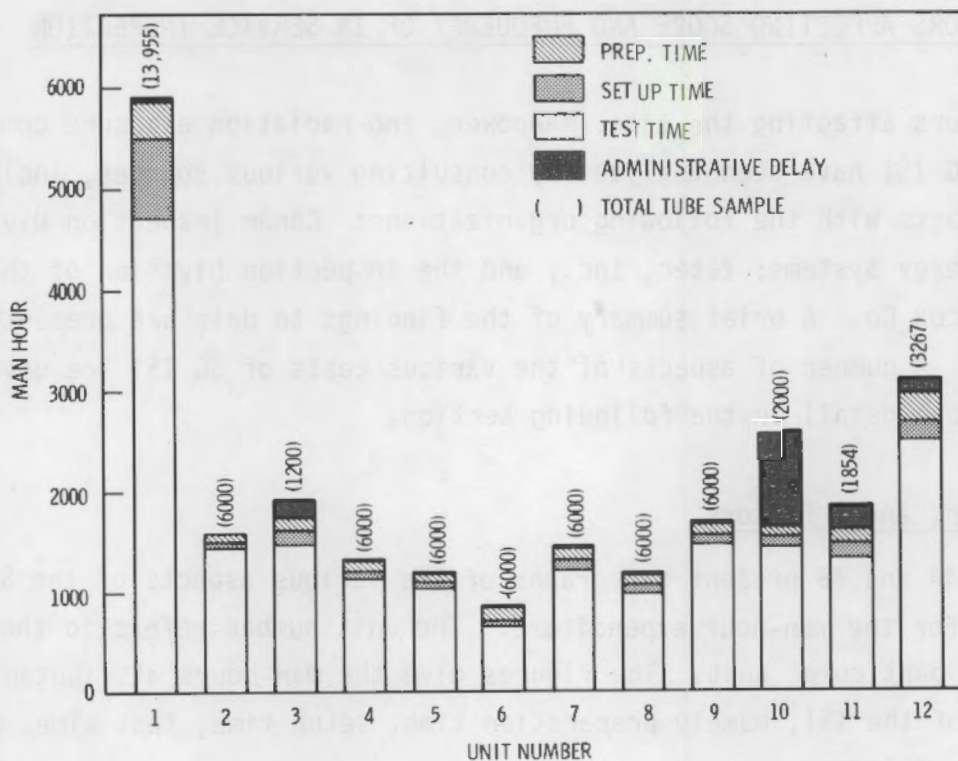


FIGURE 4A. Man-Hour Expenditure for Various ISI Items

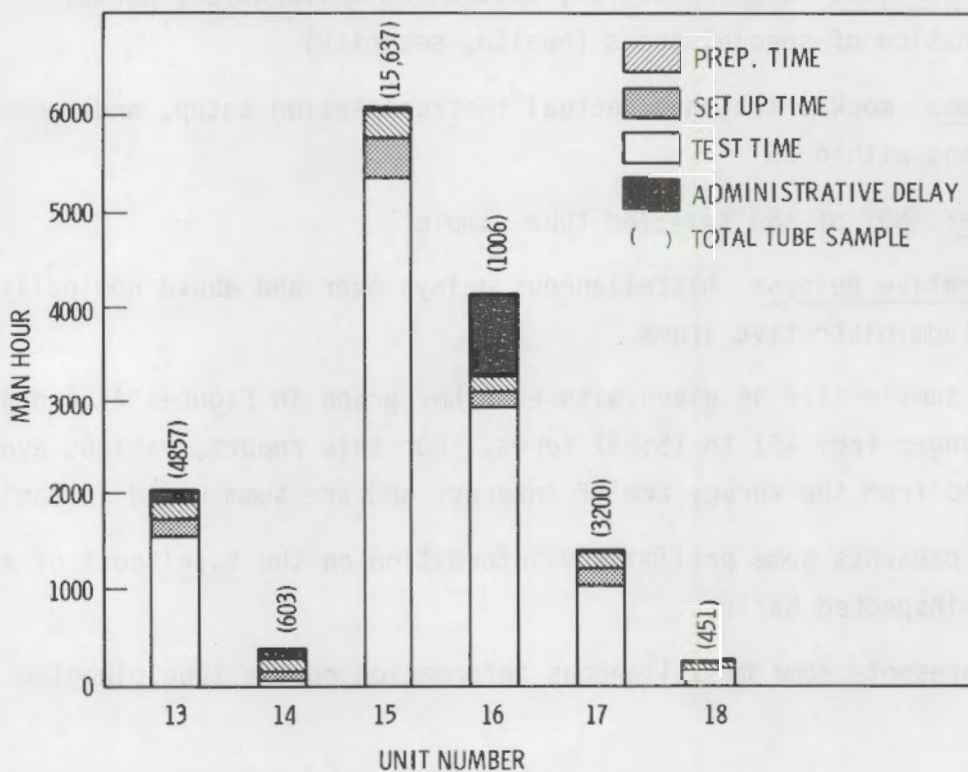


FIGURE 4B. Man-Hour Expenditure for Various ISI Items

TABLE 3. Average Data for Various Time/Manpower ISI Items

Item	Average Value(a)
tube samples	5000
preparation time	142 man-hours
setup	173 man-hours
administrative delay	162 man-hours
test time	1700 man-hours
personnel involved	10.4 men (contractor only)
total time on job ^(b)	2160 hr (contractor only)
charge-out rate	\$45/man-hour
total charge-out rate	\$450/hr

(a) Average based on units surveyed and displayed in Figures 4A and 4B.

(b) Door-to-door contractor's location.

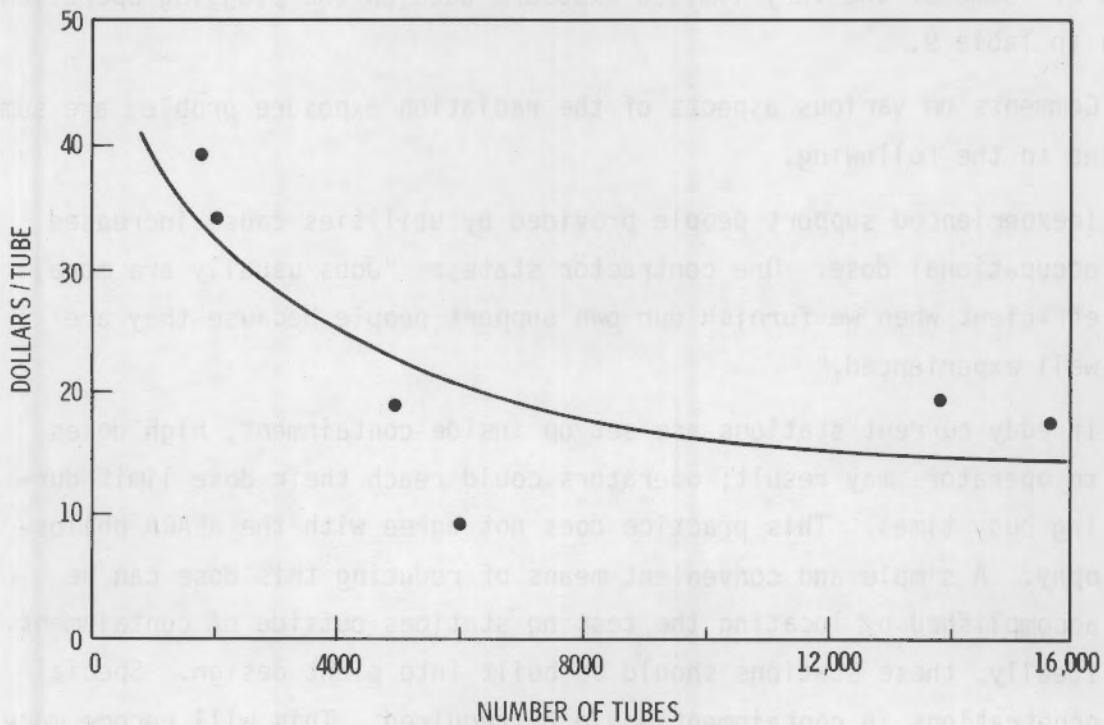


FIGURE 5. Cost/Tube for Testing Versus Sample Size

TABLE 4. Miscellaneous Tube Plugging Information

- Explosive plugging requires 20 sec-2 min per plug.
Mechanical plugging requires 1-2 min per plug.
Welding plugging requires 2 hr-1 week depending on rad field and equipment problems.
- Explosive plugging is used about 95% of the time compared to mechanical or manual plugging techniques.
- Mechanical plugging is seldom employed at present.
- Welded plugs are mainly used to supplement explosive plugs that are found to leak; the success record for explosive plugs has generally been excellent.

The Radiation Exposure Factor in SG ISI

Figures 6, 7, and 8 and Tables 5, 6, 7, 8, and 9 summarize our findings to date on the radiation exposure factor in SG ISI. Based on this review, the average exposure per ISI is about 2 rem per person. The range of exposures for the nontesting phases of the ISI operation for several types of SG is given in Table 8. Some of the very limited exposure data on the plugging operation are given in Table 9.

Comments on various aspects of the radiation exposure problem are summarized in the following.

1. Inexperienced support people provided by utilities cause increased occupational dose. One contractor states: "Jobs usually are more efficient when we furnish our own support people because they are well experienced."
2. If eddy current stations are set up inside containment, high doses to operators may result; operators could reach their dose limit during busy times. This practice does not agree with the ALARA philosophy. A simple and convenient means of reducing this dose can be accomplished by locating the testing stations outside of containment. Ideally, these stations should be built into plant design. Special penetrations in containment would be required. This will become more of a problem if 100% inspection is required.

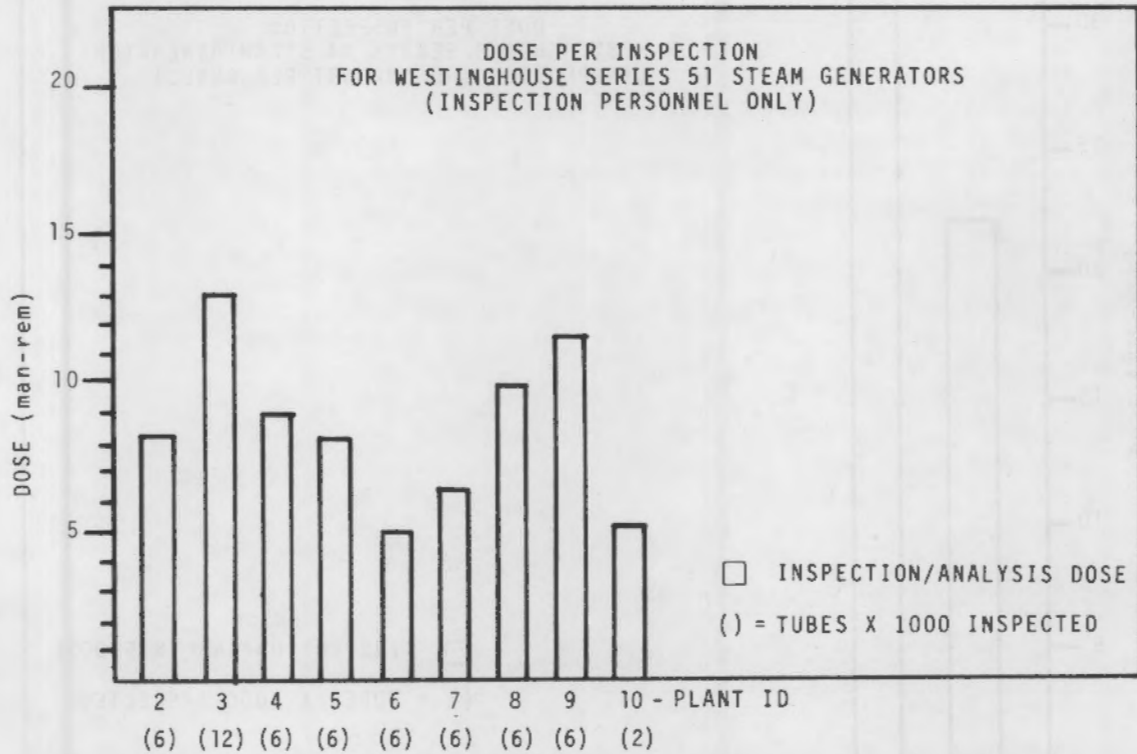


FIGURE 6. Dose Distribution for Various Units (W/Series 51);
Inspection Personnel Only

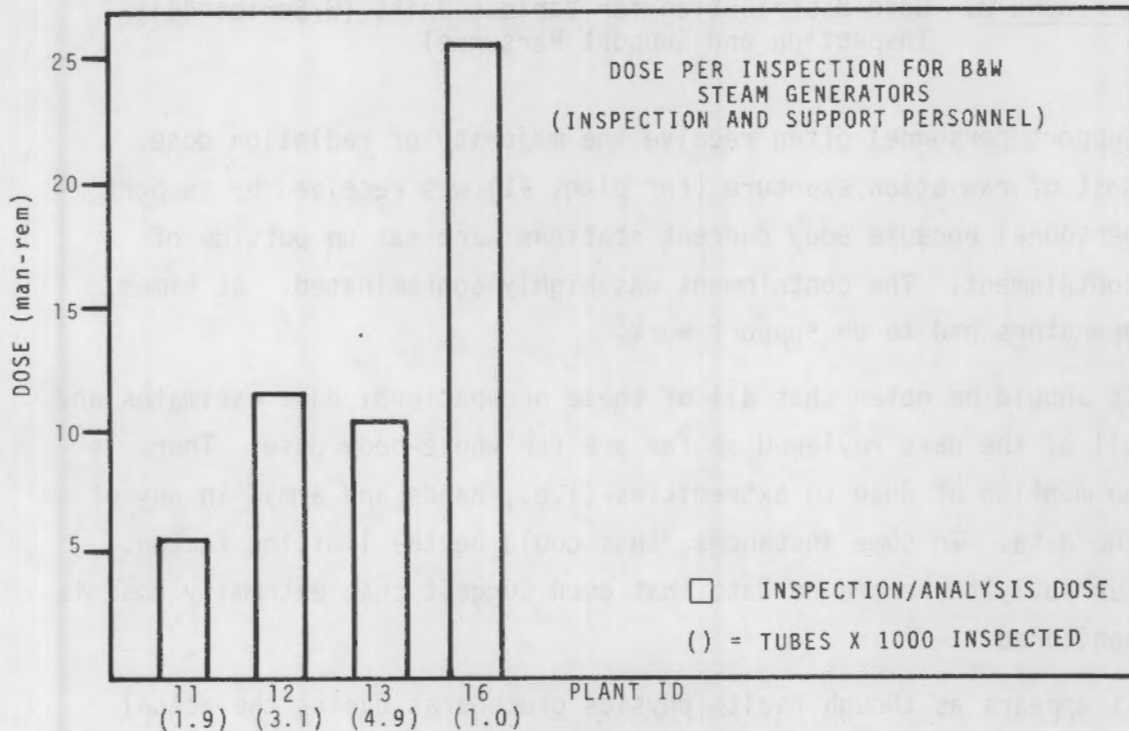


FIGURE 7. Dose Distribution for Various Units (B&W);
Inspection and Support Personnel

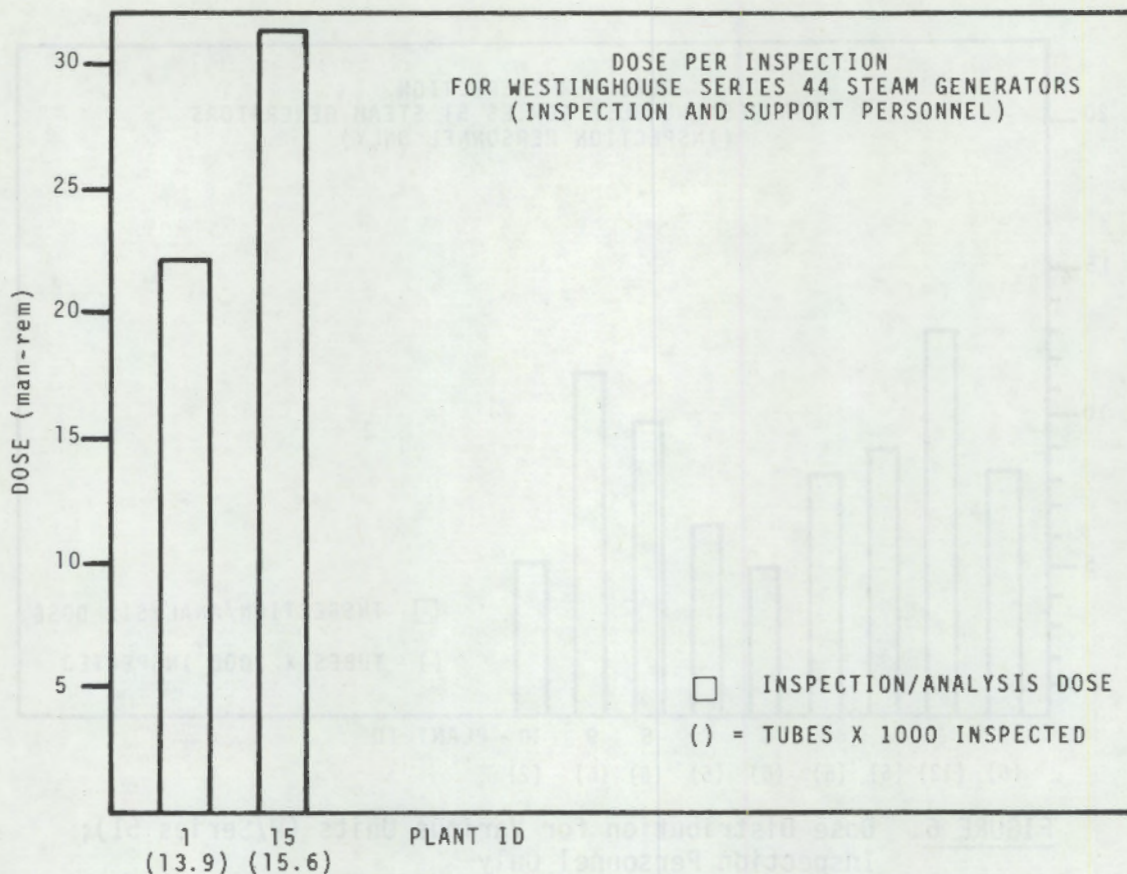


FIGURE 8. Dose Distribution for Various Units (W/Series 44);
Inspection and Support Personnel

3. Support personnel often receive the majority of radiation dose. Most of radiation exposure (for plant #1) was received by support personnel because eddy current stations were set up outside of containment. The containment was highly contaminated. At times, operators had to do support work.
4. It should be noted that all of these occupational dose estimates and all of the data reviewed so far are for whole-body dose. There is no mention of dose to extremities (i.e., hands and arms) in any of the data. In some instances, this could be the limiting factor. Currently there are no data that even suggest that extremity dose is monitored.
5. It appears as though health physics procedures during the actual inspection and setup time may actually cause increased occupational dose due to varying procedures by different health physics personnel

TABLE 5. Occupational Doses for Inspection Team Only with No Support Personnel (see Figure 6)

<u>Plant ID</u>	<u>Man-Rem</u>	<u>Tubes Inspected</u>	<u>Man-Rem/ Tubes Inspected</u>	<u>No. of Operators</u>	<u>No. of Assistants</u>	<u>No. of Analysts</u>
2	8.337	6000	1.39(-3)	4	0	1
3	12.91	12000	1.08(-3)	6	6	1
4	8.895	6000	1.48(-3)	4	4	1
5	8.265	6000	1.38(-3)	4	4	1
6	4.974	6000	8.29(-4)	3	2	1
7	6.336	6000	1.06(-3)	6	4	1
8	9.772	6000	1.63(-3)	5	1	1
9	11.534	6000	1.92(-3)	4	5	1
10	5	2000	2.5(-3)	5	0	1
Average	8.45±2.74	6200±2500	1.7(-3)	4.6±1.0	2.9±2.2	1±0

TABLE 6. Babcock & Wilcox Occupational Doses for Inspection Plus Support Personnel (see Figure 7)

<u>Plant ID</u>	<u>Man-Rem</u>	<u>Tubes Inspected</u>	<u>No. of Support Personnel</u>	<u>No. of Supervisors</u>	<u>No. of Operators</u>	<u>No. of Analysts</u>
11	5.51	1854	6	1	4	1
12	11.505	3094	8	2	4	1
13	10.57	4857	6	0	6	1
16	25.59	1006	8	0	4	1
Average	13.3±8.6	2700±1670	7.0±1.2	0.75±0.96	4.5±1.0	1

TABLE 7. Occupational Doses for Inspection Team Plus Support Personnel (Westinghouse Series 44) (see Figure 8)

<u>Plant ID</u>	<u>Man-Rem</u>	<u>Tubes Inspected</u>	<u>No. of Support Personnel</u>	<u>No. of Supervisors</u>	<u>No. of Operators</u>	<u>No. of Analysts</u>
1	22	13,995	10	2	8	2
15	31.192	15,637	8	0	8	1
Average	26.2	14,816	9	1	8	1.5

TABLE 8. Man-Rem Estimates for Setup and Removal Phases of Inspection

<u>Inspection Phases (a)</u>	<u>Westinghouse Series 51</u>	<u>B&W Vertical</u>	<u>CE Vertical U-Tube</u>
Fixture Channel Head Installation	0.8 - 5.0	0.8 - 6.0	1.7 - 6.7
Fixture Platform Setup	0.1 - 0.5	0.1 - 0.75	0.1 - 0.5
Fixture Channel Head Removal	0.4 - 2.5	0.4 - 3.0	0.67 - 2.7
Total	1.3 - 8.0	1.3 - 9.8	2.5 - 9.9

(a) The NRC Draft Regulatory Guide estimates 4.95 man-rem for these jobs.

TABLE 9. Information for Tube Plugging Operation

Exposive Rate	10 - 60 rem/hr
Explosive	0.050 - 2.0 man-rem
Mechanical	0.17 - 2.0 man-rem
Welding	0.17 - 2400 man-rem

for the same job during the same shift. This problem is caused partially by the utility hiring contract technicians who have different training and backgrounds. One solution to this problem is to have written health physics procedures and train all personnel (eddy current personnel and health physics technicians) in these procedures. There will still be variations from plant to plant, however; and this too tends to increase occupational exposure during ISIs. This situation could be remedied by having the eddy current inspection contractors provide their own health physics procedures and personnel. Utilities would retain the right to review and amend these procedures if they did not comply with plant operating philosophy (i.e., ALARA).

Fuel Outage ISI Opportunities

The frequency and time window for ISI work provided by the fuel outages can be assessed from a recent report on LWR fuel outages.⁽¹⁾ This study includes all U.S. LWRs of greater than 150 MW(e) rating over the period from January 1960 through June 1977.

Figure 9 summarizes the findings on the course of the fuel outage length with refueling number.⁽¹⁾ For the PWR units, the average curve shows that the first outage is about 13 weeks with a decrease to 7-8 weeks by the third outage. These authors⁽¹⁾ state that the minimum fuel outage length under present design and testing conditions appears to be of the order of 4-6 weeks. A comparison of the overall outage times for U.S. and foreign LWR units is given in Figure 10.

The range of the interval between first criticality and the first fuel outage is given in Figure 11A. Figure 11B shows the interval range between refuelings for first through the seventh refueling. As noted in the histograms, the mean time for the first fuel outage is 26 months, while the mean time between subsequent refuelings is about 12 months.

Using the mean data for the outage length and intervals, an ISI strategy based on fuel outages would have the frequency and work time windows shown in Figure 12. For comparison, frequencies under Regulatory Guide 1.83 recommendations for several problem cases are also given. With the possible exception

of the first postcriticality inspection, it is seen that the nominal fuel outage schedule would generally be quite conservative relative to the Regulatory Guide 1.83 position.

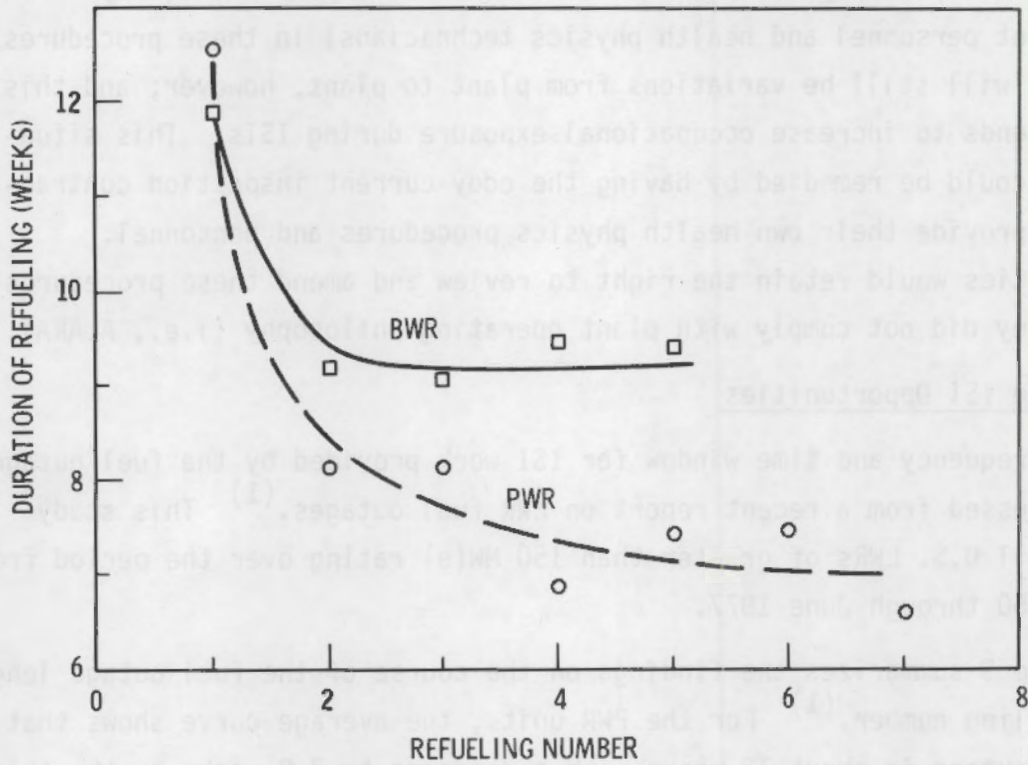


FIGURE 9. Refueling Outage Duration as a Function of the Number of Refuelings (Reference 1)

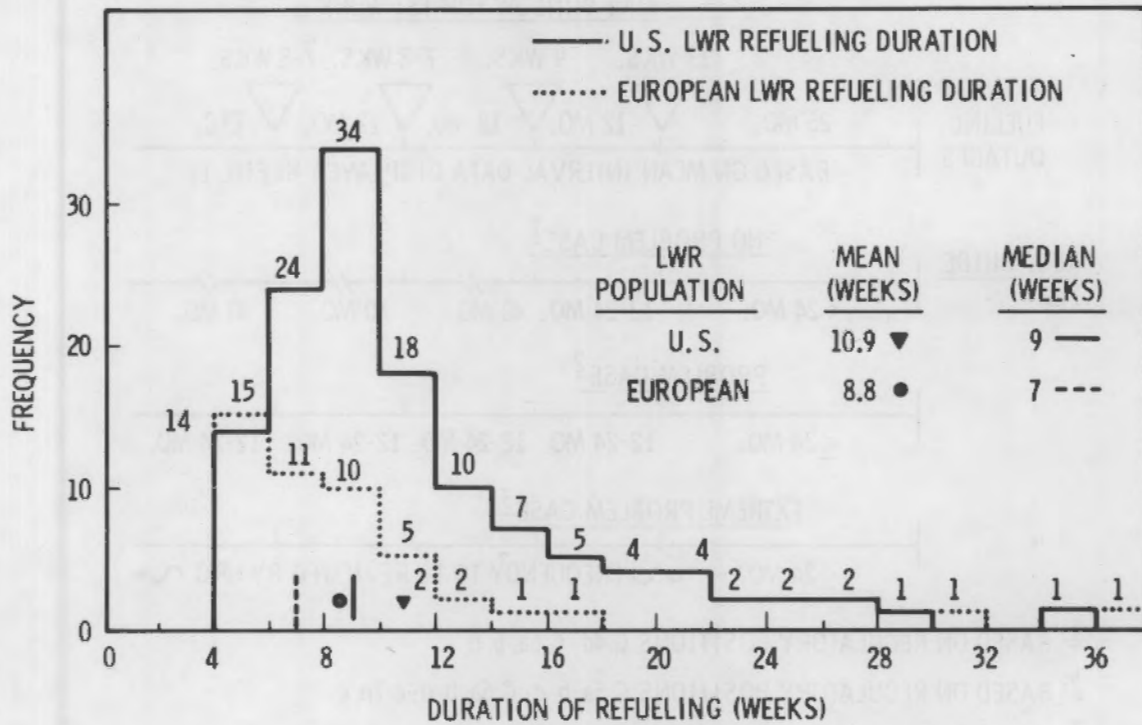


FIGURE 10. Refueling Durations: Comparison Between U.S. and European LWRs (Reference 1)

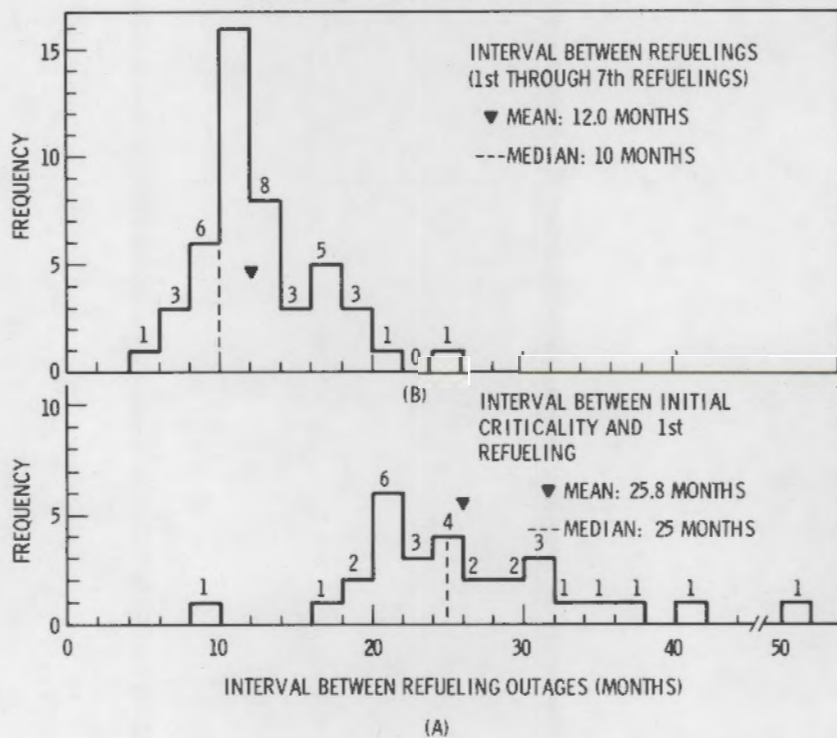
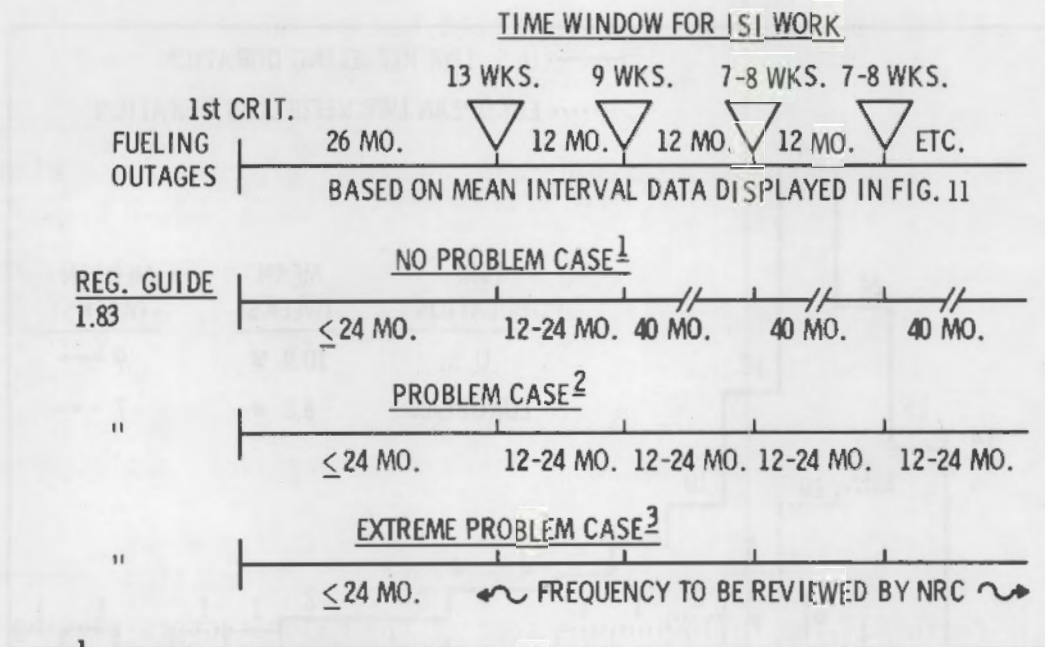


FIGURE 11. The Interval Between Refueling Outages (Reference 1)



¹: BASED ON REGULATORY POSITIONS C 4d; C 6a, b, d

²: BASED ON REGULATORY POSITIONS C 5a, b, c; C 6a, b, d; c 7b, c

³: BASED ON REGULATORY POSITIONS C 5a, b, c; C 7d

FIGURE 12. Comparison of ISI Frequencies Based on Fuel Outages with Regulatory Guide 1.83

COST OF DOWNTIME FOR NUCLEAR POWER PLANTS

The C/B analysis of increased inspection of SG tubes in nuclear power plants must include an assessment of the cost of downtime of the power plant. The downtime cost is the difference between meeting the same demand with replacement power versus meeting it with electricity generated by the nuclear power plant. The downtime cost can be separated into two parts. The first part to be discussed will be the cost of replacement power. The second part will be the cost or savings to the utility due to the forced outage. This opportunity cost is an implicit cost as opposed to the explicit replacement power cost.

The cost of replacement power is determined by the interaction among and between many factors. The following are some of the major factors causing the replacement of power to vary. The mix or type of power plants that any one utility system has will greatly affect the cost of replacement power. If a system has more base-load power available rather than intermediate or peaking load power, then the cost for replacement power will be less, all other factors being held constant. Not only the type of power plant but also the number available to supply power when one unit goes down will determine the cost of replacement power. If a utility system cannot obtain enough electricity from its own power plants or if the power can be purchased less expensively from another utility system, then the electricity will be "wheeled" in to replace the lost power. The price of this purchased power is also variable due to the same factors as discussed here.

In addition to the utility mix and the wheeling of power factors, the factor of time is very important. The utilities' power costs vary seasonally and diurnally. This can be seen in the company's load duration curve. The load duration curve charts the daily and/or seasonally varying load for the utility. At periods of high use of power, typically summer or winter depending on where the utility system is located (see Figure 22, p. 63, where the time of fuel outages is an inverse expression of this fact), the use of higher cost intermediate power and, perhaps, even peaking power may be necessary. If the utility is forced to purchase or produce power under these conditions, the price

will be much higher. Thus, the time of year and the time of the day will also influence the cost of replacement power. The load duration curve is different for each utility depending on location and uses of the power. This variation again causes the replacement cost of power to vary considerably with different regions of the country having quite different load duration curves and, consequently, different costs.

In addition to the influence of the above factors on the cost of replacement power, the amount of power needed or size of outage will also cause the cost to vary. Even though a nuclear plant goes off-line the amount of replacement power may be less because the nuclear plant may have been generating excess power for whatever reason. Also, the amount of power may be altered by actions the utility takes to reduce its load, i.e., stopping interruptible power sales. The cost of power may vary due to the amount needed to be purchased. A large amount of power may be less expensive on a per unit basis than a smaller amount. Thus, the firm's replacement power costs may vary considerably depending on external circumstances beyond the control of the utility.

To determine the cost of replacement power, historical cost data will have to be used. The reliability of these data is another factor influencing the cost of power. Given the rapid escalation in power costs over the past few years, any use of prior-year figures must be suspect. An escalation rate to adjust the cost of power leads to problems as to which rate to use and when to apply it. This entire issue, the reliability of data, will cause long-range forecasts of power costs to be much more suspect than at any time in the past.

All of the above factors interact with the others and make the estimation of replacement power costs for a utility at any one time in the future very difficult. As mentioned previously, the regions of the country have similar power costs due to the similarity of load duration curves and the fact that the plant mix of most of the utilities within a region will be similar. The wheeling of power between utilities within a region will, of course, also cause the replacement power costs to be the same. Usually a range of replacement power costs can be obtained for a region rather than a single-point estimate for one utility. This cost range would take into account all of the above factors;

but, of course, the exact cost that any one utility would face at some point in time in the future would be almost impossible to estimate accurately.

With the above factors in mind, the following overall range of replacement costs were obtained from the Bonneville Power Administration (BPA) for electricity sold to utilities either within or out of their grid system. The overall range was from 4.5-85 mills/kWh. The low end of the scale represents the use of hydroelectric generation on a massive scale in the Northwest. The upper end represents the use of gas/oil turbines of small capacity (≈ 25 MW(e)). The BPA has set a limit of 4.5-20 mills/kWh on the sale cost of hydroelectric power from the Northwest dams. In addition to the lower cost hydroelectric power base-load plants and the expensive oil/gas turbine-produced power, the Northwest has two coal plants, Centralia and Boardman, that are or will be, respectively, selling power in the 10-16 mills/kWh range. This intermediate range of power costs makes the average range of power costs for the Northwest 15-30 mills/kWh.

The overall range of power costs (4.5-85 mills/kWh) is the same for California. In California there is less of a hydroelectric base, which causes the average power cost to be between 20-50 mills/kWh. This is due to the use of more gas/oil turbines to generate electricity. The Northeast region of the country would have approximately the same average power costs as California due again to the reliance upon gas/oil-fired, electricity-generating units. The average replacement power costs for the rest of the nation would fall between the values for the Northwest and California. This is due to the use of coal-fired units, which generate electricity that is priced less than the gas/oil turbine derived power but more than the hydroelectric power.

To determine the downtime cost due to SG failure, a value for the utility's added costs must be calculated. This cost consists of the replacement cost and an adjustment to the replacement cost to account for any savings or expenses due to the reactor being out of operation. When the reactor is operating, there are two main costs being incurred. The first is the fixed costs, which have to do with the investment of the capital; and the second is the variable costs, which include some of the operations and maintenance costs and fuel costs. When the reactor is not operating, the fixed costs are still being incurred but

the variable costs are not. The difference between the costs when the reactor is operating and the costs when it is down is due to the variable cost differences. In this case it was assumed that the maintenance and operating costs would be the same and that the only difference would be the fuel costs. By not operating the reactor the fuel costs are not incurred.

From the viewpoint of the utility, the fuel costs are "saved" and the downtime cost is simply the replacement cost minus the fuel cost "saved." The latest average fuel cost for nuclear reactors in the United States in 1979 is 5 mills/kWh, obtained from the EPRI Report PS-1201-SR, Technical Assessment Guide July 1979. Thus, the cost of downtime is the cost over and above the regular cost of producing power.

The downtime costs can now be calculated for nuclear power plants in various regions of the United States. The average value for downtime in the Northwest is 17.5 mills/kWh (22.5-5). For California and the northeastern United States, the average cost of downtime is 30 mills/kWh (35-5). For the rest of the nation the average cost of downtime is 23.75 mills/kWh (28.75-5). These figures are, of course, quite approximate and vary with the factors mentioned above for replacement power costs. The downtime costs do not include the extra maintenance cost associated with increased inspection and repair of SG tubes. The downtime costs, as mentioned above, are the costs over and above the regular costs incurred in operating the nuclear power plant. The above outage cost estimates are summarized below.

<u>Region</u>	<u>Approximate Outage Cost</u>
Northwest	17.5 mills/kWh
California and Northeast	30.0 mills/kWh
Rest of Nation	23.8 mills/kWh

In the following section, very rough estimates are given of the \$ cost impact of various ISI strategies and of USO_{sg} . For the essentially illustrative purposes of these calculations a value of 21 mills/kWh was used for the

lost power cost equivalent of outage time; for comparing the \$ impact of various ISI strategies with the cost of USO_{SG} of various degrees of severity, a range of values of 15-27 mills/kWh was used. These values all fall within or are close to the outage cost data band given above and are probably well within this band considering possible uncertainties in the estimates. We regard a comprehensive analysis of outage costs for units of various rating and location to be indispensable to a significant C/B analysis of SG ISI. Accordingly, this phase of the work is highlighted in the concluding section on proposed future work for this program.

CHARACTERISTIC INDICES FOR IN-SERVICE INSPECTIONS AND THEIR APPLICATION

In this section several indices are suggested for characterization of ISIs, and they are applied to a number of ISI cases for three types of units. The indices can be used for individual inspections and for an ISI program extending over an arbitrary evaluation period for a given unit. The latter application is used in the present instance. For the purposes of this report, the inspections coincide with the inspection opportunities presented by the nominal fuel outages for PWR units. The section is concluded with a brief comparison between the costs of unscheduled outages attributable to SG problems (USO_{sg}) and the costs of the most ambitious ISI case considered in this report, namely 100% inspection scope over the evaluation period.

The NDT Information Index (Iisi)

An NDT information index is defined as follows for the individual and evaluation period ISI cases:

individual ISI:

$$Iisi^* = \frac{(\text{scope})_i \times U_i}{100} = \frac{S_i \times U_i}{100} \quad (1)$$

evaluation period:

$$Iisi = \sum_i \frac{(S_i \times U_i)}{100 \times \Theta_{ev}} (\text{yr})^{-1} \quad (1a)$$

where $(\text{scope})_i = S_i = \frac{(\text{number of tubes inspected})}{(\text{total unit tubes})} \times 100 (\%)$

$U_i =$ the distribution factor (a measure of the size of the sample space available for selecting tubes for inspection)

$$= \frac{\text{no. of SGs involved in inspection}}{\text{no. of SGs in unit}}$$

$$= n_i / N_{sg}$$

θ_{ev} = evaluation period (yr) ≥ 1 yr

i = summation index over all inspections performed during evaluation period.

The range of the Iisi* and Iisi indices is indicated by the following minimum and maximum inspection cases:

	Minimum	Maximum
Iisi*:	3% scope; 1x4 SGs inspected	100% scope; 4x4 SGs inspected
	$Iisi^* = \left(\frac{3 \times 1}{4 \times 100}\right) = 0.0075$	$Iisi^* = \left(\frac{100 \times 4}{4 \times 100}\right) = 1.0$
Iisi:	3% scope all inspections 1x4 SGs inspected each inspection 1 inspection every 3 years 9-year evaluation period	100% scope all inspections 4x4 SGs inspected each inspection 1 inspection every year 9-year evaluation period
	$Iisi = \frac{1}{9} \left[\left(\frac{3 \times 1}{4 \times 100}\right) \times 3 \right]$	$Iisi = \frac{1}{9} \left[\left(\frac{100 \times 4}{4 \times 100}\right) \times 9 \right]$
	$Iisi = 0.0025 \text{ yr}^{-1}$	$Iisi = 1.0 \text{ yr}^{-1}$

The distribution factor (U) defined here gives no "information" credit for rotation of the SGs on successive partial (scope <100%) inspections. While such rotation does improve the information somewhat, this increment becomes less significant the longer the interval between inspections. Rotation credit was considered an unnecessary elaboration for this preliminary analysis. For the ISI cases considered later in this section for three types of PWR units (2, 3, and 4 SGs), the Iisi index ranges from 0.004 to 0.89--a max/min ratio of about 220.

Rad Exposure Index (MAN-REM)

A rad exposure index (MAN-REM) is defined as follows for individual and evaluation period ISI cases:

individual ISI:

$$MAN-REM^* = (MR)_{nti} \times n_i + (MR)_{ti} \times t_i \quad (\underline{man-rem}) \quad (2)$$

evaluation period:

$$\text{MAN-REM} = \sum_i (\text{MR})_{nti} \times n_i + \sum_i (\text{MR})_{ti} \times t_i \quad (\text{man-rem}) \quad (2a)$$

or
$$\text{MAN-REM} = (\text{MR})_{nt} \sum_i n_i + (\text{MR})_t \sum_i t_i \quad (2b)$$

if average values of $(\text{MR})_{nti}$ and $(\text{MR})_{ti}$ are used over θ_{ev}

where $(\text{MR})_{nti}$ = aggregate rad exposure for nontesting phases of inspection
(i) (NOT equipment setup and removal) (man-rem)

n_i = number of SGs involved in inspection (i)

$(\text{MR})_{ti}$ = aggregate rad exposure per tube for the testing phase of
inspection (i) (man-rem)

t_i = no. of tubes involved in inspection (i)

i = summation index over θ_{ev} .

For the ISI cases, unit types, and rad field cases considered later in this section, the rad exposure index for the 9-year evaluation period ranges from 7.5 to 780 man-rem, giving a max/min ratio of about 100.

§ Impact Index (§isi)

A § impact index (§isi) is defined as follows for individual and evaluation period ISI cases:

individual ISI:

$$\text{§isi}^* = (\text{§/tube})_i \times t_i + F_i \times \theta_i \times \text{§}_{0i} \quad (10^6 \text{§}) \quad (3)$$

evaluation period:

$$\text{§isi} = \sum_i (\text{§/tube})_i \times t_i + \sum_i F_i \times \theta_i \times \text{§}_{0i} \quad (10^6 \text{§}) \quad (3a)$$

or
$$\text{§isi} = (\text{§/tube}) \sum_i t_i + F \times \text{§}_0 \sum_i \theta_i$$

if average values of $(\text{§/tube})_i$, F_i , and §_{0i} are used over θ_{ev} and where

$(\$/\text{tube})_i$ = the total cost of the inspection (i) on a per tube tested basis ($10^6 \$/\text{tube}$)

t_i = tubes tested during inspection (i)

F_i = the interference factor, which with θ_i gives the critical path time assignable to a given inspection (i)

θ_i = the nominal work time window for inspection (i) (day)

$\$_{oi}$ = the cost per day of outage at time of inspection (i) ($10^6 \$/\text{day}$)

i = summation index over θ_{ev} .

For the ISI cases, unit types, interference factors, inspection costs, work time windows, and outage costs considered later in this section, the $\$isi$ index for the 9-year evaluation period ranges from 3.7×10^{-2} to 23 (millions of \$), giving a max/min ratio of about 620.

Composite Indices (C_1 and C_2)

Several combinations of the above indices may have some utility as measures of the incentive for individual ISIs at given times and of the merit of various ISI strategies over an evaluation period. The C_1 index is defined as follows:

for individual ISI:

$$C^*_1 = Iisi^*/(MAN-REM)^* \quad (\text{man-rem})^{-1} \quad (4)$$

evaluation period:

$$C_1 = Iisi/(MAN-REM) \quad (\text{yr} \times \text{man-rem})^{-1} \quad (4a)$$

where, as noted, the Iisi and MAN-REM indices appropriate to the individual or evaluation period ISI cases are used.

For the various ISI cases considered in this section over a 9-year evaluation period, the C_1 index ranges from 1.0×10^{-4} to 9.9×10^{-3} C_1 units $(\text{yr} \times \text{man-rem})^{-1}$, giving a max/min ratio of about 99.

The C_2 index is defined as follows:

for individual ISI:

$$C_2^* = \frac{I_{isi}^*}{(MAN-REM)^* \times \beta_{isi}^*} \quad (man-rem \times 10^6 \beta)^{-1} \quad (5)$$

evaluation period:

$$C_2 = \frac{I_{isi}}{(MAN-REM) \times \beta_{isi}} \quad (man-rem \times yr \times 10^6 \beta)^{-1} \quad (5a)$$

again using the indices appropriate to the ISI case.

In the following analysis for a 9-year evaluation period, the value of the C_2 index ranges from 9.6×10^{-4} to 5.1×10^{-3} C_2 units $(yr \times man-rem \times 10^6 \beta)^{-1}$, giving a max/min ratio of about 5.

Values of the above indices have been calculated for a number of ISI cases using the ground rules given in Table 10. The ISI cases are defined in Table 11. The values of the various parameters involved in calculation of the indices are given in Table 12. The various cases considered in the calculation are given in Table 13. Data from the calculation are given in Appendix B. Obviously, there is not necessarily a one-to-one relationship between the Iisi index and the other indices. The given value couplings between these indices result from the application of the arbitrary rules given in Table 10. A more general analysis of the functional relationship among these indices would be interesting but outside the scope of this report.

The MAN-REM index is given as a function of the Iisi index in Figures 13 and 14 for the high rad field and "zero T" cases, respectively (see Table 13). The average MAN-REM/Iisi characteristics for the high field case all display a monotonical increase with Iisi, with magnitude of the MAN-REM index decreasing with unit type in the order: 2 SG, 4 SG, 3 SG, for a given Iisi value above about 0.03. Below this Iisi value (in the regime of the A and B ISI cases, see Table 11) no distinction is made among the three unit types. The MAN-REM/Iisi characteristics for the zero T case (Figure 14) all display a plateau over an Iisi range of about 0.01 to 0.1. The characteristics for individual units are not well distinguished on this plot until the Iisi index reaches a value of about 0.1. Above this Iisi value, the MAN-REM index decreases with unit type

TABLE 10. Ground Rules for Calculation of ISI Indices

1. The evaluation period is 9 years and starts with the beginning of commercial operation.
2. The timing of the inspection opportunities is as follows:
1st opportunity: 2 years from date of commercial operation
2nd opportunity: 3 years from date of commercial operation
3rd opportunity: 4 years from date of commercial operation
4th opportunity: 5 years from date of commercial operation
5th opportunity: 6 years from date of commercial operation
6th opportunity: 7 years from date of commercial operation
7th opportunity: 8 years from date of commercial operation
8th opportunity: 9 years from date of commercial operation
3. Indices are calculated for the following units:
4 SG unit: using Westinghouse SGs of 3,260 tubes/SG
3 SG unit: using Westinghouse SGs of 3260 tubes/SG
2 SG unit: using Babcock & Wilcox SGs of 15,531 tubes/SG
4. Indices are calculated for 14 ISI cases; three representing minimum inspection under Regulatory Guide 1.83 rules (A cases), two representing minimum inspection under ASME Code XI rules (B cases), and nine representing arbitrary cases over a wide range of inspection scope (C cases).
5. The distribution of the inspection samples among the unit SGs is determined by Regulatory Guide 1.83 and Code XI rules for the A and B cases, respectively; for the C cases, the number of SGs involved in a given inspection is determined as follows: $n_i = (\text{scope})_i \times N_{sg} \times 1/100$ (see nomenclature sheet, Appendix A). For noninteger values of n_i , use next highest integer; for the first inspection only for 4 and 3 SG units, the minimum value of n_i is 2.
6. The work time windows for the inspection opportunities are as follows:
first: 13 weeks (91 days); second: 9 weeks (63 days); subsequent:
7.5 weeks (53 days).

TABLE 11. Definition of ISI Cases

ISI Case	No. Insp. Over 9 Yr	Description (a)														
		Scope (%)			Intervals (Yr)			SGs Involved Each Inspection								
		1st	2nd	Subs.	1st	2nd	Subs.	1st			2nd			Subs.		
							4W	3W	2BW	4W	3W	2BW	4W	3W	2BW	(Nsg)
A-1	8	3	3	3	2	1	1	2	2	1	1	1	1	1	1	1
A-2	5	3	3	3	2	1	2	2	2	1	1	1	1	1	1	1
A-3	4	3	3	3	2	1	3	2	2	1	1	1	1	1	1	1
B-1	8	3	1.5	1.5	2	1	1	4	3	2	1	1	1	1	1	1
B-2	4	3	1.5	1.5	2	1	1	4	3	2	1	1	1	1	1	1
C-1	8	100	100	100	2	1	1	4	3	2	4	3	2	4	3	2
C-2	8	100	100	50	2	1	1	4	3	2	4	3	2	2	2	1
C-3	8	100	50	50	2	1	1	4	3	2	2	2	1	2	2	1
C-4	8	100	33.3	33.3	2	1	1	-	3	-	-	1	-	-	1	-
C-5	8	100	25	25	2	1	1	4	3	2	1	1	1	1	1	1
C-6	8	33.3	33.3	33.3	2	1	2	-	2	-	-	1	-	-	1	-
C-7	8	50	25	25	2	1	1	2	2	1	1	1	1	1	1	1
C-8	8	25	25	25	2	1	1	2	2	1	1	1	1	1	1	1
C-9	8	10	10	10	2	1	1	2	2	1	1	1	1	1	1	1

(a) Where less than 100% scope is involved, SGs are rotated for subsequent inspections to improve information for given scope limitation.

TABLE 12. Parameter Values Used for Calculation of Indices

Index	Parameter Values
Iisi	S_i : see Table 11 U_i : see Table 11; $U_i = n_i/N_{SG}$ θ_{ev} : 9 years (see Table 10); for number of inspections and inspection interval, see Table 11
MAN-REM	$(MR)_{nt}$: <u>high field case</u> = 9.8 man-rem/SG (see Table 8) $(MR)_{nt}$: <u>low field case</u> = 1.3 man-rem/SG (see Table 8) $(MR)_{nt}$: <u>average case</u> = 5.6 man-rem/SG (see Table 8) $(MR)_t$: <u>high field case</u> = 2.5×10^{-3} man-rem/tube (see Table 5) $(MR)_t$: <u>low field case</u> = 8.3×10^{-4} man-rem/tube (see Table 5) $(MR)_t$: <u>average case</u> = 1.7×10^{-3} man-rem/tube (see Table 5)
$\$isi$	$(\$/tube)_i$: = see Figure 5 t_i : = (scope)x(tubes/SG)x(SGs/unit)x(1/100) = $S_i \times 130.4$ for 4 SG unit = $S_i \times 97.80$ for 3 SG unit = $S_i \times 310.6$ for 2 SG unit (see Tables 10 and 11) F_i : values of 0 and $F = 0.1 \times (Iisi)$ are used θ_i : $\theta_1 = 91$ days; $\theta_2 = 63$ days; subsequent = 53 days $\$_0 = \$_{oi}$: value equivalent to a lost power cost of 21.00 mills/kWh is used for a unit of 1000-MW(e) rating (\$500,000 per day)
time	$(MH)_{nt}$: 315 man-hour per SG (see Table 3) $(MH)_t$: 2.9×10^{-1} man-hr per tube (from plot of data for man-hour for testing versus sample size given in Figures 4A and 4B)

TABLE 13. Cases Used for Calculation of Indices

Index	Case
Iisi	all ISI cases given in Table 11
MAN-REM	(a): high field parameters; all ISI cases (b): low field parameters; all ISI cases (c): case assuming the "T" component of the rad exposure is zero due to use of remote analytical techniques; for this case the average value is used for $(MR)_{nt}$ all ISI cases
$\$isi$	(a): no interference case ($F=0$); all ISI cases (b): proportional F case; $F_i = F_{max} \times (Iisi)_i$; $F_{max} = 0.1$; interference begins with second inspection and continues for all subsequent; all ISI cases
C_i	(a): the MAN-REM index used for C_1 is for the $T = 0$ case; all ISI cases
C_2	(a): the MAN-REM index used for C_2 is the $T=0$ case; the $\$isi$ index used for C_2 is for the $F=0$ case; all ISI cases

in the order: 4 SG, 3 SG, 2 SG, for a given Iisi. The latter order is an interesting cyclic permutation of the order given for the high field case (Figure 13). The difference in magnitude of the MAN-REM index between the high field and zero T cases for a given Iisi value is noteworthy and indicates the substantial rad exposure incentive for developing remote testing (T) techniques for ISI of SGs.

The $\$isi$ index is given as a function of the Iisi index in Figures 15 and 16 for the $F=0$ and the proportional F cases (see Table 13), respectively. The $\$isi/Iisi$ characteristics for the $F=0$ case (Figure 15) display a monotonical increase with Iisi over the range of Iisi calculation. Above an Iisi value of about 0.01 the characteristics for the three unit types are distinguishable on

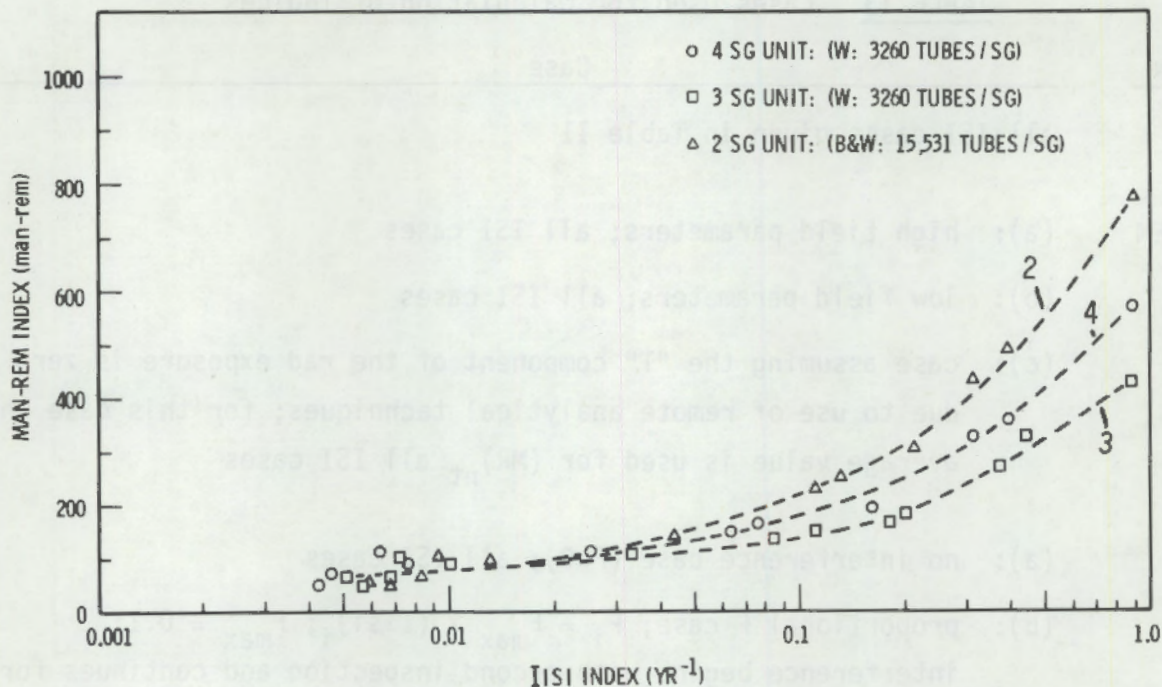


FIGURE 13. MAN-REM Index Versus Iisi; Index High Field Case

this plot, with the magnitude of the $\$isi$ index decreasing with unit type in the order: 2 SG, 4 SG, 3 SG, for a given Iisi. The 3 SG and 4 SG characteristics are close over the full range of Iisi. All of the $\$isi/Iisi$ characteristics for the proportional F case (Figure 16) display a plateau within an Iisi range of about 0.09–0.2. For this case, the 2 SG unit again gives the highest $\$isi$ values, although the characteristics for all units are quite close. The difference in magnitude of the $\$isi$ index between the F=0 and the proportional F cases for Iisi values in excess of about 0.2 is noteworthy and affords some quantification of the importance of minimizing the interference factor (F) in ISI operations where large nuclear units are involved.

The composite indices, C_1 and C_2 , are given as a function of Iisi in Figures 17 and 18, respectively. As opposed to the MAN-REM and $\$isi$ indices, it is desirable to maximize both of these indices, i.e., secure maximum NDT information with a minimum of rad exposure and $\$$ costs. As noted in Table 13 and on Figures 17 and 18, the MAN-REM component of these composite indices corresponds to the T=0 case. For the C_2 index, the additional $\$isi$ component

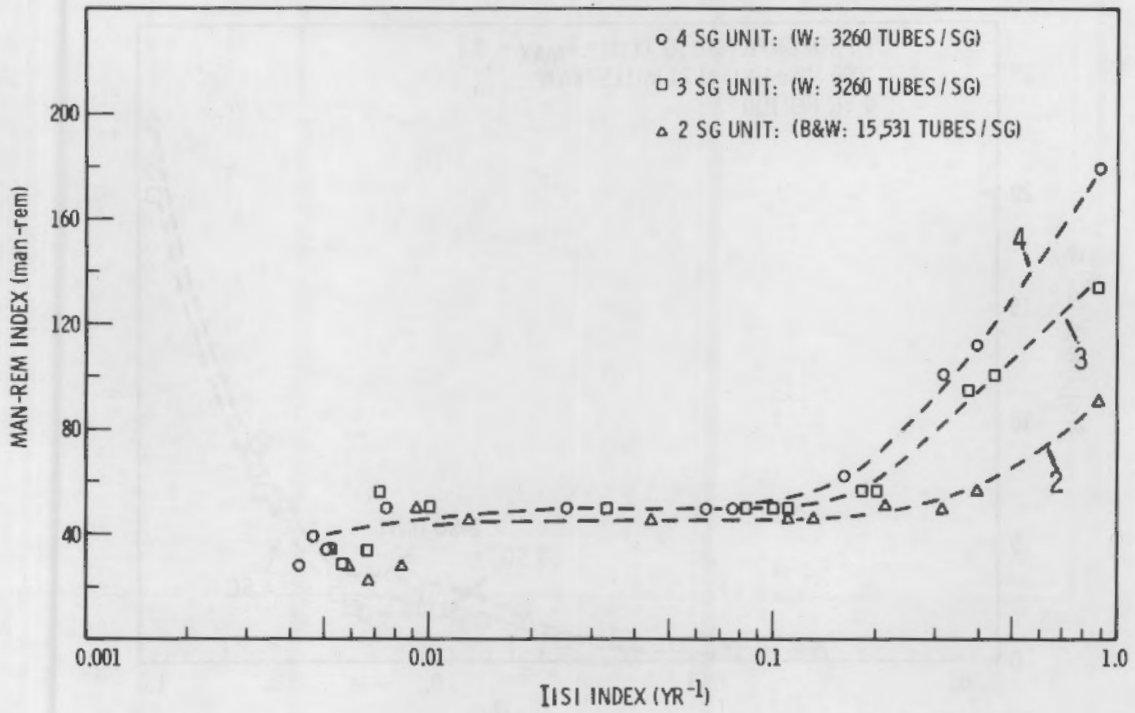


FIGURE 14. MAN-REM Index Versus Iisi; Index Zero T Component Case

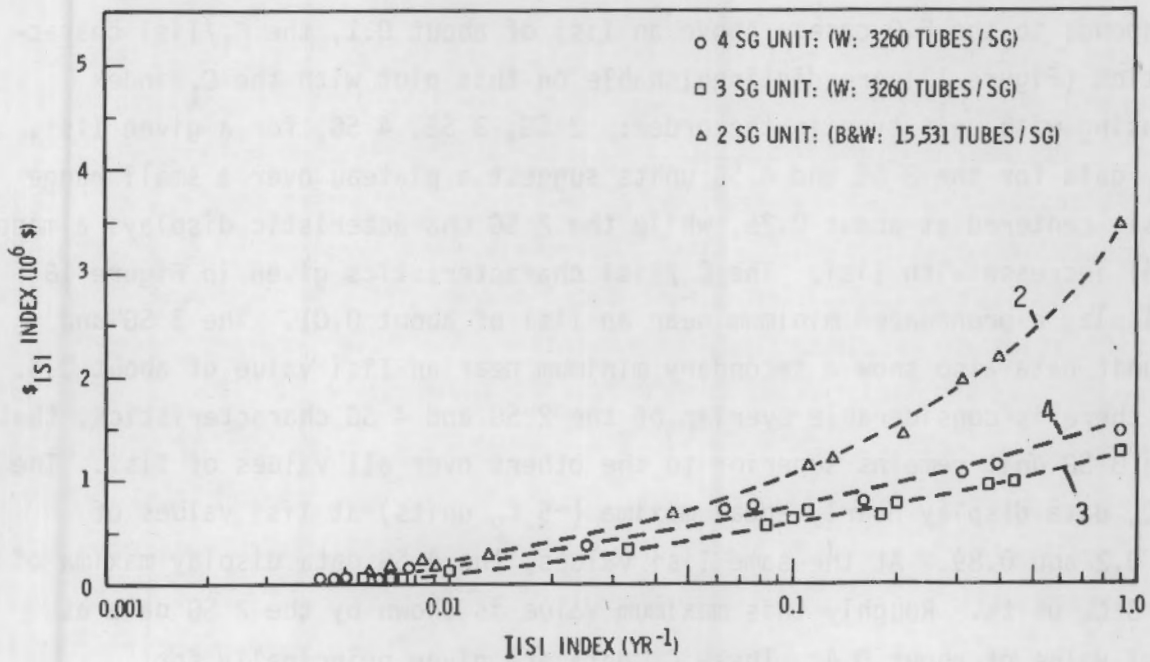


FIGURE 15. \$Iisi Index Versus Iisi Index; F = 0 case

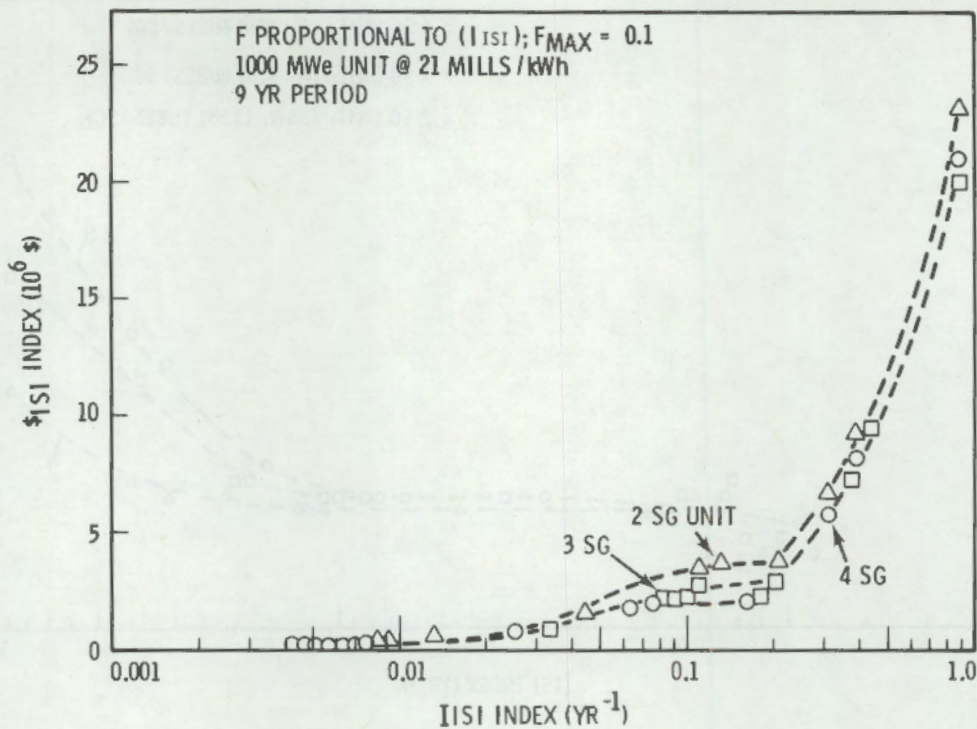


FIGURE 16. $\$ISI$ Index Versus $IISI$ Index; Proportional F Case ($F_{max} = 0.1$)

corresponds to the $F=0$ case. Above an $IISI$ of about 0.1, the $C_1/IISI$ characteristics (Figure 17) are distinguishable on this plot with the C_1 index decreasing with unit type in the order: 2 SG, 3 SG, 4 SG, for a given $IISI$. The C_1 data for the 3 SG and 4 SG units suggest a plateau over a small range of $IISI$, centered at about 0.25, while the 2 SG characteristic displays a monotonical increase with $IISI$. The $C_2/IISI$ characteristics given in Figure 18 all display a pronounced minimum near an $IISI$ of about 0.01. The 3 SG and 4 SG unit data also show a secondary minimum near an $IISI$ value of about 0.4. While there is considerable overlap of the 2 SG and 4 SG characteristics, that of the 3 SG unit remains superior to the others over all values of $IISI$. The 3 SG C_2 data display nearly equal maxima ($\sim 5 C_2$ units) at $IISI$ values of about 0.2 and 0.89. At the same $IISI$ values, the 4 SG data display maxima of about $3 C_2$ units. Roughly this maximum value is shown by the 2 SG data at an $IISI$ value of about 0.4. These C_2 data are given principally for

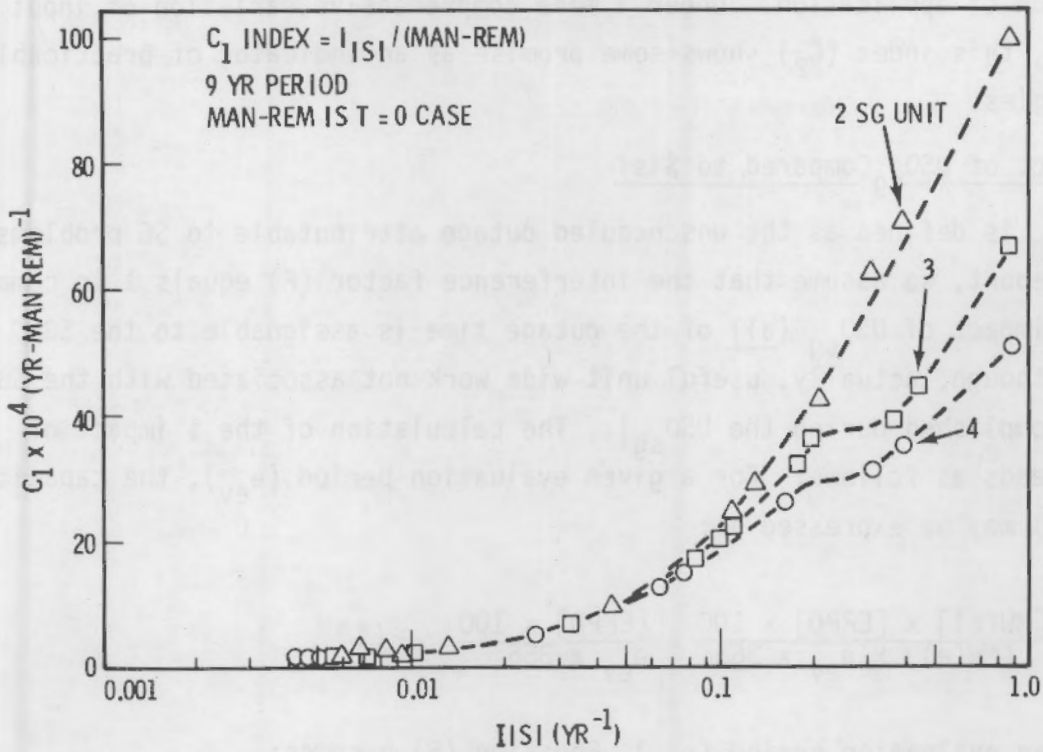


FIGURE 17. C_1 Index Versus Iisi Index

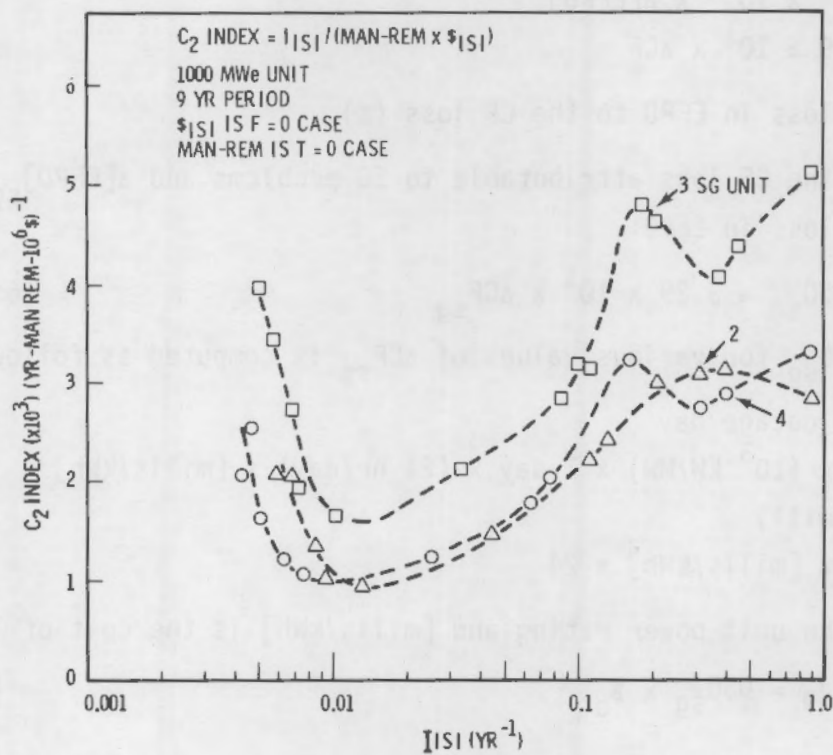


FIGURE 18. C_2 Index Versus Iisi Index

illustration of application. Under a more comprehensive variation of input parameters, this index (C_2) shows some promise as an indicator of practicable ISI strategies.

The \$ Impact of USO_{sg} Compared to \$isi

USO_{sg} is defined as the unscheduled outage attributable to SG problems. For this report, we assume that the interference factor (F) equals 1 in computing the \$ impact of USO_{sg} (all of the outage time is assignable to the SG problem although, actually, useful unit-wide work not associated with the SGs may be accomplished during the USO_{sg}). The calculation of the \$ impact of USO_{sg} proceeds as follows: For a given evaluation period (θ_{ev}), the capacity factor (CF) may be expressed as:

$$CF = \frac{[MW(e)] \times [EFPD] \times 100}{[MW(e)] \times \theta_{ev} \times 365} = \frac{[EFPD] \times 100}{\theta_{ev} \times 365} \quad (\%) \quad (6)$$

For a 9-year evaluation period (θ_{ev}), Equation (6) becomes:

$$CF = 3.04 \times 10^{-2} \times [EFPD] \quad (\%) \quad (6a)$$

and $\Delta CF = 3.04 \times 10^{-2} \times \Delta[EFPD]$

or $\Delta[EFPD] = 3.29 \times 10^1 \times \Delta CF \quad (6b)$

which relates the loss in EFPD to the CF loss (%).

Let ΔCF_{sg} be the CF loss attributable to SG problems and $\Delta[EFPD]_{sg}$, the corresponding loss in EFPD:

$$\Delta[EFPD]_{sg} = USO_{sg} = 3.29 \times 10^1 \times \Delta CF_{sg} \quad (6c)$$

The \$ impact of USO_{sg} for various values of ΔCF_{sg} is computed as follows:

$$\begin{aligned} \$_0 &= \text{cost per outage day} \\ &= [MW(e)] \times (10^3 \text{ kW/MW}) \times 1 \text{ day} \times (24 \text{ hr/day}) \times [\text{mills/kWh}] \times \\ &\quad (10^{-3} \text{ \$/mill}) \\ &= [MW(e)] \times [\text{mills/kWh}] \times 24 \end{aligned} \quad (7)$$

where $[MW(e)]$ is the unit power rating and $[\text{mills/kWh}]$ is the cost of lost power. Now, $\$USO_{sg} = USO_{sg} \times \$_0$. (8)

Substituting for USO_{sg} and $\$_0$ from Equations (6c) and (7), respectively:

$$\begin{aligned} \$USO_{sg} &= 3.29 \times 10^1 \times \Delta CF_{sg} \times [MW(e)] \times [mills/kWh] \times 24 \quad (\$) \\ &= 7.90 \times 10^2 \times \Delta CF_{sg} \times [MW(e)] \times [mills/kWh] \\ &= 7.90 \times 10^{-4} \times \Delta CF_{sg} \times [MW(e)] \times [mills/kWh] \quad (10^6 \$) \quad (8a) \end{aligned}$$

Table 14 presents $\$USO_{sg}$ data calculated from (8a) for a 1000-MW(e) unit for ΔCF_{sg} values up to 6% and for three values of the [mills/kWh]. These data are plotted in Figure 19.

TABLE 14. USO_{sg} $\$$ Impact versus ΔCF_{sg} for 1000-MW(e) Unit

ΔCF_{sg} (%)	USO_{sg} EFPD (day)	$\$USO_{sg}$ 9-Year Period ($10^6 \$$)		
		15 mills/ kWh	21 mills/ kWh	27.0 mills/ kWh
1	32.9	11.9	16.6	21.3
2	65.8	23.7	33.2	42.6
3	98.7	35.6	49.8	64.0
4	132	47.4	66.4	85.3
5	165	59.3	83.0	107
6	197	71.1	99.5	128

Values of the $\$isi$ index for the C-1 ISI case (see Table 11) were also calculated for the same (mills/kWh) values for a 1000-MW(e) unit. For comparison with $\$USO_{sg}$, the F=0 and F=0.1 cases were used for $\$isi$. Values of $\$isi$ were calculated for the three unit types (2, 3, and 4 SGs) and the unit average values were used for the USO_{sg} comparison. These $\$isi$ data are superimposed on Figure 19.

The $\$isi$ data for the F=0 case are trivial compared to USO_{sg} for ΔCF_{sg} in excess of roughly 0.5%. For the F=0.1 case, the points of equivalence with $\$USO_{sg}$ on the ΔCF_{sg} axis are close to 1.3% for all power cost assumptions.

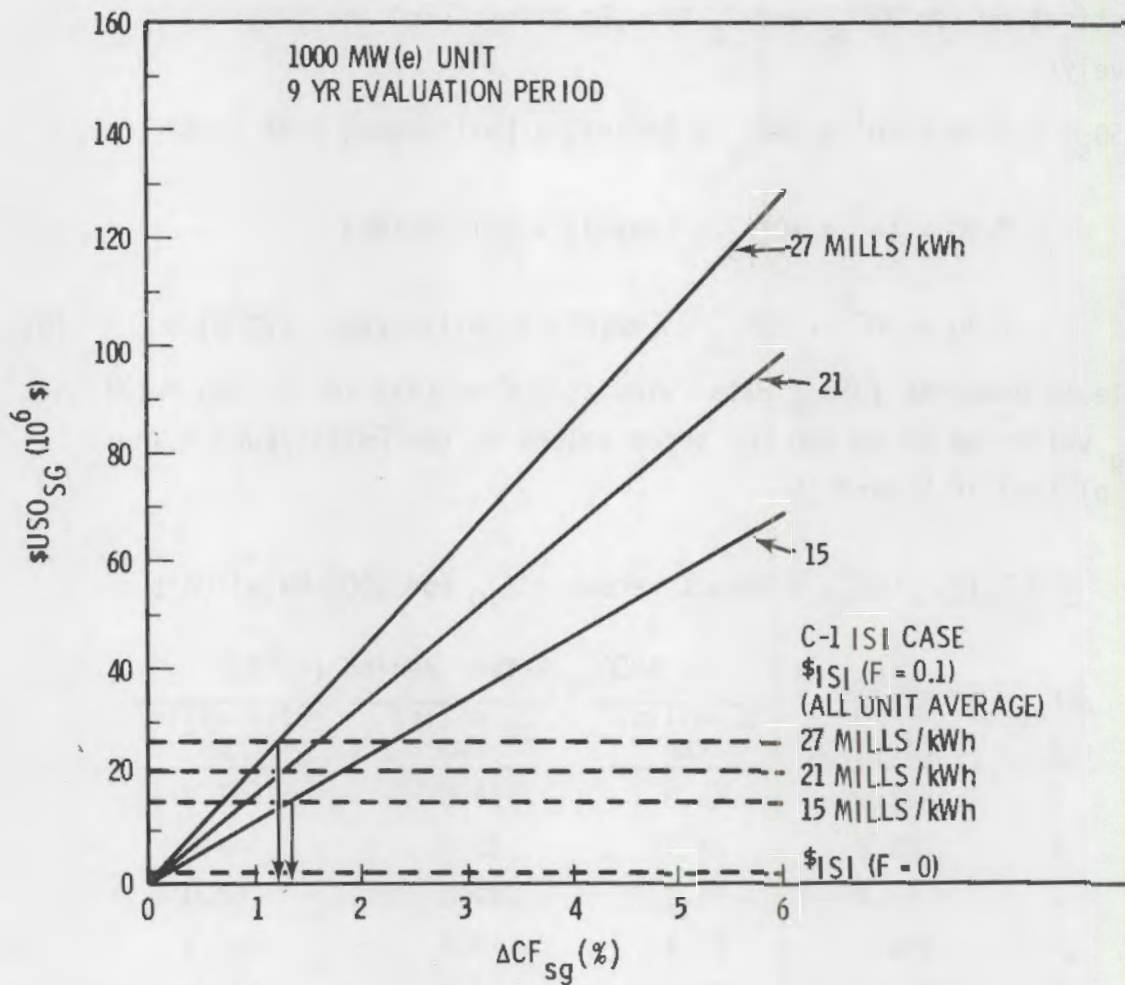


FIGURE 19. $\$USO_{sg}$ Versus ΔCF_{sg} . $\$USO_{sg}$ is compared with $\$isi$ for the C-1 ISI case (100% inspection scope for each year of the evaluation interval) under $F = 0.1$ and $F = 0$ assumptions.

In other words, over a 9-year evaluation period and under the rather pessimistic assumption that the average $F=0.1$ the cost of the most ambitious ISI strategy considered in this report (C-1, 100% scope all inspections; see Table 11) would be exceeded by $\$USO_{sg}$ if the ΔCF_{sg} exceeded about 1.3. Earlier in this report, it was noted that a ΔCF value of about 3.6% was assignable to SG problems over a 2-year period ending in June 1978. According to the data of Figure 19, the $\$USO_{sg}$ corresponding to this ΔCF level exceeds the cost of the C-1 ISI case ($F=0.1$) by roughly a factor of three for all power cost levels. Under more careful management of the ISI work ($F \sim 0$), the ISI cost would be trivial compared to $\$USO_{sg}$ for ΔCF_{sg} in excess of about 0.5%.

IN-SERVICE INSPECTION TIME AND MANPOWER ESTIMATES FOR 40-UNIT PWR POPULATION

Estimates of the manpower requirements to perform ISI of SG tubes comprised by a given PWR unit population can be made on several bases; namely a minimum aggregate inspection crew for the population can be estimated using a maximum rad exposure allowance per man per year; a somewhat more realistic estimate of manpower requirements can be made by assuming a certain crew size for the nontesting (NT) and testing (T) phases of the inspection per SG. The time for an inspection can be estimated using these crews, average man-hour values for NT and T phases, and making assumptions as to the simultaneity of the work on the various phases of the inspection. The manpower and time data enable an assessment of practicable nationwide ISI campaigns for the current PWR population.

Manpower Estimate—Rad Exposure Basis

For the purpose of a rough estimate of the manpower requirement, it is assumed that the inspection scope is the same for all units for a given year (S_u); and that the number of SGs involved per inspection per unit (n_u) is proportional to the scope (S_u), where, as previously, noninteger values of n_u are taken as the next highest integer. $(Men)_{nt}$ and $(Men)_t$ may be expressed:

$$(Men)_{nt} = \frac{(MR)_{nt}}{R^*} \times \sum_u \left(\frac{S_u \times N_{sg,u}}{100} \right) = \frac{(MR)_{nt}}{R^*} \times \sum_u n_u \quad (1)$$

$$(Men)_t = \frac{(MR)_t \times S_u}{100 \times R^*} \times \sum_u N_{sg,u} \times t_{sg,u} \quad (1)$$

where R^* = the maximum acceptable rad exposure per man per year

u = the summation index over the units involved in a given inspection campaign and the other terms have been defined previously (see Appendix A).

For this manpower estimate, the following parameter values are used (see Table 12):

$$(MR)_{nt} = \text{average case} = 5.6 \text{ man-rem/SG}$$

$$(MR)_t = \text{average case} = 1.7 \times 10^{-3} \text{ man-rem/tube}$$

$R^* = 4$ rem per man per year (5 rem per man per year is current occupational maximum dose specified in 10 CFR 20, p. 20.1).

The 40-unit PWR population considered here is given in Table 15. With the above assumptions for $(MR)_{nt}$, $(MR)_t$, R^* , and the unit population given in Table 15, the $(Men)_{nt}$ and $(Men)_t$ expressions become:

$$(Men)_{nt} = 1.4 \left[\left(\frac{S_u \times 4}{100} \right) \times 10 + \left(\frac{S_u \times 3}{100} \right) \times 10 + \left(\frac{S_u \times 2}{100} \right) \times 20 \right] \quad (2)$$

$$(Men)_t = 2.64 \times S_u$$

where, for $(Men)_{nt}$, actual or next highest integer values are used for the terms involving S_u . The $(Men)_{nt}$ and $(Men)_t$ values were calculated for a number of S_u values, and these data are given in Table 16 and plotted in Figure 20. Data for the $U=1.0$ case [all SGs are inspected each time irrespective of scope (S_u)] are also given in Table 16 but are not plotted. The manpower compliments shown in Figure 20 would be "perpetual" for inspection of the 40 units providing the 4 rem per man per yr limit was observed.

Manpower Estimate—Crew Assumption Basis

To avoid assumptions as to the selection of the units for a given inspection campaign, the average unit identified in Table 15 will be used for the manpower estimate for this case. Accordingly, the unit referred to here has 15,500 tubes, 2.75 SGs (rounded to 3), and 5,600 tubes per SG.

It is assumed that the NT crew has five men per SG involved in inspection and the T crew has five men per SG involved in inspection, irrespective of scope, where, as noted previously, the NT crew is supplied by the utility and the T crew, by the NDT contractor(s). The NT crew is largely confined to one or several units of a given utility whereas the T crew would be expected to service the units on a nationwide basis. Because of the limited number of the

TABLE 15. 40-Unit PWR Population Considered in In-Service Inspection Manpower and Time Estimates

2 SG Units	3 SG Units	4 SG Units
Arkansas 1 (BW/15,500) ^(a)	Beaver Valley (W/3400)	Cook 1 (W/3400)
Calvert Cliffs 1 (CE/8,500)	Maine Yankee (CE/5700)	Haddam Neck (W/3400)
Calvert Cliffs 2 (CE/8,500)	Robinson 2 (W/3300)	Haddam Neck (W/3800)
Crystal River (BW/15,500)	San Onofre 1 (W/3800)	Indian Point 2 (W/3800)
Davis-Besse 1 (BW/15,500)	Surry 1 (W/3400)	Indian Point 3 (W/3800)
Kewaunee (W/3,400)	Surry 2 (W/3400)	Salem 1 (W/3400)
Ft. Calhoun (CE/5,000)	Turkey Point 3 (W/3300)	Trojan (W/3400)
Ginna (W/3,300)	Turkey Point 4 (W/3300)	Yankee Rowe (W/1620)
Oconee 1 (BW/15,500)	North Anna 1 (W/3400)	Zion 1 (W/3300)
Oconee 2 (BW/15,500)	Farley 1 (W/3400)	Zion 2 (W/3300)
Oconee 3 (BW/15,500)		
Palisades (CE/8,500)		
Point Beach 1 (W/3,300)		
Point Beach 2 (W/3,300)		
Prairie Island 1 (W/3,300)		
Prairie Island 2 (W/3,300)		
Rancho Seco (BW/15,500)		
St. Lucie (CE/8,500)		
3 Mile Island 1 (BW/15,500)		
Millstone 2 (CE/8,500)		

Summary: • 40 units
 • 620,000 tubes } = average unit of 15,500 tubes/unit;
 • 110 SGs. } 2.75 SGs (rounded to 3.0)/unit;
 5,600 tubes/SG

(a) Information in parentheses indicates manufacturer and tubes per SG rounded to nearest 100.

TABLE 16. Manpower Estimate for 40-Unit Inspection;
Rad Exposure Basis

Scope (%)	Variable U (SGs inspected proportional to scope)			U = 1.0 (All SGs inspected, all scopes)		
	M_t	M_{nt}	ΣM	M_t	M_{nt}	ΣM
3	8	56	64	8	150	160
10	27	56	83	27	150	180
25	66	56	120	66	150	220
26	69	70	140	69	150	220
33.3	88	70	160	88	150	240
36	95	84	180	95	150	250
50	130	84	220	130	150	290
55	150	130	270	150	150	300
66.6	180	130	300	180	150	330
68	180	140	320	180	150	330
75	200	140	340	200	150	350
76	200	150	360	200	150	360
100	260	150	420	260	150	420

See Table 15 for unit population.

See Table 12 for average $(MR)_{nt}$ and $(MR)_T$ used.

Table entry is size of crew satisfying 4 rem/year dose limit (M_t = test crew; M_{nt} = setup crew).

latter specialized personnel, the T crew requirements are of particular interest and the following discussion is so oriented. On the basis of the above crew assumptions, the $(Men)_t$ requirement is as follows:

$$(Men)_t = Y_u \times (\text{SGs involved per unit}) \times 5 = Y_u \times n_u \times 5 \quad (3)$$

where Y_u is the number of units of a given type involved in a given campaign. For simplicity, it is assumed that n_u is equal for all units for a given campaign. Let campaign refer to an ISI operation within a given year in which

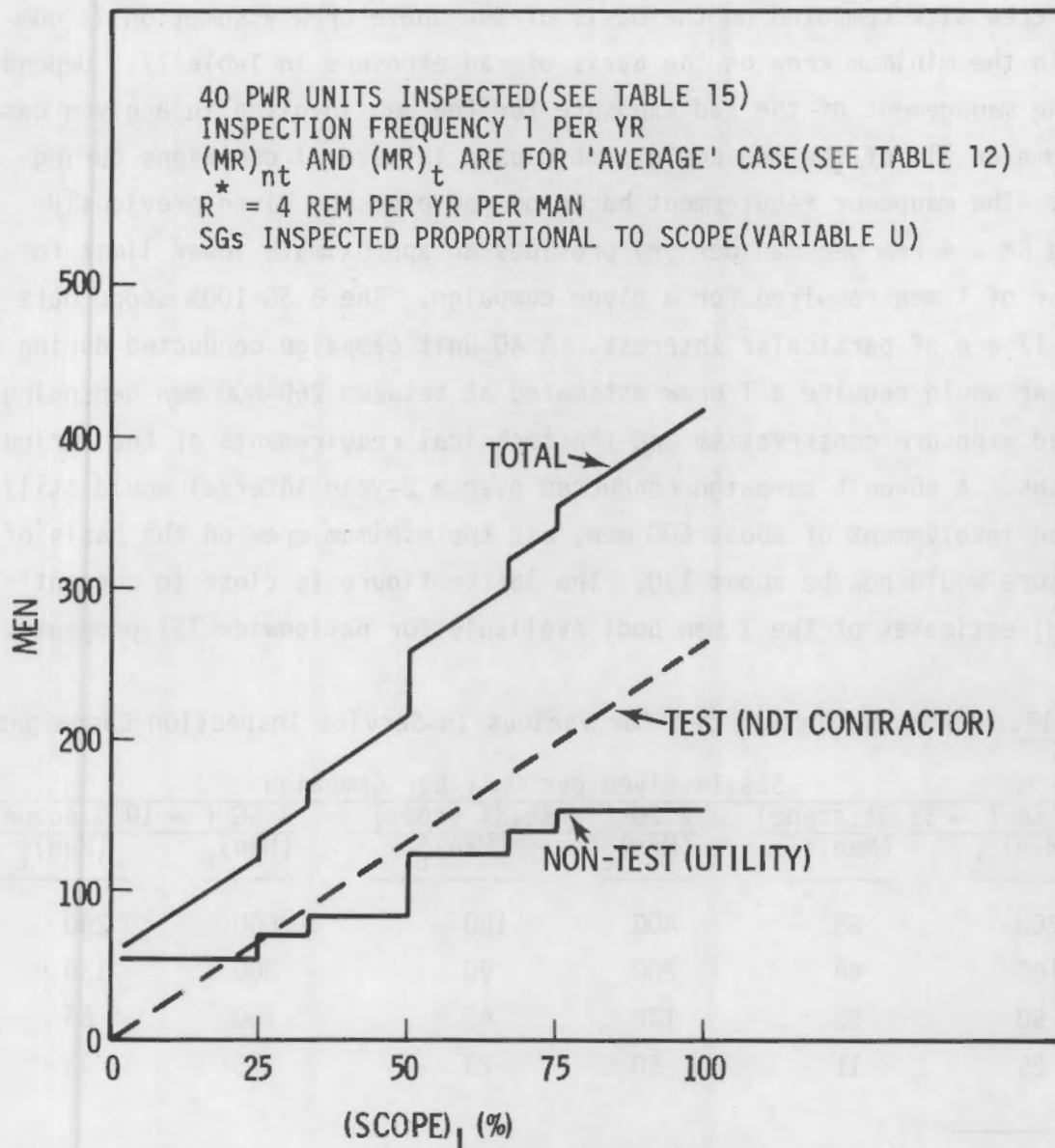


FIGURE 20. Minimum Personnel for Inspection of 40 PWR Units;
 Rad Exposure Basis

a given number of units is inspected in the most time- and cost-efficient manner. The campaign would, therefore, involve some simultaneous inspection, some overlap of inspections to various extents, and some isolated inspections that are fairly closely coupled in time to the rest of the campaign.

The crew size computed on the basis of the above crew assumption is compared with the minimum crew on the basis of rad exposure in Table 17. Depending on the management of the rad exposure for the men involved in a given campaign, some or all of the men could participate in several campaigns during the year. The manpower requirement based on rad exposure given previously (assuming $R^* = 4$ rem per man per yr) provides an approximate lower limit for the number of T men required for a given campaign. The 3 SG 100% scope data of Table 17 are of particular interest. A 40-unit campaign conducted during a single year would require a T crew estimated at between 260-600 men depending on the rad exposure conservatism and the technical requirements of the various inspections. A 40-unit campaign conducted over a 2-year interval would still require an involvement of about 600 men, but the minimum crew on the basis of rad exposure would now be about 130. The latter figure is close to current (May 1980) estimates of the T men pool available for nationwide ISI programs.

TABLE 17. Estimated Crew Sizes for Various In-Service Inspection Campaigns

Y	SGs Involved per Unit per Campaign					
	1 SG (→ 33.3% scope)		2 SG (→ 66.6% scope)		3 SG (→ 100% scope)	
	(Men) _t	(Men) _t [*]	(Men) _t	(Men) _t [*]	(Men) _t	(Men) _t [*]
40	200	88	400	180	600	260
20	100	44	200	90	300	130
10	50	22	100	45	150	65
5	25	11	50	23	75	33

Notes: Y = units involved in given campaign
 (Men)_t = T crew size, assuming a 5-man crew per SG, irrespective of scope
 (Men)_t^{*} = T crew size for given maximum scope based on 4 rem per man per yr dose limit and average test rad field condition given in Table 12
 = (40-unit crew requirement for given maximum scope) x Y/40 (see Table 16)
 Unit = average unit given in Table 15.

Time Estimate for ISI

An approximation of the time required for an inspection of given scope is obtained from the following expressions:

$$(\text{Time})_{nt} = \alpha \left(\frac{S_i \times N_{sg}}{100} \right) \times \left(\frac{(\text{MH})_{nt}}{C_{nt}} \right) \quad (4a)$$

$$(\text{Time})_t = \alpha \left(\frac{S_i \times N_{sg} \times t_{sg}}{100} \right) \times \left(\frac{(\text{MH})_t}{C_t} \right) \quad (4b)$$

where, for $(\text{Time})_{nt}$, the next highest integer is taken for noninteger values of the term involving S_i . In the above expressions:

α = time efficiency factor (a value of 1.0 = simultaneous work by all of crew; higher values mean less efficient work)

$(\text{MH})_{nt}$ = the man-hours per SG for NT work

$(\text{MH})_t$ = the man-hours per tube for T work

C_{nt} = the crew size for NT work; similarly for C_t

and the other terms have been defined previously (see Appendix A).

For the time estimates of this section, the following parameter values are used:

α = 1.0 for both NT and T work

$(\text{MH})_{nt}$ = 315 man-hours per SG (see Table 12)

$(\text{MH})_t$ = 2.9×10^{-1} man-hours per tube (see Table 12)

C_{nt} = 5 men per SG

C_t = 5 men per SG irrespective of inspection scope.

Values of the $(\text{Time})_{nt}$ and $(\text{Time})_t$ are given for the average unit (see Table 15) and for several specific units in Tables 18 and 19, respectively. The variable U case is used for the specific units. The variable U and U = 1.0 cases are computed for the average unit. The total time value

TABLE 18. In-Service Inspection Time Values for Average Unit

Scope (%)	Variable U Case				U = 1.0 Case			
	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	ΣTime (wk)	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	ΣTime (wk)
100	190	900	1090	6.5	190	900	1090	6.5
66.7	130	600	730	4.3	190	600	790	4.7
50	130	460	590	3.5	190	460	650	3.9
33.3	60	300	360	2.1	190	300	490	2.9
25	60	240	300	1.8	190	240	430	2.6
10	60	90	150	0.9	190	90	280	1.7
3	60	30	90	0.5	190	30	220	1.3

Notes: Variable U case - number of SGs involved depends on scope.

U = 1.0 case - all SGs involved in inspection irrespective of scope.

See Table 15 for definition of average unit.

given in Tables 18 and 19 assumes that there is no simultaneity between the NT and T phases of the inspections, which is not necessarily true. The time data for the average unit are plotted in Figure 21 against the scope for both the variable U and the U = 1.0 cases. Comparing the conservative total ISI time given in Table 18 for 100% scope (6.5 weeks) with the average work time windows given in Figure 12 for the fuel outages (7-13 weeks), it appears that the time factor should present no problem for well-organized ISIs.

Information on both the frequency and work time window opportunities presented by the fuel outages for ISI activity was given previously in this report. It was also noted that certain calendar periods are favorable to ISI activity on the basis of expected power demand. Some further comment on the latter fact is appropriate to this section. The calendar period favorability is quantified somewhat in Figure 22, where a histogram is presented of the beginning calendar date of fuel outages for U.S. PWR units. These data were obtained from a computer analysis of the NRC SIOSOR data base. There are several reservations about the data from which Figure 22 was obtained, namely the data are reported monthly and since a normal fuel outage lasts from 6-8 weeks, there was some data manipulation involved in identifying the beginning of the outage.

TABLE 19. In-Service Time Values for Specific Units (Variable U)^(a)

Type of Unit	100% Scope			66.7% Scope			50% Scope			33.3% Scope			10% Scope		
	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)	(Time) _{nt} (hr)	(Time) _t (hr)	ΣTime (hr)
<u>2 SG</u>															
B&W (15,500 Tubes/SG)	130	1800	1930	130	1200	1320	60	900	960	60	600	660	60	180	240
CE (8,500)	130	980	1110	130	660	780	60	500	560	60	320	380	60	100	160
W (3,300)	130	380	510	130	260	380	60	200	260	60	130	190	60	40	100
<u>3 SG</u>															
W (3,400)	190	600	790	130	400	520	130	300	430	60	200	260	60	60	120
<u>4 SG</u>															
W (3,400)	260	780	1040	130	540	660	130	400	530	130	260	390	60	80	140

(a) Variable U case (SGs inspected proportional to scope)

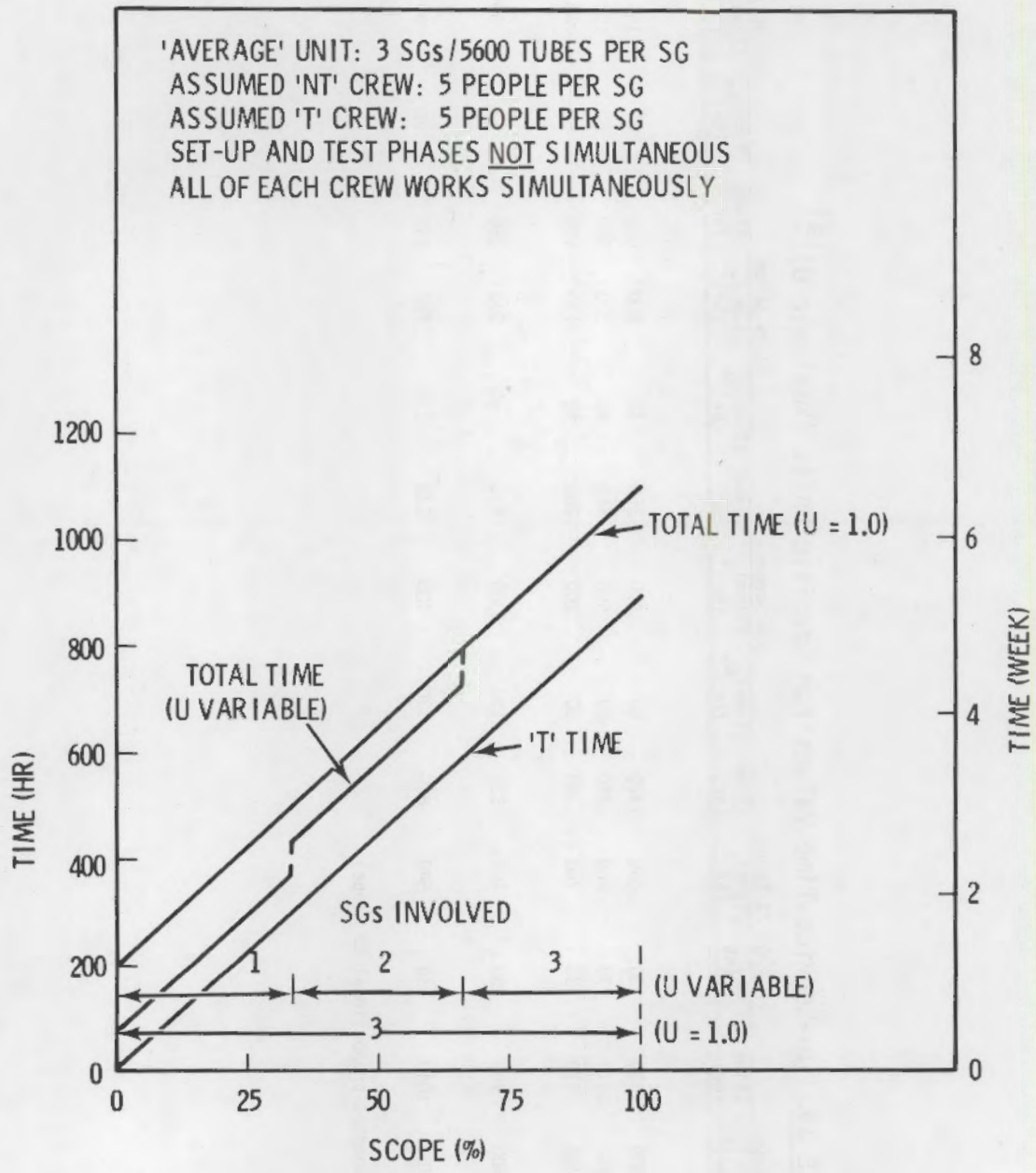


FIGURE 21. ISI Time Versus Scope for Average Unit

The bimodal characteristic of Figure 22 suggests that a two-campaign-per-year ISI strategy involving a unit population appropriate to the current ISI manpower situation would be feasible.

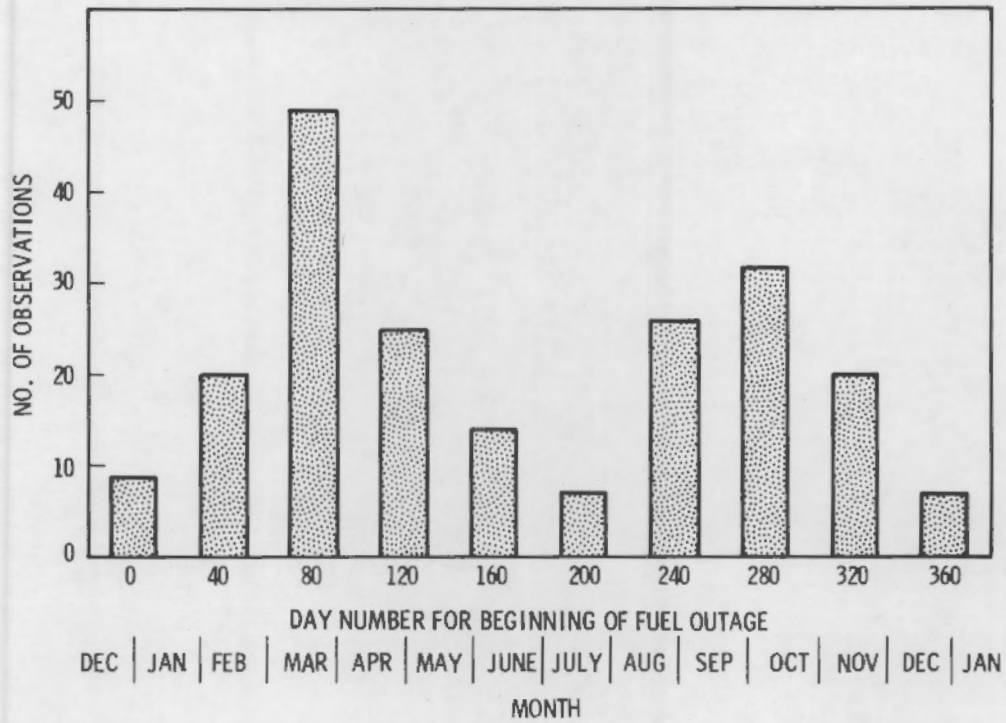


FIGURE 22. Beginning Dates of Fuel Outages

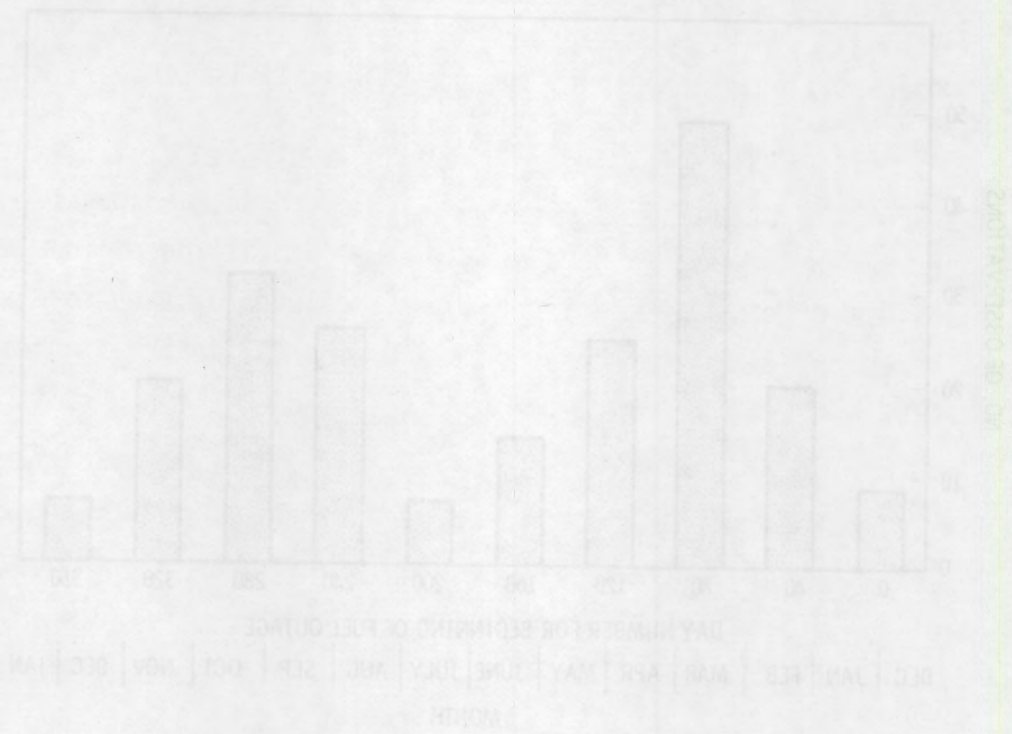


FIGURE 55. Beginning Dates of Fuel Outages

COMMENTS ON PROBABILISTIC ANALYSIS OF STEAM GENERATOR TUBING PROBLEMS

The fundamental relationship in the ISI C/B analysis is:

$$[USO_{sg}] = f([ISI]) \quad (1)$$

where $[USO_{sg}]$ is the intensity of SG attributed unscheduled outages, measured by the number and length of the outages over some evaluation period and $[ISI]$ is the intensity of the SG inspection program, measured by the scope and frequency of the inspections (or more generally by the NDT information developed over the evaluation period).

ISIs can influence tubing failure in two ways: 1) by providing guidance to unit D/O/M practice that will tend to minimize tubing failure and 2) by censoring those tubes that are within an arbitrary degradation regime (as defined by the "plugging limit").

The second influence is the principal concern of this report. It will be successful only to the extent that uncensored tubes are not degraded to "leaker" status in the interval between inspections. This condition depends on: the validity of the criteria used to identify unacceptable tubes (as summarized by the plugging limit); the sensitivity of the NDT technique(s) to significant structural change; and the rate of deterioration of the tubing containment ability, which could vary substantially with time over the tubing population of a given SG and from zone-to-zone for a given tube of a single SG.

Corrosion attack (e.g., pitting, cracking, erosion-corrosion, or "uniform" attack from oxidation or other chemical action) may be accelerated as the degradation progresses, depending on the local physico-chemical and stress situation. Judging the conservatism of a given plugging limit is therefore difficult unless there is good knowledge of the rates of all operable degradation processes as a function of the defect state of the tubing. For the following necessarily qualitative discussion, let D be some measure of the degradation state of a tube. D is a monotonically increasing characteristic of various extent for all working tubes of the unit population and is difficult to quantify even for very simple cases involving a single structural defect, well-characterized metallurgical conditions adjoining the defect, and a good

knowledge of the nominal local working conditions. The success of a given ISI strategy, in the sense of the second (censoring) ISI influence noted above, depends on all tubes of the unit satisfying the relationship:

$$\theta_f > \theta_{op} \quad (2)$$

where θ_f is the time to failure of a given tube measured from the last inspection and θ_{op} is the unit operating time between ISIs. θ_f and D are related by the following expression:

$$D + \int_0^{\theta_f} \dot{D} d\theta = D + \Delta D = D_f \quad (3)$$

where \dot{D} = the instantaneous rate of the tubing degradation

D = the degradation state of the tubing at the start of the operating period

ΔD = the degradation increment realized at time of tube failure

D_f = the degradation state corresponding to tube failure under the working and metallurgical conditions specific to the tube.

The degradation rate (\dot{D})-operating time characteristic may be expected to vary widely over the unit tubing population and, in fact, over the length of a given tube for those cases where the tube is subject to various significant degradation processes (see Figure 23). Quantitative knowledge of the \dot{D} - θ characteristic is, in general, quite limited. Let D_{pl} represent the degradation state corresponding to the plugging limit (the current plugging limit is based on the penetration of a detectable degradation effect through the tube wall, i.e., on the percent of wall penetration by the defect). The success criterion expressed by Equation (2) can be recast in terms of θ_{op} and D_{pl} as follows:

$$D + \int_0^{\theta_f} \dot{D} d\theta > D + \int_0^{\theta_{op}} \dot{D} d\theta \quad (D < D_{pl}) \quad (4)$$

$$\text{or} \quad \int_0^{\theta_f} \dot{D} d\theta > \int_0^{\theta_{op}} \dot{D} d\theta \quad (4a)$$

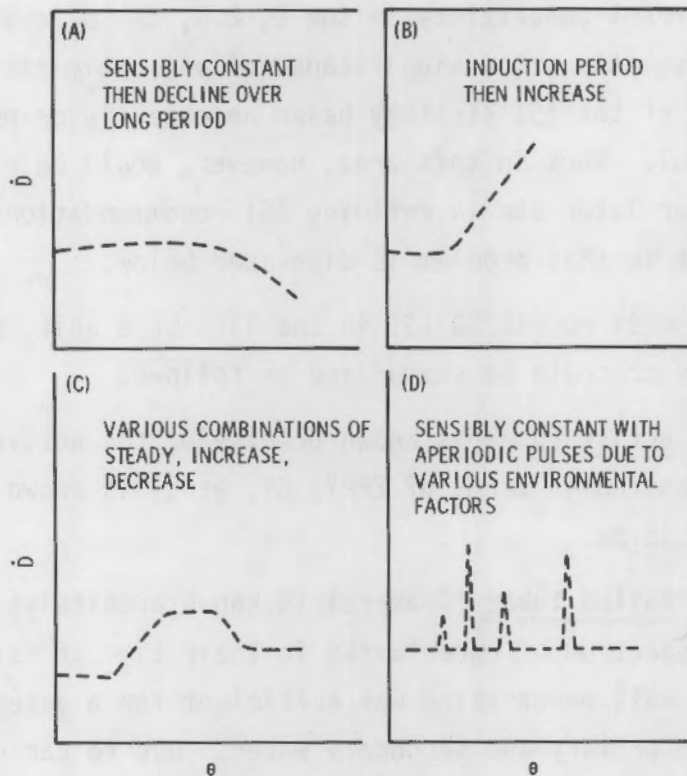


FIGURE 23. Schematics of Conceivable $D-\theta$ Characteristics for Steam Generator Tubing

Considering the possible complexity of the $\dot{D}-\theta$ relationship, Equation (4) is left in integral form.

Easterling⁽¹⁰⁾ has analyzed the NDT uncertainty with respect to simple defect conditions. This is obviously an important factor in establishing censoring limits that can maximize the number of tubes satisfying criterion (4) for practicable values of θ_{op} . It is also obvious that the further the departure of the ISI scope (percent of unit tubing population inspected during an ISI) from 100%, the greater the possibility of tubes not satisfying criterion (4). Easterling⁽¹⁰⁾ has also addressed the implications of partial sampling to some extent. Problems arising from partial sampling may be expected to decrease in importance as better knowledge is acquired of the degradation of a unit tubing population with operating time.

In view of current uncertainty in the D , $\dot{D}-\theta$, and D_f characteristics for the unit tubing population, the significance of any optimization of the θ_{op} (frequency) factor of the ISI strategy based necessarily on probabilistic analysis is doubtful. Work in this area, however, would be expected to yield valuable insight for later use in refining ISI recommendations for specific units. An approach to this problem is discussed below.

Following the most recent SG ISI in the life of a unit, the knowledge of the SG tubing behavior could be summarized as follows.

- The number of active tubes is known precisely; the active tube service life (measured in terms of EFPY, CY, etc.) is known within an arbitrary precision.
- The number of failed tubes (leakers) is known precisely; there is a fairly broad spectrum of uncertainty in their time of failure (the time when the wall penetration was sufficient for a detectable interchange between primary and secondary waters) due to various problems of leak detection and identification of leakers.
- The number of unfailed plugged tubes is presumably known precisely; while the time of plugging is known precisely (hence the corresponding service life), these tubes represent a spectrum of residual life expectancy whose range is dependent on the conservatism of the plugging practice. The plugging of these tubes is, therefore, a statistical life censoring act that may pose some difficulty in tubing reliability analysis considering the difficulty in relating residual life expectancy to a specific defect state. Studies of defected SG tubing will contribute to a practical resolution of the latter problem.⁽¹¹⁾

The above tubing information represents a complex, unplanned censored data situation that may be treated in the literature although a review of this analysis has been outside the scope limitations of this report. A reliability analysis technique for multiple time-censored data satisfying certain statistical requirements has been discussed in several reports by W. B. Nelson of General Electric.⁽¹²⁾ An associated computer program for the calculation and

plotting of the cumulative failure rate function is reported by Nelson and Hendrickson.⁽¹³⁾ The elements of this technique are outlined in Appendix C.

The limits of application of the above technique to the SG tubing data situation remain to be studied theoretically and by some application of the technique to tubing data from several units. Any practicable technique should be capable of accommodating both the long-term tubing performance history as well as recent trends in performance within some arbitrary evaluation period. It should also be readily assimilated into an overall SG ISI C/B code for analysis of the ISI frequency factor, along with the various costs of ISI strategies discussed previously in this report.

A useful quantification of the fundamental relationship (1) appears to be largely inaccessible at this time considering its complexity and the limited scope of information pertaining to the two ISI influences noted on p. 65. Knowledge of this relationship will be served by good reporting of comprehensive ISI strategies and careful correlation of this ISI information with unit D/O/M practice that affects SG tubing performance.

ESTIMATED COSTS FOR DISPOSAL OF SOLID WASTES ASSOCIATED WITH
PRIMARY TO SECONDARY LEAKAGE IN PWR STEAM GENERATORS

Leaks in the SG tubing of a PWR result in the transfer of radionuclides in the primary coolant to the secondary system water. When the radionuclide content of the secondary system water exceeds a value of 1×10^{-7} $\mu\text{Ci/ml}$, it is necessary to treat this water if it is removed for discharge to the environment. In order to maintain a high level of water quality in the SG, a portion of this water is normally removed continuously as a blowdown stream. When the radionuclide content exceeds the discharge limit, the blowdown stream is typically routed through an ion exchange treatment system. When the ion exchange capacity of the resin is exhausted, the spent resin is removed and discarded as solid waste. Until recently, it has been common practice to decant as much water from the spent resin as possible and package the resin with some free water remaining for disposal. A new regulatory stance will require complete removal of any free water from the resin before shipment and disposal. This may be accomplished by various fixation techniques such as the cement silicate system.

The conventional approach to ion exchange treatment of the SG blowdown has involved a deep bed of mixed cation and anion exchange resins. There are no firm data available on the quantity of this resin discarded as waste per unit of reactor operating time, although it has been estimated to be about 4500 ft³ per year for a typical PWR.

An alternate approach to treatment of SG blowdown involves the use of full-flow condensate treatment with Powdex[®] ion exchange resins. This approach is expected to keep secondary system water pure enough to avoid blowdown from the SG. One operating reactor reported that a retrofit Powdex system for PWR condensate included blending of the blowdown with the condensate before treatment, thereby avoiding discharge of the blowdown. The Powdex resin is disposed of as radioactive waste and is estimated to be about the same order of magnitude as the volume given above.

[®]Graver Water Conditioning Co., Division of Ecodyne Corporation, Union, New Jersey.

The volume of spent Powdex resin is normally not related to the radionuclide content of the secondary system condensate or blowdown. The resin is used for both ion exchange and filtration, and it is the latter (high-pressure differential buildup) that determines the life of the resin and, therefore, the volume of resin used.

The cost of disposing spent ion exchange resin from SG blowdown and/or condensate treatment can vary widely depending principally on whether or not it is considered radioactive. The lowest cost was estimated for unrestricted release of the resin for disposal to a local sanitary landfill (\$15,000 annually). The highest cost was estimated for disposal as solidified waste to a radwaste burial site located 1000 miles from the reactor (\$164,000 annually). All cost figures were based on January 1980 prices. The following text examines the costs associated with treatment of water contaminated by primary to secondary leaks. Results are placed into a matrix that lists costs as a function of leakage activity.

The following economic analysis evaluates the costs associated with treatment of radwastes from the secondary heat exchange fluid loop. This fluid is periodically contaminated by primary fluid passing through breaks in the tubes of the SG heat exchanger.

The basis of the analysis is from an interoffice memorandum (IOM) from the Washington Public Power Supply System (by Steen) dated April 5, 1979. The IOM reports on the costs associated with various treatment methods for secondary fluids in the SG. It was recommended that the standard ureaformaldehyde (UF) radwaste solidification system be replaced by a more efficient and less expensive cement-sodium silicate system. This report will assume use of the cement-sodium silicate system and will, as the reference report did, assume retrofit capital costs for the conversion of the UF system to the cement-sodium silicate system. Data used from the IOM are extrapolated to reflect on the treatment of radwastes associated with SG leakage. The analysis results in a range of values (\$/yr) associated with treatment of secondary rad-contaminated waters from nuclear SGs.

The assumptions used in this analysis are presented below. Facility life expectancy is 15 years and the interest rate used is 10%. The burial site used

is Hanford, Washington, except for Cases A and K (see Table 20). It was calculated that 45% of the spent resin generated in the reference study (5300 ft³ by volume) was due to SG leakage. This fact was verified in a de minimus study⁽¹⁴⁾ that estimated the quantity of spent resin at 4500 ft³/yr. Therefore, the analysis should be conservative.

Assumptions

1. Liners^(a) used by the plants under construction (WNP 1/4) will accommodate waste of the following radiation ranges:
 - a) 20% of the wastes will have been contaminated to 1-5 rem/hour
 - b) 35% of the wastes will have been contaminated to 200 mrem-1 rem/hour
 - c) 45% of the wastes will have been contaminated to 0-200 mrem/hour.
2. Liners of 100-ft³ capacity will be used for solidification of wastes.
3. Approximately 8,400 ft³/yr of waste must be solidified per facility.
4. Shipping charges are 95¢/mile or \$100/shipment, whichever is higher.
5. Liners cost \$650 each.
6. Liners with dose rates 1-5 rem/hour are shipped one per truck; all others are shipped two per truck.
7. Burial charges for secure radwaste burial are based upon Nuclear Engineering Companies, Hanford, Washington, charge-out rates (see attachment).
8. Modification capital and installation cost for cement-sodium silicate system will be \$1,050,000. Keeping the old UF system will have no capital costs (basis, July 1978).
9. Interest rate on capital costs is 10%/yr.
10. Life expectancy of solidification process is 15 years.
11. Cost data basis: July 1978 and January 1980.

(a) Liner is the container for the waste, exclusive of shielding.

TABLE 20. Summary of Annual Operating Costs

Case	A	B	C	D	E	F	G	H	I	J	K
Cost	40,660	83,115	83,390	84,065	86,990	87,865	88,440	100,280	100,665	101,230	
\$/yr	(45,540)	(93,090)	(93,400)	(94,150)	(97,430)	(98,410)	(99,050)	(112,310)	(112,740)	(113,380)	(14,850)

Case

- A Radwaste at 0-0.005 rem/hour, buried onsite (negligible burial costs).
- B Radwaste at 0-0.200 rem/hour, buried at Hanford, Washington, travel distance maximum of 50 miles.
- C Radwaste at 0-0.200 rem/hour, buried at Hanford, Washington, travel distance maximum of 500 miles.
- D Radwaste at 0-0.200 rem/hour, buried at Hanford, Washington, travel distance maximum of 1000 miles.
- E Radwaste at 0.200-1 rem/hour, buried at Hanford, Washington, travel distance maximum of 50 miles.
- F Radwaste at 0.200-1 rem/hour, buried at Hanford, Washington, travel distance maximum of 500 miles.
- G Radwaste at 0.200-1 rem/hour, buried at Hanford, Washington, travel distance maximum of 1000 miles.
- H Radwaste at 1-5 rem/hour, buried at Hanford, Washington, travel distance maximum of 500 miles.
- I Radwaste at 1-5 rem/hour, buried at Hanford, Washington, travel distance maximum of 500 miles.
- J Radwaste at 1-5 rem/hour, buried at Hanford, Washington, travel distance maximum of 1000 miles.
- K Radwaste below de minimus levels, buried in sanitary landfill, travel distance maximum of 50 miles.

n = basis July 1978
(n) = basis January 1980

Table 20 presents initial operating costs for operating this facility under a variety of conditions (cases A through K). Conditions varied including transportation charges (mileage to secure radwaste site) and levels of radwaste contamination. Initial operating costs varied from \$15.8K to \$101.2K. The charge associated with initial capital expenditure is \$69.6K over the 15-year lifetime of the facility (see Table 21).

Table 22 presents a breakdown of the total cumulative costs of the various options over the lifetime of the plant. A 10% annual inflation rate on annual operating costs is included in the computation, and a sample calculation is provided.

TABLE 21. Capital Costs (January 1980 Basis)

Cost of Equipment and Installation: \$1,050,000 -- July 1978 Basis
 (\$1,176,000) -- January 1980 Basis

Assume Facilities Life Span of 15 Years, No Salvage Value.

Assume Interest Rate of 10%.

$$\begin{aligned}
 \therefore \text{Capital Costs/yr} & \\
 \text{of Operation} &= (\$1,176,000) \left(\frac{i(1+i)^n}{(1+i)^n - 1} \right) \text{Capital Recovery} \\
 & \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \text{Factor (n)} \\
 &= (\$1,176,000) (0.13147) \\
 &= \$155,000/\text{yr for Entire Facilities Wastes} \\
 &= (\$155,000) \left(\frac{5,300}{11,800} \right) = \$69,600/\text{yr for} \\
 & \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \text{Steam Generator} \\
 & \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \text{Waste Solidification}
 \end{aligned}$$

Next, it was necessary to determine which of the options (A-K) reflect both the actual state-of-the-art operating conditions and the projected operating conditions. To obtain these data, several organizations were contacted, including the Washington Public Power Supply System, Trojan Power reactor of Pacific Gas and Electric (PGE), and NRC. A de minimus study on wastes from Powdex systems (which are commonly used for secondary, SG, and waste water treatment) was also referenced. Results from these sources were two-fold.

TABLE 22. Total Costs Associated with Decontamination of Steam Generator Water (January 1980 Basis)

Total Cost of System up to X Years (\$)	Case					
	A	B	C	D	E	F
1	115,140	162,690	163,000	163,750	167,030	168,010
2	234,830	334,690	335,340	336,920	343,800	345,860
5	626,020	916,310	918,210	922,790	942,810	948,790
10	1,421,770	2,179,580	2,184,520	2,196,470	2,248,740	2,264,360
15	2,490,900	4,001,660	4,011,500	4,035,330	4,134,670	4,170,680
	G	H	I	J	K	
1	168,650	181,910	182,340	182,980	15,840	
2	347,210	375,050	375,950	377,300	33,260	
5	952,700	1,033,650	1,036,280	1,040,180	96,700	
10	2,274,560	2,485,880	2,492,740	2,502,940	252,440	
15	4,191,020	4,612,310	4,625,980	4,646,310	503,270	

EX: Year 2, Case A

$$\text{Total Cost} = n(69,600) + \left[\left(\frac{(1+i)^n - 1}{i} \right) (45,540) \right] = 234,830$$

$n = 2; i = 0.1$

First, the utilities expect the resin will normally be low enough in radwaste contamination that it could be sent to sanitary landfills. In the worst case, contaminated resin would have to be taken to a secure radwaste landfill, without contamination penalties. However, apparently many utilities will send these spent resins to secure radwaste disposal facilities due to public pressure. Therefore, cases A, B, C, D, and K reflect the situations and ranges of costs expected. First-year total costs ranged from \$15.8K to \$163.7K and increase substantially if the contaminated resin must be solidified due to capital costs associated with solidification equipment. Cost data are given in Appendix D, which also gives calculations of the annual operating costs presented in this section.

Possible costs associated with storage of solid wastes pending offsite shipping arrangements would be quite site-specific and were not considered at this stage of the C/B analysis.

FURTHER COST/BENEFIT ANALYSIS OBJECTIVES

A practicable C/B analysis technique for SG ISI will require a synthesis of many technical, personnel, and \$ cost factors, some of which have been given only a very cursory review in this report. Several further work areas for the subject program are briefly discussed here.

Analysis of Outage Costs for PWR Units

The critical path time cost for large nuclear units is a strong constraint on the scope and frequency parameters of ISI strategies. Some of the factors affecting this cost were discussed briefly in this report. A C/B analysis technique for appraising SG ISIs, both individual inspections and an inspection program over an evaluation period, must be able to accommodate the complex of outage cost factors specific to a given unit at a given time. The purpose of this task is to perform an in-depth analysis of outage cost factors of PWR units and to evolve a technique for incorporating successively refined elements of this analysis into an overall C/B code.

Analysis of SG Tubing Performance

The success of any C/B analysis code for SG ISI will be measured by the service it can render to units on a nationwide basis. Accordingly, a practicable code must accommodate a wide range of tubing performance, considering both overall and recent trend behavior. Ultimately, the purview of the C/B code could conceivably include the influence of various D/O/M factors on tubing performance. The current state of the information on tubing performance (i.e., the accessibility, the quality and scope of the data, and its relationship to pertinent unit D/O/M factors) does not appear adequate for the tubing reliability analysis needed for prudent specification of inspection intervals for specific units. This task would have several concomitant efforts: 1) participation with the cognizant public and private organizations in improving the scope, codification, and dissemination of performance data for PWR SG tubes and 2) study of the current tubing data bank with the objective of identifying practicable techniques for probabilistic analysis of tubing performance. In

accordance with progress in the latter phase of this task, the probabilistic component (as related to tubing performance) would be incorporated in the overall C/B analysis code.

Analysis of Foreign SG ISI Strategies and Related PWR SG Performance

While the focus of this program is on PWR units in the United States, it is expected that much valuable information on ISI strategies and the related PWR SG tubing experience could be obtained from foreign sources. The purpose of this task is to review relevant foreign SG ISI practice and the related SG tubing performance. Coordination of this work with the parent U.S. program would be expected to add both scope and authority to recommendations forthcoming from the program.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and/or the National Technical Information Service, Springfield, VA 22161.

APPENDIX A

NOMENCLATURE

APPENDIX A

NOMENCLATURE

<u>Symbol</u>	<u>Identification</u>	<u>Units</u>
ALARA	as low as reasonably achievable	
α	time efficiency factor for given inspection phase	
CF	capacity factor	
CTFI	cumulative tube failure index	(SG EFPY) ⁻¹
C_1	composite index for evaluation period [Iisi/(MAN-REM)]	(yr man-rem) ⁻¹
C_1	composite index for individual inspection [Iisi*/(MAN-REM*)]	(man-rem) ⁻¹
C_2	composite index for evaluation period [Iisi/(MAN-REM §isi)]	(yr man-remx10 ⁶ §) ⁻¹
C_2	composite index for individual inspection [Iisi*/(MAN-REM* §isi*)]	(man-remx10 ⁶ §)
C_t	nominal crew size for <u>testing</u> phase of inspection	
C_{nt}	nominal crew size for <u>nontesting</u> phase of inspection	
D	symbol of degradation state of SG tubing	
D	rate of change of D	
§isi	§ impact index for evaluation period	(10 ⁶ §)
§isi*	§ impact index for individual inspection	(10 ⁶ §)
§oi	outgage cost per day for unit at time of inspection (i)	(10 ⁶ §/day)

Symbol	Identification	Units
$(\$/\text{tube})_i$	total cost of ISI on a per tube inspected basis	$(10^6\$/\text{tube})$
$\$USO_{sg}$	$\$$ impact of unscheduled outage attributable to SG problems	$(10^6\$)$
EFPY	effective full power year	
f	number of tubes failed (plugged)	
F_i	time interference factor for inspection (i)	
$f(\theta)$	probability density for tube failure	
$F(\theta)$	cumulative failure probability	
i	summation index over inspections for given unit	
ISI	in-service inspection	
[ISI]	intensity of an in-service inspection program	
I_{isi}	NDT information index for evaluation period for given unit	$(\text{yr})^{-1}$
I_{isi}^*	information index for individual inspection	
$\lambda(\theta)$	tube failure rate	
$\Lambda(\theta)$	cumulative tube failure rate	
$(MR)_t$	aggregate rad exposure for testing phase per tube tested	$(\text{man-rem}/\text{tube})$
$(MR)_{nt}$	aggregate rad exposure for nontesting phase per SG involved	$(\text{man-rem}/\text{SG})$
MAN-REM	rad exposure index for evaluation period	(man-rem)
MAN-REM*	rad exposure index for individual inspection	(man-rem)

Symbol	Identification	Units
$(Men)_t$	crew needed for <u>testing</u> phase	
$(Men)_{nt}$	crew needed for <u>nontesting</u> phase	
NDT	nondestructive testing	
N_{sg}	number of SGs per unit	
n_i	number of SGs involved in the i th inspection of unit	
n_u	number of SGs involved in inspection campaign for given type unit	
$P(\theta+\Delta\theta/\theta)$	conditional probability of tubing failure within interval $\Delta\theta$	
R^*	maximum permissible occupational rad exposure per man per year	(man-rem)
S_i	inspection scope [(tubes inspected/total unit tubes) x 100]	(%)
S_u	inspection scope common to units of given type for inspection campaign	(%)
θ	duration or endurance variable	(day, yr, EFPY)
θ_{ev}	length of evaluation period	(yr)
θ_{op}	interval between inspections	(month, yr)
t_i	tubes involved in inspection (i)	
t_{sg}	tubes per SG	
$(Time)_t$	time to perform <u>testing</u> phase of inspection	(hr, week)
$(Time)_{nt}$	time to perform <u>nontesting</u> phase of inspection	
u	summation index over the units involved in inspection campaign	

<u>Symbol</u>	<u>Identification</u>	<u>Units</u>
U_i	distribution factor (SGs involved in inspection/total SGs in unit)	
unit	a PWR power plant in present context	
USO_{SG}	unscheduled outage attributable to SG problem(s)	(day)
$[USO_{SG}]$	intensity of unscheduled outages attributable to SG problems	
Y_u	number of units of given type involved in inspection campaign	

APPENDIX B

DATA FOR CHARACTERIZATION INDICES

TABLE B.1. Values of Indices for ISI Cases

4-SG Unit

ISI Case	Iisi (Yr ⁻¹)	MAN-REM (High) (man-rem)	MAN-REM (Low)	MAN-REM (T = 0)	§isi (F = 0) (10 ⁶ §)	§isi Proportional F (F _{max} = 0.1)	(a)	(b)
							C ₁ (yrxMR) ⁻¹	C ₂ (yrxMRx10 ⁶ §) ⁻¹
A-1	7.5(-3) ^(c)	96	14	50	1.4(-1)	2.9(-1)	1.5(-4)	1.1(-3)
A-2	5.0(-3)	64	9.4	34	9.0(-2)	1.7(-1)	1.5(-4)	1.6(-3)
A-3	4.2(-3)	53	7.8	28	7.2(-2)	1.4(-1)	1.5(-4)	2.1(-3)
B-1	6.3(-3)	112	16	62	8.4(-2)	1.6(-1)	1.0(-4)	1.2(-3)
B-2	4.6(-3)	71	9.9	39	4.6(-2)	7.8(-2)	1.2(-4)	2.6(-3)
C-1	8.9(-1)	574	129	179	1.5	2.1(+1)	5.0(-3)	3.3(-3)
C-2	3.9(-1)	359	80	112	1.2	8.3	3.5(-3)	2.9(-3)
C-3	3.1(-1)	323	72	101	1.1	5.9	3.1(-3)	2.8(-3)
C-4								
C-5	1.6(-1)	198	44	62	8.0(-1)	2.0	2.6(-3)	3.2(-3)
C-6								
C-7	7.6(-2)	161	36	50	7.5(-1)	2.0	1.5(-3)	2.0(-3)
C-8	6.3(-2)	153	34	50	7.0(-1)	1.9	1.3(-3)	1.8(-3)
C-9	2.5(-2)	114	21	50	3.9(-1)	8.7(-1)	5.0(-4)	1.3(-3)

(a) C₁ = Iisi/MAN-REM, T = 0 case

(b) C₂ = Iisi / (MAN-REMx§isi); T = 0 for MAN-REM, F = 0 for §isi

(c) 7.5(-3) = 7.5 x 10⁻³, etc.

TABLE B.1. (contd)

3-SG Unit

ISI Case	I_{isi} (Yr ⁻¹)	MAN-REM (High) (man-rem)	MAN-REM (Low)	MAN-REM (T = 0)	$\$isi$ (F = 0) (10 ⁶ \$)	$\$isi$ Proportional F (F _{max} = 0.1)	C ₁ (yrxMR) ⁻¹	C ₂ (yrxMRx10 ⁶ \$) ⁻¹
A-1	1.0(-2)	94	14	50	1.2(-1)	3.1(-1)	2.0(-4)	1.7(-3)
A-2	6.7(-3)	63	9	34	7.2(-2)	1.8(-1)	2.0(-4)	2.7(-3)
A-3	5.6(-3)	52	7.5	28	5.8(-2)	1.4(-1)	2.0(-4)	3.5(-3)
B-1	7.2(-3)	101	14	56	6.6(-2)	1.6(-1)	1.3(-4)	2.0(-3)
B-2	5.0(-3)	61	8.4	34	3.7(-2)	7.9(-2)	1.5(-4)	4.0(-3)
C-1	8.9(-1)	431	96	134	1.3	2.0(+1)	6.6(-3)	5.1(-3)
C-2	4.4(-1)	323	72	101	9.9(-1)	9.5	4.4(-3)	4.4(-3)
C-3	3.7(-1)	277	59	95	9.5(-1)	7.4	3.9(-3)	4.1(-3)
C-4	2.0(-1)	180	40	56	7.7(-1)	2.9	3.6(-3)	4.6(-3)
C-5	1.8(-1)	166	36	56	6.7(-1)	2.3	3.2(-3)	4.8(-3)
C-6	1.1(-1)	153	34	50	7.0(-1)	2.8	2.2(-3)	3.1(-3)
C-7	1.0(-1)	143	30	50	6.3(-1)	2.2	2.0(-3)	3.2(-3)
C-8	8.3(-2)	137	28	50	5.8(-1)	2.2	1.7(-3)	2.9(-3)
C-9	3.3(-2)	108	19	50	3.1(-1)	9.4(-1)	6.6(-4)	2.1(-3)

TABLE B.1. (contd)

2-SG Unit

<u>ISI Case</u>	<u>Iisi</u> (Yr ⁻¹)	<u>MAN-REM</u> (High) (man-rem)	<u>MAN-REM</u> (Low)	<u>MAN-REM</u> (T = 0)	<u>\$isi</u> (F = 0) (10 ⁶ \$)	<u>\$isi</u> Proportional F (F _{max} = 0.1)	<u>C1</u> (yrxMR) ⁻¹	<u>C2</u> (yrxMRx10 ⁶ \$) ⁻¹
A-1	1.3(-2)	97	16	45	3.0(-1)	5.8(-1)	2.9(-4)	9.6(-4)
A-2	8.3(-3)	61	10	28	2.2(-1)	3.9(-1)	3.0(-4)	1.4(-3)
A-3	6.7(-3)	48	8.3	22	1.5(-1)	2.8(-1)	3.1(-4)	2.0(-3)
B-1	9.2(-3)	99	16	50	1.8(-1)	3.3(-1)	1.8(-4)	1.0(-3)
B-2	5.8(-3)	55	8.4	28	1.0(-1)	1.6(-1)	2.1(-4)	2.1(-3)
C-1	8.9(-1)	778	227	90	3.5	2.3(+1)	9.9(-3)	2.8(-3)
C-2	3.9(-1)	486	142	56	2.2	9.3	7.0(-3)	3.2(-3)
C-3	3.1(-1)	438	128	50	2.0	6.7	6.2(-3)	3.1(-3)
C-4								
C-5	2.1(-1)	302	83	50	1.4	3.8	4.2(-3)	3.0(-3)
C-6								
C-7	1.3(-1)	253	68	45	1.2	3.6	2.9(-3)	2.4(-3)
C-8	1.1(-1)	233	62	45	1.1	3.5	2.4(-3)	2.2(-3)
C-9	4.4(-2)	140	31	45	6.7(-1)	1.6	9.8(-4)	1.5(-3)

APPENDIX C

A RELIABILITY ANALYSIS TECHNIQUE

APPENDIX C

A RELIABILITY ANALYSIS TECHNIQUE

The failure rate $\lambda(\theta)$ is a prominent element of current reliability analysis. It is a conditional failure probability defined as:

$$\lambda(\theta) = \frac{f(\theta)}{1 - F(\theta)} \quad (1)$$

where $f(\theta)$ is the probability density for failure at time θ and $F(\theta)$ is the cumulative failure probability at time θ . $\lambda(\theta)$ is, therefore, a measure of the probability of failure at time θ given that a component has survived up to time θ . The cumulative failure rate $\Lambda(\theta)$ is the integral of $\lambda(\theta)$ over the period of interest:

$$\Lambda(\theta) = \int_0^{\theta} \lambda(\theta) d\theta \quad (2)$$

Substituting the above definition of $\lambda(\theta)$ into Equation (2):

$$\Lambda(\theta) = -\ln[1 - F(\theta)] \quad (3)$$

Hence,

$$F(\theta) = 1 - e^{-\Lambda(\theta)} \quad (3a)$$

Relationship (3a) between $F(\theta)$ and $\Lambda(\theta)$ is independent of an assumption as to the statistical model of failure (exponential, lognormal, Weibull, etc.).

The conditional probability of failure of a component within an arbitrary interval, given survival up to the interval, is a statistical finding of immediate interest to the steam generator (SG) in-service inspection (ISI) problem.

This probability is a measure of the safety of a given interval between inspections, assuming the statistical analysis is appropriate to the current tube failure situation for the unit under study. This conditional probability may be expressed:

$$P(\theta + \Delta\theta/\theta) = 1 - \frac{1 - F(\theta + \Delta\theta)}{1 - F(\theta)} \quad (4)$$

Substituting for $F(\theta)$ from Equation (3a)

$$P(\theta + \Delta\theta/\theta) = 1 - e^{-[\Lambda(\theta + \Delta\theta) - \Lambda(\theta)]} \quad (4a)$$

W. B. Nelson⁽¹²⁾ has discussed a graphical procedure for evaluating Equation (4a), and Nelson and Hendrickson⁽¹³⁾ discussed a time-sharing computer program for deriving the cumulative failure rate function from multiple time-censored failure data and computing the statistical values of interest. The problem of analyzing existing SG tubing data was discussed briefly in the text of this report. While it appears that some of the statistical prerequisites for applying the technique discussed by Nelson may not be satisfied by the current SG tubing data bank, it is of some interest to demonstrate this technique using very limited data for the Palisades pressurized water reactor (PWR) obtained from References 8 and 9. For this illustration, the effective fuel power year (EFPY) is used for the endurance variable (θ) (see Table C.1). In Table C.2 the data are restated together with the number of tubes surviving at a given cumulative EFPY level. The failure rate at a given EFPY level is:

$$\lambda(\text{EFPY}) = \frac{\text{tubes failing at EFPY level}}{\text{tubes surviving}} \times 100 \quad (5)$$

The failure rate (λ) and the cumulative failure rate (Λ) data are given in Table C.2. Failure plotting paper is available for a number of failure statistical models (normal, exponential, lognormal, Weibull, extreme value, etc.). The basic characteristics of these papers are: 1) a plot of the endurance variable (e.g., EFPY) versus the cumulative failure function (Λ) will yield a

TABLE C.1. Tubing Performance Data for Palisades PWR Unit through 1977

Σ EFPY	Tubes Plugged
0.5	0
0.7	1,700
1.2	1,260
1.6	285
2.1	711
2.14	<u>16</u>
	3,972
	17,038 tubes in unit

TABLE C.2. Failure Rate and Cumulative Failure Rate Data from Table C.1 Data

Σ EFPY	Tubes Plugged	Reverse Rank (a)	λ (EFPY) (%)	Λ (EFPY) (%)
0.5	0	17,038	--	--
0.7	1,700	15,338	11.08	11.08
1.2	1,260	14,078	8.95	20.03
1.6	285	13,793	2.07	22.10
2.1	711	13,082	5.44	27.54
2.14	16	13,066	0.12	27.66

(a) Number of tubes surviving up to given EFPY total.

straight line if the paper statistics are valid, and 2) the cumulative failure probability (F) corresponding to a given cumulative failure rate (Λ) is obtained from the upper horizontal scale on the plot. For illustration purposes only, the data of Table C.2 are plotted on a smallest extreme value paper in Figure C.1 and a straight line is fitted to the points by eye. The conditional failure probability within an interval $\Delta\theta$ after a period θ is obtained as follows from such a plot:

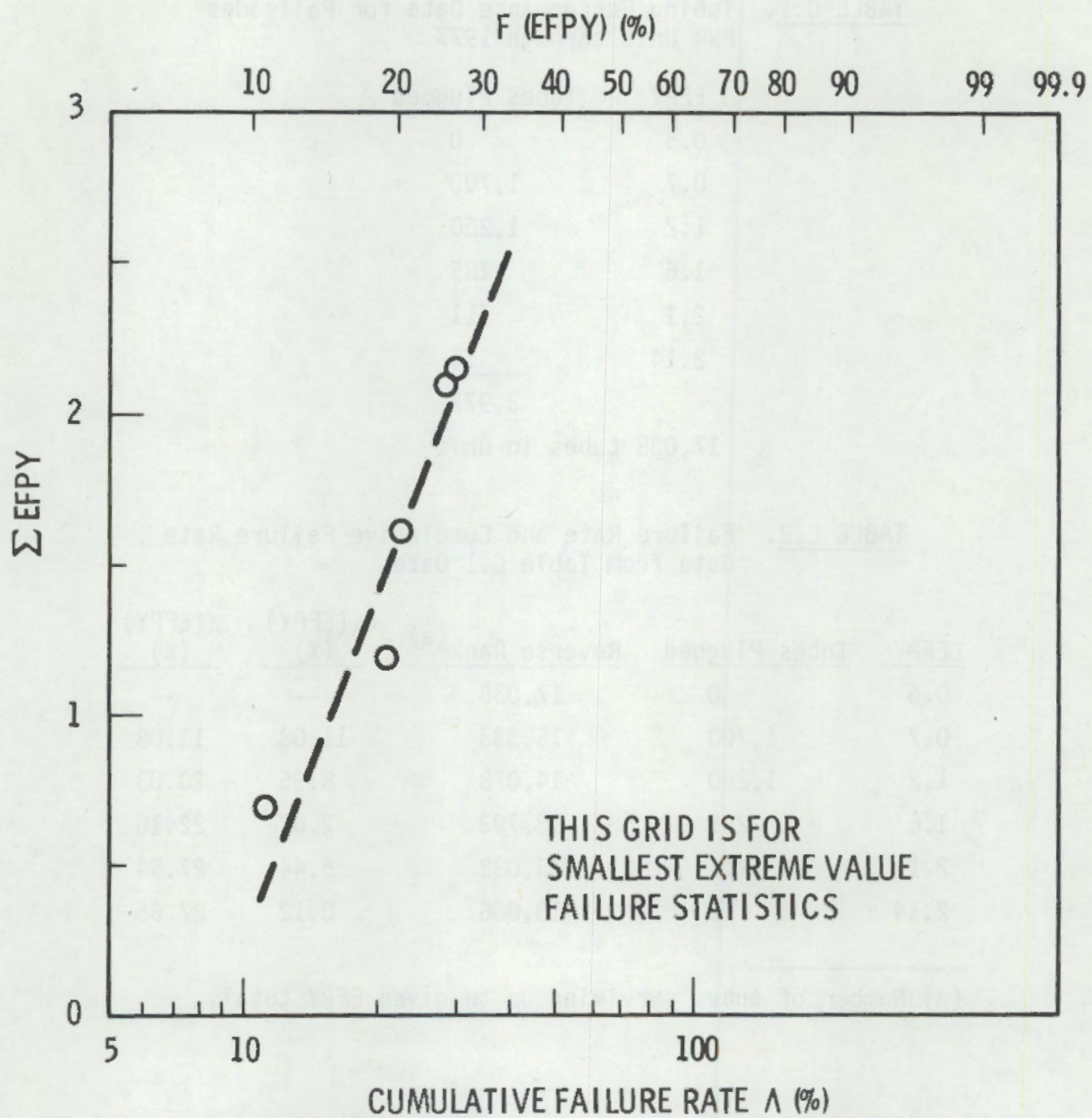


FIGURE C.1. Cumulative Failure Rate Versus Cumulative EFPY

- find the Λ value corresponding to θ (current tube life in EFPY)
- find the Λ value corresponding to $\theta + \Delta\theta$ (life plus inspection interval measured in EFPY)

- calculate $\Delta\Lambda = \Lambda(\theta + \Delta\theta) - \Lambda(\theta)$
- enter plot at $\Delta\Lambda$ and read the cumulative failure probability (F) on the upper scale, which is the desired conditional failure probability.

For example, using the characteristic line of Figure C.1:

- Λ at a life of 1 EFPY \approx ~16%
- Λ at 1 EFPY + a 1-EFPY interval = ~28%
- $\Delta\Lambda =$ ~12%
- F(EFPY) from upper scale = ~13%.

Hence, according to this analysis there is a conditional probability of tubing failure of about 13% within the next 1 EFPY past a tube life of 1 EFPY. One interpretation of this is that about 2,200 out of 17,038 tubes would be expected to fail within a 1-EFPY interval after a life of 1 EFPY.

Fortunately, the early Palisades data used for this illustration represent a very extreme case of poor tubing performance and are far from representative of current general tubing performance. Providing reasonably good applicability to current, or obtainable, tubing data can be demonstrated, the computer-assisted technique outlined here may prove a useful step toward incorporating probabilistic analysis of tubing performance into overall cost/benefit (C/B) analysis of SG ISI.

APPENDIX D

DATA FOR COSTING SOLID WASTE DISPOSAL

TABLE 0.1. Cost Data from IOM Report^(a)

Efficiency (waste-to-agent ratio)	2.5:1	1.5:1		
	70%	60%		
Number of Liners per Year	118	140		
Chemical Cost (\$/lb)			\$0.035 ^(a)	
Chemical Cost/yr	\$ 11,178	\$ 19,529		
Costs of Liners/yr				
\$650/Liner	\$ 76,700	\$ 91,000		
Burial Cost/yr	\$ 80,365	\$ 95,235		
1-5 rem	\$16,800	\$19,600		
200 mrem-1 rem	22,140	26,460		
0-200 mrem	25,175	29,925		
Cask Handling	16,250	19,250		
Total	\$80,365	\$95,235		
Shipping Cost/yr			\$ 7,100	\$ 8,400
Total			\$175,883	\$214,164
Average Annual Cost				\$195,025

(a) Cement = \$0.03/lb
Sodium silicate = \$0.035/lb

Calculations to Approximate Percent of Total Radwaste
Decontamination Costs Due to Steam Generator Leakages

$$1) \quad 8400 \text{ ft}^3 = \text{unsolidified waste/yr} = \frac{8400}{x} = \frac{2.5}{3.5}x$$

$$= 11,760 \text{ ft}^3 \text{ of Solidified Waste per year}$$

- 2) x_1 = cubic feet of 0.00-0.2 rem/hour material (cost \$4.75/ft³)
 x_2 = cubic feet of 0.201-1.0 rem/hour material (cost \$5.20/ft³)
 x_3 = cubic feet of 1-5 rem/hour material (cost \$7.10/ft³)

$$x_1 + x_2 + x_3 = 11,760 \text{ ft}^3$$

$$(x_1)(\$4.75) = \$25,175 \quad x_1 = 5,300 \text{ ft}^3$$

$$(x_2)(\$5.20) = \$22,140 \quad x_2 = 4,260 \text{ ft}^3$$

$$(x_3)(\$7.20) = \$16,800 \quad x_3 = 2,330 \text{ ft}^3$$

11,800 ~ 11,760 ft³ as expected

(a) Interoffice memorandum from Washington Public Power Supply System (by Steen), April 5, 1979.

TABLE D.1. (contd)

- 3) Assuming that the (X_1) component comes from the steam generator, the figure of 5300 ft³ should be conservative. In other words, this is a maximum waste/yr/reactor to be expected.
- 4) Generate annual operating costs (AOC) based upon this figure (i.e., ratio of volumes for associated costs):

$$\frac{5,300}{11,800} = 0.45$$

Cases

- A) Radwaste at 0-0.005 rem/hour, buried onsite--minimum.
- B) Radwaste at 0-0.200 rem/hour, buried <50 miles away.
- C) Radwaste at 0-0.200 rem/hour, buried 200-500 miles away.
- D) Radwaste at 0-0.200 rem/hour, buried ~1000 miles away.
- E) Radwaste at 0.2-1 rem/hour, buried <50 miles away.
- F) Radwaste at 0.2-1 rem/hour, buried ~500 miles away.
- G) Radwaste at 0.2-1 rem/hour, buried ~1000 miles away.
- H) Radwaste at 1-5 rem/hour, buried <50 miles away.
- I) Radwaste at 1-5 rem/hour, buried 500 miles away.
- J) Radwaste at 1-5 rem/hour, buried 1000 miles away.
- K) Disposal to municipal landfill.

All calculations assume 45% of given total volume = (11,800 ft³/yr or 14,000 ft³/yr).

TABLE D.2. Calculations for Annual Operating Costs (AOC)

CASE A

	Efficiency	2.5:1	1.5:1
a) Number of Liners		53	63
b) Chemical Cost, \$/yr		5,030	8,790
c) Cost of Liners, \$/yr		34,500	41,000
d) Burial Cost, \$/yr		0	0
e) Shipping Cost, \$/yr		0	0
Total Cost, \$/yr		39,530	49,790
Average AOC		\$40,660	

- (a) $X = (0.45)y$
 $X_1 = (0.45)(118) = 53$
 $X_2 = (0.45)(140) = 63$
 (b) 0.45 of reference studies
 (c) 0.45 of reference
 (d) Onsite burial, assume no cost

CASE B

	Efficiency	2.5:1	1.5:1
a) Number of Liners		53	63
b) Chemical Cost, \$/yr		5,030	8,790
c) Cost of Liners, \$/yr		34,500	41,000
d) Burial Cost, \$/yr		32,500	38,600
e) Shipping Cost, \$/yr		2,660	3,150
Total Cost, \$/yr		74,690	91,540
Average AOC		\$83,115	

- (a-c) Same as Case A
 (d) Fraction (0.45) of original; for example,
 $2.5:1 = 25,175 + (0.45)(16,250) = 32,500$
 (e) Shipping Costs: 37.5% due to X_1
 39.0% due to X_2
 33.0% due to X_3

Only have type one for Case B.

TABLE D.2. (contd)

CASE C

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	32,500	38,600
e) Shipping Cost, \$/yr	3,135	3,425
Total Cost, \$/yr	74,965	91,815
Average AOC		\$83,390

(a-d) Same as for Case B

(e) Add cost of 95¢/mile at 500 miles

CASE D

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	32,500	38,600
e) Shipping Cost, \$/yr	3,610	4,100
Total Cost, \$/yr	75,640	92,490
Average AOC		\$84,065

(a-d) Same as for Case B

(e) Add cost of 95¢/mile at 1000 miles

CASE E

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	36,500	43,350
e) Shipping Cost, \$/yr	2,660	3,150
Total Cost, \$/yr	79,165	96,565
Average AOC		\$86,990

(a-c) Same as for Case B

(d) $(5,300 \text{ ft}^3)(\$5.20/\text{ft}^3) + (0.55)(16,250) = \$36,500$
 $(6,300 \text{ ft}^3)(\$5.20/\text{ft}^3) + (0.55)(19,250) = \$43,350$

TABLE 0.2. (contd)

CASE F

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	36,500	43,350
e) Shipping Cost, \$/yr	3,135	3,425
Total Cost, \$/yr	79,165	96,565
Average AOC		\$87,865

- (a-d) Same as for Case E
 (e) Add cost of 95¢/mile at 500 miles

CASE G

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	36,500	43,350
e) Shipping Cost, \$/yr	3,610	4,100
Total Cost, \$/yr	79,640	97,240
Average AOC		\$88,440

- (a-d) Same as for Case E
 (e) Add cost of 95¢/mile at 1000 miles

CASE H

Efficiency	2.5:1	1.5:1
a) Number of Liners	53	63
b) Chemical Cost, \$/yr	5,030	8,790
c) Cost of Liners, \$/yr	34,500	41,000
d) Burial Cost, \$/yr	48,190	57,240
e) Shipping Cost, \$/yr	2,660	3,150
Total \$/yr	90,380	110,180
Average \$/yr		\$100,280

- (a-c) Same as for Case B
 (d) $(5,300 \text{ ft}^3)(\$7.10/\text{ft}^3) + (0.65)(16,250) = \$48,190$
 $(6,300 \text{ ft}^3)(\$7.10/\text{ft}^3) + (0.65)(19,250) = \$57,240$

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16. ABSTRACT (200 words or less) <p>This report discusses a number of aspects of cost-benefit (C/B) analysis for inservice inspection (ISI) of PWR steam generators (SG) and identifies several problem areas which must be addressed prior to a full C/B analysis capability. Following a brief review of the impact of SG problems on the productivity of PWR units and of the scope and variability of SG problems among USA PWRs, various occupational implications of SG ISI are considered, namely: manpower, time and rad exposure. The opportunities provided by refueling outages in respect of ISI inspection frequency and work-time-windows are reviewed. Indices for characterizing the NDT information, rad exposure, \$ impact, manpower and time attributes of single ISIs, and a series of ISIs over an arbitrary evaluation period, are presented and calculated for a number of ISI cases using SG parameters for three typical PWR units. A comparison of the \$ impact of unscheduled outages attributable to SG problems with the \$ cost of ambitious ISI strategies indicated that the \$ cost is a virtually negligible consideration for well planned ISIs. Considering the ALARA constraint on occupational rad exposure, the skilled manpower pool for NDT work appears to be the principal factor limiting ISI scope and frequency. Analysis of the manpower and time requirements for inspection of a 40-unit PWR population indicates, however, that an ISI strategy embodying 2 campaigns per year, and a total population inspection within a 2-year interval, is not far beyond current capability.</p>					
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