Attachment 2

RISK CONSIDERATIONS ASSOCIATED WITH GSI-191, "ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE."

Arthur Buslik

1.0 **Introduction**

In this report, the risk associated with sequences involving sump screen clogging (in PWRs) will be addressed. Because there are many plant specific considerations which enter, and because there were insufficient resources to treat each plant individually, these estimates will necessarily be rather crude. Estimates of the core damage frequency contribution, of the associated offsite risk, and of the associated onsite expected costs, from the accidents associated with sump screen clogging, will be given. (The onsite costs considered here are the costs that would be averted if the sump screen clogging problem were fixed.) The core damage frequency estimates will all depend on the probability of sump screen clogging. This will be initially treated as a parameter. Our LANL contractors have classified the likelihood of sump screen clogging as "very likely", "likely", "possible", or "unlikely". Mike Marshall (private communication) has indicated that "very likely" corresponds to a probability of unity, "likely" corresponds to a probability of 60%, "possible" corresponds to a probability of 30%, and "unlikely" corresponds to a negligible probability. These probabilities are best interpreted in the Bayesian sense. They represent subjective probabilities, not an estimate of the frequency of sump blockage in a large number of trials.

Of course, sump screen clogging is only relevant for LOCAs where it is necessary to go to sump recirculation. Some LOCAs can be handled by cooldown and depressurization of the primary without the necessity of going to sump recirculation. First the various size LOCAs used in this study will be given, together with their frequencies. Then the accident sequence delineation will be given, together with the quantification of the sequence core damage frequencies. Next, the offsite risk and expected onsite costs associated with the core damage events caused by sump screen clogging will be considered, on a per plant basis, using a range of possible values for the probability of sump screen clogging. Finally, estimates of aggregate benefits (expected averted costs) will be presented for sets of plants which may implement the fix.

LANL has supplied us with a draft report (D.V. Rao et al., "GSI-191: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance", July 2001, Rev. 0) in which for 69 "parametric cases" the subjective likelihood of sump screen clogging is given. This LANL report will be referred to as "the LANL GSI-191 parametric study." Each case corresponds to a PWR plant. The word "case" was used because the case corresponding to a plant approximated individual plant features and therefore each individual case did not represent a complete perspective of sump screen clogging at its corresponding plant. However, for the purposes of estimating aggregate benefits it is considered adequate to equate the "cases" with plants.

2.0 **LOCA Types and Their Frequencies**

The various LOCA types used in this study will correspond to those given in NUREG/CR-5750, ("Rates of Initiating Events at U.S. Nuclear Power Plants: 1987-1995", February 1999). Then the frequencies of various LOCA types can be taken directly from this document. The LOCA types, and their frequencies are:

Large LOCA (> 6 inches)	7E-6/yr
Medium LOCA (2 to 6 inches)	4E-5/yr
Small LOCA (0.5 to 2 inches)	5E-4/yr
Very Small LOCA	6.2E-3/yr
Stuck-Open Safety Relief Valve	5E-3/yr
Reactor Coolant Pump Seal LOCA	2.5E-3/yr

Except for the Large LOCA, the frequencies are taken from Table 3-1 of NUREG/CR-5750. The Large LOCA frequency was updated (private communication from Sunil Weekakkody) to take into account the V.C. Summer event of 10/12/2000, LER 39500008. The numbers in parentheses after the LOCA types refer to the inside pipe diameter, and are taken from Table J-1 of NUREG/CR-5750.

<u>Seismically-induced LOCAs</u>

One should also consider LOCAs caused by external events. The Surry seismic analysis done for the NUREG-1150 studies was used to determine the fragility curves for the various size LOCAs. The conditional probabilities of core damage for a given peak ground acceleration, from Table 4.19 of NUREG/CR-4550, Vol. 3, Rev. 1, Part 3, were fitted to lognormal distributions. The lognormal parameters were:

Small LOCA:	a_{median}=1.33, β=0.81
Medium LOCA:	a_{median}=1.88, β=0.70
Large LOCA:	a_{median}=1.14, β=0.61

The revised LLNL hazard functions (see NUREG-1488) for the Surry site were approximated by the expression (see R.P. Kennedy, Nucl. Eng. Design **192**, 117 (1999))

$$H(a)=K_1 a^{-K_H},$$

with K_1 = 1.29E-6 and K_H = 2.23; these values were obtained by a least squares fit to log(H(a)). Here H(*a*) is the exceedance frequency for the peak ground acceleration *a.*

With the lognormal fragility curves, and the approximation to the hazard function given above, the integration of the fragility over the hazard function can be done analytically. The results are:

Seismically-induced large LOCA	2E-6/yr
Seismically-induced medium LOCA	1E-6/yr
Seismically-induced small LOCA	3E-6/yr

Comparing these frequencies to the internal events LOCA frequencies (7E-6/yr for large LOCA, 4E-5/yr for medium LOCA, and 5E-4/yr for small LOCAs), one sees that the seismic contributions can be neglected, except possibly for large LOCAs. However, for seismic events, at the higher peak ground accelerations, there is an appreciable probability of core damage even without sump screen clogging, so the absence of sump screen clogging may not affect the core damage frequency appreciably. Also, the fragility curves used are considered to be typical for all PWRs; they were generated originally for the SSMRP Zion analysis (see p. 4-71 of NUREG/CR-4550, Vol. 3, Rev. 1, Part 3). Newer plants may have higher seismic capacities, with respect to LOCAs. The seismic hazard curves were unique for Surry. Nevertheless, it was assumed that the seismic contributions to the LOCA frequencies can be neglected, for the purposes of this study.

3.0 **Accident Sequence Delineation and Quantification**

The core damage sequence which is of interest is the following:

LOCA(n)*RECIRC*SUMP-CLOGS*NON-RECOVERY

Here the n indexes the various size LOCAs.

LOCA(1)= Large LOCA=A

LOCA(2)=Medium LOCA=S1

LOCA(3)=Small LOCA=S2

LOCA(4)=RCP Seal LOCA

RECIRC= Event that ECCS recirculation is required

SUMP-CLOGS= Event that the sump screen clogs to the point that ECCS recirculation fails

NON-RECOVERY= Event that recovery actions fails

For other LOCAs (very small LOCAs, stuck-open pressurizer safety valves), the discussion below will show that the contribution of sump screen clogging to the core damage frequency is negligible.

<u>Very-small LOCA</u>

For very small LOCAs, the likelihood of having to go to recirculation is very small. Very small LOCAs are defined on p. 45 of NUREG/CR-5750 as pipe breaks or component failure resulting in a reactor coolant system leak rate between 10 to 100 gpm. These leaks would be controllable by the charging system. There does appear to be a gap in the range of LOCA sizes: a 3/8" diameter pipe may, at system pressure, exceed 100 gpm leak, and yet is too small to be considered a small LOCA. However, the frequency of all LOCAs controllable by the charging system is dominated by LOCAs less than 100 gpm. These are the only very small LOCAs that have occurred.

Stuck-open pressurizer safety valve

For stuck-open pressurizer safety valves, the likelihood of having to go to recirculation may not be small, in some plants. However, such LOCAs are considered to be relatively benign from a sump-screen clogging point of view. The discharge from the safety valves is routed to a quench tank, and is released at relatively low pressure from the quench tank rupture valve. Therefore, the opportunity for the stuck-open pressurizer safety valve to generate much debris is minimal. If this were not the case, the stuck-open pressurizer safety valves would have to be treated together with the small break LOCAs.

Large and medium LOCAs

For large LOCAs and medium LOCAs, the chance of not having to go to sump recirculation is very low. Westinghouse emergency response guidelines for post-LOCA cooldown and depressurization (guideline ES-1.2) indicate that this procedure should only be entered for those cases where (within the first twenty-five minutes or so) the low pressure injection (LPI) pumps do not inject because the reactor coolant system pressure exceeds the LPI shutoff head (or in the low probability case that the LPI system is failed). Even if, for some plants, some medium LOCAs as we have defined them (2 to 6 inch breaks) could be handled with the high pressure pumps alone, there would be questions of whether there is sufficient water in the refueling water storage tank to control the LOCA without having to go to sump recirculation. Westinghouse emergency contingency action guidelines (in particular, ECA-1.1) address actions which can be taken in case sump recirculation fails. However, given the timing for large and medium LOCAs, it is unlikely that much credit can be given for these procedures for large and medium LOCAs. It may be that although there is insufficient net positive suction head (NPSH) for the ECCS pumps drawing suction from the sump when both low pressure ECCS pumps are operating, there is sufficient NPSH for the operation of one pump. This is assumed to be incorporated into the probability of sump clogging, since the overall estimate of sump clogging takes into account both favorable cases where one pump is operating and unfavorable cases where both pumps are operating. Accordingly, for large and medium LOCAs the contribution to the core damage frequency is simply the product of the initiating event frequency and the probability of sump screen clogging, given the initiating event. Thus:

	Contribution to CDF From Sump-Clogging
Large LOCA	(7E-6/yr)*P(sump-clogs|large LOCA)
Medium LOCA	(4E-5/yr)*P(sump-clogs|medium LOCA)

RCP seal LOCAs

- Non-Ice-Condenser Plants

Let us now consider RCP seal LOCAs. These correspond to LOCAs in the small break range (perhaps 400 gpm). They are however towards the small end of the range, and it seems very likely that the operator can cool down and depressurize the plant before needing to go to recirculation. Ice condenser plants may be an exception here. For plants other than ice condensers, even if the containment spray comes on initially, it can be shut off later. Assuming an operator error of 5% (partly diagnosis error and partly action error, somewhat similar to the operator error in the Sequoyah NUREG-1150 study (ref: p. D-70 of NUREG/CR-4550, vol. 5, Rev. 1, Part 2), and a probability of failing to recover from loss of sump recirculation of 0.1(estimate from the Comanche Peak IPE, on p. 3-198), one obtains:

	PROBABILITY/ FREQUENCY
I.E. freq, RCP seal LOCA:	2.5E-3/yr
RECIRC	.05
NON-RECOVERY	0.1
SUMP-CLOGS	P(SUMP-CLOGS|RCP seal LOCA)

Thus, for non-ice-condenser plants, one estimates about 1.25E-5/yr*P(sump-clogs) for the contribution of RCP seal LOCA sequences involving sump screen clogging to the core damage frequency.

- Ice-Condenser Plants

For ice condenser plants, the NUREG-1150 study for Sequoyah estimates (see p. D-70, NUREG/CR-4550, vol. 5, rev. 1, part 2) that 40% of RCP seal LOCAs were so large as to result in spray actuation. For such cases, the NUREG-1150 study assumed that it would be necessary to go to recirculation. This may not be the case, with cooldown and depressurization of the primary system. Nevertheless, in the absence of calculations showing the contrary, we will assume this is the case. For the other 60% of the RCP seal LOCAs, we can assume a 5% chance of failing to cooldown and depressurize before it is necessary to go to sump recirculation, as we did above for non-ice-condenser plants. This means that the fraction of RCP seal LOCAs where it is necessary to go to recirculation is 0.40+0.60*(0.05), or 0.43. The Sequoyah IPE estimated that the probability of non-recovery from small break LOCA sequences with failure of sump recirculation was 0.3 (Event HAMU3, given in Table 3.3.3.-4 on p. 3.3.3-29 of the IPE). Then the contribution to the core damage frequency in an ice condenser plant, from RCP seal LOCA sequences involving sump screen clogging is:

	Probability/ Frequency
RCP seal LOCA	2.5E-3/yr
RECIRC	0.43
NON-RECOVERY	0.3
SUMP-CLOGS	P(SUMP-CLOGS|RCP seal LOCA)

One obtains for the contribution to the core damage frequency, for the ice condenser plants, an estimate of 3.2E-4*P(sump-clogs), from the RCP seal LOCA sequences involving the clogging of the sump.

Small-Break LOCA

There are several plant specific considerations here, which affect the likelihood that the plant can be depressurized and cooled down without having to go to recirculation. These include:

-- The size of the RWST
-- The containment pressure at which the containment sprays are actuated
-- Whether or not there are emergency fan coolers

• Plants with Large Dry Containments, Emergency Fan Coolers, and Large RWSTs

At one extreme, there are plants like Callaway and Comanche Peak which have large RWST tanks (420,000 gallons or larger) and emergency fan coolers. These plants can with high probability cooldown and depressurize to RHR conditions for all small break LOCAs. In fact, the background information for Westinghouse emergency response guideline ES-1.2 states that such LOCAs can be handled without going to sump recirculation, for the reference plant, which appears similar to Callaway and Comanche Peak. A probability of failing to go to recirculation of 0.1 seems to be a reasonable estimate; some small fraction of small break LOCAs cannot be mitigated without going to sump recirculation, since the break location is below the midplane of the hot legs, and it would not be possible to use the residual heat removal pumps, drawing suction from the hot legs, as is done in a normal hot shutdown. The human error probability for failing to cooldown and depressurize may also be somewhat larger, for the larger small breaks, than it is for a RCP seal LOCA. A non-recovery probability (following, for example, for Westinghouse plants, the plant specific procedures corresponding to ECA-1.1) of 0.1 is chosen (from the Comanche Peak IPE, p. 3-198). For such plants:

	Probability/ Frequency
Small-Break LOCA	5E-4/yr
RECIRC	0.1
NON-RECOVERY	0.1
SUMP-CLOGS	P(sump-clogs|small LOCA)

One obtains, for these plants, 5E-6/yr*P(sump-clogs) as the contribution to the core damage frequency from small break LOCAs involving clogging of the recirculation sump.

• Ice-Condenser Plants

At the other extreme, one can consider ice-condenser plants. For such plants, the containment spray will actuate on nearly every small break LOCA. The NUREG-1150 study for Sequoyah, and the IPE for Sequoyah, conclude that it will be necessary to go to sump recirculation on small break LOCAs. The IPE for Sequoyah assumes that recovery procedures will have a 30% chance of failure. Accordingly, considering Sequoyah as typical of ice-condenser plants, we have:

	Probability/ Frequency
Small-Break LOCA	5E-4/yr
RECIRC	1.0
NON-RECOVERY	0.3
SUMP-CLOGS	P(sump-clogs|small LOCA)

One obtains, for the ice-condenser plants, 1.5E-4/yr*P(sump-clogs|small LOCA), as the contribution to the core damage frequency from small break LOCAs involving clogging of the recirculation sump.

- Sub-Atmospheric Containments

The analysis performed was for Surry, which was assumed typical of these plants. Surry has containment fan coolers which are normally operated and not isolated until a containment hi-hi pressure is reached. No calculations were performed as to what size small break LOCAs can be mitigated by cooling down and depressurizing and using the RHR before needing to go to sump recirculation. The RHR pumps are inside containment, are not safety-grade, and are not environmentally qualified. Nevertheless, it was judged that for small break LOCAs of one inch in diameter or less the RHR system will very likely operate. It was judged that about 30% of small break LOCAs could be mitigated without going to sump recirculation, and that of the small break LOCAs where it was necessary to go to sump recirculation, the probability of non-recovery was 0.3. A relatively high probability of non-recovery was chosen because, for the larger small break LOCAs where it was necessary to go to sump recirculation, it was not clear what the reliability of the RHR system would be, and recovery without the RHR system appeared more difficult.

Accordingly, for sub-atmospheric containments one obtains:

	Probability/ Frequency
Small-Break LOCA	5E-4/yr
RECIRC	0.7
NON-RECOVERY	0.3
SUMP-CLOGS	P(sump-clogs|small LOCA)

Thus, for sub-atmospheric containments, 1E-4/yr*P(sump-clogs|small LOCA) is the contribution to the core damage frequency from small break LOCAs involving clogging of the recirculation sump.

4.0 Benefits from Averting Accidents Associated with Sump Screen Clogging (per plant basis)

This section will consider the monetized benefits associated with eliminating completely the accidents associated with sump screen clogging. These benefits will be considered here on a per plant basis, and the probability of sump screen clogging for the various size LOCAs will be treated parametrically. The benefits to be considered are:

-- expected averted population dose to 50 miles, monetized at $2000/p-rem (Year 2001 dollars)

-- expected averted offsite financial costs

-- expected averted onsite financial costs (cleanup and decontamination; replacement power)

-- expected averted onsite occupational dose

The benefits of course depend on the years of remaining life of the plant, for which the fix to the sump has been made. The assumption was made that the fix would be in place in three years. The average remaining years for a PWR, without license renewal, would be 14 years in 2004. The years of remaining life was taken as a free parameter, ranging from 14 years to 34 years.

For the population dose, the data given for Zion in Table 5.3 of NUREG/BR-0184 (Regulatory Analysis Technical Evaluation Handbook, January 1997) was used. The data for Zion in this table does not use the actual population density around the Zion site, but rather that for a site which had an 80th percentile population density. The particular values taken from Table 5.3 of NUREG/BR-0184 for Zion were for a LOCA. The calculations done for Table 5.3 of NUREG/BR-0184 were based on NUREG-1150 models. The dominant LOCA in the NUREG-1150 calculation for Zion was that which arose from a loss of component cooling water with consequential reactor coolant pump seal LOCA and loss of high pressure injection. In such a sequence, the reactor cavity is not filled at the time of vessel breach, and the radioactive source term may be larger (because of less scrubbing of the radioactive releases by the reactor cavity water) than if the failure occurred during recirculation, with more water in the reactor cavity. This is a conservative approximation, for our case. We assumed that the probability of early containment failure was 0.02. This value was obtained by estimating the probability of early containment failure as 0.05 for a sequence where vessel breach occurs with the reactor vessel internal pressure high (> 200 psi), and as 0.01 for a sequence where the reactor vessel pressure at vessel breach was low (< 200 psi). A 20% chance of vessel breach at high pressure was assumed. This corresponds to the NUREG-1150 estimate for a small break LOCA. Since there are substantial contributions of large and medium LOCAs to the core damage frequency associated with sump screen clogging, this is again a conservative approximation.

The discount rate used to convert costs in the future to present value was 7%.

For averted offsite financial consequences the Sequoyah NUREG-1150 study was used, with modifications to correct errors in the calculation of offsite financial consequences which were found by Mubayi (see NUREG/CR-4695). The CRIC-ET code (see: Letter report for FIN L1672, "NUREG-1150 Data Base Assessment Program: A Description of the Computational Risk Integration and Conditional Evaluation Tool (CRIC-ET) Software and the NUREG-1150 Data Base, prepared by T.D. Brown, J.D. Johnson, S.L. Humphreys, and J.J. Gregory, Sandia National Laboratories, March 1995) was used, with the offsite financial consequences data modified to correct for the errors in the NUREG-1150 calculation. One reason Sequoyah was used was that it was less time consuming to make the changes to the consequence data for Sequoyah than it would have been for Zion. Also, the Zion site may be atypical, if only one calculation is being performed. Again a 2% chance of early containment failure was assumed, which is conservative because of the contribution of large and medium LOCAs where the probability of early containment failure is less. The sequences chosen were LOCA sequences with failure of containment sprays, which matches our case.

For onsite financial costs, cleanup and decontamination is given on p. 5.42 of NUREG/BR-0184 as $1.5E9 per accident, in 1993 dollars. From http://www.jsc.nasa.gov/bu2/inflateGDP.html the conversion factor to year 2001 dollars is 1.15. The costs were assumed to be spread over 10 years after the accident, and were discounted accordingly, using a 7% discount rate. For replacement power costs, formulae for a generic reactor are given on p. 5.44 of NUREG/BR-0184. These formulae are empirical, and the error in their use has not been determined. The generic reactor is a 910 MWe reactor.

The averted onsite occupational dose was calculated following the guidelines in NUREG/BR-0184. The best estimate immediate dose (per accident) is 3300 person-rem, and the best estimate long-term dose (per accident) is 20000 person-rem. The long-term dose is spread over a 10 year period after the accident.

Tables 1 through 7 on the following pages give the expected averted monetized costs, for various combinations of probabilities of sump screen clogging, for the various size LOCAs, and for the different containment types considered (large dry, subatmospheric, and ice condenser). The probability of sump screen clogging for a RCP seal LOCA was assumed equal to the probability for a small LOCA.

The following observations can be made, from the tables.

- For a plant with a large dry containment, medium LOCAs are the most important for a plant which is "very likely" to have clogged screen sumps, for all size LOCAs. For a plant with a large dry containment, the results are not sensitive to the probability of sump screen clogging for a small LOCA, because of the high likelihood of being able to mitigate a small LOCA without going to sump recirculation, in a plant with a large dry containment. Large LOCAs contribute less because of a low initiating event frequency.

- For ice condenser plants, and plants with subatmospheric containments, small LOCAs can be important contributors to core damage sequences involving sump screen clogging, if the probability of sump screen clogging is sufficiently high.

- The expected averted onsite costs (replacement power and cleanup) dominate the benefits; however, expected offsite health costs are appreciable. It is to be remembered that for the purpose of calculating offsite consequences it was assumed that all LOCAs were small LOCAs, which is conservative, since the chances of early containment failure are greater for small LOCAs than for medium or large LOCAs.

- From Table 1, if a plant with a large dry containment is very likely (probability unity) to have sump screen clogging on all size LOCAs, then, if the plant has 24 years of remaining life with the fix in place, the total benefit (i.e., total expected averted costs) from completely fixing the sump is 1.8 million dollars. For an ice condenser, from Table 1, the total expected benefit for a reactor with 24 years of remaining life is about 14 million dollars, if sump screen clogging is very likely for all size LOCAs. The other results are to be interpreted similarly.

Tables 5,6, and 7 can be used to generate the results for other cases not given, since the expected monetized averted costs depend linearly on the probabilities of sump screen clogging for the various size LOCAs. If $C(p_1,p_2,p_3)$ denotes an expected averted cost, and p_1,p_2,p_3 represents the probabilities of sump screen clogging for small, medium, and large LOCAs respectively, then

$$C(p_1,p_2,p_3)=p_1*C(1,0,0)+p_2*C(0,1,0)+p_3*C(0,0,1)$$

The quantities C(0,0,1), C(0,1,0), and C(1,0,0) are given in Tables 5, 6, and 7, respectively. For example, the expected total averted costs (total expected benefit) for a plant with a subatmospheric containment with 34 years of remaining life (including license renewal) with the fix in place, and with a probability of sump screen clogging of 0.3 for a small LOCA, and unity for medium and large LOCAs, is given by

C(0.3,1,1)= (0.3)*(3.91E6)+(1)*(1.39E6)+(1)(2.43E5)=$2.80E6 (year 2001 dollars)

(Note that cases 6 and 7 given in Tables 6 and 7 do not appear to physically realizable, but are useful for determining the results for cases not given, since the expected averted costs depend linearly on the sump screen clogging probabilities.)

It is to be remembered that the large dry case refers to a Westinghouse reactor, like Callaway or Comanche Peak, which has a large dry containment, fan coolers which do not isolate (except possibly on a hi-hi containment pressure signal) and a large RWST of 420,000 gallons or more. It may therefore be a somewhat optimistic case for many reactors with large dry containments. Some plants with large dry containments may be intermediate between plants with large dry containments and plants with sub-atmospheric containments, if small break LOCAs are important.

5.0 Aggregate Benefits from Averting Accidents Associated with Sump Screen Clogging

Here, the aggregate benefits from fixing the sump screen clogging problem will be considered. Table 5-1 of the LANL GSI-191 parametric study gives for each "case ID" (surrogate plant) the likelihood of sump screen clogging for the various size LOCAs. Each ID is associated with either a plant with a large dry containment, a plant with a sub-atmospheric containment, or a plant with an ice condenser containment, as given in Table A-1 of the LANL report. Therefore, using the results given in Section 4 of the present report, it would be possible to determine the benefit from fixing the sump screen clogging problem for each surrogate plant represented by a case ID. The terms "very likely", "likely", "possible", and "unlikely" in this table are to identified with probabilities of sump screen clogging (to the point of ECCS recirculation failure) of 1, 0.6, 0.3, and 0, as noted in the introduction. (For RCP seal LOCAs, the likelihood of sump screen clogging is identified with the likelihood of sump screen clogging for small LOCAs, as was noted in Section 4 of this report.) One can therefore obtain the benefits from fixing the sump screen clogging problem of various sets of plants. The first set of plants to be considered will be the 23 plants which are "very likely" to have the sump screens clogged for all size LOCAs. The second set of plants to be considered are those which are "very likely" to have the sump screen clogged for medium and large LOCAs, irrespective of their likelihood of sump screen clogging for small LOCAs. There are 32 plants in this category, including the 23 plants in the first set. The third set of plants adds to the 32 plant set the plants which are "very likely" to have sump screen clogging for large LOCAs, and are "likely" to have sump screen clogging for medium LOCAs. This adds 8 plants to the 32 plant set, so that the third set contains 40 plants. The results are given in Table 8, where the three sets of plants considered above are labeled "23 plant set", "32 plant set", and "40 plant set". The column TotalCost in the tables represents total averted costs--in other words, total benefits. If one considers the t=14 years row as corresponding, in some average sense, to the case of no license renewal, then one sees that the total benefit for the 23 plant case is 32.7 million dollars. If one considers the case of all license renewal as corresponding in some average sense to the t=34 years row, then the total benefit for the 23 plant case is 68 million dollars. The other tables are to be interpreted similarly.

Table 8 also gives the average core damage frequency reduction (per plant) for each of the cases considered. There are 5 sub-atmospheric containment plants in the 23 plant case, and the average core damage frequency reduction for fixing these is 1.6E-4 per reactor-year. No additional sub-atmospheric containment plants are added for the 32 plant case or 40 plant case. There are 3 ice condenser plants in the 32 plant case, and the average core damage frequency reduction for fixing these is 3.3E-4 per reactor-year. No additional ice condenser plants are added for the 40 plant case. The average core damage frequency reduction for a large dry containment plant is about 6E-5 per reactor-year (6.4E-5 for the 23 plant case, 6.3E-5 for the 32 plant case, and 5.6E-5 for the 40 plant case).

One can obtain from the cost analysis portion of the analysis that the cost for fixing N plants is given by:

($6.12E5)*N+$9.221E6   (year 2001 dollars)

From this it can be seen that it is not cost effective to fix an additional plant if the benefit (from averted cost of accidents) is less than $612K. It appears unlikely, using our best estimate values, that it would be cost effective to fix any of the plants beyond the 40 plants considered in the "40 plant set". From the above equation, the cost for fixing 23 plants is 23.3 million dollars, the cost for fixing 32 plants is 28.8 million dollars, and the cost for fixing 40 plants is 33.7 million dollars. One can see that adding the 8 plants to the 32 plant case, to obtain the 40 plant case gives an added benefit per plant of about 6E5 dollars per plant for t=14 years, and just barely fails to meet a cost benefit case. However, if the plants operate longer than 14 years, in some average sense, then it is cost beneficial to add the 8 plants.

For the purposes of the cost-benefit analysis, it was assumed that 50% of the plants would seek license renewal, and that the benefits could here be adequately approximated by taking the average of the benefits for t=14 years, and t=34 years. Fourteen years is the average remaining lifetime for a PWR with the fix in place (in about 3 years from now). With a 20 year license renewal period, the average remaining lifetime would be 34 years. Then the total monetized benefits are given by:

	Benefit	
23 plant case	$50E6	(year 2001 dollars)
32 plant case	$85E6	
40 plant case	$92E6	

It may be of interest to see how the benefits are reduced if onsite costs are omitted. For the 23 plant case, the benefit is reduced from 50 million dollars to 10 million dollars; for the 32 plant case, the benefit is reduced from 85 million dollars to 17 million dollars, and for the 40 plant case the benefit is reduced from 92 million dollars to 19 million dollars.

6.0 Uncertainties

A qualitative discussion of the uncertainties will be presented here. The frequencies of the LOCAs are uncertain, because of sparse data. Without taking into account the Summer event of 10/12/2000, Table 3-1 of NUREG/CR-5750 gives as an 95th percentile upper bound of the PWR large LOCA frequency the value 1E-5 per year. NUREG/CR-5750 assumes a lognormal distribution for the uncertainty distribution, with an error factor of 10. Including the Summer event, the mean estimate of the frequency of a large LOCA is 7E-6/yr. For a lognormal distribution with an error factor of 10, the median estimate of the large LOCA frequency is (7E-6/yr)/2.664, and the 95th percentile upper bound is a factor of 10 greater than this, or about 3E-5 per year. The mean estimate of the medium LOCA frequency is 4E-5/yr, and the 95th percentile upper bound is 1E-4 per year. The lognormal uncertainty distribution with the error factor of 10 was not developed by a statistical process, but was based on engineering judgement. In addition, seismically-induced LOCAs were neglected based on the mean estimate of the frequency of seismically-induced LOCAs. The seismic LOCA contributions are dominated by the higher peak ground accelerations. One sees from NUREG-1488 that for Surry the mean frequency of exceedance of 1g is about 1.6E-6/yr, while the 85th percentile value is 2.1E-6/yr. Therefore, it is not likely that seismically-induced LOCAs will contribute significantly, since they do not contribute significantly when mean values are used.

The probability of sump screen clogging is also uncertain. The failure criteria used are uncertain, as is discussed in the LANL GSI-191 parametric report, in section 5.2. There are uncertainties arising from lack of plant specific information. Note that the probability of sump screen clogging does not represent a frequency of sump screen clogging in a large number of trials. It incorporates subjective uncertainty. This means that if one were interested in a "probability of frequency" description of uncertainty [as defined by Kaplan and Garrick, Risk Analysis **1**, p. 11 (1981)] one would first have to do this for the probability of sump screen clogging, obtaining a probability distribution for the frequency of sump screen clogging.

Human error probabilities enter into the assessment of recovery, given that it was necessary to go to sump recirculation and sump recirculation failed. The estimates used here came from two IPEs, which did not take into account the specific cause of loss of sump recirculation. Also, the assessment by LANL of the likelihood of loss of sump recirculation took into account the fact that the operator may shut off one pump if there is loss of net positive suction head, but it is unclear what likelihood was assigned to this operator action. The Westinghouse emergency response guidelines ECA-1.1 on loss of sump recirculation state that the operator should shut off any pump which has lost its suction source, so it is very likely that the operator would shut off an operating pump which has lost net positive suction head, at least if the plant specific procedures for the plant correspond to the Westinghouse guidelines.

The assumption was made that the likelihood of having to go to sump recirculation for a plant with a large dry containment was the same as the likelihood for a Westinghouse plant like Callaway or Comanche Peak, which have emergency fan coolers and large RWSTs. This may be optimistic for some plants with large dry containments.

The probability of having to go to sump recirculation in subatmospheric containments, given a small break LOCA, may have been overestimated. The frequency of small break LOCAs is not uniformly distributed across all break sizes; instead the smaller size piping is more likely to rupture. Section J-5.1.1 of NUREG/CR-5750 notes that ruptures that have occurred in primary system piping have all been in piping less than one inch in diameter. Thus the probability, given a small break LOCA in a subatmospheric containment, that one can reach RHR conditions, and that the RHR system will be operable may be greater than 30%. In other words, the probability of needing to go to sump recirculation may be less than 70% for a small break LOCA in a subatmospheric containment.

The probability of early containment failure given core damage was based on the assumption that the LOCA was a small break LOCA. This is a conservative bias, since medium and large LOCAs are treated the same as small LOCAs, for the purpose of assessing the chance of early containment failure. Nevertheless, the chance of early containment failure was small (see Section 4), and this may not be significant. Note also that the benefits are dominated by the averted onsite costs (replacement power and accident cleanup costs), and are insensitive to an overestimate of the probability of early containment failure.

Table 1. BENEFIT FROM FIXING SUMP SCREEN-- Case 1

Sump screen clogging probability for S2 LOCA= 1
Sump screen clogging probability for S1 LOCA= 1
Sump screen clogging probability for A LOCA= 1

Plant type is Large Dry
Core Damage Freq= 6.45E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.27E+05	3.25E+04	8.03E+05	1.65E+04	1.08E+06
19	2.67E+05	3.83E+04	1.11E+06	1.94E+04	1.44E+06
24	2.96E+05	4.24E+04	1.40E+06	2.15E+04	1.76E+06
29	3.16E+05	4.52E+04	1.64E+06	2.29E+04	2.03E+06
34	3.30E+05	4.72E+04	1.84E+06	2.40E+04	2.24E+06

Plant type is Sub-Atmospheric
Core Damage Freq= 1.59E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	5.62E+05	8.04E+04	1.99E+06	4.08E+04	2.67E+06
19	6.61E+05	9.47E+04	2.75E+06	4.80E+04	3.56E+06
24	7.32E+05	1.05E+05	3.46E+06	5.31E+04	4.35E+06
29	7.81E+05	1.12E+05	4.06E+06	5.67E+04	5.01E+06
34	8.16E+05	1.17E+05	4.55E+06	5.93E+04	5.54E+06

Plant type is Ice-Condenser
Core Damage Freq= 5.17E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.82E+06	2.61E+05	6.44E+06	1.32E+05	8.65E+06
19	2.14E+06	3.07E+05	8.92E+06	1.56E+05	1.15E+07
24	2.37E+06	3.40E+05	1.12E+07	1.72E+05	1.41E+07
29	2.53E+06	3.62E+05	1.32E+07	1.84E+05	1.62E+07
34	2.64E+06	3.79E+05	1.47E+07	1.92E+05	1.80E+07

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 2. BENEFIT FROM FIXING SUMP SCREEN-- Case 2

Sump screen clogging probability for S2 LOCA= .6
Sump screen clogging probability for S1 LOCA= 1
Sump screen clogging probability for A LOCA= 1

Plant type is Large Dry
Core Damage Freq= 5.75E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.02E+05	2.90E+04	7.16E+05	1.47E+04	9.62E+05
19	2.38E+05	3.41E+04	9.92E+05	1.73E+04	1.28E+06
24	2.64E+05	3.78E+04	1.25E+06	1.92E+04	1.57E+06
29	2.82E+05	4.03E+04	1.46E+06	2.05E+04	1.81E+06
34	2.94E+05	4.21E+04	1.64E+06	2.14E+04	2.00E+06

Plant type is Sub-Atmospheric
Core Damage Freq= 1.14E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	4.03E+05	5.77E+04	1.43E+06	2.93E+04	1.92E+06
19	4.75E+05	6.80E+04	1.97E+06	3.45E+04	2.55E+06
24	5.25E+05	7.52E+04	2.48E+06	3.82E+04	3.12E+06
29	5.61E+05	8.03E+04	2.92E+06	4.07E+04	3.60E+06
34	5.86E+05	8.39E+04	3.27E+06	4.26E+04	3.98E+06

Plant type is Ice-Condenser
Core Damage Freq= 3.29E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.16E+06	1.66E+05	4.10E+06	8.42E+04	5.50E+06
19	1.36E+06	1.95E+05	5.67E+06	9.91E+04	7.33E+06
24	1.51E+06	2.16E+05	7.14E+06	1.10E+05	8.97E+06
29	1.61E+06	2.31E+05	8.38E+06	1.17E+05	1.03E+07
34	1.68E+06	2.41E+05	9.38E+06	1.22E+05	1.14E+07

Key:

t=	Number of years of reactor operation with the fix in place
OffHealth =	Expected Averted Monetized Offsite Health Costs
OffProp =	Expected Averted Offsite Property Costs
OnProp =	Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose=	Expected Averted Onsite Occupational Dose Costs
TotalCost=	Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 3. BENEFIT FROM FIXING SUMP SCREEN-- Case 3

Sump screen clogging probability for S2 LOCA= .3
Sump screen clogging probability for S1 LOCA= .6
Sump screen clogging probability for A LOCA= 1

Plant type is Large Dry
Core Damage Freq= 3.62E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.28E+05	1.83E+04	4.51E+05	9.27E+03	6.07E+05
19	1.50E+05	2.15E+04	6.25E+05	1.09E+04	8.08E+05
24	1.66E+05	2.38E+04	7.86E+05	1.21E+04	9.88E+05
29	1.78E+05	2.54E+04	9.24E+05	1.29E+04	1.14E+06
34	1.85E+05	2.65E+04	1.03E+06	1.35E+04	1.26E+06

Plant type is Sub-Atmospheric
Core Damage Freq= 6.47E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.28E+05	3.26E+04	8.06E+05	1.66E+04	1.08E+06
19	2.68E+05	3.84E+04	1.12E+06	1.95E+04	1.44E+06
24	2.97E+05	4.25E+04	1.40E+06	2.16E+04	1.77E+06
29	3.17E+05	4.54E+04	1.65E+06	2.30E+04	2.04E+06
34	3.31E+05	4.74E+04	1.85E+06	2.41E+04	2.25E+06

Plant type is Ice-Condenser
Core Damage Freq= 1.72E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	6.06E+05	8.67E+04	2.14E+06	4.40E+04	2.88E+06
19	7.13E+05	1.02E+05	2.97E+06	5.18E+04	3.83E+06
24	7.89E+05	1.13E+05	3.73E+06	5.73E+04	4.69E+06
29	8.42E+05	1.21E+05	4.38E+06	6.12E+04	5.41E+06
34	8.80E+05	1.26E+05	4.90E+06	6.39E+04	5.97E+06

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 4. BENEFIT FROM FIXING SUMP SCREEN-- Case 4

Sump screen clogging probability for S2 LOCA= 0
Sump screen clogging probability for S1 LOCA= 1
Sump screen clogging probability for A LOCA= 1

Plant type is Large Dry
Core Damage Freq= 4.70E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.66E+05	2.37E+04	5.85E+05	1.20E+04	7.86E+05
19	1.95E+05	2.79E+04	8.11E+05	1.42E+04	1.05E+06
24	2.16E+05	3.09E+04	1.02E+06	1.57E+04	1.28E+06
29	2.30E+05	3.30E+04	1.20E+06	1.67E+04	1.48E+06
34	2.40E+05	3.44E+04	1.34E+06	1.75E+04	1.63E+06

Plant type is Sub-Atmospheric
Core Damage Freq= 4.70E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.66E+05	2.37E+04	5.85E+05	1.20E+04	7.86E+05
19	1.95E+05	2.79E+04	8.11E+05	1.42E+04	1.05E+06
24	2.16E+05	3.09E+04	1.02E+06	1.57E+04	1.28E+06
29	2.30E+05	3.30E+04	1.20E+06	1.67E+04	1.48E+06
34	2.40E+05	3.44E+04	1.34E+06	1.75E+04	1.63E+06

Plant type is Ice-Condenser
Core Damage Freq= 4.70E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.66E+05	2.37E+04	5.85E+05	1.20E+04	7.86E+05
19	1.95E+05	2.79E+04	8.11E+05	1.42E+04	1.05E+06
24	2.16E+05	3.09E+04	1.02E+06	1.57E+04	1.28E+06
29	2.30E+05	3.30E+04	1.20E+06	1.67E+04	1.48E+06
34	2.40E+05	3.44E+04	1.34E+06	1.75E+04	1.63E+06

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 5. BENEFIT FROM FIXING SUMP SCREEN-- Case 5

Sump screen clogging probability for S2 LOCA= 0
Sump screen clogging probability for S1 LOCA= 0
Sump screen clogging probability for A LOCA= 1

Plant type is Large Dry
Core Damage Freq= 7.00E-06 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.46E+04	3.53E+03	8.72E+04	1.79E+03	1.17E+05
19	2.90E+04	4.16E+03	1.21E+05	2.11E+03	1.56E+05
24	3.21E+04	4.60E+03	1.52E+05	2.33E+03	1.91E+05
29	3.43E+04	4.91E+03	1.78E+05	2.49E+03	2.20E+05
34	3.58E+04	5.13E+03	2.00E+05	2.60E+03	2.43E+05

Plant type is Sub-Atmospheric
Core Damage Freq= 7.00E-06 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.46E+04	3.53E+03	8.72E+04	1.79E+03	1.17E+05
19	2.90E+04	4.16E+03	1.21E+05	2.11E+03	1.56E+05
24	3.21E+04	4.60E+03	1.52E+05	2.33E+03	1.91E+05
29	3.43E+04	4.91E+03	1.78E+05	2.49E+03	2.20E+05
34	3.58E+04	5.13E+03	2.00E+05	2.60E+03	2.43E+05

Plant type is Ice-Condenser
Core Damage Freq= 7.00E-06 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	2.46E+04	3.53E+03	8.72E+04	1.79E+03	1.17E+05
19	2.90E+04	4.16E+03	1.21E+05	2.11E+03	1.56E+05
24	3.21E+04	4.60E+03	1.52E+05	2.33E+03	1.91E+05
29	3.43E+04	4.91E+03	1.78E+05	2.49E+03	2.20E+05
34	3.58E+04	5.13E+03	2.00E+05	2.60E+03	2.43E+05

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 6. BENEFIT FROM FIXING SUMP SCREEN-- Case 6

Sump screen clogging probability for S2 LOCA= 0
Sump screen clogging probability for S1 LOCA= 1
Sump screen clogging probability for A LOCA= 0

Plant type is Large Dry
Core Damage Freq= 4.00E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.41E+05	2.02E+04	4.98E+05	1.02E+04	6.69E+05
19	1.66E+05	2.37E+04	6.90E+05	1.20E+04	8.92E+05
24	1.83E+05	2.63E+04	8.68E+05	1.33E+04	1.09E+06
29	1.96E+05	2.80E+04	1.02E+06	1.42E+04	1.26E+06
34	2.05E+05	2.93E+04	1.14E+06	1.49E+04	1.39E+06

Plant type is Sub-Atmospheric
Core Damage Freq= 4.00E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.41E+05	2.02E+04	4.98E+05	1.02E+04	6.69E+05
19	1.66E+05	2.37E+04	6.90E+05	1.20E+04	8.92E+05
24	1.83E+05	2.63E+04	8.68E+05	1.33E+04	1.09E+06
29	1.96E+05	2.80E+04	1.02E+06	1.42E+04	1.26E+06
34	2.05E+05	2.93E+04	1.14E+06	1.49E+04	1.39E+06

Plant type is Ice-Condenser
Core Damage Freq= 4.00E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.41E+05	2.02E+04	4.98E+05	1.02E+04	6.69E+05
19	1.66E+05	2.37E+04	6.90E+05	1.20E+04	8.92E+05
24	1.83E+05	2.63E+04	8.68E+05	1.33E+04	1.09E+06
29	1.96E+05	2.80E+04	1.02E+06	1.42E+04	1.26E+06
34	2.05E+05	2.93E+04	1.14E+06	1.49E+04	1.39E+06

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 7. BENEFIT FROM FIXING SUMP SCREEN-- Case 7

Sump screen clogging probability for S2 LOCA= 1
Sump screen clogging probability for S1 LOCA= 0
Sump screen clogging probability for A LOCA= 0

Plant type is Large Dry
Core Damage Freq= 1.75E-05 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	6.16E+04	8.82E+03	2.18E+05	4.48E+03	2.93E+05
19	7.26E+04	1.04E+04	3.02E+05	5.27E+03	3.90E+05
24	8.03E+04	1.15E+04	3.80E+05	5.83E+03	4.77E+05
29	8.57E+04	1.23E+04	4.46E+05	6.23E+03	5.50E+05
34	8.95E+04	1.28E+04	4.99E+05	6.50E+03	6.08E+05

Plant type is Sub-Atmospheric
Core Damage Freq= 1.12E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	3.96E+05	5.67E+04	1.40E+06	2.88E+04	1.88E+06
19	4.66E+05	6.68E+04	1.94E+06	3.39E+04	2.51E+06
24	5.16E+05	7.39E+04	2.44E+06	3.75E+04	3.07E+06
29	5.51E+05	7.89E+04	2.87E+06	4.00E+04	3.54E+06
34	5.75E+05	8.24E+04	3.21E+06	4.18E+04	3.91E+06

Plant type is Ice-Condenser
Core Damage Freq= 4.70E-04 per year

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.66E+06	2.37E+05	5.85E+06	1.20E+05	7.86E+06
19	1.95E+06	2.79E+05	8.11E+06	1.42E+05	1.05E+07
24	2.16E+06	3.09E+05	1.02E+07	1.57E+05	1.28E+07
29	2.30E+06	3.30E+05	1.20E+07	1.67E+05	1.48E+07
34	2.40E+06	3.44E+05	1.34E+07	1.75E+05	1.63E+07

Key:

t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs

TotalCost= Expected Total Averted Costs

(All costs are in 2001 dollars.)

Table 8. AGGREGATE BENEFITS FROM FIXING THE SUMP SCREEN CLOGGING PROBLEM (see Section 5)

23 plant case:

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	6.90E+06	9.87E+05	2.44E+07	5.01E+05	3.27E+07
19	8.12E+06	1.16E+06	3.38E+07	5.90E+05	4.37E+07
24	8.98E+06	1.29E+06	4.25E+07	6.53E+05	5.34E+07
29	9.60E+06	1.37E+06	4.99E+07	6.97E+05	6.16E+07
34	1.00E+07	1.43E+06	5.58E+07	7.27E+05	6.80E+07

Average CDF reduction=8.5E-5 per reactor-year

32 plant case:

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.16E+07	1.66E+06	4.09E+07	8.41E+05	5.49E+07
19	1.36E+07	1.95E+06	5.67E+07	9.89E+05	7.32E+07
24	1.51E+07	2.16E+06	7.13E+07	1.10E+06	8.95E+07
29	1.61E+07	2.30E+06	8.36E+07	1.17E+06	1.03E+08
34	1.68E+07	2.41E+06	9.36E+07	1.22E+06	1.14E+08

Average CDF reduction=1E-4 per reactor-year

40 plant case:

t	OffHealth	OffProp	OnProp	OnDose	TotalCost
14	1.26E+07	1.80E+06	4.44E+07	9.14E+05	5.97E+07
19	1.48E+07	2.12E+06	6.16E+07	1.08E+06	7.96E+07
24	1.64E+07	2.34E+06	7.74E+07	1.19E+06	9.73E+07
29	1.75E+07	2.50E+06	9.09E+07	1.27E+06	1.12E+08
34	1.83E+07	2.62E+06	1.02E+08	1.33E+06	1.24E+08

Average CDF reduction=9E-5 per reactor-year

Key:
t= Number of years of reactor operation with the fix in place
OffHealth = Expected Averted Monetized Offsite Health Costs
OffProp = Expected Averted Offsite Property Costs
OnProp = Expected Averted Onsite Property Costs (cleanup and decontamination, replacement power)
OnDose= Expected Averted Onsite Occupational Dose Costs
TotalCost= Expected Total Averted Costs
(All costs are in 2001 dollars.)