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Assessment of Value-Impact Associated with the
Elimination of Postulated Pipe Ruptures from
the Design Basis for Nuclear Power Plants

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ABSTRACT

The U.S. Nuclear Regulatory Commission is proposing to amend the regulations that currently require that the design basis for nuclear power plants include the postulation of dynamic effects from loss of coolant accidents up to and including the double-ended rupture of the largest pipe in the reactor coolant system. Proposed modifications would allow analyses to serve as a sufficient basis for excluding dynamic effects, including but not necessarily limited to pipe whip and jet impingement, associated with specific pipe ruptures. Only dynamic effects would be impacted; current design requirements for containment sizing and discharge capacity of emergency core cooling systems would remain unchanged. This report presents a detailed analysis of value-impact associated with the proposed amendment for PWR reactor coolant loop piping and for BWR recirculation loop piping. The effect of extending application of the proposed rule change to other piping systems is also assessed in a less quantitative manner.

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	ii
LIST OF TABLES	v
ACKNOWLEDGMENTS	vi
EXECUTIVE SUMMARY	vii
1. INTRODUCTION	1
2. PROPOSED ACTION AND POTENTIAL ALTERNATIVES	2
3. AFFECTED DECISION FACTORS	6
4. VALUE-IMPACT ASSESSMENT SUMMARY	6
4.1 Pressurized Water Reactor Plants	6
4.2 Boiling Water Reactor Plants	6
5. UNQUANTIFIED RESIDUAL ASSESSMENT	6
6. DEVELOPMENT OF QUALIFICATION	9
6.1 Pressurized Water Reactor Plants	9
6.1.1 Public Health	10
6.1.2 Occupational Exposure - Accidental	17
6.1.3 Occupational Exposure - Routine	18
6.1.4 Offsite Property Damage	28
6.1.5 Onsite Property Damage	29
6.1.6 Industry Implementation Costs	31
6.1.7 Industry Operating Costs	38
6.1.8 NRC Development and Implementation Cost	46

TABLE OF CONTENTS - Cont.

	<u>Page</u>
6.1.9 NRC Operation Cost	47
6.2 Boiling Water Reactor Plants	47
6.2.1 Public Health	48
6.2.2 Occupational Exposure - Accidental	53
6.2.3 Occupational Exposure - Routine	53
6.2.4 Offsite Property Damage	60
6.2.5 Onsite Property Damage	61
6.2.6 Industry Implementation Costs	63
6.2.7 Industry Operating Costs	69
6.2.8 NRC Development and Implementation Costs	74
6.2.9 NRC Operation Cost	74
7. APPLICATION TO OTHER PIPING SYSTEMS	74
7.1 Operating Plants and Plants Under Construction	74
7.2 Future Plants	81
8. SUMMARY	85
REFERENCES	88
APPENDIX A	A-1
APPENDIX B	B-1

LIST OF TABLES

1. Summary of potential impact areas.
2. Value-impact summary, PWR reactor coolant loop piping
3. Value-impact summary, BWR recirculation loop piping.
4. Occupational exposure due to accidents (PWR).
5. Summary of reductions in routine occupational exposure (PWR) (man-rem/plant).
6. Summary of offsite property damage (PWR).
7. Summary of onsite property damage (PWR).
8. Summary of PWR implementation costs.
9. Summary of avoided industry operating costs (PWR).
10. Occupational exposure due to accidents (BWR).
11. Summary of reductions in routine occupational exposure (BWR).
12. Summary of offsite property damage (BWR).
13. Summary of onsite property damage (BWR).
14. Summary of BWR implementation costs.
15. Summary of avoided industry operating costs (BWR).
16. Summary of piping systems affected by GDC-4 modification.
17. Summary of piping systems affected by GDC-4 modification.
18. Summary of piping systems affected by GDC-4 modification.
19. Summary of labor and radiation exposure for removal of restraints and carriers.
20. Summary of piping systems affected by GDC-4 modification.
21. Potential cost savings for future plants.
22. Summary of value-impact assessment (PWR).
23. Summary of value-impact assessment (BWR).

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EXECUTIVE SUMMARY

The Code of Federal Regulations (Title 10, Part 50) requires that structures, systems, and components important to the safety of nuclear power plants in the United States be designed to withstand effects of natural phenomena and the effects of normal and accident conditions. General Design Criterion 4 (GDC-4), "Environmental and Missile Design Bases," requires that safety-related structures, systems, and components to withstand the effects of a large loss-of-coolant accident (LOCA). To account for these effects, the design basis of nuclear power plants has historically included the postulation of double-ended guillotine breaks (DEGB) in certain high-energy piping systems. This, in turn, has significantly increased the amount of analysis required to evaluate hydrodynamic loads and the resultant response of structures and mechanical components, and has led to the placement of massive pipe whip restraints and jet impingement barriers near piping as protection against the dynamic effects of postulated breaks. Nuclear power plant designers have generally contended that the likelihood of such pipe breaks is so low as to be considered incredible. Furthermore, many experts believe that pipe whip restraints and jet impingement barriers may actually decrease the reliability of piping systems by limiting access to pipe welds, therefore reducing the effectiveness of in-service inspection, and by potentially restricting the movement of piping during routine operation and thus increasing pipe stresses caused by restraint of thermal expansion.

Until recently, no basis acceptable to the NRC staff existed for excluding DEGB from the plant design basis. Over the past few years, however, extensive deterministic fracture mechanics research has supported the "leak before break" concept for nuclear power plant piping. The fundamental premise of leak-before-break is that the materials used in nuclear power plant piping (particularly piping connected to the reactor coolant pressure boundary) are sufficiently tough that even large through-wall cracks resulting in coolant leak rates well in excess of those detectable by present leak detection systems would remain stable and not result in a DEGB. The results of independent confirmatory analyses funded by the NRC, in which probabilistic techniques were used to estimate the probability of a DEGB in the reactor

coolant loop piping of pressurized water reactor (PWR) plants, indicated that the probability of DEGB is sufficiently low under all plant conditions, including earthquakes, to justify eliminating it entirely as a basis for plant design.

The availability of advanced methods of fracture mechanics analysis has provided substantial motivation for plant owners to seek partial exemptions to GDC-4. Plant owners could, for example, eliminate pipe whip restraints from piping systems for which the pipe break exclusion could be justified. The NRC Executive Legal Director has, however, expressed the view that extensive use of exemptions to authorize the elimination of pipe whip restraints is inappropriate. Therefore, the NRC has elected to undertake rulemaking at this time to modify the provisions of GDC-4.

The proposed rule change will modify the current requirements of GDC-4 to exclude dynamic effects associated with loss-of-coolant accidents from the design basis. Under the proposed rule change, the direct dynamic effects of pipe rupture are: missile generation; pipe whipping; pipe break reaction forces; influence of discharging fluids, including jet impingement forces, decompression waves within the ruptured pipe, and pressurization in vessel cavities, subcompartments, and compartments. This exclusion would be allowed for a piping system when analyses demonstrate that the likelihood of rupture is negligible under conditions consistent with the design basis for the piping. Based on analyses already performed, it is now possible to defend this exclusion for main reactor coolant loop piping in PWR plants. It is anticipated that the eventual scope of application will be expanded to include other piping systems as well, subject to acceptance criteria along the lines of those recommended by the NRC Piping Review Committee, Pipe Break Task Group, in NUREG-1061 (Vol. 3). In its evaluation, the Task Group recommended deterministic fracture mechanics analyses that would be required and other criteria that would have to be met before a piping system could be considered a leak-before-break candidate. The Task Group also recommended several instances in which leak-before-break should not be applied, such as when operating experience has indicated a particular susceptibility to failure from the effects of corrosion (e.g., intergranular stress corrosion cracking), water hammer, or low- and high-cycle (i.e., thermal, mechanical) fatigue.

The report presented here provides a regulatory analysis of value-impact associated with the proposed rule change. Both costs and benefits associated with the proposed rule change are included. Although the rule change itself will, in principle, be applicable to all piping systems, the detailed value-impact assessment has been limited to the main reactor coolant loop (RCL) piping in PWR plants and to recirculation piping in BWR plants. The potential ramifications of expanding application of the proposed rule change to other piping systems is, however, also addressed in a less quantitative manner. The results of this assessment are summarized below:

	Value (man-rem)	Impact (\$)
<u>PWR Reactor Coolant Loops</u>		
Best Estimate	3.4E+4	-186E+5
High Estimate	1.1E+5	-277E+5
Low Estimate	8.6E+3	-87E+6
<u>BWR Recirculation Loops</u>		
Best Estimate	8.6E+3	-30E+6
High Estimate	1.0E+4	-65E+6
Low Estimate	5.9E+3	-15E+6

In this table, "value" represents reduction in occupational radiation exposure. The nominal estimates of cost and radiation dose indicate that substantial reductions in both would result from implementation of the proposed action. In addition, the proposed action would increase public risk only negligibly (by less than 1 man-rem for all plants considered) in either case.

In addition to these results, the following general observations are noteworthy:

- A review of cost items typically in the domain of a nuclear power plant architect-engineer indicated for future plants that cost savings of \$100 million each could be achieved through selective exclusion of pipe breaks.
- Both the PWR and BWR assessments indicated that the greatest benefits result from those areas that are most schedule-intensive, particularly when costs of replacement power are considered. For PWR plants, the largest single contributor to overall impact was eliminating the need to install plant modifications to resist asymmetric blowdown loads. For BWR plants, it was eliminating recirculation loop pipe whip restraints in plants currently replacing or planning to replace existing pipe with pipe fabricated from IGSCC-resistant materials. Indirect sources would account for the largest cost reductions to be gained by excluding breaks from high-energy piping system other than primary loop piping. Of the \$90 million per plant in total avoided costs estimated in one study for future plants, approximately two-thirds could be attributed to improvements in construction schedule and to reductions in construction financing costs.
- The largest single contributors to avoided dose are those associated with major plant modifications. For ISI and plant maintenance, dose reductions are also substantial in those instances where, for example, restraints must be removed and replaced during the course of these activities. In those cases where restraint removal would not be required for ISI or maintenance, net benefit (i.e., dose reductions during maintenance activities compared to exposure incurred during removal) would be more marginal. This result implies that the net benefit would be greatest if it were left to the plant owner to select which restraints would or would not be removed from a particular piping system, given that the piping system qualified for the break exclusion.
- The overall impact was not affected significantly by the discount rates assumed in the analysis.

INTRODUCTION

The Code of Federal Regulations requires that structures, systems, and components important to the safety of nuclear power plants in the United States be designed to withstand effects of natural phenomena and the effects of normal and accident conditions.¹ Designing safety-related structures, systems, and components to withstand the effects of a large loss-of-coolant accident (LOCA) is one important load requirement. To account for these effects, the design basis of nuclear power plants has historically included the postulation of double-ended guillotine breaks (DEGB) in certain high-energy piping systems. This, in turn, has significantly increased the amount of analysis required to evaluate hydrodynamic loads and the resultant response of structures and mechanical components, and has led to the placement of massive pipe whip restraints and jet impingement barriers near piping as protection against the dynamic effects of postulated breaks. Nuclear power plant designers have generally contended that the likelihood of such pipe breaks is so low as to be considered incredible. Furthermore, many experts believe that pipe whip restraints and jet impingement barriers may actually decrease the reliability of piping systems by limiting access to pipe welds, therefore reducing the effectiveness of in-service inspection, and by potentially restricting the movement of piping during routine operation and thus increasing pipe stresses caused by restraint of thermal expansion.

Until recently, no basis acceptable to the NRC staff existed for excluding DEGB from the plant design basis. Over the past few years, however, extensive deterministic fracture mechanics research has supported the "leak before break" concept for nuclear power plant piping. The fundamental premise of leak-before-break is that the materials used in nuclear power plant piping (particularly piping connected to the reactor coolant pressure boundary) are sufficiently tough that even large through-wall cracks resulting in coolant leak rates well in excess of those detectable by present leak detection systems would remain stable and not result in a DEGB.

The Lawrence Livermore National Laboratory, in an independent confirmatory research effort for the NRC Office of Nuclear Regulatory Research, estimated the probability of a DEGB in the reactor coolant loop

piping of pressurized water reactor (PWR) plants. The results of these probabilistic analyses, documented in several NUREG reports, indicate that the probability of DEGB is sufficiently low under all plant conditions, including earthquakes, to justify eliminating it entirely as a basis for plant design.^{2,3,4} On the basis of these results, LLNL recommended that reactor coolant loop DEGB be eliminated as a basis for PWR plant design, with emphasis on the elimination of pipe whip restraints as well as the need to design reactor pressure vessel supports to withstand asymmetric blowdown loads. A similar investigation of recirculation, main steam, and feedwater piping in boiling water reactor (BWR) plants is currently in progress.

The NRC Piping Review Committee, Pipe Break Task Group, recommended in NUREG-1061 that the leak-before-break approach be applied in the NRC licensing process.⁵ In its evaluation, the Task Group recommended deterministic fracture mechanics analyses that would be required and other criteria that would have to be met before a piping system could be considered a leak-before-break candidate. The Task Group also recommend several instances in which leak-before-break should not be applied, such as when operating experience has indicated a particular susceptibility to failure from the effects of corrosion (e.g., intergranular stress corrosion cracking), water hammer, or low- and high-cycle (i.e., thermal, mechanical) fatigue.

2. PROPOSED ACTION AND POTENTIAL ALTERNATIVES

It is proposed to undertake rulemaking to modify the current requirements of 10CFR50, General Design Criterion 4, "Environmental and Missile Design Bases," to exclude dynamic effects associated with loss-of-coolant accidents from the plant design basis. Under the proposed rule change, the direct dynamic effects of pipe rupture are: missile generation; pipe whipping; pipe break reaction forces; influence of discharging fluids, including jet impingement forces, decompression waves within the ruptured pipe, and pressurization in vessel cavities, subcompartments, and compartments. Only dynamic effects would be impacted; current design requirements for containment sizing and discharge capacity of emergency core cooling systems would remain unchanged. This exclusion would be allowed for a piping system when analyses

demonstrate that the likelihood of rupture is negligible under conditions consistent with the design basis for the piping. Based on analyses already performed, it is now possible to defend this exclusion for main reactor coolant loop piping in PWR plants. It is anticipated that the scope of application will eventually be expanded to include other piping systems as well, subject to acceptance criteria along the lines of those recommended in NUREG-1061 by the Pipe Break Task Group.

The only alternatives to rulemaking would be the granting of partial exemptions to General Design Criterion 4 or reinterpretation of the text of the existing rule. Now that analytical methods are available for application and acceptance criteria for implementing the analytical methods are being developed by NRC and industry groups, there exists substantial motivation to seek exemptions. The NRC Executive Legal Director has, however, expressed the view that extensive use of exemptions to authorize the elimination of pipe whip restraints is inappropriate. Therefore, it appears most appropriate to undertake rulemaking at this time.

Eliminating the need to design against dynamic effects of pipe breaks will have significant potential impact on plant design. Table 1 presents a list of structures, systems and components affected by the rule change and the potential impact on each. Although this list is intended to be neither exhaustive nor necessarily applicable in all regards to all plants, it nevertheless illustrates the potential ramifications of this rulemaking action.

This report presents a regulatory analysis of value-impact associated with the proposed rule change following the guidelines of NUREG/CR-3568.⁶ Both costs and benefits associated with the proposed rule change are included. Although the rule change itself will, in principle, be applicable to all piping systems, the detailed value-impact assessment has been limited to the main reactor coolant loop (RCL) piping in PWR plants and to recirculation piping in BWR plants. This was done for the following reasons:

Table 1. Summary of Potential Impact Areas

Structures, Systems, Components Considered for Potential Impact	Potential Impact
Reactor Coolant Loop Pipe Whip Restraints	Delete from design (new plants); remove existing restraints (operating plants).
Jet Impingement Barriers	Elimination of jet impingement barriers. Reduced analysis of jet impingement loads.
RCL Tributary Piping, Control Element Drive Mechanisms, In-Core Instrumentation	Eliminate analysis of hydrodynamic loads and vibratory motion due to RCL pipe break.
Vessel Sub-Compartments	Eliminate analysis of mass and energy release due to RCL pipe break. No design changes.
Reactor Coolant System Piping	Eliminate analysis of hydrodynamic loads and vibratory motion due to RCL pipe break.
Reactor Internals and Fuel	Eliminate analysis of response to RCL pipe break loads.
Reactor Cavity, Reactor Vessel Supports	Eliminate analysis for asymmetric blowdown loads.
Neutron Streaming Shield ^a	Install permanent shield in plants not so equipped.
Refueling Pool Seal ^a	Install permanent seal in plants not so equipped. Reduce ORE and eliminate potential for seal damage due to handling.
RCL Component Supports	No change.
Emergency Core Cooling Systems	No change in performance requirements. Piping design may be affected as for "tributary piping" above.
Containment Design	No change.
Reactor Coolant Piping Leakage Detection Systems	No change. ^b

Notes:

- (a) In certain older plants, a permanent component of this type capable of withstanding postulated asymmetric blowdown loads cannot be installed.
- (b) Upgrading of leakage detection systems in certain plants may be necessary before exclusion of pipe breaks would be allowed.

- (1) analyses necessary to exclude dynamic effects from the design basis have been applied only for main PWR reactor coolant loop piping. Similar analyses may be applied in the near future for BWR recirculation piping. Main steam, feedwater and other piping systems in both PWR and BWR plants are expected to also be addressed eventually.
- (2) required input information for the assessment was available in greatest detail for reactor coolant loop piping and for recirculation piping.
- (3) the eventual scope of application will undoubtedly vary from plant to plant depending on several factors, one of which will be economics. It is anticipated for small-diameter piping systems that the gains to be derived from eliminating postulated pipe breaks may be negated or exceeded by the cost of analysis necessary to gain the exclusion.

Although not included in the detailed value-impact assessment, the effect of expanding the application of the proposed rule change to other piping systems is less quantitatively addressed in Section 7 of this report.

3. AFFECTED DECISION FACTORS

Major decision factors affected by the proposed rule change and addressed in this value-impact assessment are summarized as follows:

Decision Factors	Causes Quantified Change	Causes Unquantified Change	No Change
Public Health	X		
Occupational Exposure (Accidental)	X		
Occupational Exposure (Routine)	X		
Public Property	X		
Onsite Property	X		
Regulatory Efficiency		X	
Improvements in Knowledge		X	
Industry Implementation Cost	X		
Industry Operation Cost	X		
NRC Development Cost	X		
NRC Implementation Cost	X		
NRC Operation Cost	X		

4. VALUE-IMPACT ASSESSMENT SUMMARY

4.1 Pressurized Water Reactor Plants

See Table 2.

4.2 Boiling Water Reactor Plants

See Table 3.

5. UNQUANTIFIED RESIDUAL ASSESSMENT

The following decision factors were not quantified in the assessment of this action:

- Regulatory efficiency. The current use of plant-specific exemptions to the regulations entails a significant allocation of NRC resources for both technical and legal effort. It is anticipated that substantially

Table 2. Value-Impact Summary, PWR Reactor Coolant Loop Piping
(Total for 85 Plants)^a

Factors	Best Estimate	High Estimate	Low Estimate
<u>Values (man-rem)</u>			
Public Health	-2.8E-4	-1.8E+1	0
Occupational Exposure (Accidental)	-2.2E-3	-9.9	0
Occupational Exposure (Routine)	3.4E+4	1.1E+5	8.6E+3
Values Sub-Total	3.4E+4	1.1E+5	8.6E+3
<u>Impacts (\$)</u>			
Industry Implementation Cost ^b	-1.1E+8	-1.7E+8	-5.6E+7
Industry Operating Cost	-1.6E+7	-1.8E+7	-1.4E+6
NRC Develop. & Implementation Cost	2.0E+5	3.0E+5	1.0E+5
NRC Operating Cost	0	0	0
Power Replacement Cost ^c	-6.0E+7	-9.0E+7	-3.0E+7
Offsite Property ^d	4.9E+1	7.6E+5	0
Onsite Property ^d	3.2E+1	1.3E+5	0
Impact Sub-Total	-186E+6	-277E+6	-87E+6
(w/o replacement power)	(-126E+6)	(-187E+6)	(-57E+6)

Notes:

- (a) Primary reactor coolant loop piping only.
- (b) Does not include industry costs expended to date to prepare plant fracture mechanics analyses.
- (c) A-2 plants only.
- (d) 10% discount factor.

Table 3. Value-Impact Summary, BWR Recirculation Loop Piping
(Total for 38 Plants)^a

Factors	Best Estimate	High Estimate	Low Estimate
<u>Values (man-rem)</u>			
Public Health	-1.7E-1	-8.3E+2	0
Occupational Exposure (Accidental)	-9.6E-4	-4.3	0
Occupational Exposure (Routine)	8.6E+3	1.1E+4	5.9E+3
Values Sub-Total	8.6E+3	1.0E+4	5.9E+3
<u>Impacts (\$)</u>			
Industry Implementation Cost ^b	-1.8E+7	-2.8E+7	-9.5E+6
Industry Operating Cost	-4.3E+6	-7.4E+6	-2.6E+6
NRC Develop. & Implementation Cost	included in PWR summary		
NRC Operating Cost	0	0	0
Power Replacement Cost ^c	-8.1E+6	-3.0E+7	-2.4E+6
Offsite Property ^d	2.2E+1	3.4E+5	0
Onsite Property ^d	1.5E+1	6.1E+4	0
Impact Sub-Total	-30E+6	-65E+6	-15E+6
(w/o replacement power)	(-22E+6)	(-35E+6)	(-12E+6)

Notes:

- (a) Reactor recirculation loop piping only.
- (b) Does not include industry costs expended to date to prepare plant fracture mechanics analyses.
- (c) Plants currently replacing or planning to replace recirculation piping.
- (d) 10% discount factor.

less effort would be required under the proposed rule change, resulting in improved regulatory efficiency.

- Improvements in knowledge. Recent investigations using both deterministic and probabilistic analysis techniques have indicated that an acceptable technical basis exists for excluding double-ended guilloine breaks and equivalent longitudinal ruptures of the main primary loops of PWR reactors. Development of this technical basis has increased understanding of piping failure mechanisms and has fostered development of advanced fracture mechanics and other analysis techniques. Implementation of the proposed rule change would promote additional investigations to determine under what other conditions and for what other piping systems the exclusion of pipe breaks could be applied.

6. DEVELOPMENT OF QUALIFICATION

6.1 Pressurized Water Reactor Plants

This section presents the detailed development of value-impact for PWR primary reactor coolant piping. This assessment is based on the following general assumptions:

- (1) A total of 85 plants are considered. The vendor-by-vendor breakdown of operating plants and plants under construction is given in Appendix A.
- (2) The 85 plants have a total remaining lifetime of 2922 plant-years (py), assuming a design lifetime of 40 years.
- (3) The 85 plants overall have an average remaining lifetime of 34.4 years.
- (4) Cost data for the 16 plants addressed by Generic Issue A-2 has been extracted directly from the value-impact analysis attached to NRC Generic Letter 84-04,⁷ hereafter referred to as the "A-2 evaluation," except where noted otherwise.

6.1.1 Public Health

The changes in risk and core melt frequency associated with the proposed rule change were evaluated in a manner similar to that used in the value-impact analysis of Westinghouse A-2 Owners Group plants addressed in NRC Generic Letter 84-04.* In the present evaluation, the probability of reactor coolant loop DEGB was taken from the results of the LLNL probabilistic study discussed in Section 1. To estimate the probability of DEGB, LLNL considered two causes of pipe break: pipe fracture due to the growth of cracks at welded joints ("direct" DEGB), and pipe rupture indirectly caused by the seismically-induced failure of critical supports or equipment ("indirect" DEGB).

The probability of direct DEGB was estimated using a probabilistic fracture mechanics model that calculated the growth of as-fabricated surface flaws at welded joints, taking into account loads on the piping due to normal operating conditions as well as seismic events. Other factors, such as the capability to detect cracks by non-destructive examination and the capability to detect pipe leaks, were also considered. The best-estimate probability of direct DEGB for Westinghouse plants east of the Rocky Mountains was about $1.0\text{E-}12/\text{py}$, with a 90th-percentile value (i.e., 90% confidence limit) of $1.0\text{E-}10/\text{py}$; this latter value also bounds the direct DEGB probabilities for west coast plants and for Combustion Engineering plants. Although no evaluation of direct DEGB was performed for Babcock & Wilcox plants, a review of reactor coolant loop stress information inferred that the direct DEGB probability should be equally low. Therefore, this estimate appears applicable to all PWR plants.

The probability of indirect DEGB was estimated by considering the seismically-induced failure of the following "critical" components: reactor pressure vessel supports, steam generator supports, and reactor coolant pump supports. The median probability of an indirect DEGB in reactor coolant piping for all Westinghouse plants east of the Rocky Mountains was $1.0\text{E-}7/\text{py}$, with 10th- and 90th-percentile values of $2\text{E-}9/\text{py}$ and $7\text{E-}6/\text{py}$, respectively. These values bound or exceed the median probabilities of indirect DEGB in

*In support of an interim GDC-4 rulemaking action, LLNL extended the results of the A-2 evaluation to all PWR plants. See Appendix B for details.

reactor coolant loop piping for west coast Westinghouse plants, as well as for Combustion Engineering and Babcock & Wilcox plants.

These results were used to estimate the change in core-melt frequency, ΔF , resulting from implementation of the proposed rule change. The best-estimate of ΔF was based on the 90th-percentile probability of direct DEGB for Westinghouse plants east of the Rocky Mountains. As in the A-2 evaluation, it was assumed that only a DEGB inside the reactor cavity would unconditionally cause core melt. For breaks outside of cavity, core melt would occur only after the subsequent failure of safety systems designed to keep the core cool. The independent failure of these systems is presumably accounted for in plant design; therefore, the break itself is assumed to contribute no additional risk. To account for dependent failures of safety systems, the conditional probability of core melt (i.e., conditioned upon the occurrence of an out-of-cavity DEGB) was taken from the A-2 evaluation. As discussed in Generic Letter 84-04, systems interactions typically contribute 10% to total core-melt frequency (and risk), with a range of 1% to 20% as assessed in Supplement 1 to NUREG/CR-2800. The upper end of this range was applied in the present risk analysis.

The total probability of DEGB was allocated 20% inside and 80% outside the reactor cavity; an examination of LLNL results for Westinghouse and Combustion Engineering reactor coolant loop piping showed this to be reasonable. Summing the contributions of pipe breaks inside and outside the reactor cavity therefore yields the best-estimate increase in core-melt frequency as follows:

$$\begin{aligned}\Delta F &= 0.20(1.0E-10/\text{py})(1.0) + 0.80(1.0E-10/\text{py})(0.2) \\ &= 2.0E-11/\text{py} + 1.6E-11/\text{py} \\ &= 3.6E-11/\text{py}\end{aligned}$$

The median probability of indirect DEGB for Westinghouse plants east of the Rocky Mountains was taken as the upper bound increase in core melt frequency. This value is regarded as conservative for several reasons:

- If we were to follow the same logic as we did calculating the best-estimate of ΔF , core melt would be unconditional only if the pipe were to fail inside the reactor cavity. The computational method used to estimate the probability of indirect DEGB, however, does not distinguish between pipe breaks inside and outside of cavity. Furthermore, it cannot be said with certainty that support failure outside of the cavity (e.g., steam generator supports) would not result in a pipe break inside of the cavity. Therefore, any indirect DEGB is assumed to result in core melt.
- In developing the probabilities of indirect DEGB, it was conservatively assumed that failure of any critical support unconditionally led to DEGB. In other words, no credit was taken for large inelastic deformation of the pipe that might occur, resulting in only partial break or no break at all.
- The probability of indirect DEGB for plants east of the Rocky Mountains was estimated using generic seismic hazard curves developed specifically for the LLNL study (west coast plants were evaluated using site-specific seismic hazard information). The wide spread of uncertainty in the generic curves, combined with the assumption of a 0.15g minimum safe shutdown earthquake, was intended to cover all sites in the eastern and midwestern U.S. Using the generic curves in lieu of site-specific seismic hazard information may be overly conservative for certain sites. In those instances where site-specific seismic hazard curves were also used for an individual plant, the estimated probability of indirect DEGB was generally lower (often by several orders of magnitude) than when the generic curves were used for that plant.

As further evidence that the probability of indirect DEGB represents a conservative upper bound, it is important to point out that although the probability of indirect DEGB is significantly higher than that of direct DEGB, elimination of dynamic effects of pipe break should not cause it to change (i.e., increase). This is because under the proposed rule change, current

Design margins in primary loop component supports would be maintained. Existing heavy component supports designed for the effects of pipe rupture would not be affected. New plants would be designed with supports having margins comparable to equivalent margins in older plants. Thus, support reliability (and with it the probability of an indirect DEGB) would presumably not be affected by the proposed rule change.

The estimated change in core-melt frequency is summarized as follows:

Best Estimate = $3.6\text{E-}11/\text{py}$

High Estimate = $1.0\text{E-}7/\text{py}$

Low Estimate = 0

where the lower bound on DEGB probability has been taken to be zero.

As was done in the A-2 evaluation, the best-estimate of public risk was developed in two steps. For breaks inside the reactor cavity, it was assumed that asymmetric blowdown unconditionally causes core melt. Release sequences analogous to those for reactor pressure vessel rupture in WASH-1400 were assumed to apply. These sequences (Table V.3-14, Appendix V, dominant only), with their corresponding release frequencies, are as follows:

RC- α (PWR-1) with frequency = $2\text{E-}12/\text{py}$

RC- γ (PWR-2) with frequency = $3\text{E-}11/\text{py}$

RF-6 (PWR-2) with frequency = $1\text{E-}11/\text{py}$

RC-6 (PWR-2) with frequency = $1\text{E-}12/\text{py}$

R- α (PWR-3) with frequency = $1\text{E-}9/\text{py}$

R- ϵ (PWR-7) with frequency = $1\text{E-}7/\text{py}$

WASH-1400 assumes a vessel rupture frequency (and therefore core melt frequency) of $1.0\text{E-}7/\text{py}$. Replacing this value with $2.0\text{E-}11/\text{py}$ and using the WASH-1400 dose estimates for each release category results in the following best-estimate of risk from an in-cavity DEGB:

$$\begin{aligned}
 \text{Risk} &= (4.0\text{E-}16/\text{py})(5.4\text{E+}6 \text{ man-rem}) + (8.2\text{E-}15/\text{py})(4.8\text{E-}6 \text{ man-rem}) + \\
 &\quad (2.0\text{E-}16/\text{py})(5.4\text{E+}6 \text{ man-rem}) + (2.0\text{E-}11/\text{py})(2.3\text{E+}3 \text{ man-rem}) \\
 &= 8.0\text{E-}8 \text{ man-rem/py}
 \end{aligned}$$

where the frequency of each release category was scaled linearly by the ratio of core melt frequencies used in the current analysis and in WASH-1400. Note that the probability of DEGB estimated by LLNL (and therefore the estimated change in core-melt frequency) already accounts for variations in the number of reactor coolant loops among plants. Therefore, no further correction is necessary.

The risk contribution from breaks outside the reactor cavity was estimated assuming accident sequences analogous to those for a large LOCA in WASH-1400 were applicable. The dominant large LOCA release sequences (Table V.3-14, Appendix V) are:

AB- α (PWR-1) with frequency = $1\text{E-}11/\text{py}$
 AF- α (PWR-1) with frequency = $1\text{E-}10/\text{py}$
 ACD- α (PWR-1) with frequency = $5\text{E-}11/\text{py}$
 AG- α (PWR-1) with frequency = $9\text{E-}11/\text{py}$
 AB-Y (PWR-2) with frequency = $1\text{E-}10/\text{py}$
 AB- δ (PWR-2) with frequency = $4\text{E-}11/\text{py}$
 AHF-Y (PWR-2) with frequency = $2\text{E-}11/\text{py}$

AD- α (PWR-3) with frequency = $2\text{E-}8/\text{py}$
 AH- α (PWR-3) with frequency = $1\text{E-}8/\text{py}$
 AF- δ (PWR-3) with frequency = $1\text{E-}8/\text{py}$
 AG- δ (PWR-3) with frequency = $9\text{E-}9/\text{py}$

ACD- β (PWR-4) with frequency = $1\text{E-}11/\text{py}$

AD-B (PWR-5) with frequency = $4\text{E-}9/\text{py}$
 AH- β (PWR-5) with frequency = $3\text{E-}9/\text{py}$

AB-ε (PWR-6) with frequency = $1\text{E-}9/\text{py}$
 AHF-ε (PWR-6) with frequency = $2\text{E-}10/\text{py}$
 ADF-ε (PWR-6) with frequency = $2\text{E-}10/\text{py}$

AD-ε (PWR-7) with frequency = $2\text{E-}6/\text{py}$
 AH-ε (PWR-7) with frequency = $1\text{E-}6/\text{py}$

WASH-1400 assumes a median large LOCA frequency of $1.0\text{E-}4/\text{py}$. If we replace this value with the nominal increase in core-melt frequency estimated previously ($1.6\text{E-}11/\text{py}$), the risk from an out-of-cavity DEGB becomes:

$$\begin{aligned} \text{Risk} &= (1.6\text{E-}17/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (1.0\text{E-}17/\text{py})(4.6\text{E}+6 \text{ man-rem}) + \\ &\quad (3.1\text{E-}15/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (6.3\text{E-}19/\text{py})(2.7\text{E}+6 \text{ man-rem}) + \\ &\quad (4.4\text{E-}16/\text{py})(1.0\text{E}+6 \text{ man-rem}) + (8.1\text{E-}17/\text{py})(1.5\text{E}+5 \text{ man-rem}) + \\ &\quad (1.9\text{E-}13/\text{py})(2.3\text{E}+3 \text{ man-rem}) \\ &= 1.7\text{E-}8 \text{ man-rem/py} \end{aligned}$$

Note that the core-melt frequency used here already includes the 80% allocation of total DEGB probability to out-of-cavity breaks, as well as the 20% systems interaction contribution to account for core melt due to dependent failures of safety equipment.

The best-estimate of per-plant risk due to a reactor coolant loop DEGB therefore becomes:

$$\begin{aligned} \text{Risk} &= 8.0\text{E-}8 \text{ man-rem/py} + 1.7\text{E-}8 \text{ man-rem/py} \\ &= 9.7\text{E-}8 \text{ man-rem/py} \end{aligned}$$

To estimate the upper bound on risk, the upper bound change in core-melt frequency ($1.0\text{E-}7/\text{py}$) was applied to the release sequences previously described. For in-cavity breaks, the risk contribution is:

$$\begin{aligned}
 \text{Risk} &= (2.0\text{E-}12/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (4.1\text{E-}11/\text{py})(4.8\text{E}+6 \text{ man-rem}) + \\
 &\quad (1.0\text{E-}9/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (1.0\text{E-}7/\text{py})(2.3+3 \text{ man-rem}) \\
 &= 5.8\text{E-}3 \text{ man-rem/py}
 \end{aligned}$$

For out-of-cavity breaks, the risk contribution is:

$$\begin{aligned}
 \text{Risk} &= (2.5\text{E-}13/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (1.6\text{E-}13/\text{py})(4.8\text{E}+6 \text{ man-rem}) + \\
 &\quad (4.9\text{E-}11/\text{py})(5.4\text{E}+6 \text{ man-rem}) + (1.0\text{E-}14/\text{py})(2.7\text{E}+6 \text{ man-rem}) + \\
 &\quad (7.0\text{E-}12/\text{py})(1.0\text{E}+6 \text{ man-rem}) + (1.3\text{E-}13/\text{py})(1.5\text{E}+5 \text{ man-rem}) + \\
 &\quad (3.0\text{E-}9/\text{py})(2.3\text{E}+3 \text{ man-rem}) \\
 &= 2.8\text{E-}4 \text{ man-rem/py}
 \end{aligned}$$

The upper bound per-plant risk due to a reactor coolant loop DEGB therefore becomes:

$$\begin{aligned}
 \text{Risk} &= 5.8\text{E-}3 \text{ man-rem/py} + 2.8\text{E-}4 \text{ man-rem/py} \\
 &= 6.1\text{E-}3 \text{ man-rem/py}
 \end{aligned}$$

The lower bound on risk is taken to be zero. Multiplying each of the risk calculations by the number of remaining plant years (= 2922) results in the following estimates of incremental increase in total risk to the public due to elimination of reactor coolant loop DEGB as a design requirement:

$$\text{Best Estimate} = 2.8\text{E-}4 \text{ man-rem}$$

$$\text{High Estimate} = 1.8\text{E}+1 \text{ man-rem}$$

$$\text{Low Estimate} = 0 \text{ man-rem}$$

Note that this analysis results in an increase (albeit extremely small) in public risk. Many experts believe, however, that the proposed rule change could conceivably reduce public risk, arguing that pipe whip restraints and jet impingement barriers may actually decrease the reliability of piping systems by limiting access to pipe welds, therefore reducing the effectiveness

of in-service inspection, and by potentially restricting the movement of piping during routine operation and thus increasing pipe stresses caused by restraint of thermal expansion. This latter situation could occur, for example, if pipe whip restraints (which are designed to accommodate thermal expansion displacements without binding, and are later shimmed according to actual displacements measured during preoperational plant testing) were to be installed incorrectly. The results of a separate NRC research program at LLNL have indicated that piping system reliability does indeed tend to increase with flexibility.⁸ In this value-impact assessment, however, we have assumed that restraints are installed as designed and have not attempted to quantify any effect that avoidance of possible pipe binding might have on public risk. Similarly, we have not attempted to take credit for increased piping reliability due to improved effectiveness of in-service inspection.

6.1.2 Occupational Exposure - Accidental

The increased occupational exposure from accidents can be estimated as the product of the change in total core-melt frequency and the occupational exposure likely to occur in the event of a major accident. The nominal change in core-melt frequency was estimated to be 3.6E-11/py . The occupational exposure in the event of major accident has two components. The first is the immediate exposure to personnel on site during the span of the event and its short-term control. The second is the long-term exposure associated with cleanup and recovery from the accident. The incremental occupation exposure due to an accident is calculated as follows:

$$D_{TOA} = NTD_{OA}; \quad D_{OA} = (\Delta F)(D_{IO} + D_{LTO})$$

where

D_{TOA}	=	total accidental occupational dose
N	=	number of affected facilities
T	=	average remaining lifetime
D_{OA}	=	accidental occupational dose per plant-year
ΔF	=	change in core-melt frequency
D_{IO}	=	immediate occupational dose
D_{LTO}	=	long-term occupational dose

Table 4 presents the resultant occupational exposure due to accidents, based on cleanup and decommissioning estimates given in NUREG/CR-2800.⁹

6.1.3 Occupational Exposure - Routine

The proposed rule change would reduce occupational radiation exposure during routine operation and maintenance by (1) eliminating the need to remove and reinstall pipe whip restraints blocking access to welds during in-service inspection (ISI), and (2) generally relieving congestion in the vicinity of the recirculation piping, making maintenance operations (primarily ISI) more efficient.

Removal and Reinstallation of Pipe Whip Restraints

For plants under construction (and future plants), elimination of pipe whip restraints would mean avoidance of radiation exposure during removal and reinstallation of pipe whip restraints for routine ISI. The avoided dose is estimated on the basis of a safety analysis performed by Bechtel for Georgia Power as part of a request to eliminate the dynamic effects of reactor coolant loop breaks from the design of the Vogtle Electric Generating Station (VEGP) Units 1 and 2.¹⁰

In this analysis, review of the plant design indicated that the RCL pipe whip restraints were located such that there is sufficient access to perform ISI, except for the crossover pipe welds. It was assumed that the crossover restraints (two per loop, or eight per unit) would have to be removed four

Table 4. Occupational Exposure Due to Accidents (PWR)

	Change in Core-Melt Probability	Immediate Occupational Dose	Long-Term Occupational Dose	Total Occupational Exposure
	events/py	man-rem/event	man-rem/event	man-rem
Best Estimate	3.6E-11	1E+3	2E+4	2.2E-3
High Estimate	1.0E-7	4E+3	3E+4	9.9
Low Estimate	0	0	1E+4	0

times during the life of plant, or once every ten years. It was further assumed that 32 man-hours would be required for restraint removal and an additional 32 man-hours would be required for reinstallation. Based on exposure rates of 0.02 to 0.2 rem/hr in the vicinity of the RCL piping, this implies an expected dose of 1.3 to 13 man-rem per restraint per ISI. The VEGP evaluation assumed ORE for removal and reinstallation of each restraint would range from 1 to 40 man-rem, with 10 man-rem being a nominal value. These assumptions yielded the following estimated doses for each unit:

Best Estimate = 320 man-rem/plant

High Estimate = 1280 man-rem/plant

Low Estimate = 32 man-rem/plant

These results bracket similar exposure estimates provided by Combustion Engineering (560 man-rem per plant) for removal and reinstallation of RCL pipe whip restraints during ISI; therefore, the above estimates appear reasonable for all PWR plants.

For operating plants, the proposed rule change would allow pipe whip restraints removed for routine ISI to be left off the pipe system. Exposure for initial restraint removal would be incurred as a part of the ISI procedure; the avoided dose would therefore be that associated with the initial reinstallation of restraints plus that for subsequent removal and reinstallation. This has been estimated by prorating the dose values estimated above by the ratio of average years of remaining life to assumed total plant life (i.e., $\approx 30/40 = 75\%$), less the exposure for initial restraint removal.

Restricted Access for In-Service Inspection

The radiation dose due to restricted access during ISI is estimated based on the Vogtle value-impact assessment. Removing all RCL pipe whip restraints (i.e., not only the crossover restraints) would generally improve access for of the following activities:

- In-service inspection of reactor coolant piping, including removal and reinstallation of insulation from the reactor vessel nozzles and coolant piping.
- In-service inspection of steam generator welds (lower shell).
- Eddy current testing of steam generator tubes.

In the VEGP evaluation, the estimated annual ORE for performing these activities was 11.65 man-rem averaged over a ten-year period. Assuming that restraint removal results in a 10% increase in work efficiency yields the following estimates of ORE reduction over the 40-year lifetime of each unit are obtained:

Best Estimate = 50 man-rem/plant

High Estimate = 80 man-rem/plant

Low Estimate = 20 man-rem/plant

where the high and low estimates were based on ISI exposures of 20 man-rem/yr and 5 man-rem/year, respectively. The reductions in ORE presented in the VEGP analysis were based on a 1% increase in work efficiency; however, it was also stated in the VEGP evaluation that actual increases were expected to exceed 10% considering the instruments and equipment that must be manipulated during ISI activities, and the general difficulty of working in protective clothing.

For operating plants, the above estimates are reduced by 25% as was done for restraint removal and reinstallation.

Restricted Access for Routine Maintenance

The VEGP evaluation quantified ORE for the following routine maintenance activities:

- Restraint Gap Verification

It is anticipated that restraint gap verification will be performed once every ten years. Assuming that ORE averages 0.1 man-rem for each restraint results in the following per-plant reduction for eliminating all 24 RCL pipe whip restraints (i.e., not performing gap verification):

Best Estimate = 10 man-rem/plant

High Estimate = 50 man-rem/plant

Low Estimate = 1 man-rem/plant

where the high and low estimates are based on average exposures of 0.5 and 0.01 man-rem per restraint, respectively.

- Reactor Coolant Pump Seal Maintenance

Each reactor coolant pump is expected to require seal maintenance once every two years during refueling outages, resulting in a nominal exposure of 7 man-rem per pump maintenance activity. Assuming restraint removal will increase work efficiency by 10% results in the following nominal reductions over the 40-year lifetime of each unit:

Best Estimate = 56 man-rem/plant

High Estimate = 120 man-rem/plant

Low Estimate = 8 man-rem/plant

where the high and low estimates are based on exposures of 15 man-rem and 1 man-rem per pump maintenance activity, respectively. As for ISI, the VEGP study presented a 1% increase in work efficiency, but acknowledged that the actual increase would likely exceed 10% in the pump area.

- Special Maintenance

The VEGP evaluation considered improvements in access for the following special maintenance activities resulting from removal of pipe whip restraints on the crossover leg and vertical piping at the outlet of the steam generator: steam generator tube plugging and welding, and sludge lancing. The annual exposure from these activities was estimated at 12.1 man-rem averaged over a 10-year period. On this basis, the following ORE reductions over the lifetime of each unit were obtained:

Best Estimate = 24 man-rem/plant

High Estimate = 48 man-rem/plant

Low Estimate = 5 man-rem/plant

Here a nominal increase in work efficiency of 5% is assumed, with high and low values of 10% and 1%, respectively.

For plants under construction, the above reductions in ORE due to improved access during ISI and routine maintenance can be used directly because the RCL piping is not yet radioactive. For operating plants having pipe whip restraints, however, these estimates must be reduced by the ORE incurred during removal of those restraints not normally removed for ISI (i.e., not on the crossover legs). Assuming an additional 16 restraints would be removed and that the per-restraint exposure for removal would be one-half that for removal and reinstallation results in the following ORE estimates:

Best Estimate = 80 man-rem/plant

High Estimate = 320 man-rem/plant

Low Estimate = 8 man-rem/plant

This is entered as a negative value in Table 5 to reflect the dose increase.

Table 5. Summary of Reductions in Routine Occupational Exposure (PWR)
(man-rem/plant)

Factor	Operating Plants ^a			Plants Under Construction ^b		
	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>
<u>ISI</u>						
Eliminate removal, reinstallation of whip restraints	240	960	24	320	1280	32
Improve access	38	60	15	50	80	20
Initial restraint removal	-40	-160	-8	n/a	n/a	n/a
<u>Maintenance</u>						
Gap verification	8	38	1	10	50	1
Pump seals	42	90	6	56	120	8
Special maintenance	18	36	4	24	48	5
Removal of non-ISI restraints	-80	-320	-16	n/a	n/a	n/a
Total Reduction	226	930	26	460	1578	66

Notes:

- (a) Plants with pipe whip restraints only. Excludes operating plants not included in the A-2 evaluation, C-E plants benefitting from installing permanent neutron streaming shields and fuel pool seals, and Crystal River 3 (B&W).
- (b) It is assumed that pipe whip restraints are not yet installed in plants under construction.

Development of Overall Routine Occupational Exposure

The reductions in routine occupational exposure summarized in Table 5 are assumed to apply only to operating plants now having pipe whip restraints and to plants under construction (which are all assumed to incorporate pipe whip restraints in their design). The overall reduction in routine ORE for PWR plants is estimated by applying the above estimates to plants not included in the A-2 evaluation, and then adding in the A-2 exposure estimates from Generic Letter 84-04. This is done as follows:

- Westinghouse

There are 19 operating Westinghouse plants not included in the A-2 evaluation, all of which are assumed to have pipe whip restraints, and 24 plants under construction. Therefore, the best estimate of avoided ORE is:

$$\begin{aligned}\text{Best Estimate} &= (19 \text{ plants})(226 \text{ man-rem/plant}) + \\ &\quad (24 \text{ plants})(460 \text{ man-rem/plant}) \\ &= 15334 \text{ man-rem} = 1.5\text{E}+4 \text{ man-rem}\end{aligned}$$

$$\text{High Estimate} = 5.6\text{E}+4 \text{ man-rem}$$

$$\text{Low Estimate} = 1.6\text{E}+3 \text{ man-rem}$$

- Combustion Engineering

One C-E plant (Fort Calhoun) is included in the A-2 group. For five operating plants having no pipe whip restraints or jet impingement barriers, 81 man-rem/plant in ORE could be avoided by installing a permanent neutron streaming shield in the reactor cavity. For all operating plants, regardless of whether they have pipe whip restraints or not, installation of a permanent refueling pool seal would save an additional 61 man-rem/plant. Therefore, the total avoided ORE for all C-E plants (exclusive of A-2 dose reductions) is:

Best Estimate = (2 plants)(226 man-rem/plant) +
 (5 plants)(460 man-rem/plant) +
 (5 plants)(81 man-rem/plant) +
 (11 plants)(61 man-rem/plant)
 = 3828 man-rem $\approx$ 3.8E+3 man-rem

High Estimate = 1.1E+4 man-rem

Low Estimate = 9.3E+2 man-rem

where the high and low estimates include a $\pm 50\%$ uncertainty range on the exposure values given for installation of the permanent pool seal and neutron streaming shield.

- Babcock & Wilcox

One B&W plant (Crystal River 3) uses eight large-bore snubbers (18 to 25 inches diameter) on each of the four reactor coolant pumps to withstand large LOCA loads. A value-impact study performed for Florida Power & Light has indicated that reducing the total number of snubbers from 32 to 8 would result in a reduction in routine ORE of 2340 man-rem, due mainly to the saving of over 150,000 exposure hours over plant life for routine snubber maintenance. The total estimated ORE reduction for B&W plants is:

Best Estimate = (1 plant)(226 man-rem/plant) +
 (3 plants)(460 man-rem/plant) +
 (1 plant)(2340 man-rem/plant)
 = 3946 man-rem $\approx$ 3.9E+3 man-rem

High Estimate = 8.0E+4 man-rem

Low Estimate = 2.6E+3 man-rem

The estimated ORE reduction for Crystal River resulted from a detailed evaluation of snubber maintenance costs performed for Florida Power by

B&W and Fluor Engineers, and can be regarded as very reliable. The 2340 man-rem estimate was therefore retained in both the high and low estimates given above.

- A-2 plants

Operational ORE estimates for the 16 A-2 plants were taken directly from Generic Letter 84-04, which broke down the avoided occupational doses as follows:

- for the three Group 1 plants (i.e., those requiring extensive modifications), 7800 man-rem avoided by not installing primary system pipe restraints at the RPV nozzles and not modifying pump and steam generator supports, less 100 man-rem incurred to upgrade and calibrate leak detection systems; net avoided dose is 7700 man-rem.
- for the remaining (i.e., Group 2) plants, a net avoided dose of 2000 man-rem associated with the same activities as above.
- for all plants, at total of 840 man-rem avoided dose for maintaining the above modifications, based on 80 man-hr/py of labor in radiation zones.

The total estimated ORE reduction for the A-2 plants is summarized as follows:

Best Estimate	1.1E+4 man-rem
High Estimate	3.2E+4 man-rem
Low Estimate	3.5E+3 man-rem

where the high and low estimates are based, respectively, on three times and 1/3 times the expected operational doses.

The total reduction in occupational ORE was then estimated by including the A-2 values from Generic Letter 84-04 as follows:

$$\begin{aligned}\text{Best Estimate} &= (1.5\text{E}+4 + 3.8\text{E}+3 + 3.9\text{E}+3) + (1.1\text{E}+4) \\ &= 3.4\text{E}+4 \text{ man-rem}\end{aligned}$$

$$\text{High Estimate} = 1.1\text{E}+5 \text{ man-rem}$$

$$\text{Low Estimate} = 8.6\text{E}+3 \text{ man-rem}$$

6.1.4 Offsite Property Damage

The effect of the proposed action upon the risk to offsite property is calculated by multiplying the change in accident frequency by a generic offsite property damage estimate. This estimate was derived from the mean value of CRAC2 calculations, assuming an SST1 release (major accident), for 154 reactors.¹¹ CRAC2 includes costs for evacuation, relocation of displaced persons, property decontamination, loss of use of contaminated property through interdiction and crop and milk losses. Litigation costs, impacts to areas receiving evacuees and institutional costs are not included. The damage estimate is converted to present value by discounting at 10%. A 5% discount rate was also considered as a sensitivity case.

The following discounting formula is employed:

$$\frac{D}{V} = \frac{e^{-It_i} - e^{-It_f}}{I}$$

where

D = discounted value

V = damage estimate

t_i = years before reactor begins operation; 0 for operating plants

t_f = years remaining until end of plant life

I = discount rate

For the purposes of this assessment, no distinction is made between operating

and planned reactors; the average remaining life of the entire population of 85 reactors is 34.4 years. The 10% discount factor is therefore 9.7, the 5% discount factor 16.4. The risk to offsite property, V_{FP} , is estimated as:

$$V_{FP} = N(\Delta F)D$$

where N and ΔF are, respectively, the number of plants and the change in core-melt frequency. The results are summarized in Table 6; upper and lower bounds are values calculated in Ref. 11 for Indian Point 2 and Palo Verde 3 coupled with the bounds on the core-melt frequency.

6.1.5 Onsite Property Damage

The effect of the proposed action on the risk to onsite property is estimated by multiplying the change in accident frequency by a generic onsite property cost. This generic onsite property cost in NUREG/CR-2800 was taken. Costs included are for interdicting or decontaminating onsite property, replacement power and capital cost of damaged plant equipment. Onsite property damage costs were discounted using the following formula:

$$\frac{D}{V} = \frac{1}{m!^2} \{ e^{-It} \} \{ (1 - e^{-Im}) [1 - e^{-I(t_f - t_i)}] \}$$

where

D = discounted value

V = damage estimate

m = years required for plant recovery (= 10 years)

t_i = years before reactor begins operation; 0 for operating plants

t_f = years remaining until end of plant life

I = discount rate

For the purposes of this assessment, no distinction is made between operating and planned reactors. The 10% discount factor is therefore 6.1, the 5% discount factor 12.9. The risk to onsite property is estimated as:

Table 6. Summary of Offsite Property Damage (PWR)

	Offsite Property Damage (\$/event)	Discounted Offsite Property Damage (\$/event)		Value of Offsite Property Damage (\$)	
		10%	5%	10%	5%
Best Estimate	1.7E9	1.6E+10	2.8E+10	4.9E+1	8.6E+1
High Estimate	9.2E9	8.9E+10	1.5E+11	7.6E+5	1.3E+6
Low Estimate	8.3E8	8.0E+9	1.4E+10	0	0

$$V_{OP} = N(\Delta F)U$$

where

V_{OP} = value of avoided onsite property damage
 N = number of affected facilities
 ΔF = change in accident frequency
 U = present value of property damage occurring with frequency ΔF

The results are summarized in Table 7; the uncertainty bounds reflect a $\pm 50\%$ spread in the generic property cost coupled with the bounds on core-melt frequency.

6.1.6 Industry Implementation Costs

Description of Costs

Significant cost benefits to industry are foreseen as a result of the proposed rule change. Costs (or more appropriately cost savings) developed for reactor coolant loop piping are summarized in Table 8 for plants in the design stage (including future plants), plants under construction, and operating plants (both with and without pipe whip restraints). It is generally assumed for plants under construction that all initial design activities (which comprise the bulk of analysis costs) are complete. Cost areas are categorized as follows:

- Elimination of pipe whip restraints. Overall cost estimates are grouped according to (1) design and fabrication, and (2) installation and adjustment of pipe whip restraints. For new plants, the first group includes costs for engineering design, interface documentation between the nuclear steam supply system vendor and the architect-engineer, and restraint materials and fabrication. For plants under construction, it

Table 7. Summary of Onsite Property Damage (PWR)

	Onsite Property Damage (\$/event)	Discounted Onsite Property Damage (\$/event)		Value of Onsite Property Damage (\$)	
		10%	5%	10%	5%
Best Estimate	1.7E9	1.1E+10	2.2E+10	3.2E+1	6.7E+1
High Estimate	2.5E9	1.5E+10	3.2E+10	1.3E+5	2.7E+5
Low Estimate	8.2E8	5.0E+9	1.1E+10	0	0

Table 8. Summary of PWR Implementation Costs
(K\$/plant)

Cost Item (PWR)	Initial Design Stage ^a	Under Construc- tion ^b	Operating	
			With Restraints	Without Restraints ^c
<u>Pipe Whip Restraints</u>				
Design, fabrication	-3100 ^d	-16 ^e	n/a	16
Installation, adjustment	-1390	-890	n/a	n/a
<u>Jet Impingement</u>				
Target load analysis	-300	-300	n/a	n/a
Design, fabricate, install jet impingement barriers	[-45] ^f	[-45] ^f	n/a	n/a
<u>General Analysis</u>				
Thermalhydraulics and piping response	-1910	-734		
Structural response and support design	-650	0		
RPV internals	-150	0	-50	-50
<u>Plant-Specific Hardware Modifications</u>				
Install permanent neutron streaming shield (C-E only)	n/a	n/a	n/a	[-155]
Install permanent fuel pool seal (C-E only)	n/a	n/a	[-150]	[-150]
A-2 Plants, Group 1 (<u>W</u>)	n/a	n/a	n/a	[-31500] ^g
A-2 Plants, Group 2 (<u>W</u>)	n/a	n/a	n/a	[-14000] ^g
Crystal River 3 (B&W)	n/a	n/a	n/a	[-8900]
Net total costs	-7500	-1940	-50	-34

Notes:

- (a) Includes future plants.
- (b) Assumes initial design activities are complete. Assumes pipe whip restraints have been designed, procured, and fabricated but not installed.
- (c) Not including A-2 Owners Group plants, except where explicitly noted.
- (d) Includes \$800K first time cost for new product line design. Eventual per-plant cost saving would be spread over the number of new plants.
- (e) Assumes standard pipe whip restraint design. Costs are primarily for installation follow and preparation of licensing documentation.
- (f) Estimated cost per barrier. Plants designed by C-E normally do not use jet impingement barriers; plants designed by Westinghouse and B&W may have on the order of 8 to 16 for postulated RCL breaks. Costs in brackets are not included in the net total costs.
- (g) Total cost for all plants in group, not including replacement power during installation of modifications. Costs are not included in the net total costs.

is assumed that restraints have been designed and procured, that foundations have been constructed, but that installation has not yet taken place. The design costs for new plants include an \$800K one-time cost for new product line restraint development (Combustion Engineering is developing a 2800 MWt version of its present 3800 MWt "System 80" configuration, Westinghouse a new three-loop PWR configuration); this cost would eventually be spread out over the total number of plants constructed. For established product lines restraint design becomes highly standardized, limiting "design" costs to installation follow and preparation of specifications and licensing documentation. Installation costs include foundation preparation, machining of saddles, initial installation, and adjustment of restraint gaps.

- Jet impingement. Costs associated with jet impingement can be broken down into (1) target load analysis and (2) design, fabrication, and installation of jet impingement barriers. Jet impingement can be designed for either by identifying, analyzing, and (if necessary) placing bumpers at targets (i.e., not installing barriers), or by placing barriers in front of targets. In either case, a jet load analysis must be performed. Combustion Engineering typically takes the former approach, Westinghouse and Babcock & Wilcox have taken the latter. In those PWR plants where barriers are installed, the number of barriers varies from plant to plant, and their removal may be subject to plant-specific considerations. Rather than conduct an exhaustive review of jet impingement barriers in every PWR plant, per-barrier costs have been extracted from a value-impact assessment performed by Texas Utilities for the Commanche Peak nuclear power plant. These costs are presented in Table 8, but have not been included in the final overall value-impact analysis for reactor coolant loop piping.
- Thermalhydraulic and piping response analysis. This category includes the following analysis costs: reactor coolant system hydrodynamic loads and resultant piping response caused by a pipe break; response of the

surge line, control rod drive mechanisms, and in-core instrumentation to pipe break loads; response of tributary piping to pipe break loads; mass and energy releases to the environment (subcompartment blowdown).

For plants originally designed with restraints, a revised seismic analysis of the RCL piping might have to be performed if restraints were removed, and it was determined that the restraints could have conceivably limited pipe motion induced by an earthquake. This would represent an actual cost of implementation.

- Structural response and support design. This category includes avoided or reduced costs for: reactor cavity analysis ("asymmetric blowdown"); design of RPV supports for in-cavity loads; preparation of component and support stress reports.
- RPV internals response analysis. This category includes analysis of depressurization loads that would be placed on the reactor fuel and internal mechanical structures in the event of a pipe break.

The above cost reductions would generally apply to all PWR plants. It is clear that the largest reduction would be in analysis costs for new plants. In addition to these general costs, we have also included the following costs which apply to individual reactor vendors:

- Combustion Engineering. For five operating plants having no pipe whip restraints or jet impingement barriers, an additional \$155K/plant could be saved by installing a permanent neutron streaming shield in the reactor cavity. For all operating plants, installation of a permanent refueling pool seal would save an additional \$150K/plant and eliminate potential damage from handling of the seal. These costs are not included in the net totals in Table 8, but are included in the development of overall avoided costs.

- Net avoided implementation costs for all A-2 Owners Group plants are taken from NRC Generic Letter 84-04. These costs are not included in the net totals in Table 8, but are included in the development of overall avoided costs.

Development of Overall Industry Implementation Costs

The overall reduction in implementation costs for all PWR plants is estimated by applying general estimates to plants not included in the A-2 evaluation, and then adding plant-specific costs and the A-2 implementation costs from Generic Letter 84-04. This is done as follows:

- **Westinghouse**

There are 19 operating Westinghouse plants not included in the A-2 evaluation and 24 plants under construction. Therefore, the best estimate of avoided implementation costs (excluding A-2 costs) is:

$$\begin{aligned}\text{Best Estimate} &= (19 \text{ plants})(50\text{K/plant}) + (24 \text{ plants})(1940\text{K/plant}) \\ &= \$47510\text{K} \approx \$4.8\text{E}+7\end{aligned}$$

$$\text{High Estimate} = \$7.2\text{E}+7$$

$$\text{Low Estimate} = \$2.4\text{E}+7$$

where the high and low estimates reflect a $\pm 50\%$ uncertainty range.

- **Combustion Engineering**

One operating C-E plant is included in the A-2 evaluation. Assuming that ten operating C-E plants install a permanent refueling pool seal and that five of these also install a permanent neutron streaming shield, the total avoided implementation costs (excluding A-2 costs) is:

$$\begin{aligned}
 \text{Best Estimate} &= (5 \text{ plants})(\$155\text{K}/\text{plant} + \$150\text{K}/\text{plant} + \$50\text{K}/\text{plant}) + \\
 &\quad (5 \text{ plants})(\$150\text{K}/\text{plant} + \$50\text{K}/\text{plant}) + \\
 &\quad (5 \text{ plants})(\$1940\text{K}/\text{plant}) \\
 &= \$12475 = \$1.2\text{E}+7
 \end{aligned}$$

$$\text{High Estimate} = \$1.8\text{E}+7$$

$$\text{Low Estimate} = \$6.0\text{E}+6$$

where the high and low estimates reflect a $\pm 50\%$ uncertainty range.

- Babcock & Wilcox

The total avoided implementation costs for B&W plants are:

$$\begin{aligned}
 \text{Best estimate} &= (8 \text{ plants})(\$50\text{K}/\text{plant}) + (3 \text{ plants})(\$1940\text{K}/\text{plant}) \\
 &= \$6220\text{K} = \$6.2\text{E}+6
 \end{aligned}$$

$$\text{High Estimate} = \$9.3\text{E}+6$$

$$\text{Low Estimate} = \$3.1\text{E}+6$$

where the high and low estimates reflect a $\pm 50\%$ uncertainty range on all costs.

- A-2 Plants

Implementation costs for the 16 A-2 plants represent costs avoided by not installing primary system pipe whip restraints at the RPV nozzles as well as various modifications to heavy component supports, less costs incurred to upgrade and calibrate leakage detection systems. The total nominal costs for plant Groups 1 and 2 are \$31.5 million and \$14.0 million, respectively, not including replacement power. The total avoided implementation costs for A-2 plants are:

Best estimate = \$4.6E+7

High Estimate = \$6.8E+7

Low Estimate = \$2.3E+7

where the high and low estimates reflect a $\pm 50\%$ uncertainty range.

The total avoided implementation costs for all PWR plants are then estimated by including the A-2 values from Generic Letter 84-04 as follows:

Best Estimate = $(\$4.8E+7 + \$1.2E+7 + \$6.2E+6) + \$4.6E+7$
= \$1.1E+8

High Estimate = \$1.7E+8

Low Estimate = \$5.6E+7

Avoided costs of replacement power during installation of A-2 plant modifications are taken directly from Generic Letter 84-04 and included as a separate line item in Table 2.

6.1.7 Industry Operating Costs

The proposed rule change would reduce operating costs during routine operation and maintenance by (1) eliminating the need to remove and reinstall pipe whip restraints blocking access to welds during in-service inspection (ISI), and (2) generally relieving congestion in the vicinity of the reactor coolant loop piping, making maintenance operations (primarily ISI) more efficient. The avoided costs are estimated on the basis of the VEGP safety analysis used to estimate occupational radiation exposure during routine operation. In the case of removal and reinstallation of pipe whip restraints, manpower estimates cited in the safety analysis are used directly. In those cases where no manpower estimates were given, labor hours were estimated by taking the best estimate exposure and assuming a 0.15 rem/hr radiation environment. Nominal labor costs were based on a \$40/hour rate; high and low estimates were obtained assuming a $\pm 25\%$ uncertainty in labor rates.

Removal and Reinstallation of Pipe Whip Restraints

For plants under construction (and future plants), elimination of pipe whip restraints would mean avoidance of costs for removal and reinstallation of pipe whip restraints during routine ISI. The VEGP safety analysis assumed that the crossover restraints (two per loop, or eight per unit) would have to be removed four times during the life of plant, or once every ten years. It was further assumed that 32 man-hours would be required for restraint removal and an additional 32 man-hours would be required for reinstallation. Based on a labor cost of \$40/hour, this implies a cost of about \$2.6K per restraint per ISI. These assumptions yielded the following estimated costs over the lifetime of each unit:

Best Estimate = \$82K/plant

High Estimate = \$102K/plant

Low Estimate = \$62K/plant

For operating plants, the proposed rule change would allow pipe whip restraints removed for routine ISI to be left off the pipe system. Exposure for initial restraint removal would be incurred as a part of the ISI procedure; the avoided dose would therefore be that associated with the initial reinstallation of restraints plus that for subsequent removal and reinstallation. This has been estimated by prorating the estimated costs by the ratio of average years of remaining life to assumed total plant life (i.e., $\approx 30/40 = 75\%$), less the cost of initial restraint removal.

Restricted Access for In-Service Inspection

Removing all RCL pipe whip restraints would generally improve access (and therefore reduce costs) for the following activities:

- In-service inspection of reactor coolant piping, including removal and reinstallation of insulation from the reactor vessel nozzles and coolant piping.

- In-service inspection of steam generator welds (lower shell).
- Eddy current testing of steam generator tubes.

Assuming that restraint removal results in a 10% increase in work efficiency yields the following estimated cost reductions based on the ORE reductions estimated in Section 6.1.3:

$$\begin{aligned}\text{Best Estimate} &= (50 \text{ man-rem})(\$40/\text{man-hour})/(0.15 \text{ rem/hr}) \\ &= \$13\text{K}/\text{plant}\end{aligned}$$

$$\text{High Estimate} = \$17\text{K}/\text{plant}$$

$$\text{Low Estimate} = \$10\text{K}/\text{plant}$$

where the high and low estimates were based on a $\pm 25\%$ uncertainty range in labor rates.

For operating plants, the above estimates are reduced by 25% as was done for restraint removal and reinstallation.

Restricted Access for Routine Maintenance

Based on the nominal occupational ORE values estimated by VEGP, avoided costs are estimated for the following routine maintenance activities:

- Restraint Gap Verification

$$\text{Best Estimate} = \$3\text{K}/\text{plant}$$

$$\text{High Estimate} = \$3\text{K}/\text{plant}$$

$$\text{Low Estimate} = \$2\text{K}/\text{plant}$$

● Reactor Coolant Pump Seal Maintenance

Best Estimate = \$15K/plant
High Estimate = \$19K/plant
Low Estimate = \$11K/plant

● Special Maintenance

Best Estimate = \$6K/plant
High Estimate = \$8K/plant
Low Estimate = \$5K/plant

For plants under construction, the above cost reductions due to improved access can be used directly because the RCL piping is not yet radioactive. For operating plants, however, these estimates must be reduced by the cost of removing those restraints not normally removed for ISI (i.e., not on the crossover legs). Assuming an additional 16 restraints would be removed and that the per-restraint removal cost would be half that for removal and reinstallation yields the following cost estimates:

Best Estimate = \$21K/plant
High Estimate = \$27K/plant
Low Estimate = \$16K/plant

Development of Overall Avoided Operating Costs

The avoided operating costs summarized in Table 9 are assumed to apply only to operating plants now having pipe whip restraints and to plants under construction (which are all assumed to incorporate pipe whip restraints in their design). The overall reduction in operating costs for PWR plants is estimated by applying the above estimates to plants not included in the A-2 evaluation and then adding in the A-2 exposure estimates from Generic Letter 84-04. This is done as follows:

Table 9. Summary of Avoided Industry Operating Costs (PWR)
(\$K/plant)

Factor	Operating Plants ^a			Plants Under Construction ^b		
	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>
<u>ISI</u>						
Eliminate removal, reinstallation of whip restraints	64	80	48	85	107	64
Improve access	10	13	18	13	17	10
Initial restraint removal	-11	-13	-8	n/a	n/a	n/a
<u>Maintenance</u>						
Gap verification	2	3	1	3	3	1
Pump seals	11	14	8	15	19	11
Special maintenance	5	6	4	6	8	5
Removal of non-ISI restraints	-21	-27	-16	n/a	n/a	n/a
Total Reduction	60	76	45	122	154	92

Notes:

- (a) Plants with pipe whip restraints only. Excludes operating plants included in the A-2 evaluation, C-E plants benefiting from installing permanent neutron streaming shields and fuel pool seals, and Crystal River 3 (B&W).
- (b) It is assumed that pipe whip restraints are not yet installed in plants under construction.

- Westinghouse

There are 19 operating Westinghouse plants not included in the A-2 evaluation, all of which are assumed to have pipe whip restraints, and 24 plants under construction. Therefore, the best estimate of avoided costs is:

$$\begin{aligned}\text{Best Estimate} &= (19 \text{ plants})(\$60\text{K}/\text{plant}) + (24 \text{ plants})(\$122\text{K}/\text{plant}) \\ &= \$4068\text{K} = \$4.1\text{E}+6\end{aligned}$$

$$\text{High Estimate} = \$5.1\text{E}+6$$

$$\text{Low Estimate} = \$3.1\text{E}+6$$

- Combustion Engineering

Two operating plants have pipe whip restraints; five plants are under construction. Therefore, the total avoided operating costs for Combustion Engineering plants is:

$$\begin{aligned}\text{Best Estimate} &= (2 \text{ plants})(\$60\text{K}/\text{plant}) + (5 \text{ plants})(\$122\text{K}/\text{plant}) \\ &= \$730\text{K} = \$7.3\text{E}+5\end{aligned}$$

$$\text{High Estimate} = \$9.2\text{E}+5$$

$$\text{Low Estimate} = \$5.5\text{E}+5$$

- Babcock & Wilcox

One B&W plant (Crystal River 3) uses eight large-bore snubbers (18 to 25 inches diameter) on each of the four reactor coolant pumps to withstand large LOCA loads. The same value-impact study from which the estimated reductions in O&M were obtained indicated that reducing the number of snubbers from 32 to 8 would result in a cost saving of \$8.9 million due mainly to the avoidance of over 250,000 man-hours of labor over plant life for routine snubber maintenance. The total avoided operating costs for B&W plants are:

$$\begin{aligned}
 \text{Best Estimate} &= (1 \text{ plant})(\$60\text{K}/\text{plant}) + (3 \text{ plants})(\$122\text{K}/\text{plant}) + \\
 &\quad (1 \text{ plant})(\$8900\text{K}/\text{plant}) \\
 &= \$9266\text{K} = 9.3\text{E}+6
 \end{aligned}$$

$$\text{High Estimate} = \$9.4\text{E}+6$$

$$\text{Low Estimate} = \$9.2\text{E}+6$$

The estimated avoided maintenance costs for Crystal River can be regarded as very reliable. The \$8.9 million cost estimate was therefore retained in both the high and low estimates given above.

- A-2 Plants

In the A-2 evaluation, it was assumed that not installing plant modifications would save 80 man-hr/py in labor, resulting in an annual saving of \$4540/plant in avoided maintenance costs. The A-2 evaluation discretely discounted this value over the 23.5 years of average remaining life using 5% and 10% annuity discount factors of 13.6 and 8.9, respectively.

In the present analysis, the \$4540/plant annual cost of avoided maintenance has been retained, but was used in its raw, undiscounted form. As noted in Appendix C of NUREG/CR-3568, recurrent costs can be discounted only if they are the same amount for each time period. However, it is reasonable to expect that labor costs for plant maintenance would more-or-less follow the inflation rate from year to year. Therefore, it is felt that using the undiscounted operating costs more accurately reflects the real costs (or in this case, cost savings) to the plant owner. The estimated avoided operating costs for the A-2 plants are:

Best Estimate = (16 plants)(\$4540/py)(23.5/yr)
= \$1707K = \$1.7E+6

High Estimate = \$2.6E+6

Low Estimate = \$8.5E+5

where the high and low estimates reflect a $\pm 50\%$ uncertainty range.

The total reduction in operating costs was then estimated as follows:

Best Estimate = (\$4.1E+6 + \$7.3E+5 + \$9.3E+6) + (\$1.7E+6)
= \$1.6E+7

High Estimate = \$1.8E+7

Low Estimate = \$1.4E+7

Note that this value is heavily dominated by the avoided costs for Crystal River. If these costs are omitted, the estimated reductions in operating costs become:

Best Estimate = \$6.9E+6

High Estimate = \$9.1E+6

Low Estimate = \$4.8E+6

To investigate the effect of neglecting the discount factor, a simple uncertainty calculation can be performed. The average annual cost of avoided maintenance for the 69 plants not included in the A-2 evaluation is estimated as follows:

Best Estimate = (\$1.4E+7)/(2922-377 py)
= \$5500/py

Noting that these plants have an average of 36.9 years of remaining life and assuming a 10% discount factor results in an annuity discount factor of 9.7. The present value of avoided operating costs for all 69 plants over this time period is therefore:

$$\begin{aligned} PV &= (\$5500K/py)(69 \text{ plants})(9.7) \\ &= \$3.7E+6 \end{aligned}$$

Adding this value to the discounted avoided operating costs for the A-2 plants taken directly from Generic Letter 84-04 results in the following estimate of discounted costs for all 85 PWR plants:

$$\begin{aligned} \text{Best Estimate} &= \$3.7E+6 + \$6.5E+5 \\ &= \$4.3E+6 \end{aligned}$$

This value is about 27% of the undiscounted cost. The variation in cost, however, has only a minor effect on the total impact summarized in Table 2.

6.1.8 NRC Development and Implementation Cost

Development and implementation costs incurred by the NRC were estimated assuming one man-year of labor at \$100K/man-year will be expended during the course of the rulemaking effort. This includes costs for developing the rule change itself, as well as staff review leading to the final modification to 10CFR50, Appendix A. Costs of developing the technical basis for the rule change, and costs of reviewing previous industry fracture mechanics submittals related to "leak before break" have not been included.

Although a technical basis appears to exist at this time for excluding double-ended pipe breaks from reactor coolant loop piping, extension of this exclusion to other piping systems will likely require that NRC develop a Regulatory Guide or other formal guidelines outlining suitable acceptance criteria. It is estimated that one man-year of effort would be required for this purpose. The total estimated development and implementation costs are as follows:

Best Estimate = \$200K

High Estimate = \$300K

Low Estimate = \$100K

where a $\pm 50\%$ uncertainty range has been used to define the high and low cost estimates.

6.1.9 NRC Operation Cost

It is assumed that review of industry submittals seeking exclusions under the modified version of General Design Criterion 4 will require the same amount of effort (about 0.25 man-year per plant site) as is currently expended reviewing requests for partial exemptions to GDC-4. Therefore, no additional NRC operating costs are assumed for reactor coolant loop piping. It is anticipated that less effort would actually be required under the proposed rule change; therefore, a reduction in NRC operating costs could be expected.

6.2 Boiling Water Reactor Plants

This section presents the detailed development of value-impact for BWR recirculation loop piping. This assessment was based on the following general assumptions:

- (1) A total of 38 plants are considered. The breakdown of operating plants and plants under construction is given in Appendix A.
- (2) The 38 plants have a total remaining lifetime of 1314 plant-years, assuming a design lifetime of 40 years.
- (3) The 38 plants overall have an average remaining lifetime of 34.6 years.

6.2.1 Public Health

The changes in risk and core-melt frequency for BWR recirculation loop piping were estimated in a manner similar to that used for PWR reactor coolant loop piping.

A comprehensive assessment of the probability of DEGB in BWR recirculation piping, analogous to that for PWR reactor coolant loop piping, is in progress. Preliminary results generated by LLNL indicate however that in the absence of intergranular stress corrosion cracking (IGSCC), the best-estimate probability of direct DEGB is less than $1.0E-12$ /py. Therefore, lacking more precise uncertainty results, a value of $1.0E-10$ /py appears to be a reasonable estimate of direct DEGB probability. Note that use of this value presumes exclusion of pipe breaks would not be allowed for recirculation piping considered sensitive to IGSCC (such as that fabricated from Type 304 stainless steel). This assumption is consistent with the recommendations made by the NRC Piping Review Committee, Pipe Break Task Group, in NUREG-1061.⁵

The LLNL evaluations of PWR reactor coolant loop piping consistently indicated that indirect causes, namely the seismically induced failure of certain "critical" components (reactor pressure vessel supports, steam generator supports, reactor coolant pump supports), were the predominant potential cause of DEGB. In the absence of IGSCC, it is anticipated that this will be true for BWR plants as well. For BWR plants, failure of the RPV support structure appears to be the only plausible cause of an indirect DEGB. An evaluation of indirect DEGB in BWR plants is currently in progress; however, it seems reasonable to assume that heavy component supports in BWR plants are as reliable as in PWR plants. Under this assumption, the median results for PWR plants east of the Rocky Mountains imply that $1.0E-7$ /py can be used as a reasonable upper bound probability of DEGB due to indirect causes (note that there are no BWR plants on the west coast).

These results were used to estimate the change in core-melt frequency, ΔF , resulting from implementation of the proposed rule change. The best-estimate of ΔF was based on the $1.0E-10$ /py probability of direct DEGB previously discussed. It was assumed that only breaks inside the sacrificial shield wall would unconditionally cause core melt due to annulus

pressurization loads on the reactor vessel. For breaks outside the shield wall, a 20% conditional probability of core melt due to systems interaction was applied to account for dependent failures of safety equipment. The total probability of DEGB was allocated 20% inside and 80% outside of the shield wall.

Summing the contributions of pipe breaks inside and outside the reactor cavity therefore yields the best-estimate increase in core-melt frequency as follows:

$$\begin{aligned}\Delta F &= 0.20(1.0E-10/\text{py})(1.0) + 0.80(1.0E-10/\text{py})(0.2) \\ &= 2.0E-11/\text{py} + 1.6E-11/\text{py} \\ &= 3.6E-11/\text{py}\end{aligned}$$

The median probability of indirect DEGB for Westinghouse plants east of the Rocky Mountains was taken as the upper bound increase in core-melt frequency. Note that because RPV support failure appears to be the only plausible cause of indirect DEGB, the assumption that indirect DEGB automatically causes core-melt appears more reasonable than for the PWR reactor coolant loop piping.

As in the PWR risk analysis, it is important to point out that although the probability of indirect DEGB is significantly higher than that of direct DEGB, elimination of dynamic effects of pipe break would not cause it to change (i.e., increase). This is because under the proposed rule change, current design margins in primary loop component supports would be maintained. Existing heavy component supports designed for the effects of pipe rupture would not be affected. New plants would be designed with supports having margins comparable to equivalent margins in older plants. Thus, support reliability (and with it the probability of an indirect DEGB) would presumably not be affected by the proposed rule change.

Assuming that the lower bound on DEGB probability is zero, the estimated change in core-melt frequency is summarized as follows:

Best Estimate = $3.6\text{E-}11/\text{py}$
High Estimate = $1.0\text{E-}7/\text{py}$
Low Estimate = 0

As was done in the PWR analysis, the best-estimate of public risk was developed in two steps. For breaks inside the shield wall, it was assumed that annulus pressurization unconditionally causes core melt. Release sequences analogous to those for reactor pressure vessel rupture in WASH-1400 were assumed to apply. These sequences are as follows (Table V.3-16, Appendix V, dominant only);

RPV rupture, oxidizing atmosphere (BWR-2) with frequency = $2\text{E-}8/\text{py}$
RPV rupture, nonoxidizing atmosphere (BWR-3) with frequency = $1\text{E-}7/\text{py}$

WASH-1400 assumes a vessel rupture frequency (and therefore core melt frequency) of $1.0\text{E-}7/\text{py}$. Replacing this value with $2.0\text{E-}11/\text{py}$ and using the WASH-1400 dose estimates for each release category results in the following best-estimate of risk from DEGB inside the shield wall

$$\begin{aligned}\text{Risk} &= (4.0\text{E-}12/\text{py})(7.1\text{E}+6 \text{ man-rem}) + (2.0\text{E-}11/\text{py})(5.1\text{E}+6 \text{ man-rem}) \\ &= 1.3\text{E-}4 \text{ man-rem/py}\end{aligned}$$

where the frequency of each release category has been scaled by the ratio of core-melt frequencies.

The risk contribution from breaks outside the shield wall was estimated assuming accident sequences analogous to those for a large LOCA in WASH-1400 were applicable. The dominant large LOCA release sequences (Table V.3-16, Appendix V) with their corresponding release frequencies, are:

AE- α (BWR-1) with frequency = $2E-9/py$
 AJ- α (BWR-1) with frequency = $1E-10/py$
 AHI- α (BWR-1) with frequency = $1E-10/py$
 AI- α (BWR-1) with frequency = $1E-10/py$

AE-Y' (BWR-2) with frequency = $3E-8/py$
 AE-B (BWR-2) with frequency = $1E-8/py$
 AJ-Y' (BWR-2) with frequency = $2E-9/py$
 AI-Y' (BWR-2) with frequency = $2E-9/py$
 AHI-Y' (BWR-2) with frequency = $2E-9/py$

AE-Y (BWR-3) with frequency = $1E-7/py$
 AJ-Y (BWR-3) with frequency = $1E-8/py$
 AI-Y (BWR-3) with frequency = $1E-8/py$
 AHI-Y (BWR-3) with frequency = $1E-8/py$

AGJ- δ (BWR-4) with frequency = $6E-11/py$
 AEG- δ (BWR-4) with frequency = $7E-10/py$
 AGHI- δ (BWR-4) with frequency = $6E-11/py$

WASH-1400 assumes a median large LOCA frequency of $1E-4$ per plant-year. By replacing this value with the nominal increase in core-melt frequency estimated previously ($1.6E-11/py$), the risk from a DEGB outside of the shield wall becomes:

$$\begin{aligned} \text{Risk} &= (3.7E-16/py)(5.4E+6 \text{ man-rem}) + (7.4E-15/py)(7.1E+6 \text{ man-rem}) + \\ &\quad (2.1E-14/py)(5.1E+6 \text{ man-rem}) + (1.3E-16/py)(6.1E+5 \text{ man-rem}) \\ &= 1.6E-7 \text{ man-rem/py} \end{aligned}$$

where the frequency of each release category has been scaled by the ratio of core-melt frequencies. Note that the core-melt frequency used here already includes the 80% allocation of total DEGB probability to breaks outside of the shield wall, as well as the 20% systems interaction contribution to account for core melt due to dependent failures of safety equipment.

The best-estimate of per-plant risk due to a recirculation loop DEGB therefore becomes:

$$\begin{aligned}\text{Risk} &= 1.3\text{E-}4 \text{ man-rem/py} + 1.6\text{E-}7 \text{ man-rem/py} \\ &= 1.3\text{E-}4 \text{ man-rem/py}\end{aligned}$$

To estimate the upper bound on risk, the upper bound change in core-melt frequency ($1.0\text{E-}7/\text{py}$) was applied to the release sequences previously described. For breaks inside the shield wall, the risk contribution is:

$$\begin{aligned}\text{Risk} &= (2.0\text{E-}8/\text{py})(7.1\text{E+}6 \text{ man-rem}) + (1.0\text{E-}7/\text{py})(5.1\text{E+}6 \text{ man-rem}) + \\ &= 0.65 \text{ man-rem/py}\end{aligned}$$

Because RPV support structure failure is assumed to be the only plausible cause of indirect DEGB, no indirectly-induced breaks outside the shield wall are assumed to occur. Therefore, 0.65 man-rem/py represents the upper bound plant risk due to recirculation loop DEGB.

The lower bound on risk is taken to be zero. Multiplying each of the risk calculations by the number of remaining plant years (≈ 1314) results in the following estimates of incremental increase in total risk to the public due to elimination of reactor coolant loop DEGB as a design requirement:

$$\begin{aligned}\text{Best Estimate} &= 1.7\text{E-}1 \text{ man-rem} \\ \text{High Estimate} &= 8.5\text{E+}2 \text{ man-rem} \\ \text{Low Estimate} &= 0 \text{ man-rem}\end{aligned}$$

Note that this analysis results in a very small increase in public risk. As in the PWR risk analysis, however, we have not attempted to take credit for increased piping reliability due to avoidance of possible pipe binding or to improved effectiveness of routine in-service inspection, factors which could conceivably reduce public risk associated with the proposed rule change (see Sec. 6.1.1).

6.2.2 Occupational Exposure - Accidental

The increased occupational exposure from accidents can be estimated as the product of the change in total core-melt frequency and the occupational exposure likely to occur in the event of a major accident. The nominal change in core-melt frequency was estimated as $3.6E-11$ /py. The occupational exposure in the event of major accident has two components. The first is the immediate exposure to personnel on site during the span of the event and its short-term control. The second is the long-term exposure associated with cleanup and recovery from the accident. The incremental occupational exposure due to an accident is calculated as follows:

$$D_{TOA} = NTD_{OA}; D_{OA} = (\Delta F)(D_{IO} + D_{LTO})$$

where

- D_{TOA} = total accidental occupational dose
- N = number of affected facilities
- T = average remaining lifetime
- D_{OA} = accidental occupational dose per plant-year
- ΔF = change in core-melt frequency
- D_{IO} = immediate occupational dose
- D_{LTO} = long-term occupational dose

Table 10 presents the resultant occupational exposure due to accidents, based on cleanup and decommissioning estimates given in NUREG/CR-2800.⁹

6.2.3 Occupational Exposure - Routine

The proposed rule change would reduce occupational radiation exposure during routine operation and maintenance by (1) eliminating the need to remove and reinstall pipe whip restraints blocking access to welds during in-service inspection (ISI), and (2) generally relieving congestion in the vicinity of the recirculation piping, making maintenance operations (primarily ISI) more efficient.

Table 10. Occupational Exposure Due to Accidents (BWR)

	Change in Core-Melt Probability	Immediate Occupational Dose	Long-Term Occupational Dose	Total Occupational Exposure
	events/py	man-rem/event	man-rem/event	man-rem
Best Estimate	3.6E-11	1E3	2E4	9.9E-4
High Estimate	1.0E-7	4E3	3E4	4.5
Low Estimate	0	0	1E4	0

Removal and Reinstallation of Pipe Whip Restraints

For plants under construction (and future plants), elimination of pipe whip restraints would mean avoidance of radiation exposure during removal and reinstallation of pipe whip restraints for routine ISI. The avoided dose is estimated assuming 80 man-hours in a radiation area would be required to remove and reinstall each restraint (the total estimated labor for removal and reinstallation is 120 man-hours). In this assessment, a restraint is considered "removed" if it is functionally disengaged, in other words, only the restraining device itself (e.g., cable, collar, U-bolts) would actually be removed. The additional radiation dose associated with removal of restraint support structures (which are often much more complex than the restraints themselves) has not been quantified.

Assuming that 80 man-hours of labor in a radiation area (18 mR/hr near the recirculation pump) are required to remove and reinstall each restraint results in a unit dose of 1.5 man-rem/restraint. If it is assumed that during plant lifetime 13 out of 25 restraints will be removed for ISI (i.e., about 50%), the resultant avoided dose per plant is:

Best Estimate = (13 restraints)(1.5 man-rem/restraint)
= 20 man-rem/plant

High Estimate = 38 man-rem/plant

Low Estimate = 10 man-rem/plant

High and low estimates are based on 100% and 25% of the pipe whip restraints being removed and reinstalled, respectively.

For operating plants (excluding those older plants potentially affected by IGSCC), the proposed rule change would allow pipe whip restraints removed for routine ISI to be left off the pipe system. Exposure for restraint removal would be incurred as a part of the ISI procedure; the only avoided dose would therefore be that associated with reinstallation of restraints. This has been estimated by reducing the dose values estimated above by 50%.

Restricted Access for In-Service Inspection

The radiation dose due to restricted access during ISI is estimated as a percentage of the total ISI dose. If we assume an average dose of 0.8 man-rem per inspected weld¹² and a total of 60 welds inspected (typical of later-generation BWR recirculation systems), the total ISI exposure is 48 man-rem/plant. According to General Electric figures, approximately 28% of recirculation system labor can be attributed to whip restraint interference; thus, the estimated avoided dose due to restricted access during ISI is:

Best Estimate = 0.28 (48 man-rem/plant) = 13 man-rem/plant

High Estimate = 30 man-rem/plant

Low Estimate = 3 man-rem/plant

High and low estimates are based on exposure values of 3.0 and 0.3 man-rem per weld, respectively.¹²

Restricted Access for Routine Maintenance

Occupational radiation exposure is estimated for the following routine maintenance activities:

- Restraint Gap Verification

It is assumed that restraint gap verification will be performed once every ten years. Assuming that ORE averages 0.1 man-rem for each restraint (based on the PWR analysis in Section 5.1.3) results in the following reductions for eliminating 13 recirculation loop pipe whip restraints (i.e., not performing gap verification):

Best Estimate = 5 man-rem/plant

High Estimate = 25 man-rem/plant

Low Estimate = 1 man-rem/plant

where the high and low estimates are based on average exposures of 0.5 and 0.01 man-rem per restraint, respectively.

• Recirculation Pump Maintenance

Each recirculation pump is expected to require periodic maintenance refueling outages. Based on General Electric estimates, pump maintenance accounts for an average of 16.8 man-rem of annual exposure. Assuming restraint removal will increase work efficiency by 28% results in the following nominal reductions over the 40-year lifetime of each plant:

Best Estimate = 188 man-rem/plant

High Estimate = 224 man-rem/plant

Low Estimate = 112 man-rem/plant

where the high and low estimates reflect annual exposures of 20 man-rem and 10 man-rem, respectively.

These values apply directly to plants under construction. For operating plants, the values are prorated by the ratio of averaging remaining life to total plant lifetime ($\approx 30/40 = 75\%$).

Plants Undergoing Recirculation Loop Pipe Replacement

It has been assumed that no plant determined to be sensitive to IGSCC would be allowed to take advantage of the proposed rule change. For plants undergoing recirculation loop pipe replacement, the above dose estimates for plants under construction are assumed to apply. In addition, General Electric has estimated that eliminating pipe whip restraints on the new piping would save an additional 500 man-rem per plant in avoided installation exposure. If it is assumed that not installing restraints saves 24 to 30 calendar days of construction time (27 days average), the avoided installation exposure is:

Best Estimate = 500 man-rem/plant

High Estimate = 555 man-rem/plant

Low Estimate = 444 man-rem/plant

Summary of Routine Occupational Exposure

The per-plant reductions in routine occupational exposure associated with the proposed rule change are summarized in Table 11. The overall reduction in ORE is assessed as follows for the population of BWR plants considered.

- plants under construction potentially benefit from avoided dose for removal and replacement of pipe whip restraints during ISI, and from reduced congestion in the vicinity of the recirculation loop piping (14 plants).
- operating plants insensitive to IGSCC (i.e., having recirculation piping fabricated from IGSCC-resistant material), including plants which have already replaced piping, benefit from avoided dose for reinstallation of pipe whip restraints following ISI, and from reduced congestion in the vicinity of the recirculation loop piping (4 plants).
- operating plants which are currently replacing piping or which are committed to replacing piping take advantage of the same benefits as plants under construction, plus the avoided dose for not installing pipe whip restraints on the replaced piping (4 plants).
- operating plants for which no decision has been made on replacement have been omitted from the assessment.

Therefore, the total reduction in routine occupational exposure is estimated as follows:

Table 11. Summary of Reductions in Routine Occupational Exposure (BWR)
(man-rem/plant)

Factor	Operating Plants			Plants Under Construction		
	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>
<u>ISI</u>						
Eliminate removal, reinstallation of whip restraints	20 ^a	38 ^a	10 ^a	20	38	10
Improve access	13	30	3	13	30	3
Eliminate whip restraints from replacement pipe ^b	500	555	444	n/a	n/a	n/a
<u>Maintenance</u>						
Gap verification	4	18	1	5	25	1
Recirculation pump work	141	168	84	188	224	112
Total Reduction ^c	678 (168)	809 (235)	542 (93)	226	317	126

Notes:

- (a) Indicated values are for plants where change-out of recirculation piping is either planned or in progress. Values for other operating plants (excluding plants sensitive to IGSCC) are reduced by 50% to account for initial removal of pipe whip restraints.
- (b) Indicated values are for plants where change-out of recirculation piping is either planned or in progress.
- (c) Values in parentheses are for plants having IGSCC-resistant recirculation piping (e.g., change-out of recirculation piping complete).

$$\begin{aligned}\text{Best Estimate} &= (14 \text{ plants})(226 \text{ man-rem}) + (4 \text{ plants})(168 \text{ man-rem}) + \\ &\quad (7 \text{ plants})(678 \text{ man-rem}) \\ &= 8582 \text{ man-rem} \approx 8.6\text{E}+3 \text{ man-rem}\end{aligned}$$

$$\text{High Estimate} = 1.1\text{E}+4 \text{ man-rem}$$

$$\text{Low Estimate} = 5.9\text{E}+3 \text{ man-rem}$$

Note that the largest potential contributor to this exposure reduction is the avoided dose for reinstallation of pipe whip restraints on replacement recirculation piping.

6.2.4 Offsite Property Damage

The effect of the proposed action upon the risk to offsite property is calculated by multiplying the change in accident frequency by a generic offsite property damage estimate. This estimate was derived from the mean value of CRAC2 calculations, assuming an SST1 release (major accident), for 154 reactors.¹⁰ CRAC2 includes costs for evacuation, relocation of displaced persons, property decontamination, loss of use of contaminated property through interdiction and crop and milk losses. Litigation costs, impacts to areas receiving evacuees and institutional costs are not included. The damage estimate is converted to present value by discounting at 10%. A 5% discount rate was also considered as a sensitivity case.

The following discounting formula is employed:

$$\frac{D}{V} = \frac{e^{-It_1} - e^{-It_f}}{I}$$

where

D = discounted value

V = damage estimate

t_i = years before reactor begins operation; 0 for operating plants

t_f = years remaining until end of plant life

I = discount rate

For the purposes of this assessment, no distinction is made between operating and planned reactors; the average remaining life of the entire population of 38 reactors is 34.6 years. The 10% discount factor is therefore 9.7, the 5% discount factor 16.4. The risk to offsite property, V_{FP} , is estimated as:

$$V_{FP} = N(\Delta F)D$$

where N and ΔF are, respectively, the number of plants and the change in core-melt frequency. The results are summarized in Table 12; upper and lower bounds are values calculated in Ref. 10 for Indian Point 2 and Palo Verde 3 coupled with the bounds on the core-melt frequency.

6.2.5 Onsite Property Damage

The effect of the proposed action on the risk to onsite property is estimated by multiplying the change in accident frequency by a generic onsite property cost. This generic onsite property cost in NUREG/CR-2800 was taken. Costs included are for interdicting or decontaminating onsite property, replacement power and capital cost of damaged plant equipment. Onsite property damage costs were discounted using the following formula.

$$\frac{D}{V} = \frac{1}{mI^2} \{e^{-It_i}\} \{(1 - e^{-Im})[1 - e^{-I(t_f - t_i)}]\}$$

Table 12. Summary of Offsite Property Damage (BWR)

	Offsite Property Damage (\$/event)	Discounted Offsite Property Damage (\$/event)		Value of Offsite Property Damage (\$)	
		10%	5%	10%	5%
Best Estimate	1.7E9	1.6E+10	2.8E+10	2.2E+1	3.8E+1
High Estimate	9.2E9	8.9E+10	1.5E+11	3.4E+5	5.7E+5
Low Estimate	8.3E8	8.1E+9	1.4E+10	0	0

where

D = discounted value

V = damage estimate

m = years required for plant recovery (= 10 years)

t_1 = years before reactor begins operation; 0 for operating plants

t_f = years remaining until end of plant life

r = discount rate

For the purposes of this assessment, no distinction is made between operating and planned reactors. The 10% discount factor is therefore 6.5, the 5% discount factor 12.9. The risk to onsite property is estimated as:

$$V_{OP} = N(\Delta F)U$$

where

V_{OP} = value of avoided onsite property damage

N = number of affected facilities

ΔF = change in accident frequency

U = present value of property damage occurring with frequency ΔF

The results are summarized in Table 13; the uncertainty bounds reflect a $\pm 50\%$ spread in the generic property cost coupled with the bounds on core-melt frequency.

6.2.6 Industry Implementation Costs

Description of Costs

Significant cost benefits to industry are foreseen as a result of the proposed rule change. Costs (or more appropriately cost savings) developed for recirculation loop piping are summarized in Table 14 for plants in the design stage (including future plants), plants under construction, and

Table 13. Summary of Onsite Property Damage (BWR)

	Onsite Property Damage (\$/event)	Discounted Onsite Property Damage (\$/event)		Value of Onsite Property Damage (\$)	
		10%	5%	10%	5%
Best Estimate	1.7E9	1.1E+10	2.2E+10	1.5E+1	3.0E+1
High Estimate	2.5E9	1.6E+10	3.2E+10	6.1E+4	1.2E+5
Low Estimate	8.2E8	5.3E+9	1.1E+10	0	0

Table 14. Summary of BWR Implementation Costs
(K\$/plant)

Cost Item	Initial Design Stage ^a	Under Construction ^a	Operating
<u>Pipe Whip Restraints</u>			
Design, fabrication	-170	-15	n/a
Installation, adjustment	-1440	-840	175
<u>Jet Impingement</u>			
Target load analysis	-40	-40	n/a
<u>General Analysis</u>			
Thermal hydraulics and piping response	-1050	-300	n/a
Structural response and support design	-650		n/a
RPV internals	-150	0	n/a
Net total costs	-3500	-1195	-175

Notes:

- (a) Includes future plants.
- (b) Assumes initial design activities are complete. Assumes pipe whip restraints have been designed, procured, and fabricated but not installed.
- (c) Plants currently replacing recirculation piping with IGSCC-resistant materials or committed to pipe replacement.

operating plants. Note that all operating BWR plants are equipped with pipe whip restraints, typically 10 to 15 per recirculation loop. It is generally assumed for plants under construction that all initial design activities (which comprise the bulk of analysis costs) are complete. Cost areas are categorized as follows:

- Elimination of pipe whip restraints. Overall cost estimates are grouped according to (1) design and fabrication, and (2) installation and adjustment of pipe whip restraints. For new plants, the first group includes costs for engineering design, interface documentation between NSSS vendor and architect-engineer, and restraint materials and fabrication. For plants under construction, it is assumed that restraints have been designed and procured, but that installation has not yet taken place. The design costs for new plants assume that standard restraint designs would be used on new product lines; therefore, no first-time design costs are included as was done for PWR plants. Installation costs include the estimated contribution of pipe whip restraint interference to the overall costs of installing the recirculation piping; this can amount to over \$1 million for new plants and about half this amount for plants under construction.
- Jet impingement. Jet impingement barriers are typically not installed for postulated breaks in recirculation loop piping. Costs are limited to target load analyses performed by General Electric at customer request. These analyses typically include develop of jet maps and detailed analysis of loads associated with those jets identified as significant.
- Thermalhydraulic and piping response analysis. This category includes the following analysis costs: reactor coolant system hydrodynamic loads and resultant piping response caused by a pipe break; response of the tributary piping, control rod drive mechanisms, and in-core instrumentation to pipe break loads; mass and energy releases to the environment (subcompartment blowdown).

- Structural response and support design. This category includes avoided or reduced costs for: reactor cavity analysis ("annulus pressurization"); design of RPV supports for in-cavity loads; preparation of component and support stress reports.
- RPV internals response analysis. This category includes analysis of depressurization loads that would be placed on the reactor fuel and internal mechanical structures in the event of a pipe break.

Plants Undergoing Recirculation Loop Pipe Replacement

It has been assumed that no plant determined to be sensitive to IGSCC would be allowed to take advantage of the proposed rule change. For plants undergoing recirculation loop pipe replacement, the above cost estimates for plants under construction are assumed to apply. In addition, General Electric has estimated that eliminating pipe whip restraints on the new piping would save an additional 3500 man-hours per plant in avoided installation costs, based on a time-motion study performed at the Hatch nuclear generating station. If it is assumed that not installing restraints saves 24 to 30 calendar days of construction time (27 days average), the avoided installation cost is:

Best Estimate = \$175K/plant

High Estimate = \$194K/plant

Low Estimate = \$156K/plant

If piping change-out took place during an unscheduled plant outage, this improvement in installation schedule could also result in avoided costs for replacement power over this period (assuming that restraint installation was the only activity taking place during this period). The estimated cost of replacement power is:

Best Estimate = (27 days)(\$300K/day) = \$8.1E+6K

High Estimate = \$3.0E+7

Low Estimate = \$2.4E+5

where the high and low estimates are based on \$1000K/day over 30 days and \$100K/day over 24 days, respectively.

Development of Overall Implementation Costs

The overall implementation costs associated with the proposed rule change is assessed as follows for the population of BWR plants considered.

- it is assumed that initial design is complete for all plants currently under construction; therefore, the primary benefit would come from avoided costs for installation of pipe whip restraints and from reduced congestion in the vicinity of the recirculation loop piping (14 plants). The actual cost benefit would depend largely on the construction status, and the point at which restraint installation was scheduled. To account for cost variations, a $\pm 50\%$ uncertainty range was applied to the costs given above.
- operating plants which are currently replacing piping or which are committed to replacing piping take advantage of avoided costs for installation of pipe whip restraints on the replaced piping (7 plants). High and low cost estimates (\$194K and \$156K, respectively) were developed in a manner analogous to that used for high and low ORE estimates associated with this activity. Costs for replacement power were not included in assessing overall implementation costs, but are included in the value-impact summary in Table 3.
- operating plants for which no decision has been made on replacement have been omitted from the assessment.

Therefore, the overall implementation costs are estimated as follows:

$$\begin{aligned}\text{Best Estimated} &= (14 \text{ plants})(\$1195\text{K}) + (7 \text{ plants})(\$175\text{K}) \\ &= \$1.8\text{E}+7\text{K}\end{aligned}$$

$$\text{High Estimate} = \$2.8\text{E}+7\text{K}$$

$$\text{Low Estimate} = \$9.5\text{E}+6\text{K}$$

Note that the largest benefit comes from reduced congestion in the recirculation loop area during plant construction.

6.2.7 Industry Operating Costs

The proposed rule change would reduce operating costs during routine operation and maintenance by (1) eliminating the need to remove and reinstall pipe whip restraints blocking access to welds during in-service inspection (ISI), and (2) generally relieving congestion in the vicinity of the recirculation piping, making maintenance operations (primarily ISI) more efficient. These costs, summarized in Table 15 were developed as follows.

Removal and Reinstallation of Pipe Whip Restraints

For plants under construction (and future plants), elimination of pipe whip restraints would mean avoidance of costs for removal and reinstallation of pipe whip restraints during routine ISI. The avoided costs are estimated assuming that for each restraint 60 man-hours would be required for removal and 60 man-hours would be required for reinstallation. These 60 man-hours include 20 man-hours for preparation and access to the pipe whip restraint, and 40 man-hours for actual removal (or reinstallation), including transport. In this assessment, a restraint is considered "removed" if it is functionally disengaged, in other words, only the restraining device itself (e.g., cable, collar, U-bolts) would actually be removed. The additional costs for removing restraint support structures (which are often much more complex than the restraints themselves) have not been quantified.

Table 15. Summary of Avoided Industry Operating Costs (BWR)
(\$K/plant)

Factor	Operating Plants			Plants Under Construction		
	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>	<u>Best Estimate</u>	<u>High Estimate</u>	<u>Low Estimate</u>
<u>ISI</u>						
Eliminate removal, reinstallation of whip restraints	80 ^a	152 ^a	44 ^a	80	152	44
Improve access	50	96	37	50	96	37
<u>Maintenance</u>						
Gap verification	2	3	1	2	3	1
Pump seals	39	47	23	52	62	31
Total Reduction	171 ^b (131)	298 ^b (222)	105 ^b (83)	184	313	113

Notes:

- (a) Indicated values are for plants where change-out of recirculation piping is either planned or in progress. Values for other operating plants (excluding plants sensitive to IGSCC) are reduced by 50% to account for initial removal of pipe whip restraints.
- (b) Values in parantheses are for plants IGSCC-resistant recirculation piping (e.g., change-out of recirculation piping complete).

Any activity involving removal or reinstallation of restraints would also be followed by an additional 30 man-hours of effort, independent of the number of restraints involved, to prepare a drawing of the new "as-built" restraint configuration.

Assuming 120 man-hours of labor at \$50/hour yields a cost of \$6K to remove and reinstall each restraint. Drawing preparation would cost an additional \$1.5K. If it is assumed that during plant lifetime 13 out of 25 restraints will be removed for ISI (i.e., about 50%), the resultant avoided cost per plant is:

$$\begin{aligned}\text{Best Estimate} &= (13 \text{ restraints})(\$6\text{K/restraint}) + \$1.5\text{K} \\ &= \$80\text{K/plant}\end{aligned}$$

$$\text{High Estimate} = \$152\text{K/plant}$$

$$\text{Low Estimate} = \$44\text{K/plant}$$

High and low estimates are based on 100% and 25% of the pipe whip restraints being removed and reinstalled, respectively.

For operating plants (excluding those older plants potentially affected by IGSCC), the proposed rule change would allow pipe whip restraints removed for routine ISI to be left off the pipe system. Costs for restraint removal would be incurred as a part of the ISI procedure; the only avoided costs would therefore be those for reinstallation of restraints. This has been estimated by reducing the costs estimated above by 50%.

Restricted Access for In-Service Inspection

The additional cost due to restricted access during ISI is estimated as a percentage of the total ISI cost. If we assume an average cost of \$3.0K per inspected weld and a total of 60 welds inspected (typical of later-generation BWR recirculation systems), the total ISI cost is \$180K per plant.¹² From General Electric figures, about 28% of recirculation system labor can be attributed to whip restraint interference; thus, the estimated avoided cost due to restricted access during ISI is:

Best Estimate = $0.28(\$180\text{K}/\text{plant}) = \$50\text{K}/\text{plant}$

High Estimate = $\$96\text{K}/\text{plant}$

Low Estimate = $\$37\text{K}/\text{plant}$

High and low estimates are based on inspection costs of \$5.7K and \$2.2K per weld, respectively.¹²

Restricted Access for Routine Maintenance

Avoided costs due to restricted access are estimated for the following routine maintenance activities:

- **Restraint Gap Verification**

It is assumed that restraint gap verification will be performed once every ten years. Assuming that ORE averages 0.1 man-rem for each restraint (see Section 6.2.3) in a 0.18 rem/hr environment yields the following approximate costs avoided by eliminating 13 recirculation loop pipe whip restraints (i.e., not performing gap verification):

$$\begin{aligned}\text{Best Estimate} &= (1.3 \text{ man-rem})(\$50/\text{hr})/(0.18 \text{ rem/hr}) \\ &= \$2\text{K}/\text{plant}\end{aligned}$$

High Estimate = $\$3\text{K}/\text{plant}$

Low Estimate = $\$1\text{K}/\text{plant}$

where the high and low estimates are based on average exposures of 0.5 and 0.01 man-rem per restraint, respectively.

- **Recirculation Pump Maintenance**

Based on the exposures for pump maintenance estimated in Section 6.2.3 and assuming a 0.18 rem/hr radiation environment, the following avoided costs due to restricted access during pump maintenance are estimated for the 40-year lifetime of each plant:

Best Estimate = \$52K/plant
High Estimate = \$62K/plant
Low Estimate = \$31K/plant

It is assumed that operating plants with replacement recirculation piping would have all welds inspected over the remainder of their operating lives. Therefore, these values apply directly both to operating plants and to plants under construction.

Summary of Industry Operating Costs

The overall reduction in operating costs associated with the proposed rule change is assessed as follows for the population of BWR plants considered.

- plants under construction potentially benefit from avoided costs for removal and replacement of pipe whip restraints during ISI, and from reduced congestion in the vicinity of the recirculation loop piping (14 plants).
- operating plants insensitive to IGSCC (i.e., having recirculation piping fabricated from IGSCC-resistant material), including plants which have already replaced piping, benefit from avoided costs for reinstallation of pipe whip restraints following ISI, and from reduced congestion in the vicinity of the recirculation loop piping (4 plants).
- operating plants which are currently replacing piping or which are committed to replacing piping take advantage of the same benefits as plants under construction (7 plants).
- operating plants for which no decision has been made on replacement have been omitted from the assessment.

Therefore, the total reduction in operating costs is estimated as follows:

$$\begin{aligned}\text{Best Estimate} &= (14 \text{ plants})(\$184\text{K}/\text{plant}) + (4 \text{ plants})(\$131\text{K}/\text{plant}) + \\ &\quad (7 \text{ plants})(\$171\text{K}/\text{plant}) \\ &= \$4297\text{K} = \$4.3\text{E}+6\end{aligned}$$

High Estimate = $\$7.4\text{E}+6$

Low Estimate = $\$2.6\text{E}+6$

6.2.8 NRC Development and Implementation Costs

It is assumed that no additional development and implementation costs specifically for BWR plants will be incurred by the NRC during the course of the rulemaking effort. Therefore, the costs developed in Section 6.1.8 cover BWR plants as well.

6.2.9 NRC Operation Cost

It is anticipated that review of industry submittals seeking exclusions under the modified version of General Design Criterion 4 would require about the effort as reviewing requests for exemptions to GDC-4 assuming a suitable technical basis were to exist for recirculation piping. Therefore, no additional NRC operating costs are anticipated for BWR recirculation piping. It is anticipated that less effort would actually be required under the proposed rule change; therefore, a reduction in NRC operating costs could be expected.

7. APPLICATION TO OTHER PIPING SYSTEMS

7.1 Operating Plants and Plants Under Construction

The precise benefit of applying the proposed rule change to other piping systems will vary from plant to plant. For any given plant, the benefit will depend on specific physical characteristics as well as upon future administrative decisions by the utility owner. Typical variables affecting any decision on implementing the rule change might include:

- the cost of analysis to justify exclusion of pipe breaks. It is anticipated for small-diameter piping that the gains to be derived from eliminating postulated pipe breaks may be negated or exceeded by the cost of analysis necessary to gain the exclusion.
- demonstrating that leakage detection systems are sufficiently reliable, redundant, diverse, and sensitive to take credit for leak-before-break. This would include the cost of installing a leakage detection capability for piping systems not already so equipped, or possibly upgrading existing leakage detection systems.
- the cost of removing protective devices, once installed. The actual cost of removing a pipe whip restraint, for example, can vary by two orders of magnitude (i.e., from hundreds to tens-of-thousands of dollars each) depending on restraint size, type of mounting, rigging and scaffolding required, and general accessibility. Some protective devices also serve as supports for other piping, which would have to be rerouted (at additional cost) if the device were removed. Examination of data from operating plants indicates a somewhat marginal "payback" in terms of cost and ORE for wholesale removal of protective devices. The cost-benefit picture improves substantially if devices are removed selectively (e.g., only in high-maintenance areas). This is particularly true for devices that have to be routinely removed for maintenance or ISI, and whose removal costs are therefore already accounted for as a part of plant operation.
- for plants under construction with protective devices already installed, whether the devices would be removed before start-up (possibly resulting in schedule delays) or after plant operation had begun (in which case additional ORE would be incurred).

These and other factors would affect the eventual extent to which the proposed rule change would be applied. Because the factors are variable (and, in most cases, as yet unquantified), any assessment for other piping systems would be highly uncertain at best. However, limited data developed by industry sources participating in our assessment lends insight into the potential benefits of applying the proposed rule change to other piping systems.

One effort reviewed several PWR piping systems and identified all pipe rupture protection devices (i.e., pipe whip restraints and jet impingement barriers). The following criteria were then applied to itemize those devices which would have to be retained for special reasons (e.g., specific safety concerns, multi-purpose applications):

- (1) The piping is not seismically qualified.
- (2) The piping is less than six inches in diameter.
- (3) The protective device is required for "special protection."
- (4) The protective device acts as a pipe support.
- (5) Supports for other piping are attached to the protective device.
- (6) The device protects against through-wall cracks.
- (7) The device protects against feedwater line breaks at steam generator nozzles.

It was assumed that any device subject to one or more of these criteria would be retained, leaving the remaining devices as "candidates" for removal. Tables 16 through 18 summarize these results for three PWR plants: Plant "A", an operating Westinghouse plant; Plant "B", an NTOL (near-term operating license) Westinghouse plant; Plant "C", a B&W plant in the construction permit stage. These tables show for all three plants that 40 to 55 percent of the pipe whip restraints, and from 20 to 100 percent of the jet impingement barriers would be candidates for removal.

Finally, estimates were made of (1) the labor required for device removal, (2) the ORE dose received during removal, and (3) the ORE dose reduction over plant life resulting from improved access during operation and maintenance. Table 19 summarizes these results for each of the three PWR

Table 16. Summary of Piping Systems Affected by GDC-4 Modification
(Plant A: Westinghouse PWR, In Operation)

Piping System	Pipe Whip Restraints		Jet Impingement Barriers	
	Total ¹	To be removed ²	Total ¹	To be removed ²
Reactor Coolant Loops	20	16	4	4
Residual Heat Removal	1	1	0	0
Main Steam	50	32	12	0
Main Feedwater	43	10	2	0
Auxiliary Feedwater	21	0	1	0
Chemical Volume Control	16	0	0	0
Safety Injection	12	10	0	0
Steam Generator Blowdown	25	0	0	0
Upper Head Injection	31	14	4	0
Pressurizer Surge Line	17	17	1	1
Totals	236	100	24	

Notes:

- (1) Total number of restraints or barriers in system, i.e., number that would be affected if removal were required.
- (2) Number of restraints or barriers that would be affected if removal were optional. Only those devices (restraints or barriers) to which none of the following criteria applied were considered "candidates" for removal:
 - (a) The piping system was not seismically qualified.
 - (b) The piping is less than six inches in diameter.
 - (c) The device is required for "special protection".
 - (d) The device also acts as a pipe support.
 - (e) Pipe supports are attached to the device
 - (f) The device protects against feedwater line breaks at steam generator nozzles.

Table 17. Summary of Piping Systems Affected by GDC-4 Modification
(Plant B: Westinghouse PWR, NTOL Stage)

Piping System	Pipe Whip Restraints		Jet Impingement Barriers	
	Total ¹	To be removed ²	Total ¹	To be removed ²
Reactor Coolant Loops	20	16	0	0
Residual Heat Removal	8	8	1	1
Main Steam	57	33	14	4
Main Feedwater	42	14	0	0
Auxiliary Feedwater	11	10	8	1
Chemical Volume Control	1	1	0	0
Feedwater Bypass	3	0	0	0
Safety Injection	8	8	0	0
Steam Generator Blowdown	27	2	0	0
Pressurizer Surge Line	6	6	5	5
Upper Head Injection	4	4	4	0
Totals	187	102	32	11

Notes:

- (1) Total number of restraints or barriers in system, i.e., number that would be affected if removal were required.
- (2) Number of restraints or barriers that would be affected if removal were optional. Only those devices (restraints or barriers) to which none of the following criteria applied were considered "candidates" for removal:
 - (a) The piping system was not seismically qualified.
 - (b) The piping is less than six inches in diameter.
 - (c) The device is required for "special protection".
 - (d) The device also acts as a pipe support.
 - (e) Pipe supports are attached to the device
 - (f) The device protects against feedwater line breaks at steam generator nozzles.

Table 18. Summary of Piping Systems Affected by GDC-4 Modification
(Plant C: Babcock & Wilcox PWR, Construction Permit Stage)

Piping System	Pipe Whip Restraints		Jet Impingement Barriers	
	Total ¹	To be removed ²	Total ¹	To be removed ²
Reactor Coolant Loops	10	10	8	8
Residual Heat Removal	13	11	0	0
Main Steam	25	8	0	0
Main Feedwater	14	8	0	0
Pressurizer Surge Line	0	0	7	7
Make-Up and Purification	17	0	0	0
Totals	79	37	15	15

Notes:

- (1) Total number of restraints or barriers in system, i.e., number that would be affected if removal were required.
- (2) Number of restraints or barriers that would be affected if removal were optional. Only those devices (restraints or barriers) to which none of the following criteria applied were considered "candidates" for removal:
 - (a) The piping system was not seismically qualified.
 - (b) The piping is less than six inches in diameter.
 - (c) The device is required for "special protection".
 - (d) The device also acts as a pipe support.
 - (e) Pipe supports are attached to the device
 - (f) The device protects against feedwater line breaks at steam generator nozzles.

Table 19. Summary of Labor and Radiation Exposure for Removal of Restraints and Barriers^a

	Plant A	Plant B ^b	Plant C ^b
Number of Restraints/ Barriers Removed	100/5	102/11	37/15
Utility labor in radiation zones implementation (man-hr)	9700	10500	4900
Dose reduction, implementation	-114	- 124	- 57
Utility labor in radiation zones, operation and maintenance	(This information was not explicitly developed)		
Dose reduction, operation and maintenance (man-rem)	754	863	397
Net dose reduction (man-rem)	640	739	340

Notes:

- (a) Restraints and barriers are grouped together as "protective devices" for estimating labor requirements and ORE doses. Device removal is assumed to be at owner option.
- (b) For plants under construction, it has been assumed that implementation (i.e., device removal) would occur after plant operation had begun.

plants above. For the two Westinghouse plants, implementation of the rule change would cost some 10,000 man-hours in labor (or about \$400K at \$40/hour) and about 120 man-rem in ORE. Improved access would, however, reduce subsequent ORE during operating and maintenance by six to seven times this value, for a net ORE reduction of 640 to 740 man-rem. Corresponding values for the B&W plant are about half those for each Westinghouse plant, owing to the smaller number of protective devices. Note that for the two plants under construction it has been assumed that device removal would take place after plant operation had begun, hence the ORE dose for implementation. Removing the devices before start-up would eliminate implementation ORE (and thus improve the net dose reduction), but at the risk of potentially costly schedule delays.

As mentioned earlier, several factors may affect the potential benefit for an individual plant. Consequently, no attempt is made here to portray the values in Tables 16 through 19 as necessarily typical or exhaustive for all PWR plants. These values do, however, serve as an indicator of possible benefits that would result from extending the proposed rule change beyond primary reactor coolant piping.

Table 20 summarizes BWR piping systems that would potentially be affected by extending the proposed rule change beyond recirculation piping. The total number of pipe whip restraints in each system is also given; it is expected that about 40 percent of these would be candidates for removal.

7.2 Future Plants

A second industry effort performed in support of this value-impact assessment estimated cost savings for future plants, given extension of the proposed rule change to piping other than primary reactor coolant piping. Table 21 summarizes these estimates, based on the assumption that breaks will continue to be postulated in a limited number of large-bore systems (e.g., pressurized surge lines, portions of feedwater lines) as well as in small-bore systems where the burden of justifying break elimination may not prove to be cost-effective. Note that reductions in operating costs due to improved accessibility have not been included; the estimates in Table 21 concentrate on activities traditionally in the domain of an architect-engineer.

Table 20. Summary of Piping Systems Affected by GDC-4 Modification
(GESSAR 251 Standard BWR Plant)

Piping System	Pipe Whip Restraints ^a
Recirculation Loops	28
Main Steam	48
Feedwater	18
Residual Heat Removal	1
High Pressure Core Spray	2
Low Pressure Coolant Injection	8
Reactor Core Insulation Cooling	3
Total	110

Notes:

- (a) Total per plant. General Electric has indicated that removal of approximately 40 percent of pipe whip restraints would be considered under the proposed rule change.

The estimated \$90 million in per-plant cost savings split evenly among direct costs (design and construction), improvements in schedule (e.g., avoided costs for replacement power), and financing costs. Two observations are worthy of note:

- of the \$30 million in avoided direct costs, about \$12 million are for engineering. Reducing the number of postulated pipe breaks would reduce the problems inherent in locating restraints and barriers in congested areas. This, in turn, would decrease the complexity (i.e., the number of multi-disciplinary iterations) of laying out suitable high-energy piping systems.
- approximately two-thirds of the estimated cost savings come from indirect sources. This is consistent with the value-impact summaries for PWR reactor coolant loop piping (Table 2) and BWR recirculation piping (Table 3), where in each case avoided costs for replacement power (i.e., schedule improvement) represented one of the largest single contributors to the total impact.

Tables 8 and 14 indicate future per-plant savings of \$7.5 million for PWR reactor coolant loop piping and \$3.5 million for BWR recirculation piping, respectively. For BWR plants, simultaneous exclusion of breaks from the systems in Table 20, as well as from the reactor water cleanup system and control rod drive system, would increase the total per-plant savings by about \$2 million by reducing or eliminating analysis of suppression pool loads, response of piping and RPV internals, and annulus pressurization loads. For either reactor type, it can be generally said that future cost savings on the order of \$100 million per plant are not out of the question, given broader applications of the proposed rule change.

Table 21. Potential Cost Savings for Future Plants^a

<u>Direct Costs</u>		<u>Sub Total</u>
Hazards Evaluation		
Engineering	\$ 3,250,000	
Design and Procurement of Restraints, Shields and Supporting Steel		
Engineering	3,250,000	
Fabrication and Installation	7,250,000	
Piping Restress to Shift Break Points or Lower Stress, Additional Supports Required		
Engineering	500,000	
Fabrication and Installation	750,000	
Structural Embedments, Penetrations, Cubicle Design and Reevaluation		
Engineering	1,250,000	
Reinforcing Bars (Installed)	1,500,000	
Improved Piping Layout (Reduced pipe length)	4,250,000	
Specialty Insulation	125,000	
Primary Equipment Supports		
Engineering	2,750,000	
Fabrication and Installation	5,000,000	\$29,875,000
<u>Operating Costs</u>		
Lost Power and Heat Removal Due to Reduced Insulation	\$ 615,000	\$ 615,000
<u>Indirect Costs</u>		
Improvement in Construction Schedule (30-90 days est.)	\$30,000,000(min.)	
Financing (Interest accrued during construction)	\$30,000,000	\$60,000,000
Total Estimated Cost Savings		\$90,000,000(min.)

Notes:

(a) Piping systems other than primary reactor coolant piping.

8. SUMMARY

The results of the value-impact assessment are summarized in Tables 22 and 23 for, respectively, PWR primary reactor coolant loop piping and BWR recirculation loop piping.

In these tables, "value" represents reduction in occupational radiation exposure. The nominal estimates of cost and radiation dose indicate that substantial reductions in both would result from implementation of the proposed action. In addition, the proposed action would increase public risk only negligibly (by less than 1 man-rem for all plants considered) in either case.

In addition to these results, the following general observations are noteworthy:

- both the PWR and BWR assessments indicated that the greatest benefits result from those areas that are most schedule-intensive, particularly when costs of replacement power are considered. For PWR plants, the largest single contributor to overall impact was eliminating plant modifications associated with Generic Issue A-2. For BWR plants, it was eliminating recirculation loop pipe whip restraints in plants currently replacing or planning to replace existing pipe with pipe fabricated from IGSCC-resistant materials.

Indirect sources would account for the largest cost reductions to be gained by excluding breaks from high-energy piping system other than primary loop piping. Of the \$90 million per plant in avoided costs estimated in one study, approximately two-thirds could be attributed to improvements in construction schedule and to reductions in construction financing costs.

- The largest single contributors to avoided dose are those associated with major plant modifications. For ISI and plant maintenance, dose reductions are also substantial in those instances where, for example, restraints must be removed and replaced during the course of these activities. In those cases where restraint removal would not be required

Table 22. Summary of Value-Impact Assessment
(PWR primary reactor coolant loop piping)

	Value (man-rem)	Impact (\$)	
		10%	5%
Best Estimate	3.4E+4	-186E+6	-186E+6
High Estimate	1.1E+5	-277E+6	-276E+6
Low Estimate	8.6E+3	-87E+6	-87E+6

Table 23. Summary of Value-Impact Assessment
(BWR recirculation loop piping)

	Value (man-rem)	Impact (\$)	
		10%	5%
Best Estimate	8.6E+3	-30E+6	-30E+6
High Estimate	1.0E+4	-65E+6	-65E+6
Low Estimate	5.9E+3	-15E+6	-15E+6

for ISI or maintenance, net benefit (i.e., dose reductions during maintenance activities compared to exposure incurred during removal) would be more marginal. This result implies that the net benefit would be greatest if it were left to the plant owner to select which restraints would or would not be removed from a particular piping system, given that the piping system qualified for the break exclusion.

- except where noted otherwise, avoided costs for the 16 plants included in the value-impact analysis attached to NRC Generic Letter 84-04 were extracted directly from the A-2 evaluation. Since the time this evaluation was performed, these plants have been granted partial exemptions from GDC-4 requirements; therefore, including these plants in the present evaluation may "double credit" avoided costs and thus improperly inflate the negative impact (i.e., benefit) of the proposed rule change. Even when the contribution of all A-2 plants is neglected, however, the nominal benefit is still about \$80 million. The fundamental conclusion that the proposed rule change would result in substantial cost reductions remains unchanged.
- The overall impact was not affected significantly by the discount rates assumed in this analysis for onsite and offsite (public) damage, nor by the decision not to discount recurrent operating costs.

REFERENCES

1. "Design Bases for Protection Against Natural Phenomena," Code of Federal Regulations, Title 10, Part 50, Appendix A.
2. Probability of Pipe Fracture in The Primary Coolant Loop of a PWR Plant, Lawrence Livermore National Laboratory, Livermore, California, Report UCID-18967, NUREG/CR-2189, Vols. 1-9 (September 1981).
3. Probability of Pipe Failure in The Reactor Coolant Loops of Westinghouse PWR Plants, Lawrence Livermore National Laboratory, Report UCID-19988, NUREG/CR-3660, Vols. 1-4 (1984).
4. Probability of Pipe Failure in The Reactor Coolant Loops of Combustion Engineering PWR Plants, Lawrence Livermore National Laboratory, Report UCRL-53500, NUREG/CR-3663, Vols. 1-3 (1984).
5. Report of The U.S. Nuclear Regulatory Commission Piping Review Committee: Evaluation of Potential for Pipe Breaks, NUREG-1061, Vol. 3 (October 1984).
6. Heaberlin, S.W., et al., A Handbook for Value-Impact Assessment, Pacific Northwest Laboratory, Report PNL-4646, NUREG/CR-3568 (December 1983).
7. Generic Letter 84-04, "Safety Evaluation of Westinghouse Topical Reports Dealing With Elimination of Postulated Pipe Breaks in PWR Primary Main Loops," U.S. Nuclear Regulatory Commission (February 1984).
8. Lu, S. and C. K. Chou, Reliability Analysis of Stiff Versus Flexible Piping - Final Project Report, Lawrence Livermore National Laboratory, UCID, in preparation (April, 1985).
9. Andrews, W.B., et al., Guidelines for Nuclear Power Plant Safety Issue Prioritization Information Development, Pacific Northwest Laboratory, Report PNL-4297, NUREG/CR-2800 (1983).
10. Georgia Power Company, "Safety Balance for The Elimination of Reactor Coolant System Main Loop Protective Devices", letter from D.O. Foster to H.R. Denton (NRC/NRR) dated April 2, 1984.
11. Strip, D.R., Estimates of The Financial Consequences of Nuclear Power Reactor Accidents, Sandia National Laboratories, Report NUREG/CR-2373 (1982).
12. Report of The U.S. Nuclear Regulatory Commission Piping Review Committee: Investigation and Evaluation of Stress Corrosion Cracking in Piping of Boiling Water Reactor Plants, NUREG-1061, Vol. 1 (1984).

APPENDIX A

Plants Included in Assessment

Table A.1
General Electric Plants

<u>Operating Plants</u>	<u>Under Construction</u>
Pilgrim 1 ^a	Shoreham
Millstone 1	Nine Mile Point 2
Susquehanna 1	Susquehanna 2
Peach Bottom 2 ^a	Limerick 1
Peach Bottom 3	Limerick 2
Dresden 2	Hope Creek 1
Dresden 3 ^d	Perry 1
La Salle 1	Perry 2
La Salle 2	Fermi 2
Quad Cities 1	Clinton
Quad Cities 2	River Bend
Cooper ^b	Grand Gulf 2
Monticello ^b	Hartsville A1
Brunswick 1 ^c	Hartsville A2
Brunswick 2	
Hatch 1	
Hatch 2 ^a	<u>Not Included</u>
Grand Gulf 1	
Vermont Yankee ^d	Oyster Creek
Duane Arnold	Nine Mile Point ^a
Brown's Ferry 1 ^b	Dresden 1
Brown's Ferry 2	Big Rock Point
Brown's Ferry 3 ^d	
WNP-2	

Total operating plants considered:	24	Average remaining life:	31.4
Total plants under construction:	14	Average remaining life:	40.0
Total plants considered:	38	Average remaining life:	34.6
		Remaining plant-years:	1314

Notes:

- (a) recirculation piping replacement complete
- (b) recirculation piping replacement in progress
- (c) recirculation piping replacement on hold (piping procured, not installed)
- (d) committed to pipe replacement (e.g., ordering pipe, vendor identified, outage scheduled)
- (e) assessment limited to BWR-3 and later reactor generations

Table A.2
Westinghouse Plants

<u>Operating Plants</u>	<u>Under Construction</u>
Haddam Neck ^a	Beaver Valley 2
Indian Point 2	Millstone 3
Indian Point 3	Seabrook 1
Beaver Valley 1	Seabrook 2
Salem 1	Byron 1
Salem 2	Byron 2
Robert E. Ginna ^b	Braidwood 1
Yankee Rowe ^a	Braidwood 2
Zion 1 ^b	Carroll County 1
Zion 2 ^b	Carroll County 2
Donald C. Cook 1 ^b	Callaway 1
Donald C. Cook 2 ^b	Wolf Creek
Prairie Island 1	Shearon Harris 1
Prairie Island 2	Catawba 1
Point Beach 1 ^b	Catawba 2
Point Beach 2 ^b	Vogtle 1
Kewaunee	Vogtle 2
Joseph M. Farley 1	Watts Bar 1
Joseph M. Farley 2	Watts Bar 2
H. B. Robinson 2 ^b	South Texas 1
McGuire 1	South Texas 2
McGuire 2	Commanche Peak 1
Turkey Point 3 ^b	Commanche Peak 2
Turkey Point 4 ^b	Diablo Canyon 2
Virgin C. Summer 1	
Sequoyah 1	
Sequoyah 2	
Surry 1 ^b	
Surry 2 ^b	
North Anna 1	
North Anna 4	
San Onofre 1 ^a	
Diablo Canyon 1	
Trojan	
Total operating plants considered: 34(15) ^c	Average remaining life: 30.4
Total plants under construction: 24	Average remaining life: 40.0
Total plants considered: 58	Average remaining life: 34.4
	Remaining plant-years: 1995

Notes:

- (a) 4-2 plant, Group 1
- (b) A-2 plant, Group 2
- (c) value in parantheses indicates number of A-2 plants

Table A.3
Combustion Engineering Plants

<u>Operating Plants</u>		<u>Under Construction</u>	
Calvert Cliffs 1		Waterford 3 ^b	
Calvert Cliffs 2		Palo Verde 1 ^b	
Maine Yankee		Palo Verde 2 ^b	
Millstone 2		Palo Verde 3 ^b	
Palisades		WNP 3 ^b	
Fort Calhoun ^a			
Arkansas 2			
St. Lucie 1		<u>Not Included</u>	
St. Lucie 2			
San Onofre 2 ^b		Yellow Creek 1 ^b	
San Onofre 3 ^b		Yellow Creek 2 ^b	
Total operating plants considered:		11(1) ^c	Average remaining life: 32.6
Total plants under construction:		5	Average remaining life: 40.0
Total plants considered		16	Average remaining life: 34.9
			Remaining plant-years: 558

Notes:

- (a) A-2 plant, Group 2
- (b) plant with pipe whip restraints specifically designed to resist reactor coolant loop DEGB
- (c) value in parantheses indicates number of A-2 plants

Table A.4
Babcock & Wilcox Plants

<u>Operating Plants</u>		<u>Under Construction</u>	
Three Mile Island 1		Bellefonte 1 ^b	
Oconee 1		Bellefonte 2 ^b	
Oconee 2		WNP 1 ^b	
Oconee 3			
Crystal River 3 ^a			
Rancho Seco		<u>Not Included</u>	
Davis Besse 1 ^b			
Arkansas 1		Three Mile Island 2	
		Midland 1 ^b	
		Midland 2 ^b	
Total operating plants considered:	8	Average remaining life:	31.1
Total plants under construction:	3	Average remaining life:	40.0
Total plants considered:	11	Average remaining life:	33.5
		Remaining plant-years:	369

Notes:

- (a) no passive pipe whip restraints; large-bore snubbers on reactor coolant pump used to resist DEGB loads
- (b) plant with pipe whip restraints specifically designed to resist reactor coolant loop DEGB

APPENDIX B

Extension of A-2 Value-Impact to All PWR Plants

1. INTRODUCTION

Parallel to its main effort to modify GDC-4, the NRC also undertook an interim rulemaking action specifically to expedite application of the proposed rule change to PWR primary reactor coolant loop piping only. As part of this effort, the NRC requested that LLNL take the results of the value-impact analysis included in NRC Generic Letter 84-04 ("Safety Evaluation of Westinghouse Topical Reports Dealing with Elimination of Postulated Breaks in PWR Primary Main Loops"), hereafter referred to as the "A-2 evaluation," and extend them to PWR plants not included in the original A-2 evaluation. Because the A-2 evaluation had already undergone extensive review, the intent was to minimize the amount of additional review required in connection with the interim rule change.

In order to accomplish this objective, departures from the original A-2 evaluation were kept to a minimum. As a result, the "interim" value-impact assessment does not include many of the avoided costs developed in Sec. 6.1 of the main report and therefore represents a "lower bound" on impact associated with the exclusion of pipe breaks from PWR primary reactor coolant loop piping.

The following basic assumptions were made in extending the results of the A-2 evaluation to plants not addressed by Generic Issue A-2:

- (1) A total of 85 plants are considered, compared to 16 in the A-2 evaluation.
- (2) The 85 plants have a total remaining lifetime of 2922 plant-years, compared to 377 plant-years in the A-2 evaluation.
- (3) The 85 plants have an average remaining lifetime of 34.4 years, compared to 23.5 years for the 16 A-2 plants alone.
- (4) The 85 plants have an average of four reactor coolant loops, compared to 3.1 loops in the A-2 plants alone.

Basic assumptions made in the A-2 evaluation, as well as sources of costs and occupational radiation exposure (ORE) were retained; no new sources were added, nor were any radical departures made, for example, in the estimation of public risk.

The estimate of value-impact for all PWR plants based on the A-2 evaluation and these assumptions is summarized in Table B.1. A detailed description of how these values were arrived at begins in the following section.

2. PUBLIC RISK

The estimated public risk in the A-2 evaluation was based on WASH-1400 release categories and a total of 377 plant-years of remaining life for the 16 A-2 plants. Total nominal risk for a two-loop nuclear steam supply system (i.e., from both in-cavity and out-of-cavity breaks), based on fracture mechanics results generated by Science Applications Inc., was estimated to be 0.006 man-rem/py. Assuming that this value can be applied to all 85 PWR plants, and assuming further (and conservatively) that all plants have four loops, the nominal increase in public risk becomes:

$$\text{Risk} = (0.006 \text{ man-rem/py})(2922 \text{ py})(4/2) = 35 \text{ man-rem}$$

$$\text{High Estimate} = 351 \text{ man-rem}$$

$$\text{Low Estimate} = 0 \text{ man-rem}$$

where the high estimate is based on the 0.12 man-rem/py value developed using the $1\text{E-}5/\text{py}$ pipe rupture frequency indicated by Bush that was referenced in the A-2 evaluation. As in the A-2 evaluation, the high estimate is independent of the number of loops.

The increase in core-melt frequency developed in the A-2 evaluation is assumed to be applicable to all plants, modified for the number of loops. The nominal estimate from the A-2 evaluation is:

$$\Delta F = (3.1/2)[9.8\text{E-}8/\text{py} + 0.2(3\text{E-}6/\text{py})/250] = 1.4\text{E-}7/\text{py}$$

Table B.1
Leak Before Break Value-Impact Summary
(Total for 85 Plants)

Factors	Dose (man-rem)			Cost (\$)		
	Nominal Estimate	Lower Estimate	Upper Estimate	Nominal Estimate	Lower Estimate	Upper Estimate
<u>Values (man-rem)</u>						
Public Health	-35	0	-3.5E+2	--	--	--
Occupational Exposure (Accidental)	-11	0	-2.3E+2	--	--	--
Occupational Exposure (Operational)	+1.1E+4	+3.5E+3	+3.2E+4	--	--	--
Values Subtotal	+1.1E+4	+3.5E+3	+3.2E+4	--	--	--
<u>Impacts (\$)</u>						
Industry Implementation Cost ^a	--	--	--	-5.0E+7	-2.5E+7	-7.5E+7
Industry Operating Cost ^c	--	--	--	-3.7E+6	-1.9E+6	-5.6E+6
NRC Development and Implementation Cost	--	--	--	-4.0E+5	-2.0E+5	-6.0E+5
Power Replacement Cost	--	--	--	-6.0E+7	-3.0E+7	-9.0E+7
Public Property ^c	--	--	--	+2.5E+5	0	+1.5E+6
OnSite Property ^c	--	--	--	+1.5E+5	0	+2.6E+6
Impact Subtotal	--	--	--	-114E+6	-57E+6	-154E+6

Notes:

- (a) Does not include industry costs expended to date to prepare plant asymmetric pressure load analyses and pipe fracture mechanics analysis.
- (b) Does not include NRC cost expended to date to develop issue (NUREG-0609) and to evaluate Westinghouse pipe fracture mechanics analysis.
- (c) Reflects 10% discount factor.

Note that in the A-2 evaluation, this value is rounded off to $1.0\text{E-}7/\text{py}$ for subsequent calculations of damage costs and accidental ORE.

Assuming that all plants have four loops, the nominal value applicable to all PWR plants becomes:

$$\Delta F = (4/3.1)(1.4\text{E-}7/\text{py}) = 1.8\text{E-}7/\text{py}$$

High Estimate = $2\text{E-}6/\text{py}$

Low Estimate = 0

where, as in the A-2 evaluation, the high estimate is independent of the number of reactor coolant loops.

3. OCCUPATIONAL EXPOSURE - ACCIDENTAL

The nominal value of ORE due to accidents developed in the A-2 evaluation is modified as follows for differences in total remaining plant life and in core-melt frequency:

$$\text{Dose} = 0.8 \text{ man-rem } (1.8\text{E-}7/1.0\text{E-}7(2922/377)) = 11.2 \text{ man-rem}$$

High Estimate = $2.3\text{E+}2 \text{ man-rem}$

Low Estimate = 0 man-rem

where the high estimate in the A-2 evaluation has been modified only to account for added remaining life (recall that the high estimate of core-melt frequency is independent of the number of reactor coolant loops).

4. OCCUPATIONAL EXPOSURE - OPERATIONAL

Occupational exposure associated with installation of plant modification applied only to A-2 plants; therefore, the only operating dose estimates from the A-2 evaluation assumed applicable to other plants are those associated with maintenance of the plant modifications (it has been assumed that such maintenance would be typical of that required for PWR pipe whip restraints in general). Assuming 80 man-hr/py for maintenance activities, the additional avoided operational ORE for plants not included in the A-2 evaluation would be:

$$\text{Dose} = (80 \text{ man-hr/py})(0.025 \text{ R/hr})(2922 \text{ py} - 377 \text{ py}) = 64 \text{ man-rem}$$

The total avoided dose for all 85 PWR plants, therefore, becomes:

$$\begin{aligned} \text{Dose} &= \text{Installation Dose (A-2 plants)} + \text{Operating dose (A-2 plants)} + \\ &\quad \text{Operating dose (other plants)} \\ &= 9700 \text{ man-rem} + 840 \text{ man-rem} + 64 \text{ man-rem} \\ &= 10604 \text{ man-rem} = 1.1\text{E}+4 \text{ man-rem} \end{aligned}$$

Note that the A-2 value is effectively unchanged by adding the other plants. The high and low estimates are based, respectively, on 3 times and 1/3 times the expected dose as was done in the A-2 evaluation.

$$\text{High Estimate} = 3.2\text{E}+4 \text{ man-rem}$$

$$\text{Low Estimate} = 3.5\text{E}+3 \text{ man-rem}$$

5. INDUSTRY IMPLEMENTATION COSTS

Industry implementation costs developed in the A-2 evaluation are for installation of specific plant modifications and do not apply to other plants. Therefore, these costs are assumed to remain unchanged. It has been assumed that restraint removal in plants not included in the A-2 evaluation would be performed as necessary for in-service inspection of other maintenance. As a result, the cost of restraint removal would be incurred as a normal cost of maintenance, and not as a specific cost of implementing the proposed rule change.

Note that extension of the A-2 evaluation does not address avoided costs for other factors affected by the proposed rule change. Elimination of pipe breaks in reactor coolant loop piping would result in (but not necessarily be limited to) reductions in the costs of:

- analysis of thermal hydraulic and piping response to breaks
- analysis of structural response; structural design

- design, fabrication, installation, and adjustment of pipe whip restraints in plants under construction
- jet impingement target load analysis; design, fabrication, and installation of jet impingement barriers

As discussed in the main body of this report, inclusion of these significant cost items substantially increases the impact of the proposed rule change. However, they have not been included here in accordance with the desire to simply extend the existing A-2 evaluation to other plant.

6. INDUSTRY OPERATING COSTS

Avoided costs for operation and maintenance were developed by modifying the costs from the A-2 evaluation to account for (1) the difference in the number of plants, and (2) the difference in average remaining lifetime of plants, which in turn affects the discount factors applied to costs. The \$4540/py cost of cost of avoided maintenance developed in the A-2 evaluation is assumed applicable to all PWR plants. To estimate present value, 5 percent and 10 percent discount factors of 16.3 and 9.6, respectively, are used based on an average of 34.4 years of remaining life. These compare to equivalent values of 13.6 and 8.9, respectively, based on an average of 23.5 years of remaining life in the A-2 evaluation. The avoided operation and maintenance costs from the A-2 evaluation are modified as follows:

$$\begin{aligned} 5\% \text{ discount factor: Cost} &= 1.0\text{E}+6(85/16)(16.3/13.6) = \$6.4\text{E}+6 \\ 10\% \text{ discount factor: Cost} &= \$6.5\text{E}+5(85/16)(9.6/8.9) = \$3.7\text{E}+6 \end{aligned}$$

	<u>5%</u>	<u>10%</u>
High Estimate	\$9.6E+6	\$5.6E+6
Low Estimate	\$3.2E+6	\$1.9E+6

where the high and low estimates reflect a ± 50 percent uncertainty range.

7. NRC DEVELOPMENT AND IMPLEMENTATION COSTS

Development and implementation costs for plants included in the A-2 evaluation have been retained. For other plants, it has been assumed that because an acceptable technical basis is available for excluding breaks from reactor coolant loop piping, no additional NRC development effort is necessary. Costs expended during the rule-making effort have not been included.

8. NRC OPERATING COSTS

It is assumed that review of industry submittals seeking exclusions from pipe break under the proposed rule change would require the same amount of effort as is currently expended reviewing requests for partial exemption from the current version of GDC-4. Therefore, no additional NRC operating costs are anticipated for reactor coolant loop piping. It is anticipated that less effort would actually be required under the proposed rule change; therefore, a reduction in NRC operating costs could be expected.

9. PUBLIC (OFFSITE) PROPERTY DAMAGE

Public property damage costs were estimated by modifying the costs from the A-2 evaluation to account for (1) the difference in number of plants, (2) the difference in average remaining life of plants, which in turn affects the discount factors applied to costs, and (3) the difference in core-melt frequency, where applicable. To estimate present value, 5 percent and 10 percent discount factors of 16.4 and 9.7, respectively, were used based on an average of 34.4 years of remaining life. These compare to equivalent values in the A-2 evaluation of 13.8 and 9.0, respectively, based on an average remaining life of 23.5 years. The nominal public property damage costs from the A-2 evaluation were modified as follows:

$$5\% \text{ discount factor: } V_{FP} = (\$3.8E+4)(85/16)(1.8E-7/1.0E-7) = \$4.3E+5$$

$$10\% \text{ discount factor: } V_{FP} = (\$2.4E+4)(85/16)(1.8E-7/1.0E-7) = \$2.5E+5$$

The high and low estimates are summarized below. Note that these incorporate a ± 50 percent uncertainty range on the cost per event, plus the high and low estimates of core-melt frequency. Note also that no adjustment is made in the high estimate of core-melt frequency because it is independent of the number of reactor coolant loops.

	<u>5%</u>	<u>10%</u>
High Estimate	\$2.6E+7	\$1.5E+7
Low Estimate	0	0

10. ON SITE PROPERTY DAMAGE

Onsite property damage costs were estimated by modifying the costs from the A-2 evaluation to account for (1) the difference in the number of plants, (2) the difference in average remaining life of plants, which in turn affects the discount factors applied to costs, and (3) the difference in core-melt frequency, where applicable. To estimate present value, 5 percent and 10 percent discount factors of 12.9 and 6.1, respectively, were used based on an average of 34.4 years of remaining life. These compare to values of 11.0 and 5.7, respectively, in the A-2 evaluation based on an average remaining life of 23.5 years. The nominal on site property damage costs from the A-2 evaluation were modified as follows:

$$5\% \text{ discount factor: } V_{OP} = (\$2.9E+4)(85/16)(12.9/11.0)(1.8E-7/1.0E-7) = \$3.3E+5$$

$$10\% \text{ discount factor: } V_{OP} = (\$1.5E+4)(85/16)(6.1/5.7)(1.8E-7/1.0E-7) = \$1.5E+5$$

The high and low estimates are summarized below. Note that these incorporate a ± 50 percent uncertainty range on the cost per event, plus the high and low estimates of core-melt frequency. Note also that no adjustment is made in the high estimate of core-melt frequency because it is independent of the number of reactor coolant loops.

	<u>5%</u>	<u>10%</u>
High Estimate	\$5.5E+6	\$2.6E+6
Low Estimate	0	0