

CEOG

COMBUSTION ENGINEERING OWNERS GROUP

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4/19/91 56FR/16130

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Palo Verde 1, 2, 3
Baltimore Gas & Electric
Calvert Cliffs 1, 2

Consumers Power Co.
Palisades
Florida Power & Light Co.
St. Lucie 1, 2

Energy Operations
ANO 2
WSES Unit 3

Maine Yankee Atomic Power Co.
Maine Yankee
Northeast Utilities Service Co.
Millstone 2

Omaha Public Power District
Ft. Calhoun
Southern California Edison Co.
SONGS 2, 3

DS09

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33

September 27, 1991
CEOG-91-531

Ms. Carol Ann Reed
Chief (Acting), Regulatory Publications Branch
Division of Freedom of Information and
Publications Services
Office of Administration
U.S. Nuclear Regulatory Commission
Washington, DC 20555

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Subject: Solicitation of Public Comments on Generic Issue 23, "Reactor Coolant Pump Seal Failure;" and Draft Regulatory Guide; Issuance, Availability. Federal Register Volume 56, Number 76 - April 19, 1991

Dear Ms. Reed:

The purpose of this letter is to respond to the Nuclear Regulatory Commission's request for public comment on the Staff's current understandings, findings, and potential recommendations regarding Generic Issue 23 (GI-23).

The Combustion Engineering Owners Group (CEOG) has participated fully in the preparation of the Nuclear Management and Resources Council responses to the solicitation of public comments on GI-23 and we endorse their comments. In addition, the CEOG wishes to provide information which addresses the particular aspects of Reactor Coolant Pump (RCP) seal design and operating data at CEOG utility plants.

The CEOG has prepared the enclosed report, CEN-408 "Evaluation of the Reactor Coolant Pump Seal Integrity Issue," to respond to the NRC's request for comments on draft NUREG-1401, draft Regulatory Guide DG-1008 and to respond to the series of Federal Register questions on RCP seal performance. This report contains current information on RCP seal design and performance history obtained by a CEOG survey of its members. Since CEN-408 is being provided in response to the NRC's solicitation of public comments, the CEOG does not expect CEN-408 to be subject to any review fees.

It is the CEOG's conclusion that the Staff's proposed resolution of GI-23 will not increase the level of safety in CEOG utility plants. If the proposed resolution is adopted, however, the costs associated with additional quality assurance requirements and plant modifications will be substantially greater than that estimated by the Staff. The importance of RCP seal reliability to overall plant reliability has been the motivating factor for CEOG utilities to improve seal performance through modified or advanced seal designs, stringent handling and installation requirements, and improved maintenance and procedures. As a result of these efforts, CEOG utilities have achieved excellent RCP seal performance with few instances of significant seal degradation, particularly since 1986. None of the cases of RCP seal degradation have resulted in leakage in excess of normal makeup capability.

The proposed generic resolution of GI-23 fails to recognize the diversity which exists in RCP seal design. CEOG utility plants utilize Byron Jackson SU, Byron Jackson N-9000, Sulzer Bingham, AECL CAN 4, or KSB seals. It is inappropriate to apply a model based on the Westinghouse RCP seal design to these CEOG utility plant seals because of fundamental differences in their design. For example, the seal designs employed at CEOG utility plants operate with a lower controlled bleedoff flow than the Westinghouse design and the pressure drop across the stages is controlled by a pressure breakdown device. Operating experience and testing have demonstrated that the seals of the designs utilized in CEOG utility plants perform significantly better than the AECL model of the Westinghouse seals with regard to the ability to tolerate loss of cooling without significant seal leakage.

The Staff has proposed applying quality assurance requirements of Appendix B and applicable General Design Criteria of Appendix A of 10 CFR 50 to RCP seal assemblies. Some CEOG utilities have already chosen to apply Appendix B requirements to RCP seals as means of ensuring reliable RCP seal performance. Other CEOG utilities, however, have chosen other commercial programs to achieve the same results. Current operating experience demonstrates that these different approaches to quality programs have been equally effective in achieving high quality RCP seal assemblies. Mandating that a utility who now utilizes an effective commercial quality program change to an Appendix B program cannot be shown to improve RCP seal performance or plant safety and is, therefore, not justified.

Ms. Reed
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The Staff has also proposed requiring RCP manufacturer-recommended instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal failures. Manufacturers for the RCPs in CEOG utility plants have recommended the monitoring of controlled bleedoff flow, controlled bleedoff temperature, and the seal staging pressures. This instrumentation is present in all CEOG utility plants and is sufficient, along with existing plant operating procedures for monitoring RCP seal performance, to identify degraded seal performance early enough to take corrective action to mitigate seal failures and to maintain plant safety. Further requirements are unnecessary.

The Staff has proposed a requirement to provide RCP seal backup cooling during off-normal plant conditions involving loss of all seal cooling including beyond-design-basis events such as station blackout. Testing of RCP seals of the designs utilized in CEOG utility plants has provided confidence in the ability of the seals to limit leakage to well below the station blackout coping analysis limit of 25 gpm during a loss of cooling event. In fact, loss of cooling and degraded cooling events during operation at CEOG utility plants have shown the resiliency of these seal designs during loss of cooling. Further requirements to provide for an enhanced cooling capability cannot be justified, particularly in light of the Staff's underestimation of the costs associated with such a change.

Thank you for the opportunity to provide our input to the Commission's evaluation process. If you have any questions on this matter, please do not hesitate to contact me.

Very truly yours,



John J. Hutchinson, Chairman
C-E Owners Group

JJH/SAT/sjc
Enclosure

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CEN-408

GENERIC ISSUE - 23
EVALUATION OF THE
REACTOR COOLANT PUMP SEAL
INTEGRITY ISSUE

PREPARED FOR THE
C-E OWNERS GROUP
SEPTEMBER, 1991

ABB COMBUSTION ENGINEERING
NUCLEAR POWER
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EXECUTIVE SUMMARY

The Nuclear Regulatory Commission (NRC) has had Generic Issue 23, Reactor Coolant Pump (RCP) Seal Failure and the need for further licensing requirements to reduce the potential core-melt risk resulting from RCP seal failure under consideration for many years. This issue and an evaluation program was initiated because of several RCP seal leaks which occurred in the late 70's and analysis which indicated the frequency of seal leaks dominated the LOCA probabilities. In the April 19, 1991 Federal Register Notice, the NRC announced the release of their proposed resolution to Generic Issue 23 in Draft Regulatory Guide DG-1008 and supporting NUREG documents.

The proposed resolutions that the NRC has issued for comments are summarized as:

- I. Treat the RCP seal assembly as an item performing a safety-related function similar to other components of the reactor coolant pressure boundary, applying quality assurance requirements consistent with Appendix B to 10CFR50 and applicable General Design Criteria of Appendix A to 10 CFR 50.
- II. Provide the instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal failures as recommended by RCP seal manufacturers.
- III. Provide RCP seal cooling during off-normal plant conditions involving loss of all seal cooling such as station blackout.

In conjunction with accepting comments on the proposed draft regulatory guide and the supporting NUREG documents, the NRC has requested responses to a series of questions presented in the Federal Register Notice. In response to the NRC inquiry, the Combustion Engineering Owners Group (CEOG) surveyed its members to obtain current information on reactor coolant pump seal design and performance history. The information obtained is used in responding to the NRC questions and proposed resolutions.

All the NRC questions were individually addressed in this report by using the data obtained from the CEOG survey. The answers confirmed previous information that indicated that the proposed regulations are not required. The plants are already operating and maintaining the RCP seals in a safe manner.

The NUREG documents referenced and used by the NRC to support their contention that the seals are a safety risk were addressed. They were reviewed and the areas of disagreement and discrepancies were highlighted to show that their contentions do not apply to the reactor coolant pump seals operated by the CEOG.

It is the CEOG position that the three resolutions proposed by the NRC are unnecessary. Their objectives are already being obtained without imposing additional requirements and expenses.

The KSB three stage seal system or the Byron Jackson style seal system with a fourth stage vapor seal that are used by the CEOG have proven to be the better design configurations compared to the rest of the industry. The CEOG reactor coolant pump seals have proven their reliable service for extended life.

The manufacturer recommended instrumentation and instructions for monitoring the reactor coolant pump seal performance have been incorporated into the plant operating procedures throughout the CEOG. Also in place are operating procedures for handling the seals for normal plant operations, loss of cooling and station blackout.

There are economic pressures in place which will cause the utilities and their seal vendors to continue to address the seal performance and life as a critical issue. As a result of these pressures utilities are committed to give the seals the highest level of care and attention. The station shutdown requirements for seal failure are clearly and conservatively defined for each utility and it is very expensive for a utility to be in a plant shutdown due to seal degradation or failure. Utilities will therefore continue to ensure

high quality seal performance to avoid this situation. The desire to avoid unnecessary seal failure shutdowns has produced the equivalent level of seal quality emphasis which the NRC is proposing to regulate.

INTRODUCTION

In October 1975, WASH-1400, "The Reactor Safety Study", was published. This study indicated that breaks in the reactor coolant pressure boundary with an equivalent diameter of 0.5 to 2 inches could occur with a frequency of 10^{-3} per reactor-year and were the largest potential contributor to PWR core-melt. A 1980 NRC study based upon reactor coolant pump (RCP) seal failures experienced at operating plants showed that the RCP seal failure leakage rates were comparable to the small-break LOCA rates of WASH-1400, but these seal failures had actually occurred at a frequency of 10^{-2} per reactor-year. This frequency was actually an order of magnitude greater than the pipe breaks frequency used in WASH-1400. The Nuclear Regulatory Commission (NRC) began to believe that the overall probability of core-melt due to small-break LOCAs could be dominated by RCP seal failures.

The NRC has had Generic Issue 23, RCP Seal Failure and the need for further licensing requirements to reduce the potential core melt risk resulting from RCP seal failures under consideration for many years. In the Friday, April 19, 1991 Federal Register Notice (Vol. 56, No. 76, Page 16130), the NRC announced the release of their proposed resolution to Generic Issue 23. Supporting documentation includes Draft Regulatory Guide DG-1008, "Reactor Coolant Pump Seals"; Draft NUREG-1401, "Regulatory Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure"; NUREG/CR-4948, "Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure"; and NUREG/CR-5167, "Cost/Benefit Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure".

The reactor coolant pumps of all light water reactors contain mechanical seals to limit the leakage of pressurized coolant from the reactor coolant system to the containment during normal

operation. The NRC has taken the position that, because these seals are cooled during normal operations, they will be subject to failure during events that involve loss of seal cooling such as station blackout. Under such postulated conditions, seal failure could cause a significant loss of reactor coolant when the normal makeup systems and the emergency core cooling systems are potentially unavailable. Thus, the NRC argues that this safety concern could directly affect the probability of core damage sequences in some plants.

They have addressed these concerns by issuing the regulatory guide with the following objectives:

- (1) Reduce the probability of RCP seal failure,
- (2) Have plant procedures that would minimize the safety impact of RCP seal failure or degradation,
- (3) Have sufficient instrumentation to permit proper implementation of the procedures, and
- (4) Have independent means of providing cooling to the RCP seals for severe events, such as station blackout, which make the normal seal cooling systems inoperable.

The NRC proposes to address the above issues by imposing the following requirements:

- I. Treat the RCP seal assembly as an item performing a safety-related function similar to other components of the reactor coolant pressure boundary, applying quality assurance requirements consistent with Appendix B to 10CFR50 and applicable General Design Criteria of Appendix A to 10 CFR 50.

- II. Provide the instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal failures as recommended by RCP seal manufacturers.
- III. Provide RCP seal cooling during off-normal plant conditions involving loss of all seal cooling such as station blackout.

The NRC staff is now soliciting comments and additional information to insure that all relevant information is considered prior to reaching a decision on the above resolutions. In conjunction with accepting comments on the proposed draft regulatory guide and the above listed supporting NUREG documents, the NRC has requested responses to a series of questions presented in the Federal Register Notice.

In response to the NRC inquiry, the Combustion Engineering Owners Group (CEOG) surveyed their members to obtain current information on reactor coolant pump seal design and performance history. The survey consisted of three questionnaires requesting information on (1) seal information and history, (2) seal procedures, and (3) the NRC's Resolution cost/benefit analysis. Responses were obtained from all ten utilities in the CEOG representing fifteen operating nuclear steam supply systems. The information obtained was used in responding to the NRC questions and proposed resolutions.

2.0

FEDERAL REGISTER QUESTIONS

The NRC has formulated a series of questions which were published in the Federal Register in order to extend their knowledge of seal performance. They have solicited comments from interested organizations, groups, and individuals on the questions.

The specific NRC questions and the Combustion Engineering Owners Group (CEOG) responses, comments, and data (obtained with the questionnaire in Appendix A) are presented in the section that follows.

2.1

Question 1.0 - Introduction (Federal Register)

"The priority for the resolution of Generic Issue 23 was originally based on the number and the magnitude of seal leaks that occurred prior to 1983. The failure rate appeared to exceed the assumptions made for the WASH-1400 study for small loss-of-coolant accidents by an order of magnitude. There appears to be some evidence that reactor coolant pump seal operating experience has since improved, at least in magnitude of leakage from seal failures. The NRC is seeking data to determine if this is the case and whether the apparent improvement is applicable to all reactor coolant pump seals, to those from specific manufacturers, or to those that had particular quality assurance provisions applied during design, installation, operation, and maintenance."

2.1.1

Question 1.1 (Federal Register)

"Has the operating experience with the reactor coolant pump seals changed since 1983? If it has, then information regarding the history of reactor coolant pump failures, including occurrences of forced outages is of interest. Information regarding all types of operation, including start-up, is desired."

Response 1.1

The reactor coolant pump seals at all CEONG plants have had improved operation performance or have remained excellent since 1983.

The CEONG plants have had a good record with very few seal failures. A history of failure that have occurred at the fifteen CEONG plants since 1983 to the present is presented below. The seal failures have been ordered chronologically and separately by plant.

The NRC has not been consistent in their definition of seal failure classifying some degraded conditions as failures and tends to infer that if a seal stage fails it is a serious threat to the reactor coolant system integrity, which is not true.

In developing the following list, a seal failure has been defined as an occurrence when two or more seal stages are not operating normally (no longer able to maintain pressure differential), the controlled bleedoff temperature or flow is not within normal operating range, or the external seal leakage is above the acceptable value in accordance with the plant specific operating procedures. A seal failure may or may not result in external leakage (loss of reactor coolant system inventory) but in all the occurrences listed below where leakage, was involved, it was at least 4 to 5 times less than the station blackout coping value of 25 gpm except one failure which was caused by the failure of a sensing line. Not included are occurrences where only one seal stage failed and a plant shutdown was not required and the seal was replaced during a normal outage.

As illustrated in the seal failure history below, most of the seal failures since 1983 have occurred in the 1983-1986 time frame. This emphasizes the improvement trend from 1983 to present.

Plant A

No history of seal failure.

Plant B

7/86

During hot stand by, pumps 2A and 2B 3rd stage rotating seal face failed. Seal injection and nuclear cooling water were simultaneously lost for approximately 3 hours. The pumps was operated, for the first 10 minutes and controlled feedoff was unisolated for the first 18 minutes. The 3rd stage rotating element thermally disassembled, with 2-3 gpm leakage. Seals were replaced and returned to operation. Seals had operated eight (8) months prior to shutdown for replacement.

Plant C

3/3/89

During power operation, pump 1B 3rd stage rotating seal face failed. Seal failure was after a loss of seal injection, loss of CCW, and CBO valve not closed for 1 hour and 13 minutes. The seal maximum temperature rose to 437°F while the vapor seal leakage was 1.25 gpm. Failure was from thermal disassembly of 3rd stage rotating element. All seals were replaced and returned to operation. Seals had operated sixteen (16) months prior to shutdown for replacement. See Section 3.2.3.5 for additional information.

Plant D

9/13/85

During power operation, there was degradation of the 1st, 2nd and 3rd stationary seal faces on pump 2P32A.

The 1st and 2nd stage pressure oscillations preceded seal degradation and occurred continuously for 1-1/2 months prior to the failure. CBO flow went from 2 gpm to greater than 3.5 gpm nearly instantaneously. Three hours later, the 2nd stage seal opened completely. Approximately one hour after that, the 1st and 3rd stage seals opened completely applying full reactor pressure to the 4th stage vapor seal. The fourth stage seal had no leakage. Peak CBO temperature was approximately 195°F. Peak lower seal temperature was approximately 140°F. Carbon fractured on 1st, 2nd and 3rd stages and indication of 1st stage lower "O"-Ring leakage. Seal was replaced and returned to operation. Seal had operated for four months prior to shutdown for replacement.

8/1/88

During power operation, all four stages on pump 2P32A failed. Failure was initiated by sensing line break of middle cavity pressure transmitter. Full RCS pressure was applied to the vapor seal. Peak lower seal temperature exceeded 350°F (pegged high). Seal became overheated due to RCS coolant flow overcoming capability of seal heat exchanger. Seal failed with broken carbon on 2nd and 4th stages and cracked carbon on 1st and 3rd stages with partial U Cup extrusion. All other elastomers were not extruded and were in good condition. Seal cartridge was replaced and sensing line weld repaired. Seal had operated four (4) months prior to shutdown and replacement. See Section 3.2.3.1 for additional information.

Plant F

7/30/85

During power operation, pump 1B vapor seal failed. The vapor seal had a seal face break and was chipped.

The controlled bleedoff flow rate was 2.3 gpm. The external leakage was unrecorded, not a significant event. It was discovered from operational abnormalities which caused a 7 day forced outage. Fourth stage was replaced.

3/18/86 During power operation, pump 1B 1st stage failed. Controlled bleedoff flow rate not recorded, limited between 1 & 10 gpm. External leakage was not recorded, not a significant event. Seal was replaced during a 7 day forced outage. This is one stage only, not a seal failure.

10/31/88 During power operation, pump 1B 2nd stage failed. The seal was inspected and debris was found under the seal cartridge. Seal was replaced with seal of another vendor during a 14 day forced outage. This is one stage only, not a seal failure. No controlled bleedoff or external leakage was recorded but RCS leakage did not exceed 1 gpm.

03/02/89 During power operation, pump 1B 2nd stage failed. No controlled bleedoff or external leakage recorded. Total system leakage was .46 gpm. Seal was replaced with seal of another vendor. This is one stage, not a seal failure.

Plant F

4/25/85 During power operation, pump 1A 2nd stage failed. Seal degradation was due to pressure fluctuation induced by component cooling water temperature oscillations. The controlled bleedoff leakage increased to 10 gpm at which time the controlled bleedoff excess check valve closed stopping leakage flow. There was no external

known leakage from the vapor seal. The seal was replaced during an 11 day forced outage and returned to operation.

12/3/85 Pump 1A seal failed during heatup following an outage. Controlled bleedoff flow rate not recorded, limited between 1 & 10 gpm. External leakage was not recorded, not a significant event. Seal was replaced during a 7 day outage.

Plant G

The plant has never had a "Seal failure" per definition in their Operating Procedure. The plant has experienced loss of a stage on occasion with leaks on the order of 3 gpm. See Section 3.2.3.3 for additional information.

Plant H

6/84 Pump 1B2 seal degraded after 3rd stage failed following Outage.

7/90 Pump 1A1 operated with a bent shaft for 30 days before inducing multi-stage seal failure. Controlled bleedoff increased to 2.5 gpm. See Section 3.2.3.8 for additional information.

Plant J

11/84 Pump 2A1 seal degraded due to 1st stage failure. Pump 2B2 seal degraded due to fluctuating pressure following refueling.

12/84 Pumps 2B1 and 2A2 seals failed due to loss of component cooling water caused by power loss to component cooling water valves.

8/85 Pumps 2A1, 2A2, 2B1 and 2B2 seals failed due to loss of component cooling water caused by incorrect fuse size.

Plant K

2/20/85 All pump seals were replaced after operator error actuated containment isolation signal, securing component cooling water. There was 3 gpm maximum leakage. Only one seal actually failed (RCP1A). See Section 2.2.

10/3/85 Pump 2B Controlled Bleed-Off and staging pressure oscillation increased over several weeks until excess flow check valve closed. Plant was forced to shut down. Seal was changed.

12/8/85 During recovery from trip, pump 2B seal failed to stage (all staging pressures equalized) and pressure breakdown decreased on pump 2A. Some shaft leakage occurred on pump 1B. Only pump 2B seal was an actual failure but seals were changed on all pumps.

10/17/87 During plant startup, pump 2B Controlled Bleed-Off and staging pressure ramped up. Pressures approached equalization and destaged near 1100 lbs. Controlled Bleed-Off flow rate reached 2.8 gpm before shutdown. Seal cartridge was removed and inspected. Seal was replaced.

11/9/88 A new model seal failed on start-up three times. Controlled Bleed-Off pressure and temperature were higher than normal. Staging pressures looked good at low RCS pressure but seals destaged as pressure increased to NOT/NOP. Seal was inspected for

misalignment, axial play, shaft eccentricities and design tolerance errors. All four were replaced with older models. See Section 3.2.3.2 for additional information.

Plant L

12/21/88

Following refueling outage, three (3) N-9000 seals began to degrade and were changed out. Seal degrading was caused by a ceramic abrasive from a ceramic filter getting into the seal faces. The CBO flow was less than 5 gpm and there was no vapor seal leakage. Seals were in operation for six (6) days. The N-9000 seals were replaced with SU seals from storage. See Section 3.2.3.4 for additional information.

11/07/89

During operation, pump #1 SU seal drive lock ring lugs broke off and caused seal face wear. Seal staging pressure degraded and the plant was shutdown. CBO flow was less than 5 gpm and there was no vapor seal leakage. The SU seal was replaced with a N-9000 seal. See Section 3.2.3.6 for additional information.

Plant M

6/23/85

Pump D seal failed during start up. High CBO temperature was 195°F. 1st and 2nd stage stationary face had cracked and the 2nd and 3rd stage rotating face was cracked. The seal CBO flow and external leakage were within bounded limits.

11/11/85

Pump C seal failed during heat up. The Controlled Bleed Off high temperature alarm recorded temperature of 190 °F. On site inspection of the seal found that the vapor seal was leaking but flow was not recorded, not significant. Seal was replaced and returned to

operation. Seal failure was attributed to improper seal installation.

Plant N

8/24/90

During power operation, pump 1B 1st seal stage pressure breakdown device became blocked with safety wire. Seal cartridge was replaced and lockwiring procedure was revised. Seal was in operation three (3) months prior to shutdown. See Section 3.2.3.9 for additional information.

Plant P

1/14/88

Pump 2B middle and upper seals experienced degradation with respective pressures of 600 and 460 psia and a controlled bleed off rate of 3.48 gpm. No external leakage from the vapor seal. Plant removed from service for replacement of seals. Cause of degradation unknown.

4/10/91

Pump 2A middle and upper seals experienced degradation when seal pressures dropped to 70 psi and controlled bleed off rate dropped to zero. No external leakage from the vapor seal. The unit tripped, followed by RCP trip. Cause of seal degradation unknown.

Plant U

6/11/84

Pumps 1B and 2A were experiencing controlled bleed off rates of 2.5 and 1.5 gpm respectively. No external leakage from the vapor seal. Unit shutdown from a reactor trip and entered a scheduled outage to replace seals. Cause of degradation unknown.

2.1.2 Question 1.2 (Federal Register)

"If the operating experience has changed, to what do you attribute the change (e.g., improved quality assurance and quality control, improved maintenance, better procedures, improved instrumentation, design changes)?"

Response 1.2

The reactor coolant pumps seal operating experience at all CEOP plants has improved in the last eight years. All plants were driven by commercial considerations to improve their seal life and they have approached their seal life improvement differently. One utility had their cognizant system engineer take over responsibility for the pump seals from QA/QC and has shown improved seal life and obtained a significant man-rem savings. No two utilities have used the same combination nor number of methods. The following is a list of methods applied and the number of plants that used the method to improve seal life. This list is a summary of the data obtained from question B.2 of the information questionnaire in Appendix A.

Method	Number of plants
improved quality assurance	3
improved quality control	4
improved maintenance	9
better procedures	8
improved instrumentation	3
design changes (seal or plant)	10
installation inspection	10
special storage	7
other	3

All plants used the information provided by the reactor coolant pump and seal vendors to develop and improve their maintenance methods and procedures.

Seven plants have also changed to a different seal configuration. The following table provides the number of seal configurations used in 1983 and 1991 at CEQG plants.

Seal Vendor	Number of seal assemblies in service	
	1983	1991
KSB	0	12
Byron Jackson SU	47	23
Byron Jackson N-9000	0	7
Bingham	0	16
AECL CAN 4	0	1

2.1.3

Question 1.3 (Federal Register)

"How often are seals being routinely replaced (e.g., every refueling)?"

Response 1.3

The utilities are driven by economics in scheduling seal replacement to ensure that the seals can safely perform to the next refueling. The economic concerns provide the desire to ensure that extra care is taken in seal maintenance and operation. Nine of the CEQG plants have routinely replaced their seals during every refueling, four plants replace the seals at every other refueling, and two plants replace the seals at every third

refueling. In the future the nine plants that replace the seals during every refueling anticipate extending their replacement cycle to every other refueling. There is no direct correlation between seal configuration and their replacement cycle. The improved performance history of RCP seals supports longer replacement cycle times.

2.2

Question 2.0 (Federal Register)

"The NRC staff is interested in obtaining any available data regarding degraded cooling or loss of cooling to the seals to support assertions that seals can survive long periods of time (i.e., hours) without cooling."

Response 2.0

The CEQG plants have experienced operating conditions where cooling has been degraded or lost. In order to identify incidents the following guidelines were used. A degraded cooling incident is when a reduced cooling flow or the loss of one of the cooling methods has occurred. A loss of cooling is when no cooling medium to the seals is available.

At some of the CEQG plants, the pumps operate in a mode where the seals are exposed to a reduced cooling environment for several hours. For Combustion Engineering nuclear steam supply systems with four pumps, the fourth pump can not be started until the reactor coolant temperature has reached 475 to 500°F. Seal cooling is affected during the heatup on the Byron Jackson pumps that have an auxiliary impeller. While the reactor coolant is not being pumped by the auxiliary impeller through the integral heat exchanger for cooling, the only cooling protection to the seal is the thermal barrier. The control bleed off temperature has typically risen to 350°F before the pump is started. Upon pump

operation the control bleed off parameters return to normal and the seals function without difficulty for an extended period of time (e.g., for one or more refueling cycles). There are four pumps in the reactor coolant system, so the standby mode is rotated among the pumps to minimize the possibility of seal degradation.

A history was compiled of degraded and loss of cooling incidents at the CEQG plants. There were 5 incidents of degraded seal cooling and 5 incidents of loss of cooling. In all 10 incidents the seals held pressure and prevented excessive leakage. The following are the particulars for each incident.

I. DEGRADED COOLING

a) Plant D

Degraded seal cooling occurred for thirty five (35) minutes on 6/3/88. Low component cooling water (CCW) flow alarms sounded on all four pumps. The corrective action was to vent the CCW pumps and restore flow. Seal failure did not result.

b) Plant H

Seal Cooling has been degraded for minutes to hours with total loss of flow.

c) Plant J

Seal Cooling has been degraded for minutes to hours with total loss of flow.

d) Plant K

Degraded seal cooling of 5-10% has occurred for less than 10 minutes on all four pumps. This condition occurs on a quarterly basis during ASME IST of CCW pumps. The maximum seal temperature was less than 180 °F. Seal failure has not occurred.

e) Plant L

Lost of seal injection on the same pump twice in the past ten years. Maximum seal temperature during each occurrence was less than 200°F. Seal failure did not occur.

II. LOSS OF COOLING

a) Plant A

Component cooling water and seal injection were intermittently lost on RCP 2B for eight (8) hours in 7/6/88. The loss was caused by an auxiliary transformer loop transient. The seals reached 152°F after experiencing conductive heating through the pump shaft for approximately 6 hours. Seal failure did not result.

b) Plant C

Plant operated for approximately 1 1/2 hours without component cooling water or seal injection to the reactor coolant pump seals and CBO was not isolated for 1 1/4 hours. See Section 3.2.3.5 for additional information.

c) Plant D

Seal cooling was lost in June of 1980 for approximately six minutes during a partial loss of offsite power. One RCP had a vapor seal leak of 1.5-2 gpm and was replaced, all other stages were acceptable.

d) Plant K

Seal cooling has been lost for one hour when operator error actuated containment signal and secured CCW to the seals. Seals were changed.

e) Plant M

During the 11/16/84 plant hot standby (RCS= 530°F) the CCW for two pumps was isolated for 6 hours for replacement of leaking flex hoses. The lower seal cavity temperature exceeded 360°F (monitor pegged out) and the CBO temperature increased to 330°F for one pump and 275°F for the other pump for 3 hours. There was no abnormal CBO flow or fourth seal leakage. Upon pump restart, one pump experienced first stage operating problems for several weeks before obtaining normal operation. Both pumps operated normally for 3 months until the plant refueling outage.

2.3

Question 3.0 - Introduction (Federal Register)

"The staff acknowledges that procedures related to the operation of the seals play an important role in avoiding a small-break LOCA caused by seal failure. It is not clear that past and current treatment of the seals reflect their safety importance. The NRC

staff is therefore considering the need for improvements in the related procedures, training, and information provided to operators and their actions."

2.3.1 Question 3.1 (Federal Register)

"Are there procedures currently in place that are intended to prevent seal leaks from becoming small-break LOCAs during both normal plant operation and loss-of-seal-cooling events such as station blackout? Are the required operator actions (e.g., isolating leakoff lines) the same for normal plant operation and loss-of-seal-cooling events?"

Response 3.1

Yes, all member plants of the CEQG have procedures currently in place to prevent a reactor coolant pump seal leak from becoming a small-break LOCA. No, the operator actions are not the same for normal plant operation, loss-of-seal cooling, and station blackout. Individual procedures for operator action have been developed by each plant for their own unique conditions. As an example, only during station blackout is the controlled bleedoff isolated to maintain the reactor coolant system inventory.

2.3.2 Question 3.2 (Federal Register)

"Has the RCP instrumentation been evaluated to determine whether operators have sufficient information to implement the procedures?"

Response 3.2

The CEQG plants have various amounts of instrumentation but all are equipped with controlled bleedoff flow, controlled bleedoff

temperature, and three stage pressure indications for monitoring and evaluating seal performance. All CEOG plants responded in the survey that their instrumentation has been evaluated to ensure that the operators have sufficient information to implement the operator procedures.

2.3.3 Question 3.3 (Federal Register)

"How is RCP seal vendor information used in establishing operation and maintenance practice for the RCP seals?"

Response 3.3

The CEOG plants have used the reactor coolant pump seal vendor information in establishing their own operating procedures. In most cases by directly transferring the criteria into the procedure or for determining the seal degradation criteria.

2.3.4 Question 3.4 (Federal Register)

"In some cases, industry practice allows continued plant operation with the RCP seal when first or second stages have failed. Do you limit this practice? If so, what are the limiting conditions?"

Response 3.4

There are two basic configurations represented by the CEOG and they do not have exactly the same approach to seal stage failure. They are the KSB seal configuration and the Byron Jackson SU, Byron Jackson N-9000, Bingham, and AECL seal configurations.

The criteria for pump shutdown for the KSB seal is that upon one seal stage failure, the pump may be shut down depending on which stage has failed. The pump's shutdown is required per the

technical manual and procedure when two stages have failed or the leakage is in excess of that allowed by the plant's technical specification.

The Bryon Jackson SU, Bryon Jackson N-9000, Bingham, and AECL seal configurations do not require pump shutdown when one seal stage has failed. The seal performance will then be closely monitored and the pump will be run as long as necessary. The pump will be shut down if a second seal stage fails. Some of the other criteria that are used to determine seal failure are overall leakage, component cooling water leakoff temperature above 165 °F, or the vapor seal cavity pressure <250 psi.

The wording of the question does not acknowledge the four-stage design utilized in these configurations. Seal stage failure responses in the four stage configuration do not differentiate the operator actions for which of the lower three seal stages fails first or second.

2.3.5 Question 3.5 (Federal Register)

"What additional quality assurance and procedural measures can be taken regarding RCP seals to improve safety?"

Response 3.5

The CEOG does not believe that there are any additional generic quality assurance or procedural measures that will improve safety.

Each utility is always attempting to improve the integrity and life of the RCP seals. There is a very strong financial motivation that will always exist to improve the seal performance and avert a forced outage, whether the NRC imposes additional

requirements or not. The utilities and their seal vendors will continue to strive to achieve maximum seal reliability, through extended training of installation teams, tight parts control and inspection, and performance monitoring. These programs, already in place, achieve what the NRC is proposing to regulate.

2.4 Question 4.0 - Introduction (Federal Register)

"As part of the probabilistic risk assessment performed for GI-23, a seal model (Appendix A of NUREG/CR 5167) was developed for use in estimating the core damage frequency associated with loss of RCP seal cooling."

Note:

The model was developed by Atomic Energy of Canada Limited, a seal vendor. The function of the model is stated by AECL to be a failure model for Westinghouse RCP seals during station blackout.

2.4.1 Question 4.1 (Federal Register)

"Is the staff's model, or other models, adequate to predict RCP seal leakage (i.e., modes of seal failure, time-dependent failure probability and leakage estimates) and handle the uncertainties in the models? Do the models correlate to actual plant or test data?"

Response 4.1

The model presented is for Westinghouse RCP seals during station blackout. Westinghouse was chosen because it represents the majority of PWRs in the United States (53 of 76). However, because of what AECL termed "basic design similarities", the rest of the PWRs in the United States were assumed to behave in the same manner as the AECL model. This is not a valid assumption.

Because the model was built to simulate the Westinghouse plant, it does not incorporate the different seal configurations and operating methods used on the CEQG plants. The CEQG plants operate with a lower CBO flow than the Westinghouse design and the pressure drop across stages is controlled by a pressure breakdown device. The seal configurations are either a fourth stage vapor seal or the KSB three stage system which will prevent any seal leakage. Therefore the CEQG plants will not behave as predicted by the AECL model. See the seal history including occurrences of fourth stage or last stage performance in Section 2.1.1, 2.2, and 3.2.3.

2.4.2 Question 4.2 (Federal Register)

"Of particular interest to the staff are alternatives to the probabilistic RCP seal leakage model developed for Westinghouse seals and alternative models for other seal designs (i.e., for seals by Byron Jackson, Bingham International, or Combustion Engineering/KSB) to predict seal leakage during loss-of-all-seal-cooling events. Can you provide information regarding any alternate models?"

Response 4.2

No, however, testing has been performed to show that the seals used in CE plants, especially those with the fourth stage vapor seals, will perform significantly better than the AECL model of the Westinghouse seals. See Appendix C for complete description of tests performed.

2.5 Question 5.0 (Federal Register)

"In exploring alternatives to providing additional seal cooling, one approach might be to test the existing seals to demonstrate

conclusively that they will not leak excessively if not cooled for extended periods of time, even though such conditions exceed the seal design basis and possibly the conditions of warranty. If testing was an option to demonstrate acceptable seal performance under loss of cooling conditions, what conservative conditions should be imposed on the RCP seal for the test program (e.g., length of time, maximum wear on seal, number of tests)?"

Response 5.0

The CEOG position is that no additional seal testing is warranted. Operating experience under adverse conditions and seal testings have illustrate the resilience of CEOG seals. See Appendix C for description of seal tests.

A description of the loss of cooling could be prepared for every plant in terms of an event profile showing RCS pressure and temperature versus time. This information would make it possible to evaluate seal operating histories and seal capabilities. It is possible to extrapolate expected seal behavior from data which shows past testing, or inadvertent events in any plant which used that particular or very similar seals.

Establishment of the loss of cooling event profiles may show that the expected conditions are not as severe as imagined at present. For example, if it is shown that for a particular plant the loss of cooling is not expected to exceed 4 hours, and there is seal performance data available to show that similar seals have survived for time periods exceeding 4 hours, such data would facilitate the completion of the evaluation of that seal type. For CEOG plants there would be no need to search for data to show acceptable performance for more than 8 hours.

3.0

NRC PROPOSED RESOLUTION

The NRC has proposed an approach for the resolution of Generic Issue 23 by announcing the availability of Draft Regulatory Guide DG-1008 in the Federal Register, Vol. 56, No. 76/ Friday, April 19, 1991. They have solicited comments from interested organizations, groups and individuals on their approach.

A regulatory analysis was not prepared as part of this draft guide. Instead, draft NUREG-1401, "Regulatory Analysis for Generic Issue 23, Reactor Coolant Pump Seal Failure" is used as the regulatory basis. The cost/benefit analysis of the proposed resolutions is contained in NUREG/CR-5167, "Cost/Benefit Analysis for Generic Issue 23, Reactor Coolant Pump Seal Failure". NUREG/CR-4948, "Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure", is referenced throughout all these documents as a summary of the technical findings of the staff's studies of the reactor coolant pump seal failure issue.

The Draft Regulatory Guide and the NUREG documents referenced in the draft and the Federal Register Notice were reviewed in detail. The Combustion Engineering Owners Group (CEOG) response, comments and data (obtained with the questionnaire in Appendix A) are presented as follows.

3.1 Draft Regulatory Guide DG-1008 Review Comments

The Draft Regulatory Guide DG-1008 states the position the NRC has identified as the approach for resolving Generic Issue 23.

3.1.1 Summary of Content

The Introduction to this draft guide summarizes the requirements of 10 CFR Part 50 General Design Criteria (GDC) 1, 13, 14, 30 and

44, which are applicable to maintaining the reactor coolant pressure boundary, as well as certain requirements of 10 CFR 50.63 which deal with station blackout: loss of offsite electric power concurrent with reactor trip and unavailability of on-site emergency AC power.

This draft guide also describes means acceptable to the NRC for including the RCP seals in a QA program as well as methods acceptable to the NRC for enhancing the capability of nuclear plants to withstand loss of cooling events as they relate to RCP seals.

The Discussion section covers seal design and quality control as well as seal failures both during normal plant operation and during loss of cooling events.

The Regulatory Position section discusses QA considerations for RCP seals, plant operating procedures and instrumentation to facilitate the implementation of operating procedures (for both normal and abnormal conditions). This section also reiterates NRC concerns regarding seal loss of coolant accidents (LOCAs) coincident with loss of Emergency Core Cooling System (ECCS) functions.

The Implementation section states that this guide has been released to encourage public participation in their development of a guide which will be used in the evaluation of PWR licensees and applicants.

Additional information in this guide covers an example of independent seal cooling, examples of conditions for which Westinghouse provides instructions, examples of vendor-recommended instrumentation and operating limits for Westinghouse, Byron Jackson and Bingham RCP seals.

Appendix A contains the NRC design guidelines for independent seal cooling. Appendix B covers QA for non-safety related independent seal cooling.

3.1.2 CEOG Comments

3.1.2.1 Quality

The present RCP shaft seals are designed to provide reliable service for extended life. While nuclear safety is a primary concern in these designs, economics is the driving force ensuring the quality of the seals, implementing their reliable design. It is very expensive for a utility to be in a plant shutdown. When the plant cannot operate, not only is it not producing revenue but it may also have to purchase replacement power from some other source. Economics will continue to drive this issue as long as the plants are operating. There is no such thing as a "best" seal. Some utilities are continuing to use the seal types which were provided with the original pumps, while others have chosen to purchase new designs which have become available in recent years. All utilities have found their seals to have sufficient reliability once they learned how to operate them, i.e., the do's and the don't's in assembly, rebuilding, installation, operation and monitoring.

Imposing additional QA requirements will significantly increase the costs and will extend delivery schedules, not because the seals will be made of better materials or will be made more carefully, but because of the additional requirements which will have to be produced, checked, copied, shipped, filed and audited. The seals themselves will remain the same because economic concerns have already imposed a high level of quality. The seal vendors have contributed to this improved seal reliability by

instituting rigid material, dimensional, and manufacturing controls on the seals they produce.

3.1.2.2 Operating Limits

A review of seal operating histories shows that there have not been any serious seal problems which came close to causing a LOCA type discharge of primary coolant. (See the CEOG plant histories in Section 2.1.1, degraded and loss of cooling histories in Section 2.2, and NUREG 1401 Table A-1 seal failures in Section 3.2.3). It is not logical to point to events which have occurred 10 or more years ago, because not only have the seal vendors improved the reliability of their seals but also the plants have upgraded their operating procedures, maintenance techniques, personnel experience and training. Economic conditions have changed in the last 10 years.

All of the CEOG plants have incorporated the seal vendors recommended instrumentation into their operating procedures. The operators are trained to use the instrumentation to monitor and evaluate the seal performance for normal operation, loss of cooling, and station blackout.

3.1.2.3 Seal Cooling for Off-Normal Conditions

Many of the postulated seal failure scenarios resulting from loss of cooling for extended periods are based on studies which were faulty, in that they used only a single seal stage, seal sizes which were other than the actual seals, elastomers which were of other materials or materials no longer in use, and even in one study an U-cup was spliced because the correct size was not available. When a failure of the splice occurred it was attributed to a seal failure and the test was not declared invalid.

The CEOG accumulated seal history demonstrates that the pump seals are quite resilient to abnormal operation and can survive a loss of cooling event. In Section 2.2 is presented the CEOG seal history of degraded and loss of cooling occurrences, which have been small in number. They do show that the seals have experienced various levels of degradation and may need to be refurbished at some point following the event, but they do not illustrate LOCA failures as predicted by the NRC. The leakage that has occurred has been well within the original assumptions for station blackout rules. The actual seal experience only confirms the tests presented in Appendix C.

The present plants use safeguard systems which are powered by high-quality, high-reliability diesel generators (DGs). 10 CFR 50.63, however, requires the assumption of unavailability of the on-site emergency AC power sources during a station blackout (SBO). The acquisition of an emergency power source to drive the component cooling water (CCW) pumps or seal injection pumps and associated instrumentation and valves may end up in the same category as the existing DGs.

3.2 NUREG-1401 Review Comments

Title: Regulatory Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure; Draft Report for Comment, Published April 1991

This regulatory analysis was referenced in the regulatory analysis section of Draft Regulatory Guide DG-1008 and the Federal Register Notice as providing the regulatory basis and cost and benefit analysis of implementation. The research, technical data, and other analysis supporting the resolution of this issue are summarized in the technical findings report, NUREG/CR-4948 and cost/benefit report, NUREG/CR-5167, referenced throughout this document.

3.2.1 Summary of Content

Three key items are part of the NRC's proposed solution to the seal failure problem:

1. Safety-related designation and additional QA requirements for the seals.
2. Manufacturer-recommended instrumentation and procedures for monitoring seal performance.
3. RCP seal cooling during station blackout (SBO) conditions.

This draft report also covers an evaluation of the proposed resolution, the decision rationale and a plan for implementation of the resolutions.

The appendices deal with evaluations of potentials for core damage and cost benefit evaluations for independent seal cooling systems.

The report also considers a number of other means for addressing RCP seal performance which were rejected. Among these is seal testing to verify that excessive leakage does not occur when seals are not cooled. The NRC feels that a very large number of tests would be required to statistically demonstrate a reliability comparable to that of a backup cooling system. The NRC more or less rejects existing test results and plant experiences as inadequate.

3.2.2

CEOG Comments

Executive Summary

In the Executive Summary the NRC defines a RCP seal failure as a loss of integrity of the primary coolant system pressure boundary. It would appear then that counting every seal degradation (which on occasion did not even require the plant to be shut down quickly for seal repair) is an erroneous approach which only bolsters the volume of statistical data to incorrectly conclude that there is a problem. In fact, when there has been a degradation in seal performance such as a loss of one seal stage, there has not been a loss of pressure boundary integrity which required plant shutdown.

If the definition of a station blackout includes the loss of emergency in-plant AC power, then how will the reliability of a backup cooling system be considerably superior to that of present-day safeguard systems which are of top quality already?

In "Statement of the Problem" the report defines seal failure as the degradation of seals that limit primary coolant leakage along the shafts of the RCPs. This definition is excessively all-inclusive. By this definition any seal behavior which deviates however minutely from perfect operation, must be called a failure. Such a definition is unrealistic. Individual seal stage failures lead to increased CBO, which is contained in the closed loop CVCS. See Section 2.1.1 for a definition of seal failure.

The present RCP Seals are fabricated to the highest standards and of the best materials for this application. Imposing additional QA requirements will only increase the cost and extend delivery times. Conflicts with the Code will have to be resolved through special rulings or Code Cases since some of the materials used in the seals are not listed in the Code as approved for pressure

boundary applications. If the manufacturer were limited to the materials in the code, the seals probably could not be made to work at all.

The plants in operation already use the RCP instrumentation recommended by the pump/seal suppliers. These consist of monitoring the seal staging pressures (pressure transducers), the flow (flowmeter), and temperature (resistance temperature detector - RTD) of the controlled bleedoff. These instruments are periodically calibrated and have appropriate alarm settings to warn the operators of a condition outside of predetermined values. The outputs from these instruments are recorded on the plant computers for record, subsequent retrieval, or trending purposes.

The report states that the seal failure models are based on the Westinghouse RCP seal design and testing by AECL. This was done because there are more Westinghouse seals in use than any other kind and more data was available for these seals. The NRC states that since there are basic design similarities between the seals, the cost/benefit analysis should be applicable to all commercial FWRs in the US. The CEOG does not agree that there are sufficient similarities among all plants to allow imposing a blanket approach. A cost/benefit analysis for the CEOG plants is presented in Section 3.3. It contains dual results in order to take into consideration the difference in seal configuration just within the owners group. Byron Jackson seals, Bingham, and AECL seals used in CEOG plants use a 4 stage design. The KSB seals use a 3 stage design but are not at all similar to the Westinghouse seals which are classified as a hydrostatic design. The KSB seals are more similar to the BJ, Bingham, and AECL seals which are of the mechanical/hydrodynamic design. All of the seal types have either been tested at SBO conditions or similar conditions, or have been inadvertently subjected to high temperatures during plant operation. None of these tests or operations have resulted

in a reactor coolant leakage approaching a LOCA incident in magnitude.

NRC's rejection of Alternative #3 is based on criticisms of shortcomings in the tests which had been performed on various seals, and yet the NRC uses data from various NRC-funded studies which had serious shortcomings. The fact that elastomers were found to have degraded, and seal parts were chipped or cracked should not be a primary criterion in evaluating a seal. We do not believe that one of the objectives is to have a seal which will be ready for continued operation (without refurbishment) after having been subjected to relatively severe conditions during an extended SBO event. There are probably several other plant components which will require inspection before the plant returns to operation. The main question should be did the seal maintain the pressure boundary without allowing uncontrolled leakage? We believe that the industry tests (summarized in Appendix C to this report) have demonstrated the resilience of the seals used by CEONG members. The NRC states that the tests have not represented all the conditions that can occur during loss of cooling events. The seal history in Section 2.2 shows that the seals have indeed survived a loss of cooling event without excessive leakage.

We believe that the 50-hour exposure of the St Lucie seal cartridge to full power RCS pressure and temperature conditions was considerably more than would be experienced during an SBO event. The NRC have criticized this test because there was no vertical motion of the pump shaft as would be expected during a station blackout event. However, some shaft movement must have occurred as a result of thermal expansion.

The San Onofre seal test was performed to demonstrate to the NRC that uncontrolled discharge of primary fluid would not occur if operator intervention did not occur for 20 minutes following the

loss of component cooling water (CCW) flow. CCW flow was restored to the seal cooler after 30 minutes. This resulted in a significant thermal shock. It should be noted that the pump was not tripped off at this point, but continued to operate (without seal failure) for over an hour while the test loop was cooling down and the pressure was lowering. Shaft movement must have occurred both during the operation without cooling as well as during the cooldown process. Such shaft motion would have been the result of the significant thermal expansions during heatup after loss of cooling and contractions after initiation of cooling.

The NRC statistical approach to testing results in an argument that between 14 and 59 successful tests would be needed to statistically demonstrate a 95% probability that the RCP seals will not fail upon loss of cooling, which would be comparable with the reliability of the backup cooling system. This approach is not feasible since the CEQG members use 5 different seal types. This would mean 70 to 295 separate tests. The cost would be prohibitive and it would take many years to complete these tests. If the last test of a series resulted in a failure, that would mean a redesign and starting all over. We believe that additional testing is not necessary since the existing test data and 20 years of in-plant experience indicate that the seals are not expected to fail and cause uncontrolled discharge of primary coolant. The NRC also does not indicate what it would consider to be adequate evidence that the backup cooling system is reliable if such a system were installed (another 59 tests?).

Appendix A of this NUREG presents a list of pump seal failure events in Table A-1. The list contains nine occurrences attributed to CEQG plants. The NRC considers all of the occurrences to be incidents of seal failure, an indication of their lack of performance. Each case has been reviewed and a

detailed explanation of what actually occurred is presented below. Of all nine cases, only one could actually be attributed to the seal and that was during the startup of a new seal configuration. This record only shows how resilient the seals are.

3.2.3 Pump Seal Failures According to NUREG 1401, Table A-1

3.2.3.1 Event Date: AUG 1, 1988
Plant: ANO-2
Seal Type: BJ SU Seal
Description of Failure Event: 1st & 2nd Seal Stages Failed;
(according to NUREG-1401) Leakage 40 GPM

Description of Failure (according to the Utility):

The pump shaft seal failure was initiated by a break of the rigid sensing line of the middle seal cavity pressure transmitter. Full RCS pressure was applied to the vapor seal. Lower seal temperature exceeded 350°F. Carbon faces in 2nd and 4th stages were broken, carbon faces in 1st and 3rd stages were cracked. There was partial U-cup extrusion. The RCS peak leak rate was 40 GPM. Most of this leakage was coming from the sensing line and not the seal. The sensing line leakage could be as much as 37 gpm. After the sensing line was isolated the leak rate was 20 GPM. The seal became overheated since the high rate of coolant flow overcame the capability of the seal cooling heat exchanger to adequately cool the fluid entering the seal cartridge.

The seal had been in operation for about 4 months. The failure was discovered through staging pressure indications.

Corrective Action:

The sensing line weld was repaired and flex hoses were installed on all seal cavity pressure sensing lines to replace part of the rigid pipes. The failed shaft seal cartridge was replaced.

Comment:

The seal failure was caused by a fracture of a pressure sensing pipe. This pipe is not part of the seal. The proposed regulations would not have prevented this failure. It must be emphasized that this was not a seal initiated failure.

3.2.3.2

Event Date:	Nov 9, 1988
Plant:	Waterford, Unit 3
Seal Type:	BJ N-9000 Seal
Description of Failure Event: (according to NUREG 1401)	Seals failed after startup. Replaced with old BJ seals.

Description of Failure (according to the Utility):

Three shaft seal cartridges degraded after startup. Controlled Bleedoff temperatures and pressure were higher than normal. Staging pressures were normal at low RCS pressures but seals destaged as RCS approached normal operating pressure and temperature. Suspected causes were pump mis-alignment, axial play, shaft eccentricities and dimensional tolerance stackups.

Corrective Action:

All four N-9000 seal cartridges were replaced with old (SU) type BJ seals.

Comment:

The degradation of the BJ N-9000 seals occurred after startup. This was a new type of seal and improper performance was detected during startup using the instrumentation already installed. Backup cooling would not have been of assistance. Controlled bleedoff flow was normal. This was a seal degradation rather than a failure. These were the first N-9000 seals installed in a plant. Design and manufacturing problems associated with this failure have been corrected. Three N-9000 seals were installed at Waterford in 5/91.

3.2.3.3

Event Date:	Dec 5, 1988
Plant:	Palisades
Seal Type:	BJ SII Seal
Description of Failure Event:	Description not available. (according to NUREG-1401)

Description of Failure (according to the Utility):

The plant was started up and one stage in one seal cartridge was not working. Controlled bleedoff was between 1.5 and 2 GPM. A month later the plant was shut down for a steam generator tube problem.

Corrective Action:

The seal cartridge was replaced at that time. This event, therefore should not be classified as a seal failure.

Comment:

The improper functioning of the seal was the result of undetermined causes. During plant startup it was noted that one seal stage was not staging (i.e., it was not taking its portion of the pressure drop). The plant continued operation until a month later, when the plant was brought down for steam generator tube problem at which point the seal was replaced. It is standard procedure not to bring a plant down unless at least two stages are not functioning. This event does not constitute a seal failure.

3.2.3.4	Event Date:	Dec 21, 1988
	Plant:	Maine Yankee
	Seal Type:	N-9000 Seal
	Description of Failure Event:	Degraded seal performance.
	(according to NUREG-1401)	Seals replaced with BJ N-9000 seal.

Description of Failure (according to the Utility):

The SU seals had been upgraded with N-9000 seals during a refueling outage. A ceramic filter in the seal water system degraded and many sand-like particles entered the N-9000 seal cartridge. This caused significant wear of the seal faces. Controlled bleedoff (CBO) flow increased to about 5 GPM. The vapor seal functioned properly so that no leakage external to the pump and piping resulted from this event.

Corrective Action:

The filter and the N-9000 seal cartridges were replaced. SU seals were removed from storage and reinstalled.

Comment:

The seal degradation was the result of sand-like material introduced into the N-9000 seals from a filter which had disintegrated. The controlled bleedoff had increased but not significantly. The proposed regulations would not have prevented this seal degradation.

3.2.3.5	Event Date:	March 3, 1989
	Plant:	Palo Verde (PVNGS)
	Seal Type:	CE/KSB Seal
	Description of Failure Event:	Seals damaged.
	(according to NUREG-1401)	Seal leakage 2 GPM.

Description of Failure (according to the Utility):

PVNGS Unit 3 was at 100% power and was scheduled to come down for a refueling outage in the next few days. Due to a loss of site power all 4 RCP's experienced a loss of Seal Injection and component cooling water (CCW). In addition the CBO was inadvertently not isolated. These conditions lasted for approximately 90 minutes, seal temperatures reached 437°F.

Seal damage to pump 1B was evident by abnormal CBO/staging pressure after reestablishment of Seal Injection. Following reestablishment of seal injection 2 of the RCP's were started to establish forced circulation in the RCS and run approximately 7 to 8 hours at RCS NOP/NOT with subsequent run time at decreasing RCS temp/press for cooldown, which took approximately 29 hours. External seal leakage from pump 1B was later verified to be 1.25 GPM. Only pump 1B experienced leakage. Seals in all four pumps were replaced.

Corrective Action:

The shaft seals in all 4 RCPs were replaced during the refueling outage.

Comment:

The event occurred while the plant was preparing to come down for a refueling outage. Both seal injection and CCW cooling were lost for an extended period of time. The seals reached a temperature of 437°F. Vapor seal leakage was 1.25 gpm. After disassembly no seal damage was noted. The seals, however, were replaced because this was considered to be prudent.

3.2.3.6

Event Date:	Nov 7, 1989
Plant:	Maine Yankee
Seal Type:	BJ SU
Description of Failure Event: (according to NUREG-1401)	N-9000 was earlier replaced by SU type, which failed. Plant shut down.

Description of Failure (according to the Utility):

One N-9000 type seal and two SU type seals were in operation. The SU seal installed in pump #1 had the drive lock ring lugs broke off into the seal and the resulting filings caused seal face wear. Seal staging pressure degraded and the plant was shutdown in an orderly manner before any problems occurred. The CBO flow was less than 5 gpm and the vapor seal did not leak.

Corrective Action:

The SU seal in pump #1 was replaced with a rebuilt N-9000 seal cartridge.

Comment:

In the event some internal seal parts (drive lock ring lug) broke. This produced filings inside the seal cartridge causing wear of seal faces. Seal staging pressures became degraded. This was noted on the existing instrumentation and the plant was brought down for seal replacement. Controlled bleedoff remained less than 5 gpm. The proposed regulations would not have had any effect on this seal degradation.

3.2.3.7

Event Date:	Jan 20, 1990
Plant:	Waterford 3
Seal Type:	BJ N-9000
Description of Failure Event (according to NUREG-1401)	Seal leak found during shutdown while checking reactor coolant system leaks.

Description of Failure (according to the Utility):

SU seals were in use. Some minor leakage was found in the driver mount. The source was determined to be the upper shaft sleeve O-ring. At the time of the leakage the seal pressure staging was found to be proper.

Corrective Action:

Two O-rings were installed per instructions from BJ. No further leakage was observed.

Comment:

The seal leak discovered had apparently been going on for some time. The leakage was discovered when standing fluid was found in the motor mount during a walkdown. After consultation with BJ it was decided to replace an O-ring between the shaft and the shaft sleeve with two O-rings. No further leakage was observed. The proposed regulations would not have had any effect on this seal degradation. This was very minor leakage past the upper shaft sleeve O-rings. There was no degradation at any stage. The seal was not replaced.

3.2.3.8

Event Date:	Jul 2, 1990
Plant:	St Lucie 1
Seal Type:	BJ
Description of Failure Event: (according to NUREG-1401)	1st and 2nd seal stages deteriorated. Leakage 3 GPM.

Description of Failure (according to the Utility):

The pump shaft was bent. It is suspected that this may have been caused by the temporary seal injection when the fourth pump was idle during plant heat-up. The pump ran with the bent shaft for about 30 days. The shaft orbit was not significantly higher than normal. Wear was found in the hydrostatic bearing area. The shaft sleeve also wore producing very small metal slivers and particles which in turn caused accelerated wear of other seal parts. Controlled Bleed-off increased from 1 to 1.6 GPM in one

day and then to 2.5 GPM the next day. Later the shaft was found to be bent (approximately 0.050").

Corrective Action:

Installed a new shaft sleeve and a new pump rotating assembly (pump shaft, impeller and hydrostatic bearing journal).

Comment:

The seal degradation was caused by a bent pump shaft. Despite the use of shaft instrumentation, no abnormal shaft orbit had been noted. Seal pressure staging was degrading and the controlled bleedoff was increasing. Plant was brought down for replacement of the shaft and impeller and the seal carriage. The pressure staging and controlled bleedoff were noted on the existing instrumentation. The bending in the shaft was caused by backup seal injection being used during plant startup and shutdown operations. This backup seal injection was installed for use in the event CCW flow was lost.

3.2.3.9

Event Date:	Aug 24, 1990
Plant:	Fort Calhoun
Seal Type:	BJ
Description of Failure Event: (according to NUREG-1401)	Inlet pressure on 2nd stage steadily decreased. Plant shut down. Seal replaced.

Description of Failure (according to the Utility):

Plant was at 100% power and had been in operation for about 3 months since the last outage. The IB pump controlled bleedoff flow started to decrease and the second stage inlet pressure

decreased resulting in alarms for both. The plant was brought down and the seal cartridge was replaced. The cause was determined to be a piece of lockwire which lodged in the pressure breakdown tube and blocked the staging flow.

Corrective Action:

The seal cartridge was replaced. The safety wiring technique was changed to preclude a repetition of this problem.

Comment:

The seal degradation occurred about 3 months after a refueling outage. A piece of lockwire broke off and lodged in the pressure breakdown capillary tube, partially blocking the controlled bleedoff. Seal pressure staging degraded and was noted by means of existing instrumentation and alarms. The proposed regulations would not have had an effect on this event.

3.3 NUREG/CR-5167 Review Comments

Title: Cost/Benefit Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure

This report provides a Cost/Benefit Analysis of the three items, which were selected for consideration by the Nuclear Regulatory Commission. Item 1 consists of treating the RCP seal assembly as a component performing a safety-related function similar to other components of the reactor coolant pressure boundary, and applying quality assurance requirements consistent with Appendix B of 10CFR50 and applicable General Design Criteria of Appendix A to 10CFR50. The second item would require utilities to provide RCP manufacturer-recommended instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal

failures. Item 3 requires utilities to provide RCP seal cooling during off-normal plant conditions, such as station blackout, involving loss of all seal cooling. The Cost/Benefit Analysis used the AECL model to obtain the core melt probabilities due to seal failure. The rest of the values used in the analysis are estimates taken from various sources. The general format of the analysis follows the Handbook for Value-Impact Assessment (NUREG/CR-3568) precisely. The handbook uses estimated costs and person rem to analyze the value per person rem for evaluating a particular project.

The estimates in the analysis were poor and lacked consistency. The CEQG plants were requested to provide plant specific estimates for the data points used in the Scientech NUREG/CR-5167 analysis. See questionnaire in Appendix A Section A.4. The responses received demonstrated inaccuracy of the Scientech estimates. The benefits of implementing the items were overestimated by as much as twice their value. The costs are severely underestimated as low as a half to a quarter of their expense.

Page 1-1 States that past seal failure data demonstrates relatively high seal failure rates and the possibility of resulting leakage rates well into the range of small loss of coolant accidents. The CEQG plants should be excluded, because there have never been any leaks approaching the size of a small-break LOCA as a result of RCP seal failures.

Table 1-1 This table presents estimates for Core-Melt frequencies induced by RCP seal failure for normal and off-normal conditions. These estimates were taken from the AECL model in Appendix A of NUREG/CR-5167. The frequencies given in this table are not accurate for CEQG plants. The model was made to simulate

Westinghouse plants only. For CEQG plants the values for Core-Melt should be obtained instead from NUREG/CR-4948, Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure.

Page 3-3 The report states that power supply reliabilities of 99%, 90% and 95% were used in the analysis as high, best and low estimates respectively. The reliabilities for the power supply are accurate only for the power supply itself. The estimated reliabilities in the analysis are 99%, 90%, and 95% for high, low and best respectively, however, these do not take into account reliabilities for associated valves, switches, circuit breakers and others factors including human performance. One utility supplied estimates taking all this into account. When everything is added in the reliabilities drop to at most 90%, 60% and 75% respectively.

Page B-1 The model upon which the analysis is based excludes PWRs not employing Westinghouse pumps. This statement conflicts with page F-30 in the actual calculation of the cost/benefit.

Page F-30 The analysis refers to 76 PWR plants, which would be all the plants in the United States. The Cost/Benefit Analysis for CE plants would be significantly different as can be seen in the following tables.

A Cost/Benefit Analysis was performed using the CEQG plant data to show the difference with the NUREG/CR-5167 model. A questionnaire was sent to the CEQG members with six utilities responding for ten plants. The data was used to calculate the values for a generic CEQG plant. The analysis used two different values for the

probability of core melt due to loss of CCW. The value of $.352 \times 10^{-6}$ was used for plants with a fourth stage vapor seal and 6×10^{-6} was used for plants with KSB seals.

The results of the CEOG analysis were calculated the same way as NUREG/CR-5167, which followed NUREG/CR-3568, "The Handbook for Valve-Impact Assessment". The benefits are calculated in person-rem and are broken into three categories. The first benefit is Public Health which represents the exposure reduction from core-melt as a result of improved seal performance.

Public Health (person-rem)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	0	930	2,256,658/ 2,302,121	930
Best	0	648	5,323/10,375	648
Low	0	254	3/48	254

* The first number is for plants with a vapor seal and the second is for those without.

The second benefit group is Accidental Occupational Exposure, which represents the reduction in exposure to onsite personnel as a result of improved seal performance. This includes both the immediate and the long-term cleanup exposure.

Accidental Occupational Exposure (person-rem)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	0	15	3,821/3,898	15
Best	0	6	42/81	6
Low	0	1	1/14	1

The last benefit group is Operational Occupational Exposure, which is the reduction of exposure as a result of less maintenance.

Operational Occupational Exposure (person-rem)				
	Item 1	Item 2	Item 3	Item (1&2)
High	-428	-746	-	-663
Best	-184	-502	-	-486
Low	-2,365	-2,603	-	-2,683

Costs are broken down into several categories. The first two categories are Industry Implementation and Industry Operation, where implementation refers to the single cost of installing the item, and operation refers to the annual costs of maintaining the item.

Industry Implementation (dollars)				
	Item 1	Item 2	Item 3	Item (1&2)
High	789,750	6,263,250	56,499,990	7,053,000
Best	526,500	6,175,500	5,499,990	6,702,000
Low	263,250	6,087,750	56,499,990	6,351,000

Industry Operation (dollars)				
	Item 1	Item 2	Item 3	Item (1&2)
High	325,419	701,051	949,764	-2,130,284
Best	139,765	1,137,017	917,947	334,033
Low	1,799,553	3,604,104	886,605	3,604,104

The values for NRC Development, Implementation and Operation Costs are assumed to be accurate as presented in NUREG/CR 5167 so they are not presented. Off-site and On-site represent the costs due to core-melt that would be averted if the items are implemented.

Offsite Property (dollars)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	0	-31,240	-19,462,696/ -19,854,793	-31,240
Best	0	-160,633	-1,034,228/ -2,025,376	-160,633
Low	0	-1,269,676	-417,839/ -6,937,050	-1,269,676

Onsite Property (dollars)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	0	-13,605	-8,475,826/ -8,646,581	-13,605
Best	0	-69,535	-449,864/ -876,751	-69,535
Low	0	-48,934	-48,934/ -812,405	-148,693

The last category is Plant Availability Improvement Savings, which is the savings resulting from not buying replacement power for reduced outages. A negative number represents a savings, which means the following table shows a large expense due to lengthened outages.

Plant Availability Improvement Savings (dollars)				
	Item 1	Item 2	Item 3	Item (1&2)
Best	0	24,509,609	7,922,638	24,509,609

The Basic Cost/Benefit Ratio is calculated by dividing the industry and NRC costs by the Public Health benefit.

Basic Cost/Benefit Ratio (\$/person-rem)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	ERROR	8,125	26/25	6,565
Best	ERROR	11,510	10,814/5,549	11,311
Low	ERROR	38,606	19,875,430/ 1,197,156	40,034

The values for item 2 and 3 greatly exceed the values presented in NUREG/CR-5167 and the recommended \$1400/person-rem guidelines. The value for item 1 is shown as an error which is caused by dividing by a zero benefit.

The Supplemental Cost/Benefit Ratio is calculated using all the parameters except Plant Availability Improvement Savings. All the monetary costs (and savings) are divided by all the exposure terms.

Supplemental Cost/Benefit Ratio (\$/per person-rem)				
	Item 1	Item 2	Item 3*	Item (1&2)
High	-3,990	37,683	13/13	21,484
Best	-4,430	47,266	10,452/5,228	42,075
Low	-914	-3,448	15,175,103/ 797,296	(3,597)

Again, the values for item 2 and 3 exceed the values presented in NUREG/CR-5167. They are clearly not within the \$1400/person-rem guidelines and should not be implemented.

The negative numbers for Item 1 are provided by dividing a positive cost by a negative person-rem savings. The negative manrem savings comes from the operational occupational exposure from implementing Item 1. This demonstrates a problem with this current Cost/Benefit analysis, because what appears to be very cost beneficial is actually paying for increased exposure.

The major cause for these unorthodox results is that plant data showed no benefit for Item 1. Many plants, due to commercial pressure and necessity, have already implemented systems for decreasing seal replacements. They have already achieved the benefit of a quality assurance program by instituting programs

similar to quality assurance, improved maintenance system or by establishing an engineering group to oversee and continuously improve seal performance.

It has been shown that for the CEOG the Sciencetech Cost/Benefit Analysis, NUREG-CR-5167, is inconsistent and did a poor job estimating both the costs and benefits for all three of the proposed items. When accurate estimates for CEOG plants are used in the NUREG/CR-5167 format the results are strongly against the three items. This confirms that the plants are handling seal improvement on their own and the proposed NRC items should not be considered for implementation.

3.4

NUREG/CR-4948 Review Comments

Title: Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure

This report addresses the various fact-finding issue tasks developed for the Generic Issue 23 action plan and provides background information on seal failure as well as an evaluation of seal cooling and mechanical and maintenance-induced failure mechanisms. While generally informative, the report relies too heavily on the AECL findings of NUREG/CR-4821 and re-reports the test results while omitting the test shortcomings. Qualitative judgements are passed and general conclusions are drawn with very little basis provided. The report also summarizes inputs from seal manufacturers but appears overly biased toward another vendor in the manner in which their arguments relative to the issue and the conclusions being drawn are included in the document. Given the significant design differences between the seals offered by the various vendors, conclusions about the applicability of test analysis results should be drawn more carefully and vendor "defenses" should be given equal consideration in a report

summarizing "technical findings". More specific comments are provided below:

Page v The terms "seal degradation" and "seal failure" are used frequently throughout the document. The "seal failure" description is used to describe several distinctly different occurrences. The terms being used should be carefully defined and used consistently and appropriately throughout the document. It may be more appropriate to consider the following definitions.

- 1) "Seal Degradation" is where one of the individual seal stages is not operating normally but the pump can continue to operate in accordance with the plant specific operating procedures.

- 2) "Seal Failure" is when two or more seal stages are not operating normally, the control bleedoff temperature or flow is not within normal operating range, or the external seal leakage is above the normal acceptable value in accordance with the plant specific operating procedures. A seal failure requires a plant shutdown or a plant trip depending on severity as determined by the operating procedures. A seal failure may or may not result in external leakage (loss of reactor coolant system inventory) but if there is leakage it is within the normal (charging) capacity of the plant.

- 3) "Gross" or "Catastrophic" failure is when a seal failure has occurred per the above definition and in addition the leakage rate has exceeded the plant makeup capacity (i.e. LOCA).

Page vi

The third paragraph refers to "catastrophic loss of CCW". The word "catastrophic" should be reserved for only the most severe events. The loss of CCW is rarely "catastrophic".

The report acknowledges that, in comparison to the seals used at other plants, a significantly smaller (incremental) contribution is obtained for the CE/BJ seal system if credit is given to the presence of the fourth stage vapor seal. This difference is vitally important in judging the adequacy of CE/BJ seals, or four-stage Bingham seals for that matter, since the fourth stage vapor seal is an integral part of both seal designs and a major difference in comparing these seals with other seal systems. While operation of the pump when the other three seals have failed is not recommended, the vapor seal will function during a pump spindown and during the subsequent pump start-up period.

The safety impact of loss of all seal cooling scenarios was also assessed. When full credit is given appropriately to the fourth stage vapor seal in the CEOG plants, a negligible core damage frequency is obtained. The advantage of the vapor seal in this respect seems to be overlooked elsewhere in the document.

Page vii The first paragraph discusses the high temperature survivability of seal elastomers. The statement concerning the extreme hardening of BJ seal elastomers due to high temperatures is apparently based on the "findings" in NUREG/CR-4821 where spliced BJ seal materials were tested. The splice failed causing the fluid to leak and, subsequently, exposing the elastomer to dry heat. This is not a representative condition because it is reasonable to expect the elastomer hardening process to vary depending upon whether or not it remains wet. Under all conceivable conditions of operation, the elastomers are expected to remain wet with either steam or water.

Page 1-1 Section 1.2. To be consistent with the seal failure definitions of page v comments, it is important to note that there have been seal degradations and seal failures but very few LOCAs; none of which have occurred in CEOG plants. For a history of CEOG seal performance since 1983 see Section 2.1.1, response to question 1.1.

Page 2-7 Section 2.1.3. Bingham seal systems in PWRs are described as consisting of three stages. Bingham also has 4-stage seal cartridges installed at SONGS 2 & 3 and Calvert Cliffs 1 and 2. This only highlights the vast variety of seal designs in use and the care that must be taken when comparing seal designs and drawing conclusions as to their performance characteristics.

Section 2.3. It is important to point out the absence of CEOG plants from the list of significant seal failures that led to the current seal integrity issue. The performance of the four-stage seal designs used at

CEOG plants has been such that no gross seal failures induced by a loss of seal cooling have occurred at any CEOG plants in spite of being subjected to some rather extreme operating conditions (pump operation without CCW, idle pump at hot standby without CCW, CCW reinitiation to a hot cartridge). [A hydraulically induced failure of the 4-stage seal system, however, has occurred at ANO-2]. It is also important to note the time period in which all the significant seal failures have occurred (1974-1980) and the absence of any such events in the recent past. This can be attributed to industry wide improvements in operator training, seal handling, seal maintenance and seal design.

Page 3-3

Section 3.2.1. Shaft warpage is targeted for additional investigation into the effects of re-initiating seal cooling. Re-initiation of seal cooling has many other effects besides shaft warpage, such as a severe thermal transient on the entire seal cartridge.

Page 4-5

Section 4.1.1.2. The recommendation concerning "divergent face deflection" needs additional explanation. Convergent face operation is desirable as discussed below and it is not feasible for the convergence to change to divergence due to flashing. See Appendix B Section B.1 for additional explanation of the desirability for the CEOG shaft seals to operate with a convergent face configuration.

In well aligned, high pressure, balanced end face seals for incompressible liquids, performance is primarily dependent on hydrostatic effects. Water

leaking between seal faces causes a separating force dependent on the pressure gradient. When the faces are flat and parallel, the pressure gradient is almost linear and the separating force is independent of the face separation. Under these conditions hydrostatic lubrication with a stable, balanced separation is not possible. When the faces deflect to form a diverging gap in the direction of leakage, the separating force is small and full hydrostatic lubrication impossible resulting in hard rubbing of seal faces. When seal faces deflect to form a converging gap in the direction of leakage, however, the separating force is dependent on face separation. Smaller separation would cause a greater separating force while greater separation would result in less separating force. Full film hydrostatic lubrication is achieved at a stable separation dependent on the amount of convergence and the balance ratio.

Page 4-12 Section 4.1.2.5. Conclusions on O-ring tests are relevant only if the manufacturer of the seals has not changed materials over the years. Also, specific seal elastomers vary from design to design making these particular tests applicable to a limited number of comparable seal types. Qualitative generalizations are made about the relative impact of various parameters (e.g.; water vs. steam, temperature, irradiation and gap sizes). More specific quantitative comparisons would be necessary in demonstrating more conclusively the overall impact on seal performance.

Page 4-18 Section 4.1.3.1. Statistics on seal failures are presented in the third paragraph. Not only is the term "seal failure" not adequately defined, but quoting mechanical- and maintenance-induced seal failures per NSSS supplier/pump manufacturer without stating the total number of plants/pumps involved can be misleading. Also, lumping old designs and new designs, with no corrections or explanations regarding significant changes in seal design, training, system design and procedures, results in statistical misinformation.

Figure 4.1.4. Statistics are presented for what are classified as end of life failures, yet no clear definition is provided for what constitutes the seal life. Typical seal lives range from 2 to 4 years.

Page 4-22 Section 4.1.3.2. More frequent seal inspection is recommended in this section as a means of minimizing seal failures. Inspection of seals means seal removal and disassembly. This in itself could lead to problems as has been identified in reviews of maintenance- induced seal failures. When the seals are removed the utilities may find it more economical to replace the seals. A greater emphasis should be placed on seal performance monitoring as a means of detecting potential problems.

Page 4-23 Section 4.1.3.2. The second paragraph recommends isolating the controlled bleed-off flow upon excessive leakage of any seal stage. The controlled bleedoff line is equipped with a flow check valve which will close on excessive flow. In the CEOG plant design the closing of the valve then places the total system

pressure on the last or vapor seal for which it is designed to carry.

Page 4-27 Section 4.2.1.2. Calculation results are discussed that bring into question the validity of the analytical models. It is not clear, for example, how the seal could be leaking 200 gpm and be operating in a "stable manner". Admittedly, there are significant differences between seal designs and all designs are geometrically complex. Modelling seal behavior, therefore, would be extremely difficult. It is acknowledged further, that, while the leakage rate is recognized to be a function of the "primary stability parameters" and the closing balance ratio, the exact "functional form" of this dependence has not been determined. All of this and the fact that analytical results have consistently predicted significantly worse seal performance than tests and operating history have demonstrated makes it appear unreasonable to draw such conclusions as are presented at the top of page 4-28.

Page 4-31 Section 4.2.1.3. Comments on BJ seals are not valid for all BJ pumps. New N9000 seals, for example, have no U-cups and have a lower balance ratio. Also, it is not clear what the "certain conditions" are that will result in unstable seal behavior during station blackout.

Comments on Bingham seals do not identify the type or vintage of the seal. Bingham seals at SONGS 2&3 have 4 stages. Similar seals are also being installed at Calvert Cliffs. Leak rates are stated but no mention is made as to where the leakage is going. In CEOG

plants, if the leakage is into CBO piping the excess flow check valves will close as the leak rate reaches 10-15 gpm.

Page 4-56 Section 4.2.4.1. BJ seals used in CEQG plants are four-stage, but it is incorrect to state that they are totally dependent on the thermal barrier for cooling. The correct term is "seal cooling heat exchanger". The thermal barrier only pre-cools the approximately one gpm of RCS fluid which passes into the seal cartridge cavity. This 1 gpm then joins the rest of the controlled bleed-off fluid which is being circulated thru the seal cooling heat exchanger by the recirculating impeller (when the pump is running) at a rate of about 40 gpm in most CEQG plants.

Page 4-60 Section 4.2.4.3. The "newer information" developed by AECL on seals popping open is not the final word on this subject. There are several tests and incidents in operating plants which do not support this AECL study.

In the St Lucie test the BJ SU seal cartridge was exposed to full pressure and temperature for about 50 hours in a non-rotating condition with controlled bleedoff continuing at about 1 gpm for the entire test. Seal staging remained normal.

The BJ N-9000 seal cartridge was exposed to an 8 hour simulated station blackout test with controlled bleedoff shut off at 30 minutes into the test. There were no pressure fluctuations or separation of seal faces during the entire test.

A scale model of the Bingham seal cartridge was subjected to a series of tests involving loss of seal cooling. The seal behaved in a stable manner.

The KSB seals were inadvertently subjected to loss of cooling conditions. Controlled bleedoff was not isolated. There was no evidence of seal face separation.

CEOG plants do not start the fourth RCP until the RUS temperature reaches 475 - 500°F. Pumps with SU seals and no seal injection typically subject the seals to around 350°F in a non-rotating condition with controlled bleedoff. Subsequently these pumps start and operate normally for extended periods without any reported problems.

Page 4-62 Section 4.3.2.1. Using "representative" plants is valid only for other similar plants but not valid for plants that are significantly different. It is inappropriate to make the resulting conclusions applicable to all plants by a particular NSSS supplier and risk the information being used incorrectly.

Page 4-70 Table 4.3.4. The information in this table may be misleading. BJ CBO flow meters typically have a range of 0-3.5 gpm at CEOG plants and shaft orbit instrumentation is not used in all plants. In most cases, in plants where it is installed, the shaft orbit instrumentation was not supplied by BJ. Therefore, there may be some differences in individual installations.

Recording of data varies from plant to plant, as does data retention, retrievability and trending.

This table should also mention CCW temperature and flow monitoring.

Page 5-3 Section 5.2. This study recognizes vast differences in plant designs yet does not hesitate to proceed with calculations of "typical" core-melt frequencies. These design differences should be more adequately reflected in the comparison of respective core-melt frequencies.

Full credit should have been given throughout these studies to the benefits provided by the fourth stage vapor seal in CEQG plants with BJ and Bingham seal systems.

Page 5-6 Section 5.3. It is claimed that station blackouts of "extended duration" must be included when considering loss of seal cooling scenarios. "Extended duration" has not been defined, but many of the analyses supporting the conclusions of this report are based on a 24 hour station blackout. Such extended duration SBO analyses may be appropriate from an academic perspective but are unreasonable given the NRC rule on Station Blackout and the need for most licenses to demonstrate a coping capability of only 4 hours. The plant-specific coping times have been developed through an intelligent and systematic evaluation of the reliability of offsite and onsite normal and emergency power sources. To run SBO analyses for extended periods of time simply to demonstrate that core damage is possible goes beyond reason and clouds

the issue with unrealistic core melt probabilities. Several factors come into play in determining whether or not core uncovering will occur during a SBO event:

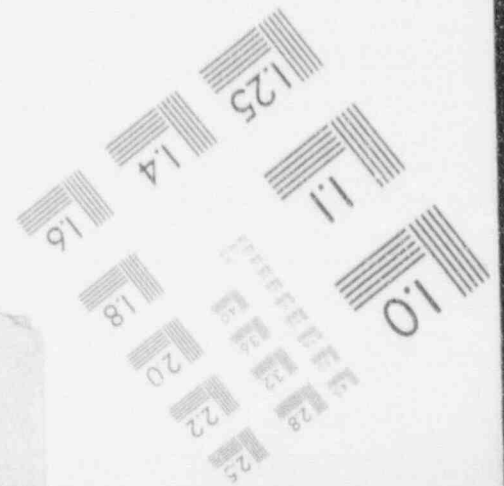
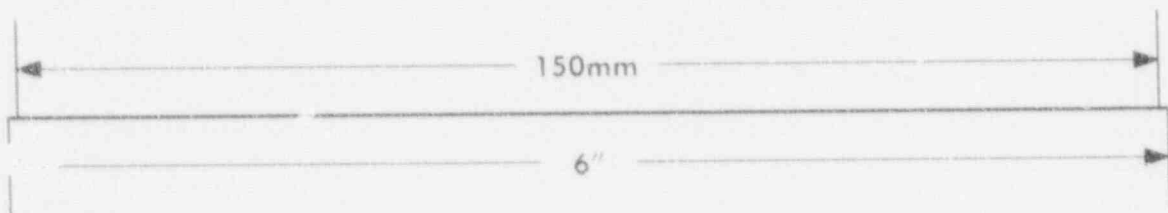
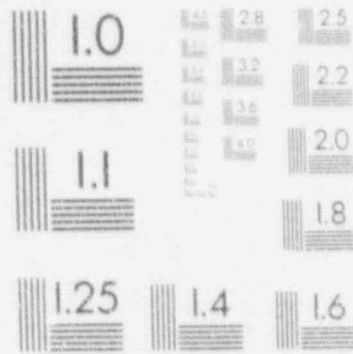
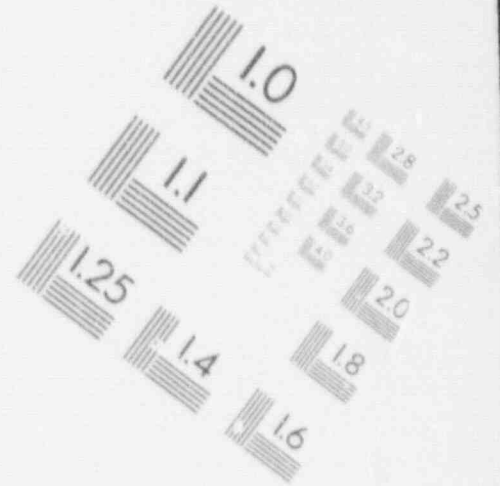
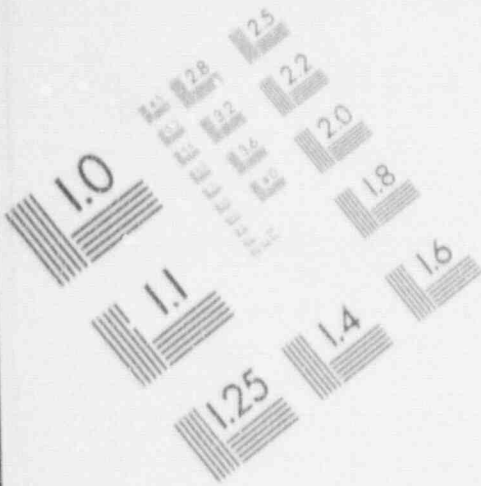
- o actual inventory loss rate
- o auxiliary cooling capability
- o time to restore offsite power

These factors must be balanced reasonably when it becomes necessary for licensees to demonstrate their ability to cope with an SBO. With a time to restore offsite power determined by plant-specific power source availabilities and reliabilities and a given plant-specific cooling capability, it is prudent for realistic inventory loss rates to be included as well. This means that, early in any SBO event at a CEOP plant, total RCS leakage can be reasonably expected to be relatively low -- much lower than the 25 gpm per pump currently required by the Station Blackout rule. This, in turn, leads to less severe consequences during the duration of the SBO.

Page 5-12 The term "divergent face deflection" should be clarified. It appears to be in conflict with the desirable convergent face arrangement.

1

IMAGE EVALUATION TEST TARGET (Mī-3)



The NRC had requested understandings, findings, and potential recommendations regarding resolution of Generic Issue 23, Reactor Coolant Pump Seal Failure. They presented their solution to GI-23 in Draft Regulatory Guide DG-1008 along with the supporting documents of Draft NUREG-1401, Regulatory Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure; NUREG/CR-5167, Cost/Benefit Analysis for GI-23, Reactor Coolant Pump Seal Failure; and NUREG/CR-4948 Technical Findings Related to GI-23, Reactor Coolant Pump Seal Failure. In the Federal Register the NRC also presented a series of questions for comment.

In order to respond to the NRC request for up to date information the CEOS undertook a survey of all member plants in order to obtain the requested information. This data was used to respond to the Federal Register questions. The questions and the CEOS responses are presented in Section 2.0.

The Draft Regulatory Guide DG-1008 and the supporting documents NUREG-1401, NUREG/CR-5167, and NUREG/CR-4948 were reviewed relative to the survey data and the CEOS interpretations, corrections, and comments were presented in Section 3.0.

The NRC has presented their three action items for resolution of Generic Issue 23. The CEOS comments and recommendations of these three items are presented in this section.

4.1

RESOLUTION ITEM 1

The NRC resolution Item 1 is:

Treat the RCP seal assembly as an item performing a safety-related function similar to other components of the reactor coolant pressure boundary, applying quality assurance requirements consistent with Appendix B to 10 CFR 50 and applicable General Design Criteria of Appendix A to 10 CFR 50.

They project that this resolution will accomplish the following improvements.

- Quality control over seal materials and fabrication
- Quality control over installation and maintenance through the use of process specification
- Quality control over plant operations through the use of operating procedures designed to avoid damage during pump start-up and shutdown.

The CEOG does support this resolution to apply quality assurance requirements consistent with Appendix B to 10 CFR 50 and applicable General Design Criteria of Appendix A to 10 CFR 50. It is not necessary. The seals are presently being handled with the highest level of care to insure that the risk of failure has been minimized. As stated in our answer to question 1.2 the seals are already receiving the level of attention that this resolution was intended to produce. Additional regulated requirements will not provide additional assurance of improved performance.

The seals, at present, are manufactured of materials which have been selected to perform the design function. These materials are not necessarily listed in ASME Section III as acceptable pressure boundary materials. Section III deals with the pressure boundary

materials in vessels, pumps and valves and specifically excludes seals. Certain portions of the seal cartridge, such as the housing and flanges are subject to Section III and are designed in accordance with applicable Code rules.

The present RCP shaft seals are designed to provide reliable service for extended life. While nuclear safety is a primary concern in these designs, economics is the driving force ensuring the quality of the seals, implementing their reliable design. It is very expensive for a utility to be in a plant shutdown. Economics will continue to drive this issue as long as the plants are operating. All utilities have found their seals to be reliable once they have learned how to assemble, rebuild, install, operate, and monitor them.

Plant operation is at present in accordance with operating procedures which would not change if the seals were declared to be safety-related. Operating personnel are very much aware of the safety importance of the seals and are under great pressure to insure the seals' long life.

4.2 RESOLUTION ITEM 2

The NRC resolution Item 2 is:

Provide RCP-manufacturer-recommended instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal failures.

They project that this resolution will accomplish the following improvement.

Improved monitoring capability identifies degraded seal performance early enough to take corrective action to mitigate seal failures.

The CEOG does not support this resolution because the existing instrumentation is sufficient and additional instrumentation would not add additional confidence. The manufacturer recommended instrumentation and instructions for monitoring the reactor coolant pump seal performance have been incorporated into the plant operating procedures throughout the CEOG. As stated in our answers to question 3.0 (Section 2.3) the CEOG members already have in place operator procedures for handling the seals for normal plant operation, loss-of-cooling, and station blackout. The intent of the resolution has already been met and is unnecessary.

The RCP manufacturers have recommended the monitoring of the controlled bleedoff flow, the controlled bleedoff temperature, and the seal staging pressures. This instrumentation has been supplied by the pump manufacturers and is in use in the plants. Additional diagnostic instrumentation has been installed by some utilities for monitoring pump performance as a result of shaft concerns. Instrumentation is also used to monitor pump vibration and other characteristics. The present instrumentation, is adequate to monitor the state of the seals and no additional instrumentation proposed by the NRC is necessary.

4.3

RESOLUTION ITEM 3

The NRC resolution Item 3 is:

Provide RCP seal cooling during off-normal plant conditions involving loss of all seal cooling such as station blackout.

They project that this resolution will accomplish the following improvements.

- Maintain RCP seal temperatures within system design conditions
- Avoid two-phase flow through the seals.

The CEOG does not support this resolution. The addition of backup seal cooling is not necessary because it has been demonstrated that the seals can survive station blackout conditions. Seal damage may occur and the seals may have to be replaced following such an event, but the seal leakage is not expected to approach the 25 gpm leakage rate used for the station blackout coping analysis. A review of the seal history in Section 2.1.1, 2.2, and 3.2.3 would indicate that the external leakage would be well below the 25 gpm leakage rate and provide an additional 4 to 5 safety margin. The NRC studies generally assume that the entire seal will attain the temperature of the RCS fluid which is not supported by test data. In the case of a station blackout the controlled bleedoff is isolated in order to maintain the reactor coolant system inventory. This eliminates flow of hot reactor coolant system water up through the seal assembly and prevents seal heatup except by shaft conduction. Tests have shown that the temperature in the vapor seal may be as much as 200°F lower than the temperature of the bottom seal even after 8 hours into the SBO event. See Appendix C for seal tests. The fact that elastomers have been found to be hardened after exposure to high temperatures tells us that their characteristics have been degraded for the purposes of continued use, but this has nothing to do with their ability to survive a SBO event. The capability of the seals to survive operational transients is an economic consideration - if the seals have to be replaced following such as transient, the plant will be down and will not be producing electricity. This is highly undesirable to the plant management. If a seal fails in a

gross manner, the safety systems will protect the core, but the subsequent cleanup is expensive and will keep the plant off-line for a considerable period of time. The plants therefore have great economic incentives to use the best seals available and to protect the seals from operational damage.

The NRC has proposed the addition of a backup cooling system as a generic solution to ensure that there is real cooling available during a station blackout. There is no guarantee that this additional cooling system would be reliable for station blackout.

4.4

SUMMARY

The CEQG does not support the three resolutions presented in the Draft Regulatory Guide and its supporting documents. These are items that are not required to ensure the integrity of the reactor coolant pump seals. The economic pressures are in place which have forced the utilities to address the seal performance and life as a critical issue. They can no longer afford not to give the seals the highest level of care and attention.

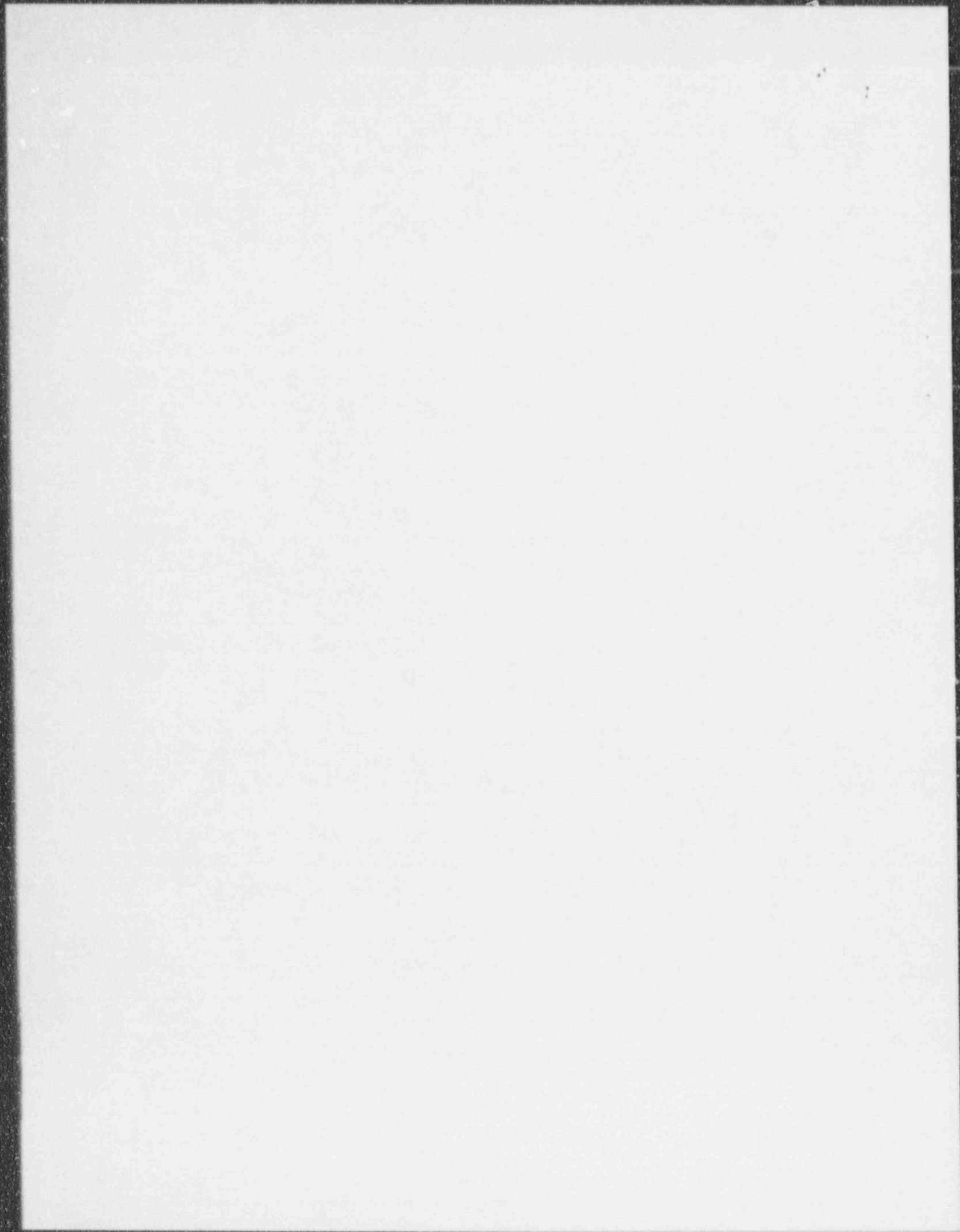
The seals at the present time have had a good performance record. Eight of the last nine seal failures attributed to the CEQG plants in NUREG-1401 were not seal initiated failures but the results of other occurrences that effected the seals until their performance was reduced or failure was induced. When seal failure did result there was very small leakage increase from the controlled bleedoff and the external stage seal. In all cases the leakage attributed to the seal failure was well below the 25 gpm station blackout coping valve and never approached a LOCA situation. This can be attributed to the instrumentation and operator procedures in use for recognizing, identifying, monitoring, and evaluating seal failure for initiation of corrective action that ensure the system safety.

The impetus to consider reactor coolant pump seal failure a generic issue was a result of significant seal failure events that occurred in the 70's and the early 80's. It is not valid now, considering the improved record the seals have obtained in the late 80's to the present time.

The reactor coolant pump seal integrity should not be a generic issue that imposes the same requirements on the entire industry. There are a variety of pump designs with different seal configurations in use. The seal configuration used on the CEOG pumps have shown their reliability to be well above the industry.

The seals of the CEOG have shown their ability to function during a station blackout event with only minimal loss of reactor coolant from the system. They have shown this in situations equal to a station blackout as demonstrated in the responses to question 2.0 (Section 2.2). The seals have functioned during occurrences of degraded cooling and loss of cooling. Also the last pump to start in a four pump NSSS is exposed to a reduced cooling environment before starting and then have functioned properly. In all the above examples there was none to minimal leakage which was well below a station blackout coping value of 25 gpm. Seal testing as presented in Appendix C supports the CEOG position that the seals will function properly during a station blackout.

It is the CEOG position that the three resolutions proposed by the NRC are unnecessary. Their objectives are already being obtained without imposing additional requirements and expenses.



APPENDIX A
SURVEY SUMMARY

A.1 Objective

The NRC had requested information about the reactor coolant pump seals. In order to obtain the quantity of current information being requested, it was decided to prepare and submit questionnaires to the CEOG. Three questionnaires were produced to address the different areas of seal information, seal procedures, and cost/benefit. They were submitted to the members of the CEOG for completion and return. Responses were obtained from all ten utilities in the CEOG for their fifteen operating nuclear steam supply systems. The information received was used to develop the responses to the NRC questions and proposed requirements. Each questionnaire is presented in the following sections.

A.2 Seal Information Questionnaire

The seal information questionnaire was developed to obtain the up-to-date information about the plant current status. The questionnaire addresses the following areas:

- (A) Reactor coolant pumps seal data. Configuration data was requested about the pump seals in 1983 and 1991 and what cooling and instrumentation is available for protecting the seals.
- (B) Reactor coolant pump seal quality assurance/quality control. Had the seal performance improved or not since 1983 and if it had what methods had been incorporated to accomplish it.

- (C) Maintenance schedule. What methods had been developed to promote seal life.
- (D) Loss of Seal Cooling. Had the seals ever experienced a reduction or loss of cooling and if so what caused it and what happened.
- (E) Reactor coolant pump seal failure history since 1983. Information was requested on all occurrences of seal failures and a description of what happened.

The information developed by this questionnaire was used to respond to questions 1 and 2 in the Federal Register.

All fifteen utility plants responded to the following six page seal information questionnaire.

SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23) Page 1 of 6
CEOG TASK 689

Utility: _____

Station: _____ Unit: _____

Name: _____ Phone No. _____ Date: _____

A. Reactor Coolant Pump Seal Data		Present	Other	1983
1.	Pump & Drive Motor Vendors	_____	_____	_____
2.	Seal Vendor (If recent change gave month/year)	_____	_____	_____
3.	Seal Configuration	_____	_____	_____
	- 3 stages			
	+ 4 th vapor seal	_____	_____	_____
4.	Rotary Face Seal Material	_____	_____	_____
5.	Stationary Face Seal Material	_____	_____	_____
6.	Static Seal Material	_____	_____	_____
	- "O"-Rings			
	- back-up rings			
	- U cup	_____	_____	_____
7.	Normal controlled bleed off (CBO) flow?	_____	_____	_____
8.	Cooling method - component cooling water (CCW)?	_____	_____	_____
	- seal injection?			
9.	CCW or Seal injection	_____	_____	_____
	(normal & range)			
	- Flow?			
	- Pressure?	_____	_____	_____
	- Temperature?	_____	_____	_____
10.	Seal monitoring instrumentation	_____	_____	_____
	(range & alarm point)			
	CBO flow?			
	Pressure?			
	(No. of Stages)	_____	_____	_____
	Temperature?	_____	_____	_____
	(No. of Stages)	_____	_____	_____

**SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23)**

Page 2
of 6

CEOG TASK 689

	Present	Other	1983
10. Seal Monitoring Instrumentation (Cont'd)			
Other Location			
- Flow?	_____	_____	_____
- Pressure?	_____	_____	_____
- Temperature?	_____	_____	_____
11. Instrumentation Function			
- monitor performance?	_____	_____	_____
- monitor seal leakage?	_____	_____	_____
12. Are the instrumentation readings readily accessible to the operator?			
13. Has the seal cooling water system been modified? _____			
a) If so, how? _____			
b) Why? _____ for station blackout? _____			
14. Is shaft orbit vibration instrumentation installed on each pump? _____			
a) Where? above seal cartridge? _____			
below seal cartridge? _____			
motor bearing? _____			
other? _____			
b) Type of instrumentation? _____			
proximity probe? _____			
accelerometer? _____			
c) Is a vertical shaft displacement probe in use? _____			
If not, are there any plans to install in future? _____			
d) Is the data monitored/recorded full time or only on demand? _____			
How is historical data saved? _____			
e) Is trending monitored? _____			
f) How is the data recorded? _____			

SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23) Page 3 of 6
CEOG TASK 23

14. (Continued)

g) What are the operating limits? _____

15. Any Seal Testing? _____ To prove seal integrity during station
blackout? _____

If yes, please provide test report.

16. Provide P&ID of RCP with corresponding seal injection or component cooling water systems.

B. Reactor Coolant Pump Seal Quality Assurance/Quality Control

1. Has seal operating experience improved in last 8 years? _____

2. If yes, what was changed to cause improvement?

a) improved quality assurance? _____ of what? _____ when? _____

b) improved quality control? _____ of what? _____ when? _____

c) improved maintenance? _____ of what? _____ when? _____

d) better procedures? _____ of what? _____ when? _____

e) improved instrumentation? _____ of what? _____ when? _____

f) Design changes? _____ of what? _____ when? _____

g) Seal parts inspected just prior to installation? _____

h) Special storage conditions used for seal parts? _____ If yes,
what kind? (i.e. light, ozone, temperature, moisture) _____

i) Other? _____

3. Was RCP/RCP seal vendor information used in developing maintenance c
seals? _____

4. What, if any, additional measures can be taken to improve seal reliability?

5. If your plant-specific Quality Assurance procedures were applied to the RCP
seals would there be an increase in seal reliability? _____

6. Has seal operating experience degraded in last 8 years? _____

SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23) Page 4 of 6
CEOG TASK 689

B. Reactor Coolant Pump Seal Quality Assurance/Quality Control (Cont'd)

7. If yes, has cause of degradation been established? _____
Provide details on cause:
- a) Repeated losses of seal cooling (component cooling water and/or seal injection)? _____ Record date in Section D.
 - b) High vibration levels; provide shaft orbit values versus time or summary of data? _____
 - c) Poor spare part quality, provide details? _____
 - d) Poor maintenance practices, provide details? _____
 - e) Improper seal venting prior to pump startup? _____
 - f) Pump to motor alignment out of tolerance? _____
 - g) Other plant operating causes? _____
 - h) Other mechanical causes? _____

C. Maintenance Schedule

- 1. How often are RCP seals routinely replaced? _____
- 2. What criteria are used to determine the need to replace a seal that "fails" prior to normal replacement interval (i.e. what constitutes seal failure)? _____
- 3. Are seals replaced by a dedicated especially trained maintenance crew? _____
If not, how are the crews trained in seal maintenance? _____
- 4. Is a seal cartridge tester used to check controlled bleedoff and pressure breakdown after rebuilding seal cartridge but just prior to installation in pump? _____

D. Loss of Seal Cooling

- 1. Has seal cooling ever been degraded? _____ how long? _____
 - a) If so, how much was component cooling water or seal injection flow reduced? _____
 - b) What was seal maximum temperature? _____
 - c) When? _____ how often? _____ which pump? _____

SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23) Page 5 of 6
CEOG TASK 689

D. Loss of Seal Cooling (Cont'd)

- d) What corrective action was taken? _____
- e) If seal failure resulted, is recorded data in Section E? _____
- 2. Has seal cooling ever been lost? _____ how long? _____
 - a) What was seal maximum temperature? _____
 - b) When? _____ how often? _____
 - c) What corrective action taken? _____
 - d) If seal failure resulted, is recorded data in Section E? _____
- 3. Have system changes been made since 1983? _____
 - a) If so, what are they? _____
- 4. What time must the unit survive Station Blackout? _____ hours

E. Reactor Coolant Pump Seal Failure History since 1983

- (per occurrence) date? _____
- 1. Plant mode of operation (e.g., startup) _____
 - 2. Pump involved? 1A, 1B, 2A, 2B
 - 3. Seal vendor? _____
 - 4. Which seal? 1st, 2nd, 3rd, stage, or vapor seal?
 - 5. Type seal part? rotating seal face, stationary seal face, "O"-ring, U cup, backup ring, other.
 - 6. Seal failure mode? wear, "O"-ring extrusion, "O"-ring hardness, "O"-ring break, seal face break, pop-open, other _____
 - 7. Controlled bleed off leakage rate (GPM)? start _____ end _____
 - 8. Last seal or vapor seal leakage rate (GPM)? start _____ end _____
 - 9. Corrective action? _____
 - 10. Forced outage? _____
 - 11. How was failure first discovered? Staging pressure? _____
Temperature? _____ Flow? _____

SEAL INFORMATION QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23) Page 6 of 6
CEOG TASK 689

E. Reactor Coolant Pump Seal Failure History since 1983 (Cont'd)

12. Length of plant operation before shutdown/replacement? _____

13. Additional comments? _____

F. SUPPLEMENTAL INFORMATION

1. Is there any other pertinent information regarding seal performance history, operating procedures, maintenance practices, and seal quality control at your plant that could be shared with other plants? (Use additional sheets as necessary)

G. COMPLETION OF QUESTIONNAIRE

1. Please use additional sheets to complete questions as necessary.
2. Please FAX questionnaire response to (203) 285-4232, Attention H. C. Perrine on or before June 7, 1991.
3. Please mail all supplemental information to:
H. C. Perrine
Department 9421-0421
ABB Combustion Engineering Nuclear Power
1000 Prospect Hill Road
Windsor, CT 06095-0500
4. Questions concerning the information requested should be directed to Harry Perrine at (203) 285-9904.

A.3

Seal Procedure Questionnaire

The seal procedure questionnaire was developed to obtain up to date information about the current plant operating procedures and operator responses. The questionnaire addresses the area of normal plant operation, loss of cooling, and station blackout. The information developed by this questionnaire is used to respond to question 3 in the Federal Register.

All fifteen utility plants responded to the following two page seal procedure questionnaire.

SEAL PROCEDURE QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23)
CEOG TASK 689

Page 1 of 2

Utility: _____

Station: _____ UNIT _____

Name: _____ Phone No. _____ Date _____

1. Are there operating procedures in place that are to prevent RCP seal leaks from becoming small-break LOCA's? _____
 - a) During normal plant operation? _____
 - b) During loss-of-seal cooling? _____
 - c) During station blackout? _____
2. Are the required operator actions identified in question 1a, 1b, 1c the same? _____
What, if anything, is different about these procedures? _____
3. Has any special operator training been implemented? _____
If so, what? _____
4. Please send copies of procedures.
5. Has the RCP instrumentation been evaluated to determine whether operators have sufficient information to implement the procedures? _____
6. How long does it take for the operator to determine that an abnormal plant operation exists (loss of CCW, station blackout)? _____ minutes.
7. Is it feasible to shut the controlled bleedoff isolation valve manually? _____
If so, how soon after the start of Station Blackout? _____ minutes.
8. Was RCP seal vendor information used in establishing operation procedures for RCP seals? _____ if so, how? _____
9. Is plant operation allowed to continue when one seal stage has failed? _____
Two seal stages have failed? _____ Three seal stages have failed? _____
 - a. Is this practice limited? _____
 - b. What are the limiting conditions? _____
10. What additional procedural measures can be taken to improve seal reliability? _____
11. What would be done differently if the seals were designated as "Safety Related"? _____

SEAL PROCEDURE QUESTIONNAIRE
REACTOR COOLANT PUMP SEAL INTEGRITY (GI-23)
CEOG TASK 689

Page 2 of 2

12. Please use additional sheets to complete questions as necessary.
13. Please FAX questionnaire responses to (203) 285-4232, Attention H. C. Perrine on or before June 7, 1991.
14. Please mail all supplemental information to:
H. C. Perrine
Department 9421-0421
ABB Combustion Engineering Nuclear Power
1000 Prospect Hill Road
Windsor, CT 06095-0500
15. Questions concerning the information requested should be directed to Harry Perrine at (203) 285-9904.

A.4

Cost/Benefit Questionnaire

The questionnaire was developed to obtain up to date information on the actual costs and benefits for the CEQG plants to implement the NRC three draft requirements. Those responses were used in a Cost/Benefit Analysis using the same equations Scientech used for the analysis in NUREG/CR-5167.

The areas of interest were general information, accident information, installation and maintenance, and statistical information. Not all the utilities who answered, did so completely. Some utilities did not have ample time to complete the questionnaires, where others had no access to some of the information, or had no PRA data. Some utilities responded that a chance of core melt due to seal leak is not applicable.

**Cost/Benefit Questionnaire
Reactor Coolant Pump Seal Integrity (GI-23)
CEOG Task 689**

Utility: _____
Station: _____ Units: _____
Name: _____ Telephone No.: _____ Date: _____

This questionnaire is for obtaining the required information from each utility for preparing a CEOG response to the NRC proposed resolution of Generic Issue 23 and developing answers to NRC questions. This particular questionnaire will be used to examine the validity of the NRC Cost/Benefit analysis (NUREG/CR 5167).

The term *Item #* is used throughout this survey. Items 1-3 are defined below as taken directly from NUREG/CR 5167.

- Item (1) Treat the RCP seal assembly as a component performing a safety-related function similar to other components of the reactor coolant pressure boundary, applying quality assurance requirements consistent with Appendix B of 10 CFR 50 and applicable General Design Criteria of Appendix A.
- Item (2) Provide RCP manufacturer-recommended instrumentation and instructions for monitoring RCP seal performance and detecting incipient RCP seal failures.
- Item (1&2) The implementation of items 1 and 2 overlap costs and benefits. Therefore a cost/benefit analysis is performed for the combination of both items.
- Item (3) Provide RCP seal cooling during off-normal plant conditions, such as station blackout, involving loss of all seal cooling.

To comply with the requirements of Item 3, it is proposed that plants provide additional piping, connections and valves to allow make-up cooling water to be provided from another existing plant water system (e.g. fire protection system or service water system, figure 1). This system will provide back-up cooling for the CCW pump as well as the RCP seals (figure 2). In addition, in order to provide power to the CCW pump and the make-up pump during station blackout a non-safety grade diesel generator must be installed.

It was noted in the NRC Cost/Benefit analysis that some CE plants rely solely on CCW cooling of the thermal barrier heat exchanger for RCP seal cooling, and do not utilize seal injection from the CVCS. These plants would require modifications to provide back-up cooling to the thermal barrier heat exchanger in lieu of a back-up power supply to the make-up pump to implement item 3 (figure 3).

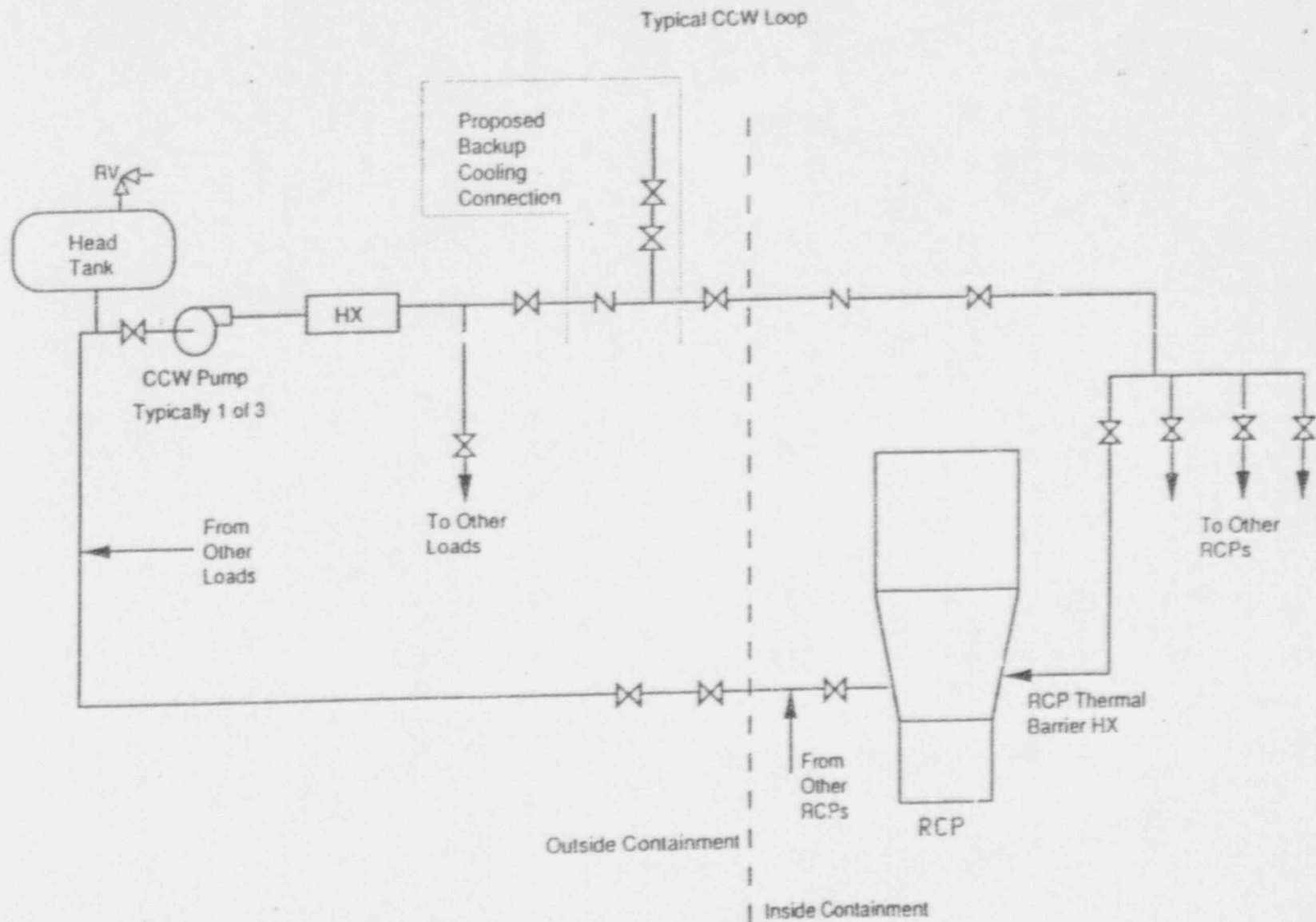


Figure 3 Simplified diagram for plants without RCP seal injection cooling.

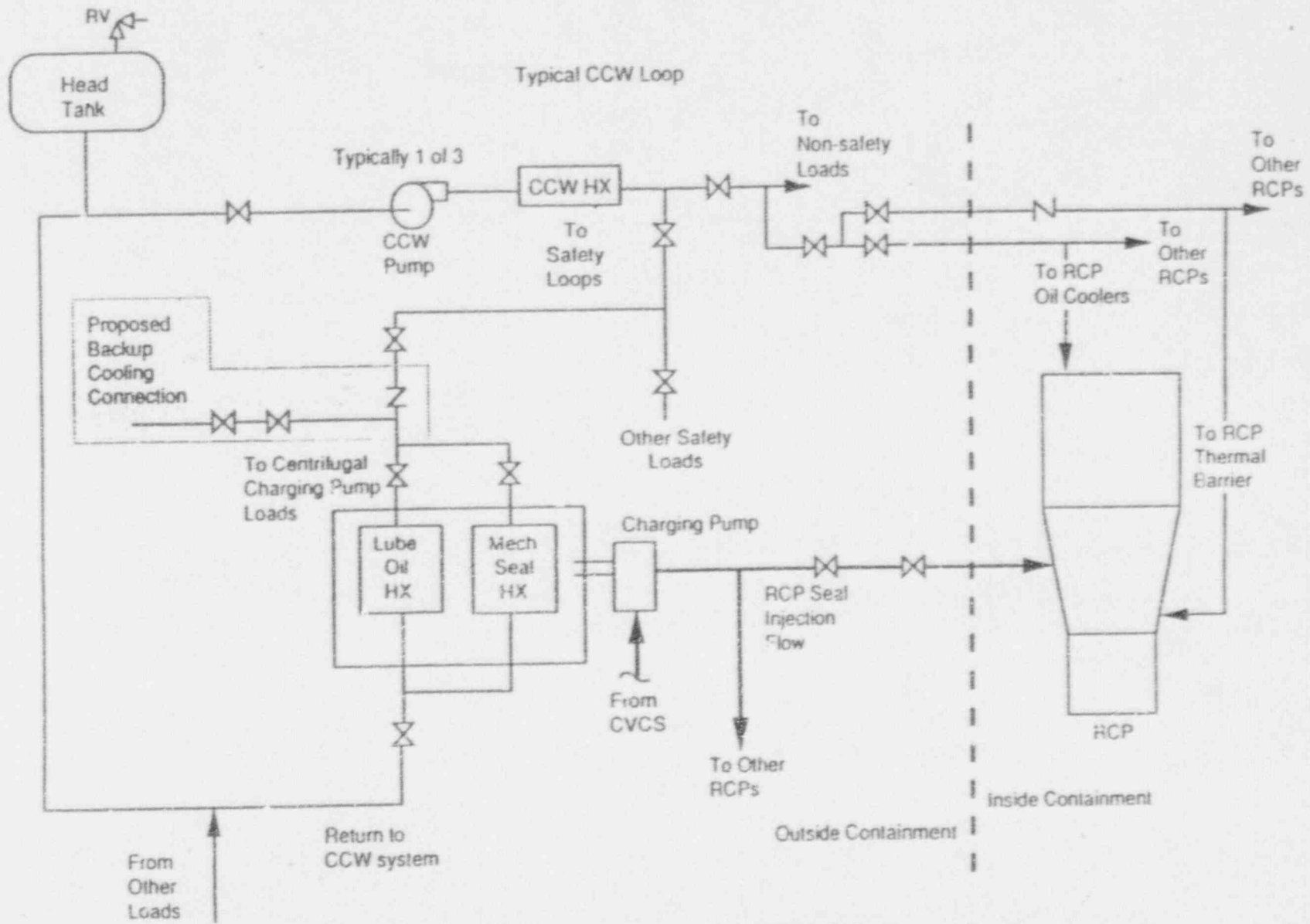
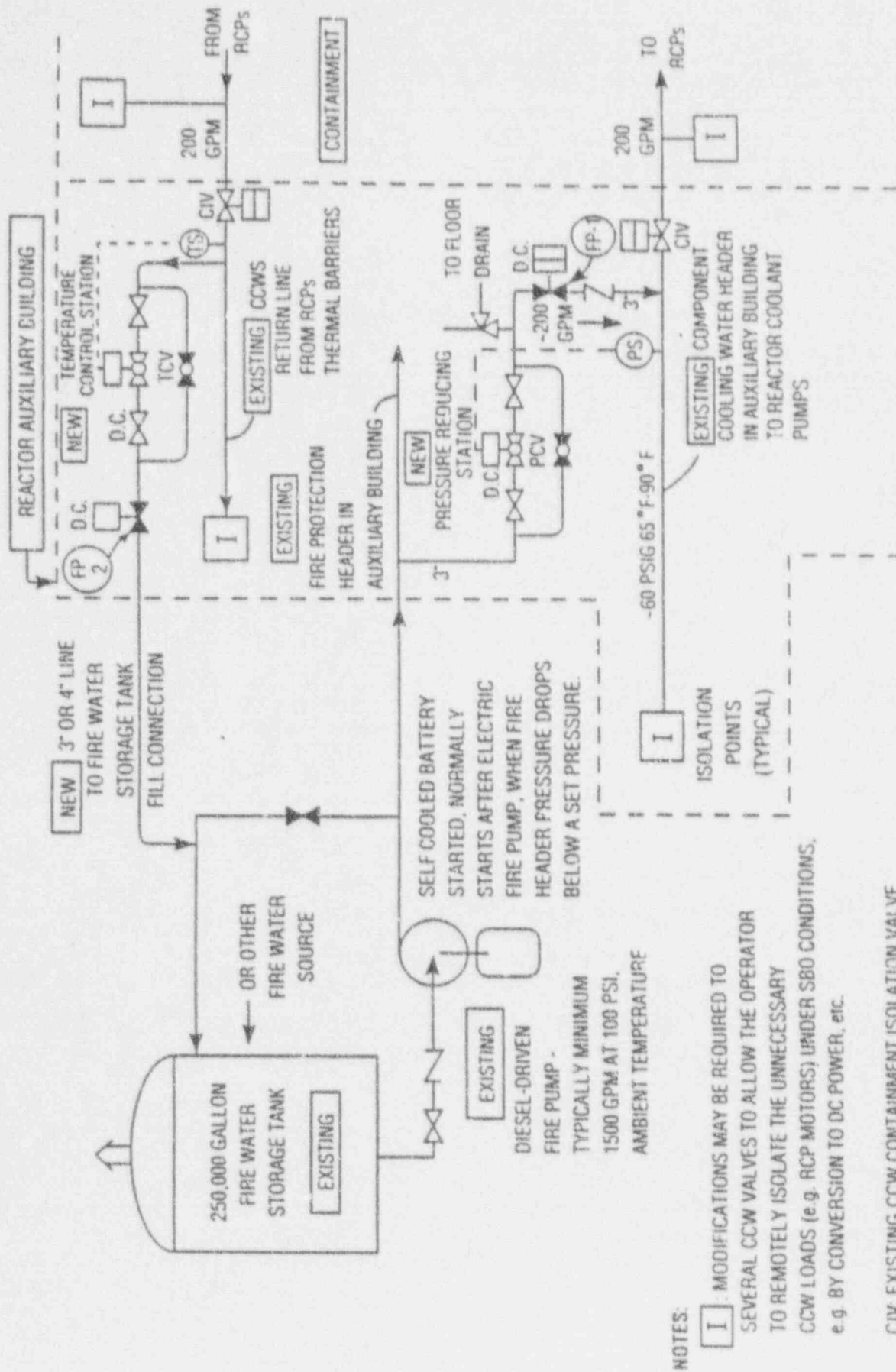


Figure 2 Simplified diagram for plants with RCP seal injection cooling.



NOTES:

- I . MODIFICATIONS MAY BE REQUIRED TO SEVERAL CCW VALVES TO ALLOW THE OPERATOR TO REMOTELY ISOLATE THE UNNECESSARY CCW LOADS (e.g. RCP MOTORS) UNDER SBO CONDITIONS, e.g. BY CONVERSION TO DC POWER, etc.

CIV: EXISTING CCW CONTAINMENT ISOLATION VALVE

Figure 1. Example of Independent Seal Cooling

	NRC			Your plant(s)		
	High	Best	Low	High	Best	Low
A. General Plant Information						
1. N=number of plants (plants)		76				
2. T=average remaining plant lifetime (years)		25				
3. I=outage interval (months/outage)		18				
4. CO=current outage time ((days/plant)/year)		2.18				
5. IR=industry labor rate (dollars/month)		8,333.00				
6. SEAL=average cost of replacement RCP seal (dollars/seal)		150,000.00				
7. PC=replacement power cost (dollars/day)		300,000.00				
B. Accident Information						
1. DCM=total dose expected from core melt accident (person-rem)						
a. Items 1,2,(1&2)		4.700E+06				
b. Item 3	2.000E+07	3.000E+06	5.000E+04			
2. ID=immediate accidental dose (person-rem)	4,200	1,000	0			
3. LT=long-term accidental dose (person-rem)	30,000	20,000	10,000			
4. COff=offsite property costs associated with a core melt accident (dollars)	9.200E+09	1.670E+09	8.300E+08			
5. COn=onsite property costs associated with a core-melt accident (dollars)	1.553E+09	1.035E+09	5.170E+08			
C. NRC Statistics - for your information						
1. NR=NRC labor rate (dol./week)		2,433.00				
2. NLD=NRC labor required to develop item (weeks/plant) Item 1,2,3	6	2	0.67			
3. NLI=NRC labor required to implement item (weeks/plant) Item 1,2,3	1	0.2	0.2			
4. NLO=NRC labor required for item operation ((weeks/plant)/year) Item 1,2,3	1	0.2	0.2			

	NRC			Your plant(s)		
	High	Best	Low	High	Best	Low
D. Installation and Maintenance Information						
1. S1=average number of seals changed per outage prior to implementation of any item ((seals/plant)/outage)						
	4	2	1.33			
2. S2=average number of seals changed per outage after implementation of item ((seals/plant)/outage)						
a. Item 1						
	3.6	1.8	1.2			
b. Item 2						
	3.6	1.8	1.2			
c. Item (1&2)						
	3.2	1.6	1.1			
3. L1=labor per change of single seal prior to implementation of any item (hours/seal)						
	600	400	200			
4. L2=labor per change of single seal after implementation of item (hours/seal)						
a. Item 1						
	600	460	230			
b. Item 2						
	690	460	230			
c. Item (1&2)						
	690	460	230			
5. L3=installation labor (hours/plant)						
Item 2						
		210				
6. L4=periodic maintenance labor ((hours/plant)/year)						
a. Item 2						
		28				
b. Item 3						
	40	30	20			
7. L5=monitoring time for equipment ((months/plant)/year)						
Item 2						
	2	1	0.25			
8. IL=industry labor required to implement item (months/plant)						
a. Item 1						
	9	6	3			
b. Item 2						
	3	2	1			
9. CAP1=capital costs of additional instrumentation and equipment (dollars/plant)						
Item 2						
		250,000.00				

NRC			Your plant(s)		
High	Best	Low	High	Best	Low
10. CAP2=equipment and installation costs of new system and modifications (dollars/plant) Include all costs for added components, piping, connections and valves.					
a. If a seal injection plant this includes back-up cooling for the seal injection pump and a dedicated non-safety grade diesel generator to power the CCW pump.					
b. If not a seal injection plant then this includes back-up cooling for the thermal barrier heat exchanger and a dedicated non-safety grade diesel generator to power the CCW pump and the make-up pump.					
Item 3					
848,200.00					
<u>E. Statistical Information</u>					
1. PSF=fractional reduction in frequency of RCP seal failures attributable to item					
a. Item 1					
0.31	0.18	0.06			
b. Item 2					
0.33	0.23	0.09			
c. Item (1&2)					
0.53	0.35	0.14			
d. Item 3					
0.99	0.95	0.9			
2. PCM=probability of core melt due to RCP seal leak (normal operation)					
Item 1,2,(1&2)					
1.630E-05					
3. PC _{Mccw} =probability of core melt due to RCP seal leak caused by loss of CCW					
Item 3					
6.000E-06					
Either complete PC _{Msbo} or the three (3) following it which are used to calculate PC _{Msbo} .					
4. PC _{Msbo} =probability of core melt due to RCP seal leak due to station blackout					
Item 3					
2.800E-04	5.600E-06	1.800E-07			
a. PC(t)=the incremental probability of core uncoverly between t-1 and t hours following station blackout					
b. PC(6)=the cumulative probability of a core uncoverly at six hours					
c. FSB(6)=the frequency of a station blackout six hours or longer					
<u>F. Questionnaire Completion</u>					
1. Please provide your best estimate for the variables provided.					
2. FAX completed questionnaire to (203) 285-4232 attention Bob Eager on or before 6/7/91.					
3. Mail questionnaire and any supplemental information to:					
R.A.Eager 9421-0421					
ABB Combustion Engineering					
1000 Prospect Hill Road					
Windsor, CT 06095-0500					
4. Questions concerning the information requested should be directed to					
Bob Eager (203) 285-9603					

Addendum to Cost/Benefit Questionnaire--Generic Issue 23

On the last page there are two errors in the shaded portion. The first is in question 4a. I ask for 6 incremental probabilities (t=1-6 hours) and leave only one space. The second error is the absence of a variable:

FSB(t-1/2)=the probability of a station blackout lasting at least t-1/2 hours (t=1-6 hours)

						FSB(t-1/2)
						pc(t)

If you chose to complete the shaded portion please provide the 12 values [t-1/2], FSB(t-1/2]

The third error is the omission of a variable of importance:

DR=dose rate while replacing an RCP seal (millirem/hour)

NRC=

15

Your Plant=

APPENDIX B
SEAL DESCRIPTIONS

B.1 General Description

Reactor coolant pump seals limit the leakage of reactor coolant along the pump shaft, directing the majority of this flow back to the chemical and volume control system with the remainder being directed to the reactor coolant drain tanks. In limiting the reactor coolant leakage to containment, the RCPs use a series of primary and secondary seals. Therefore, these seals become part of the reactor coolant system pressure boundary but were excluded from code requirements. The primary seals (metallic oxides, carbides and graphite) limit the leakage of reactor coolant across the interface between rotating and stationary RCP elements. The secondary seals (elastomer O-rings, I-rings, U-cups and teflon channel seals) prevent leakage between stationary mechanical elements of the RCP seal or those elements which have only a slight relative motion. Both the primary and secondary seals require continuous cooling during pump operation and at hot shutdown conditions with RCPs stationary.

The reactor coolant may be cold or hot; the pump shaft may be idle or rotating with varying degrees of shaft runout. The seals must also cope with transient conditions of temperature changes (both slow and rapid), pressure changes and oscillations, as well as shaft vibration (such as above-normal shaft orbits during pump startup and spindown), and shaft tilt due to eccentric dynamic hydraulic forces. While the RCP does not perform safety-related operational functions, it has to maintain the integrity of the reactor coolant system pressure boundary.

Since the PWR RCP shaft seal application is relatively severe, all seal designs presently in use utilize a pressure breakdown system and controlled leakage, called controlled bleedoff. A cool liquid is intentionally leaked through the seal cartridge in order to provide

lubrication and cooling for the moving parts. This liquid can provide challenges for normal operation if it is not pre-cooled properly or if it contains abrasive contaminants.

The cool, controlled bleedoff water can come from one of two sources: directly from the pump casing or from the seal injection system. The hot water from the pump casing is cooled by component cooling water in the seal cooling heat exchanger prior to entering the seals. The seal injection water comes from the charging system and is filtered to remove any particulates. The only C-E plants to use full-time seal injection are Maine Yankee and Palo Verde Units 1, 2 and 3.

A number of seal designs have evolved over the last thirty or forty years. The CE NSSS RCP's were initially supplied with Byron Jackson (BJ) or KSB seals. The Byron Jackson (BJ) seals have four stages: three for breaking down the primary pressure from about 2250 psi to 50-100 psi, and the fourth seal (also called the "vapor seal") to act as a backup and to minimize external leakage. The KSB seals have three stages: two for breaking down the primary pressure by 84%, and the third stage vapor seal with 16% pressure breakdown. Each of the three stages is capable to operating at full system pressure.

In some cases the original BJ seals have been replaced with N-9000, Bingham International, or AECL CAN 4 seals. All of these replacement seals have a fourth stage seal configuration and are operated the same as the replaced seal.

Pump seals are also classified as either hybrid hydrostatic or hydrodynamic. The hydrostatic seal operates with a controlled seal face clearance gap produced by axial force balance from hydrostatic pressure on top of the seal and film pressure between the seal faces. This type of seal is energized by external pressure to develop the fluid film which separates the seal surfaces. This fluid film in the wedge-shaped gap between the seal faces is relatively thick and the seal leakage is high,

usually on the order of gallons per minute. The Westinghouse multi-stage seal is called hybrid hydrostatic because the first stage is hydrostatic and the other stages are hydrodynamic.

The hydrodynamic seal faces ride on a very thin film. This results in very low seal leakage, on the order of cc's per hour. This thin fluid film requires very flat and parallel (although slightly converging during operation) seal faces. The BJ, Bingham, KSB, and Atomic Energy of Canada Limited (AECL) seals are of the hydrodynamic type.

One of the major requirements of seal design is for the mating faces to be very slightly convergent from the high pressure to the low pressure regions during operation and to remain so under all steady state and transient operating conditions. This has been the major reason for seal problems with BJ seals. The original BJ design is such that under some operating conditions the faces become divergent, lose the liquid film between them and rub hard. Even after reestablishing favorable operating conditions, the seal no longer operate properly and degradation continues, eventually it could lead to failure.

B.2 Byron Jackson (BJ) SU RCP Seal System Design

The majority of Combustion Engineering plants utilize reactor coolant pumps supplied by Byron Jackson. All of these pumps have seal systems consisting of four stages in series. The primary system pressure is broken down equally across the three lower stages. The equistaged pressure breakdown is accomplished by bleeding a bypass (staging) flow of water through a flow resistance path parallel to each seal stage. The controlled bleedoff (CBO) flow (or controlled leakage) is about 1-1.5 gpm during normal operation. Any leakage past the vapor seal (fourth stage) is piped to the drain system and is usually less than 3 gph.

Multistage mechanical seal cartridges with two component stationary and rotating face assemblies and rotating springs have been used in reactor

coolant pumps. Mechanical seals of this design have some undesirable responses to pressure and temperature transients which can limit seal life to one or two fuel cycles. A new mechanical seal system (N-9000) was developed by Byron Jackson with the objective of 50,000 hour life expectancy. The seal utilizes hydrodynamic effects between single component stationary and rotating faces. The design was verified by three-dimensional finite element analysis and a three stage seal cartridge was successfully tested in a 6,600 hour laboratory test with very low wear rates.

A research and development program was started in 1983 with the objective to design a long-lived seal cartridge for PWR reactor coolant pumps which currently use mechanical seals originally designed in the 1960's with life expectancy of less than two fuel cycles.

The reactor coolant pumps differ depending upon the NSSS vendor as to the method of cooling the seals. In C-E plants (except for Maine Yankee and Palo Verde Units, 1,2 & 3 which have seal injection), an injectionless system is used where primary coolant is circulated through a seal cooling heat exchanger and then introduced to the seals, which are in a four-stage design. In a typical C-E injectionless system, controlled reactor coolant leakage (CRO) provides seal lubrication and cooling while the pumps are operating. This leakage is pumped by a recirculation impeller through a heat exchanger where it is cooled by the CCW system. From this point, it is delivered to the seals and discharged from the seal assembly as CRO flow. On several of the installations, circulation through the heat exchanger ceases if the impeller spins to a stop but the leakage flow is maintained across the seals because of the pressure drop across each stage. On other BJ installations, the CRO leakage circulates through a separate internal heat exchanger and continues to flow while the pump is idle.

B.3 Byron Jackson N-9000 Seal

The newly designed Byron Jackson nuclear seal cartridge contains three N-9000 seals in a series staging arrangement. A fourth stage vapor seal is included on the seal assemblies installed in member CEONG plants. The N-9000 seal embodies the results of over five years of seal research to develop a nuclear shaft seal cartridge with improved performance, reliability and maintainability.

The design is based on a system approach which considered reactor coolant system steady-state and design transients, compatibility with existing equipment, and seal response to external influences such as pump shaft orbital characteristics experienced during pump operation. Extensive analytical work and operational testing support a predicted seal life in excess of five years.

The N-9000 seal has successfully undergone over 400 individual component, single stage, and cartridge tests including over 6,600 hours of verification and qualification testing in a cartridge configuration with three stages. Tests completed include steady state and transient operating conditions which meet or exceed all PWR NSSS reactor coolant systems requirements. In addition, the three stage cartridge has also successfully completed nearly eight hours of full scale testing without component cooling or seal injection flow. This test was specifically designed to evaluate seal performance under postulated station blackout conditions.

At present, N-9000 seals have been installed on 3 pumps at Waterford Unit 3, 3 pumps at Maine Yankee and one pump at Millstone Unit 2.

B.4 Bingham International RCP Seal System Design

The Bingham International (formerly Bingham-Williamette) RCP seal system consists of three seal stages which operate on principles similar to the

BJ design discussed in Appendix B Section B.2. The differences between the two designs are in the small but significant details of the individual seal stages. It should be noted, however, that the Bingham seals used at CEQG plants (SONGS 2 and 3 and Calvert Cliffs 1 and 2) utilize a fourth stage vapor seal, similar to the BJ seal design.

The early Bingham two-stage rotating balanced starter seal designs experienced performance problems related to shaft axial and radial displacements. Shaft tilt can be caused by unbalanced radial thrust on the pump impeller or misalignment of the pump to the motor. Shaft tilt and relative angular misalignment of the rigidly-mounted seal ring during normal operations caused axial wobbling of the flexibly-mounted mating ring which damaged the axial seal and sleeve.

In the mid-seventies, a new Bingham stationary-balanced seal was designed to improve the seal face deflection characteristics and materials by having all the balance diameters on the non-rotating seal parts. The design utilized a flexibly-mounted stator with the wear face on the stator. Since the axial seal is on the stationary portion, angular misalignments can be more easily reduced by tight tolerances on fewer parts and is independent of shaft deflections.

Current Bingham seal systems in non-CEQG PWRs consist of three stages in series. Interstage pressure breakdown is accomplished with pressure breakdown coils with a staging flow of 1.5 gpm. Leakage at design conditions is less than 0.026 gpm but may be as high as 0.391 gpm during transients.

Primary seal auxiliary systems on the Bingham pumps presently installed in non-CEQG PWRs consist of a seal injection water system and a heat exchanger through which primary coolant is circulated by a separate recirculation impeller. The seal bleed off water is cooled by low pressure, externally supplied component cooling water (CCW). The seals

of BG&E Calvert Cliffs 1 & 2 and SONGS 2 & 3 are not equipped with seal injection.

The 1.5 gpm for seal staging come from the reactor coolant and the CCW system can remove sufficient heat through the recirculation loop when the pump is running. If the pump is stopped, Bingham instructions are that the seals must be known not to have exceeded 200°F in order to be qualified to be restarted.

The Bingham 4-stage seal design has been in operation on eight reactor coolant pumps at SONGS 2 and 3 for over four year. The performance has been very good up to this point even after being subjected to a variety of plant transients. BG&E Calvert Cliffs 1 & 2 have made the transition to Bingham four-stage seals with good performance to date.

B.5 CE-KSB RCP Seal System Design

The CE-KSB pump uses a system of 3 hydrodynamic seals to seal the pump shaft. Seal injection provides filtered, chemically controlled and temperature adjusted water from the chemical volume control system (CVCS). Two hydrodynamic seal stages and a third hydrodynamic stage vapor seal are arranged in series. The reactor coolant system (RCS) pressure is reduced to the volume control tank pressure in stages by the controlled bleedoff system which contains throttling devices. The first two stages decrease the pressure by about 84%, and the third stage decreases it by 16%. Each of the 3 stages is capable of operating at full system pressure.

The controlled bleedoff flow is approximately 4 GPM and is piped to the volume control tank. Any leakage past the vapor stage is piped to the reactor drain tank. The rotating faces are made of carbon and the stationary faces are made of tungsten carbide. The carbon face ring has a stainless steel support ring on both the inside diameter and the

outside diameter. The tungsten carbide face ring has an integral stainless steel support ring.

Seal injection water enters the high pressure piping at a level below the water lubricated journal bearing and is directed to the high pressure cooler before being injected into the seal system. The effluent from the high pressure cooler enters the high pressure side of the first seal stage and is divided into two flow paths. Part of the flow is pumped through the journal bearing by the auxiliary impeller. This cools the journal bearing and minimizes the ingress of contaminants into the seal system. The second flow path is through a throttle cooler to the high pressure side of the second seal. Flow from the second seal continues through a second throttle cooler to the third seal and then to the volume control tank. The controlled leakage around and through the seals is necessary for seal pressure distribution. Should seal injection flow stop, controlled bleedoff and seal leakage come from the pump case and pass through the heat exchanger to be cooled prior to entering the seal system. A portion of the flow is circulated by the auxiliary impeller through the bearing, the high pressure cooler and back to the seal area.

A seal injection flow of approximately 6.6 GPM at 120°F is normally required for each of the 4 reactor coolant pumps.

B.6 AECL CAN4 RCP Seal System Design

This seal is basically a BJ SU seal modified by Atomic Energy of Canada in Chalk River. Several critical parts are replaced: The stationary assembly includes an isolation ring to eliminate any undesirable effects from the seal cartridge flanges, and a "matched" set of composite stator and stator support rings. This "matching" eliminates seal deflection hysteresis and also the tendency for pressure oscillations. Three stationary surfaces must be lapped. O-rings of the same size are required for the three interfaces to prevent leakage.

The rotating assembly includes a reversible carbide rotating face ring (rotor) and a rotor support ring designed for very low deflection hysteresis. One O-ring seals the rotor/rotor support interface to prevent potential leakage. The interface surfaces and the rotor seal face are lapped. The U-cup is of AECL design optimized for low friction. Each stage, therefore has 6 lapped surfaces, 4 O-rings and a U-cup. Seal refurbishment, however, requires the lapping of only the seal ring surfaces.

The CAN4 seal is insensitive to temperature fluctuations and should, therefore, be able to cope with transients involving component cooling water, i.e., it should be insensitive to the operational CCW temperature swings which, on occasion, have caused the SU seals to degrade, which eventually required premature seal replacement.

One seal cartridge of this type has recently been installed at Waterford 3.

B.7 Description of Seal Failure

Degradation of RCP seals has occurred for all seal types. The causes of degradation can be grouped together as those resulting from mechanical problems and as those resulting from loss of seal cooling. Mechanical problems may result from excessive damage to the RCP during handling and shipping, from contaminant introduction, improper maintenance, and from faulty assembly, installation or adjustment. Mechanically induced failures that have occurred have not been a direct threat to public health and safety, but it is believed that the potential exists for seal failure to have significant safety consequences. It is important to make a distinction between seal failures that could be considered performance degradation requiring seal replacement, seal failures that result in leakage flow rates that are within the plant's normal makeup capacity and "gross" seal failures with leakage flow rates that are greater than the plant's normal makeup capacity (i.e.; LOCA). Most of the failures that

have occurred to date have been relatively minor. Although a few gross failures have occurred, none of these have occurred at C-E plants.

APPENDIX C
RCP SEAL TESTS

C.1 Seal Tests

Several tests have been performed to address the capability of Byron Jackson and Bingham seal assemblies to maintain integrity and limit seal leakage under loss of seal cooling/station blackout conditions. The following discussions provide brief descriptions of some of the more important tests.

C.2 St. Lucie Test

This test was a simulated station blackout test on a prototype seal cartridge performed for Florida Power & Light Company at steady state SBO conditions, i.e., no shaft rotation, no plant cooling, and at plant operating temperature and pressure. The four stage seal cartridge was mounted in the Byron Jackson test loop in order to simulate actual plant conditions. The test was run for in excess of 50 hours without loss of seal function. Seal controlled leakage remained within normal limits (approximately 1.0 gpm) and vapor seal leakage did not exceed 0.25 gpm. Vapor seal leakage is that which leaks past the fourth seal and potentially into the containment. However, with such a low leakage rate it is normally piped off by gravity drain to the reactor drain tank. Controlled leakage exits the seal cartridge between the third seal and fourth (vapor) seal and is piped off to the volume control tank. Seal pressure breakdowns remained within acceptable limits and the vapor seal temperature reached approximately 400°F. Post-test inspection showed a cracked vapor seal rotating ring and permanent deformation of the O-rings and hardening of the U-cups. After the test, the seal cartridge was rebuilt to operational standards by replacing the broken rotating ring and all elastomers. This test confirmed the capability of the seals to withstand a SBO for a time period in excess of any of the times

considered in NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants".

C.3 SONGS Test

Another significant test was a 30-minute loss of component cooling water test run on a Byron Jackson seal cartridge with the reactor coolant pump rotating. This test was potentially more severe than the SBO test because the rate of heat generation in the seals is greater for an operating pump than an idle pump without CCW. The test was run on a specially instrumented seal cartridge in a SONGS RCP in the Byron Jackson test loop at plant operating conditions. During the 30-minute test, seal function was maintained. Maximum controlled leakage was 2.0 gpm (1.0 gpm normal value) and vapor seal leakage did not exceed 0.5 gpm. Pressure breakdowns remained within acceptable limits and the vapor seal temperature peaked at 450°F. After CCW was restored the pump ran 2.5 hours and the seal leakage rates returned to normal. Post-test inspection showed a cracked vapor seal rotating ring and some deterioration of the elastomers. This test confirmed the capability of the seals to withstand an abnormal event equal to or more severe than a SBO.

C.4 Bingham Seal Test

Bingham, in cooperation with Southern California Edison, subjected a 4.5 inch diameter seal (four stage) to a series of tests to demonstrate acceptable seal performance for 30 minutes following the loss of seal cooling. The seal behaved in a stable manner and seal leakage did not exceed 3 gpm.

C.5 N-9000 Seal Test

The objective of this test was to determine the ability of an age-conditioned N-9000 seal cartridge to maintain integrity when both seal

injection and component cooling water flow services to the reactor coolant pump are interrupted for an extended period of time.

The test cartridge was a 3-stage Byron Jackson N-9000 Reactor Coolant Pump Seal Cartridge which has been subjected to a 5186-hour qualification test. In this test, in addition to steady-state running conditions, over 450 operating transients were simulated which were identified as typical in a PWR. The same seal cartridge, without disassembly, was then tested for a loss of seal cooling water transient. The tester shaft was axially movable by means of a worm gear drive. The leakage was condensed and collected in a tank. Periodic measurements of leakage volume were made and recorded.

The controlled bleed-off (CBO) valve was left open for the first thirty minutes of the test to allow response time for the operator to close the valve. The system pressure of 2200 psi and lower seal cavity temperature of 555 +/- 10°F was maintained for the next hour. At this time, a gradual decrease in system pressure was initiated. In approximately 1.5 hours, the system pressure was reduced to 1687 psi. This system pressure decrease corresponds to a 20 gpm reactor coolant loss due to postulated seal leakage from four reactor coolant pumps (5 gpm outleakage per seal). After 2.5 hours at this pressure, the system pressure was gradually increased, corresponding to a postulated appearance of steam voids in the reactor coolant system. After 8.1 hours, as 2436 psi was reached, an O-ring failed in the top seal stage. The seal immediately restaged, limiting the leakage to approximately the same rate as the normal CBO flow of 1.5 gpm.

Downward and upward shaft movements, corresponding to system pressure decrease and increase were also imposed on the seal cartridge. Downward shaft movement is a very unfavorable condition for the mechanical seal in that secondary seal friction may cause separation of sealing faces, and result in severe seal leakage. A downward shaft movement of 0.040 inches was imposed on the seal cartridge during the loss of cooling water test.

The N-9000 seal cartridge was subjected to 8.1 hours of simulated reactor coolant system station blackout conditions during which time the controlled bleed-off valve was closed for 7.4 hours. During the 7.4 hours, the total outleakage was limited to less than 67 gallons; an average leak rate of 0.15 gpm which includes the leakage due to the damaged O-ring. Seal leakage alone was 0.04 gpm.

The test data indicate that the flow through the seal faces was a steady-state two phase flow; the phase change taking place between the sealing faces. There were no pressure fluctuations or separation of seal faces during the entire test. After the O-ring failure, the top stage was exposed to saturated steam.

The test represented the severity of an actual loss of seal cooling event under station blackout conditions, and the seal cartridge exhibited excellent performance. The Byron Jackson N-9000 seal cartridge, thus, more than adequately meets the 25 gpm maximum seal leakage flow rate specified by Unresolved Safety Issue 44 and the NUMARC 8700 station blackout document. Furthermore, it provides additional justification that the 25 gpm per seal leakage rate is an overly conservative assumption in regard to CEQG member plants.

APPENDIX D
HISTORICAL PERSPECTIVE

D.1 Introduction

In October 1975, WASH-1400, "The Reactor Safety Study", was published. This study indicated that breaks in the reactor coolant pressure boundary with an equivalent diameter of 0.5 to 2 inches could occur with a frequency of 10^{-3} per reactor-year and were the largest potential contributor to PWR core-melt. A 1980 NRC study based upon RCP seal failures experienced at operating plants showed that the RCP seal failure leakage rates were comparable to the small-break LOCA rates of WASH-1400, but these seal failures had actually occurred at a frequency of 10^{-2} per reactor-year. This frequency was actually an order of magnitude greater than the pipe break frequency used in WASH-1400. The conclusion was reached that the overall probability of core-melt due to small-break LOCAs could be dominated by RCP seal failures.

D.2 TMI Action Item II.K.3.25

Following the Three Mile Island Unit 2 accident in 1979, the NRC questioned the potential for a serious accident involving the failure of the reactor coolant pump seals upon a loss of offsite power. This led to the establishment, in NUREG-0737, of TMI Action Item II.K.3.25, "Reactor Coolant Pump Seal Integrity Following Loss of Offsite Power". TMI Action Item II.K.3.25 required licensees with Combustion Engineering, General Electric, and Westinghouse designed plants to evaluate the integrity of their reactor coolant pump seals for a period of two (2) hours following a loss of offsite power (LOOP) event.

During the course of attempting to resolve TMI Action Item II.K.3.25, the NRC determined that although the adequacy of the seal design was to be demonstrated for at least 2 hours, the preferred approach was to automatically start component cooling water during a LOOP. By powering

the CCW pumps by the diesel generators, no operator action would be necessary in order to provide seal cooling to the RCPs. However, four C-E plants (Calvert Cliffs, Units 1 and 2; Arkansas Nuclear On., Unit 2; and Palisades) relied on operator action to restore seal cooling. Baltimore Gas and Electric (BG&E) and Arkansas Power and Light (AP&L) decided to fight the issue (Consumers Power Company opted to start CCW automatically upon LOOP). Their responses directly addressed the issue by concluding that seal cooling was not required to assure seal integrity for LOOP conditions.

Following lengthy discussions and interaction between representatives of NRC, AP&L and BG&E, the NRC issued the final safety evaluation report (SER) for TMI Action Item II.K.3.25 on October 7, 1985. The SER included the licensees' conclusions that:

- (1) Seal failures with leakage greater than 10 gpm are non-credible events,
- (2) Restoration of CCW is not necessary in order to get the plant to cold shutdown without losing seal functional integrity,
- (3) Loss of RCP seal integrity due to loss of CCW is not a safety concern since the seals are capable of maintaining functional integrity without cooling for a static pump, and
- (4) Automation of seal cooling (following a LOOP event) is not necessary for plants with Byron-Jackson pumps.

In the staff evaluation of the AP&L and BG&E submittals, however, the NRC concluded that adequate data had been provided to support only the following findings:

- (1) Reinstating coolant to the RCP seals is not necessary for getting the plant to cold shutdown conditions,

- (2) The most severe leakage which could result from a loss-of-seal-cooling event for a four-stage Byron Jackson pump is 40 gpm. This assumes all 4 seals fail which has never occurred at any operating plant¹ with Byron-Jackson pumps (e.g., operational data and seal testing), and
- (3) If the integrity of only 3 seals is compromised, the resulting leakage will be less than 10 gpm.

Although this SER closed out TMI Action Item II.K.3.25 for ANO-2 and CC-1 and 2, it was specifically pointed out that this SER did not constitute a resolution to GI-23.

D.3 Generic Issue 65

Generic Issue 65, "Probability of Core-Melt Due to Component Cooling Water System Failures", was raised as an issue concerned with the common failure which simultaneously causes a small LOCA and renders most of the emergency core cooling system (ECCS) inoperable. Loss of CCW immediately causes a loss of cooling water to the RCP thermal barrier heat exchangers. At some plants (e.g., Maine Yankee) the loss of CCW also renders the charging pumps inoperable and the charging pumps usually supply the water for RCP seal injection. With neither cooling mechanism available, the RCP seals are postulated to fail within a short period of time (approximately 30 minutes). Loss of CCW may also render the high pressure safety injection and containment spray systems inoperable. Eventually, if no manual mitigating actions are taken, the core will uncover and melt. Moreover, unless the plant has containment fan coolers which do not utilize CCW, the containment might eventually overpressurize and fail.

In October of 1983 it was decided that, because of the close relationship between CCW system failure and RCP seal failure, GI-65 would be integrated into the resolution of GI-23, "RCP Seal Failures".

* It should be noted that, since this SER was issued, a RCP seal sensing line failure hydraulically induced a failure of the 4-stage seal system at ANO-2.

D.4 Unresolved Safety Issue A.21

Station Blackout is defined as the complete loss of alternating current (AC) electrical power to the essential and nonessential switchgear buses in a nuclear power plant. Because many safety systems required for reactor core cooling and containment heat removal depend on AC power, the consequences of a station blackout could be severe. Prior to 1988, regulations did not explicitly require that nuclear power plants be capable of withstanding a station blackout event.

In 1975, the "Reactor Safety Study" (NUREG-75/140) showed that station blackout could be an important contributor to the total risk from nuclear power accidents. In addition, as operating experience accumulated, the concern arose that the reliability of both the onsite and offsite emergency AC power systems might be less than originally anticipated. Thus, in 1979 the NRC designated station blackout as an unresolved safety issue (USI). A task action plan was issued for its resolution in July 1980 (TAP A-44), and work was initiated.

Numerous technical studies were performed to resolve this safety issue and certain dominant factors affecting both the likelihood and severity of station blackout accidents were identified. The likelihood that a station blackout will progress to core damage or core-melt is dependent upon the reliability and capability of decay heat removal systems that are not dependent upon AC power. If the capability is sufficient, additional time will be available to restore AC power to many systems normally used to cool the core and remove decay heat. One of the most important factors relating to decay heat removal identified for PWRs (without reactor coolant makeup capability during a station blackout) was the magnitude of reactor coolant pump seal leakage. In fact, if the auxiliary feedwater system can remain operable, and if primary coolant inventory can be maintained at a level adequate to maintain core cooling, a PWR should be able to stay in this mode for a substantial period of time. This time period is generally limited by primary pressure boundary

leakage and the capacity of certain support or auxiliary systems. With provisions for manual isolation of letdown lines and reduced frequency of Power Operated Relief Valve (PORV) demands, the RCP seal leakage rate is considered to be a potentially limiting factor for some designs. If the leakage rate is low (on the order of several gallons per minute) this concern is negligible. However, if the total seal leakage in the plant is on the order to 100 gpm or more, reactor coolant system inventory depletion will be a factor limiting the capability of removing decay heat for an extended period of time.

D.5 Generic Issue 23

As a result of the growing concerns over station blackout, the NRC assigned a high priority to the investigation of RCP seal failures (NUREG-0933, "A Prioritization of Generic Safety Issues" dated November 10, 1982). The Office of Nuclear Reactor Regulation (NRR) Operating Plan for fiscal year 1983 included the review of RCP seal failures as GI-23, and authorized work in October 1983. As discussed, another closely related task, GI-65, was also assigned a high priority. Due to the close relationship between GI-23 and GI-65, Generic Issue 65 was incorporated into the task action plan for Generic Issue 23. In addition, because of the dependence of RCP seal cooling on AC power supplies, RCP seal failures are linked to the reliability of onsite and offsite electrical power supplies. These concerns were heightened following two U.S. probabilistic safety studies regarding station blackout, NRC comparisons between a Westinghouse and a British plant design, and the fact that both French and British systems use steam-driven power sources to maintain RCP seal cooling under station blackout conditions. Consequently, it was decided that Generic Issue 23 would consider the effects of station blackout on RCP seal performance to the extent they were not addressed by unresolved safety issue (USI) A-44, "Station Blackout".

The purpose of Generic Issue 23 is to evaluate the adequacy of current licensing requirements relating to RCP seal integrity and to determine whether further NRC action is necessary to assure that RCP seal failures and seal auxiliary system failures do not pose an unacceptable risk. This generic issue has two main objectives:

- (1) Determine the need to improve the reliability of RCP seals during normal operations, and
- (2) Prevent small break LOCAs resulting from RCP seal failure during station blackout.

To determine what steps, if any, should be taken by the NRC to reduce RCP seal failures, the NRC funded tasks to:

- (1) Determine actual seal failure mechanisms,
- (2) Evaluate seal cooling for all relevant modes of operation, and
- (3) Review mechanical- and maintenance-induced seal failure mechanisms.

Following the review of the results of the various research programs established to address GI-23, the NRC determined that seal failures could be divided into two categories:

- (1) Those resulting from mechanical-induced and maintenance-induced failures, and
- (2) Those resulting from a loss of all seal cooling including the loss of all AC power.

Three alternative resolutions have been identified as candidates for resolution of GI-23.

Alternative 1: RCP seals would be defined as part of the primary coolant pressure boundary with the appropriate QA/QC requirements. The adoption of this alternative would mean a tighter system of quality control over materials and fabrication methods used for seal manufacturing, increased control over installation and maintenance of RCP seals, and increased procedural control over the operation of reactor coolant pumps - particularly during startup and shutdown.

Alternative 2: Additional instrumentation would be required, where necessary, in order to fully monitor RCP seal and shaft performance.

Alternative 3: An independently powered method of cooling RCP seals during station blackout conditions or on complete loss of component cooling water would be required.

The adoption of any of these alternatives could result in significant costs to utilities. Costs which, for C-E NSSSs, do not appear to be justified due to the inherent design differences and excellent operational history of the Byron Jackson 4 stage seal design (SU), the Bingham seal design, and the KSB seal design.

Furthermore, early in the resolution process for USI A-44, it was necessary to make certain assumptions in order to proceed to resolution. One of these assumptions defined the resolution interface with GI-23 such that RCP seals would leak no more than 25 gpm per pump during station blackout conditions. This assumed leakage was chosen as the result of discussions between the staff and the Nuclear Utility Group on Station Blackout (NUGSBO). It was felt that GI-23 would study the station blackout RCP seal failure issue and determine that the expected leakage