NRC FORM 658
(9-1999)

U.S. NUCLEAR REGULATORY COMMISSION

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DATE OF MEETING
07/17/2001

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Docket Number(s)	**Project No. 692**
Plant/Facility Name	**Combustion Engineering Owners Group**
TAC Number(s) (if available)	**MB0337** ML-011660510
Reference Meeting Notice	**Dated June 25, 2001**
Purpose of Meeting (copy from meeting notice)	**To discuss the RCP seal model topical report.**

NAME OF PERSON WHO ISSUED MEETING NOTICE
Jack Cushing

TITLE
Project Manager

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NRR

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DF03

CEOG MODEL
for
FAILURE OF RCP SEALS GIVEN LOSS OF SEAL COOLING
(CE NPSD-1199-P)

July 17, 2001

US Nuclear Regulatory Commission

Rockville, MD

COMBUSTION ENGINEERING OWNERS GROUP

PRESENTATION

- Purpose of Meeting
- Summary of CEOG Modeling Philosophy
- Model Applicability
- Description of Seals and Seal Performance
- Transient Challenges to Seals
- Summary of CEOG RCP Seal Failure Model

PURPOSE

- Discuss Scope of Requested Review
- Provide CEOG Philosophy in Developing an RCP Seal Failure Model
- Highlight Key Design and Operational Features and Experiential Evidence That Impacts Model Development and Implementation
- Clarify Applicability and Scope of Model

Scope of Requested Review

- Purpose of the mechanistic RCP seal model
  - Provide a flexible tool to assess RCP seal performance in PSA applications
    - uses plant specific T-H response to various scenarios, i.e., SBO, LOCCW
  - Use a model philosophy consistent with the PSA
    - realistic, not overly nor under conservative
- Scope of requested review
  - Scope only on RCP seal model, (not on NSSS response to transients or global GI-23 type issues)
    - model features
      - for example subcooling or no subcooling
    - model realism and conservatism
      - leakage based on thermal barrier only (no seal internals)

Scope of Requested Review

- Seeking specific approval of Fault Tree Models as a Reasonable Means to Reflect RCP Seals in a PSA
- NRC is expected to evaluate implementation of the model on a plant specific basis through
  - PSA applications
  - Maintenance Rule
  - SDP

OVERALL PHILOSOPHY

- Develop Seal Failure Model That Reflects:
  - Results of RCP Seal and Seal Component Experimental Data
  - Plant Operating Experience During LOCW/SBO Events
  - Explicitly Considers Significant Relationships Between Seal Stages
  - Reflects Improvements in Seal Design and Material Selection
  - Applicable to a Wide Range of Plant Operating Conditions and EOPs
  - Model to Replace "Integrated" Seal Failure Models

Model Applicability

- Model Applicable for RCP Seals In Current Use at Various Plants
- Model Is for a Single RCP Seal Only
  - SBO leads to loss of Cooling to all 4 Seals.
  - LOCCW events can affect 1 or more RCPs
  - Plant conditions are a function of Initiator and EOP actions
  - Plants incorporate RCP Seal Model within Plant PRAs for Sequences which involve Loss of Seal Cooling
    - EOP actions addressed in plant model
    - Plant conditions addressed in plant model
  - Seal Model Provides Sets of Results to cover possible initial conditions
    - Proper set must be selected to incorporate in plant model
- Model Currently Limited to Loss of Cooling Events < 8 Hrs.

RCP SEAL DESIGN-GENERAL FEATURES

* Hydrodynamic seals
* 4 stages, including vapor seal (3 stages at Palo Verde)
* Equal pressure reduction/stage - each stage capable of full system pressure for 4 stage seals, 43%, 43%, 14% for 3 stage seals
* Normal Controlled Bleed-Off (CBO) flow, 1-1.5 gpm for 4 stage seals, 3.2 gpm for 3 stage seals
* Seal injection not required
  * Palo Verde has seal injection and seal cooling. Only one required.
* Stringent vendor QA programs
* Instrumented to monitor seal performance/leakage:
  - Individual stage pressure
  - CBO flow
  - CBO temperature
  - Alarms on CBO temperature

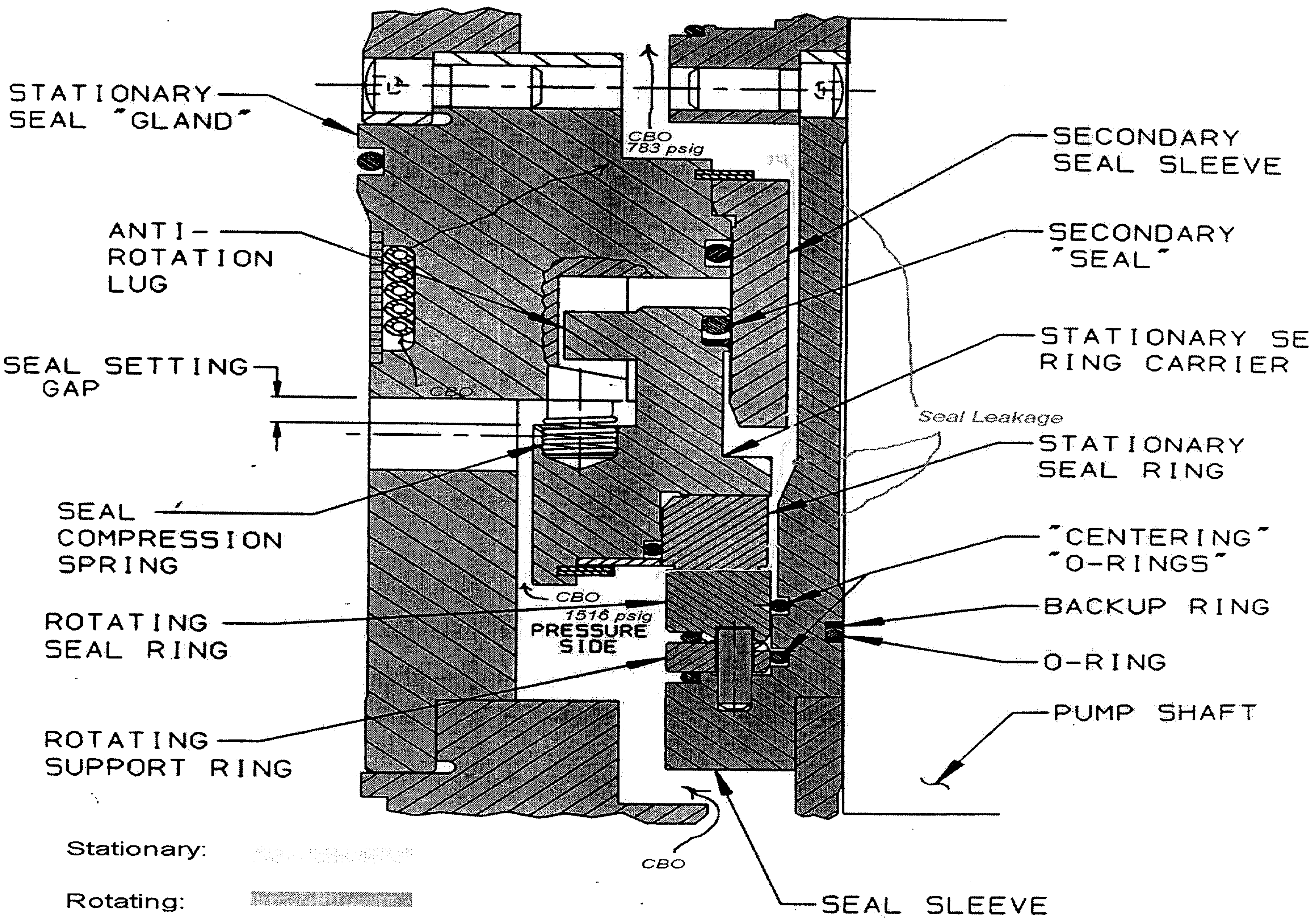
RCP SEAL DESIGN

Comparison Data

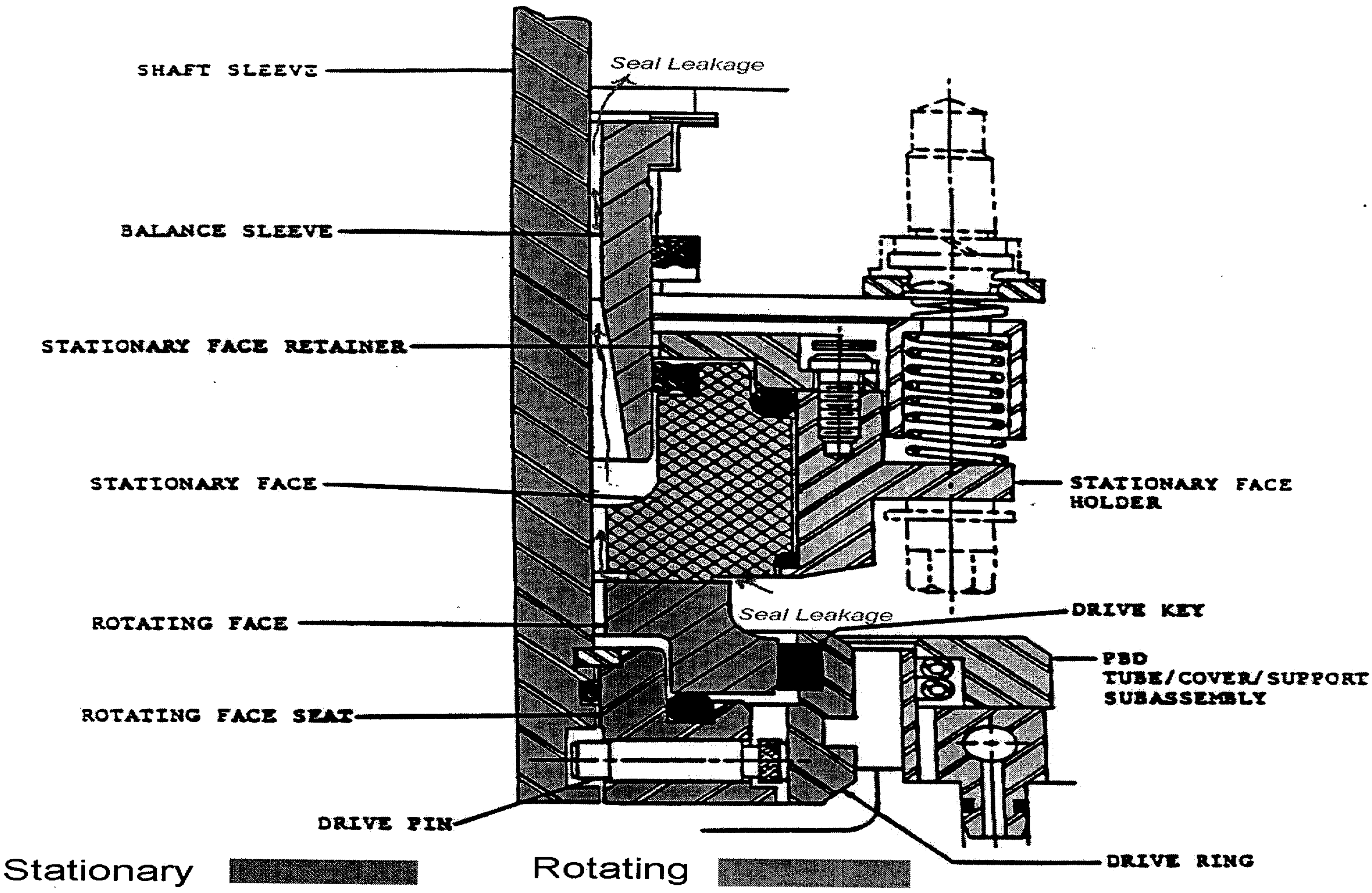
Design Feature	CEOG	Westinghouse
Number of Stages	4 (except Palo Verde)	3
Type of Seals	All hydrodynamic	First stage hydrostatic All others hydrodynamic
Pressure Breakdown	Equal press. /stage* (43%, 43%, 14% for Palo Verde)	Pressure reduction primarily by 1st stage
Seal Injection	Not Required (Palo Verde has injection)	Required
Design CBO Flow	1-1.5 gpm (3.2 gpm at Palo Verde)	3 gpm

*All stages capable of withstanding full system pressure – including vapor seal
* Complete Failure of all stages required to produce significant leakage

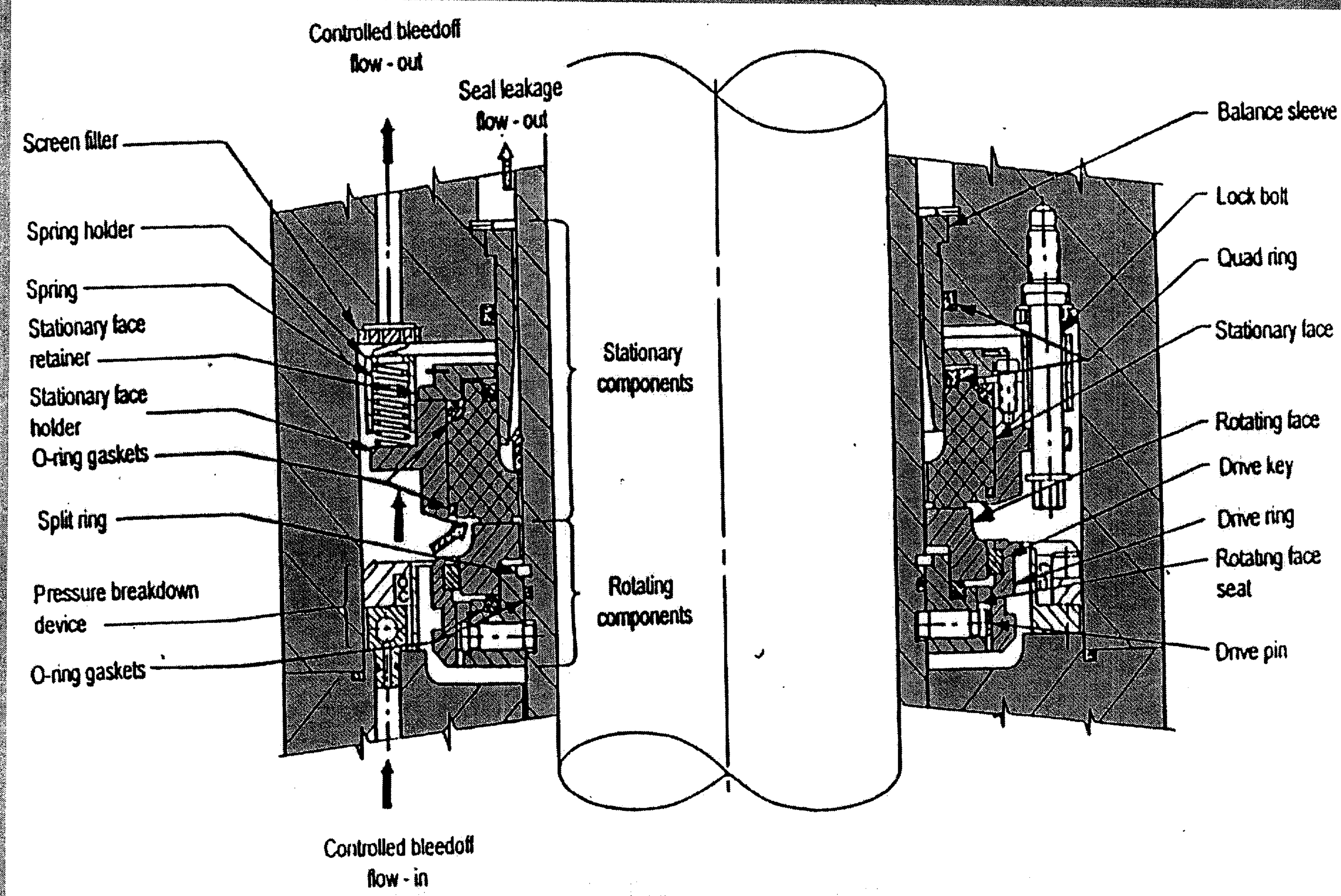
SULZER BALANCED STATOR



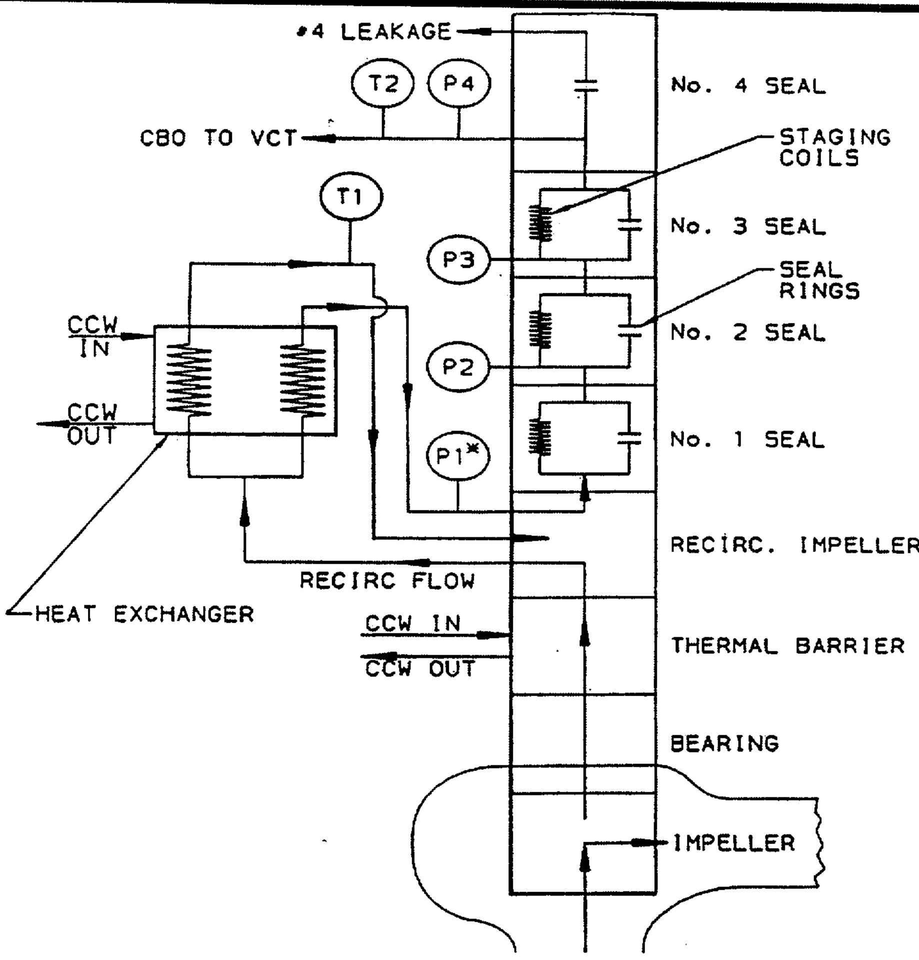
N9000 Seal Stage



N9000 Stage: Full View



Flow Schematic for FlowServe Seal Package



*Failure of one stage bypasses one PBD

OPERATIONAL CHARACTERISTICS OF THE SEALS

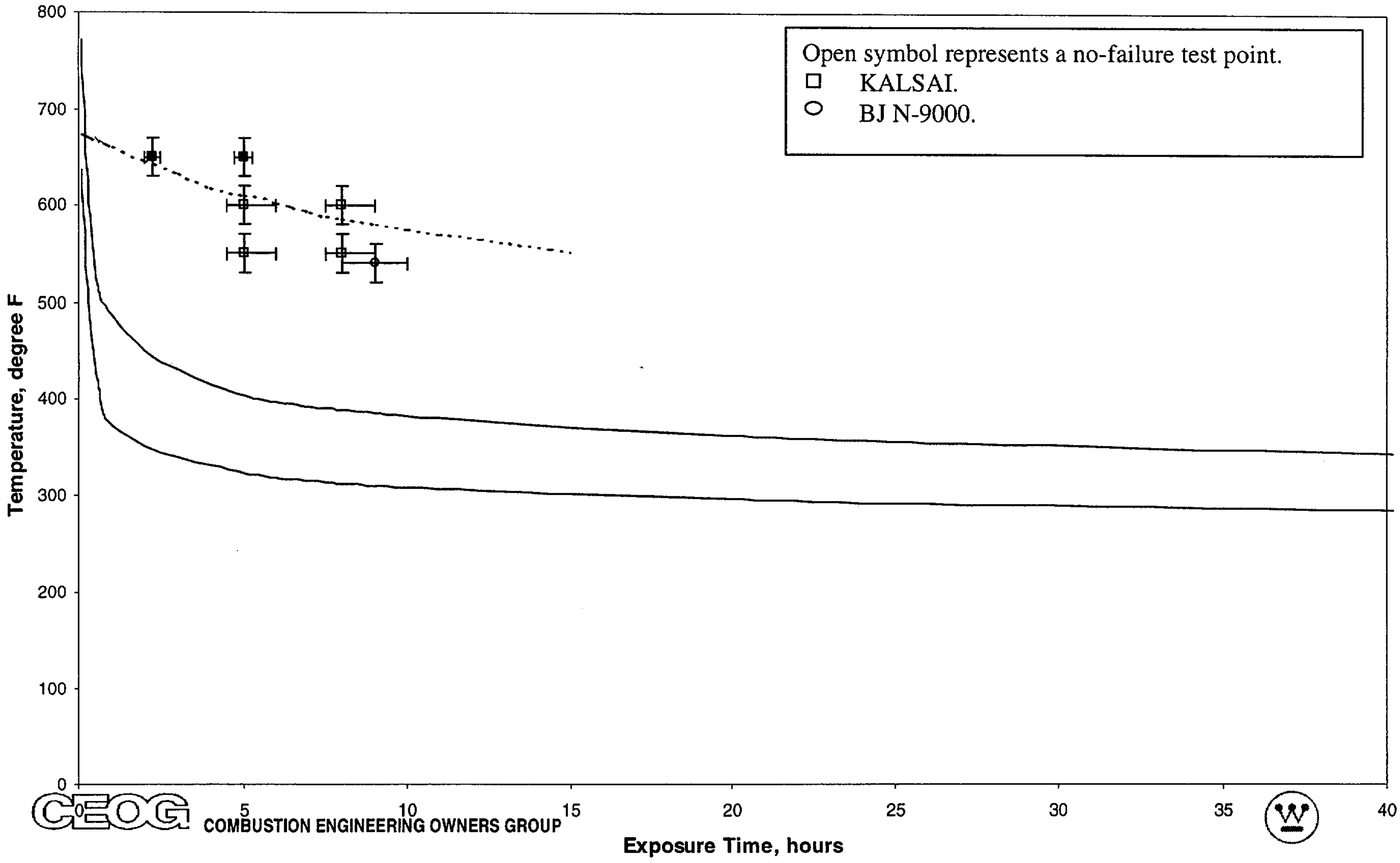
Stage Failure Configuration	Leakage
Vapor Stage Failed	Negligible
Any one of first three stages	0.22 gpm
Any two of first three stages	0.73 gpm
All three lower stages	Flow Limited by Excess Flow Check Valve (10 – 15 gpm)
Catastrophic - All four stages	Plant Specific – Flow limited by thermal barrier and extent of seal damage (Values in Report assume seals provide no flow resistance so flow limited by thermal barrier

* Small levels of flow increases consistent with experimental observations and limited events

OPERATIONAL CHARACTERISTICS OF THE SEALS
(Continued)

- Failure of All Stages Needed to Produce Significant Leakage
- Core Uncovery Times:
  - 3 - 6 hours after failure of single RCP Seal
  - 2 - 3 hours for failure of all four RCP Seals
- Use of High Quality Elastomers enables good high temperature performance of the elastomers
- Temperature Losses to Ambient Limits Upper Stage Temperature during LOCCW/SBO Events
- Eliminated Lapped Joint Support That Was the Cause of Hysteresis
- Failure of Secondary Seals Have Minimal Impact on Leakage

Comparison of RCP Seal Elatomer Properties with "Industry" Elastomer Data



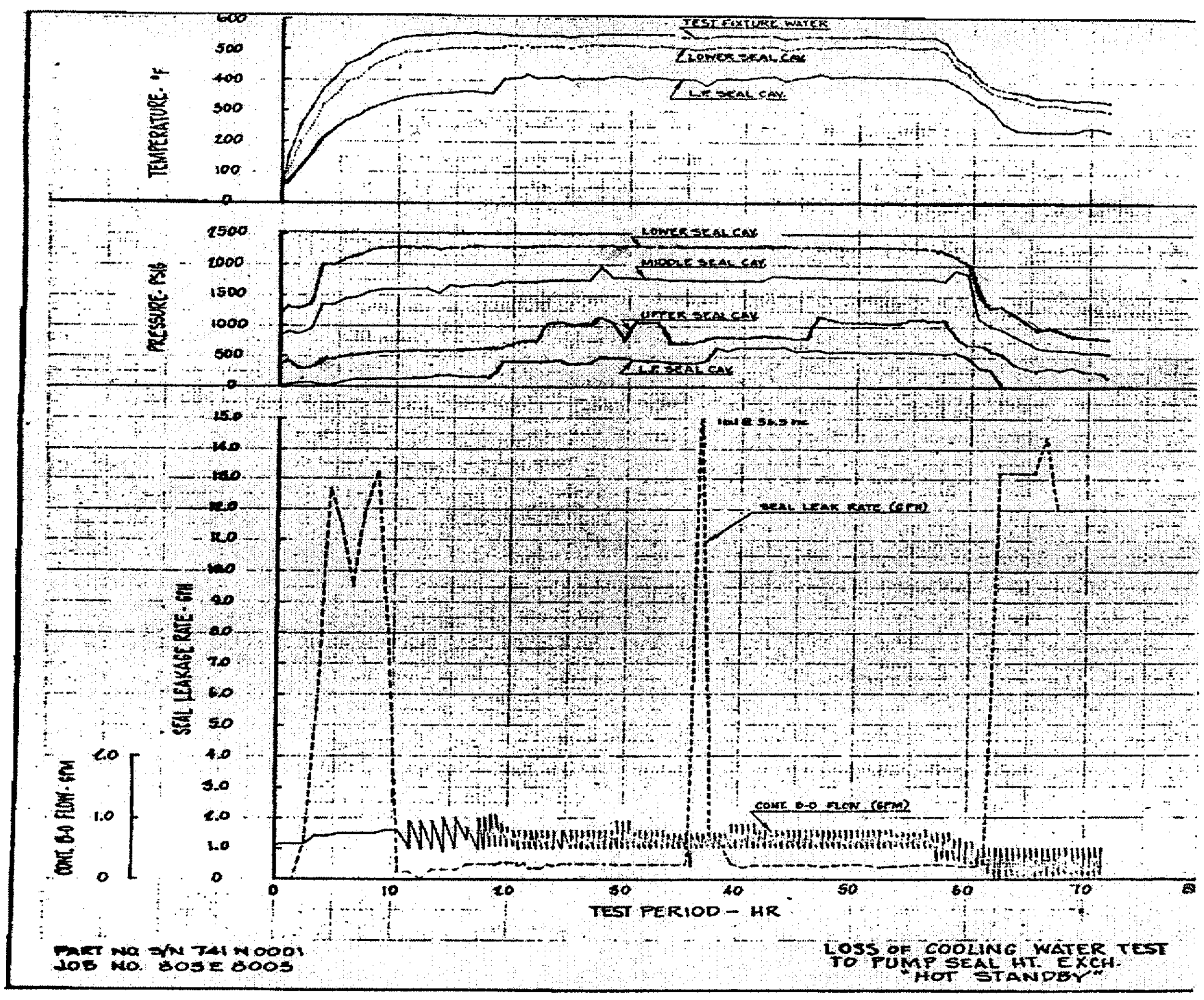
Summary of Key RCP Seal Tests

Test	Seal Design	Test Description	Highlights
30 min LOCCW Test	BJ/SU	30 min LOCCW with RCP operating	Leakage marginally increased. Vapor cavity temperature approx 400 F
30 min LOCCW Test	B-W 4.5 inch seal	30 min LOCCW with RCP operating	No significant deterioration noted
50 hr LOCCW static RCP Test (SL2)	BJ/SU	RCP off, LOCCW isolated for 50 hrs. CBO not isolated.	Max leakage < 16.1 gph. Upper seal cavity < 450 F. Partial loss of sealing capability of two stages noted. Coupling between stages limited and delayed by many hours
N-9000 Test SBO Test	BJ-N9000	CBO on/off, shaft motion simulated. 8 hr test	No seal pop-open failure observed. Leakage limited to 0.04 gpm until secondary seal failure increased leakage to 1.6 gpm.

SL2 SEAL TEST

- Static LOCCW for 50 Hours
- CBO Not Isolated
- BJ/SU Seal

SL2 Seal Test



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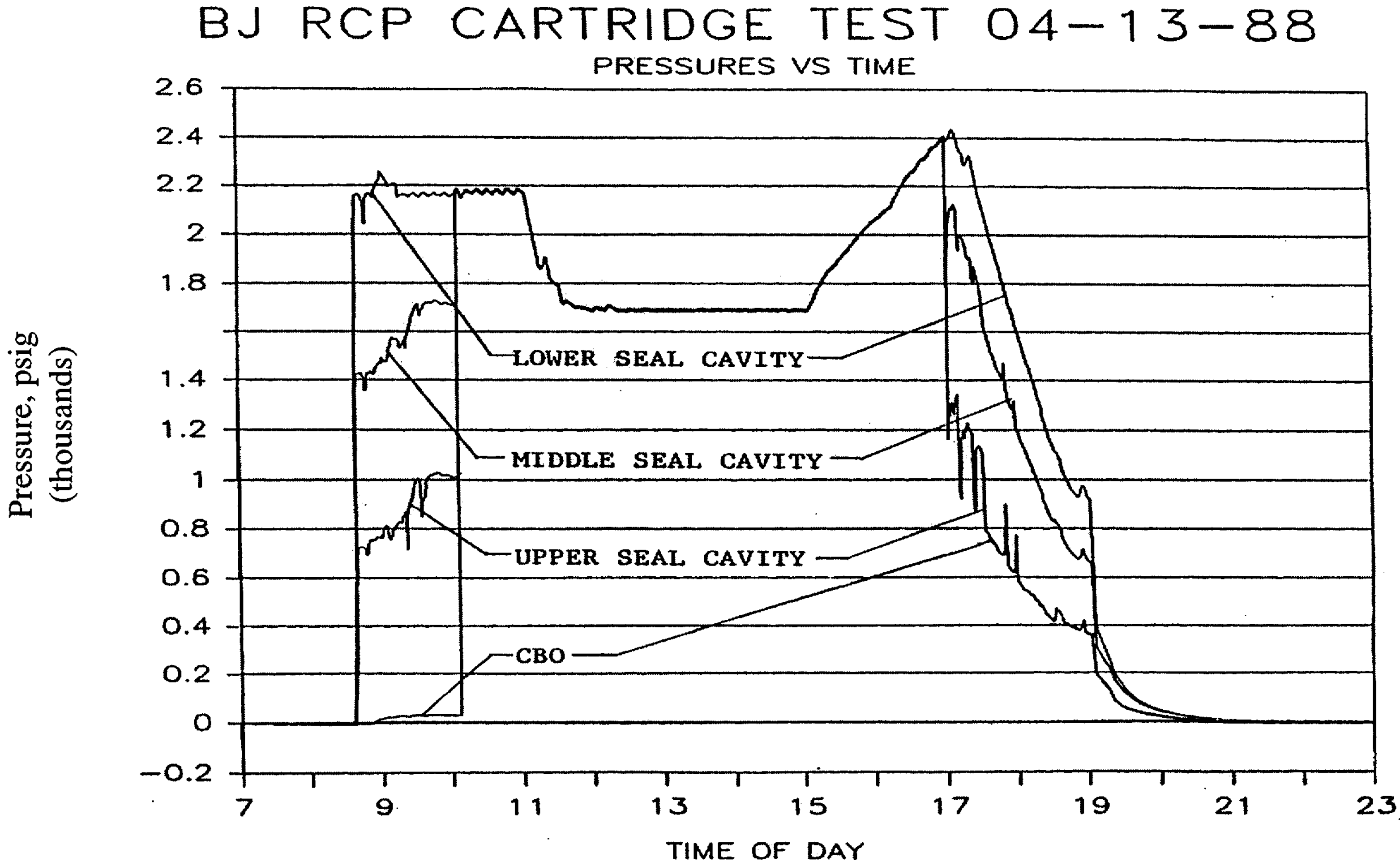
SL2 SEAL TEST CONCLUSIONS

- Leakage During 50 Hour Test Was Negligible
- Loss of Some Capability of 3rd Stage of Seal Noted After 8+ Hours of High Temperature Exposure
- No Significant Coupling Noted Between Stages

N9000 SBO Test

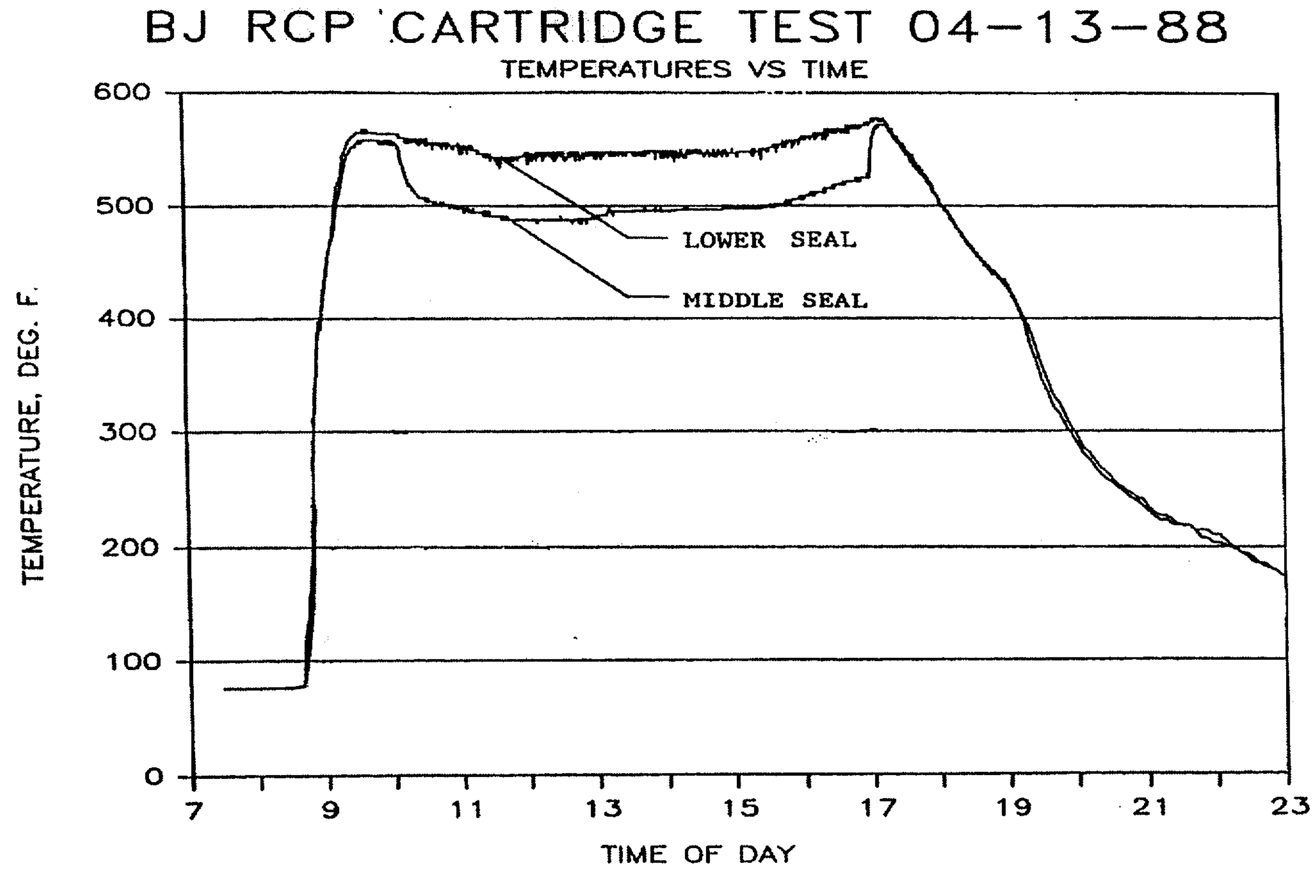
- Test Performed on a 3 Stage N9000 Seal Assembly
  - Vapor Stage Not Included (Vapor Stage Would Be Identical to other Stages)
- The Test RCP Seal had been Seasoned for 5000 hours of operation
- Test Ran 8.1 Hours Total
- After Isolation of CCW, CBO Flow Maintained for About 0.5 Hours Then Isolated
- System Pressure Held At 2200 PSIG for 1 Hour to Simulate "0 RCS Leakage"
- System Then Depressurized to 1687 PSIG Over Next 1.5 Hours and Held for 2.5 Hours to Simulate RCS Leakage Case
- RCS Then Repressurized to 2436 PSIG
- Shaft Motion Downward and Upward Accompanied Pressure Changes

N9000 SBO Test Results
Stage Pressure vs Time



Lower, Middle and Upper Seal Cavity and CBO Pressures

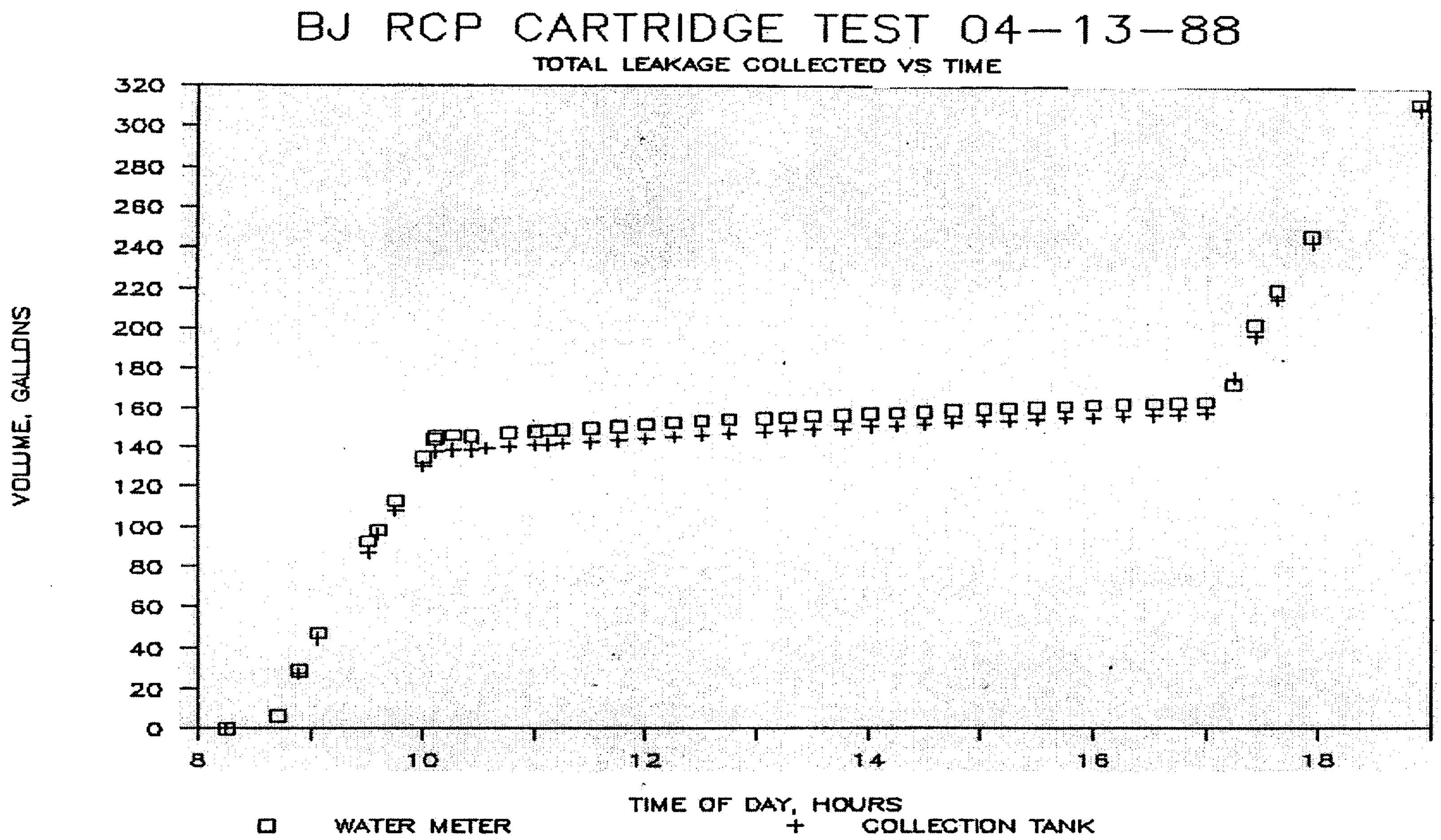
N9000 SBO Test Results
Stage Temperature vs Time



Lower Seal, Middle Seal Leakage Port, and CBO Temperatures

N9000 SBO TEST

TOTAL MEASURED LEAKAGE VS. TIME



N9000 SBO Test Results

- Seal Stages Performed Well Throughout 8 Hour Test
- Non-prototypical failure of secondary “O-Ring” Caused a 1.5 gpm Leakage Which Restaged The Seals
- Minimum Impact of High Temperature Exposure on Other Elastomers
- Upper-most Stage Temperatures Limited by Ambient Heat Losses
- No “Pop-Open” Failure or Binding Behavior Noted

TRANSIENT CHALLENGES TO SEALS

- Transient Seal Challenges Are Due to:
  - LOCCW Events
  - SBO Events
- During Any Event, EOPs Direct Operators to Maintain a Subcooled Margin of At Least 20°F But Less Than 200°F
  - Subcooled Margin is T_{sat}(Pzr) - T_{hot}
- Natural Circulation Operation Results in a T_{hot} - T_{cold} Delta of at Least 20°F

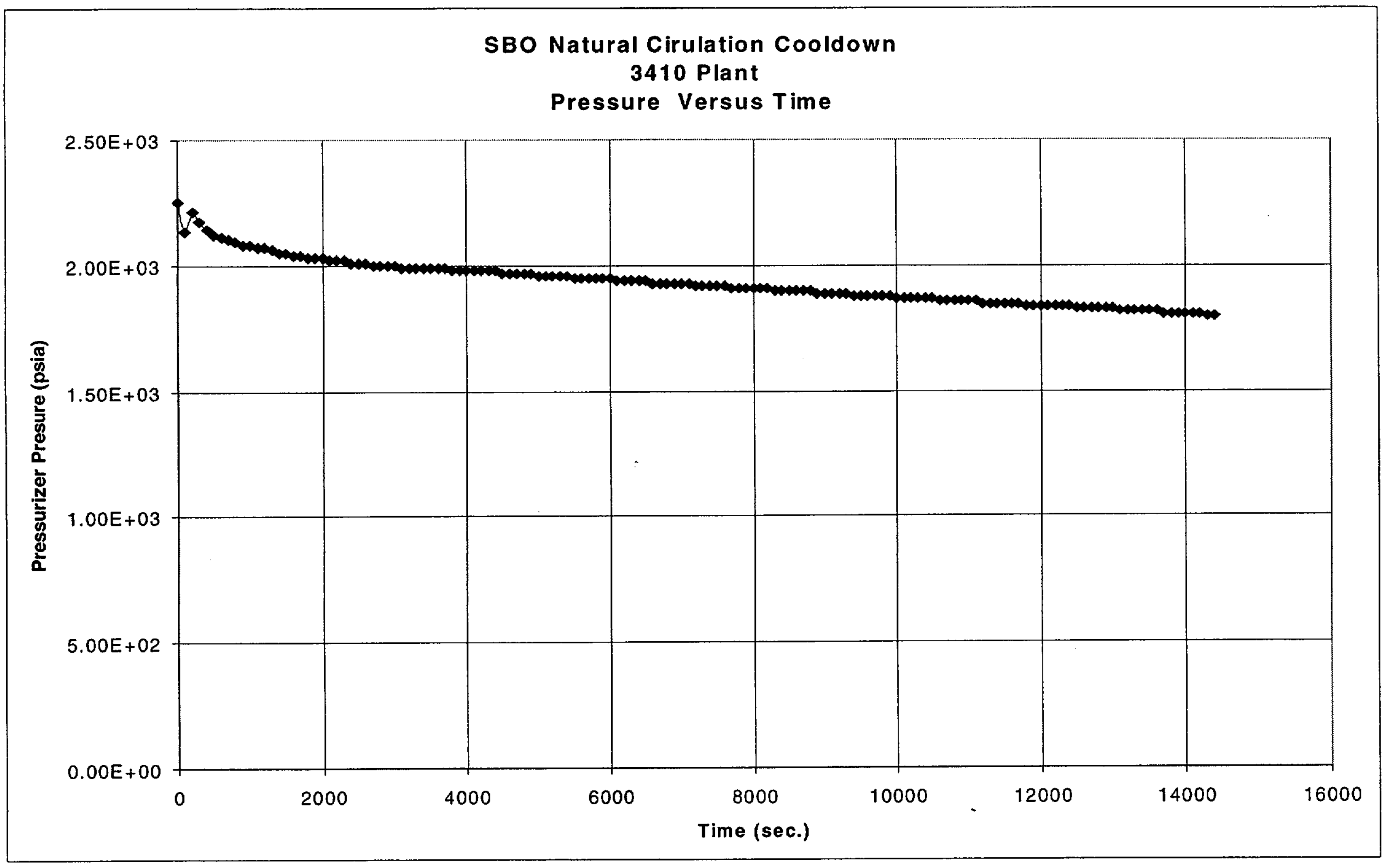
LOCCW EVENTS

- LOCCW Events are Characterized By:
  - Potentially operating RCP
  - Availability of portions of most plant systems
  - LOCCW events may affect one or more RCPs
- Experiments Demonstrate Ability of Seals to Survive LOCCW Events for > 30 Minutes w/o Leakage
- Early Life Events on BJ/SU Seals Indicates Seal Integrity Maintained for > 40 Minutes with Pumps Operating
- Typically, LOCCW Events Will Allow Operators to Control Subcooling of RCS to >> 20°F in Hot Leg
  - Subcooling in cold leg is greater
- CBO Operation Not Currently Standardized. Model Considers Alternative Operations

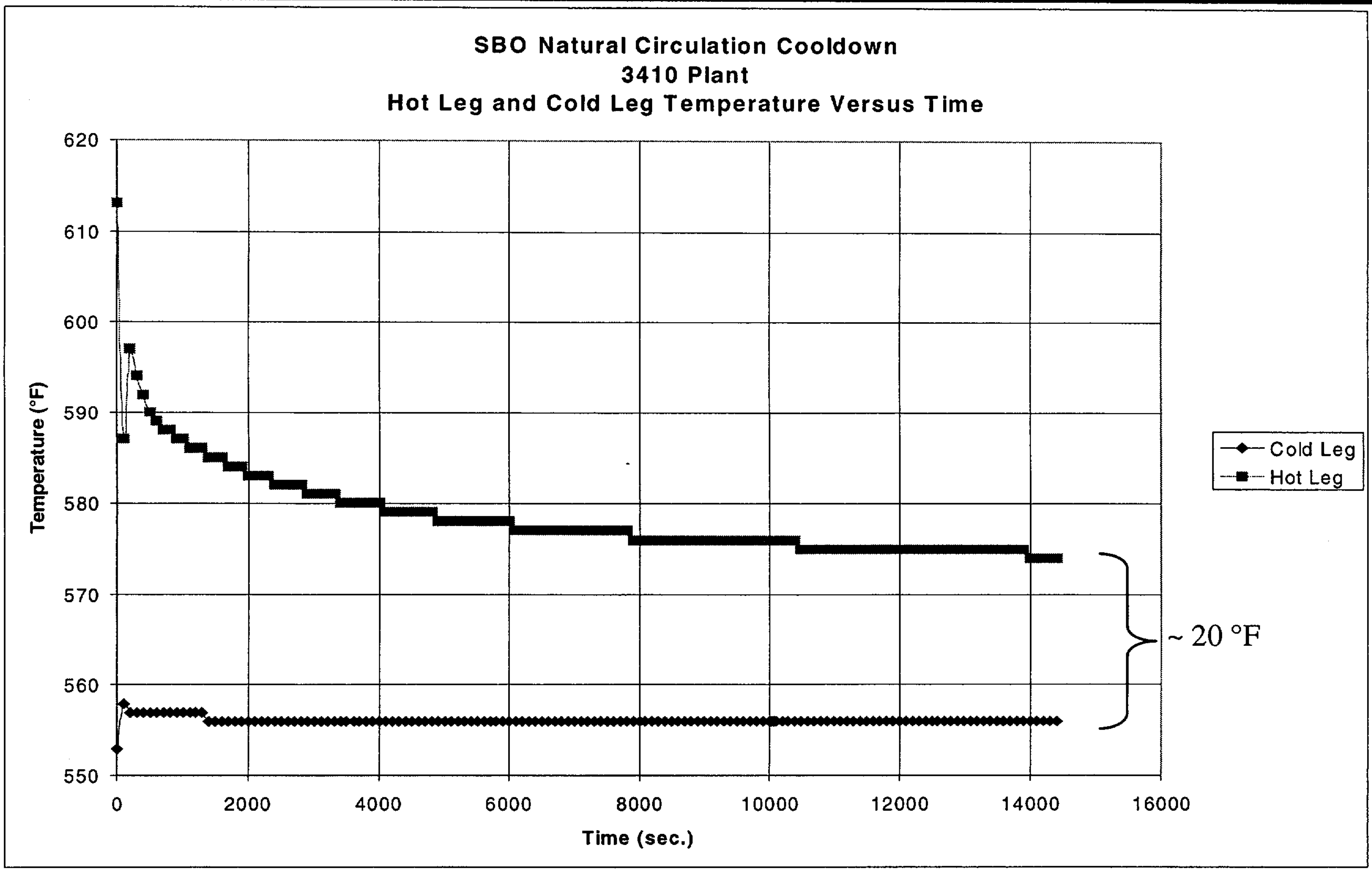
SBO Events

- SBO Events Are Characterized by:
  - Reduced control of RCS cooldown
  - Unavailability of Inventory Makeup
  - Natural circulation operation with subcooled Margin > 47 °F and hot leg/cold leg delta T of 20°F

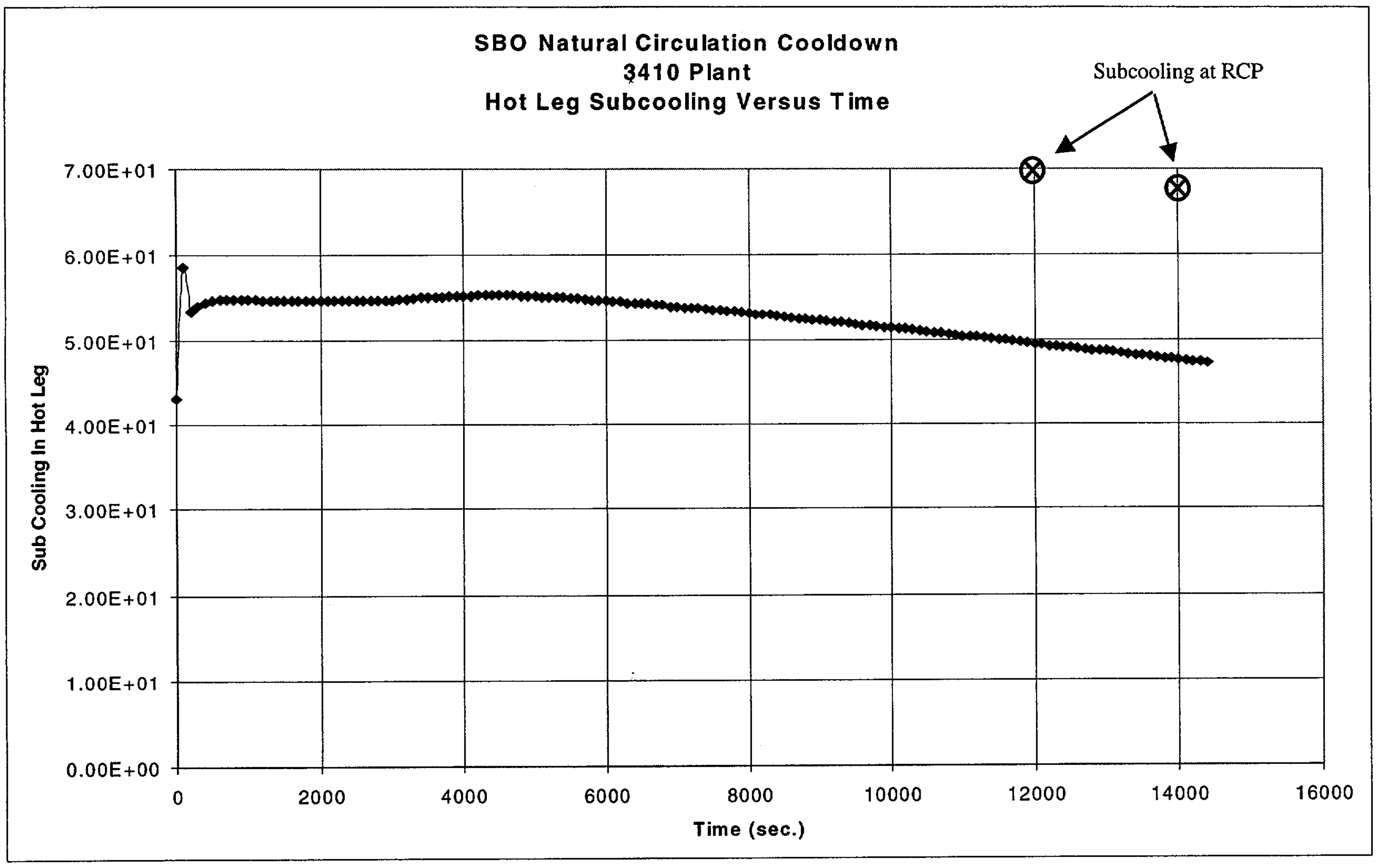
SBO EVENT: PRESSURIZER PRESSURE



SBO EVENT: HOT & COLD LEG TEMPERATURES



SBO EVENT: RCS SUBCOOLING



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Operating Experience

No.	Plant	Date	Dur.	#RCPs involved	# Stages Failed	Category	CBO Isolated
1	ANO2	6/24/80	0.1	4	0	SBO	No
2	FCS	7/1/92	0.1	1	0	LOCCW	No
3	FCS	7/92	0.1	1	0	LOCCW	No
4	SL2	8/8/85	0.23	2	0	LOCCW	No
5	SL2	12/19/84	0.5	2	0	LOCCW	No
6	SOS2-A	3/83	0.5	4	0		No
7	SOS2-T	12/19/78	0.5	1	0	LOCCW	No
8	ANO2	6/3/88	0.6	4	0	LOCCW	No
9	PV1-T	11/21/83	0.6	1	0	Test	Yes
10	WSES3	2/20/85	0.67	1	1	LOCCW	No
11	FCS	4/17/74	0.75	4	0	LOCCW	No
12	FCS	1981	1	4	0	LOCCW	No
13	PV3	3/1/89	1.2	4	0	LOCCW LOSI	No
14	SL1	6/11/80	1.5	4	0	LOCCW	No
15	PV2	4/4/86	3	1	0	LOCCW LOSI	Yes
16	SL2	8/8/85	4.5	2	0	LOCCW	No
17	WSES3	2/20/85	4.5	3	1	LOCCW	No
18	MNS2	11/15/84	5	1	0	LOCCW	No
19	PV1	7/6/88	6	1	0	LOCCW LOSI	Yes
20	MNS2	11/15/84	9	1	0	LOCCW	No
21	FCS	9/20/75	UNK	4	1	LOCCW	No
22	SLI	4/15/77	UNK	4	0	LOCCW	No
23	SL2-T	8/26/80	50	1	0	SBO	No
24	N9000	12/87	8	3	0	SBO	Y
25	PV2	7/1/86	UNK	1	0	LOCCW LOSI	N/A

Rhodes Model Predictions/Basis (NUREG/CR-4948)

- Rhodes Model only identified coupling between 2nd and 3rd stages
- Even Older BJ seals predicted to be most stable of seal designs and least subject to "Pop-Open"
- Test Predictions Using Rhodes Model for These Types of Seal Designs Indicate that Rhodes Model is Overly Conservative for Prediction of Hydrodynamic Instability
- In NUREG/CR-4821, The Model Confirmation Test Performed by AECL Was Only a Half-Scale Test
  - Test used only single stage
  - The "Full Scale" Westinghouse/Edf Test Did Not Confirm the Predicted Behavior

NUREG/CR-4821 CONCLUSIONS FOR BYRON JACKSON SU SEALS

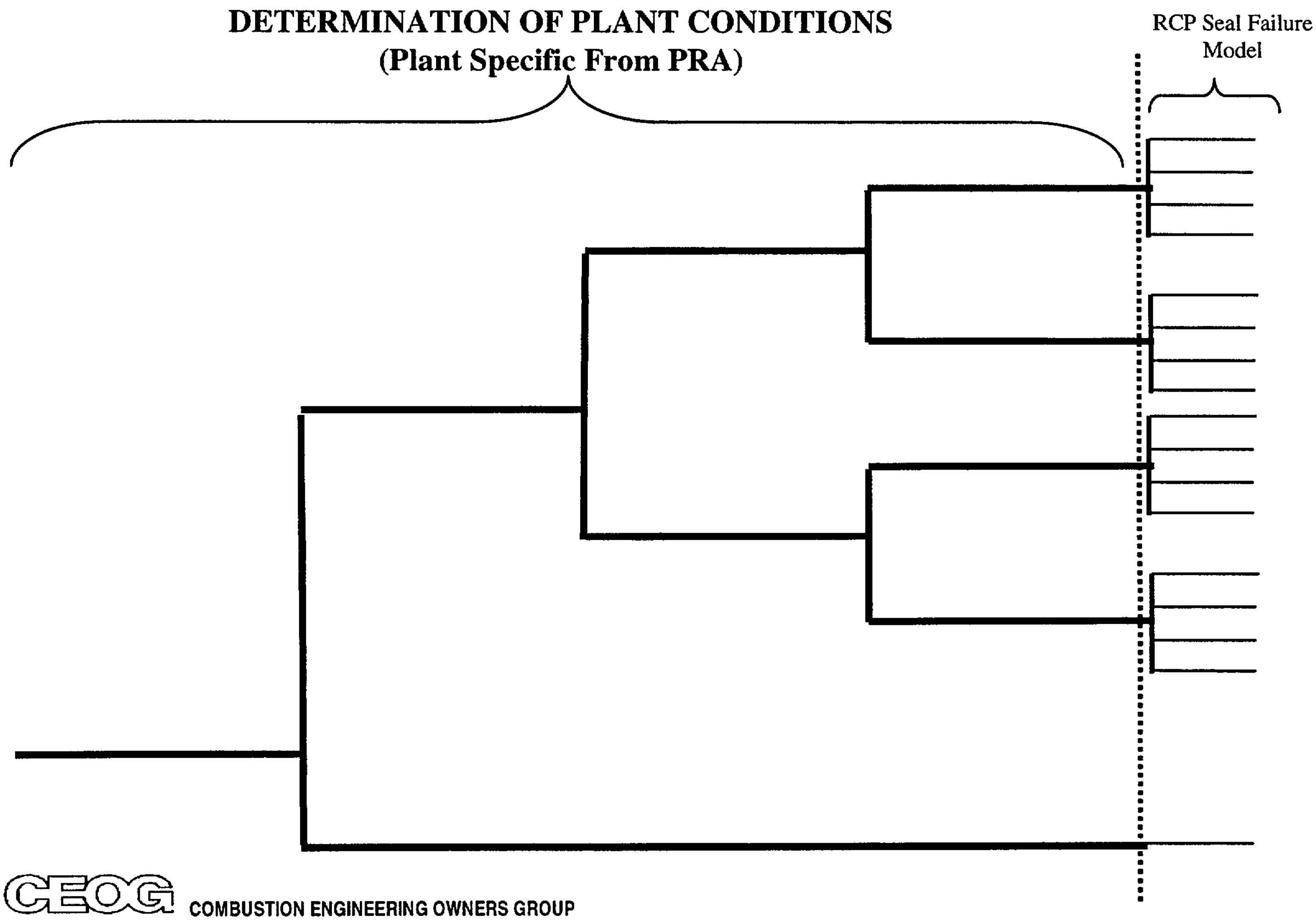
- Extrusion Failure of Byron Jackson Secondary Polymer Seals Not Expected Under SBO Conditions

- The Byron Jackson Seals Have a Higher Balance Ratio ... and Are The Least Susceptible to Instability

RCP SEAL FAILURE MODEL

- **Stage Model Addresses:**
  - ① Random Failure of Stage During Event
  - ② Pre-Existing Failure of RCP Seal Stage
  - ③ Stage Failure Due to Elastomer Deterioration and Extrusion
  - ③ Stage Failure Due to "Pop-Open" In Conjunction With Binding Separation of Stage
- **Model Conditioned By:**
  - ① Whether RCP Is Secured Within 1 Hour
  - ② Whether CBO Flow is Isolated
  - ③ Whether 50 ºF Subcooling is Maintained In RCS Cold Leg
  - ④ Thermal Exposure Time
- **Models Evaluated For Three Basic Seal Types:**
  - ① 4 Stage Seals With Nitrile Elastomers (BJ-SU)
  - ② 4 Stage Seals With "Qualified" Elastomers (BJ N-9000, Sulzer "Balanced Stator")
  - ③ 3 Stage Seals With "Qualified" Elastomers (Sulzer "Balanced Stator")

SCOPE OF MODEL TO BEVIEWED



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CONSERVATISMS IN MODEL

- Adverse Shaft Movement Assumed at All Times for "Pop-Open" Evaluation
- RCS Assumed to Be Saturated (Less Than 50 °F Subcooled) for SBO Sequence
- Do Not Credit Increase in Subcooling of a Stage Resulting From Upstream Stage Failure
- Evaluation Of Subcooled Margin Based on Hot Leg and Did Not Reflect the Additional Margin Associated With the Lower Cold Leg Temperature
- Leakage Based on the Limiting Flow Through the Thermal Barrier
  - Leakage calculated using full system pressure rather than the lower pressures expected if there was an RCS leak
  - Assumes failed seal offers no flow resistance

CONCLUSIONS

- "Pop-Open" and Binding Has Been Considered and Modeled Consistent With Observations of Relevant Data
- Model Provides Insights into the Importance of EOP Actions and Transient Challenges
- Model Provides a Tool for Risk Informed Decision Making That Can Assess the Risk Impact of the Current Operating Condition of the RCPs