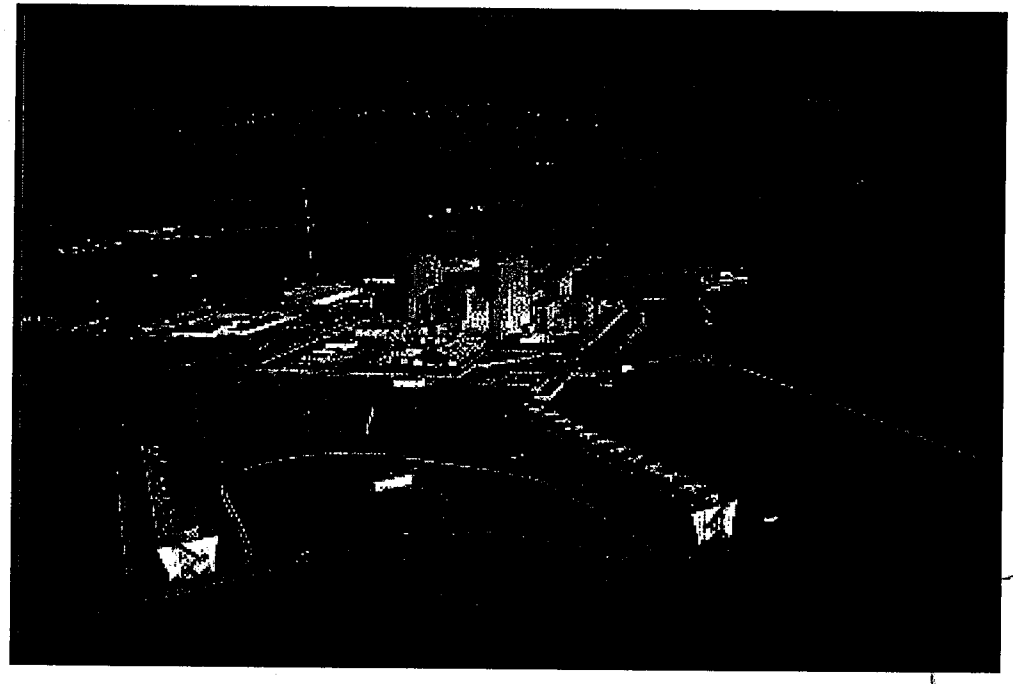
Prairie Island Nuclear Generating Plant



Regulatory Conference

November 27, 2001

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Agenda

I.	D5/D6 Design Bases	Ted Amundson
II.	Analysis of D5/D6 Condition	Ted Amundson, Mike Graddage & Clive Wotton
III.	Safety Significance	Ted Amundson
IV.	Lessons Learned	Ted Amundson
V.	Conclusion	Mano Nazar

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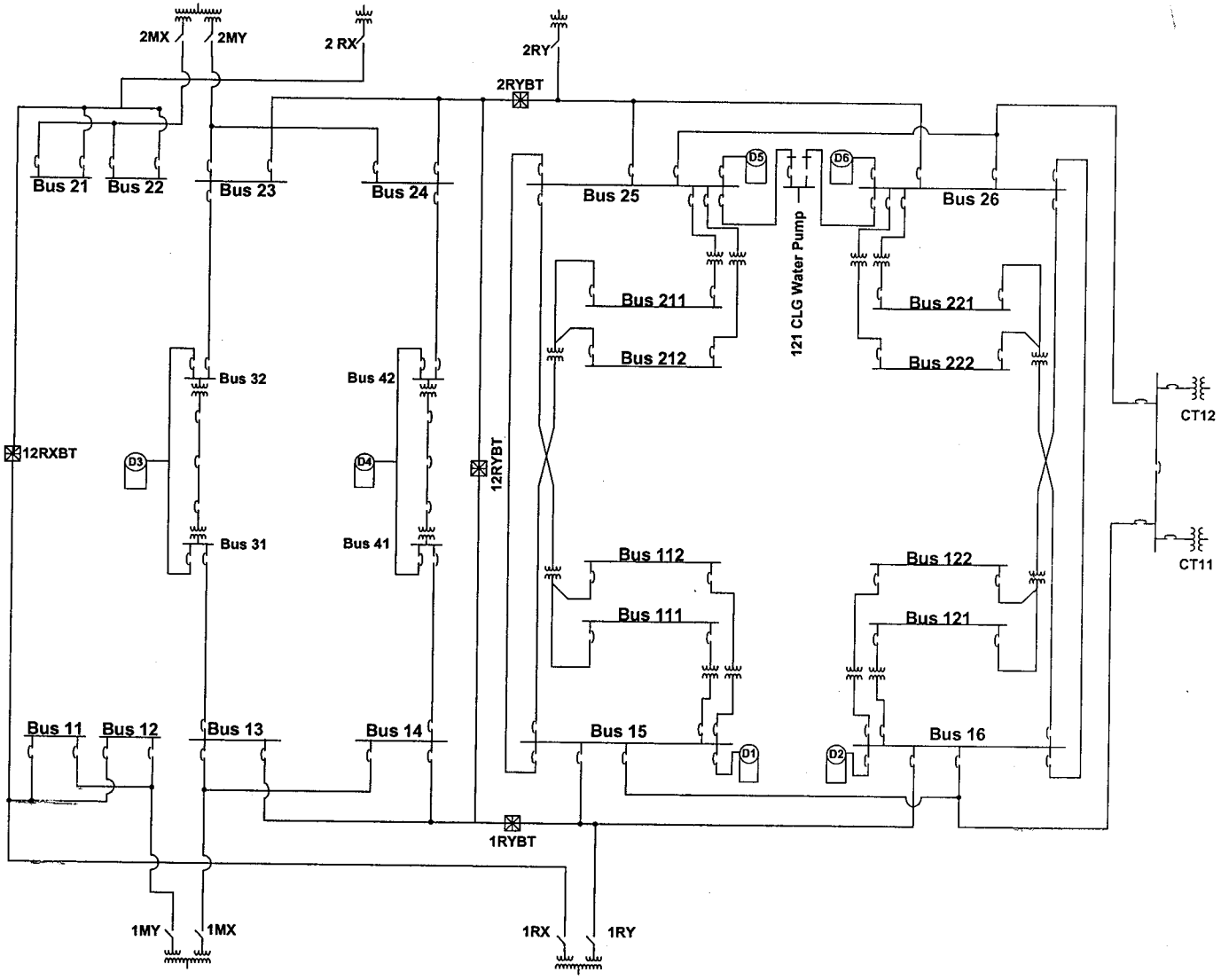
Prairie Island Electrical Distribution



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Plant Electrical System Improvements

1980s Added 2RS/2RX/2RY transformers

Added non-SR Service Building distribution

- 2 non-SR diesel generators
- 4 3-phase 125 kVA UPS's
- removed large DC loads from SR DC distribution panels

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Plant Electrical System Improvements

1992 SBO/ESU Project:

- Alternate AC SBO design
- New 1E building to house Unit 2 EDG's and busses
- Added D5 and D6
- Added two 350 MVA 4kV busses
- Included double-ended bus-tie
- Replaced Unit 2 load sequencers
- Added 4 new Unit 2 480 V busses

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Plant Electrical System Improvements

1990s Added 4 Unit 1 480 V busses and upgraded Unit 1 load sequencers

Upgraded Cooling Tower substation 4 kV breakers

2001 Completed a modification to two transferable MCC's for trained, unit-shared equipment

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Diversity & Redundancy of Electrical Supply

- Safety Related (in order of preference):
  - Normal off-site source
  - Alternate off-site source } Automatic
  - EDG
  - Cross-tie to opposite unit
  - Non-proceduralized backfeeds (e.g., D3/D4)

D5/D6 Design

- Installed to improve risk profile
- Large margin between rated capacity and event loads
  - Rated at 5400 kW
  - Max event load (short term) is 3652 kW (SBO)

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D5/D6 Design Bases

- Required to mitigate several events:
  - Design Basis Accident/LOOP
  - External Events (e.g., flood, tornado, earthquake)
- Other requirements:
  - SBO Rule
  - Appendix R
  - USI-A-46 Implementation (SQUG)
- Required run time, load, and redundancy are event-specific

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Event Run Time Summary

Event	Time Duration	Redundancy Required?	kW Load Requirment (% of rated) vs. 5400 kW continuous rating (USAR)
Appendix R (fire)	72 hours	Yes. If Train A power is affected by the fire, then rely upon Train B (D6)	2453 kW (45%) for D6 2602 kW (48%) for D5 (from LOOP analysis)
Probable Maximum Flood (limiting external event)	21 days (504 hours) -14 days to crest and recede below main transformers (USAR) -7 days to restore power (engineering judgment)	No. No single failure is assumed. Both Unit 2 EDG would be available.	2453 kW (45%) for D6 2602 kW (48%) for D5 (from LOOP analysis)
SBO	No specific requirement. Assumed to be similar to LOOP	No. A Unit 1 SBO event would rely on Unit 2 EDGs. No requirement to assume additional failures. Both Unit 2 EDG available.	3652 kW (68%)
DBA/LOOP	6 to 28 hours for a LOOP based on NUREG/CR-5496	Yes. Single Failure Criteria applicable per GDC 39, 41	3609 kW (67%) max 2580 kW (48%) after 1 hr

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D5/D6 Limiting Run Times

- For single EDG, the limiting run time is 72 hours
  - D6 has to run 72 hours at 2450 kW (45%)
- For EDG system (single failure not assumed), the limiting run time is 21 days
  - D5 in combination with D6 has to run 21 days at 2450 to 2602 kW (45 to 48%)
- By meeting these Performance Requirements, D6 is operable

D6 Condition

As-found on April 9, 2001

- Begin 24-hour test
- Run at 100% load (5400 kW) for 1 hour w/o indication
- Run at 110% load (5940 kW)
  - for almost 2 hours no abnormal crankcase pressure
  - Engine 2 crankcase pressure increases to 33 mm wc
- Load reduced to 103% (5562 kW)
  - Crankcase pressure decreases to 26 mm wc
  - Crankcase pressure increases to over 30 mm wc
- Load reduced to 74% (4000 kW)
  - Crankcase pressure decreases to zero
- Terminate test

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D6 Condition

Restoration April 9 to 17, 2001

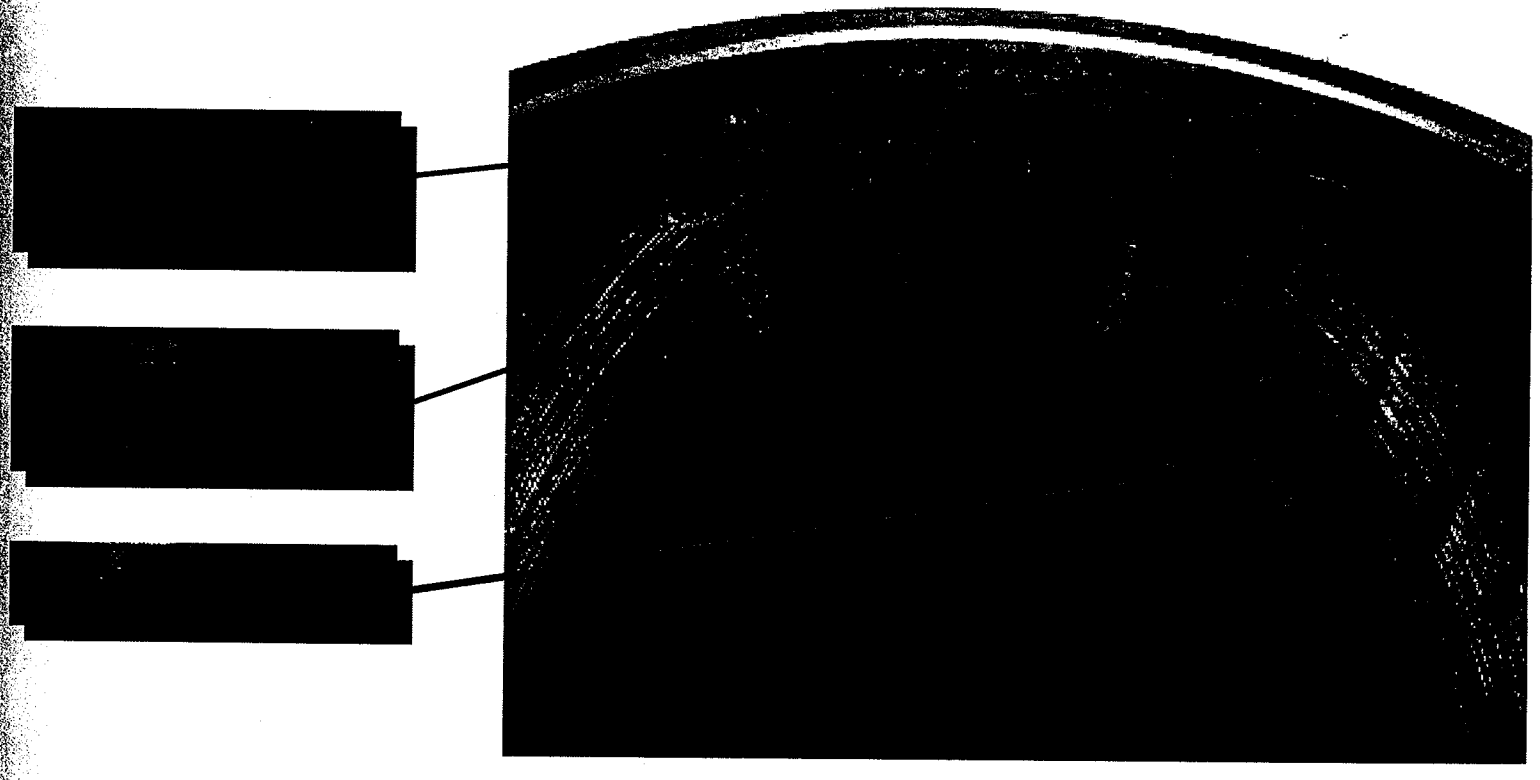
- Investigation:
  - borescope identifies indications on one D6 cylinder (E2B1)
- Repairs:
  - replaced single D6 E2B1 cylinder liner, piston and rings
- Post-maintenance testing/inspection:
  - 46 total hours of run time
  - borescope investigation
  - no indication of elevated crankcase pressure

D6 Condition - Observations

As-found condition of D6 E2B1 in April:

- Photo and visual inspection reveal minor carbon mark past TRRP. Piston examined – no stuck rings – all rings had bright surfaces indicating full contact made with liner
- Some carbon raking – but bore condition generally very good condition.

D6 E2B1 - Cylinder Liner



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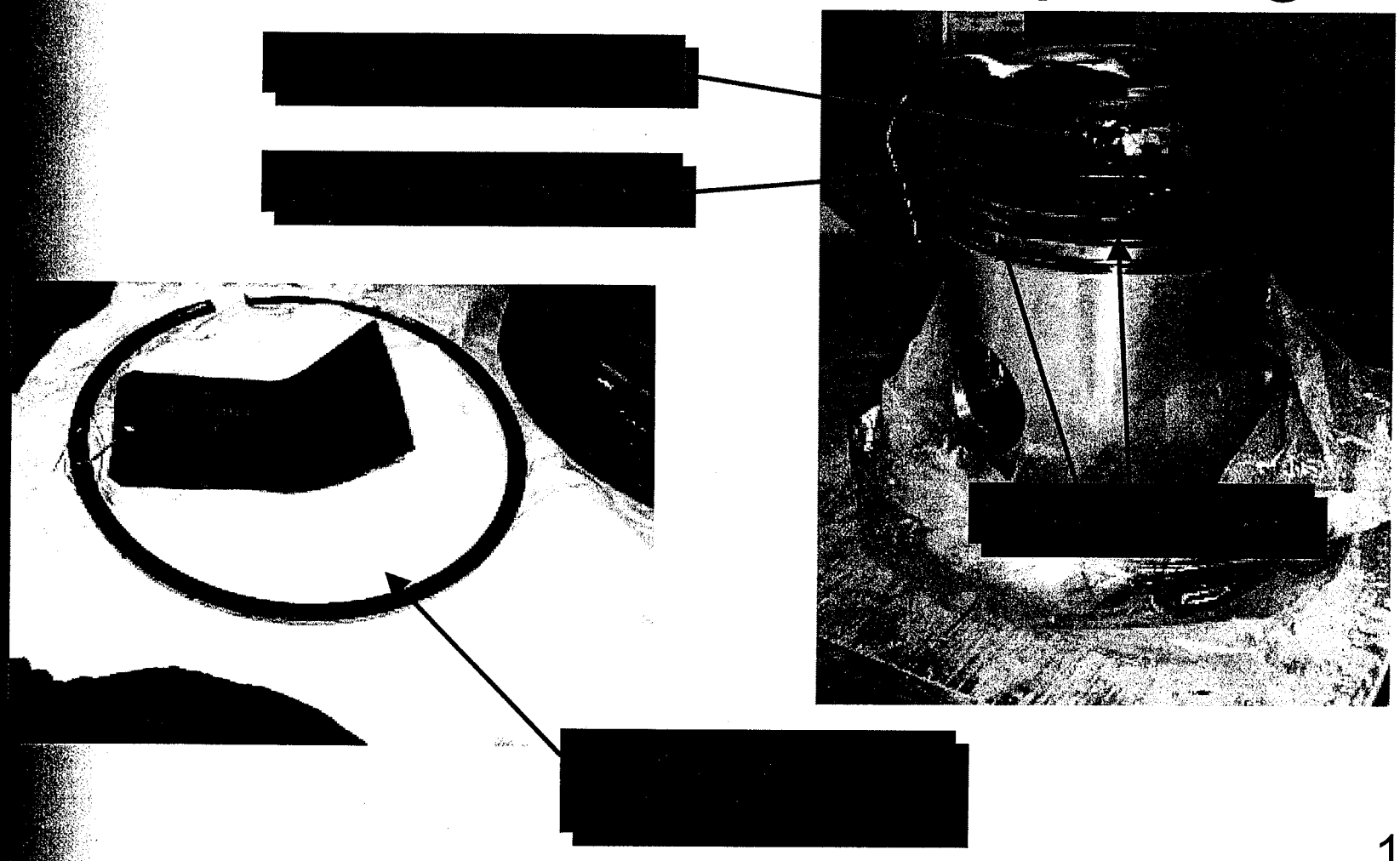
D6 E2B1 - Piston & Top Ring



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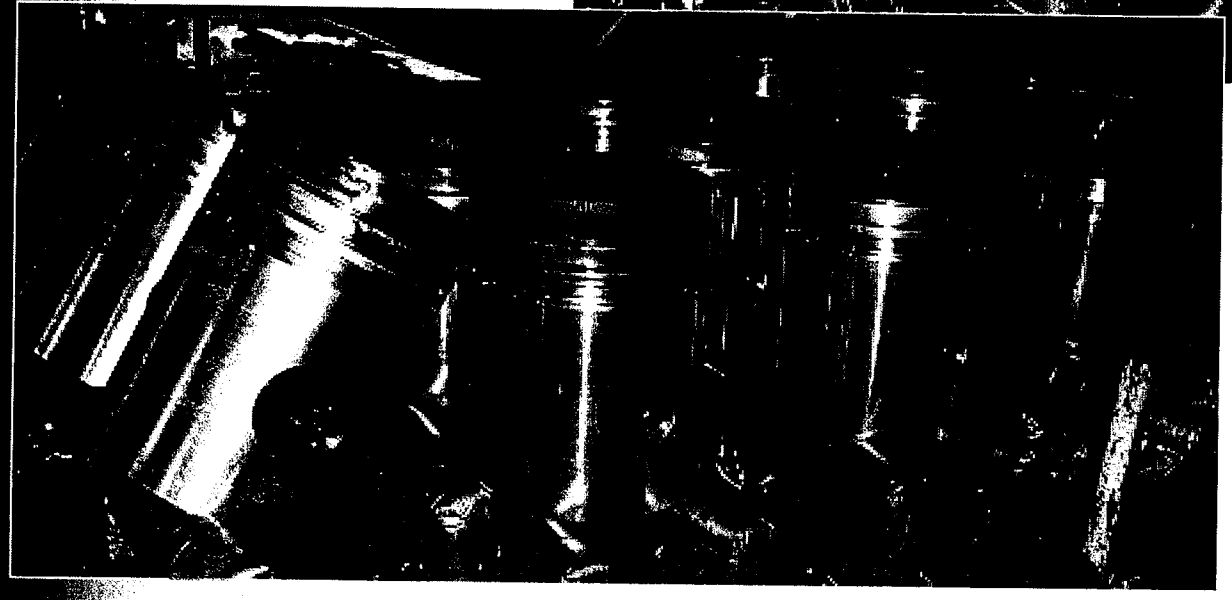
D6 - Pistons



Piston Ring Condition Ratings

1 Free Ring – Free to move under Gravity*

2 Tight Ring (Sluggish) – Not free, requires moderate finger pressure

3 Pinched Ring (Cold Stuck) - Will not move under moderate finger pressure, face polished so operates satisfactorily in use

4 Stuck Ring – Will not move under pressure, carbon/varnish on face, ring has not been in contact with the bore

5 Plugged Oil Ring – OCR with holes plugged by deposits

*Ref CRC Diesel Engine Rating Manual CRC # 18

Condition of Components - D6

- Piston E2B1 – rated 1
- Majority of pistons rated as 1
- Eight rated as 2
- One piston E1A5 – rated at 3 over one third of circumference, second and third rings would be rated 1

Conclusion: rings and pistons in fair to good condition for a Medium Speed engine

D6 Condition - Observations

During May shutdown:

- Some hard packed carbon noted on top lands.
- Minor indications of carbon cutting or raking seen on some cylinders.
- Very light patches of lacquering found on several cylinders
- Remainder of component conditions found to be good

D6 Condition - Profilometry

- Visual determination of surface finish is unreliable – quantitative methods must be used – surface profilometry.
- Taylor Hobson Surface Profilometer used
- New and used liners sampled
- Results analyzed and compared to design standards

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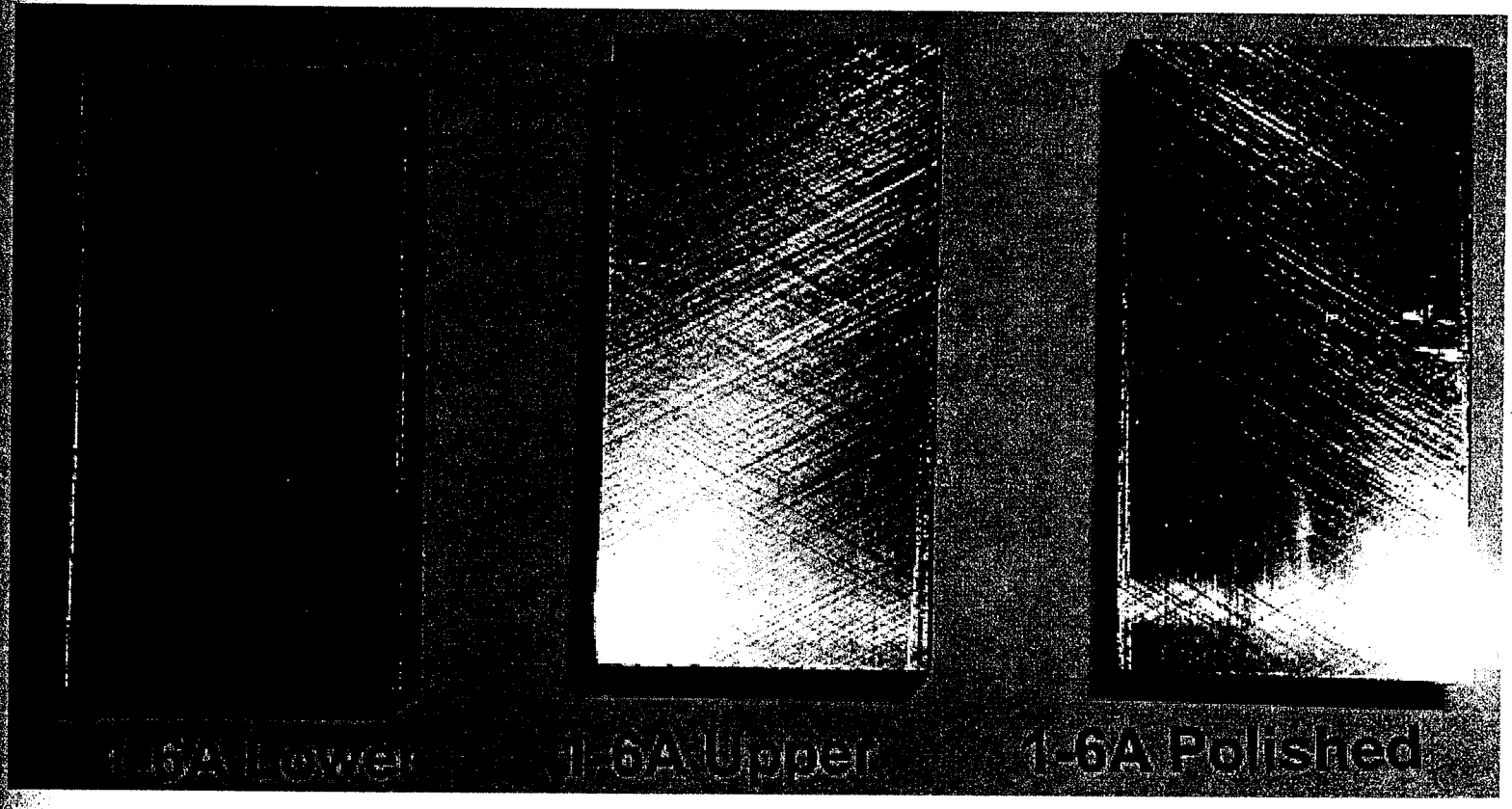
Detail of Liner Sections



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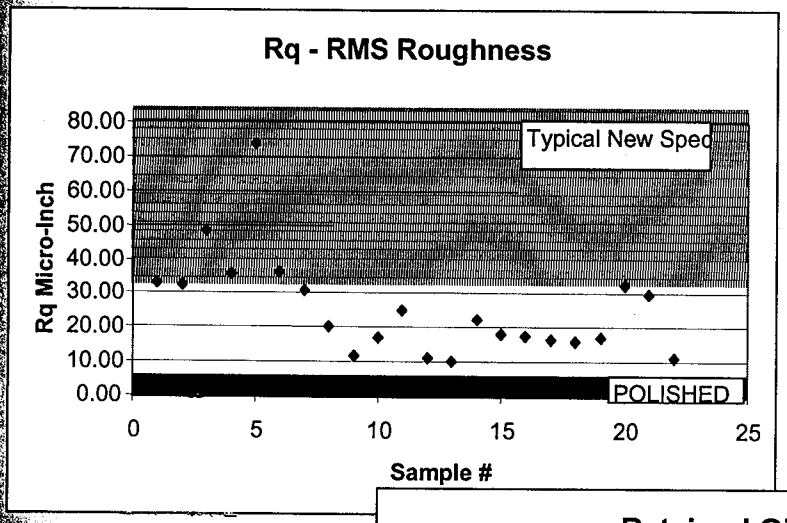
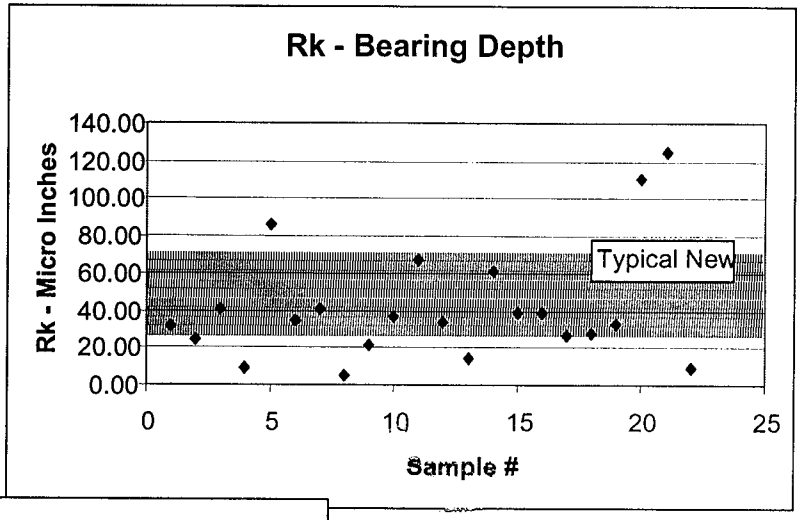
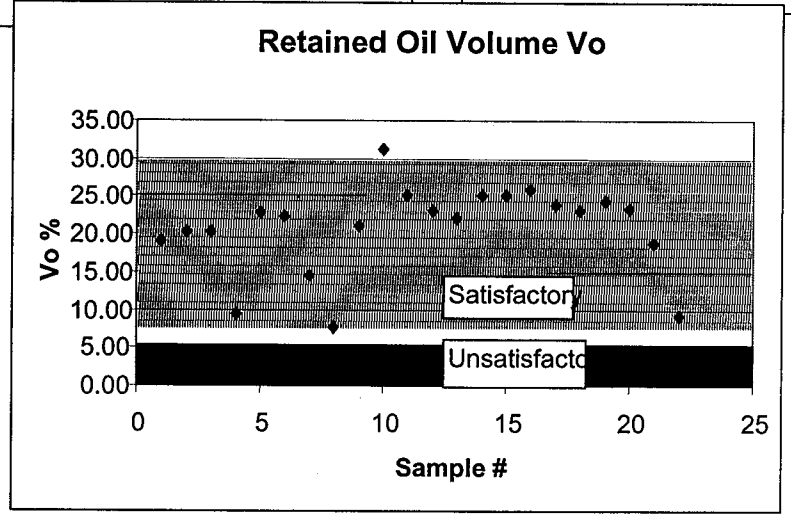
Liner Surface Parameters







D6 Condition - Profilometry

- Liners show adequate surface roughness to retain oil for lubrication
- Bearing depths are adequate
- Retained oil volume is adequate for operation No area of any liner assessed met the CRC defined criteria for "Polished"

Conclusion:

The liners are in satisfactory condition – adequate life remaining for several hundred hours operation.

Blow-by Causes

Blow-By can be initiated by the following:

•Loss of Ring Sealing	-Possible – Carbon Flakes
•Ring Pinching	-Possible – 110% Load
•Unusual Ring Motion (Flutter)	-Possible – Carbon Build-up
•Excessive Bore Polishing	-Not Found
•Excessive Ring Gap	-Not Found
•Insufficient Ring Wall Pressure	-Not Found
•Ring Gaps Aligned	-No Effect Seen in previous operation
•Bore Distortion	-Not with wet liner and Even cooling

Blow-by Causes

- Blow-by increased suddenly
- No physical damage seen on strip
- Possible Causes – pinch at 110% load – Thermal & Carbon
  - Carbon Disturbance – Carbon and Load
- Blow-by normal when load reduced to 4000kW

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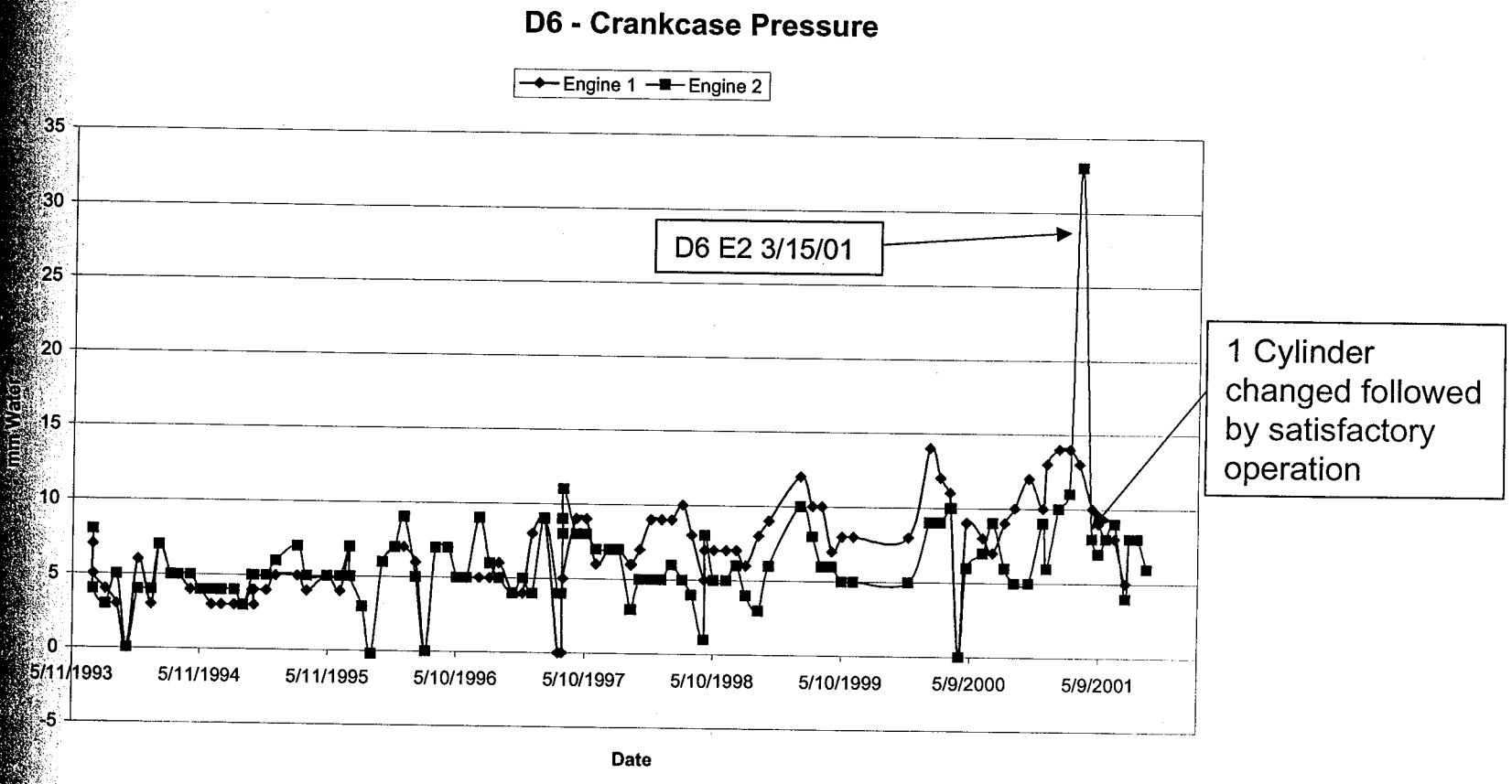
D6 Crankcase Pressure



D6 Condition - Cause

Probable Root Cause - for CCP spike

- Carbon build-up or carbon flakes on the top land and in the ring grooves causing sticky rings
- Carbon accumulation due to unreacted salts and carbon formation in the top land region.
- Combination of operating regime, oil chemistry, fuel sulfur and engine design required for the situation to occur.

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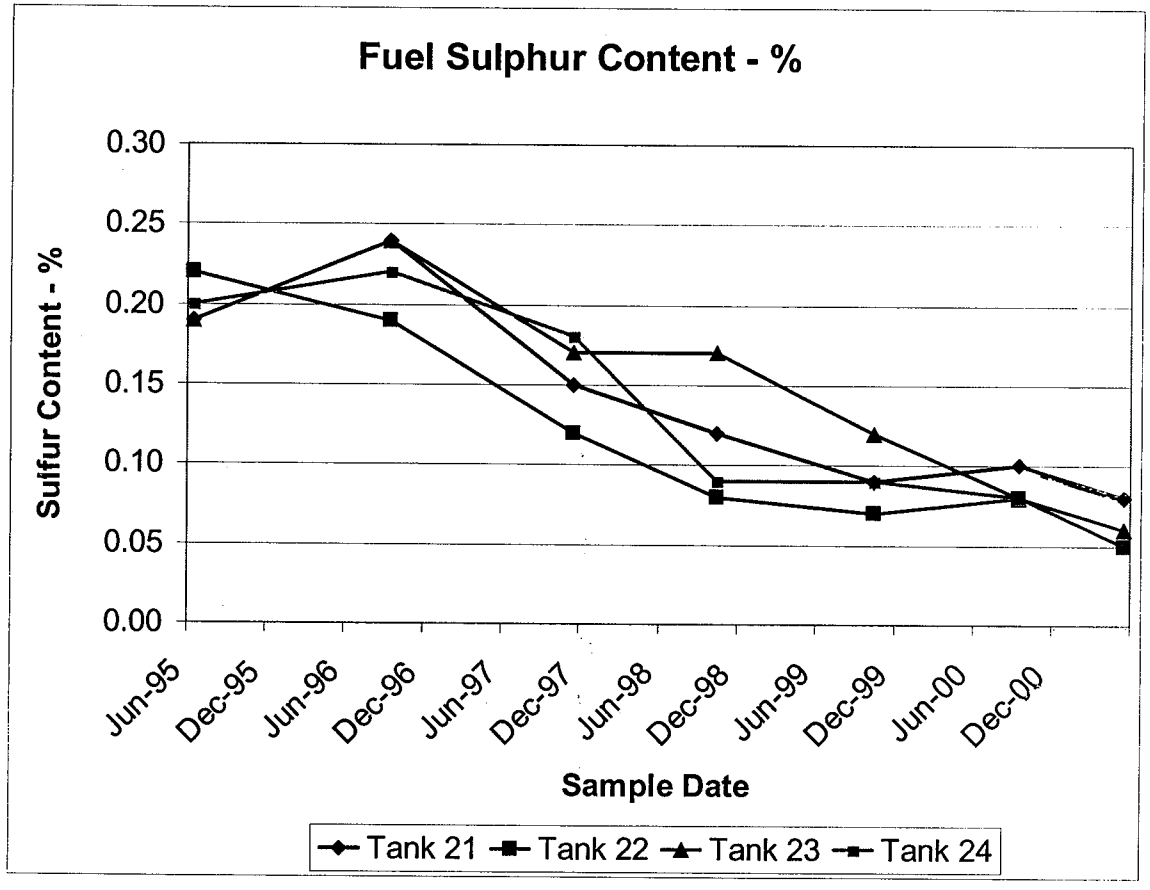
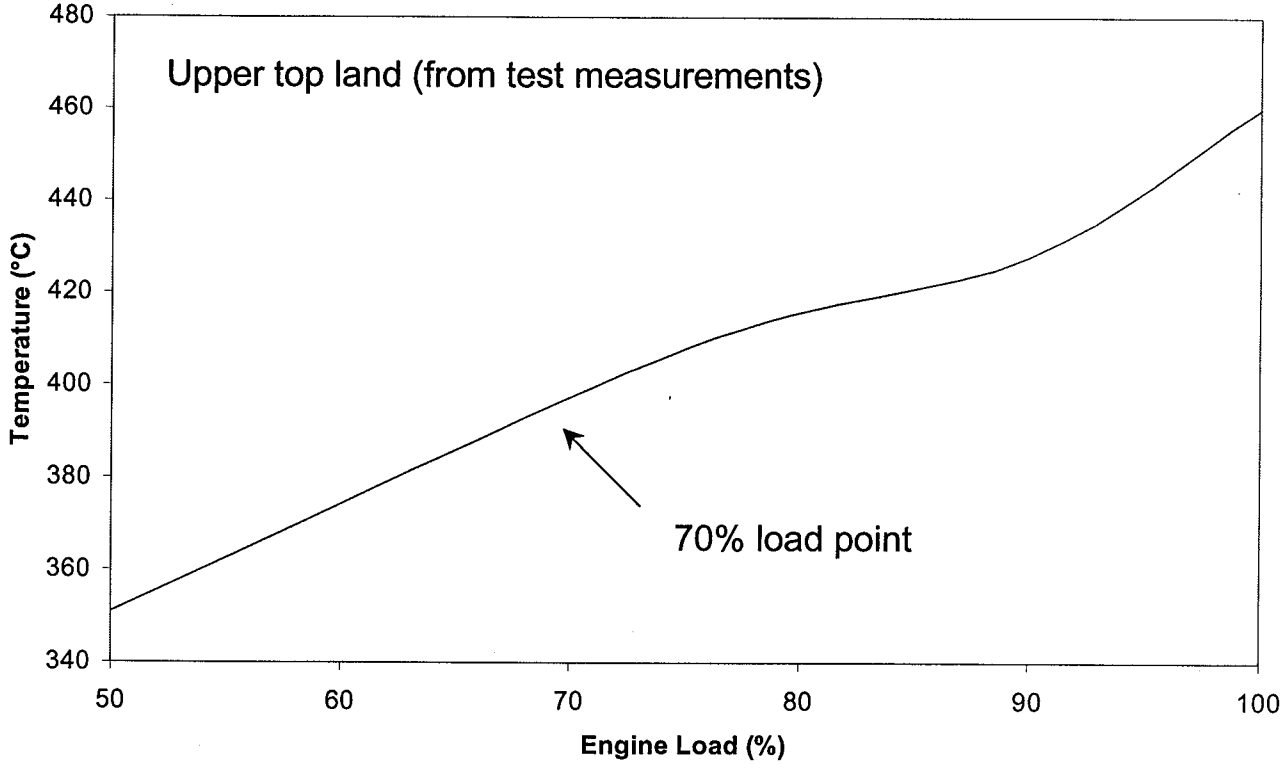
FO Sulfur



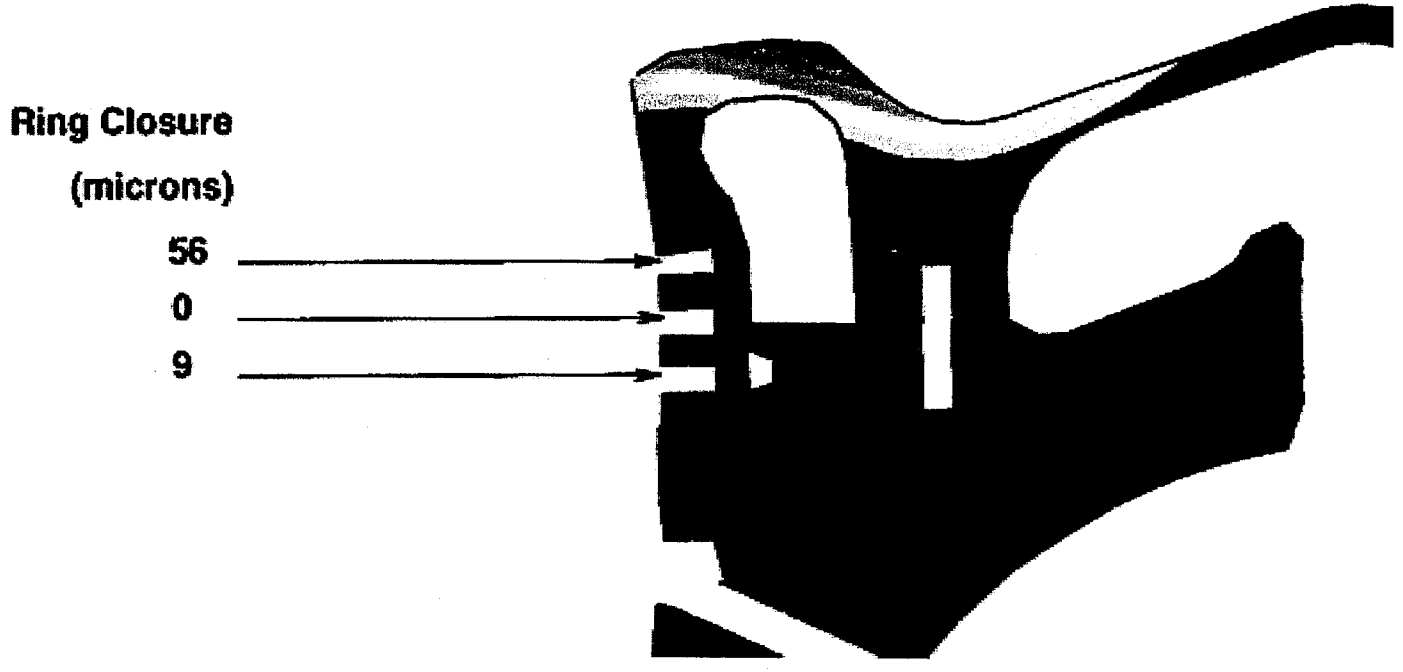
Piston Temperature

- Temperature load dependant
- Note rapid increase towards 100% load
- 110% load increases temperatures significantly



Piston Distortion

- Typical FE Analysis results at high power
- Shows effect on ring operating clearance
- Carbon/lacquer further reduces clearance



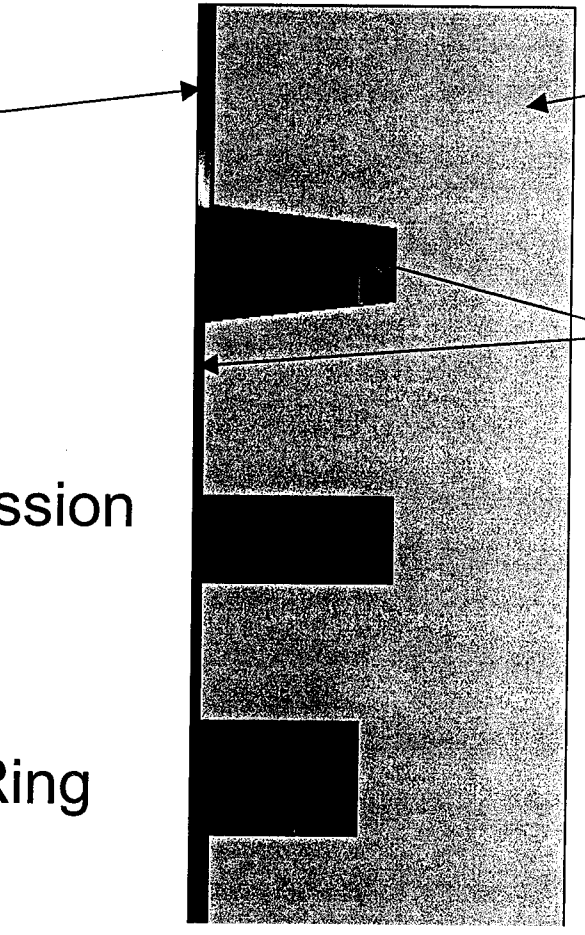
Piston Ring Pressure Distribution

Firing Gas Pressure

Top Ring

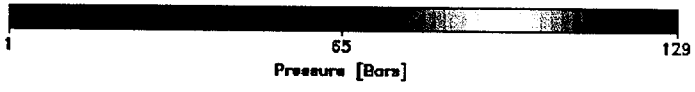
2nd Compression Ring

Oil Control Ring

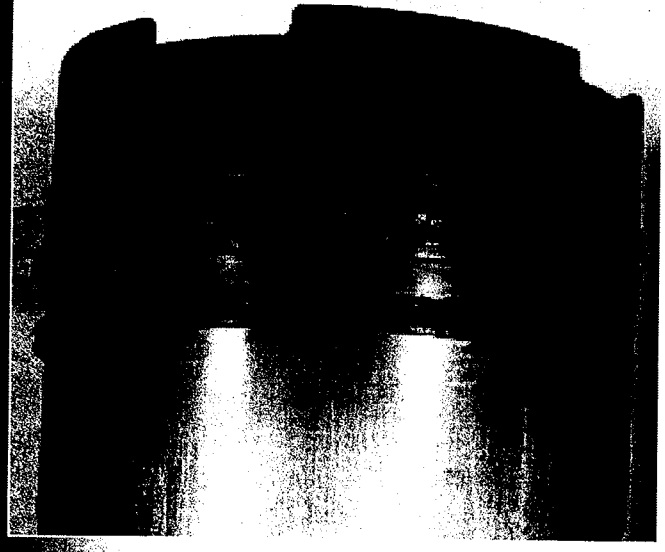


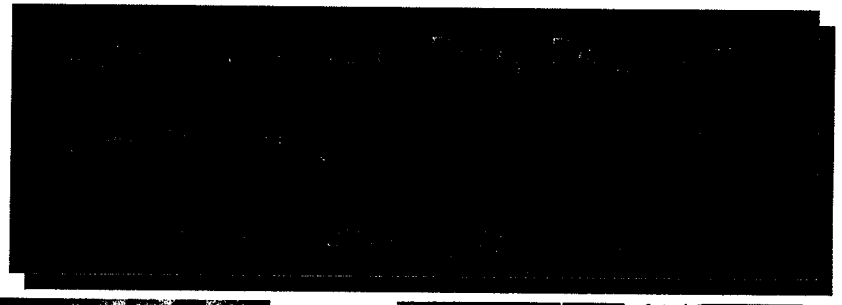
Piston

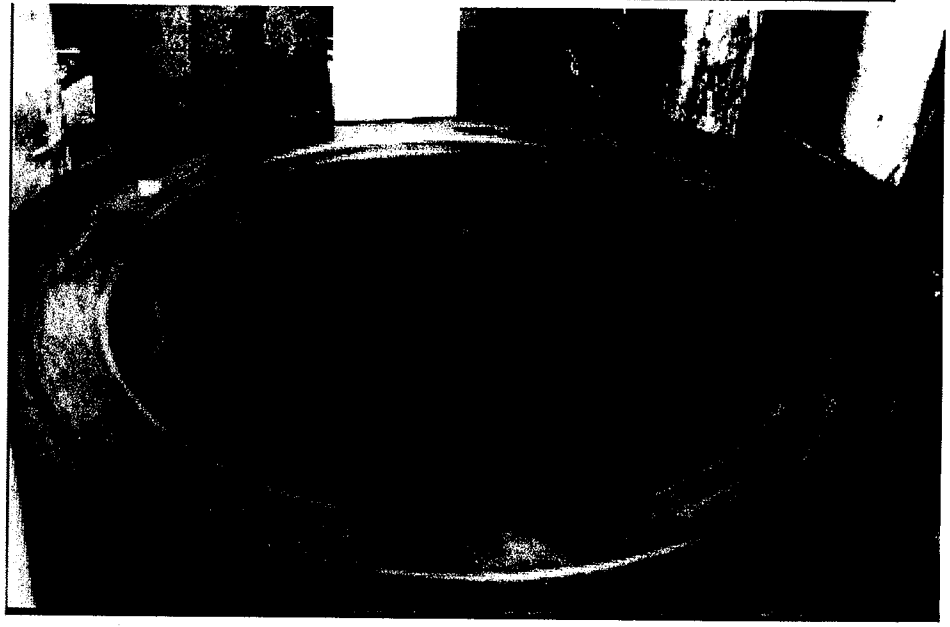
Carbon Flakes or excessive build-up of carbon upsets pressure balance



Operational Experience







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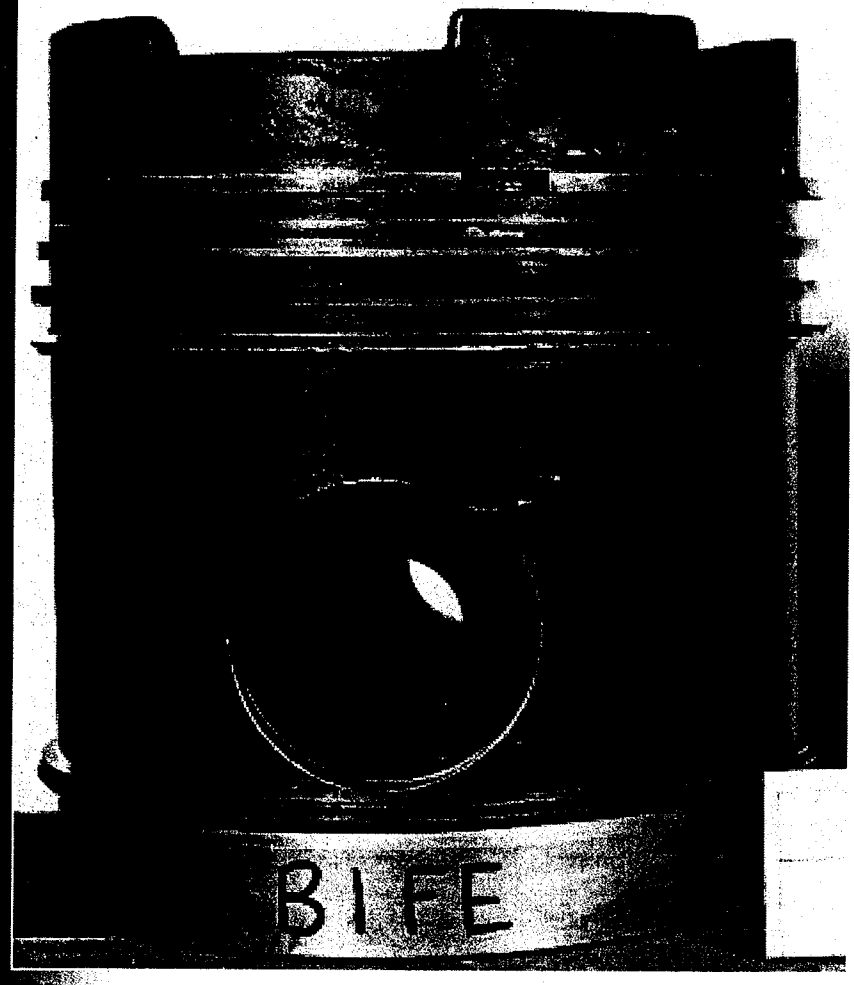
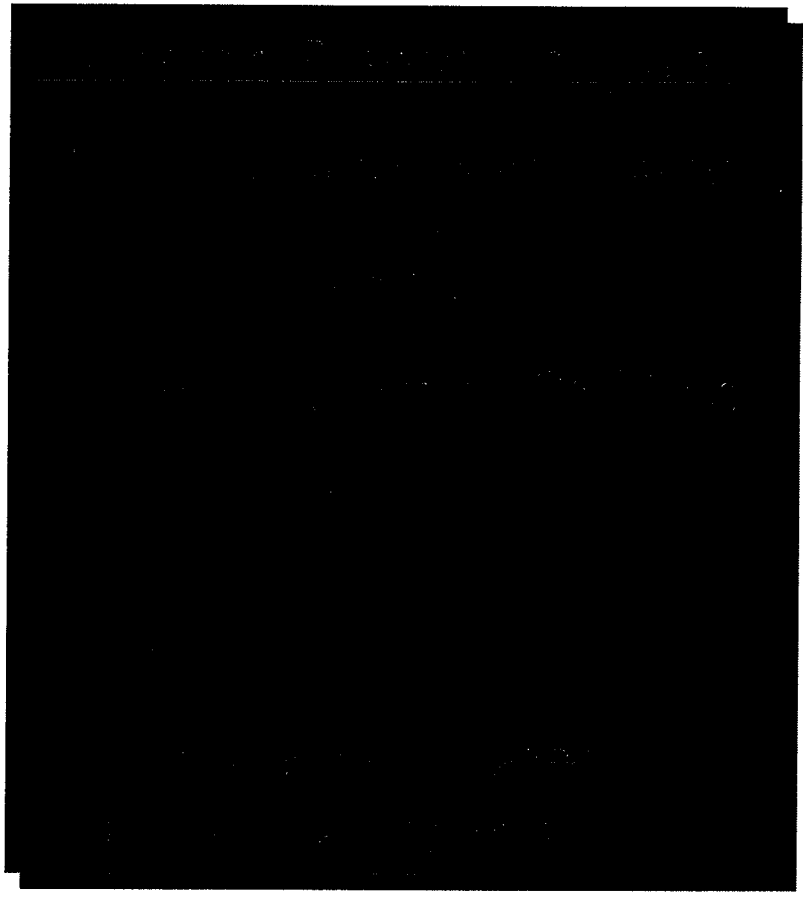
Operational Experience





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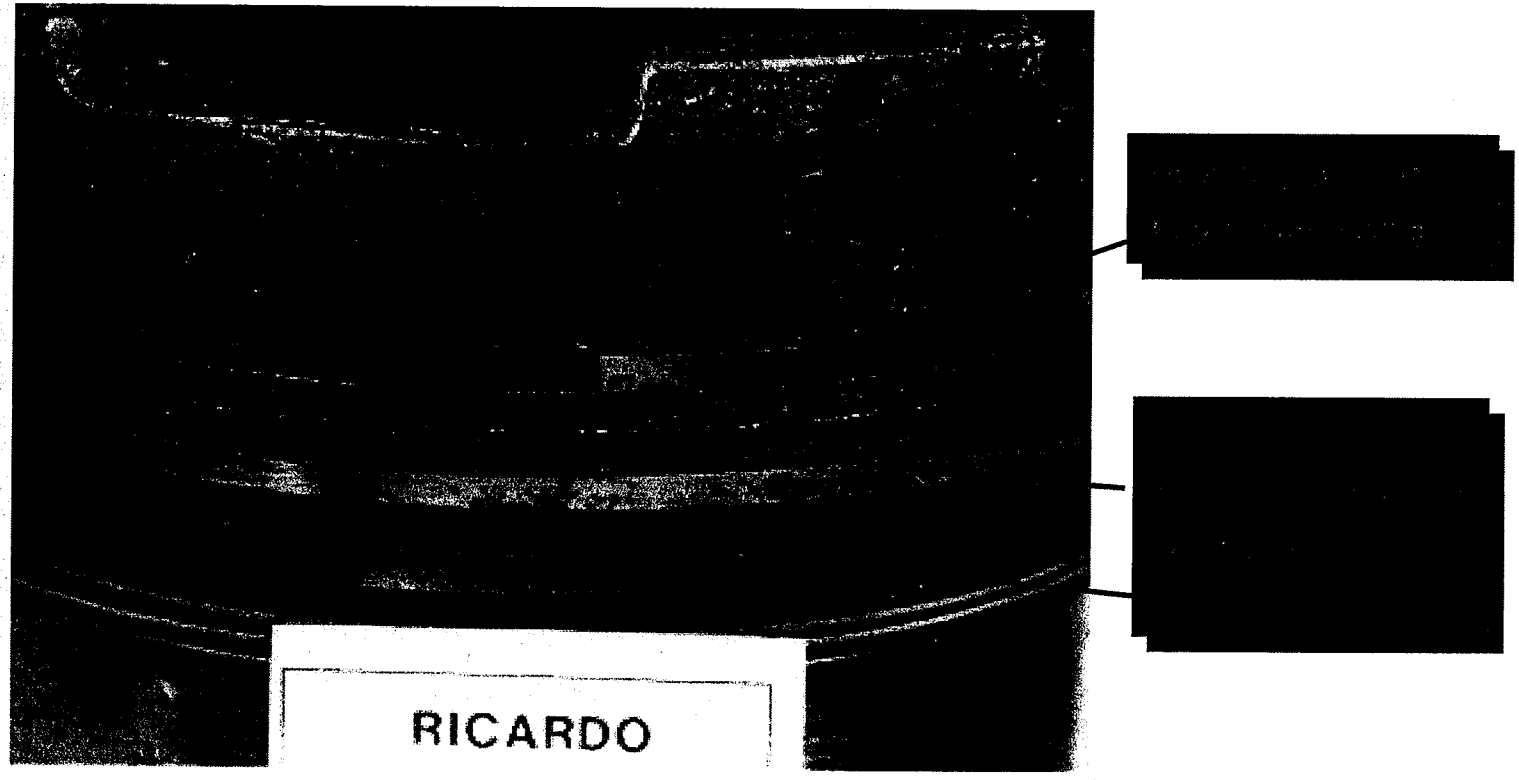
Operational Experience



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Operational Experience

Lacquer Accumulation During Durability Test

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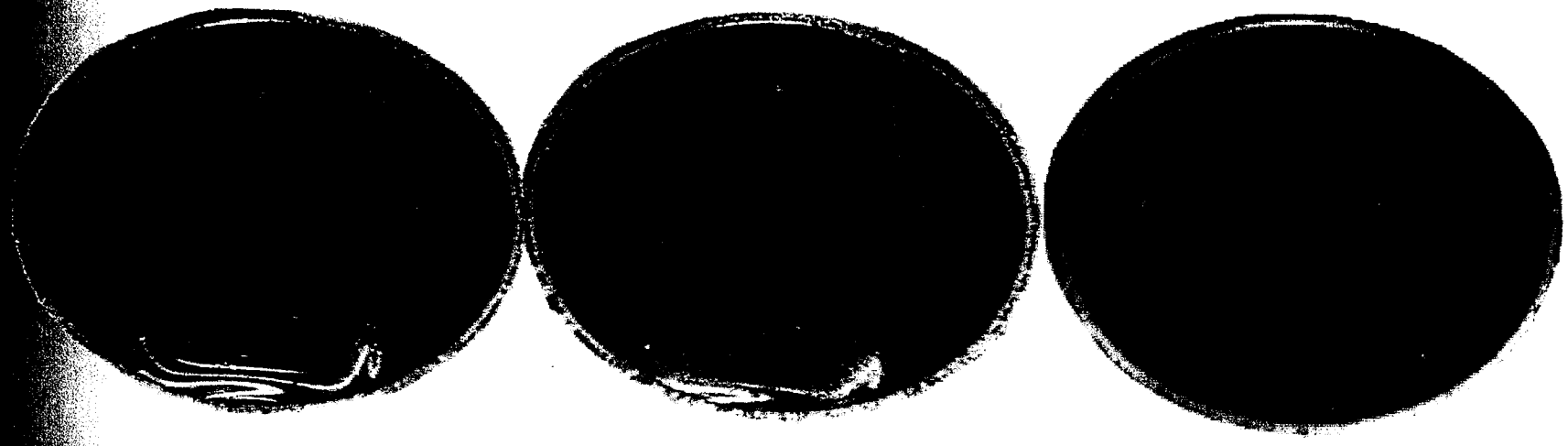
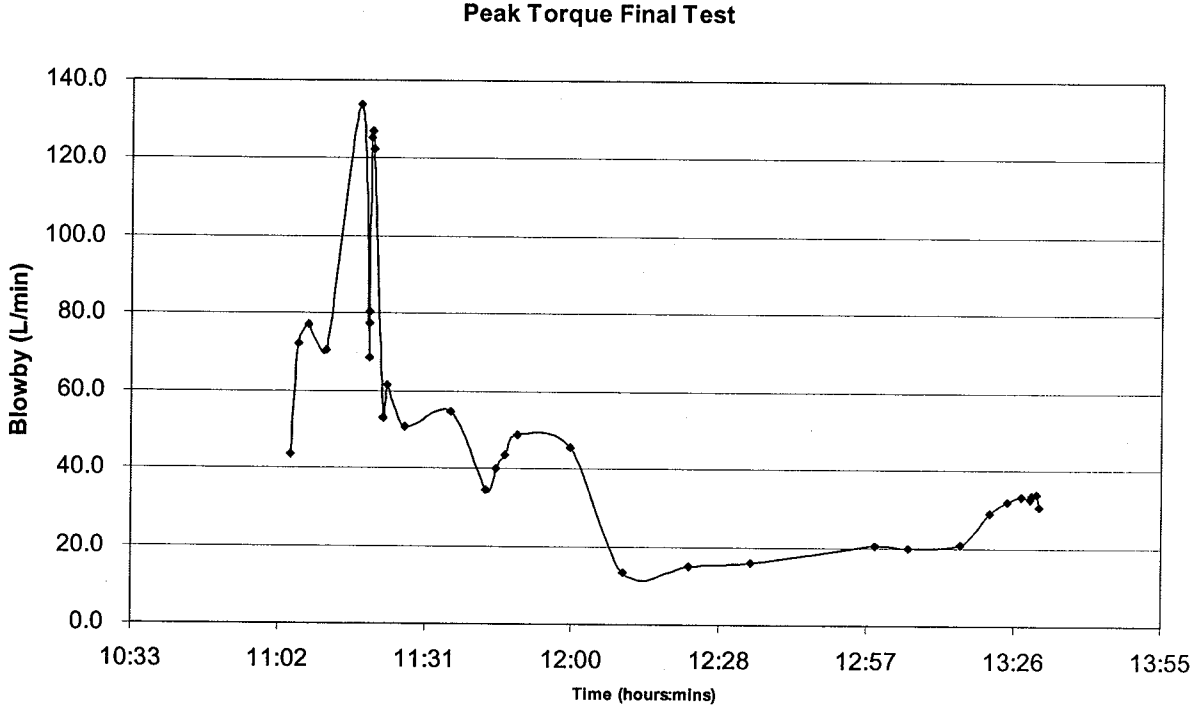


Blow-by Flow

- Temporary spikes in blow-by flow not unusual
- Example shown below from Ricardo tests
- Engine stripped and no fault found



D6 Condition - Conclusions

- Increased crankcase pressure spike was a temporary situation
- No damage to engine components or excessive wear seen
- Engine operated satisfactorily with exchange of one piston/liner (April)
- Cause of crankcase pressure spike was either high load ring-stick or carbon flakes
- Recommendation: Adopt reformulated lube oil to counteract carbon accumulation with low sulfur fuel
- Mechanical condition of liners, pistons, and rings would have sustained 72 hours operation under emergency load

D6 Operability

D6 would have performed its Design Bases safety function from March 15 to April 9, 2001

- In as-found condition, the pistons, liners and rings had 100's of hours of run time left - limiting run time on D6 is 72 hours.
- Elevated crankcase pressure not a problem by itself because:
  - Surveillance done at load >> max event load
  - At 4000 kW (still above event load) elevated crankcase pressure went away

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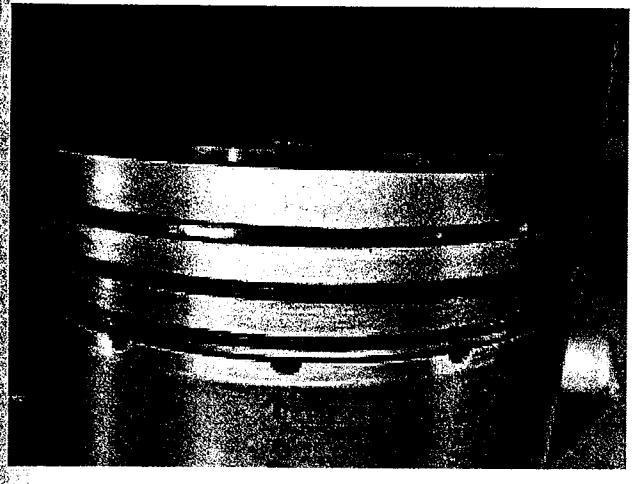
D5 Operability

Basis for D5 operability is similar, except:

- D5 fuel oil sulfur higher than D6
- D5 had less run time
- D5 borescope and investigation of two cylinders indicates good condition
- Physical examination of D5 E1A1:



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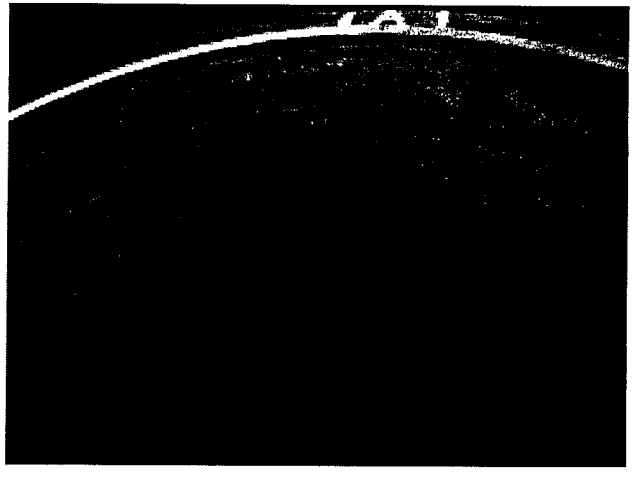

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Safety Significance Evaluation
Deterministic

- Deterministic (defense-in-depth) and Probabilistic Approaches
- Deterministic Approach - Decay Heat Removal Capability (LOOP with D6 degraded):
  - Available: AFW, x-tie MDAFW, PORV (B/F), ECCS.
  - Impact: reliability of power supply for U2 train B ECCS
  - U2 train B ECCS power supply can be restored by x-tie U1 D2 (procedure, training and can be performed in control room)

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Safety Significance Evaluation
Probabilistic

Probabilistic Approach:

- Plant PRA model (level one, at power)
- Initiating Events: a degraded D6 impacts on LOOP accident sequences only
- Sensitivity analysis covers D6 operating conditions from "degraded" to "OOS"
  - D6 failure probability: 0.1, 0.25, 0.5, 0.75, and 1.0
- Sensitivity analysis focuses on CDF (low contribution to LERF)

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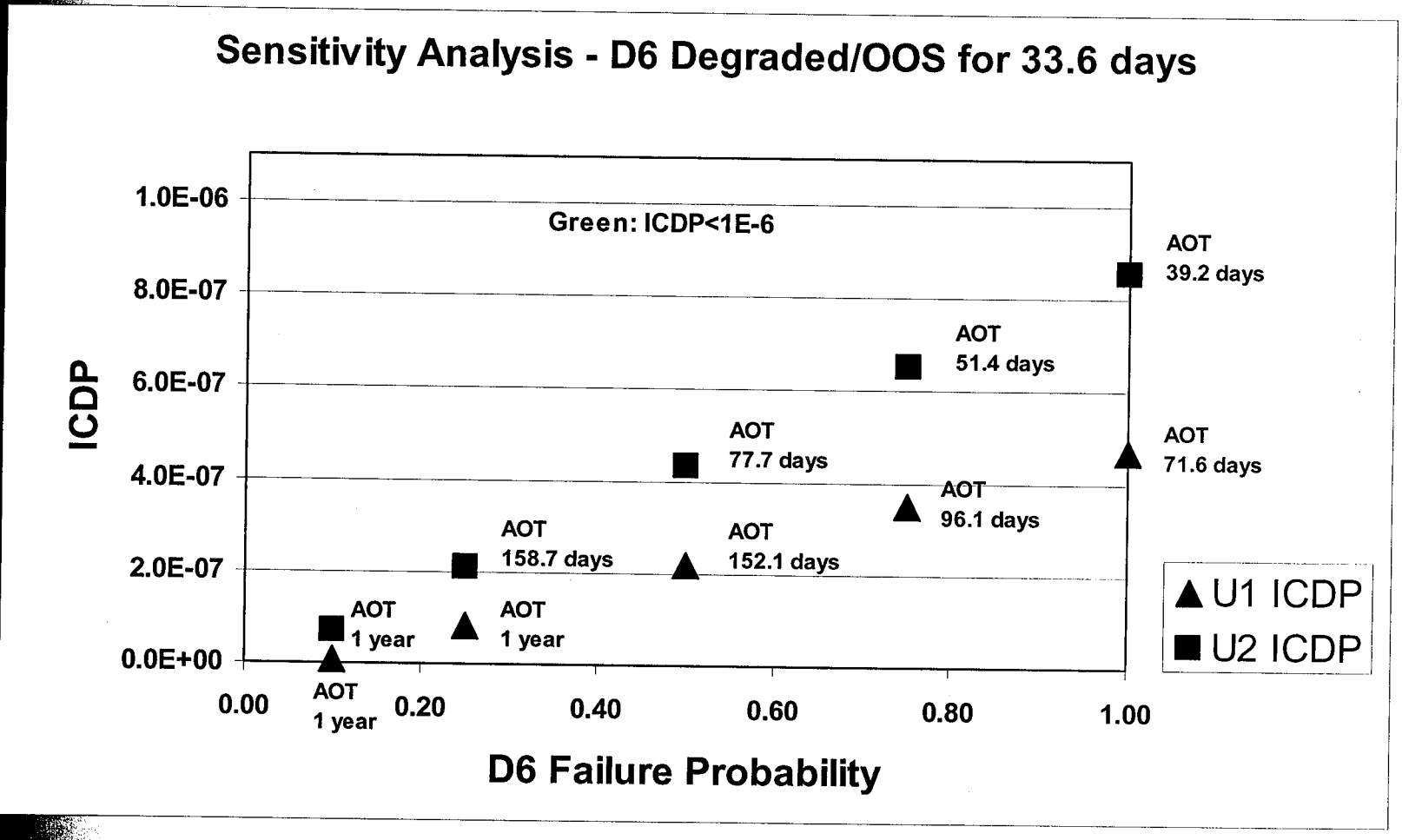
Safety Significance Sensitivity



Follow-up Actions

- Performed Root Cause Evaluation to determine organizational and programmatic causes of our misdiagnoses
- Performed Root Cause Evaluation to determine mechanical cause of the elevated crankcase pressure
- Performed an assessment of the extent of condition (lube oil/fuel oil incompatibility) with respect to other diesels on site

OE Evaluation - Calvert Cliffs

Assessed the Calvert Cliffs OE:

- Short-term assessment:
  - we still run high sulfur fuel oil
  - we do not use synthetic lube oil
- Long-term assessment:
  - monitor crankcase pressure
  - monitor cylinder condition (borescope)
- Close-out after 5-year rebuilds note exceptional condition, but continue to monitor

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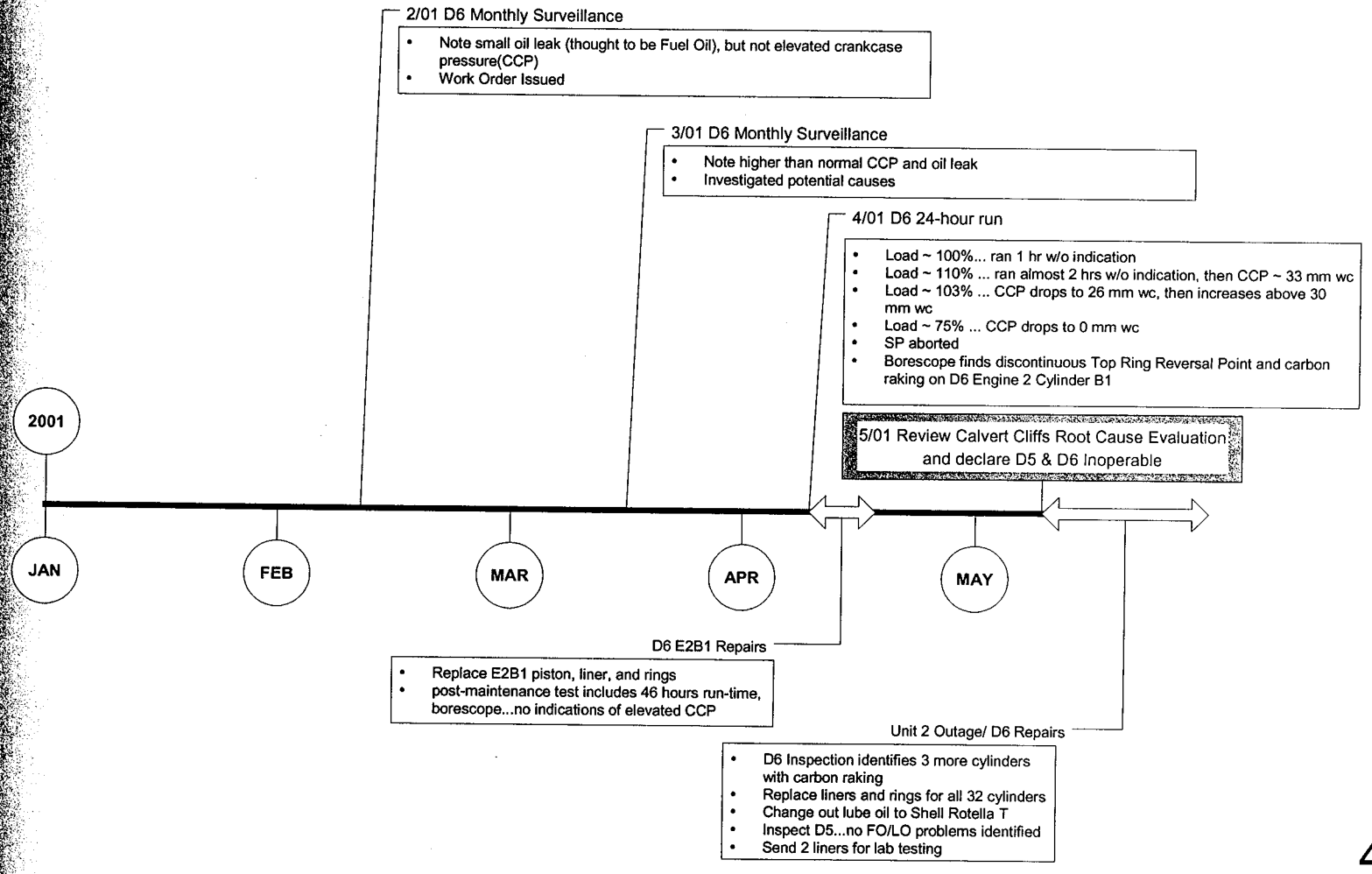
D6 Diagnosis Issues



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Lessons Learned

- Mechanical:
  - D6 degraded but operable
  - D5 condition good
  - TBN of lube oil needs to be compatible with fuel oil sulfur content
- Programmatic:
  - Missed opportunity to prevent this event due to ineffective OE assessment

Actions Taken

For mechanical causes:

- Rebuilt D6; D5 condition was good
- Changed lube oil in D5 and D6
- Established plan to ensure the lube oil change effectively corrects problem
- Assessed impact on past D5/D6 operability
- Awareness of Fuel Sulfur vs. Oil TBN Issue

Actions Taken

For organizational and programmatic causes:

- Revising methods of OE reviews to incorporate need for independent reviews
- Improved availability of SACM technical bulletins
- Revised fuel oil and lube oil specifications
- Improved trending of fuel oil and lube oil data
- Increased Engineering experience on issue

Conclusions

D6 Operability

- Between March 15 and April 9, D6 would have met its Design Bases, therefore, although degraded, D6 was operable
- Safety Significance of this condition is low

Conclusions

Prairie Island Performance

- Missed opportunities for more timely analysis
- Lessons learned are being factored into the Corrective Action Process and OE Process

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Enforcement Action

- We have acknowledged problems with the adequacy of our corrective action and OE programs
  - Safety significance is low
  - Compliance has been restored
  - Inadequacies were not willful
  - Corrective Actions are in progress
- Enforcement should be consistent with a Green Finding - Notice of Violation/Escalated Enforcement not warranted