83

From: Eric Duncan
To: Anne Boland; Bill Bateman; Bruce Boger; Charles Weil; Cynthia Pederson; David Hills; Deborah Jackson; Eric Duncan; Gary Shear; Geoffrey Grant; Geoffrey Wright; George Georgiev; Gregory Cwalina; James Caldwell; James Davis; James Heller; James Wiggins; Jared Heck; Jay Collins; Jim Dyer; John Grobe; John Jandovitz; John Rutkowski; John Tsao; Joseph Petrosino; Mark Satorius; Matthew Mitchell; Melvin Holmberg; Michael Weber; Michele Evans; Patrick Hiland; Richard Smith; Russell Gibbs; Scott Langan; Steven West; Terence Chan; Thomas Wengert; Tom Bilik ; Victor Hall; William Cullen
Date: 03/23/2007 8:52:42 AM
Subject: Slides from Davis-Besse Call

To all,

Please find attached the slides from yesterday's call with FENOC and Exponent.

Eric.

F-49

Mail Envelope Properties (4603DBAA.2B7 : 4 : 3672)

Subject: Slides from Davis-Besse Call
Creation Date 03/23/2007 8:52:42 AM
From: Eric Duncan

Created By: ERD@nrc.gov

Recipients	**Action**	**Date & Time**
nrc.gov		
ch_po.CH_DO	Delivered	03/23/2007 8:52:44 AM
ATB (Anne Boland)	Opened	03/23/2007 12:17:11 PM
CDP1 (Cynthia Pederson)	Opened	03/23/2007 12:42:15 PM
	Deleted	03/23/2007 12:52:11 PM
	Undeleted	03/23/2007 3:08:02 PM
CHW1 (Charles Weil)	Opened	03/26/2007 8:36:04 AM
	Deleted	03/26/2007 8:36:07 AM
DEH (David Hills)	Opened	03/23/2007 9:11:01 AM
ERD (Eric Duncan)	Opened	03/23/2007 8:52:48 AM
GCW (Geoffrey Wright)		
GEG (Geoffrey Grant)		
GLS (Gary Shear)	Replied	03/23/2007 8:52:42 AM
	Opened	03/26/2007 7:38:47 AM
JER7 (John Rutkowski)	Opened	03/23/2007 8:58:39 AM
	Deleted	03/23/2007 8:58:48 AM
JKH (James Heller)	Opened	03/23/2007 3:20:48 PM
JLC1 (James Caldwell)	Opened	03/23/2007 9:16:30 AM
JSJ1 (John Jandovitz)	Opened	03/23/2007 10:46:04 AM

KSW (Steven West)	Opened	03/26/2007 8:04:31 AM
MAS (Mark Satorius)	Opened	03/23/2007 10:12:00 AM
MSH (Melvin Holmberg)	Opened	03/23/2007 8:57:33 AM
RLS4 (Richard Smith)	Opened	03/24/2007 1:32:08 PM
SJL1 (Scott Langan)	Opened	03/23/2007 9:13:46 AM
	Forwarded	03/23/2007 9:14:33 AM
TXB (Tom Bilik)		
nrc.gov		
OWGWPO01.HQGWDO01	Delivered	03/23/2007 8:53:03 AM
BAB2 (Bruce Boger)	Opened	03/23/2007 9:58:44 AM
WHB (Bill Bateman)	Replied	03/23/2007 8:53:03 AM
	Opened	03/26/2007 8:05:59 AM
	Deleted	03/26/2007 8:06:03 AM
nrc.gov		
OWGWPO02.HQGWDO01	Delivered	03/23/2007 8:53:03 AM
GBG (George Georgiev)	Opened	03/23/2007 8:59:37 AM
JAG (John Grobe)	Opened	03/23/2007 9:43:43 AM
	Deleted	03/23/2007 10:16:11 AM
MGE (Michele Evans)	Opened	03/23/2007 9:03:59 AM
RAG1 (Russell Gibbs)		
nrc.gov		
OWGWPO03.HQGWDO01	Delivered	03/23/2007 8:53:03 AM
GCC (Gregory Cwalina)	Opened	03/23/2007 9:12:19 AM
JAD (James Davis)	Replied	03/23/2007 8:53:03

AM		
	Opened	03/23/2007 10:07:52
AM		
JED2 (Jim Dyer)	Opened	03/23/2007 9:01:50
AM		
	Deleted	03/23/2007 9:02:36
AM		
JXC (Jay Collins)	Opened	03/23/2007 9:23:17
AM		
	Forwarded	03/23/2007 9:24:19
AM		
TLC (Terence Chan)	Replied	03/23/2007 8:53:03
AM		
WHC (William Cullen)	Opened	03/23/2007 9:16:06
AM		
	Replied	03/23/2007 9:28:09
AM		
nrc.gov		
OWGWPO04.HQGWDO01	Delivered	03/23/2007 8:53:40
AM		
DAJ1 (Deborah Jackson)	Opened	03/23/2007 10:57:00
AM		
	Deleted	03/23/2007 2:51:51
PM		
	Emptied	03/23/2007 4:00:07
PM		
JKH3 (Jared Heck)	Opened	03/23/2007 8:59:12
AM		
PLH (Patrick Hiland)	Opened	03/23/2007 10:14:24
AM		
VXH (Victor Hall)	Opened	03/23/2007 8:57:46
AM		
nrc.gov		
TWGWPO01.HQGWDO01	Delivered	03/23/2007 8:53:22
AM		
MAM4 (Matthew Mitchell)	Opened	03/26/2007 6:46:22
AM		
	Deleted	03/26/2007 6:46:25
AM		
nrc.gov		
TWGWPO02.HQGWDO01	Delivered	03/23/2007 8:53:03
AM		

JCT (John Tsao)	Opened	03/23/2007 11:26:57 AM
nrc.gov		
TWGWPO03.HQGWDO01	Delivered	03/23/2007 8:53:03 AM
JJP1 (Joseph Petrosino)	Opened	03/23/2007 9:06:14 AM
	Deleted	03/23/2007 9:06:27 AM
nrc.gov		
TWGWPO04.HQGWDO01	Delivered	03/23/2007 8:53:04 AM
JTW1 (James Wiggins)	Opened	03/23/2007 11:45:27 AM
	Deleted	03/23/2007 11:47:16 AM
MFW (Michael Weber)	Opened	03/23/2007 6:19:36 PM
	Deleted	03/23/2007 6:19:41 PM
TJW2 (Thomas Wengert)	Opened	03/23/2007 8:54:03 AM
	Forwarded	03/23/2007 8:55:57 AM

Post Office	Delivered	Route
ch_po.CH_DO	03/23/2007 8:52:44 AM	nrc.gov
OWGWPO01.HQGWDO01	03/23/2007 8:53:03 AM	nrc.gov
OWGWPO02.HQGWDO01	03/23/2007 8:53:03 AM	nrc.gov
OWGWPO03.HQGWDO01	03/23/2007 8:53:03 AM	nrc.gov
OWGWPO04.HQGWDO01	03/23/2007 8:53:40 AM	nrc.gov
TWGWPO01.HQGWDO01	03/23/2007 8:53:22 AM	nrc.gov
TWGWPO02.HQGWDO01	03/23/2007 8:53:03 AM	nrc.gov
TWGWPO03.HQGWDO01	03/23/2007 8:53:03 AM	nrc.gov
TWGWPO04.HQGWDO01	03/23/2007 8:53:04 AM	nrc.gov

Files	Size	Date & Time
MESSAGE	661	03/23/2007 8:52:42 AM
SummarySlides.ppt	1170432	03/23/2007 8:47:40 AM

Options

Auto Delete:	No
Expiration Date:	None

Notify Recipients:	Yes
Priority:	Standard
ReplyRequested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard
To Be Delivered:	Immediate
Status Tracking:	All Information

Key Conclusions of Exponent's December 15, 2006 Report:

"Review & Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event"

Ron Latanision, Dan Bullen, David Taylor

Exponent *Failure Analysis Associates*

March 22, 2007

BN63097.001 F0T0 0307 DB11

Exponent®

Principal Conclusion

- Large undercut wastage cavity at CRDM Nozzle 3 developed between October/November 2001 and February 2002
- Basis:
  - Detailed stress analysis of nozzle/weld at Nozzle 3
  - NRC/ANL 2006 crack growth data for actual DB CRDM Nozzle 3 Alloy 600 material
  - Fracture mechanics studies of crack growth
  - Axial nozzle crack leak rate vs. crack length above weld
  - Weld crack leak rate vs. weld crack dimensions
  - Detailed CFD modeling of thermal hydraulic conditions in developing wastage cavity
  - NRC/ANL 2005 data on wetted molten metaboric acid corrosion of low alloy steel
  - Identification of thermal hydraulic conditions leading to rapid metal removal by mechanical jet action and by corrosion due to wetted molten metaboric acid
  - Final wastage cavity morphology
  - Plant operating history

Exponent®

Cracking/Wastage Timeline

- 12RFO – April/May 2000:
  - Nozzle 3 axial crack has grown to about 0.5 inches above and about 0.8 inches below the weld, total length around 2.5 inches
  - The leak rate from the 0.5 inch axial above-weld crack is estimated at 0.0004 gpm
  - Rapid evaporation to dry-out occurs at this leak rate
  - Sub-surface metal removal at a low rate occurs by mechanical erosion with very little annulus enlargement
  - Total boric acid accumulation from the leakage through this crack at 12RFO is estimated at less than 1 cubic inch
  - This boric acid accumulation may have been visible on the RPV head if there had been no boric acid deposits from leaking CRDM flanges
  - Cleaning of CRDM flange leakage boric acid from the RPV head would have removed any deposits from the leaking crack
  - No annulus enlargement would have been visible even if the RPV head had been clean

Exponent®

Cracking/Wastage Timeline (cont'd)

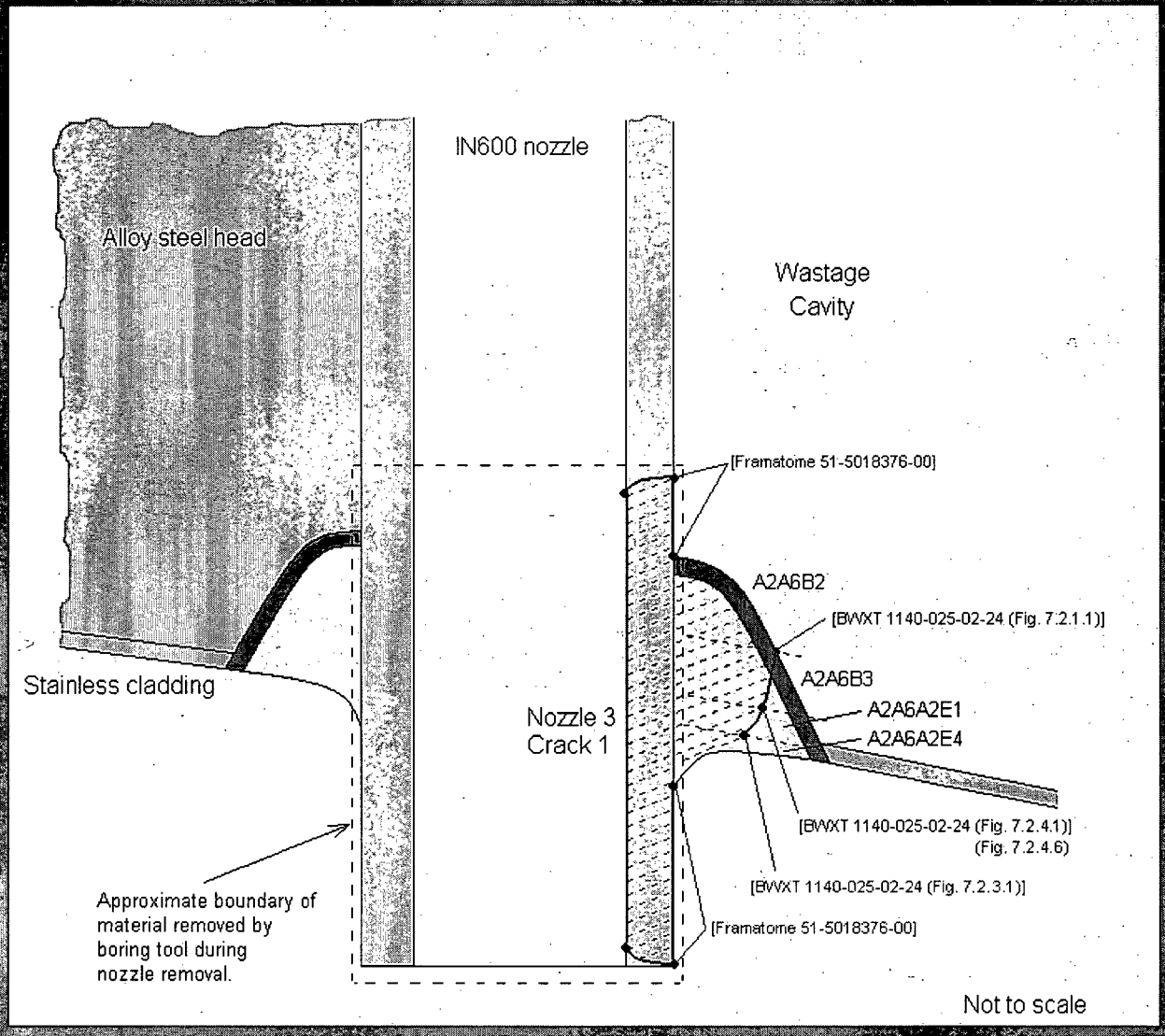
- April/May 2001:
  - Nozzle 3 axial crack has grown to about 1.0 inch above the weld
  - The leak rate from this crack is estimated at 0.01 gpm, similar to the total leakage estimated from all cracks at Nozzle 2 in February 2002
  - Sub-surface metal removal at a low rate by mechanical erosion continues and metal removal has likely caused a wastage cavity to form similar in size to that found at Nozzle 2 in February 2002
  - At this leak rate, moisture penetrates into the bottom of the wastage cavity
  - Metal temperatures remain high enough to result in phase transformation of boric acid to metaboric acid and melting
  - Presence of molten metaboric acid and moisture results in acceleration of metal removal at the bottom of the wastage cavity

Cracking/Wastage Timeline (cont'd)

- May/October 2001:
  - Nozzle 3 axial crack has grown to about 1.1 inches above the weld by October 2001
  - The leak rate from this crack is estimated at 0.02 gpm
  - The upward growing axial nozzle crack and downward growing wastage cavity have intersected
  - Mechanical erosion at the bottom of the wastage cavity increases due to the change in crack jet direction and high velocity jet impingement
  - Moisture penetrates further into the bottom of the wastage cavity due to the higher leak rate
  - Metal temperatures still remain high enough to result in phase transformation of boric acid to metaboric acid and melting
  - Combined action of wetted molten metaboric acid corrosion and mechanical action rapidly removes the 1 inch of remaining low alloy steel covering the weld
  - Undercutting of the wastage cavity likely begins

Exponent®

CRDM Nozzle 3 and Weld Cracking



Exponent®

Cracking/Wastage Timeline (cont'd)

- October/November 2001:
  - Large pre-existing weld crack is uncovered by the rapidly downward growing wastage cavity
  - Leak rate increases to around 0.16 gpm
  - Cavity metal wall temperatures remain higher than phase transformation to and melting temperature of metaboric acid
  - High velocity high flow jet impingement and wetted molten metaboric acid corrosion cause rapid wastage cavity growth, undercutting, and large cavity by February 2002
  - Significant moisture penetrates to the RPV head underneath the existing boric acid deposit from CRDM leakage
  - Head surface metal temperature remains high enough to form molten metaboric acid and presence of moisture from higher leak rate results in top-down wastage of RPV alloy steel evident in final wastage cavity morphology

Exponent®

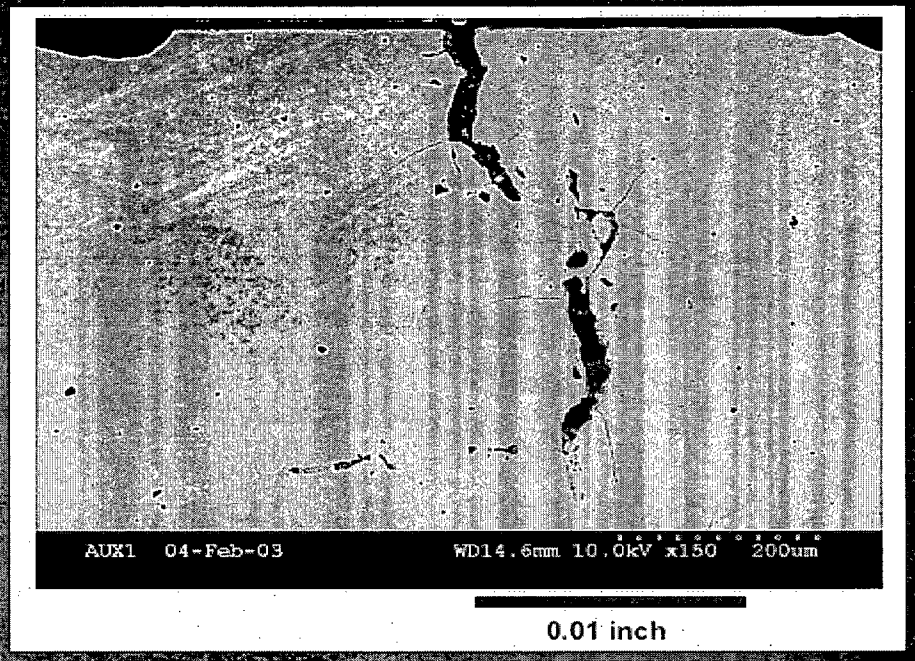
CRDM Nozzle 3 Weld Cracking

- Metallurgical examination of the Nozzle 3 weld revealed a through weld crack
  - Crack extended radially across the weld from the nozzle OD to the RPV head alloy steel
  - Crack was through weld from bottom to top
  - Crack was much wider than the axial crack in Nozzle 3 above the weld

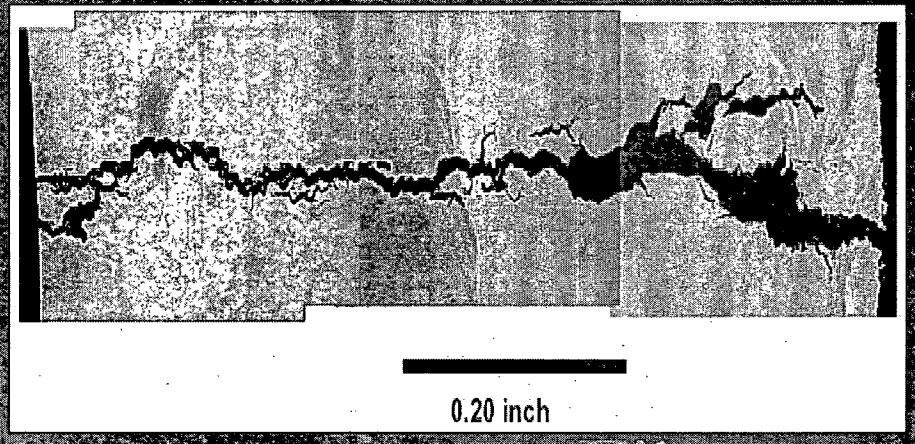
Exponent®

CRDM Nozzle 3 Weld Cracking (cont'd)

- Scanning electron micrograph of CRDM Nozzle 3 crack at 180° location showing typical width of PWSCC nozzle cracks. Maximum crack width is about 20 microns (0.0008 inches)

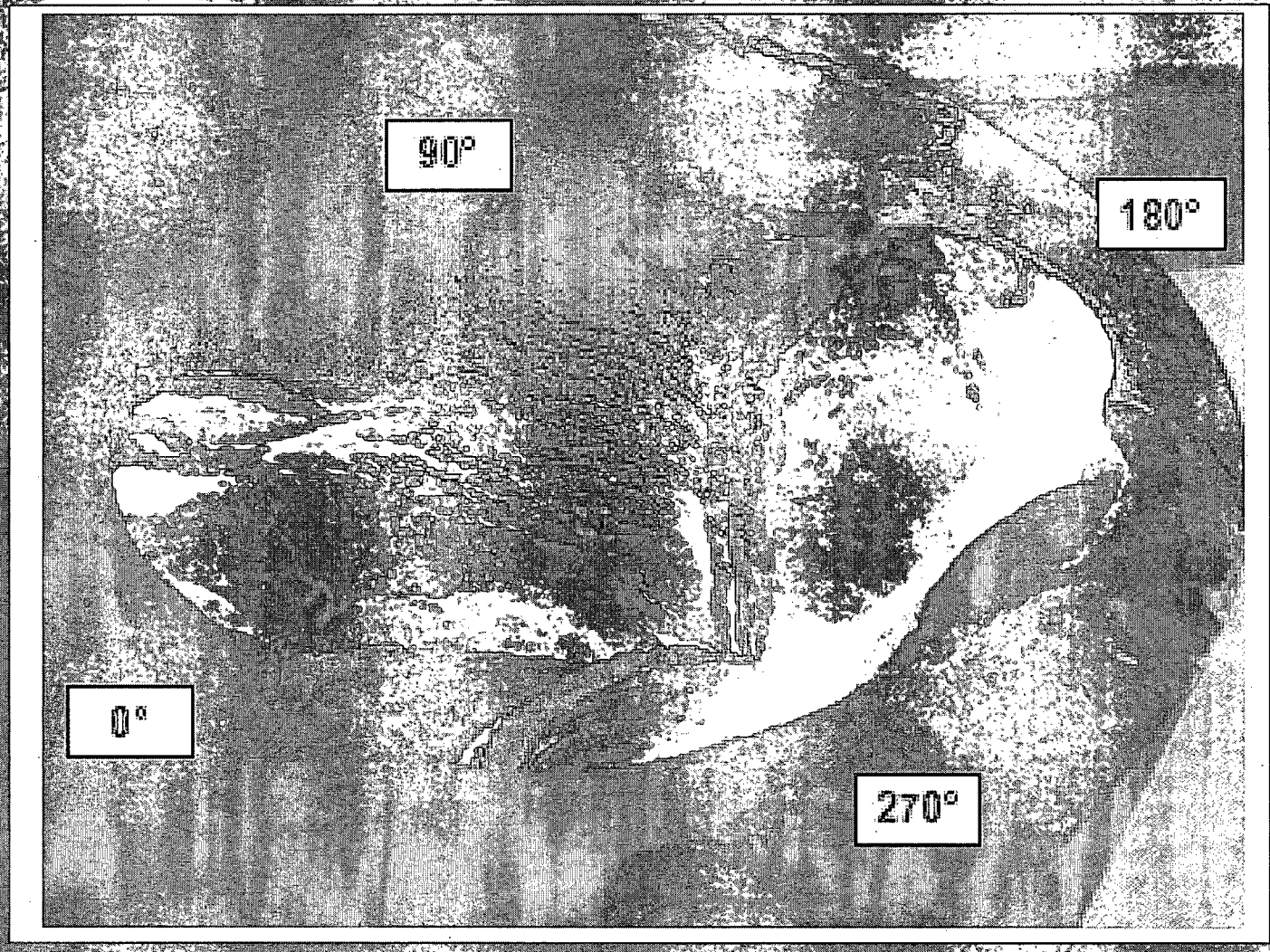


- Optical micrograph of J-groove weld crack in CRDM Nozzle 3 at 10° location. Nominal crack width is about 400 microns (0.016 inches), about 20 times larger than the PWSCC crack in the same nozzle



Exponent®

Final Wastage Cavity at CRDM Nozzle 3



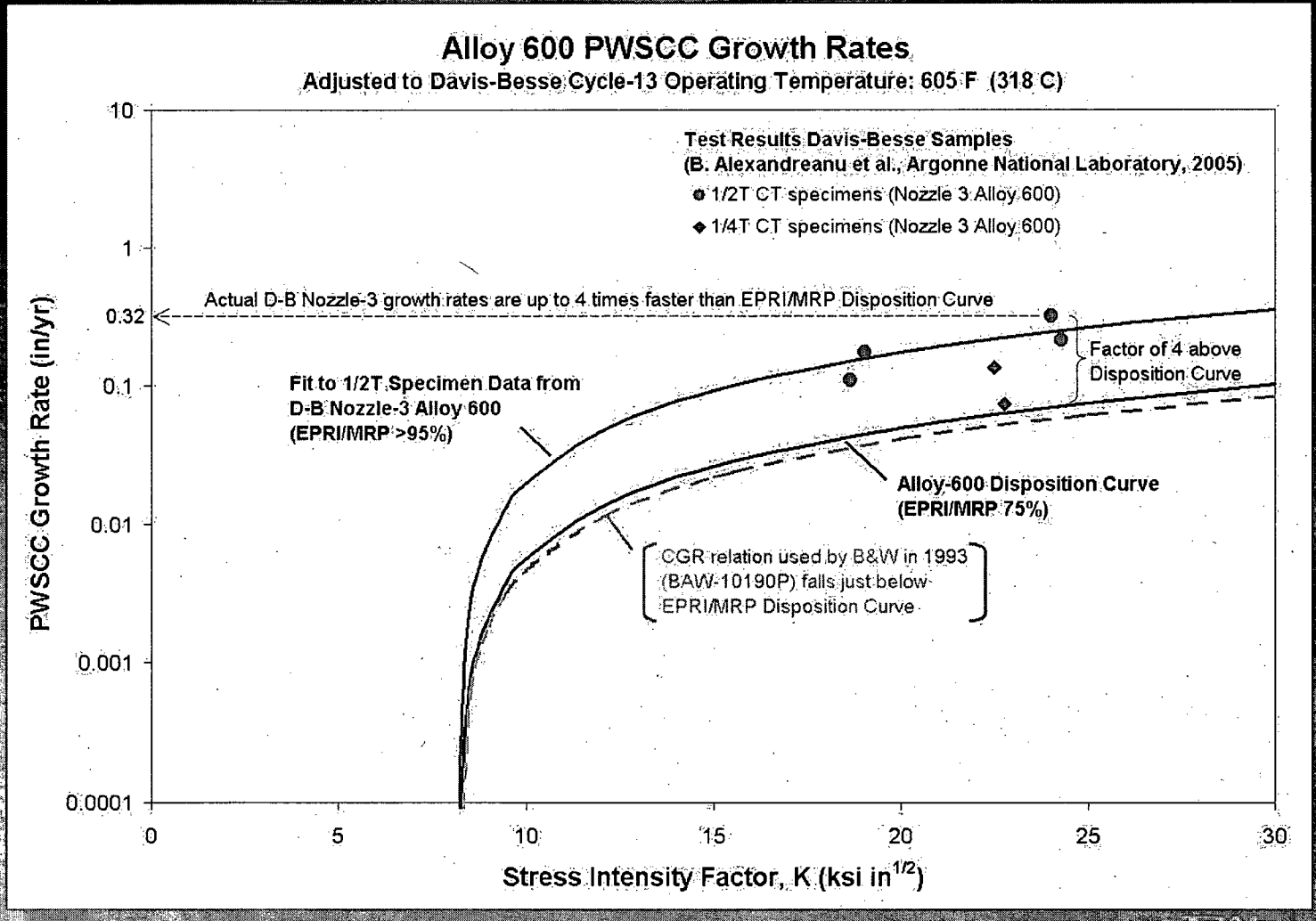
Exponent®

CRDM Nozzle 3 Cracking Behavior

- Nozzle 3 Alloy 600 Heat M3935 was shown to be highly susceptible to PWSCC
- Heat M3935 was used at Davis-Besse in the central 5 nozzles out of 69 total nozzles
- Cracking behavior of CRDM nozzles made from Heat M3935 has been highly variable

Exponent®

CRDM Nozzle 3 Cracking Behavior (cont'd)



Exponent®

CRDM Nozzle 3 Cracking Behavior (cont'd)

- Actual Nozzle 3 Alloy 600 material exhibited very high crack growth rates in NRC/ANL work reported in 2006
- Crack growth rates for Nozzle 3 Alloy 600 material were 3 to 4 times industry expected rates, at 95th percentile of data
- Explains why the Nozzle 3 axial crack grew to 1.23 inches above the weld and 4.08 inches in total length
- Led to conclusion that cracking timeline for CRDM Nozzle 3 was much shorter than previously thought

Exponent®