1 of 2

PFBC HGU Test Facility
Technical Progress Report

Second Quarter, CY 1993

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I. INTRODUCTION

This is the fifteenth Technical Progress Report submitted to the Department of Energy (DOE) in connection with the cooperative agreement between the DOE and Ohio Power Company for the Tidd PFBC Hot Gas Clean Up Test Facility. This report covers the period of work completed during the Second Quarter of CY 1993.

During this quarter, Tidd Plant remained out of service while the gas turbine was being repaired. The unit was restarted on June 30, 1993, and the results of the testing will be covered in the next quarterly report.

II. WORK ACCOMPLISHED DURING THE REPORTING PERIOD

2.1 Detailed Design-Engineering

The expansion joint heaters and control system were installed and tested this quarter. The system consists of 8 bellows heaters and 14 heaters on the adjacent piping. During initial testing, 11 of the 14 pipe and heaters failed due to overheating caused by control and installation problems. The control scheme was modified and new heaters were installed from an alternate supplier. The 8 bellows heaters were not damaged and are still in service.

During test operation, the heaters worked satisfactorily; however, in several areas adjacent to flanges, etc., additional insulation will be required to minimize heat losses and thus allow better control of temperature.

A pneumatically powered vibrator was installed in the APF manway nozzle to vibrate the hopper liner during back pulsing. This should eliminate any build-up on the pipes of the hopper. The vibrator was test operated for 50 hours after installation.

Two half capacity diesel driven back-up pulse air compressors were rented and installed at Tidd. Piping was installed from the compressors to the existing compressor air dryer. A removable spool piece was fabricated to allow quick tie-

in the back-up compressors if needed. The compressors were successfully test run during this quarter.

Installation of an emergency ash removal system was completed this quarter. The system enables ash to be removed via a line connected to the pipe between the outlet of the screw cooler and the inlet of the lockhopper system.

Installation of the spoiling air line, valves, and metering orifice to the primary cyclone was completed this quarter. This system may be used to detune the cyclone to increase ash loading to the APF.

Numerous revisions were made to the Net 90 instrumentation and control system and the POPS data trending system to enhance system control and performance monitoring capability.

We presented two papers at the DOE Contractors' Meeting on June 28-30, 1993.

We participated in the DOE sponsored Ceramic Filter Information Interchange Program at Penn State University on May 17 - 18, 1993.

2.3 Westinghouse Engineering & Design

See Appendix 1.

3.0 Test Plan

Battelle installed ash sampling isolation valves and probe holding chambers on the hot gas piping system.

Proposals for Hazardous Air Pollutants (HAP) testing at Tidd were evaluated during this quarter. Radian Corporation was selected for the work. A contract was prepared and should be signed in the third quarter.

APPENDIX 1

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ADVANCED PARTICLE FILTER

Technical Progress Report No. 12
April through June 1993

Prepared by

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Pittsburgh, Pennsylvania

For

American Electric Power Service Corporation
Columbus, Ohio

AEPSC Contract No. C8014

94 MBG-2 P11 1:38

TIDD ADVANCED PARTICLE FILTER

Site Hardware Installation

Materials were procured and a pneumatic liner vibration device was fabricated to enhance ash discharge from the APF hopper. The design and assembly of this device are described per Westinghouse drawings included in Appendix A. The vibrator has now been installed.

For all bottom plenum candles and for select surveillance candles from top and middle plenums:

- (1) New top donut gaskets were installed. These gaskets have a geometry designed to minimize the potential for gasket slippage during pulsing.
- (2) New filter holder rings were installed. These rings have a collar on their inside diameter to ensure containment of the top donut gasket.

It was noted during this installation that the filter holders were somewhat winged outward on the bottom plenums. A summary of the findings follows:

ASSESSMENT OF FILTER HOLDER OUT OF PLUMB

	+/- deg.
Estimated as-manufactured out of plumb	0.5
Estimated out of plumb after service (maximum)	2.0

Approximate number of candles out of plumb by more than one degree: 12 per bottom plenum

All bottom filter holders were corrected to less than +/- 1.0 degree by mechanical straightening.

The clusters and retrofitted APF vessel dome were reinstalled. The PFBC was restarted June 29, 1993.

Site Testing

The APF liner vibrator was tested following installation in the vessel manway. Sequencing the exhaust solenoid prior to the supply solenoid was effective in actuating the vibrator. Displacement of the liner measured 0.006 inches during this cold performance test.

Pulse solenoid valves, which were reworked by Atkomatic (revised cylinder design) and reinstalled by site personnel, were performance tested. No cylinder galling or detectable wear was evident after 250 pulses.

An accelerometer test was performed on a candle filter in place in the APF vessel with cold pulsing. Results are described in Appendix B.

Calculations

The at service temperature of the APF liner vibrator was estimated analytically. A summary of the calculations is included in Appendix C. The vibrator was assessed to run relatively cool, approximately 243 °F - even without the cooling effect of a constant air purge between pulsing and significant air flow during pulsing.

The vibrator was inspected after approximately 80 hours of service with the APF vessel at elevated temperature. Although vibrator operational problems have been encountered, the vibrator was assessed to have run at temperatures less than 400 °F.

Meetings

A review meeting was held at the Tidd site on May 25, 1993 with representation from DOE, AEP and Westinghouse. All APF retrofit work was discussed.

Other

The Tidd APF startup procedure and failure mode response plans were reviewed. Comments regarding the startup procedure were discussed with AEP. A revised failure mode response plan was submitted to AEP. This document may be found in Appendix D.

KARHULA PARTICLE FILTER TESTING

1.0 General Hardware Changes

Reassembly of the filter was completed in April, 1993. The significant changes include:

- (1) Replacement of all top gaskets
- (2) Replacement of all filter holder rings with a built-in gasket containment collar
- (3) Inclusion of solid spacers between filter holder bottom castings and main filter holder housings to rigidize the assembly
- (4) Elimination (blanking off) of the top plenum inner row candle locations (15) to eliminate nearest-neighbor bridge points
- (5) Inclusion of regenerator (heat exchanger) devices in each filter holder housing to minimize possible back pulse-induced thermal stress effects
- (6) Addition of baffle (deflection plate) near top of shroud.

2.0 Performance

A report summarizing performance during May and June 1993 has been submitted separately by Ahlstrom Pyropower (June 24, 1993). Significant problems include:

- (1) Weld cracking of bottom plenum pulse tube
- (2) A single candle breakage near its bottom
- (3) Further cracking of pulse tubes (not welds)
- (4) Ten broken bottom plenum candle filters

3.0 Analysis and Corrective Actions

Inspection by Ahlstrom has concluded that breakage of the single candle may be attributed to the clamping method used for the tension test. Refinement of this clamp should avoid such problems in the future.

It is conjectured that pulse tube cracking may be due to thermal shock/low cycle fatigue. Confirmation is awaiting analysis of a pulse pipe section upon receipt of a sample from Ahlstrom. Corrective actions under consideration include use of advanced superalloy materials for the pulse pipes (if available) or use of a thermal barrier inserted within the pulse pipe as an internal sleeve.

The cause of the ten candle failure is still under investigation. The shroud was noted to be deformed at its bottom such that a large amount of flow could have been projected near to this group of failed candles. It is possible that extreme, concentrated flow in such an area unprotected by the shroud could have caused the breakage. One corrective action under consideration involves extending the shroud to protect these lowermost candles. Flow within the Ahlstrom vessel is being studied analytically and modeled experimentally to optimize shrouding options.

MATERIAL SURVEILLANCE

Candle filter material surveillance during this report period focused on characterizing candles removed from the Karhula test facility that were exposed during the various test runs and correlating this information with alternate test programs. This information is provided in Appendix E. Major findings are:

1. Loss of bulk material strength (MOR) of the alumina/mullite on both the candle OD and ID occurred within the first 50 to 100 hours of exposure.
2. Greater reduction in strength resulted along the ID surface, perhaps indicative of thermal fatigue effect during pulse cleaning.
3. Following the initial conditioning of the material, it appears the material strength stabilized for the remaining 450 hours of operation.
4. Review of the Grimethorpe and KRW materials analysis suggest the clay bonded SiC candles exhibit similar bulk material strength behavior. Analysis of the clay bonded SiC candles exposed during the initial 500 hour operation at Tidd are ongoing.

APPENDIX A

Drawings of Vibrator for APF Hopper

APPENDIX B

APF Accelerometer Test Results

Accelerometers were fastened to the bottom and side of a "vee block" which was strapped to the end of a filter candle, BB17 in the AEP-Tidd plant filter chamber. One accelerometer read axial extension and the other, circumferential acceleration.

Experiments were performed by "bumping" the candle with a plastic covered tool and by recording acceleration during back pulsing at various pressure levels. The data attached are referred to by page numbers in the upper right hand corner.

The bump tests results are covered in pages A-1 to A-12. We should have bumped the candle continuously during the data collection period rather than only once. Therefore, there is insufficient data to obtain significant spectral data. Figure A-12 however does indicate the presence of a spurious 60 Hz component which must be neglected in all spectral analysis.

The remaining pages are either accelerometer outputs or spectral analyses of the accelerometer data. The tests are numbered with four letters and a number, e.g., BMTA 300 PSI. The first three letters are the order in which the plenums are pulsed, such as bottom, middle, top with the fourth letter either an A or an R corresponding to axial or radial accelerations respectively. The number following these letters is the pulse pressure.

The circumferential placement of the "radial" transducer results in a whirl such as is shown on A-4 where the initial impulse occurs as the vertical dashed line followed by its movement in and out of the circumferential plane. In this view we could increase the maximum accelerometers readings by about thirty percent.

The actual maximum accelerometer outputs are shown in Figure 1 plotted against pulse cleaning tank pressures and it is apparent the reaction forces on the candles increase with increasing pulse pressures.

Calculations indicate that there is a reaction force at the candle mount yielding a tensile bending stress of about 200 psi/g, well within the strength limits of the alumina/mullite. Analysis of this data is continuing.

Figure 1 -
Maximum Accelerometer Readout versus Pulse Pressure

Y=-1.2257 G'S

X=1.4225 Sec G'S

Y_a=1.03476 G'S

CAP TIM BUF

1.6

400

m

/Div

Real

G'S

-1.6

* Fxd Y

0.0

Sec

TEST 1 AXIAL BUMP

4.44

X=1.422 S $\Delta X=40.0\text{ms}$
 Ya=1.03476 $\Delta Ya=850.3\text{m}$

CAP TIM REC

X=207.03 HZ
Yb=-38.4 dBG'Srms

Y=-651.64mG.S

X=1.6812 Sec.S
Ya=642.982mG.S

CAP TIM BUF

1.6

400

m

/Div

Real

G.S

-1.6

*

Fxd Y 0.0

Sec

TEST 2 RADIAL BUMP

6.19

X=1.446 S $\Delta X=93.75\text{ms}$
Ya=401.985m $\Delta Ya=95.55\text{m}$

CAP TIM BUF
1.26

315
m
/Div

Real

G'S

-1.26

FxdY 1.35 Sec TEST 2 RADIAL BUMP 1.6

Y=-967.76mg'S

X=915.0mSec
Ya=990.911mg'S

CAP TIM BUF

1.6

400

m

/Div

Real

G'S

-1.6

*

Y 0.0

Sec

TEST 3 RADIAL BUMP

2.7

X=880.0mS ΔX=35.0mS
Ya=937.47m ΔYa=53.44m

CAP TIM BUF

1.26

315
m
/Div

Real

G'S

-1.26

FxdY 845m

Sec

TEST 3 RADIAL BUMP

966m

X=3.6788 Sec
Ya=463.786mG.S
CAP TIM BUF
1.6

400
m
/Div

Real

G.S

-1.6
Fxd Y 0.0

Sec

G

TEST 4 AXIAL BUMP

6.73

X=3.679 S $\Delta X=35.0\text{ms}$
Ya=463.786m $\Delta Ya=225.4\text{m}$

CAP TIM BUF
1.26

315
m
/Div

Real

G'S

-1.26

FxdY 3.66

Sec

TEST 4 AXIAL BUMP

3.82

X=239.84 Hz
Yb=-83.383 dBG'Srms

X=3.0062 Sec.S
Ya=-181.91mg.S

OV1

CAP TIM BUF

800m

200m

/Div

Real

G.S

--800m

FxdXY 2.67

Sec

BMTR 200 PSI

5.23

X=2.413 Sec

Y=139.654mG's

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m*

Fxd Y 0.0

Sec

BMTA 200 PSI

25.6

OV1

A-14

X=2.3812 Sec.S
Y=-116.06mg.S

CAP TIM BUF*

OV1

800 m

200 m

/Div

Real

G'S

-800 m

FxdXY 2.16

Sec

BMTA 200 PSI

4.74

A-15

X=2.8925 Sec
Ya=167.964mg's

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m*

Fxd Y 0.0

Sec

BMTR 200 PSI

25.6

OV1

A-16

X=2.2062 Sec.S
Ya=212.378mg.S

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G.S

-800 m*

Fxd Y 0.0

Sec

BMTR 300 PSI

25.6

A-17

X=1.42 Sec
Ya=i33.499mg's

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G.S

-800 m*

Fxd Y 0.0

Sec

BMTA 300 PSI

25.6

A-12

X=1.2725 Sec.S
Ya=131.602mG.S

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G.S

-800 m

Fxd Y 0.0

Sec

MBTA 300 PSI

25.6

X=2.1588 Sec
Ya=81.8536mg's

CAP TIM BUF

OV1

800 m

200 m

/Div

Real

G'S

-800 m*

Fxd Y 0.0

Sec

MBTR 300 PSI

25.6

X=23.842 Sec

Y=84.1102mG

CAP TIM BUF

800

m

200

m

/Div

Real

G'S

-800

m*

Fxd Y 0.0

Sec

TMBA 300 PSI

25.6

OV1

A-20

X=24.798 Sec
Ya=103.394mg's

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G's

-800 m*

Fxd Y 0.0

Sec

TMBR 300 PSI

25.6

0

A-21

X=1.9588 Sec.S
Y=-365.88mG.S

CAP TIM BUF

OV1

*

800 m

200 m

/Div

Real

G.S

-800 m

ExdXY 1.77

Sec

4.35

BMTR 400 PSI

X=1.9937 Sec's
Y=296.54mG's
CAP TIM BUF

OV1

X=2.0963 Sec.s
Y=210.583mg.s

CAP TIM BUF

OV1

800 m

200 m

/Div

Real

G's

-800 m*

Y 0.0

Sec

BMTA 400 PSI

25.6

X=2.18 Sec
Y=-194.38mG.S

OV1

CAP TIM BUF

800 M

200 M

/Div

Real

G'S

-800 M

FxdY 1.85

Sec

BMTA 400 PSI

4.41

X=2.335 Sec
Y=-356.96mg.S

OV1

CAP TIM BUF

800m

200m

/Div

Real

G.S

-800m

FxdXY 1.95

Sec

BMTR 500 PSI

4.52

*

A-26

X=2.7787 Sec
Ya=199.659mg.s

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m*

Fxd Y 0.0

Sec

BMTA 500 PSI

25.6

X=2.7238 Sec
Y_a=-185.66mg.s

OV1

CAP TIM* BUF

800 m

200 m

/Div

Real

G.S

-800 m

FxdXY 2.4

Sec

BMTA 500 PSI

5.1

X=2.2775 Sec.s
Ya=311.823mg.s

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m*

Fxd Y 0.0

Sec

BMTR 500 PSI

25.6

X=24.12 Sec
Ya=266.076mg.S

CAP TIM BUF

800 m

200 m

/Div

Real

G.S

-800 m*

Fxd Y 0.0

Sec

MBTR 500 PSI

25.6

OV1

A-21

X=24.0387 Sec
Ya=-350.6mG'S

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m

FxdXY 23.6

Sec

MBTR 500 PSI

25.6

X=24.201 Sec.S
Y=310.387mG.S

CAP TIM BUF

OV1

X=24.2675 Sec
Ya=-174.27mG's

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G's

-800 m

FxdXY

23.6

Sec

MBTA 500 PSI

25.6

A-35

X=3.165 Sec
Y=136.525mg's

CAP TIM BUF

Ov1

A-36

X=3.1675 Sec.S
Ya=-127.55mG.S

CAP TIM BUF

800m

200m
/Div

Real

G'S

-800m

FxdY

2.56

Sec

TMBA 500 PSI

5.18

OV1

X=2.8525 Sec
Ya=128.422mg.S

CAP TIM BUF

800

m

200

m

/Div

Real

G.S

-800

m*

Fxd Y

0.0

Sec

TMBR 500 PSI

25.6

OV1

A-38

X=2.8162 Sec
Ya=-110.52mg.s

OV1

CAP TIM BUF
800

200

/Div

Real

G'S

-800

FxdXY 2.55

Sec

TMBR 500 PSI

5.06

X=2.3425 Sec.S
Ya=-402.14mg.S

OV1

CAP TIM BUF

*

800m

200m

/Div

Real

G'S

-800m

FxdXY 2.03

Sec

BMTR 600 PSI

4.6

A-40

X=2.3125 Sec.S
Ya=289.41mg.S

OV1

CAP TIM BUF

800

m

200

m

/Div

Real

G.S

-800

m*

Fxd Y 0.0

Sec

BMTR 600 PSI

25.6

A-42

X=2.5512 Sec's
Y_a=-313.0mg's

Ov1

CAP TIM* BUF

800m

200m

/Div

Real

G's

-800m

FxdY

2.43

Sec

BMTA 600 PSI

4.99

X=2.5512 Sec's
Y=-313.0 MG'S

OV1

CAP TIM BUF

800 M

200 M

/Div

Real

G'S

-800 M

FxdXY 2.33

Sec

BMTA 600 PSI

7.44

A-44

X=2.5525 Sec.
Y=275.512 MG.S

CAP TIM BUF

OV1

A-45

X=1.8875 Sec's
Ya=-316.59mg's

OV1

CAP TIM BUF

800 m

200 m

/Div

Real

G'S

-800 m

FxdXY 1.52

Sec

~.25780~

BMTA 700 PSI

4.09

A-40

Y=350.06mG'S

OV1

X=1.8825 Sec'S
Ya=378.086mG'S

CAP TIM BUF

800 m

200 m

/Div

0

Real

G'S

-800 m

Exp Y 0.0

Sec

BMTA 700 PSI

25.6

A-49

X=9.9587 Sec
Y_a=-431.32mg.s

CAP TIM BUF
800 m

200 m
/Div

Real

G'S

-800 m
FxdXY 9.5

Sec

←.51 sec→

BMTA 700 PSI

14.6

OV1

$\frac{9.5}{50.5}$

2.5 sec

A-50

X=2.2612 Sec.S
Y=-472.09mg.S

OV 1

CAP TIM BUF

800 m

200 m

/Div

Real

G.S

-800 m

ExdXY

1.91

Sec

← 250 →

BMTR 700 PSI

4.47

$$\frac{1.3}{3(250)} = 10^{-9}$$

X=2.2413 Sec'S
Y=704.116MG'S

CAP TIM BUF

OV1

APPENDIX C

Estimates of Temperatures Within the Tidd Ash Vibrator Assembly R. M. Roidt

Estimates of Temperatures within the Tidd Ash Vibrator Assembly - M. Roidt

We consider the vibrator assembly sketched below:

Item 1 is the vibrator assembly connector; 2 is the vibrator itself; 3 is an air space surrounding the vibrator, and 4 is the entrance plenum.

We assume negligible radial heat flow from the connector through the insulation. The temperature gradient will be linear with a heat flow, Q_1 , given by

$$Q_1 = -kA_c \frac{dT}{dx} = kA_c \left(\frac{T_o - T_i}{L} \right) \quad (1)$$

where

L = length of the connector, ft

A_c = cross-sectional area of the connector, ft²

k = thermal conductivity of the connector, Btu/hr·ft²·°F

T_o = temperature of ash hopper

T_i = temperature of the vibrator

The heat received by the vibrator will be passed on to the air by convection and to the walls of the entrance plenum by radiation where

$$Q_{\text{convection}} = h A_v (T_i - T_{ai})$$

$$Q_{\text{radiation}} = \epsilon \sigma (T_i^4 - T_w^4)$$

$$\text{and } Q_2 = h A_v (T_i - T_{ai}) + \epsilon \sigma (T_i^4 - T_w^4) \quad (2)$$

where

h = free convection heat transfer coefficient, Btu/ft²·hr

A_v = surface area of the vibrator, ft²

T_{ai} = air temperature inside plenum, °F

ϵ = surface emissivity of vibration

σ = Stephen-Boltzmann constant, $1.714 \times 10^{-8} \frac{\text{Btu}}{\text{hr ft}^2 \text{°F}}$

The total heat transfer to the plenum shell consists of the radiation component of Eqn. (2) plus a convective term so that

$$Q_3 = hA_{tot}(T_{ai} - T_w) + Q_{radiation} \quad (3)$$

where

T_w = plenum shell temperature, °F
 A_{tot} = total area of the plenum shell

The total heat received by the plenum wall is radiated and convected away to the outside.

$$Q_4 = hA_{tot}(T_w - T_{ao}) + A_{tot}\epsilon\sigma(T_w^4 - T_{ao}^4) \quad (4)$$

The solution to Eqns (1), (2), (3), and (4), is iterative.

A computational loop is set up to evaluate Eqn (1) for all possible values of T_i . For each value of T_i , a value for the plenum wall temperature is found which makes $Q_4 = Q_1$. With T_i and T_w "known" Eqns (3) and (1) may be solved for T_{ai} . This value of T_{ai} is substituted into Eqn (3) to calculate Q_3 . New values of T_i are assumed until

$$Q_1 = Q_2 = Q_3 = Q_4$$

The numerical values of the various parameters are

estimated in an attachment. With those numbers we find

assuming $I = 0.2$

$$T_1 = 454^\circ\text{F}$$

$$T_{2i} = 158.5^\circ\text{F}$$

$$T_w = 130^\circ\text{F}$$

With $I = 0.22$

$$243^\circ\text{F}$$

$$123^\circ\text{F}$$

$$112^\circ\text{F}$$

for $T_{2o} = 100^\circ\text{F}$. It is of interest that radiation accounts for $\sim 55\%$ of the heat flow from the vibrator.

Calculated & Assumed Parameters for Tidd Analysis

We took the length of the connector to be:

$$L = 1.1 \text{ ft}$$

with a cross-sectional area of

$$A_c = \frac{\pi}{4} (d_o^2 - d_i^2) = \frac{\pi}{4} \frac{(4.5^2 - 4.021^2)}{144} = 0.02226 \text{ ft}^2$$

The thermal conductivity used was for steel,

$$k = 30 \text{ Btu/hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

The surface area of the vibrator was estimated as a 10 inch long piece, 4 inches in diameter.

(Plus the end)

$$A_v = \frac{10 (\pi 4)}{144} = .873 \text{ ft}^2$$

Only the cylindrical area was used in calculating A_{tot} since the conduction through the "thin" wall will be much greater than through the two inch thick cap plate. We assumed a 15 inch long cylinder, 2 ft in diameter to give:

$$A_{tot} = \frac{\pi (24)(15)}{144} = 7.854 \text{ ft}^2$$

The emissivity was chosen as that for paint:

$$\epsilon \sim .95$$

and the internal and external heat transfer coefficients were taken as $1.0 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$.

APPENDIX D

Revised APF Failure Mode Response Plan

WESTINGHOUSE ADVANCED PARTICLE FILTER (APF)
FAILURE MODE RESPONSE PLAN

NO: 1.1 FAILURE MODE: STEAM TURBINE TRIP

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
		OPERATOR ACTIONS		
AEP System Anomaly	<ul style="list-style-type: none">Process transients over 30 mins170 psia + 80 psia1550°F + 1180°F100,000 lb/hr + 57000 lb/hr		<ul style="list-style-type: none">Follow APF heat-up procedures (including 200°F/hr maximum ramp) if restart is attempted.Continue to pulse until gas turbine is removed from service.Follow normal shutdown procedures for securing valves and vessel purging.	

NO: 1.2 FAILURE MODE: COMBUSTOR TRIP

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
AEP System Anomaly	• Process transients over 10 minutes		• Follow APF heat-up procedures (including 200°F/hr maximum ramp) if restart is attempted.
	170 psia + 48 psia		
	1550°F + 450°F		
	100,000 lb/hr+39,600 lb/hr		• Continue to pulse until gas turbine is removed from service.
			• Follow normal shutdown procedures for securing valves and vessel purging.

NO: 1.3 FAILURE MODE: GAS TURBINE TRIP

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	OPERATOR ACTIONS	FOLLOW-UP ACTIONS
APP System Anomaly	<ul style="list-style-type: none"> Instantaneous drop in gas flow to 10% Secondary transient over 10 minutes 170 psia + 15 psia 1550°F + 1000°F 10,000 lb/hr + 0 lb/hr 	<ul style="list-style-type: none"> APP backpulse control mode reset to manual. Backpulse system disabled to prevent backpulsing until the process air system is switched over from gas-cooling mode to air-cooling mode. 		<ul style="list-style-type: none"> Do not attempt to restart prior to enabling backpulse system. Follow APP heat-up procedures (including 200°F/hr maximum ramp) if restart is attempted. If possible, pulse clean all plenums at least once prior to total system shutdown, to remove cake while above dewpoint. Follow normal shutdown procedures for securing valves and vessel purging.

NO: 1.4 FAILURE MODE: BLACK PLANT TRIP

POSSIBLE CAUSES	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
	DIAGNOSTICS/EFFECTS	OPERATOR ACTIONS	
• AEP System Anomaly	• Total outage of site power	• APF backpulse control mode reset to manual.	• Do not attempt restart prior to enabling backpulse system.
	• Instantaneous drop in gas flow to 10%	• Backpulse system disabled to prevent backpulsing until the process air system is switched over from gas-cooling mode to air-cooling mode.	• Follow APF heat-up procedures (including 200°F/hr maximum ramp) if restart is attempted.
	• Secondary transient over 10 minutes		• If possible, pulse clean all plenums at least once prior to total system shutdown, to remove cake while above dewpoint.
	170 psia + 15 psia 1550°F + 1000°F 10,000 lb/hr + 2 lb/hr		• Follow normal shutdown procedures for securing valves and vessel purging.
	• Black plant trip causes gas turbine trip.		

NO: 2.1 FAILURE MODE: HIGH PRESSURE DROP (DP >4 psi)

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> Insufficient pulse pressure Blinding of filters High level of ash in vessel hopper (see 2.4) Blockage in impulse lines Malfunction of pulse solenoid valves. Ash buildup in inlet nozzle or shroud. High inlet velocity (see 2.5). Misaligned pulse nozzle. 	<ul style="list-style-type: none"> Diagnostic DP (PDJRA-J717) measurement reads higher than 4 psid. 	<p>A. If DP >4 psi for more than 1 minute:</p> <ul style="list-style-type: none"> If in timer mode, APF backpulse control mode reset to DP mode and alarm. If in manual or DP mode, alarm. <p>B. If DP >4 psi for more than ten minutes:</p> <ul style="list-style-type: none"> Alarm 	<ul style="list-style-type: none"> Determine number of blocked plenums by comparing venturi meter readings: PDJRI-J714, 715, 716 PDJR2-J714, 715, 716 PDJR3-J714, 715, 716 Low relative readings indicate blockage.

NO: 2.1 (cont'd) FAILURE MODE: HIGH PRESSURE DROP (DP >4 psi)

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
		<ul style="list-style-type: none"> If pressure drop rises above 8 psi, while pulsing at pressures greater than 1300 psig, then reduce load (pressure, flow, dust loading) on APF. In addition, with DP >8 psi, if temperature is greater than 1550°F for more than 10 hours, then reduce APF inlet gas temperature to approximately 1450°F. (APF may be operated indefinitely at DP ≤10 psi and T ≤1450°F). 	
		<ul style="list-style-type: none"> C. If DP >12 psi for more than five minutes: <ul style="list-style-type: none"> • Reduce APF inlet gas temperature to approximately 1200°F. 	<ul style="list-style-type: none"> D. Implement PFBC shutdown.
		<ul style="list-style-type: none"> C. If DP >12 psi for more than five minutes: <ul style="list-style-type: none"> • Alarm 	
		<ul style="list-style-type: none"> D. If DP >18 psi for more than 2 hours after reduction of APF inlet temperature: <ul style="list-style-type: none"> • Alarm 	

NO: 2.3 FAILURE MODE: HIGH ASH PENETRATION (BREACH IN FILTER BARRIER)

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> • One or more candles broken • Failure of gasket seals • Perforation of candle cluster assembly • Perforation of tubesheet or expansion joint • Gross errors in isokinetic dust sampling 	<ul style="list-style-type: none"> • Outlet dust sample indicates >15 PPM over three sample runs. • Sudden and lasting (1 hr) decrease in pulse cleaning frequency at constant load. • Sudden and lasting (1 hr) decrease in pressure drop. • Loss of speed on screw conveyor due to jamming with candle debris (see 3.4.1). 	<ul style="list-style-type: none"> • Alert field operators to possibility of screw cooler jamming due to candle debris. If screw cooler is determined to be jammed, and cannot be cleared, then implement PFBC shutdown. 	<ul style="list-style-type: none"> • Review gas flow distribution thru nine venturi meters. Attempt to isolate failed plenum by discontinuing pulse operation to plenum showing abnormally high gas flow.

NO: 2.4 FAILURE MODE: HIGH ASH LEVEL IN APF HOPPER

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> • Screw cooler shutdown • Bridging over ash outlet port. • Ash Removal System Failure (see 3.4.1 through 3.4.5). 	<ul style="list-style-type: none"> • System pressure drop rises rapidly above established baseline. • High level alarm on nuclear gage LJSB-J862 • Low flow indication on one or more bottom plenum venturi meters • Lockhopper unloading cycle gives indications of no ash. • Drop in temperature level in APF cone, TJRA1,2,3-J709, or in screw cooler housing, TJABL-J901,2. • Indications of ash removal system failure (see 3.4.1 through 3.4.5). 	<ul style="list-style-type: none"> • See 2.1 - High Pressure Drop 		<ul style="list-style-type: none"> • Attempt to dislodge bridges in hopper by opening valves JO8B-PF119 and Y08H-PF121. • Accelerate lockhopper cycling to increase gas flow rate down APF vessel through screw cooler. • Notify field operators to check out operation of screw cooler. • Manually operate vibrator. Note: screw cooler must be in service, otherwise ash will tend to pack. (That is, if the ash cannot drain, then the vibrator may cause compaction.) • See 2.1 - High Pressure Drop • Drop plant load to reduce dust loading and temperature. • Implement PFBC shutdown if level cannot be kept down. 	

NO: 2.5 FAILURE MODE: HIGH INLET/OUTLET GAS TEMPERATURE

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
		OPERATOR ACTIONS		
• Abnormal operation of PFBC combustor.	• Alarm if TJRAX-J856 average >1670°F.	• If TJIRx-J710, 2 of 2 >1670°F for 30 min., combustor trip.	• Reduce gas temperature on the HGU system.	• Repair failed thermocouples to 2 of 2 or 2 of 3 status.
• Alarm if TJIRx-J705 average >1670°F.	• Alarm if TJIRx-J866 average >1670°F.	• If TJIRx-J710, 2 of 2 >1720°F for 5 sec., combustor trip.		
	• Alarm if TJIRx-J710 average >1670°F.	• If TJIRx-J710, 1 of 2 >1670°F for 30 min., alarm.		
		• If TJIRx-J710, 1 of 2 >1720°F for 5 sec., alarm.		

NO: 2.6 FAILURE MODE: LOW APF TEMPERATURE

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> Plugged filters, resulting in low gas flow rate and thermal input to APF. 	<ul style="list-style-type: none"> Low temperature measurements, gas inlet, vessel, gas outlet. High pressure drop. 	<ul style="list-style-type: none"> A. If gas outlet temperature <800°F, then alarm. B. If gas outlet temperature <400°F, then alarm. 	<ul style="list-style-type: none"> A. If gas outlet temperature <800°F, then introduce preheater air to APF, to maintain temperature. B. If gas outlet temperature <400°F, then implement PFBC shutdown. 	
<ul style="list-style-type: none"> Low gas flow rate detected by APF line annubar. 				
<ul style="list-style-type: none"> Low gas flow rate detected by APF venturi DPs. 				

NO: 3.1 FAILURE MODE: LOSS OF PULSE AIR SUPPLY

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> • Compressor shutdown <ul style="list-style-type: none"> - Low oil pressure - Vibration - Loss of coolant - Loss of power - Relief valve failed open • Sensor malfunction 	<ul style="list-style-type: none"> • Low pressure alarm on primary accumulator PJRAL-J723 • Compressor motor shutdown indication in control room. 	<ul style="list-style-type: none"> • After 30 minutes, <ul style="list-style-type: none"> - APF backup pulse control mode reset to manual. 	<ul style="list-style-type: none"> • Alert field operators to troubleshoot compressor. • Maintain ash removal system operation. • Reduce load (pressure, flow, dust loading) while attempting compressor system repair. • Use backup air compressors. • Implement PFBC shutdown if more than 6 pulse cycles are missed. For this purpose a cycle is defined as the average time between pulses just prior to loss of pulse air supply.

- Backup pulse all plenums manually several times immediately after pulse air supply is restored.
- Follow APF heat-up procedures (including 200°F/hr maximum ramp) if restart is attempted.

NO: 3.2 FAILURE MODE: HOT SPOT ON VESSEL

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
• Detachment and/or erosion of insulating blanket	• Vessel and dome exterior paint color changes are detected.	• None.		• Investigate extent and location of hot spot.	• Monitor extent of refractory failure using contact pyrometer. Maintain log of exposure times.
• Damaged refractory in inlet spool piece causing gas migration to carbon steel shell.	• Inlet spool piece exterior paint color change is detected.			• Reduce APF inlet temperature.	
	• Pyrometer readings.			• If hot spot temperatures exceed 650°F, then implement PFBC shut down.	

NO: 3.3 FAILURE MODE: SOLENOID VALVE FAILURE

POSSIBLE CAUSES	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
	DIAGNOSTICS/EFFECTS	OPERATOR ACTIONS	
<ul style="list-style-type: none"> Eroded seals in pilot/plunger internals. Insufficient pressure differential between pilot air and feed air. Solenoid coil failure Dirt or scale in pulse air lines. 	<ul style="list-style-type: none"> Alarm on APF MCS panel Pulse tank pressure does not drop to low level (fail-closed) or drops to low-low level (fail-open). 	<ul style="list-style-type: none"> Isolation valve closed and redundant solenoid valve energized. Verify pilot side pressure is at recommended setting. 	<ul style="list-style-type: none"> Isolate faulty solenoid by closing block valves. Close pilot side and supply side valves, disconnect solenoid valve and replace with spare valve. Open valve body and service internals.

NO: 3.4.1 FAILURE MODE: ASH REMOVAL SYSTEM FAILURE-LOSS OF SCREW SPEED

POSSIBLE CAUSES	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
	DIAGNOSTICS/EFFECTS	OPERATOR ACTIONS	
• Jamming of candle debris in screw.	• High APF ash level.	• Low screw speed alarm.	• If screw speed cannot be restored and ash level in APF rises to level of candles, PFBC system must be shut down.
• Jamming of ash in screw.	• Low screw speed alarm.	• Hydraulic fluid pump trip alarm.	• Check for proper operation of hydraulic system.
• Loss of hydraulic fluid pump.	• Drop in screw cooler flue gas temperature.	• Low hydraulic fluid level alarm.	• Check hydraulic fluid system for leaks and repair, if possible.
• Leaks in hydraulic fluid system.	• No ash collected and removed from APF ash lockhopper (detected by no change in vacuum levels during unloading).		• Check for proper setting of pressure reducing valve, PRV-J828. Adjust upwards to gain screw shaft torque.
	• Hydraulic fluid pump trip alarm.		• If loss of screw speed is due to jamming of candle and cannot be cleared, initiate PFBC shutdown.
	• Low hydraulic fluid pressure.		• If loss of screw speed is due to ash jamming in screw, lockhopper and surge hopper should be cleared (see 3.4.4) and screw shaft torque increased to clear ash from screw.
	• Low hydraulic fluid level alarm.		

NO: 3.4.2 FAILURE MODE: ASH REMOVAL SYSTEM FAILURE-LOSS OF COOLING WATER

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> • CCCWS pump failure. • Leak in CCCWS. 	<ul style="list-style-type: none"> • Low flow alarm. • CCCWS pump trip alarm. • Low expansion tank level alarm (indicates system leak). • Low expansion tank pressure alarm. 	<ul style="list-style-type: none"> • Check expansion tank level and pressure. Adjust as necessary. • Check for proper pump operation. • Check system for leaks and isolate and/or repair, if possible. • If loss of water flow is due to CCCWS pump failure, valve in and start-up auxiliary pump and valve out main pump. 	<ul style="list-style-type: none"> • If proper water flow and pressure cannot be maintained, PPBC system must be shut down.

NO: 3.4.3 FAILURE MODE: ASH REMOVAL SYSTEM FAILURE-LOSS OF LUBE OIL

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	
		OPERATOR ACTIONS	FOLLOW-UP ACTIONS
• Lube oil pump failure.	• Lube oil pump trip alarm.	• Check lube oil pump for proper operation.	• If proper lube oil system operation cannot be maintained, check temperature in screw cooler end housing drive end (TJAH-J908).
• Leak in lube oil piping.	• Low lube oil pressure alarm.	• Check for proper lube oil system pressure.	• If temperature can be maintained below 250°F, screw cooler is allowed to remain in service until next outage without lube oil system in service.
	• Low lube oil level alarm.	• Check for proper lube oil level.	• If temperature is greater than 250°F, the hydraulic system and PFBC system must be shut down.
		• Check for proper setting on lube oil recirculation valve, PRV-J835.	
		• Check system for leaks and repair, if possible	
		• Isolate lube oil system from screw cooler pressure and check for dirty oil filter.

2 of 2

NO:3.4.4 FAILURE MODE: ASH REMOVAL SYSTEM FAILURE-HIGH ASH LEVEL IN SURGE HOPPER OR LOCKHOPPER

POSSIBLE CAUSES	DIAGNOSTICS/EFFECTS	AUTOMATIC ACTIONS (VIA MCS NET-90)	OPERATOR ACTIONS	FOLLOW-UP ACTIONS
<ul style="list-style-type: none"> • Bridging of ash over surge hopper or lockhopper outlet. • Ratholing of ash in surge hopper or lockhopper. • Plugged lockhopper isolation valves. • Faulty fly ash removal system operation or loss of vacuum (see 3.4.5.). • Faulty level probe indication. 	<ul style="list-style-type: none"> • High lockhopper ash, level is indicated. • Low screw speed alarm due to ash jamming in screw (see 3.4.1.). • No ash collected and removed from APF ash lockhopper (detected by no change in vacuum levels during unloading). 	<ul style="list-style-type: none"> • High lockhopper level initiates lockhopper unloading sequence. If high level does not clear, an alarm is initiated. • Low screw speed alarm due to ash jamming in screw. (see 3.4.1.). 	<ul style="list-style-type: none"> • Operate surge hopper or lockhopper vibrator with respective hopper isolation valve(s) open at the bottom. • Clear lockhopper isolation valves using purge air or nitrogen. • Initiate manual lockhopper unloading cycle. Check vacuum levels to verify ash loading. 	<ul style="list-style-type: none"> • Increase differential set points between surge hopper (PJI-J932) and lockhopper (PJI-J933) and between lockhopper and ash transport line (PJI-J937) and initiate additional lockhopper unloading cycles. • If ash level cannot be cleared and ash builds up to level of candles in the APF vessel, PFBC system must be shut down.

NOTE: At 100 lb/hr, ash will reach candle level approximately 36 hours after high APF level alarm is initiated.

NO: 3.4.5 FAILURE MODE: ASH REMOVAL SYSTEM-LOSS OF VACUUM

POSSIBLE CAUSES	AUTOMATIC ACTIONS (VIA MCS NET-90)		FOLLOW-UP ACTIONS
	DIAGNOSTICS/EFFECTS	OPERATOR ACTIONS	
• Leaks in ash piping.	• Low vacuum level alarm.	• Check ash piping for leaks and repair, if possible.	• If vacuum cannot be restored, use vacuum truck to pull vacuum from 4" cleanout port on ash transport line.
• Vacuum pump failure.	• Loss of ash conveying capacity.	• Adjust NO LOAD, LOW LOAD, and FULL LOAD vacuum set points to allow continued operation and sequencing of ash removal system.	
	• Vacuum pump failure alarm.	NOTE: System leaks should be repaired during next outage and set points restored to normal.	
		• Check vacuum pump for normal operation.	

APPENDIX E

Summary of Candle Filter Material Characterization

*Conf. paper cycled
separately.*

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