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LONG TERM MATERIALS TEST PROGRAM

Quarterly Report for the Period October—December 1983

Work Performed Under Contract No. AC21-79ET15457

For
U. S. Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
General Electric Company
Schenectady, New York

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QUARTERLY REPORT

October Through December 1983

Prepared for

U.S. DEPARTMENT OF ENERGY

under

CONTRACT DE-AC21-79ET15457

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GENERAL **ELECTRIC**

MASTER

ABSTRACT

The long-term exposure of gas turbine vane and blade base alloys and a variety of protective coating systems to the effluent from a pressurized fluidized bed coal combustor has reached 4398 hours. After 4053 hours, FeCrAlY overlay coatings and platinum/rhodium-aluminide pack diffusion coatings show excellent resistance to corrosion attack at 1500°F. Cobalt-base coatings are somewhat more susceptible to hot corrosion, and the unprotected nickel and cobalt-base alloys are most susceptible to corrosion, although corrosion rates have decreased to less than 1 mil/1000 hours for all materials at 1500°F; i.e., corrosion penetration data is evolving parabolically.

The three-stage cyclone cleanup system became severely distorted after approximately 5600 hours total service life. Distortion of the cyclones contributed to an increased dust loading to the material test sections, 110-250 ppm versus normal loadings of 30-90 ppm, for a period of about 75 hours. This increase in dust loading caused severe erosion of the airfoils in the high-velocity test section. Metal recession ranged 4 to 18 mils of leading edge loss on the impulse airfoils, and 11 to 27 mils of leading edge loss on the reaction airfoils.

A new three-stage cyclone system was installed and dust loadings now range from 15 to 45 ppm.

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Program Manager	- R McCarron
Technical Operations	- T Bonds
Materials Support	- R Brobst
Facility Operation and Maintenance	- A deMaille
	- G Goodrich
	- P Jennes
	- E Lambrecht
	- G Logan
	- P Palmer

This program is being ably directed from the Department of Energy by McClung at the Morgantown Energy Technology Center, Morgantown, WV.

SUMMARY

The Long-Term Materials Test program being conducted in the Pressurized Fluidized Bed Combustion (PFBC) facility at Malta, New York has accumulated 4398 hours of materials exposure testing. The PFBC operating conditions include a 1650°F bed temperature, 10 atmospheres pressure and a fluidizing velocity of 2.4 to 2.7 ft/s. Pittsburgh No. 8 coal (5% sulfur, 0.15% chlorine) is being utilized in conjunction with a low alkali (0.1 wt%) dolomite sulfur sorbent.

Corrosion of gas turbine vane and blade base alloys and various protective coating systems is being evaluated at nominal metal temperatures of 1500°, 1300° and 1100°F in a 1500°F gas stream. Erosion/corrosion degradation of these materials also is being evaluated in a high-velocity test section at 800-1400 ft/s, 1350°F and nominal dust loadings of 30-90 ppm.

Significant findings from the testing to date include:

- o Short-term (<1000 hour) corrosion data yielded unacceptably high penetration rates for unprotected nickel-base and cobalt-base blade and vane alloys. Longer term exposures (4053 hours) show corrosion penetration data evolving parabolically.
- o Reducing metal temperatures 200°-400°F below the gas temperature (1500°F) produces changes in the corrosion morphology but does not provide an overall reduction in corrosion rates. In several instances, corrosion rates increase with decreasing metal temperatures.
- o Ash deposits collected on the cooled pins contain up to an order of magnitude more alkali than deposits on the uncooled pins, strongly suggesting a vapor phase alkali deposition mechanism.
- o Precious metal aluminide coatings show generally excellent corrosion resistance above 1450°F (0.1 mil/1000 hours), but are susceptible to varying degrees of pitting attack at 1100° to 1300°F. A "straight"-aluminide (RT-19) coating is unacceptable for PFBC fired gas turbine applications.
- o CoCrAlY and FeCrAlY physical vapor deposited coatings show the best overall corrosion resistance at all metal temperatures.
- o Erosion/corrosion degradation rates range from 1-4 mils/1000 hours for both base alloys, coatings and claddings at 1350°F, 800-900 ft/s and dust loadings less than 100 ppm in the high-velocity test section. Corrosion predominately occurred in areas of particle impaction indicating an erosion/corrosion synergism.

- o Base alloys have unsatisfactory erosion/corrosion resistance while (Co, Fe) CrAlY coatings appear promising at 900 ft/s even with small leading edge radius (0.015-inch) airfoils.
- o Metal recession rates of 8 mils/1000 hours on a platinum-aluminide coated IN-738 pin and 2 mils/1000 hours on a Co-23Cr-9Al-0.4Y coated pin have been observed at 1200-1400 ft/s. Thus at high velocities, coatings appear unsatisfactory for erosion/corrosion resistance even with larger leading edge (0.125-inch radius) parts.
- o Increased dust loadings of 100-250 ppm caused severe erosion of all materials at 1350°F. Metal loss at the leading edge of reaction airfoils (900 ft/s) exceeded 20 mils after approximately 1700 hours at 30-90 ppm and 75-90 hours at 100-250 ppm.

The PFBC facility continues to operate with an exceptional degree of reliability. The only significant operational problem continues to be the erosion/corrosion degradation of the in-bed heat exchanger coil assembly.

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SECTION 1
TEST DESIGN AND QUALIFICATION (TASK 1)

This phase has been completed. No further effort is planned.

SECTION 2

TEST OPERATIONS (TASK 2)

A total of 958 hours of materials testing were completed during the October-December 1983 quarter. The Long-Term Materials Test has now reached 4398 hours of testing.

Test Conditions

The operating conditions for the Long-Term Materials Test are summarized in Table 2-1. The bed is operated at a nominal temperature of 1650°F, 10 atmospheres pressure and a fluidizing velocity of 2.4 to 2.7 ft/s. Excess air through the system is kept at a minimum of 20 percent and is generally in the 30 to 40 percent range.

The temperature in the low-velocity test section varies between 1440° and 1520°F at a gas velocity of 23 ft/s. The high-velocity test section operates at nominally 1350°F with dust loadings varying between 30 and 90 ppm.

Chemical analyses of the coal and dolomite are listed in Tables 2-2 and 2-3 respectively. Pittsburgh No. 8 coal with 3-5 wt% sulfur and about 0.15 wt% chlorine was selected for use in the long-term test. Actual coal shipments to date have averaged 4.97 wt% sulfur and 0.15 wt% chlorine.

Dolomite is mixed with coal at a constant ratio of 100 lbs coal/55 lbs dolomite to yield a Ca/S ratio of 1.7 to 2.3. Sulfur capture typically ranges from 91 to 95 percent based on a nominal 5 percent sulfur coal.

Pfizer dolomite was used for the first 1923 hours of the long-term test. Pfizer discontinued mining and supplying dolomite in January 1983. Several alternate suppliers were contacted and samples of their dolomites analyzed for chemical composition and size distribution. National Lime and Stone Company's dolomite has been selected for use throughout the remainder of the Long-Term Materials Test. This dolomite is chemically similar to the Pfizer material, Table 2-3.

TABLE 2-1
LTMT Operating Conditions

Combustor

Coal	Pittsburgh No. 8
Dolomite	Pfizer, National Lime and Stone Co. No. 11
Bed Temperature	1640°-1660°F
Bed Pressure	150 psia
Fluidizing Velocity	2.4-2.7 ft/s
Bed Height	6 ft. Nominal
Excess Air	30-40%
Ca/S	1.7-2.3

Low-Velocity Test Section (LVTS)

Gas Pressure	145 psia
Gas Velocity	23 ft/s
Inlet Temp	1500°-1520°F
Outlet Temp	1440°-1480°F
Cooled Pin Temps	1300°F ⁺ 50°F, 1100°F ⁺ 50°F

High-Velocity Test Section

Temp	1325°-1375°F
Dust Loading	30-90 ppm
Mean Particle Size (Microns) ⁽¹⁾	1.9-3.1
Percent Particles >10 Microns ⁽¹⁾	2-10
Gas Velocity	800-900 ft/s (Airfoils) 1300-1400 ft/s (Erosion Pin)

⁽¹⁾Range of 15 analyses

Table 2-2

COAL ANALYSIS
PITTSBURGH NO. 8

<u>Proximate Analysis (As Received)</u>	(Wt%) Range of 3 Analyses	<u>Avg.</u>
Moisture	1.38-1.86	1.63
Ash	14.26-16.87	15.47
Volatile	35.60-37.71	36.68
Fixed Carbon	46.15-46.34	46.22
Btu/lb	12084-12485	12293
<u>Ultimate Analysis (As-Received)</u>		
Moisture	1.38-1.86	1.63
Carbon	66.22-68.38	67.41
Hydrogen	4.65-4.80	4.75
Nitrogen	1.28-1.37	1.34
Chlorine	0.13	0.13
Sulfur	4.79-5.07	4.93
Ash	14.26-16.87	15.47
Oxygen	4.16-4.53	4.34
<u>Ash Analysis</u>		
SiO ₂	35.94-39.96	38.47
Al ₂ O ₃	19.21-20.51	20.05
Fe ₂ O ₃	33.60-38.86	35.65
TiO ₂	0.84-0.98	0.93
CaO	0.70-1.04	0.84
MgO	0.66-0.70	0.67
K ₂ O	1.51-1.83	1.69
Na ₂ O	0.00-0.24	0.14
SO ₃	0.74-1.00	0.86

Table 2-3

CHEMICAL ANALYSIS OF NATIONAL LIME & STONE CO. NO. 20 DOLOMITE

	<u>wt%</u>
CO ₂ (Loss)	46.18
CaO	28.02
MgO	19.85
SiO ₂	2.07
Al ₂ O ₃	1.37
Fe ₂ O ₃	1.39
K ₂ O	0.06
Na ₂ O	0.24
SO ₃	0.69
Cl (ar)	0.20

Chemical Analysis of Bed and Cyclone Particulates

Table 2-4 lists the chemical analyses of bed and cyclone particulates sampled during the test period covered by this report. Samples of each material are collected at several times during periods of steady-state operation and composited to make a bulk sample. The analyses shown represents a single analyses of the composited or bulk sample.

The concentrations of Na_2O and K_2O are shown to increase from the first to the third cyclone catches. An explanation for this may be that Na_2O and K_2O are generally tied-up with the mineral constituents in the coal ash. The first cyclone captures the larger particles elutriated from the bed which tend to be the spent dolomite particles (CaO , MgO). The second and third cyclones capture larger relative fractions of the coal ash (Al_2O_3 , SiO_2 and Fe_2O_3). Since Na_2O and K_2O are usually associated with the ash component, their concentration would tend to be higher in the second and third cyclone catches.

Alkali Probe Measurements

Water soluble alkali levels measured since the beginning of the Long-Term Materials Test are 0.08-0.41 ppm Na, 0.17-3.21 ppm K, and 9-10 ppm chlorides in the combustion products (range of 4 measurements). These alkali levels are one to two orders of magnitude greater than the acceptable levels for industrial gas turbines; about 0.02 ppm alkali in the combustion products. There has been no measurable change in alkali levels as a result of changing dolomites.

In-Bed Heat Exchanger Corrosion

During this operating period, the stainless steel in-bed heat exchanger coil developed leaks on two occasions which required either replacement or repair of the coil assembly at intervals of 300-600 hours. The leaks are a result of severe pitting attack concentrated on the inlet and outlet ends of the 310 SS coil. The pitting attack is believed to be a result of sulfuric acid dewpoint corrosion as the coil is water-cooled producing metal temperatures below about 300°F. Another indication that the problem is acid corrosion is the fact that the downcomer tubing is Inconel 625 and shows only

Table 2-4

CHEMICAL ANALYSES OF BED AND CYCLONE PARTICULATE
 (10/83 12/83)
 wt%

	<u>Bed Material</u>	<u>First Cyclone</u>	<u>Second Cyclone</u>	<u>Third Cyclone</u>
C	2.08	2.43	0.56	0.38
CO ₂ (Loss)	7.16	6.36	0.55	0.16
CaO	33.34	26.26	16.22	19.91
MgO	24.23	17.20	7.61	11.19
SiO ₂	11.01	17.55	31.30	24.60
Al ₂ O ₃	4.67	9.86	19.14	16.45
Fe ₂ O ₃	3.63	12.95	19.23	17.55
K ₂ O	0.26	0.44	1.31	1.10
Na ₂ O	0.14	0.31	0.67	0.31
SO ₃	22.39	14.66	3.23	7.75
Cl ⁻ (ar)	0.24	0.22	0.28	0.29

isolated areas of pitting attack. Inconel 625 is significantly more resistant to pitting attack by sulfuric acid than the 310 or 316 stainless steels used to fabricate the heat exchanger coils.

Currently, a section of 310 SS which experienced the severe pitting attack is being replaced with a section of Inconel 625 tubing. This coil will be reinstalled in the combustor at a later date to determine its resistance to attack.

Replacement of Three-Stage Cyclone Cleanup System

After approximately 3600 hours of long-term testing, the dust loadings to the test sections increased from the typical 30-90 ppm range to between 100 and 250 ppm. Throughout the weeks operation, the dust loadings were monitored but the test was not interrupted since the loadings were not considered excessively high, based on the CURL 10x100 hour test experience. (The CURL 10x100-hour test ran 1000 hours at nominally 250 ppm loadings.)

Post shutdown inspection of the cyclone assembly revealed that the first cyclone was severely distorted with cracking of the welds on all three cyclones. Figure 2-1 shows a photograph of the cyclone assembly after removal from its pressure vessel. The wall of the first cyclone had bulged out and buckled near the inlet (Figure 2-1a). The vertical alignment of the outer shell with the exit tube also has been severely distorted, Figure 2-1b. Distortion to the first cyclone apparently resulted from stresses imposed by thermal expansion of the 310 SS pipe leading from the combustor to the first cyclone.

Cracking of the welds is most likely due to differential thermal elongation in the vertical direction and embrittlement caused by prolonged exposure, approximately 5500 hours, in the 1200°-1600°F temperature range. 310 stainless steel is subject to sigma phase embrittlement in this temperature range.

A new cyclone assembly, which had been on order, was installed following the week of high dust loading operation. Design of the new cyclone assembly had been modified to reduce stress due to differential thermal expansion. Balston Filter dust samples taken with the new assembly in service, showed dust loadings in the 15 to 45 ppm range.

(a)

(b)

Figure 2-1 Figure Stage Cyclone Clean-up System After 5500 Hours Total Service

SECTION 3

MATERIALS EVALUATION (TASKS 3, 5 and 6)

Corrosion testing of candidate gas turbine vane and blade alloys and protective coating systems under the Long-Term Materials Test program has reached 4398 hours. During the October-December 1983 test period, one set of uncooled (1500°F) pins was removed from the LVTS after 4053 hours exposure and metallographically evaluated for corrosion penetration.

The 24 airfoil specimens in the high-velocity test section, installed at the 2235-hour mark of testing, also were removed for evaluation of erosion/corrosion degradation at the 4053-hour test mark. This airfoil matrix originally was scheduled to remain in test for the duration of the long-term test, but an upset in dust loading (100-250 ppm) after 3600 hours operation caused severe erosion of all the test materials necessitating replacement of the airfoils. The conditions contributing to the upset in dust loading were described in the test operations section of this report. Further details of the erosion damage are presented later in this section.

Low-Velocity Test Section Corrosion Pins - 1500°F, 4053 Hours

Table 3-1 lists the maximum corrosion penetration observed on each material following 4053 hours of exposure. The unprotected base alloys, U-500, IN-738, IN-939 and FSX-414, continue to show the greatest corrosion penetration characterized by a surface oxide layer combined with internal attack of the alloy. Internal attack of the three nickel-base alloys is primarily sulfide penetration along the grain boundaries, while the cobalt-base FSX-414 exhibits preferential attack of the carbide substructure.

The precious-metal aluminide pack diffusion coatings, RT-22 and RT-44, and the FeCrAlY overlay coatings show the best resistance to corrosion attack at 1500°F. Each of these materials typically has a thin surface oxide with little or no internal attack of the coating.

TABLE 3-1
LTMT 1500°F Corrosion Data

Material	Maximum Corrosion Penetration (Mils)					
	285 Hrs	800 Hrs	1085 Hrs	1602 HRS	2687 Hrs	4053 Hrs
U-500	1.3	1.3	3.4	2.0	3.4	3.5
IN-738	1.0	1.9	2.3	2.9	3.7	3.5
IN-939	0.8	2.1	2.0	3.0	4.7	3.8
FSX-414	3.2	1.8	2.8	3.2	5.0	3.5
RT-19	1.8	1.8	1.3	2.7**	2.7**	2.0
RT-22	0.2	0.1	0.3	0.2	0.1	0.3
RT-44	N.D.*	N.D.	0.1	N.D.	0.1	0.3
FeCrAlY (Clad)	N.D.	0.2	0.3	0.5	0.3	0.5
FeCrAlY (PVD)	N.D.	0.2	0.2	0.3/0.3 ⁺⁺	0.2/0.3 ⁺⁺	0.4/0.4 ⁺⁺
CoNiCrAlY (Clad)	0.5	1.0	1.0	0.9	2.0	2.3
CoCrAlY (23Cr-9Al)	N.D.	N.D.	N.D.	N.D/0.2 ⁺⁺	0.1/0.3 ⁺⁺	0.3/1.8 ⁺⁺
CoCrAlY (30Cr-5Al)	N.D.	0.6	0.2	0.3/0.3 ⁺⁺	0.1/1.3 ⁺⁺	1.8/2.0 ⁺⁺
CoCrAlY (29Cr-6Al)	0.8	1.2	1.4	1.3	2.2	2.4
Ceramic-TBC	Spalled	Spalled	Spalled	N.T.	Spalled	Spalled
IN-611	N.T. ⁺	N.T.	6.9	N.T.	N.T.	N.T.

*N.D. - None Detected

⁺N.T. - Not Tested

**Coating Failure

⁺⁺IN-738 substrate/FSX-414 substrate

The only significant change in materials performance since the previous evaluation at 2687 hours occurred on the two CoCrAlY physical vapor deposition (PVD) coatings. Both coating compositions, Co-23Cr-10Al-0.4Y and Co-30Cr-5Al-0.4Y, previously had shown little or no corrosion attack. Following 4053 hours exposure, however, both coatings experienced internal attack with penetrations up to 2.0 mils, Figure 3-1. The internal oxidation has been identified by electron microprobe analyses as aluminum oxide with no internal sulfides. This change in corrosion resistance is the first instance of a rapid change in corrosion rate for any of the materials under evaluation.

The other cobalt-base coatings, CoNiCrAlY cladding and Co-29Cr-6Al-0.4Y plasma spray coating, also showed corrosion attack up to 2.4 mils deep. Both of these compositions have shown a general progression in penetration with longer exposure times, and have not exhibited any sudden increase in corrosion penetration.

Figure 3-2 summarizes the corrosion penetration versus exposure time data for the unprotected blade and vane alloys tested at 1500°F. The solid lines are drawn with a slope of one-half representing parabolic corrosion behavior and are shown to bracket the data fairly well.

Figure 3-3 graphically shows the corrosion penetration versus exposure data for all sixteen materials being evaluated in the LVTS at 1500°F. Each alloy is identified numerically, and the solid lines are intended to roughly bracket those materials exhibiting near parabolic corrosion behavior. The data points lying below about 0.5 mils, after 1000 hours or longer exposure, are considered to have excellent corrosion resistance; i.e., RT-22, RT-44, FeCrAlY. As noted, the two CoCrAlY coatings also showed no distress until the recent 4053-hour inspection.

High-Velocity Test Section Airfoils - 2235 to 4053 Hrs

The 24 airfoil specimens in the high-velocity test section were removed after 4053 hours of long-term testing. This array of airfoils had been installed following completion of two nominally 1000-hour screening tests (actual exposures 1085 and 1150 hours) designed to select the three or four most erosion/corrosion resistant materials of the twelve originally selected

Figure 3-1 Internal Attack of Coating Compositions After 4053 Hours

Figure 3-2 Corrosion Penetration Versus Exposure Time for Unprotected Blade and Valve Superalloys

Engineering Data Essential for Parts Life Prediction

Figure 3-3 Corrosion Penetration Versus Exposure for LVTS at 1500°F

for PFBC testing. At approximately the 3600-hour test mark, the dust loading to the test sections measured using the Balston Filter sampling system, was observed to increase from the 30-90 ppm range typically measured, to between 100 and 250 ppm. Although these loadings were higher than typically measured during the long-term test, they were not considered high by comparison with PFBC tests (CURL 10x100 hour) conducted to date, and therefore the test was not stopped during the weeks operation. Post shutdown inspection of the test facility revealed that the cyclone vessel had become severely distorted (see description in Section 2 of the report), particularly the first cyclone, which contributed to the higher dust loadings.

Inspection of the airfoils following the week's operation revealed that all of the specimens had experienced substantial erosion damage both at the leading edge and along the pressure surface. As noted in Section 2, a new three-stage cyclone cleanup system was installed at this time. Although the airfoils showed substantial erosion damage following the upset, they were reinstalled in the high-velocity test section for four additional weeks testing to ensure that the dust loadings had returned to less than 100 ppm. The airfoils were again removed at 4053 hours, having been exposed for 1818 hours. A completely new array of 24 airfoils were installed at this time.

Table 3-2 presents a listing of the materials test matrix in the high-velocity test section during the upset. The leading edge and pressure surface metal recession measurements obtained by comparing pre-test and post-test profile contour tracings of each airfoil also are listed. The variability of the profile contour tracings is estimated to be ± 1.5 mils. Figure 3-4a&b illustrates the condition of all 24 airfoils following 1818 hours exposure.

Metal loss due to erosion both at the leading edge and along the pressure surface of the airfoils was severe for all materials. Pressure surface erosion was greatest for the reaction airfoils where the gas accelerates from 900 ft/s to 1600 ft/s as it passes over the airfoils. Normalized erosion rates (mils/1000-hour basis) for the unprotected base alloys (U-500, IN-738, IN-939 and FSX-414) ranged from 2.5 to 12.7 mils/1000-hour. Erosion rates on these same materials during the two 1000-hour screening tests typically ranged

Figure 3-4 (a) The Condition of All Twenty-four Airfoils Following 1818 Hours Exposure Along the Pressure Surface

Figure 3-4 (b) The Condition of All Twenty-four Airfoils Following 1818 Hours Exposure Along the Leading Edge
3-9

Table 3-2

HIGH-VELOCITY TEST SECTION - MATERIALS TEST MATRIX
 2235 - 4053 Hour Interval 1818 Hours Exposure

Pos	Coating ID	Material	Max Metal Recession (Mils)		Typical Coat (Mils)
			Lead Edge	Press Surf	
I-1	ATD-2	Co-23Cr-10Al-0.4Y/FSX-414	4.0	0	6-8
I-2	--	RT-22 (Platinum-Aluminide)	8.0	3.0	3-4
I-3	ATD-14	Co-30Cr-5Al-0.4Y/IN-738	5.5	2.0	6-8
I-4	ATD-2	Co-23Cr-10Al-0.4Y/IN-738	11.5	6.0	6-8
I-5	ATD-17	Fe-25Cr-5Al-0.5Y/IN-738	6.5	2.5	9-12
I-6	--	IN-738	8.5	4.0	N.A.
II-1	--	FSX-414	13.5	3.5	N.A.
II-2	ATD-17	Fe-25Cr-5Al-0.5Y/IN-738	9.0	6.0	9-12
II-3	ATD-2	Co-23Cr-10Al-0.4Y/IN-738	13.0	6.5	6-8
II-4	ATD-14	Co-30Cr-5Al-0.4Y/IN-738	9.0	2.5	6-8
II-5	--	RT-22 (Platinum-Aluminide)	9.5	5.0	3-4
II-6	--	U-500	4.5	2.0	N.A.
III-1	--	RT-44 (Rhodium-Aluminide)	10.0	2.0	3-4
III-2	ATD-2	Co-23Cr-10Al-0.4Y/IN-738	17.5	8.5	6-8
III-3	--	RT-22 (Platinum-Aluminide)	18.0	16.5	3-4
III-4	ATD-17	Fe-25Cr-5Al-0.5Y/IN-738	12.0	9.0	9-12
III-5	ATD-14	Co-30Cr-5Al-0.4Y/IN-738	15.0	5.5	6-8
III-6	--	IN-939	13.5	12.0	N.A.
IV-1	ATD-17	Fe-25Cr-5Al-0.5Y/IN-738	14.0	21.5	9-12
IV-2	ATD-14	Co-30Cr-5Al-0.4Y/IN-738	23.0	32.5	6-8
IV-3	--	IN-939	23.0	24.0	N.A.
IV-4	--	RT-44 (Rhodium-Aluminide)	14.5	20.0	3-4
IV-5	ATD-2	Co-23Cr-10Al-0.4Y/IN-738	27.0	33.0	6-8
IV-6	--	RT-19 (Aluminide)	11.0	8.0	2-3

from 1.7 to 5 mils/1000 hours. Figure 3-5 shows the leading edge profiles of IN-939 (3-5a), RT-22 coated IN-738 (3-5b), CoCrAlY(3-5c) and FeCrAlY(3-5d) coated IN-738.

The six aluminide-coated (3 RT-22, 2 RT-44, 1 RT-19) airfoils lost between 8.0 and 18.0 mils of coating and substrate at the leading edge (4.4 to 9.9/mils/1000 hours). Each of these coatings is applied in thicknesses of 2.5 to 4 mils, so that in every case the aluminide coating was penetrated and appreciable erosion of the base alloy had occurred.

The FeCrAlY and two CoCrAlY physical vapor deposited coatings experienced similar severe leading edge metal loss ranging from 4 to 11.5 mils in the first cascade, 9-13.0 mils in the second, 12 to 17.5 in the third cascade, and 14 to 27 mils in the fourth cascade. The maximum leading edge recession on any of these materials during the two 1000-hour screening tests was 2.0 mils.

The high levels of metal loss on all the materials is attributed to the approximately 75-hour exposure to dust loadings of 100-250 ppm. As noted, erosion rates measured following exposure during the first two 1000-hour segments of the long-term test were considerably lower than those measured on the airfoils exposed to the upset conditions. (Table 3-3 presents a comparison of erosion rates.) Further, following the weeks operation at the higher dust loadings, all airfoils were removed from the high velocity test section, cleaned and weighed before being reinstalled. At that time, weight losses were recorded on all the materials, consistent with the observation of significant metal recession. Following the additional four weeks exposure with the new cyclone assembly in place and dust loadings reduced to 15 to 45 ppm, no additional weight loss was observed. In fact, most of the airfoils showed a slight weight gain indicative of deposit buildup.

Coulter analyses of dust samples taken during the upset loading period revealed that the mean size distribution for this period was 3-3.4 microns versus a typical mean of 1.9-3.0 microns. Although the mean was slightly larger, the fraction of particles greater than 10 microns remained less than 10 percent consistent with the 2-10 percent greater than 10 microns range observed throughout the long-term test.

(a)

(b)

(c)

(d)

Figure 3-5 Comparison of Leading Edge Profiles Showing Metal Loss Due to Erosion

Table 3-3

IMPULSE AIRFOIL LEADING EDGE EROSION RATES FOR
THREE DIFFERENT TESTING PERIODS

<u>Material</u>	Maximum Erosion Rate (Mils/1000-hours)		
	<u>0-1085</u>	<u>1085-2235</u>	<u>2235-4053</u>
U-500	2.8	--	2.5
IN-738	---	3.0	4.7
IN-939	---	1.7	7.4
FSX-414	3.7	---	7.4
FeCrAlY (GE2541)	1.5	---	---
CoNiCrAlY (PFB-6)	2.2	---	---
FeCrAlY (ATD-17)	---	0.9	6.6*
CoCrAlY (ATD-2)	---	0.7	9.6*
CoCrAlY (ATD-14)	0.4	---	8.3*
RT-22	3.3	---	9.9*
RT-44	---	0.3	5.5*

*Coatings completely penetrated with substrate erosion.

Corrosion penetration was minimal on all the materials with internal oxidation typically 1.0 mils or less and these areas were located at the leading edge or along the pressure surface. Obviously, metal loss was erosion dominated with the shallow corrosion observed probably occurring during the final 400 hours exposure when the dust loading had returned to its normal range <100 ppm.

HVTS Deposit Analysis

Table 3-4 gives the chemical analysis of the water-soluble component of ash deposits collected in the high-velocity test section. Two samples were collected: 1) loose ash lying on the blades after disassembly which was removed without brushing or scraping, and 2) the trailing edge, suction surface deposits which required light scraping to be removed from the airfoils.

The deposits are 22 to 32 wt percent water soluble with approximately three times more potassium than sodium in the deposit. These trends are consistent with previous deposit analyses of the high-velocity test section deposits. The deposits also show a good molar balance between the sodium, potassium, calcium, and magnesium with the sulfate (SO_4).

Table 3-4

CHEMICAL ANALYSIS OF HVTS ASH DEPOSITS (Wt% Water Soluble)

	<u>Loose Dust</u>	<u>Trailing Edge</u>
Na	0.082	0.16
K	0.24	0.42
Ca	7.7	5.7
Mg	0.89	0.33
SO_4	23.0	16.0
Cl	.033	.050

SECTION 4

PROGRAM MANAGEMENT

The Malta PFBC continues to operate as the most reliable test facility of its type in the world. During the quarter, total test time reached 4398 hours. Sufficient data have now accumulated so that we can begin to make preliminary estimates of materials life in the PFBC effluent. In addition to data on turbine materials life, we continue to accumulate information on the performance of other materials of construction in the overall PFBC system.

On December 12, 1983, an LTMT Program Review was held in Morgantown. The scope of the review covered the entire program from the beginning. The significant results from the program, and the application of those results to the evolution of the coal-fired combined cycle, were highlighted. It was agreed that at the 6000-hour mark changes in test conditions would be considered. The test will then proceed in 1000-hour increments with a change in test conditions every 1000 hours up to 10,000 hours. This would insure that the final 10,000-hour test results had validity over the entire range of conditions under which the PFBC will operate.

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LONG TERM MATERIALS TEST PROGRAM

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