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LONG TERM MATERIALS TEST PROGRAM

Quarterly Report for the Period July—September 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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LONG TERM MATERIALS TEST PROGRAM

QUARTERLY REPORT

July Through September 1983

Prepared for

U.S. DEPARTMENT OF ENERGY

under

CONTRACT DE-AC21-79ET15457

Program Manager
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**GENERAL ELECTRIC COMPANY
ADVANCED ENERGY PROGRAMS DEPARTMENT
SCHENECTADY, NEW YORK**

GENERAL **ELECTRIC**

ABSTRACT

Corrosion and erosion/corrosion testing of gas turbine vane and blade base alloys and a variety of protective coating systems under the Long Term Materials Test program has surpassed 3400 hours. The PFBC facility at Malta, New York continues to show an exceptionally high degree of reliability and consistency in performance. Operating conditions include a 1650°F bed temperature at 10 atmospheres pressure utilizing Pittsburgh No. 8 coal and a low alkali dolomite sulfur sorbent.

After 2687 hours, unprotected nickel and cobalt base vane and blade alloys generally experienced corrosion rates of 1-2 mils/1000 hours at metal temperatures of 1100°, 1300° and 1500°F. Precious metal aluminide and MCrAlY coatings continue to show excellent corrosion resistance (<0.5 mils/1000 hrs) at 1500°F, but are susceptible to varying degrees of pitting attack at 1100° and 1300°F. Erosion/corrosion degradation rates at 800-900 ft/s, 1350°F and less than 100 ppm dust loading ranged from 1-4 mils/1000 hours with corrosion predominately concentrated in areas of particle impaction indicating an erosion/corrosion synergism.

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SUMMARY

The Long Term Materials Test program being conducted in the Pressurized Fluidized Bed Combustion (PFBC) facility at Malta, New York has accumulated 3440 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 30-90 ppm dust loadings.

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 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.

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

ACKNOWLEDGEMENTS

The individuals at the General Electric Company with major responsibility for this program are as follows:

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

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

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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)

During the July-September quarter, 753 hours of testing were completed increasing the total number of test hours to 3440 for the Long Term Materials Test. Test operations proceeded as scheduled throughout the period with the test facility exhibiting a very high degree of reliability and consistency of performance. The only significant operational problem continues to be associated with degradation of the in-bed heat exchanger coil.

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. Coal deliveries during this period contained 5 wt% sulfur.

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 with 5 percent sulfur coal. Sulfur capture typically ranges from 91 to 95 percent based on 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 No. 20 dolomite (with a maximum of 7% -100 mesh) has been selected for use

Table 2-1

LTMT OPERATING CONDITIONS

Combustor

Coal	Pittsburgh No. 8
Dolomite	Pfizer, National Lime & Stone Co.
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	1490°-1520°F
Outlet Temp	1440°-1480°F
Cooled Pin Temps	1300°F $\pm$ 50°, 1100°F $\pm$ 50°

High Velocity Test Section

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

⁽¹⁾Range of 15 analyses

Table 2-2

COAL ANALYSIS
PITTSBURGH NO. 8
(Wt%)

<u>Proximate Analysis (As Received)</u>	<u>Range of 6 Analyses</u>	<u>Avg. of 6 Analyses</u>
Moisture	2.18-4.70	3.43
Ash	10.30-16.69	14.27
Volatile	33.40-37.60	35.16
Fixed Carbon	45.21-49.92	47.13
Btu/lb	11521-12497	12188
 <u>Ultimate Analysis (As-Received)</u>		
Moisture	2.18-4.70	3.43
Carbon	62.44-71.15	66.25
Hydrogen	4.48-4.86	4.68
Nitrogen	1.14-1.36	1.25
Chlorine	0.11-0.21	0.15
Sulfur	4.24-5.54	4.99
Ash	10.30-16.69	14.27
Oxygen	4.14-5.73	4.97
 <u>Ash Analysis</u>		
SiO ₂	32.52-37.47	34.82
Al ₂ O ₃	18.38-19.77	19.17
Fe ₂ O ₃	37.43-41.87	39.65
TiO ₂	0.81-0.90	0.85
CaO	0.66-1.67	1.09
MgO	0.54-0.76	0.63
K ₂ O	1.19-1.72	1.47
Na ₂ O	0.19-0.41	0.34
SO ₃	0.91-1.72	1.20

Table 2-3
CHEMICAL ANALYSES OF DOLOMITES
(Wt%)

	<u>Pfizer</u>	<u>National Lime & Stone #20</u>
CO ₂	43.68	48.34
CaO	31.81	29.47
MgO	22.83	21.03
SiO ₂	1.52	0.56
Al ₂ O ₃	0.57	0.17
Fe ₂ O ₃	0.22	0.21
K ₂ O	0.0	0.0
Na ₂ O	0.15	0.10
SO ₃	0.67	0.10
Cl	0.24	0.09

throughout the remainder of the Long Term Materials Test. This dolomite is similar to the Pfizer material in both chemical composition, Table 2-3 and size distribution, Table 2-4.

Alkali Probe Measurements

Water soluble alkali levels measured during the Long Term Materials Test are 0.08-0.21 ppm Na, 0.17-3.21 ppm K, and 9-10 ppm chlorides in the combustion products. 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.

Table 2-4

DOLOMITE SIZE DISTRIBUTIONS
(wt%)

<u>Sieve Mesh No.</u>	<u>Pfizer</u>	<u>National Lime No. 20</u>
10		
20	6.7	3.2
30	25.3	16.0
40	32.7	37.5
50	26.4	18.5
100	7.5	18.4
-100	1.2	6.4
Mean Particle Size (Microns)	430	360

Chemical Analysis of Bed and Cyclone Particulates

Samples of materials from the bed off-take and each of the three cyclones were bulked for the 2687-3440-hour test period. Representative samples of each of these batches of solid waste materials were analyzed for chemical composition. Table 2-5 lists these analyses.

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.

Table 2-5

CHEMICAL ANALYSES OF BED AND CYCLONE PARTICULATE
LTMT - 6/83-9/83

	<u>Bed Material</u>	<u>First Cyclone</u>	<u>Second Cyclone</u>	<u>Third Cyclone</u>
C	1.63	2.48	1.25	0.75
CO ₂	6.86	7.11	2.18	1.44
CaO	32.47	26.05	19.29	18.24
MgO	22.71	17.35	9.97	8.96
SiO ₂	8.70	15.67	23.53	23.47
Al ₂ O ₃	3.94	8.71	14.04	15.26
Fe ₂ O ₃	4.46	15.34	18.06	16.80
K ₂ O	0.36	0.64	1.08	1.14
Na ₂ O	0.29	0.24	0.48	0.53
SO ₃	26.74	15.42	12.73	14.65
Cl	0.34	0.27	0.29	0.27

In-bed Heat Exchanger Corrosion

On two occasions during this quarter, the 310 stainless steel in-bed heat exchanger coil developed small holes which were detected at post-shutdown inspection. The penetrations were located in the tube wall near the inlet end approximately 4 to 6 inches below the Swagelok fitting connecting the coil to

the Inconel 625 riser tube, Figure 2-1. Service life of the coils was 591 and 434 hours. (Both coils subsequently were repaired by replacing the corroded section of tubing with a new section of 310 ss tubing.)

Penetration of both these coils occurred by severe pitting attack of the stainless steel tubing. This pitting attack occurs primarily near the inlet end of the heat exchanger with little or no pitting on the coils or the outlet end. Figure 2-2 shows a photomicrograph of the failed area on one of these coils. Although penetration occurred near a tack weld connecting a washer to the 310 ss tubing, the corrosion is not believed to be directly related to the weld or heat affected zone, as the subsequently tested coil was corroded in an area removed from any welds.

Figure 2-1 In-Bed Heat Exchanger Coil Assembly

Figure 2-2 Through-Penetration of 310SS In-Bed Heat Exchanger Coil Tubing

SECTION 3

MATERIALS EVALUATION (TASKS 3, 5, 6)

A total of 3440 specimen exposure hours have now been completed under the Long Term Materials Test. After 2687 hours, four sets of low velocity test section pin specimens were removed for metallurgical evaluation of corrosion penetration. These four sets of pin specimens included the following: 1) 1500°F (uncooled), 2687 hours; 2) 1500°F (uncooled), 1602 hours; 3) 1300°F (cooled), 1602 hours; 4) 1100°F (cooled), 1602 hours. The following sections summarize the details of the metallurgical analyses performed on these test specimens.

Uncooled Pins - 1500°F

Table 3-1 summarizes the 1500°F maximum corrosion penetration data for each test material and exposure interval evaluated to date. Corrosion of all the materials was generally uniform around the circumference and along the length of the uncooled pins. The unprotected base alloys, U-500, IN-738, IN-939 and FSX-414, showed deeper corrosion penetration, 3.4 to 5.0 mils, than any of the protective coating systems. Corrosion of all the base alloys was characterized by surface and subsurface oxidation with some internal sulfide formation. The nickel-base alloys typically showed preferential attack along the grain boundaries, Figure 3-1, while the cobalt-base, FSX-414, exhibited oxidation of the carbide substructure, Figure 3-2.

All of the protective coating systems showed generally good corrosion resistance at 1500°F, except the "straight"-aluminide (RT-19) coating which was penetrated to the interdiffusion zone in both the 1602 and 2687-hour exposures. The precious metal aluminide coatings, RT-22 and RT-44, and the MCrAlY overlay coatings all experienced corrosion rates less than 1 mil/1000 hours after 2687 hours exposure.

The relatively high rate of attack on the plasma sprayed (PS) Co-29Cr-6Al-0.4Y coating compared to the Co-30Cr-5Al-0.4Y physical vapor deposited (PVD) coating appears to be related to the surface condition of the respective coatings. Figure 3-3 shows the internal oxidation attack of the

Table 3-1
LTMT 1500°F CORROSION DATA

<u>MATERIAL</u>	<u>Maximum Penetration (Mils)</u>					<u>Coating Thickness</u>
	<u>285 HRS</u>	<u>800 HRS</u>	<u>1085 HRS</u>	<u>1602 HRS</u>	<u>2687 HRS</u>	
U-500	1.3	1.3	3.4	2.0	3.4	--
IN-738	1.0	1.9	2.3	2.9	3.7	--
IN-939	0.8	2.1	2.0	3.0	4.7	--
FSX-414	3.2	1.8	2.8	3.2	5.0	--
RT-19	1.8	1.8	1.3	2.7**	2.7**	2-3
RT-22	0.2	0.1	0.3	0.2	0.1	3-4
RT-44	N.D.*	N.D.	0.1	N.D.	0.1	3-4
FeCrAlY (Clad)	N.D.	0.2	0.3	0.5	0.3	9-10
FeCrAlY (PVD)	N.D.	0.2	0.2	0.3/0.3 ⁺⁺	0.2/0.3	8-12
CoNiCrAlY (Clad)	0.5	1.0	1.0	0.9	2.0	9-10
CoCrAlY (23Cr-9Al)	N.D.	N.D.	N.D.	N.D./0.2	0.1/0.3	6-8
CoCrAlY (30Cr-5Al)	N.D.	0.6	0.2	0.3/0.3 ⁺⁺	0.1/1.3	6-8
CoCrAlY (29Cr-6Al)	0.8	1.2	1.4	1.3	2.2	8-9
Ceramic-TBC	Spalled	Spalled	Spalled	N.T.	Spalled	8-9
IN-671	N.T. ⁺	N.T.	6.9	N.T.	N.T.	9-10

*N.D. - None Detected

⁺N.T. - Not Tested

**Coating Failure

⁺⁺IN-738 substrate/FSX-414 substrate

Figure 3-1 IN-939 After 2687 Hours at 1500°F. This Hot Corrosion Attack Was Typical for All the Nickel-Base Alloys After 1500°F

Figure 3-2 FSX-414 After 2687 Hours at 1500°F

Figure 3-3 Plasma-Sprayed Co-29Cr-6Al-0.4Y After 2687 Hours at 1500°F

Figure 3-4 Physical Vapor Deposited Co-30Cr-5Al-0.4Y Coating After 2687 Hours at 1500°F

plasma sprayed coating. Internal corrosion attack appears to emanate from the pit-like defects on the surface of the coating. Deposits which accumulate on the pits may create a micro-environment significantly more corrosive than the nominal environment in the low velocity test section. Figure 3-4 illustrates the appearance of the PVD Co-30Cr-5Al-0.4Y coating exposed 2687 hours.

1300°F

Corrosion data for the materials tested at 1300°F are listed in Table 3-2. Depth of penetration measurements on many of the materials at 1300°F were similar to the 1500°F data after 1602 hours exposure. Corrosion morphologies, however, were significantly different in many cases.

The nickel-base alloys, U-500, IN-738 and IN-939, exhibited 3.0, 2.2 and 1.5 mils of penetration respectively. Corrosion of these materials was characterized by the formation of relatively thick surface oxides/scales with little or no internal oxidation. Internal sulfide formation was more prevalent than at 1500°F, as shown in Figure 3-5 for U-500.

Cobalt-base FSX-414 at 1300°F showed a similar corrosion behavior to that observed at 1500°F; i.e., internal oxidation of the carbide structure.

The RT-19 aluminide coating was dropped from 1300°F testing after 800 hours due to severe corrosion attack. The precious metal aluminide coatings, RT-22 (Pt-aluminide) and RT-44 (Rh-aluminide), which showed excellent resistance to corrosion at 1500°F exhibited pitting attack at 1300°F. RT-22, Figure 3-6, was severely pitted in many areas with penetration extending to the inter-diffusion zone between the aluminide coating and IN-738 substrate.

The FeCrAlY and CoCrAlY coatings showed good corrosion resistance with little or no attack. Figure 3-7 shows the typical corrosion on the FeCrAlY cladding alloy. The more extensive but generally isolated pitting attack observed on these coatings after 800 hours was absent during the 1602 hour exposure. The reason for the absence of corrosion on the longer exposure specimens is not understood. Only the CoNiCrAlY cladding showed somewhat extensive attack, typical for this material throughout the long term testing to date.

Table 3-2

LTMT 1300°F CORROSION DATA

<u>MATERIALS</u>	<u>MAXIMUM PENETRATION (MILS)</u>			<u>COATING THICKNESS</u>
	<u>285 HRS</u>	<u>800 HRS</u>	<u>1602 HRS</u>	
U-500	0.8	3.1	3.0	--
IN-738	0.8	1.0	2.2	--
IN-939	1.0	1.4	1.5	--
FSX-414	1.0	2.0	3.1	--
RT-19	N.T. [†]	2.0	N.T.	2-3
RT-22	1.2	N.T.	3.5**	3-4
RT-44	N.D.*	0.2	0.6	3-4
FeCrAlY (Clad)	1.8	2.5	0.4	9-10
FeCrAlY (PVD)	N.D.	1.5	N.D.	8-12
CoNiCrAlY (Clad)	1.8	3.5	2.2	9-10
CoCrAlY (23Cr-9Al)	N.D.	5.0	N.D.	6-8
CoCrAlY (30Cr-5Al)	N.D.	N.D.	N.D.	6-8
IN-671	---	2.8 (1085 Hrs)	---	9-10

[†]N.T. - Not Tested
 *N.D. - None Detected
 **Coating Failure (Discontinued from Test Matrix after 800 hrs)

Figure 3-5 U-500 After 1602 Hours at 1300°F

Figure 3-6 RT-22 (Platinum-Aluminide) Coated IN-738 After 1602 Hours at 1300°F

Figure 3-7 FeCrAlY Clad IN-738 After 1602 Hours at 1300°F

Figure 3-8 IN-738 After 2130 Hours at 1100°F

1100°F

Corrosion penetration data for the materials tested at 1100°F is listed on Table 3-3. Under the column of data for 1602 hours, the numbers shown in parentheses are the exposure hours for the various cooled pin specimens at the time when the 304 ss adapter tubes failed. (Failure of the 304 ss tubing was discussed in detail in the April-June 1983 LTM Quarterly Report, DOE-ET-15457-1523.)

The U-500 and IN-738 specimens exposed for 2130 hours experienced severe corrosion attack with extensive oxide scaling evident by visual examination. Metallographic examination revealed a typical low temperature hot corrosion morphology consisting of a multi-layered scale with little or no internal oxidation or sulfidation, Figure 3-8. The IN-738 and IN-939 specimens exposed for 1602 and 1488 hours respectively at 1100°F, showed significantly less attack than the IN-738 specimen tested at 2130 hours. Corrosion attack on the shorter exposure specimens consisted of a thin surface oxide layer with internal sulfide formation 1 to 2 mils deep.

FSX-414 continued to exhibit oxidation attack of the carbide structure within the metal. Corrosion penetration at 1100°F was less than at 1300° or 1500°F, but there were more internal sulfides evident in the microstructure.

The RT-19 aluminide coating tested for 1923 hours experienced corrosion attack completely through the coating with approximately 1 mil of corrosion into the IN-738 substrate. Testing of this coating has been discontinued after 800 hours because of its high susceptibility to hot corrosion.

RT-22 and RT-44 aluminide coatings showed evidence of pitting attack, although the penetration of RT-22 at 1100°F, 0.3 mils, is an order of magnitude lower than at 1300°F. Figure 3-9 illustrates the pit formation on the RT-44 coating.

The FeCrAlY coating and cladding materials showed generally good corrosion resistance with the cladding exhibiting several isolated areas of internal oxidation to 1.4 mils maximum depth and the PVD coating having only a few

Table 3-3

LTMT 1100°F CORROSION DATA
(Mils)

<u>MATERIAL</u>	<u>MAXIMUM PENETRATION (MILS)</u>			<u>COATING THICKNESS</u>
	<u>285 HOURS</u>	<u>800 HOURS</u>	<u>1602 HOURS</u>	
U-500	1.5	1.4	4.1 (2130)	--
IN-738	0.5	2.8	2.0(1602)/6.5(2130)	--
IN-939	0.6	1.0	1.0(1488)	--
FSX-414	1.2	1.1	2.7	--
RT-19	2.0**	2.0**	3.5**(1923)	2-3
RT-22	0.8	0.7	0.3	3-4
RT-44	0.8	N.D.	1.0(1798)	3-4
FeCrAlY (Clad)	N.D.*	0.2	1.4	9-10
FeCrAlY (PVD)	N.D.	1.2	0.5(1488)	8-12
CoNiCrAlY (Clad)	3.2	5.6	2.6(1488)/5.5(2130)	9-10
CoCrAlY (23Cr-9Al)	N.D.	0.2/1.0(1085)	N.D.(1602)/2.2(1507)	6-8
CoCrAlY (30Cr 5Al)	N.D.	0.5	N.D.	6-8
TN-671	N.T. ⁺	1.9(1085 Hrs)	3.0	9-10

**Coating Failure (Discontinued from test matrix after 1923 hours)
 *N.D. - None Detected
 +N.T. - Not Tested

(1) Exposure times shown in parenthesis are hours on specimen when cooling air adapter tubes failed.

Figure 3-9 RT-44 (Rhodium-Aluminide) Coated FSX-414 After 1798 Hours at 1100°F

Figure 3-10 FeCrAlY Cladding After 1488 Hours at 1100°F

isolated pits less than 0.5 mils deep. The internal oxidation attack of the cladding, Figure 3-10, is unusual as the MCrAlY alloys have typically experienced pitting attack at 1100° and 1300°F.

CoNiCrAlY cladding and Co-23Cr-9Al-0.4Y coatings showed varying degrees of pitting attack as indicated in Table 3-3. The CoNiCrAlY continues to be the cobalt-based coating most susceptible to hot corrosion attack while the Co-30Cr-5Al-0.4Y coating shows the best resistance to attack.

An IN-671 (Ni 48Cr) clad pin specimen also was tested at 1100°F for 1602 hours. This material experienced internal oxidation attack to a maximum depth of 3.0 mils with no pitting attack observed.

LVTS -Ash Deposit Analyses

Ash deposits were collected from each set of pin specimens upon removal from the LVTS and analyzed for concentrations of water soluble Na, K, Ca, Mg, SO₄ and Cl. Table 3-4 lists the chemical analyses of these deposits. The deposits collected at 1100° and 1300°F contain significantly higher levels of Na and K than the 1500°F deposits. This enrichment in alkali level in the cooled pin deposits has been consistently observed throughout the long term testing, and is attributed to vapor deposition of the alkali species (Na and K).

TABLE 3-4

Ash Deposit Analysis
(wt% Water Soluble)

	<u>1500°F</u> <u>2687-Hrs</u>	<u>1500°F</u> <u>1602-Hrs</u>	<u>1300°F</u> <u>1602-Hrs</u>	<u>1100°F</u> <u>1602-Hrs</u>
Na	0.030	0.048	0.19	0.13
K	0.44	0.18	1.0	0.63
Ca	7.1	8.9	9.0	7.6
Mg	1.8	1.2	2.3	2.3
SO ₄	32	32	34	37
Cl	0.003	0.005	0.001	0.005

SECTION 4

PROGRAM MANAGEMENT

The Malta PFBC continues to operate as the most reliable test facility of its type in the world. The goal of 3200 hours of testing during FY-83 was met on August 26, 1983--six weeks ahead of schedule. A goal of 7200 hours of total test time through the end of FY-1984 has been set. The breadth and usefulness of the data accumulated to-date is unsurpassed. In addition to data on turbine materials life, during the past quarter results on the performance of in-bed heat exchanger materials, hot gas valves, materials of construction for cyclones and the lining of ductwork have been obtained.

It is estimated that the contract cost limitation will be reached sometime in the period May-June 1984 with about 6000 hours of testing complete. A request for an amendment to increase the contract value so that the 10,000 hour goal can be met is being prepared.

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