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LONG TERM MATERIALS TEST PROGRAM

QUARTERLY PROGRESS REPORT

JANUARY - MARCH, 1980

FOR

U.S. DEPARTMENT OF ENERGY

APRIL 1980

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAMS DEPARTMENT
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SCHENECTADY, NY 12345

DISCLAIMER

GENERAL ELECTRIC

NOTICE

GENERAL PROJECT DESCRIPTION

The General Electric Company, as part of the Coal Fired Combined Cycle Program (CFCC), identified the need to protect the gas turbine from the corrosion caused by substantial amounts of alkali in the submicron aerosol and vapor phase contained in the efflux from a pressurized fluidized bed combustor (PFBC). The Long Term Materials Test Program has been established to identify corrosion resistant materials for potential utilization in a gas turbine. These candidate materials will be exposed for significant periods of time during the 14,000 hour projected life of the program.

The Long Term Materials Test rig is shown in Figure 1. The rig will be installed in an existing building which will be leased from the New York State Energy Research and Development Authority (NYSERDA). The building will be modified as required to accommodate the test rig. The building is located in the Saratoga Research and Development Center at Malta, New York.

The Long Term Materials Test rig is a specialized (PFBC) apparatus designed to determine the long term effects of coal-fueled PFBC exhaust gas exposure on candidate gas turbine materials and components.

The significant design criteria of the test rig are:

Combustor Temperature	- 1750°F maximum
Combustor Pressure	- 150 psia
Air Flow	- .75 #/sec maximum
Coal Feed Rate	- 200 #/hr
Dolomite	- 100 #/hr

The basic construction materials will be carbon steel with refractory lining added in the high temperature zones.

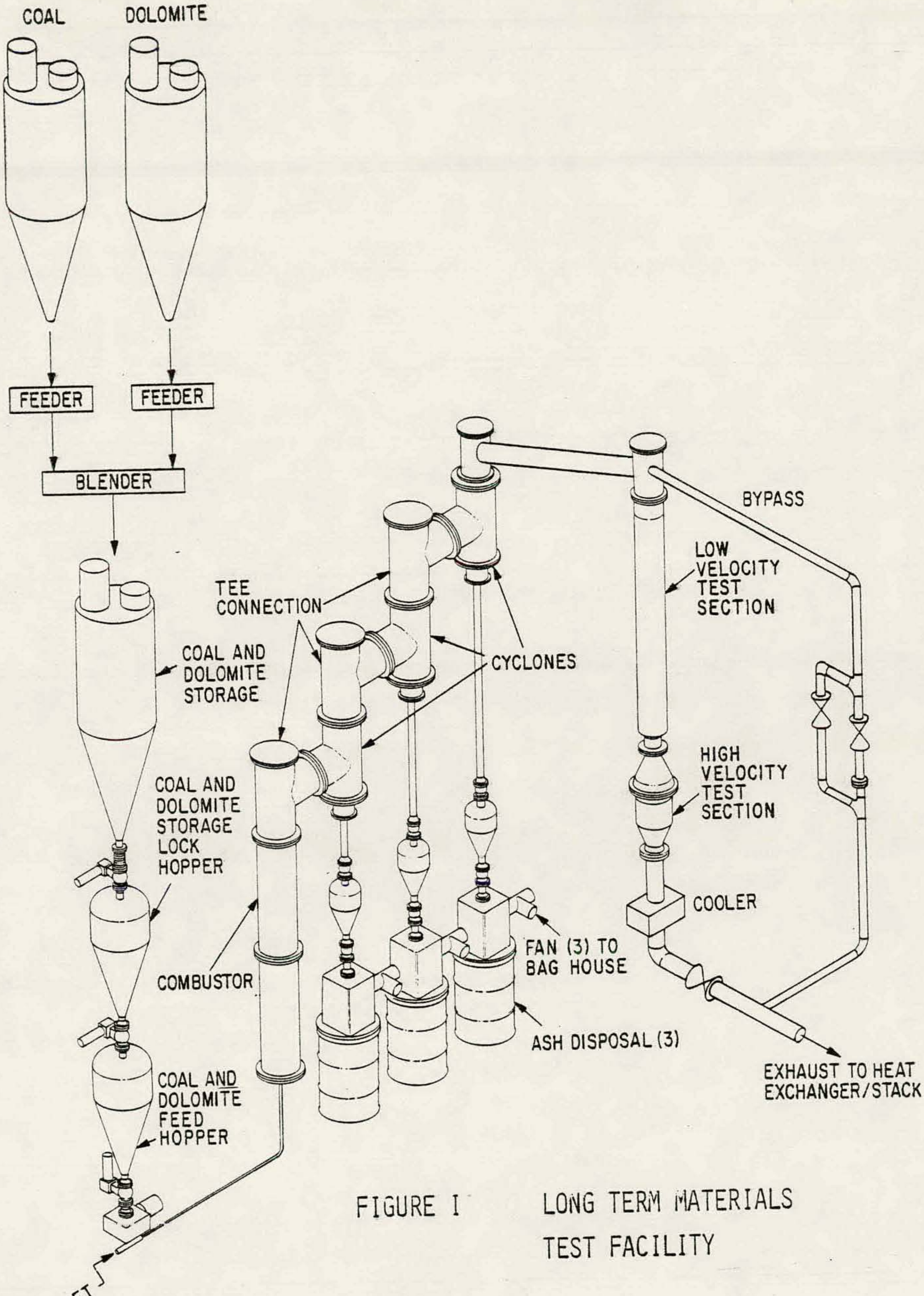

FIGURE I LONG TERM MATERIALS TEST FACILITY

WORK ACCOMPLISHED DURING REPORTING PERIOD

Task 1.0 Test Design and Qualification

General

A request for bids to perform the detailed design of the test facility based on the specification prepared during the last quarter was issued. On February 28 and 29, a PFB Materials Program Review Meeting was held in Schenectady, NY. The overall system approach, component design objectives, and experimental design plan were presented and discussed with representatives from DOE and EPRI. On March 14, 1980 a subcontract (GE funded) was signed with Rist-Frost, Associates of Glens Falls, NY, to do the detail design of the test facility. A subcontract kick-off meeting was held in which the latest design information and specifications were transmitted and reviewed.

Test Rig Process Conditions

Process conditions for the test rig has been selected to duplicate, insofar as possible, the design point conditions of the coal-fired combined cycle (CFCC) which is the particular version of the Pressruized Fluidized Bed Steam and Gas Turbine Power Plant cycle currently under development by the General Electric Company. Table 1 lists the CFCC combustor design conditions. A bed temperature of 1750°F was selected, which is high enough to provide good combustion and cycle efficiency and low enough to avoid ash fusion. Tradeoff studies have shown that the overall CFCC plant efficiency is fairly insensitive to pressure ratio over the range from 8 to 16 and a pressure ratio of 10 was selected. Excess air must, on the one hand, be kept low to minimize the gas volume flow and associated cost of hot gas cleanup equipment and, on the other hand, be high enough to avoid local reducing zones in the bed which would cause corrosion of the in-bed heat exchanger tubes. The design-point value of excess air for the CFCC combustor which we believe will meet these conditions is 20%. A bed height of 8 ft. was selected to provide the necessary bed volume for the cooling tubes and to provide for an

TABLE 1

CFCC COMBUSTOR CONDITIONS

Bed Temperature	=	1750°F	
Provides High Combustion Efficiency			
Provides High Cycle Efficiency			
Avoids Ash Fusion			
Bed Pressure	=	10 atm	
Excess Air	=	20%	
Low to Minimize Gas Volume Flow			
High Enough to Avoid Local Reducing Zones			
Bed Height	=	8.0 Ft	} = 1.8 Sec Residence
Fluidizing Velocity	=	4.5 Ft/Sec	
Combustion Efficiency Achievable			
High To Minimize Combustor Cost			
Ca/S Molar Ratio	=	1.5	
Provides 90% Sulfur Retention			

adequate gas residence time for the reactions (principally, SO_2 capture) to occur at the design point fluidizing velocity of 4.5 ft/sec. Considerations in selecting the fluidizing velocity include combustion efficiency, combustor size and cost, and particulate concentration in the gas which influences the hot gas cleanup requirements. Finally, for the CFCC combustor, a Ca/S molar ratio of 1.5 was selected to provide a 90% sulfur retention.

Table 2 summarizes the design requirements for the Long Term Materials Test Facility derived from the CFCC design conditions. In the combustor, the design requirements are identical to the CFCC conditions with the exceptions of bed height and fluidizing velocity. Experience at the CURL* indicates that, for a 1 ft chamber bed operating at 6 atm pressure, the onset of bed slugging occurs at a bed height of about 5 ft. The 1 ft diameter bed at the Exxon "miniplant" was operated without apparent slugging with a bed height of about 10 ft at a pressure of 10 atm. Since the Long Term Materials Test Facility will be operated at 10 atm pressure, it appears conservative to increase the CURL bed height to 5.3 ft. A 3.0 ft/sec fluidizing velocity was selected to duplicate the 1.8 sec gas residence time in the CFCC combustor. Included in the facility are a low velocity test section which will be used to determine long term corrosion effects on candidate gas turbine materials, and a high velocity test section to study erosion effects.

System Description

Figure 2 is a simplified flow diagram showning the essential features and components of the Long Term Materials Test Facility. A compressor delivers air at 165 psia to a receiver. The major portion of the air is delivered directly to the combustor to be used as fluidizing air, and the remainder is used as the transport medium for the solids as illustrated in Figure 2. Within the combustor, the coal is burned in a pressurized fluidized bed (PFB) of dolomite which reacts with the SO_2 to limit the sulfur in the effluent. Water flowing inside the tubes of an in-bed heat exchanger absorbs over half of the heat of the coal combustion to limit the bed temperature of 1750°F. Heat absorbed by the water is rejected to ambient in a water-to-air radiator.

The hot combustion products leave the combustor and flow through three stages of cyclones before entering the materials test sections. Exiting the high velocity test section, the gas is cooled in the exhaust gas cooler before being

*Personal communications with the staff at CURL.

TABLE 2

TEST FACILITY DESIGN REQUIREMENTS

COMBUSTOR

• Bed Temperature	=	$1750^{o}F$	
• Bed Pressure	=	150 psia	
• Excess Air	=	20%	
• Ca/S Mole Ratio	=	1.5	
• Bed Height	=	5.3 Ft	} = 1.8 sec Residence
• Fluidizing Velocity	=	3.0 Ft/Sec	
• Bed Diameter	=	1.0 Ft	

LOW VELOCITY TEST SECTION

- Gas Velocity Less Than 200 Ft/Sec
- Gas Temperature = $1650^{o}F$
- Gas Pressure = 145 psia
- Cooled and Uncooled Materials Specimens
- Specimens Easily Removed for Inspection

HIGH VELOCITY TEST SECTION

- Modify Flow Channel Used in CURL 1000 Hr Test
- Three Cascades of Impulse Vane Specimens
- One Cascade of Reaction Vane Specimens
- Erosion Pin Specimens Exposed to 1400 Ft/Sec

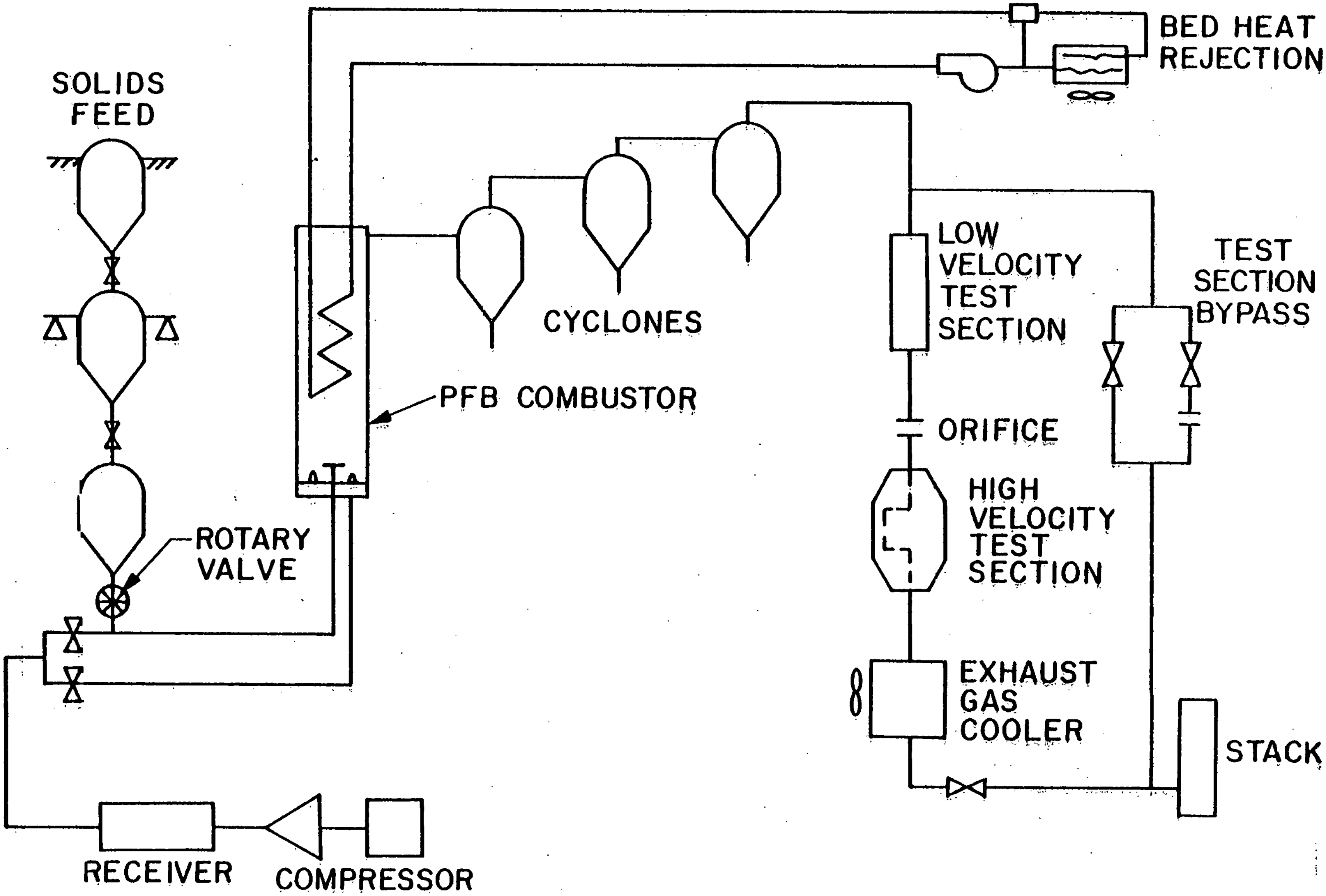

FIGURE 2 LONG TERM MATERIALS TEST FACILITY SCHEMATIC

exhausted to the stack. A bypass line around the test sections and the cooler is provided for startup purposes.

Test rig operating conditions at the design point are summarized in Table 3. At these operating conditions the rig consumes about 1.57 tons/day of coal and about 0.49 tons/day of dolomite.

TABLE 3

TEST RIG OPERATING CONDITIONS

Coal Flow Rate	131 lb/hr
Total Air Flow	1459 lb/hr (324 scfm)
Dolomite Flow	41 lb/hr
Combustion Products Flow	.4405 lb/sec (1586 lb/hr)
Gas Temperature at L.V. Test Section	$1650^{o}F$
Gas Pressure at L.V. Test Section	145 psia
Gas Pressure at H.V. Test Section Inlet	41 psia
Gas Temperature at Stack Inlet	$700^{o}F$
In-Bed Heat Exchanger Duty	801,000 BTU/hr (52% of Coal Heating Value)

Task 2.0 Test Operation

No effort planned during this reporting period.

Task 3.0 Materials Evaluation

A detailed strategy and schedule for the placement, inspection, removal and replacement of candidate materials has been developed. The schedule is based on a predetermined number of candidate alloys, the available spares in the test section and the expected shape of the corrosion curve for the materials being considered.

The low velocity test section has been designed for 132 test specimens. Seventy-two will be uncooled and sixty cooled. This design will permit the testing of 12 different materials in the uncooled configuration and ten different materials in the cooled configuration.

The preliminary low velocity inspection and removal schedule, Figure 3, is based on the expectation that corrosion will follow the general trend exhibited in Figure 4. This corrosion curve, Figure 4, illustrates a rapid initial corrosion rate followed by a stage of reduced corrosion rate in which the corrosion products are generally protective. The final stage, termed breakaway corrosion, results in very rapid attack through a loss of oxide protection. The replacement schedule permits characterization of all three of these stages of corrosion. Duplicate specimens will be removed after 250, 500, 1,000, and 2,500 hours to establish the shape of the initial rapid corrosion curve. Specimens will be withdrawn at 5,000, 7,000, and 9,000 hours to characterize the second or protective stage.

Cuncurrent with this removal schedule, cursory inspection of the specimens will be made approximately every 500 hours in order to identify the initiation of "breakaway" corrosion. For this reason three specimens have been allocated for removal in the last phase of the program after breakaway corrosion may have been initiated. If no breakaway corrosion is observed, threse three specimens will be removed at the termination of the program.

The same rationale has been used to develop the schedules for the high velocity test cascades. The six specimen locations per cascade will be utilized to generate the desired exposure times, Figure 3. Cooling of these airfoil shaped specimens is not planned. Three high potential materials will be evaluated in this test unit, as shown in matrix form, Figure 5. This matrix will simultaneously permit evaluation of materials from the same cascade while permitting evaluation of the differences in conditions which may exist between the four cascades due to slight increases in velocity throughout the high velocity unit.

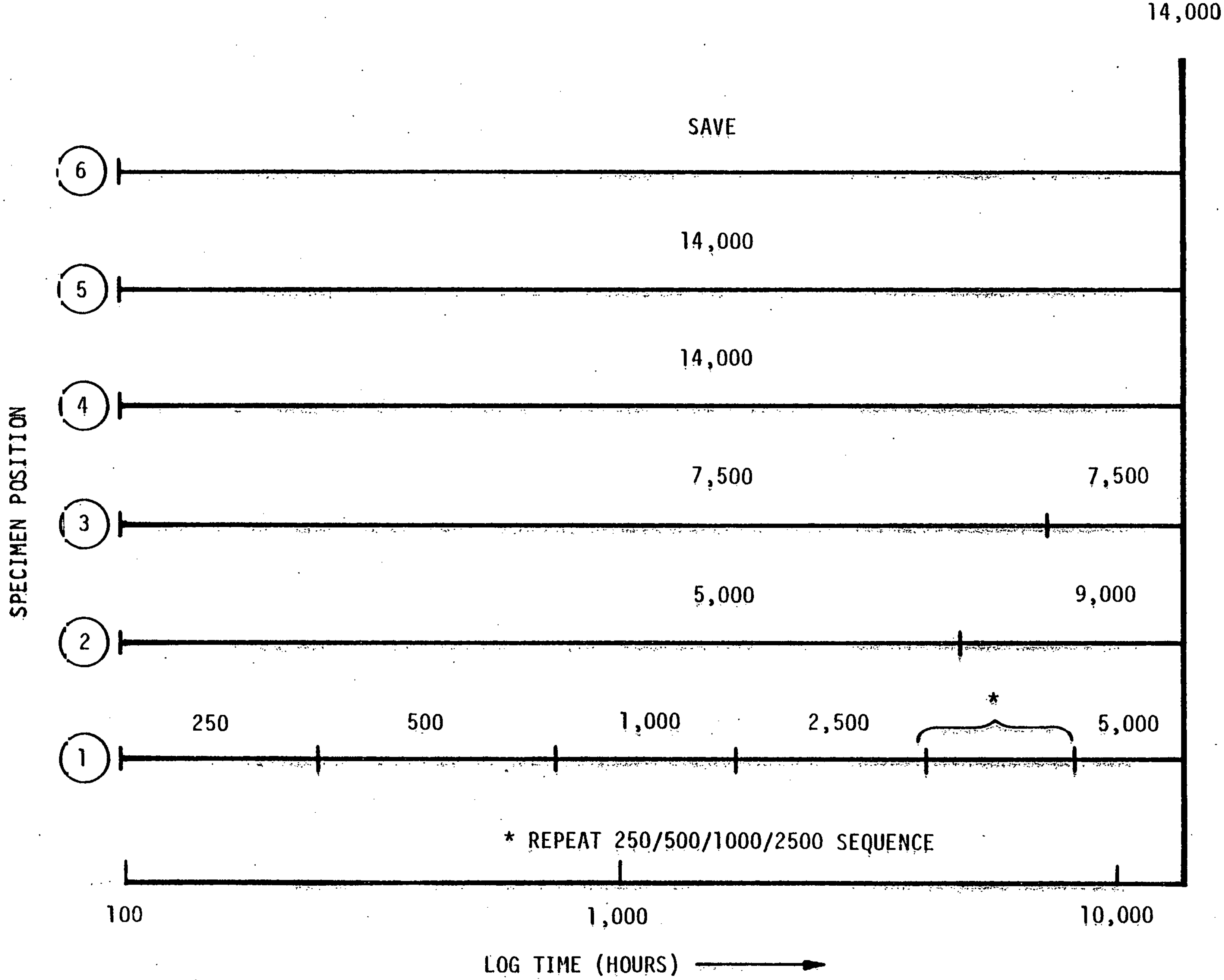

FIGURE 3 SPECIMEN REPLACEMENT SCHEDULE

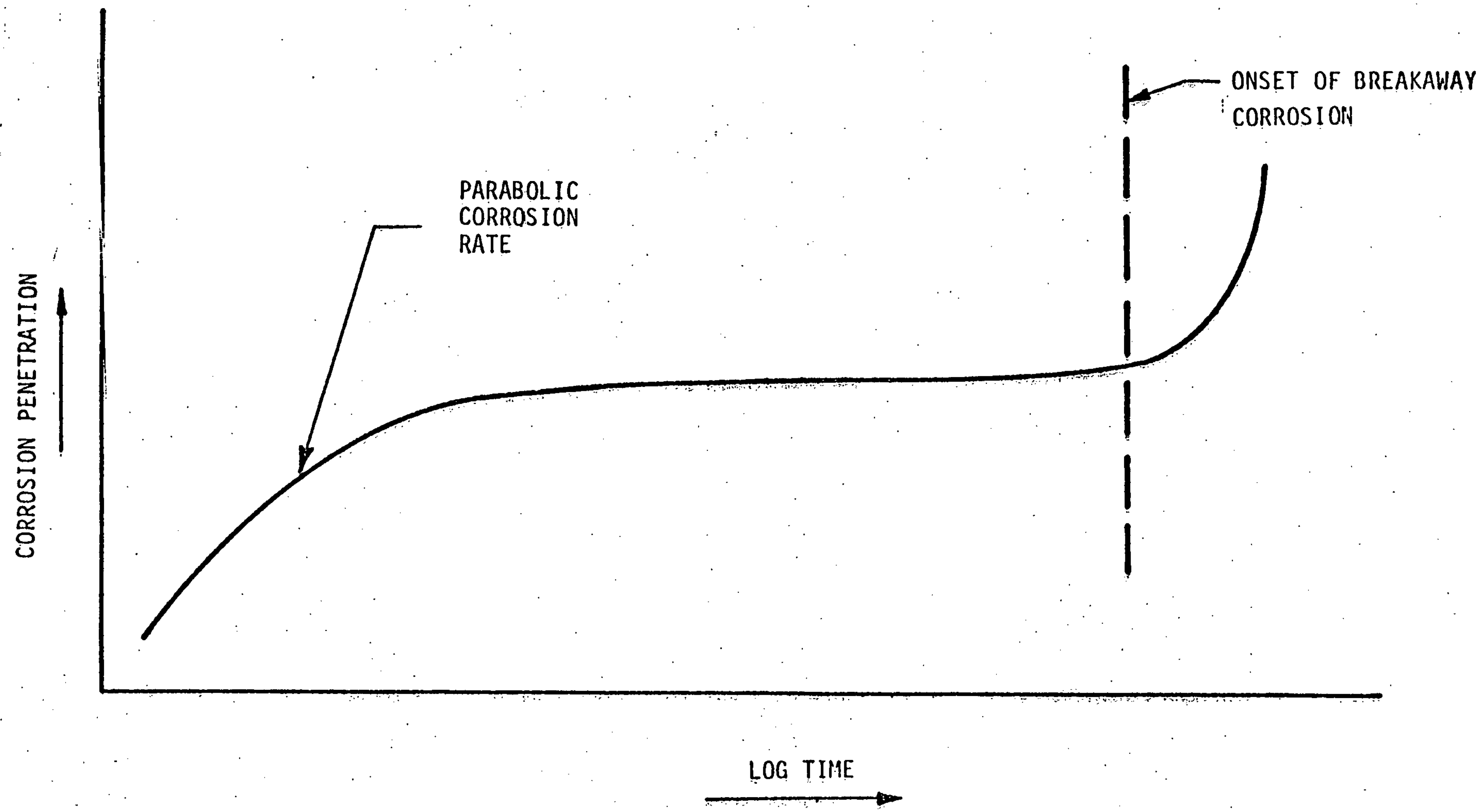

FIGURE 4 : PHILOSOPHY OF LTMT - BREAKAWAY CORROSION

POSITION / CASCADE	1	2	3	4	5	6
I	B*	A	C	C	B	A
II	A	C	B	B	A	C
III	C	B	A	A	C	B
IV	C	B	A	A	C	B
V	B	A	C			

*ALLOYS A, B AND C

FIGURE 5 PRELIMINARY MATERIALS TEST MATRIX FOR HIGH VELOCITY TEST UNIT

High velocity erosion pin specimens downstream of the fourth cascade will be inspected at intervals and replaced as required by condition of the specimens.

Task 4.0 Program Management

Deliverable End Item No. 1 titled "Management Plan" has been prepared, reviewed and delivered to DOE. This plan will be utilized as the prime management control mechanism to control and measure the performance, cost, and schedule commitments of the LTMT Program.

Deliverable End Item No. 1A titled "Preliminary Operations Plan" has been prepared and submitted for review by cognizant project personnel at Morgantown Energy Technology Center (METC).

General Electric technical personnel attended a meeting held in Morgantown, West Virginia, to review and discuss the preliminary test rig design, the preliminarly test plan, and the projected operating costs associated with the overall LTMT program.

Task 5.0 Materials Screening Tests

The value of small-burner rig screenign tests has been amply proven in the selection of materials for oil-fired gas turbines. This simple experiment provides long term exposure data, at low cost, which can be directly correlated with actual service experience. However, efforts to simulate the PFB environment utilizing the small burner rig have been generally unsuccessful. Contaminant levels (Na, K, Cl) achieved through the addition of various dopants to the fuel or combustion air have produced corrosion rates and/or morphologies in several gas turbine alloys which are atypical of results from the actual PFB environment. These differences in hot corrosion behavior may be related to the presence of significant levels of various elements, such as Ca and Mg, in the actual PFB environment which interact with the corrosive alkali sulfates.

Under the LTMT Program, an improved simulation of the PFB environment will be attempted by including the influence of flyash in the small burner rig experiments. To incorporate the effects of flyash, a slurry of the third stage cyclone catch from either the CURL 10x100 hour test or the Fireside II (Exxon) test will be sprayed on specimens prior to exposure. Initial experiments will identify the effects of exposure on the composition of the flyash with and without the addition of alkali dopants to the fuel.

The information from these first tests will then be used to design small burner rig testing conditions which are more simulative of the actual PFB environment. Candidate alloy systems will be evaluated at the established conditions. The corrosion rates and morphologies will be compared to both previous PFB testing and small burner rig testing to determine the degree of correlation. Initiation of efforts to utilize PFB flyash in small burner rig testing, as described above, has begun. The deposition characteristics of flyash and its ability adhere to the surface of specimens is being studied prior to running the tests.

Task 6.0 Materials Selection

The objective of the materials selection task (6.0) is to identify promising materials and candidate protection schemes for both nozzle and bucket use. These selected materials, coatings and claddings will be evaluated in both the long term materials test and the improved simulation test. The selection of materials will be based on the anticipated conditions in the PFB-powered gas turbine, applicable experience in coal burning and particulate laden environments, the fundamental understanding of the degradation processes of corrosion and erosion and the applicability of coatings and coating processes to commercial-scale PFB-powered gas turbines.

The key variable determining both erosion and corrosion will be evaluated with respect to the candidate systems. Specifically, the release of alkali from the system, the melting points of the sulphates, the gettering action of the kaolins and feldspars in the coal and the composition of the portective alloy system and its ability to form protective oxides will be considered in predicting the corrosion/erosion resistance of the candidate systems.

Consideration of erosion resistance in the selection of materials must take into account the many theories of erosion which currently exist. These theories incorporate fatigue damage accumulation, particle fragmentation, impact angle, local melting, time of incubation and Hertzan cracking. Even though no existing erosion theory can comprehensively model the erosion process there are several phenomena which should be considered in the selection of materials or in the evaluation of their apparent performance in similar environments:

- Erosion generally increases to the second through the fifth power of velocity
- Reduction in the leading edge diameter of an airfoil results in an increase in the number of particles impacting the surface. In other words, smaller parts are more prone to erosion than larger parts.
- Corrosion and erosion act together in a synergystic manner, producing a total degradation greater than the sum of the two processes acting independently.
- Angle of particle impact determines the some extent the degree of erosion that occurs. High impingement angle (90°) is conductive to rapid erosion of ceramics (oxides) while angles between 20-30 degrees maximize erosion of ductile materials.

The formation and maintenance of a continuous oxide film is mandatory for good resistance to corrosion. However, the influence of this oxide film on erosion resistance is unknown. In addition, the influence of the erosion process on the maintenance of the oxide scale is also unknown. The experience, to date, indicates the superior corrosion resistance also increases eroison resistance in the PFB environment. The most resistant material tested to date have been alumina (Al_2O_3) formers. The emphasis will therefore be placed on Al_2O_3 forming systems and those which form Cr_2O_3, which is well known for its resistance to corrosion, in considering alloy systems for testing.

There are several different types of protective systems and many different methods of application. From all the candidate processes of application size are best suited for use with PFB-powered gas turbines. These six, pack cementation, cladding, thermal spraying, physical vapor deposition, slurry and sputtering, will be primarily considered in selecting systems of application. A comparison of the strong and weak points of these six systems is shown in Table 4.

TABLE 4

APPLICABILITY OF COATING PROCESSES

Materials Applied	Methods Of Application	Advantages	Disadvantages
Metals	Pack Cementation	Complex Shapes Coatable	Thin, composition limitation
Ductile Metals	Cladding	Thick overlays - Some Compositional Flexibility	Complex Parts - Restricted to low Al ($\leq$ 5%)
Metals, Oxides, Carbides	Thermal Spraying	Cheap, fast, complex shapes coatable, compositional flexibility	Flaws, thickness control difficult
Metals	Physical Vapor Deposition	Complex shapes coatable, reliable	Expensive
Metals, Oxides	Slurry	Compositional flexibility, cheaply applied	Line of sight, flaws, thickness control difficult
Metals, Oxides	Sputtering	Compositional flexibility, complex shapes coatable	Slow, expensive