FOSSIL ENERGY

MASTER

Dr. 2395

DOE/ET/15602-T2

NTIS-25
Bins-250

MHD AIR HEATER DEVELOPMENT TECHNOLOGY

Technical Progress Report for Period April 1—June 30, 1980

July 1980

Work Performed Under Contract No. AC01-80ET15602

FluiDyne Engineering Corporation
Minneapolis, Minnesota

U. S. DEPARTMENT OF ENERGY

DISCLAIMER

DISCLAIMER

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A03
Microfiche A01

DOE/ET/15602-T2
Distribution Categories UC-90g and UC-93

MHD AIR HEATER
DEVELOPMENT TECHNOLOGY

Technical Progress Report
For the Period

April 1, 1980 - June 30, 1980

Prepared for
United States Department of Energy
Division of Magnetohydrodynamics
Under Contract # DE-AC01-80ET15602

Prepared by
FluiDyne Engineering Corporation
5900 Olson Memorial Highway
Minneapolis, Minnesota 55422

FluiDyne Job 1228
July, 1980

TABLE OF CONTENTS

1.0 OBJECTIVE AND SCOPE OF WORK

Work to be done under this Contract will continue the technology development of the directly-fired high temperature air heater (HTAH) for MHD power plants. The work will extend the efforts begun under previous ERDA/DOE contracts, the most recent being Contract DE-AC01-78ET10814. The Statement of Work specifies work to be done under three tasks as described in the following.

Task 1 - Materials Selection, Evaluation, and Development

The objective of this task is to continue development of ceramic materials technology for the directly-fired HTAH. The scope of the work under Task 1 will include compilation of materials data, materials selection for testing and design studies, materials property determination, liaison with refractory manufacturers and other organizations to encourage development of materials and fabrication technology, establishment of preliminary HTAH material specifications, analyses of test materials, and development of criteria for thermal stress limits for crack-tolerant refractory materials.

Task 2 - Operability, Performance, and Materials Testing

The objectives of this task are to demonstrate the technical feasibility of operating a directly-fired HTAH (including both the heater matrix and valves), to continue obtaining information on life and corrosion resistance of HTAH materials, and to obtain design information for full-scale studies and future design work. The scope of the work will include tests in the Matrix Test Facility (MTF) and Valve Test Facility (VTF) built and operated under contracts EX-76-C-01-2254 and DE-AC01-78ET10814, emissions measurements in the MTF and VTF, design of a dilatometer for performing creep measurements in the directly-fired HTAH environment, and characterization of the effluent air stream from the MTF.

Task 3 - Full-Scale Design Concepts

The objectives of this task are to begin the identification of HTAH control requirements and control system needs, and to continue full-scale study efforts incorporating updated materials and design information in order to identify development needs for the HTAH development program. The scope of the work will include size/cost analyses and parametric studies of design options using a size/cost code and other computer codes developed and refined under Contracts EX-76-C-01-2254 and DE-AC01-78ET10814, dynamic HTAH system performance calculations using the SCAMP (System Cyclic Analysis of Multiple Preheaters) computer code developed under Contract DE-AC01-78ET10814 preparation of system layouts and cost estimates, screening and definition of control systems and determination of operating methods, definition of requirements for a future test facility to test matrix support concepts at nearly full-scale, and development of design concepts for alternative heater systems and electrical isolation of the air duct from the MHD combustor.

U.S. DEPARTMENT OF ENERGY

FORM DOE 535 (1/78)

MILESTONE SCHEDULE AND STATUS REPORT

1 OF 2

1. Contract Identification	2. Reporting Period	3. Contract Number
MHD AIR HEATER TECHNOLOGY	through	DE-AC01-80ET15602

4. Contractor (name, address)
FluiDyne Engineering Corporation
5900 Olson Memorial Highway
Minneapolis, MN 55422

5. Contract Start Date: November 26,1979

6. Contract Completion Date: November 25, 1980

7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months: FY 80 (N D J F M A M J J A S), FY 81 (O N)	10. Percent Complete a) Planned	b) Actual
1.1.1	Material Selection	A, B		
1.1.2	Property Determination			
1.1.3	Liaison			
1.1.4	Specifications			
1.1.5	Materials Analyses	A, B, C		
1.1.6	Thermal Stress Criteria			
1.2.1.1	MTF Inst./Data Acq.			
1.2.1.2	MTF Modifications	A, B		
1.2.1.3	MTF Testing			
1.2.1.4	MTF Analysis/Reporting			
1.2.2.1	VTF Inst./Data Acq.			
1.2.2.2	VTF Modifications			
1.2.2.3	VTF Testing			
1.2.2.4	VTF Analysis/Reporting			

11. Remarks

Detail by WBS

12. Signature of Contractor's Project Manager and Date: [signature] 7.21.80

13. Signature of Government Technical Representative and Date

FORM DOE 536
(1/78)

U.S. DEPARTMENT OF ENERGY

MILESTONE SCHEDULE AND STATUS REPORT

1. Contract Identification MHD AIR HEATER TECHNOLOGY	2. Reporting Period through	3. Contract Number DE-AC01-80ET15602
4. Contractor (name, address) FluiDyne Engineering Corporation 5900 Olson Memorial Highway Minneapolis, MN 55422		5. Contract Start Date November 26,1979 6. Contract Completion Date November 25, 1980

7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months: FY 80 (N D J F M A M J J A S), FY 81 (O N)	10. Percent Complete a) Planned	b) Actual
1.2.3	Emissions Measurements			
1.2.4	Creep Testing Apparatus			
1.2.5	Effluent Air Stream			
1.3.1	Size/Cost	A		
1.3.2	SCAMP	A B		
1.3.3	Layout Drawings	A		
1.3.4	Cost Estimates			
1.3.5	Control Systems			
1.3.6	Matrix Support,Test Facility			
1.3.7	Alternative Heater Systems			
1.3.8	Electrical Isolation			

11. Remarks
Detail by WBS

12. Signature of Contractor's Project Manager and Date [signature] 7-21-80	13. Signature of Government Technical Representative and Date

MILESTONE LOG

Identification Number	Description	Completion Date Planned	Completion Date Actual	Comments
1.1.1A	Select. Matls for Full-Scale	Jan 80	Jan 80	
1.1.1B	Select. Matls. for Matrix Test	May 80	Jun 80	Addt'l matl's selected
1.1.1	Materials Selection	Sep 80		
1.1.2	Property Determinations	Nov 80		
1.1.3	Liaison	Nov 80		
1.1.4	Specifications	Nov 80		
1.1.5A	Analysis of Matrix and Valve Test Samples. Heat 202, VTF 1&2	Dec 79	Dec 79	
1.1.5B	Analysis of Valve Test Samples	July 80		
1.1.5C	Analysis of Matrix Test Samples	Oct 80		
1.1.5	Materials Samples Analyses	Nov 80		
1.1.6	Thermal Stress Criteria	Nov 80		
1.2.1.1	Instrumentation/Data Acquisition	Aug 80		
1.2.1.2A	Design Hot Gas Supply Duct	Jun 80	Jun 80	
1.2.1.2B	Test Hot Gas Supply Duct	Jul 80		
1.2.1.2	Reassemble Matrix	Aug 80		
1.2.1.3	Matrix Test	Sep 80		
1.2.1.4	Matrix Analysis/Reporting	Nov 80		
1.2.2.1	Instrumentation/Data Acquisition	May 80		
1.2.2.2A	Replace Valve Castable	Dec 79	Dec 79	
1.2.2.2	Reassemble VTF	Feb 80	Feb 80	
1.2.2.3	Valve Test	May 80	Jun 80	Addt'l mods. required to complete valve test.
1.2.2.4	Valve Analysis/Reporting	Nov 80		
1.2.3A	Assemble Hardware	Aug 80		
1.2.3	Emissions Measurements	Sep 80		
1.2.4	Creep Testing Apparatus	Nov 80		
1.2.5A	Assemble Hardware	Aug 80		
1.2.5B	Measurements	Sep 80		
1.2.5	Characterize Effluent Air Stream	Nov 80		

Identification Number	Description	Completion Date		Comments
		Planned	Actual	
1.3.1A	Define Base Case Dimensions	Dec 79	Dec 79	
1.3.1	Complete Parametric Studies	Nov 80		
1.3.2A	Design Point Performance	Feb 80	Feb 80	
1.3.2B	Off Design Performance	Aug 80		
1.3.2	Complete Performance Studies	Nov 80		
1.3.3	Critical Component Design Concepts - Base Case	Nov 80		
1.3.3A	Layout Drawings	Apr 80	Apr 80	
1.3.4	Cost Estimate	Nov 80		
1.3.5	Control Concepts	Nov 80		
1.3.6	Matrix Support Test Facility	Nov 80		
1.3.7	Alternate Heater Systems	Nov 80		
1.3.8	Electrical Isolation	Nov 80		

2.0 SUMMARY

During the reporting period from April 1 through June 30, 1980, work was continued on all three tasks. The work under Task 1 included materials selection for testing in the MTF, continued work on HTAH materials property determinations, liaison efforts with refractory manufacturers, initiation of work on preliminary specifications, and continued efforts on thermal stress criteria.

Under Task 2, work was done on both the MTF and VTF. The MTF hot gas supply duct was redesigned and reassembled for a test to be run during the next quarter. Reassembly of the vertical sections of the MTF was also begun. The third segment of Valve Test 3 was run, and analysis of the valve leakage data from Test 3 was completed.

The bulk of the work under Task 3 was related to three runs of the SCAMP computer code. Analysis of the results from these runs and from the first run of the FY80 example system made during the previous reporting period is continuing. In addition to the SCAMP runs, the STRHEX code was upgraded to allow two-dimensional temperature fields, a HTAH reliability analysis was reviewed, a concept for accommodation of thermal expansion was developed, and efforts on alternative heater systems and electrical isolation were initiated.

3.0 DESCRIPTION OF TECHNICAL PROGRESS

3.1 Task 1 - Materials Selection, Evaluation, and Development

3.1.1 Materials Selection and Data Base

Materials were selected for testing in the MTF during Heat 203, the next matrix test to be run (see Section 3.2). The bulk of the matrix will be reassembled with the same matrix bricks used for Heats 201 and 202 under the previous contract. These bricks are fusion cast magnesia-spinel (Corhart X-317) and have been tested for a total of 1170 hours in the previous tests.

Several bricks of a sintered spinel material were selected for testing in the low temperature region at the bottom of the matrix, in order to evaluate the performance of this relatively inexpensive material for regions of the matrix where the exceptional corrosion resistance of the fused cast material is not necessary. Full-scale HTAH designs will utilize such inexpensive materials for the lower temperature regions of the matrix in order to minimize the HTAH cost.

In addition to these two matrix materials, other fused cast materials were selected for use at the top of the matrix. Fused cast chromia (Carborundum Monofrax E) has been evaluated in earlier test work and has shown good results; this material will be used at the top of the matrix. Another fused cast material under development by Carborundum (see Section 3.1.3) will also be used at the top of the matrix. Full-scale HTAH designs will employ different materials in different positions in the matrix to use the most economically suitable material in each region. The Carborundum materials were selected in order to evaluate the performance of highly corrosion resistant materials in the region of the matrix having the highest temperature, and thus the most severe corrosion resistance requirement.

Castable spinel (Norton LS-812) was selected for the matrix hot liner and for the matrix support. This material has performed well as the hot liner in previous matrix testing, and further evaluation in this application is desired. Creep tests reported in earlier reports have shown that this material possesses sufficient creep strength for use in the matrix support. The ease of construction of the complex shapes needed for a full-scale matrix support offered by a castable material is a large economic incentive for this application. Experimental evaluation of the materials for the matrix support application in the MTF will be helpful in assessing the potential for use in full-scale systems.

Rebonded fused grain magnesia chrome (Corhart RFG) was selected for use as the hot duct liner in the MTF hot gas supply duct, based on experience in the VTF hot gas supply duct during Valve Test 3. Further discussion is given in Section 3.2.1.

Future work under this subtask will include compilation of materials for the data base, as reported in the previous progress report, and review of materials selected for use in the full-scale studies.

3.1.2 Property Determination

The objectives of this subtask are to define needs and test conditions for HTAH material property determination work being carried out at other laboratories and to interpret the results in terms of the HTAH materials data base.

A priority system was established in order to provide basic goals for the overall property determination efforts. The suggested priority rankings of properties to be determined and types of materials for which they are needed is given in Table 1. The need dates given in this table reflect the need to obtain materials data for development of the HTAH in a program which will move from the present testing scale (0.25 - 0.5 MW_{th}) to a Technology Development Unit of about 5 MW_{th}, in which all HTAH components of a single heater are tested, and finally to design of HTAH systems at progressively larger scale, for example at the CDIF and ETF MHD facilities. The work being carried out at this time and in the near future will be directed at meeting the Priority One requirements as specified in Table 1.

In the area of creep measurements, several insulating refractories were purchased and sent to Montana College of Mineral Science and Technology for creep testing. These materials were obtained from Johns-Manville and include three insulating brick materials, Yuma, JM-25, C-22Z, and a castable insulation, Blazelite 2000. These materials are potential candidates for use in full-scale HTAH systems in various locations. Those showing sufficient creep strength for the intended applications will be tested in the MTF and/or VTF.

Future work will be directed toward obtaining and improving information for the HTAH materials data base as indicated by the priority system in Table 1.

3.1.3 Liaison

The bulk of the liaison efforts during the reporting period was related to the MHD materials development program at the Carborundum Company. Carborundum is developing a fused cast material for use in the directly-fired HTAH which is based on the M_gO, $A\ell_2O_3$, Cr_2O_3 ternary. Fused cast materials have proved to be the most resistant to the corrosive HTAH environment, but most fused cast materials, which have very high density, do not have sufficient thermal stress cycling resistance for use in the HTAH. An exception has been Corhart X-317, in the M_gO-$A\ell_2O_3$ system, whose microstructure gives this fused cast material good resistance to propagation of cracks induced by cyclic thermal stresses. The intent of the Carborundum efforts is to develop a material combining the higher melting point of fused cast chromia with the better microstructure of fused cast magnesia-alumina. Samples will be provided to FluiDyne for testing in the MTF.

Development efforts are also underway at Carborundum for the production of cored brick shapes from fused cast materials. This is of great importance to the HTAH development program, since the costs of machining and drilling fused cast materials for full-scale heater matrix bricks may be economically prohibitive. The ability to obtain matrix bricks with the proper flow passages and shapes at reasonable cost will insure that the use of fused cast materials is economically feasible.

The primary goal of future liaison efforts will be to encourage development of manufacturing techniques for fusion cast cored brick shapes and of castable insulation suitable for the HTAH.

3.1.4 Specifications

Review of the requirements for refractory materials needed in the HTAH was begun, with regard to development of preliminary specifications based on material available at present. These preliminary specifications will be developed in future work.

3.1.5 Materials Analysis

No efforts were expended under this subtask during the reporting period. Future work will include analysis of materials from Valve Test 3 and from Heat 203.

3.1.6 Thermal Stress Criteria

The objective of this subtask is to develop criteria relating stress and fracture to thermal cycling. The furnace to be used for the experiments has been built by Montana Tech. The experimental work will be carried out on cylindrical refractory samples under a cyclic temperature and stress as specified by FluiDyne and reported in the previous progress report. The Montana Tech furnace has been tested and the specified temperature cycle has been achieved.

Ultrasonic characterization of the samples will be used as a non-destructive method for determination of crack propagation within the samples. This will initially be done before and after samples are tested in the furnace, and eventually will be used as an in situ method during the conducting of the thermal stress cycling experiments.

3.2 Task 2 - Operability, Performance, and Materials Testing

3.2.1 Matrix Test Facility (MTF)

During the reporting period, the MTF hot gas supply was redesigned and constructed, and reassembly of the remainder of the MTF was begun.

The operability results of previous tests in the MTF (Heats 201 and 202) have been disguised to some degree by experimental difficulties with the hot gas supply duct, in which the simulated MHD gas is produced through combustion of propane and injection of solid seed and ash particles. Both the gas temperature, on the order of 2033 K (3200 F) or greater at the combustor, and the need for vaporizing seed and melting ash (resulting in solid and liquid particles in the stream for some distance) represent more severe corrosion/erosion conditions than will exist in an actual directly-fired HTAH. The refractory material lining in this duct has undergone serious degradation during tests having duration greater than 200-300 hours, and the degradation products have flowed into the matrix and formed deposits in the flow passages.

Evaluation of the test results and discussions with the combustor manufacturer led to the conclusion that the refractory degradation was enhanced by the small size of the supply duct, which had an inside diameter of 0.15 m (6 in). The duct has been rebuilt with an inside diameter of 0.28 m (11 in) for test work under the present contract (see Figure 1). The increased duct diameter will result in a lower surface temperature and, more importantly, will provide more volume for expansion of the flame from the combustor and reduce the severity of flame and particle impingement on the refractory surface. The inner diameter of the duct is reduced to a previously existing .15 m (6 in) ID section of the duct upstream of the matrix through a transition section 2.3 m (7.5 ft) downstream of the combustor.

As discussed in Section 3.1.1, Corhart RFG was selected for the hot liner in the new section of the duct. Both RFG and X-317 (fused cast magnesia-spinel) had been used for the hot liner with the smaller diameter duct, and both had degraded badly. However, RFG was used with good success in the VTF hot gas supply duct where spinel-based materials had performed poorly under the same conditions. It appears that in the region immediately downstream of the combustor, where the injected seed particles have not vaporized, the spinel materials are more severly attacked by ash than they are in the downstream portion of the duct in the matrix. Therefore, RFG was chosen as the hot liner in the new section of the MTF hot gas supply, while the previously used X-317 was retained in the portion of the duct downstream of the transition to smaller inside diameter.

In order to confirm that the redesigned hot gas supply duct will not degrade to an extent harmful to the operability testing planned for Heat 203, a test of the duct itself will be run prior to testing with the matrix in place. If serious degradation is still evident, a more extensive modification of the duct will be required before Heat 203 is run. Heat 203 will have a duration of at least 300 hours and is intended to demonstrate operability of the cored brick matrix over long duration without fouling of the flow passages by seed/slag deposits.

Reassembly of some of the vertical sections of the MTF has also begun, including core drilling of the X-317 matrix bricks as necessary. Reassembly will be made with the materials delineated in Section 3.1.1.

3.2.2 Valve Test Facility (VTF)

During the reporting period, repairs to the VTF were completed and the third segment of Valve Test 3 was run. The total time of operation of the VTF during Test 3 has been 592 hours. During this total operating period, the facility was operated cyclically for a total of 375 cycles, and for a total of 154 hours and 282 cycles with seed/ash injection. The third segment of Valve Test 3 was stopped due to accumulation of slag deposits in the main burner. Preliminary estimates indicate that about 5-10% of the slag injected during this portion of Test 3 deposited in the burner.

The data from Test 3 has been analyzed in terms of leakage through the test valve. The procedure used to reduce the leakage data is discussed in the following.

During each pressurization phase, air phase, and depressurization phase, strip chart recordings were made of the pressure in the high pressure portion of the VTF and of the air temperature in the upper spray chamber (see Figure 2). From the strip chart recordings, the leakage through the test valve can be deduced from the rates of decay of the system pressure and temperature. The leakage mass flow is given by:

$$\dot{m} = \frac{V}{RT} \left[\frac{dp}{dt} - \frac{p}{t} \frac{dT}{dt} \right] \qquad (1)$$

where
$\dot{m}$ = leakage mass flow
p = pressure
T = bulk average temperature
V = pressurized volume
R = gas constant for air

Determination of the bulk average temperature, however, is extremely difficult since the pressurized volume includes air at temperatures ranging from ambient at the pressurization valve to about 1922 K (3000 F) in the hottest temperature regions, including temperature gradients along the storage heater and through the porous insulating refractories (Figure 2). Therefore, the method chosen for determining the test valve leakage was to monitor the temperature at a single point in the system where measurement could be accurately and reliably achieved over the course of an entire test and relate the measured temperature to the bulk average temperature through empirical constants. This gives the leakage computation in the form:

$$\dot{m} = \alpha \frac{V}{RT_m} \left[\frac{dp}{dt} - \beta \frac{p}{T_m} \frac{dT_m}{dt}\right] \qquad (2)$$

where T_m = measured temperature

The factors α and β then relate the bulk average temperature and temperature decay rate to the measured values by:

$$\alpha = \frac{Tm}{T} \qquad (3)$$

$$\beta = \alpha \frac{dT/dt}{dTm/dt} \qquad (4)$$

The values of α and β are not constant in time. The temperature measured in the spray chamber will initially have a lower value and a greater rate of decay than the bulk average temperature, since the spray chambers has water cooled metal walls with no insulation (spray quench water is not introduced to the spray chamber during the pressurization, air, and repressurization phases). As the air phase continues, however, the decay rate of the measured temperatures will eventually become smaller than that of the bulk average temperature.

If the VTF operates in a state of cyclic equilibrium, and if measurements of pressure, temperature, and decay rates are always made at the same point in the VTF cycle, the values of α and β can be considered constant for that point in the cycle. This assumption was made in order to compute the leakage mass flow through the valve during operation of the VTF from the raw measured data.

In order to determine the values of α and β, leakage data measured in so-called "cold flow" tests was compared with the strip chart recordings from Valve Test 1, in which the VTF was operated cyclically with clean flow (i.e., no seed/ash injection). The cold flow tests were conducted with the VTF at ambient temperature, and the pressurizing air was unheated. In these tests, the measured temperature closely approximated the bulk average temperature, so α and β were assumed to be unity. This allowed a straightforward calculation of the leakage mass flow from the strip chart recordings.

A heat transfer analysis showed that, for leakage flow rates less than about 0.01 kg/sec (0.022 lbm/sec), the air actually reaching the valve seats did not differ in absolute temperature by more than 10% from the temperatures in the cold flow tests regardless of the temperature level entering the main valve cavity. This is due to heat loss by the air to the water cooled valve body and stems. Furthermore, calculations of mass flow through a channel of abritrary dimension including the effects of friction and heat transfer indicated that variations of air temperature of even greater magnitude had virtually no effect on the leakage rate due to the high rate of heat loss to the cooled valve seats. Since the leakage rate during the initial cold flow tests was only about .0015 kg/sec (.0033 lbm/sec), it was concluded that the leakage flow during operation of the

VTF at elevated temperature would not differ from the cold flow measurements during the early operation of the facility before any changes in the valve sealing surfaces could occur.

The values of α and β were then empirically determined by selecting values which provided a good match between the initial cold flow measurements and the early measurements during the first test of the VTF. The values thus determined were:

$$\alpha = 0.5 \quad (5)$$

$$\beta = 0.16 \quad (6)$$

These values are also supported by estimates of the bulk average temperature which established an allowable range into which the empirically determined values fit.

The leakage mass flow results are shown in Figure 3. Results from Valve Tests 1, 2, and 3 are shown in this figure, with the leakage plotted vs. number of valve cycles since the test valve was received from the manufacturer. The cold flow measurements made at various times during the conducting of the valve tests are shown as well as the leakage measurements during actual operation of the VTF including periods with and without injection of seed and ash into the hot gas stream. Seed and ash injection rates were adjusted to produce a gas stream with 1% potassium and 0.1% ash by weight, as in previous materials and matrix tests run under the FluiDyne HTAH development program. The seed material was potassium sulfate and the ash was from Montana Rosebud coal. The level of ash represents a total carryover of approximately 10% when considering ash rejection in the combustor and radiant boiler.

A number of results are evident from the test valve leakage data shown in Figure 3. During operation with clean flow in Test 1, the leakage flow rate was quite stable. When seed/ash injection was begun in Test 2, the leakage increased slightly. The sharp increase in leakage after 385 cycles was caused by degradation of phosphate bonded spinel castable insulation, which caused scoring of the valve seats. As was shown in the previous Progress Report, this castable material was lacking in the phosphate bond phase and never attained sufficient green strength. This condition accelerated the degradation in the presence of seed and ash. The calcium aluminate bonded spinel castable insulation was installed in the test valve at this point before Test 3 was begun. The scored valve seats were not resurfaced.

The cold flow leakage measurements made immediately after Test 2 and immediately before Test 3 indicate that the leakage was reduced considerably after the valve was reassembled with the new insulation. This was perhaps due to slight misalignment of the scratches on the body and gate seats during reassembly. The leakage quickly increased to the Post-Test 2 level when Test 3 was begun. At the point when seed/ash injection was begun during Test 3, a dramatic reduction in leakage was observed. The seed material apparently deposited on the seats and helped to fill in the leakage gaps caused by earlier scoring of the seats and allowed the valve to effect a better seal.

The leakage level fluctuated about a much reduced level for about 75 cycles. The fluctuations may be due to buildup and subsequent "washing out" of the seed deposits in the leakage scratches. Operational difficulties resulted in a stoppage of the seed/ash injection and the leakage rapidly increased to the highest value yet observed. This may have been due to abrasive action of wall deposits on the seats which were no longer protected by the powdery seed material. The leakage again declined dramatically when the seed was restarted, but the range of fluctuations in leakage over the next 50 cycles was much greater.

The VTF was shut down at this point due to slag accumulation in the main burner, as reported earlier. Test 3 was restarted after some modifications were made to the hot gas supply duct. Again the leakage decreased dramatically when seed/ash injection was begun, but over the next 90 cycles the leakage steadily deteriorated. The VTF was again shut down at this point when it was discovered that a severe insulation failure had occurred in the hot gas supply duct, as reported earlier. Insulating firebrick and slag were found to have deposited on the valve seats, preventing good contact of the sealing surfaces. The cold flow measurements made after this shutdown indicated an increase in leakage of a factor of 2.2 over the cold flow measurement made 100 cycles earlier. The valve gate was removed from the valve and the slag/firebrick deposits removed from the valve body and gate, and the hot gas supply duct was repaired. Again, the scored valve seats were not resurfaced. The valve insulation refractory was not repaired or replaced.

When Test 3 was restarted for this test segment, the leakage level had returned to roughly the same value as before the duct insulation failure. Again the leakage decreased when seed/ash injection was begun, and the leakage remained roughly the same at an average value of about .005 kg/sec (.011 lbm/sec) for the remaining 90 valve cycles.

Despite the considerable operational difficulties encountered with the VTF hot gas supply duct, the test valve leakage has not shown a large increase during normal operation of the facility after a total of 780 valve cycles, including approximately 410 cycles with seed/ash injection. The peak value in leakage during the last operating period was .011 kg/sec (.024 lbm/sec) compared to the initial value of .0015 kg/sec (.0033 lbm/sec) when the valve was received, a factor of 10 increase. The increase in leakage was caused by failure of the initial valve insulation, which was shown to be defective, by operation of the VTF without seed/ash injection during a segment of Test 3, and by failure of the refractory insulation in the VTF hot gas supply duct.

Despite these severe operational problems, the final peak value of the leakage represented only 33% of the value which was allowed for leakage of the gas inlet valve at 827 kPa (120 psia) in the model used in the full-scale studies, when corrected to the dimensions of the test valve. The valve leakage model used in the full-scale studies resulted in a total leakage mass flow of 1.3% of the air delivered to the combustor for the FY 80 HTAH. At no time during operation of the VTF did the test valve leakage exceed the predicted value from the full-scale studies model.

The valve test results to date indicate that use of a gate-type gas inlet valve for HTAH systems will be technically feasible. Long term service life results must yet be obtained, but the leakage measurements during Valve Tests 1, 2, and 3 indicate that even if substantial damage to the valve seats occurs, the valve can effect an adequate seal due to the presence of seed in the gas stream which condenses on the cooled seats. However, the presence of seed and slag has not inhibited the operation of the test valve due to buildup of material.

Future efforts on the VTF will be directed toward analysis of additional data from Valve Test 3 and on solution of the problem of slag accumulation in the main burner, which must be resolved before tests on the order of 1000 hours/ 2000 cycle durations are made. Resurfacing of the valve seats may also be appropriate before long term tests are made in order to obtain a more realistic long term simulation of a newly manufactured valve.

3.2.3 Emissions Measurements

Review of previous emissions measurement techniques and results was begun during the reporting period.

Assembly of the necessary sampling hardware will be done during the next quarter, and the measurements will be conducted during Heat 203 of the MTF.

3.2.4 Creep Testing Apparatus

Review of the conceptual design of a dilatometer for creep measurements in the MTF was begun during the reporting period. The final design is now planned to be completed during the next quarter.

3.2.5 Effluent Air Stream

Review of sampling techniques was begun during the reporting period. Samples of the effluent air stream from the MTF will be collected for analysis during Heat 203.

3.3 Task 3 - Full-Scale Design Concepts

3.3.1 Size/Cost Analysis and Parametric Studies

In order to assist in identifying HTAH development needs and defining goals for the HTAH development program, work under this subtask involves use of the size/cost and other computer codes and engineering studies of the impact of particular HTAH systems or components. During the reporting period, the STRHEX computer code was upgraded, and a study of HTAH reliability considerations was reviewed.

The STRHEX code is used to make calculations of the performance of individual heaters in a system of regenerative heat exchangers. The code is upgraded from time to time to add the capacity needed for examining particular concerns of the HTAH development program. The code now has the capability to handle 2-dimensional (axial and radial) temperature fields, temperature dependent transport properties, arbitrary time functions of the inlet air and gas stream flow rate and temperature, and arbitrary specification of material properties in the axial dimension.

The upgraded STRHEX code will be used to verify the individual heater performance predictions from the SCAMP code and to test improvements to the SCAMP model; to examine the sensitivity of heater performance due to such things as variations in insulation schemes, operation at part load, and variations in material properties; to make improved calculations of thermal stresses; and to investigate transient effects and system requirements due to cleanout or standby modes. Several computer runs have been made to check out the upgraded code. A program of HTAH system-related calculations is being initiated, and results will be presented in the next quarterly report.

A study of MHD plant reliability (References 1, 2, and 3) was reviewed with respect to reliability of the HTAH. In particular, the question of valve life was considered, and it was shown that using different assumptions for valve life dramatically reduces the number of spare heater modules required in an HTAH system to achieve a given HTAH unavailability requirement. Changing the failure rates for individual valves, but following the same method outlined in Reference 2 for determining HTAH unavailability, resulted in a decrease from 8 spare modules required to only 1 spare required in order to achieve a 2% unavailability.

In the study, summarized in Reference 1, the unavailability of the MHD plant was computed from unavailability or "effective forced outage rate" due to the various system components. The HTAH unavailability was dominated by forced outage due to valves. The valve failure rates assumed in the study were based on early estimates of life in steel plant blast furnace stoves. More recent experience has shown much longer valve life. Also, the analysis of Reference 1 assumed the same failure rate (equal to the worst) for each valve in the HTAH system. There are six valves for each heater and their service requirements vary widely. The influence of longer valve life and individual valve conditions on HTAH availability were studied using the methods of Reference 1.

The approach taken in Reference 1 was to assume a mean valve life based on early steel industry experience with hot blast valves and to compute from this a failure rate, λ_v, for individual valves in an indirectly-fired HTAH. This failure rate was used for each of the six valves associated with each heater vessel giving a total failure rate of $\lambda = 6\lambda_v$ for each heater module. The failure rate was arbitrarily doubled for directly-fired HTAH systems because of the presumably more severe service environment.

The mean life assumed in Reference 1 for steel industry hot blast valves was 2.2 years, based on an estimated range of 1-5 years. This gave a failure rate for the indirectly-fired HTAH calculations of λ_v = 0.5 (each valve every 2 years). The method used in determining this value is summarized in Table 2.

However, recent information on improved blast furnace valve designs has indicated that valve life of up to 10 years has been achieved (Reference 4). The general blast furnace valve literature and discussions with blast furnace valve manufacturers indicate that the primary causes of valve failures in the steel industry are warping and cracking of cooled metal parts; this is generally due to fouling of the water cooling passages which results in a non-uniform temperature distribution. Impurities and particulate matter in the cooling water are the causes of the trouble, since untreated river water is generally used as the coolant. The 10 year life quoted above resulted from the use of treated cooling water. Since treated, boiler quality water will be used in an MHD electric power plant, it is reasonable to assume that clean water will be available for valve cooling.

The HTAH hot gas inlet valve will have the most severe conditions of temperature and pressure (and gas stream composition for the directly-fired case). The pressure and temperature are somewhat higher than for blast furnace hot valves. Therefore, an estimated mean life of 5 years seems reasonable. This results in a failure rate of $\lambda_v = 0.22$ for a gas inlet valve in the indirectly-fired HTAH availability analysis when the value of λ_v from Table 2 is ratioed by 2.2 years/5 years.

As noted earlier, it was assumed in Reference 1 that all valves have the same failure rate. Since the severity of service for some of the valves is much lower than that of the gas inlet valve, lower failure rates should be used for these valves. For example, the air inlet valve will have a service temperature of only 922 K (1200 F) with clean air passing through it in its open position. Based on the value of 0.22 for the hot gas inlet valve, we estimate failure rates for the various valves in an indirectly-fired heater to be:

Valve	Failure Rate, yr^{-1}
Gas Inlet	.22
Air Outlet	.11
Gas Outlet	.11
Depressurization	.11
Air Inlet	.07
Pressurization	.07
Total for 1 heater	$\lambda = 0.69 \; yr^{-1}$

If the rate is doubled for the severity factor arbitrarily assigned to the directly-fired heater, a rate of $\lambda = 2 \times 0.69 = 1.38\ yr^{-1}$ is obtained rather than the value of $\lambda = 2 \times 6\lambda_v = 6\ yr^{-1}$ from Table 2. The value of 1.38 for the failure rate results in a significant reduction in HTAH unavailability as shown in Figure 4. Time between MHD plant shutdowns was assumed in Reference 1 to be exponentially distributed about a mean period which was established on the basis of data from coal fired base load power plants and on an assumed overall MHD plant forced outage rate requirement of 16%. All failed valves would be replaced during these plant shutdowns for other problems in the MHD plant. Plant shutdown would not be made in the event of HTAH valve failure; a heater module including a failed valve would be off-loaded and a spare heater module with all associated valves would be brought on line until one of these repair opportunities would arise due to shutdown for other plant problems. Valve failures were also assumed to be exponentially distributed about the mean values.

A value of 2% HTAH unavailability was postulated as a requirement. Inorder to meet this requirement, 8 spare heater modules with all associated valves would be required in a HTAH system having 14 active heaters according to Reference 2. However, if the value of $\lambda = 1.38$ is used, only 1 spare module would be required to meet the 2% unavailability objective.

The effect of the assumed severity factor is shown in Figure 5. A severity factor of 2 may in fact not be justified in light of the valve test results reported in Section 3.2.2. These results indicate that the presence of seed material in the gas stream compensates for damage to the valve sealing surfaces. This may actually result in an enhancement of valve life (severity factor < 1) as compared to the steel industry experience. This situation will become clearer as long term valve tests become available. As can be seen in Figure 5, a moderate enhancement in the assumed mean valve life (severity factor = 0.84) results in reducing the required number of spare heaters to achieve 2% unavailability to zero, while an increase in the factor to as much as 3 results in a requirement of only 2 spare heaters.

The availability analysis of Reference 1 requires that spare heaters be brought on line immediately in the case of valve failures; if all spares are already in use, the HTAH is operated at reduced capacity if a module must be off-loaded. Maintaining a large number of spare heaters in a state of readiness and bringing new heaters on line represent potentially complex problems in the operation of a HTAH. Thus a minimum number of required spare heaters is desirable from a HTAH operation standpoint as well as from the obvious capital cost penalty viewpoint. However, as shown above, using different estimates for HTAH valve failure rates in the analysis results in a requirement of only 1 or 2 spare heaters at worst and shows that a 2% unavailability requirement may be achievable without the use of any spare heaters in a HTAH system.

3.3.2 Dynamic System Performance Simulation (SCAMP)

Three runs of the SCAMP computer code were made during the reporting period. The initial run to predict steady-state performance of the 30 heater example HTAH denoted the FY 80 case was made in March 1980 and was described in the previous Progress Report.

A second computer run was made in which the gas inlet temperature was subjected to a step change of 111 K (200 F), being reduced from 1936 K (3075 F) to 1852 K (2875 F). The purpose of this run was to study the system response to a variation in temperature, such as might occur due to a load change or an upset in MHD plant operating conditions.

The HTAH system response to the step change in gas inlet temperature is shown in Figure 4. The results are presented in the form of transfer functions η for the outlet air and gas temperatures where

$$\eta = \frac{T - T_{FINAL}}{T_{INITIAL} - T_{FINAL}} \qquad (7)$$

T = temperature at time t

$T_{INITIAL}$ = temperature before step change

T_{FINAL} = temperature system will reach after transient period following step change

The values of T_{FINAL} for both the outlet air and gas temperatures were computed by assuming that the heat exchanger effectiveness on the air and gas sides remained constant, i.e.,

$$\left(\frac{T_{G\ in} - T_{G\ out}}{T_{G\ in} - T_{A\ in}}\right)_{Initial} = \left(\frac{T_{G\ in} - T_{G\ out}}{T_{G\ in} - T_{A\ in}}\right)_{Final} \quad (8)$$

$$\left(\frac{T_{A\ out} - T_{A\ in}}{T_{G\ in} - T_{A\ in}}\right)_{Initial} = \left(\frac{T_{A\ out} - T_{A\ in}}{T_{G\ in} - T_{A\ in}}\right)_{Final} \quad (9)$$

As can be seen in Figure 6, the outlet air and gas temperature response can be approximated by an exponential decay from the initial state to the final state. The outlet air temperature response is much faster than the outlet gas temperature response. The transfer functions have been reduced to less than half of the initial values within 2 cycles for the air temperature and 3 cycles for the gas temperature. To reduce the system output transfer functions to 10% of the initial values would require a total of approximately 5 cycles for the air temperature and 12 cycles for the gas temperature.

The transfer functions shown in Figure 6 may now be used to estimate HTAH system response to step changes in fluid inlet temperatures without requiring a run of the SCAMP code.

The third SCAMP run was made in order to examine the effects of reducing the physical size of all manifolds and collectors. The initial FY 80 case specification limited the maximum velocity in the manifolds to

30 m/sec (100 ft/sec) or less. Since large cost savings can be effected by reducing the size of large ducts and manifolds in the HTAH, the minimum acceptable size, and thus the maximum velocity, should be used in the design. Thus the manifolds were reduced in diameter by $\sqrt{2}$, doubling the gas velocities, in order to examine the effects of such a design decision.

The result of the decreased manifold sizes was a significant amplification of the overall system temperature ripples, as seen in Table 3. The variation in delivered air and gas were increased roughly by a factor of 2 over the initial run with larger manifolds. These larger variations amounted to approximately 2.9% of the mean air temperature and 2.4% of the mean gas temperature. The larger variation in outlet temperatures is caused by increased maldistribution in the flows to the individual heaters due to larger pressure drop in the distributing manifolds and corresponding increased variation in the performance of the individual heaters.

Tradeoff studies will be required in the final design of HTAH systems in which the effects of such cost reducing design features are weighed against the required performance of the HTAH. Definiton of the performance requirements of the combustor and of the downstream components will be necessary before such tradeoff studies can be interpreted.

The fourth SCAMP run was made in order to investigate a possible scheme for control of the bottom of matrix solid temperatures of the various individual heaters. The control scheme used was to adjust the lengths of air and gas phases for the individual heaters. Further discussion is given in Section 3.3.5.

Analysis of the results of these SCAMP runs is still underway. More detailed results will be presented in the next quarterly report.

3.3.3 System Layouts

The objective of this subtask is to prepare HTAH system layouts for the purpose of integrating individual component modeling or design studies. The level of effort for the layouts will be consistent with that needed to identify development needs which should be addressed in the HTAH development program.

During the reporting period, a concept for providing for thermal expansion of the HTAH was developed. The development of a thermal expansion concept for the HTAH is complicated primarily by the operating methods and the large physical size of components. Thermal expansion accommodation must be provided during startup and shutdown when very large thermal growth occurs, but later stabilizes at operating conditions. At operating temperature, smaller displacements between components occur due to difference in temperature level. The second consideration is the impracticality of locating expansion joints in very large pipes and especially those whose cross-sections are not circular or those which carry a relatively high pressure.

The overall system layout for the FY 80 HTAH is shown in Figure 7. The size, shape, and operating pressure for the major piping components are listed in Table 4. The equivalent outer diameter given is the nominal pipe shell diameter. All of the piping is insulated internally and externally such that the pipe shell temperature is nominally 533 K (500 F) at operating conditions.

The thermal expansion design concept proposed here is guided by the following precepts:

1. Provide a set of fixed points in the gas mains located at the intersection of the centerline of the gas mains and the intersection of each gas manifold.

2. Provide a rigid connection between the gas-in manifold and the heater and allowing the heater to move horizontally along the direction of a heater run on a system of support rails.

3. Avoid expansion joints in the gas-in and gas-out manifolds due to their catenary shape and avoid expansion joints in the large, high-pressure air-out manifold.

4. Relocate the air mains near the HTAH centerline (between the gas mains) so that the location of their interface point with other MHD components does not have large lateral movements during startup and shutdown.

5. Assume that all pipe shells at any given time differ in temperature by no more than $\pm$ 28 K (50 F), i.e., a relative difference not to exceed 56 K (100 F).

A schematic diagram of the thermal expansion design concept applying these guidelines is shown in Figure 8. Expansion joints are located in the gas mains, the gas-out ducts, and the air-out ducts.

From a fixed point in the gas-in main, the gas-in manifold, the adjacent heater row, and the air-out manifold move as a rigid unit as thermal expansion occurs. It will be important to the design to maintain a small relative temperature difference between the shell of the gas-in manifold and the air-out manifold. The total thermal growth of these two manifolds is approximately 102 mm (4 in) from 288 K (60 F) to the operating temperature of 533 K (500 F) during startup. A relative temperature difference of 56 K (100 F) between these two manifolds would result in approximately 6 mm (.25 in) difference in thermal growth between each heater in a given row.

The gas-out and air-in manifolds are isolated from the heaters by expansion joints located in the ducts. These expansion joints are selected to accommodate lateral movement due to relative difference in shell temperatures. It is not necessary to accommodate the overall growth during startup since all four manifolds are parallel and expand equal amounts. A list of the required expansion joints is given in Table 5.

In summary, it is shown that a concept to accommodate the thermal expansion of the HTAH can be developed utilizing conventional engineering practices. However, without details of the actual methods of supporting the major piping elements and the heaters, some difficult engineering problems remain. The major remaining concerns are the accommodation of thermal growth in the vertical direction, particularly of the individual heaters, the restraint of piping where large pressure-area forces or thrusts are developed, and the compatibility of the expansion of the refractory insulation within the piping system.

3.3.4 Cost Estimates

The objective of this subtask is to prepare a cost estimate for the FY 80 case based on the system layouts as established under Section 3.3.3. The intent of the cost estimate is to provide a check of the ability of the size/cost computer code to produce realistic cost estimates to aid in identifying areas of the HTAH where significant cost savings can be achieved. Since the design of actual HTAH systems will not be accomplished for many years, the cost estimate will not be carried out to a great deal of accuracy.

Minimal effort was expended in this area during the reporting period, consisting of review of the cost estimate objectives for the FY 80 HTAH system.

3.3.5 Control Systems

The objective of this subtask is to screen and define HTAH control needs and systems. The performance data from dynamic modeling with the SCAMP computer code will be used to assess control needs and to determine system response to various control concepts.

Analysis of the SCAMP results for the first three runs showed that the maximum bottom of matrix solid temperature for a number of individual heaters did not reach the ideally defined level of 1400 K (2060 F). Reaching this temperature level is defined as a requirement for operating the directly-fired HTAH in order to allow drainage of seed/slag material from the heater flow passages and prevent accumulation of deposits. Some of the heaters actually showed maximum bottom of matrix solid temperatures less than 1342 K (1956 F), the freezing point of potassium sulfate seed. It is unlikely that individual heaters would operate without accumulation of deposits in the flow passages under these conditions.

A control concept was developed in order to assure that all heaters in the HTAH reach the defined limit of 1400K (2060°F). This concept is to allow those heaters which had too low a temperature to operate with a lengthened gas phase and a shortened air phase, maintaining the same total heater cycle time so that the overall HTAH sequencing was not affected.

The result of the SCAMP run with variable phase times for the individual heaters was an improvement in the uniformity of the maximum bottom of matrix solid temperature; all of the individual heaters could be controlled to the required temperature level in this manner. Details of the SCAMP run will be shown in the next quarterly report.

The control concept discussed could be used in an actual HTAH system. Sensing of a temperature which is too low or a pressure drop which is too high would result in an adjustment of the phase times by the HTAH controller. Study of the system response with regard to those parameters which affect the overall MHD plant performance will be required in order to evaluate the possible use of such a control concept. Analysis of the SCAMP data from the four runs made to date and of future SCAMP data will be directed toward this objective.

3.3.6 Matrix Support Test Facility

The objective of this subtask is to identify the requirements which must be met by a future test facility for testing matrix support concepts at nearly full-scale.

Data concerning the bed support for the FY 80 case will be reviewed and alternate support concepts will be considered.

The matrix support requirements have been reviewed and development of testing requirements will begin during the next quarter.

3.3.7 Alternative Heater Concepts

Several concepts have been identified which may bear investigation as possible directly-fired air heaters, including staged regenerative heat exchangers and regenerative heat exchangers incorporating greatly reduced inlet air and gas temperatures and/or upflow on the gas phase. These concepts will be investigated at a low level of effort to evaluate potential advantages over the basic concept as symbolized by the FY 80 case.

Modifications have been made to the size/cost computer code to allow examination of these alternative heater concepts and preliminary computer runs have been made to define material selection requirements. Additional criteria must be added to the code for selection of insulation layups in the alternative systems.

Preliminary results indicate that such systems may be feasible, and future efforts will determine whether additional consideration of these heater concepts is warranted.

3.3.8 Electrical Isolation

A request for calculations of the air stream conductivity at various potassium content levels has been made to Prof. R.H. Eustis at Stanford University. Electrical conductivity data on potential refractory insulation materials is being collected; property data which is unavailable will be obtained through the Task 1 efforts on property determination in conjunction with the Montana laboratories.

This information will be combined with chemical composition data obtained from the test work in the MTF (Section 3.2.5) in order to assess the severity of the electrical isolation problem and develop isolation concepts.

4.0 CONCLUSIONS

Material property data is being collected in a formal materials data base. Cooperation of outside organizations such as Montana Tech, MSU, and MERDI in performing measurements according to test requirements established by FluiDyne has proved to be extremely useful in assembling this information and will be needed in the future to insure that the data base requirements are met. Liaison with refractory manufacturers has been effective, resulting in programs for development of HTAH materials and fabrication techniques.

Valve testing results have shown that the test valve leakage has been less than that predicted by the leakage model used in full-scale studies. The full-scale studies model results in a total leakage mass flow on the order of 1.3% of the delivered air. Test results, which demonstrate that the presence of seed in the flow actually decreases the valve leakage, indicate that more optimistic predictions of the total leakage may be appropriate, and that previous postulates of decreased reliability of valves in a directly fired HTAH may not be appropriate. Longer term testing will be required to verify these points; the test valve has been operated for a total of 780 cycles to date.

Use of more reasonable assumptions for HTAH valve life was shown to result in a reduction in number of spare heater modules required to achieve a 2% HTAH unavailability rate. In a previous study (References 1, 2, 3) 8 spare heater modules were required in a system with 14 active heaters; different valve life assumptions reduced the number to 1 or zero spare module.

Response of the HTAH to a step change in gas temperature as calculated by the SCAMP code has been shown to approximate an exponential transfer function. In addition, the capability to control the bottom of matrix solid temperature by using variable gas and air phase durations has been demonstrated through use of the SCAMP code.

REFERENCES

1. Lippert, T. E., et al, "MHD Systems Evaluation and Requirements," Proceedings of the Seventh International Conference on MHD Electrical Power Generation, Massachusetts Institute of Technology, Cambridge, Massachusetts, June 16-20, 1980.

2. McCutchan, D. A., et al, "Operational Analysis of MHD," Progress Status Report, Period Covering April-June, 1978, EPRI Contract No. RP-639-1.

3. McCutchan, D. A., et al, "Operational Analysis of MHD," Progress Status Report, Period Covering July-September, 1978, EPRI Contract No. RP-639-1.

4. Kuckertz, W., "High-Duty Valves for Blast Furnaces and High-Temperature Stoves," Iron and Steel Engineer, December 1979, p. 53.

Need Date	Material	Bulk Density	Porosity	Elastic Modulus	Poisson's Ratio	Thermal Conduc-tivity	Specific Heat	Thermal Stress Limit	Thermal Expansion	Electrical Resistivity	Thermal Emissivity	Rupture Modulus	Fracture Parameter	Compressive Strength	Creep	Creep in HTAH Environment	Corrosion Resistance
FY 82	Matrix	1	1	1	1	1	1	1	1		1	1	1	1	1		1
	Hot Liner	1	1			1	1		1	1		1		1	1		1
	Insulation	1	1			1									1		1
FY 83	Matrix	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3		2, 3	2, 3	2	2, 3	2, 3		2, 3
	Hot Liner	2, 3	2, 3			2, 3	2, 3		2, 3	2, 3		2		2, 3	2, 3		2, 3
	Insulation	2, 3	2, 3			2, 3	3								2, 3		2, 3
FY 84	Matrix	3	3	3	3	3	3	3	3		3	3	3	3	3	3	3
	Hot Liner	3	3			3	3			3					3		3
	Insulation	3	3			3									3		
FY 85	Matrix	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4		3, 4	3, 4	3, 4	3, 4	3, 4	4	3
	Hot Liner	3, 4	3, 4	3	3	3, 4	3, 4	3	3, 4	3, 4		3, 4		3, 4	3, 4		3
	Insulation	3, 4	3, 4			3, 4								3, 4	3, 4		
FY 86	Matrix	5	5	5	5	5	5	5	5		5	5	5	5	5	5	5
	Hot Liner	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	Insulation	5	5			5	5		5	5		5		5	5		

CODE:

1 - Preliminary Data for Subscale Tests and Design Studies
2 - Data for 5 MW Technology Development Unit
3 - Updated Data for Design Studies
4 - Data for Final Long Duration Subscale Test
5 - Data Base for Design at Increased Scale

TABLE 1 PRIORITY SYSTEM FOR MATERIAL PROPERTY DETERMINATION

Table 2

BASIS OF AIR HEATER UNAVAILABILITY DUE TO VALVE FAILURES

(Extracted from Reference 2)

A. Failure Rate Assumptions

Steel Industry Experience

Quoted life of blast valves = 1 - 5 years

Average duty = 6000 cycles/year

Geometric mean life = $\sqrt{5}$ = 2.2 years or 13,400 cycles

Separately-Fired Heater Assumptions

Assumed mean life = 2.2 years = 13,400 cycles

Expected duty = 8760 (0.75) = 6,570 cycles/operating year

Mean life m = 13400/6570 = 2.0 operating years

$\lambda_V = 1/m = 0.5$ failure/year

Module failure rate = $6\lambda_V$ = 3.0/years

Range = 1 - 5 year^{-1}

Direct-Fired Heater Assumptions

Assumed "environmental severity factor" (reduction in life) = 2

Mean valve life m = 1.0 operating years

λ_V = 1.0/year failures/year

Module failure rate = $6\lambda_V$ = 6.0 failures/year

Range = 2 - 10 year^{-1}

TABLE 3 HTAH OUTLET FLUID TEMPERATURES FROM SCAMP COMPUTER CODE RUNS

	FY 80 HTAH with Large Manifolds	FY 80 HTAH with Small Manifolds
Air Temperature		
Minimum, K (F)	1737 (2667)	1723 (2642)
Maximum, K (F)	1762 (2711)	1773 (2732)
Variation, K (F)	24 (44)	50 (90)
Gas Temperature		
Minimum, K (F)	1270 (1826)	1274 (1833)
Maximum, K (F)	1286 (1855)	1305 (1889)
Variation, K (F)	16 (29)	31 (56)

TABLE 4 MAJOR FACILITY PIPING

		Equivalent O.D., m (ft)	Cross-Sectional Shape	Max. Operating Pressure, kPa (psia)
Mains	Gas-In	15.2 (50)	Double Arch	110 (16)
	Gas-Out	12.2 (40)	Double Arch	110 (16)
	Air-In	1.5-3 (5-10)	Round	869 (126)
	Air-Out	2.6-4.6 (8.5-16)	Round/Catenary	869 (126)
Manifolds	Gas-In	4.6-7.6 (15-25)	Catenary	110 (16)
	Gas-Out	3.0-5.8 (10-19)	Catenary	110 (16)
	Air-In	1.5-2.0 (5-6.5)	Round	869 (126)
	Air-Out	2.6-3.2 (8.5-10.5)	Round	869 (126)
Ducts	Gas-In	3.5 (11.5)	Round	110 (16)
	Gas-Out	2.3 (7.5)	Round	110 (16)
	Air-In	1.1 (3.5)	Round	869 (126)
	Air-Out	2.1 (7)	Round	869 (126)

TABLE 5 EXPANSION JOINT REQUIREMENTS

		No. Req'd	Location	Type	Axial Movement* mm (in)	Lateral Movement* mm (in)
Main	Gas-In	2	Between Heater Rows	Flexspan-Series 500 (12 in. face-to-face)	89 (3.5)	64 (2.5)
Main	Gas-Out	2	Between Heater Rows	Flexspan-Series 500 (12 in. face-to-face)	89 (3.5)	64 (2.5)
Duct	Gas-Out	30	Between Valve & Gas-Out Manifold	Metal (12 Convolutions)	136.4 (5.37)	10.7 (0.42)
Duct	Air-In	30	Between Valve & Air-In Manifold	Metal (16 Convolutions)	72.1 (2.84)	8.1 (0.32)

* Expansion Joint Limit

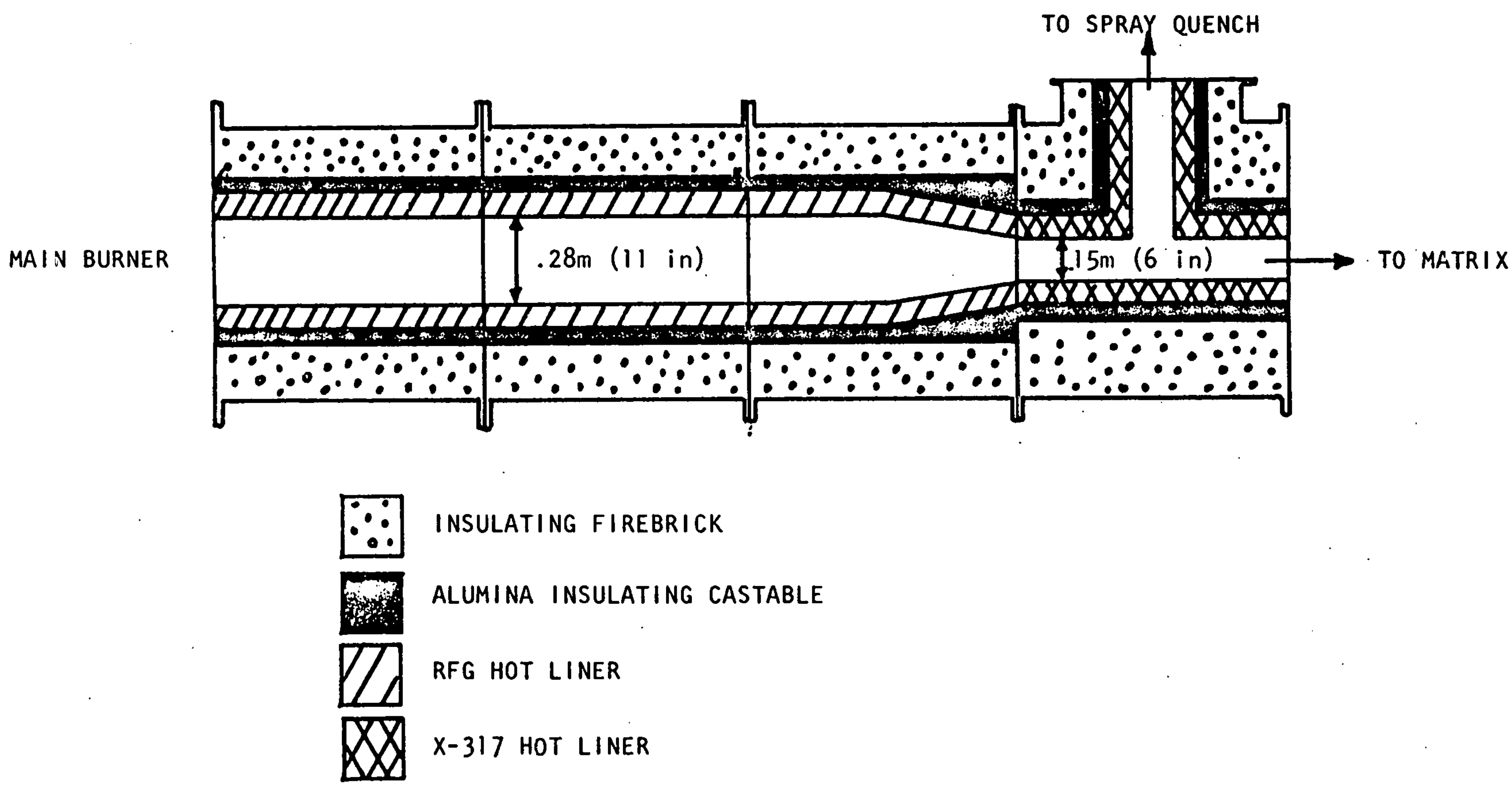

FIGURE 1. MTF HOT GAS SUPPLY DUCT CONFIGURATION

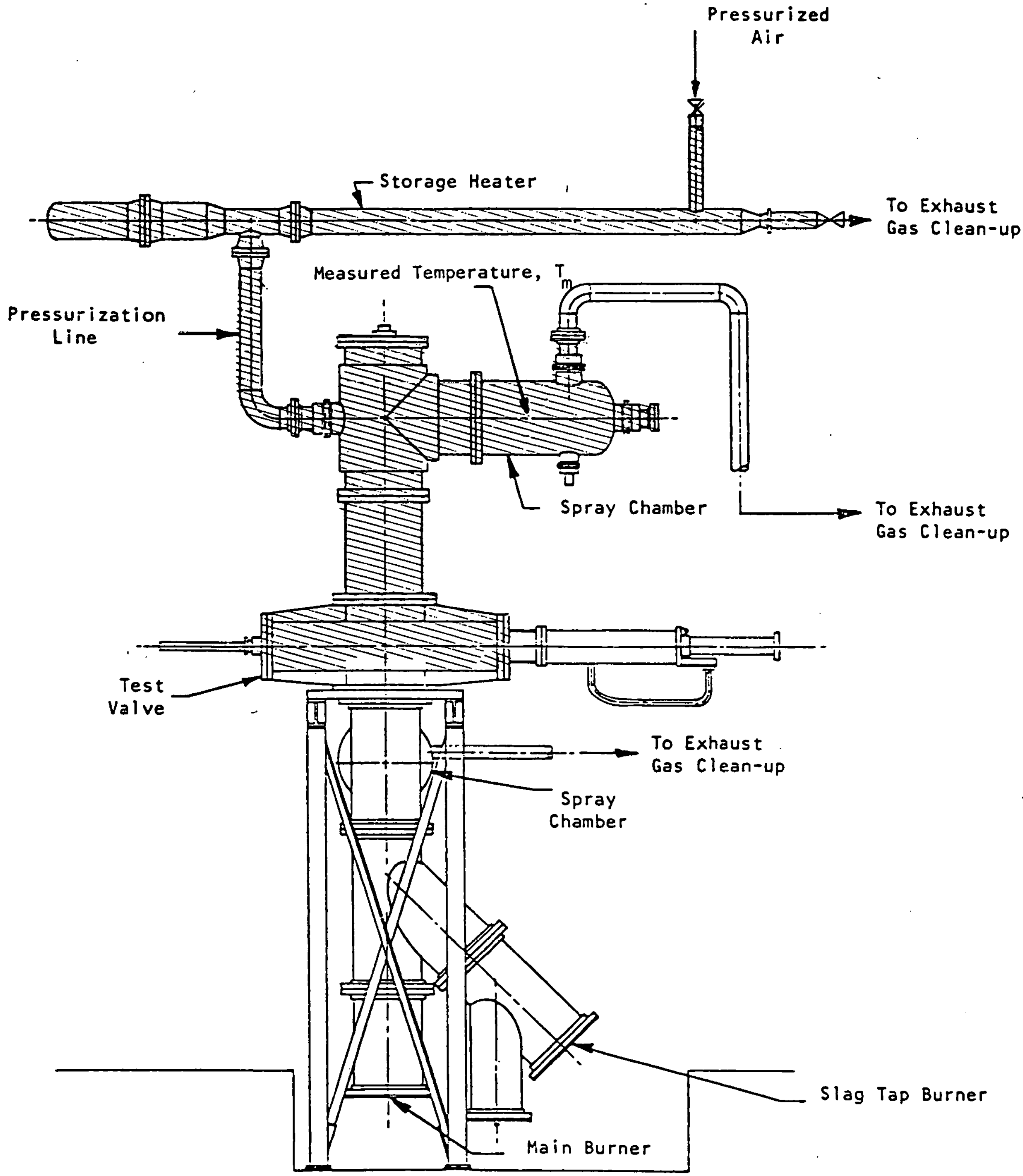

FIGURE 2. VALVE TEST FACILITY DURING AIR PHASE (SHADED AREA IS PRESSURIZED)

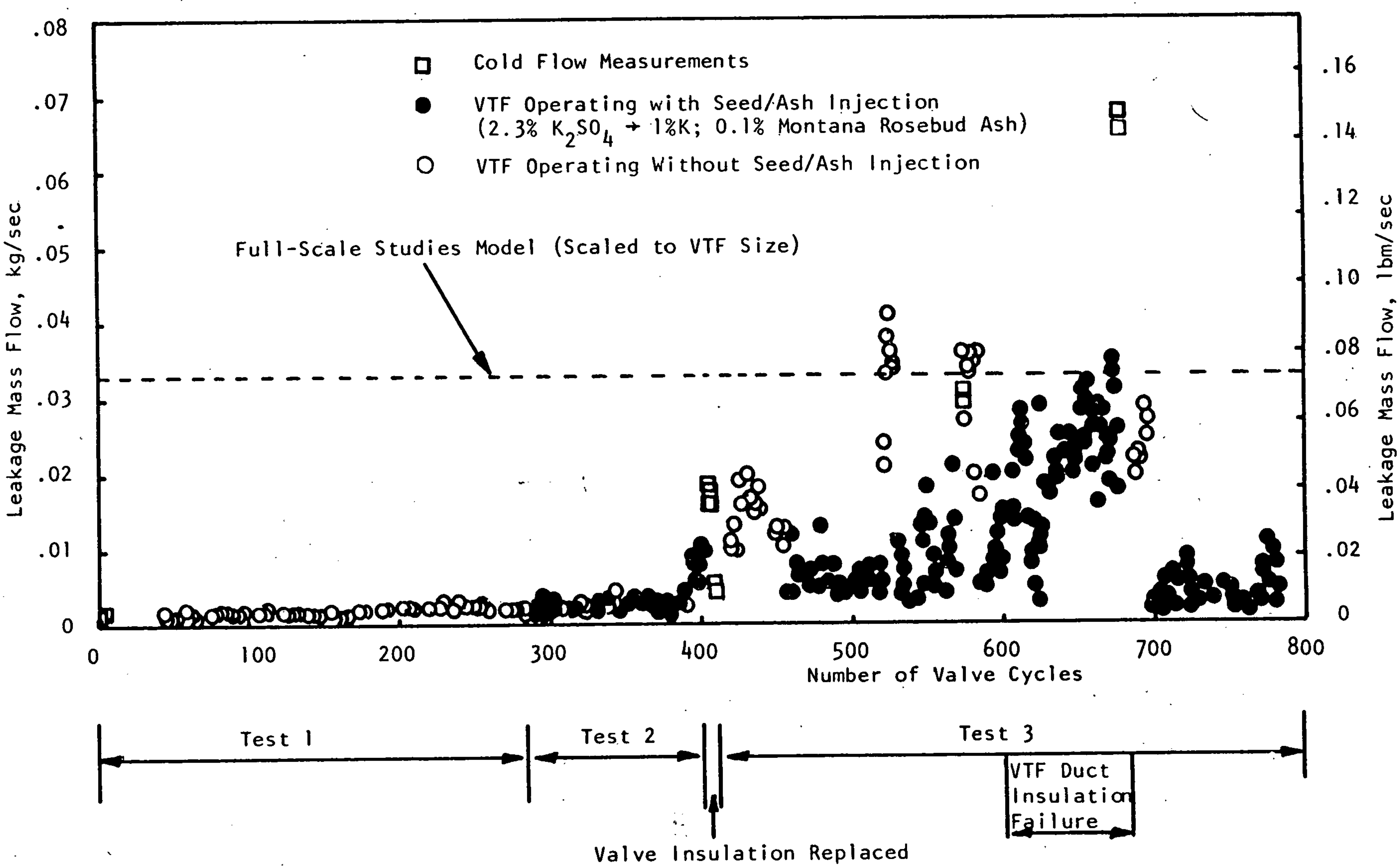

FIGURE 3 **VTF TEST VALVE LEAKAGE - 827 kPa (120 psia)**

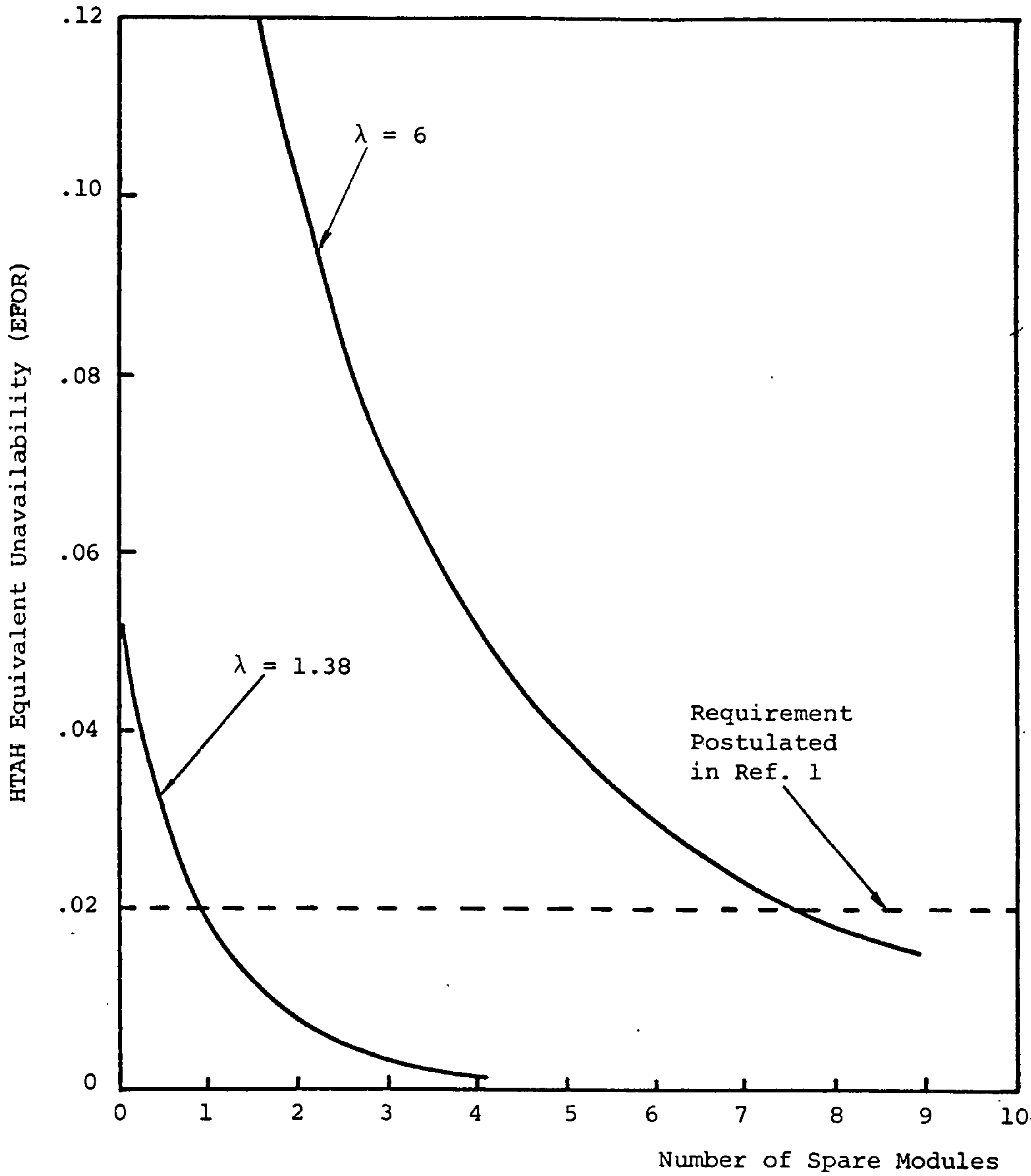

FIGURE 4. NUMBER OF SPARE HEATER MODULES REQUIRED FOR A GIVEN HTAH UNAVAILABILITY FOLLOWING METHOD OF REFERENCES 1-3

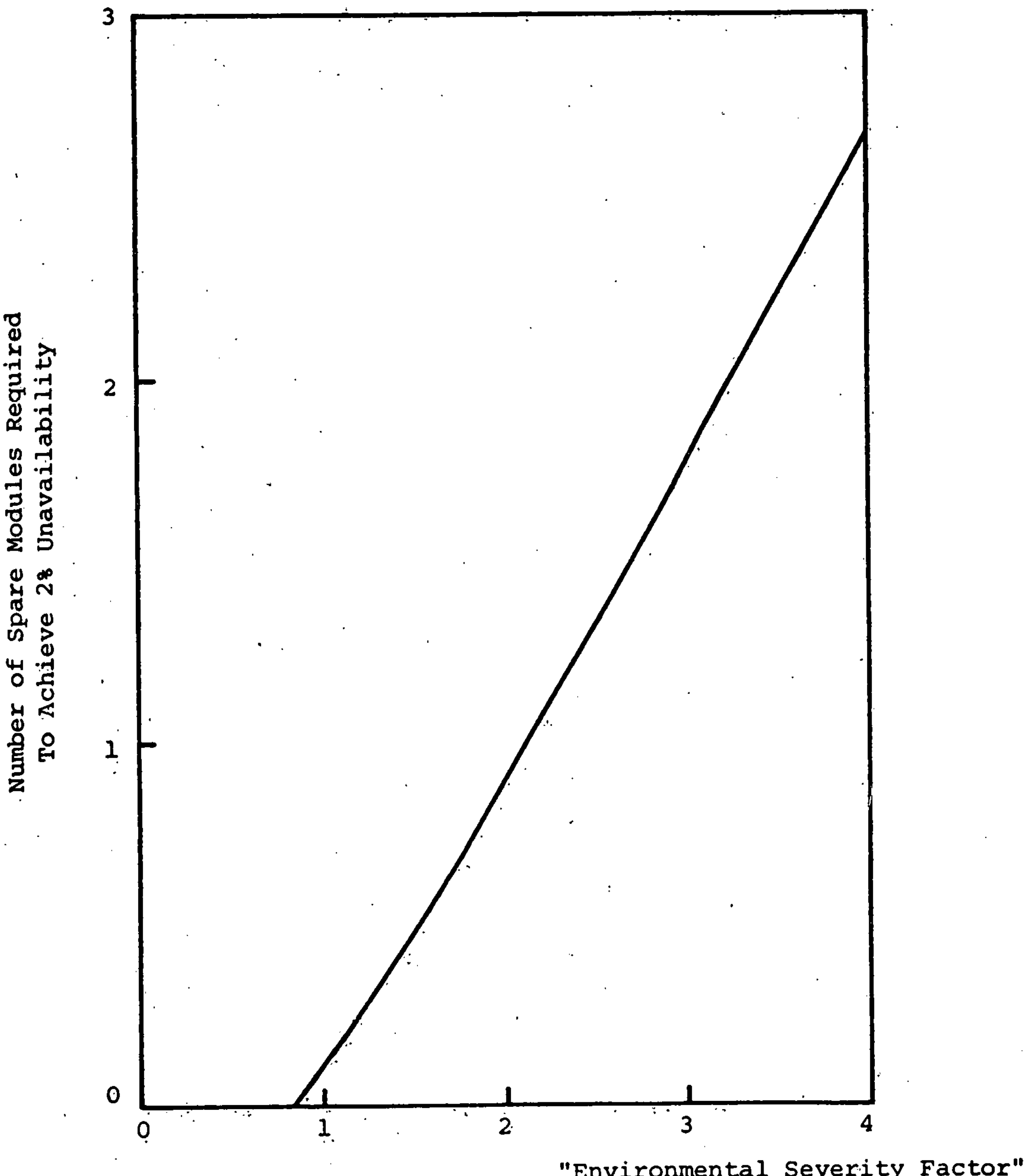

FIGURE 5. NUMBER OF SPARE HEATERS REQUIRED TO ACHIEVE 2% UNAVAILABILITY FOR $\lambda = 1.38$ VS. ASSUMED SEVERITY FACTOR

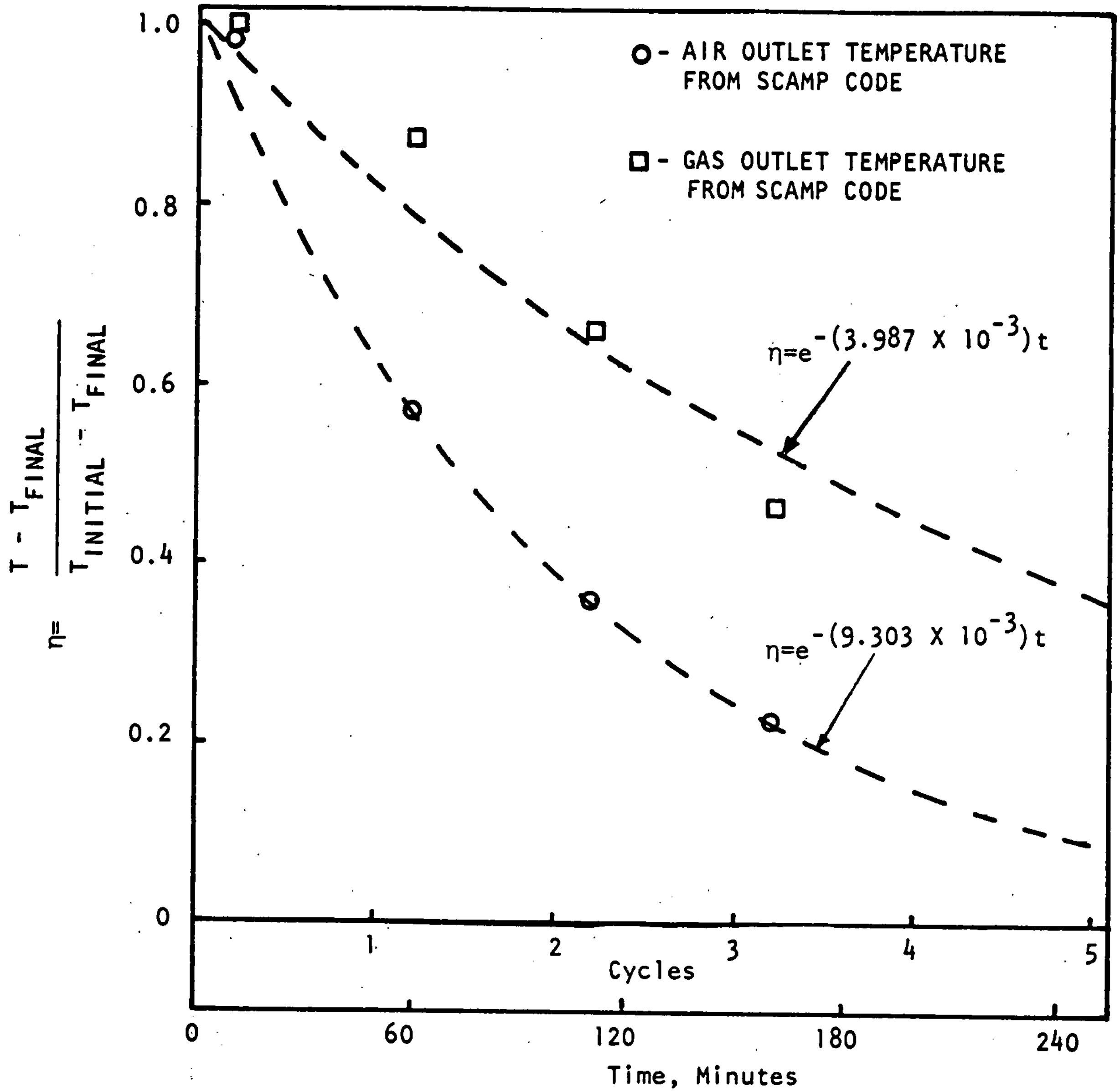

FIGURE 6. TRANSFER FUNCTIONS FOR HTAH AIR AND GAS OUTLET TEMPERATURES

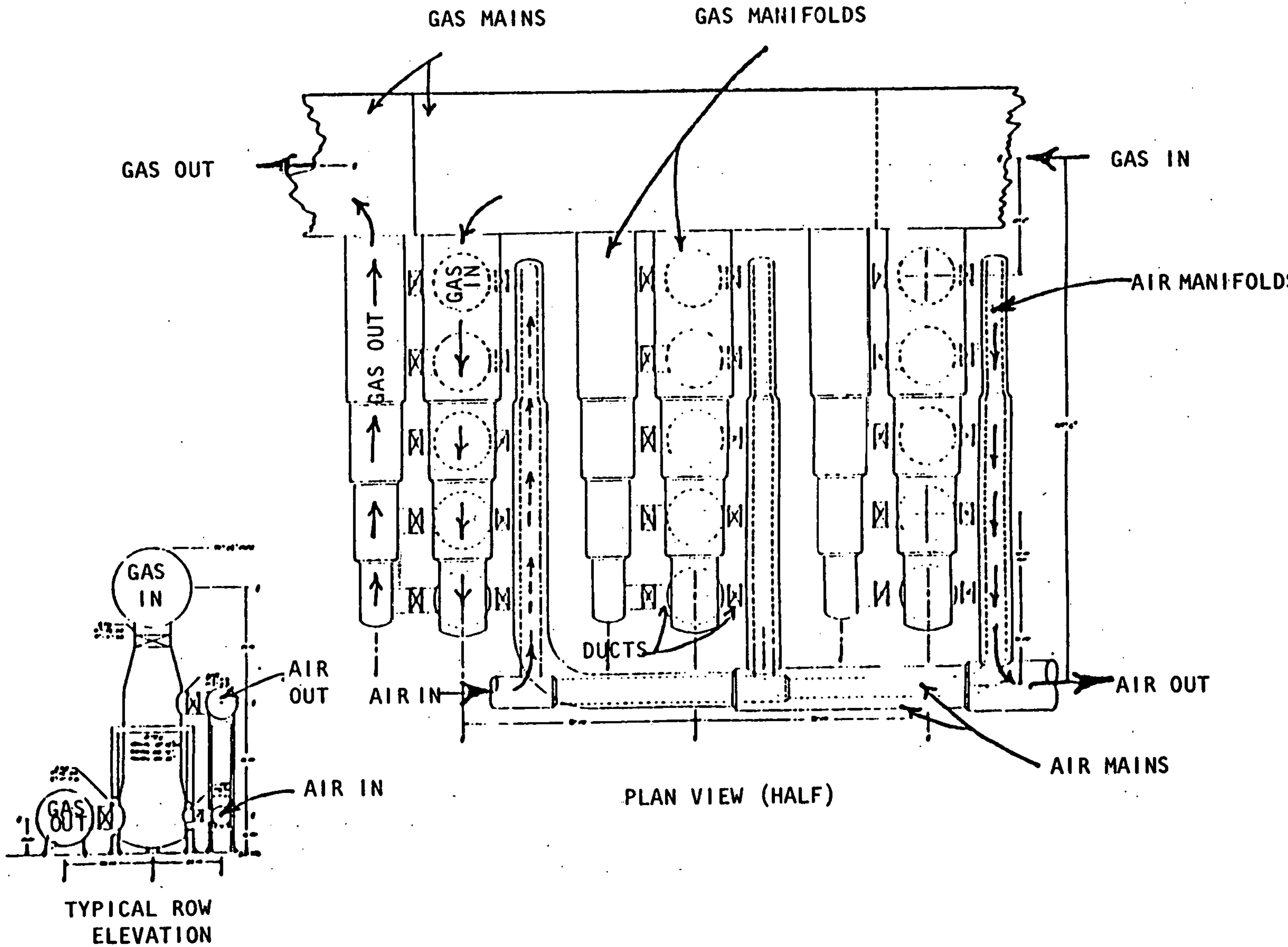

FIGURE 7. HTAH LAYOUT

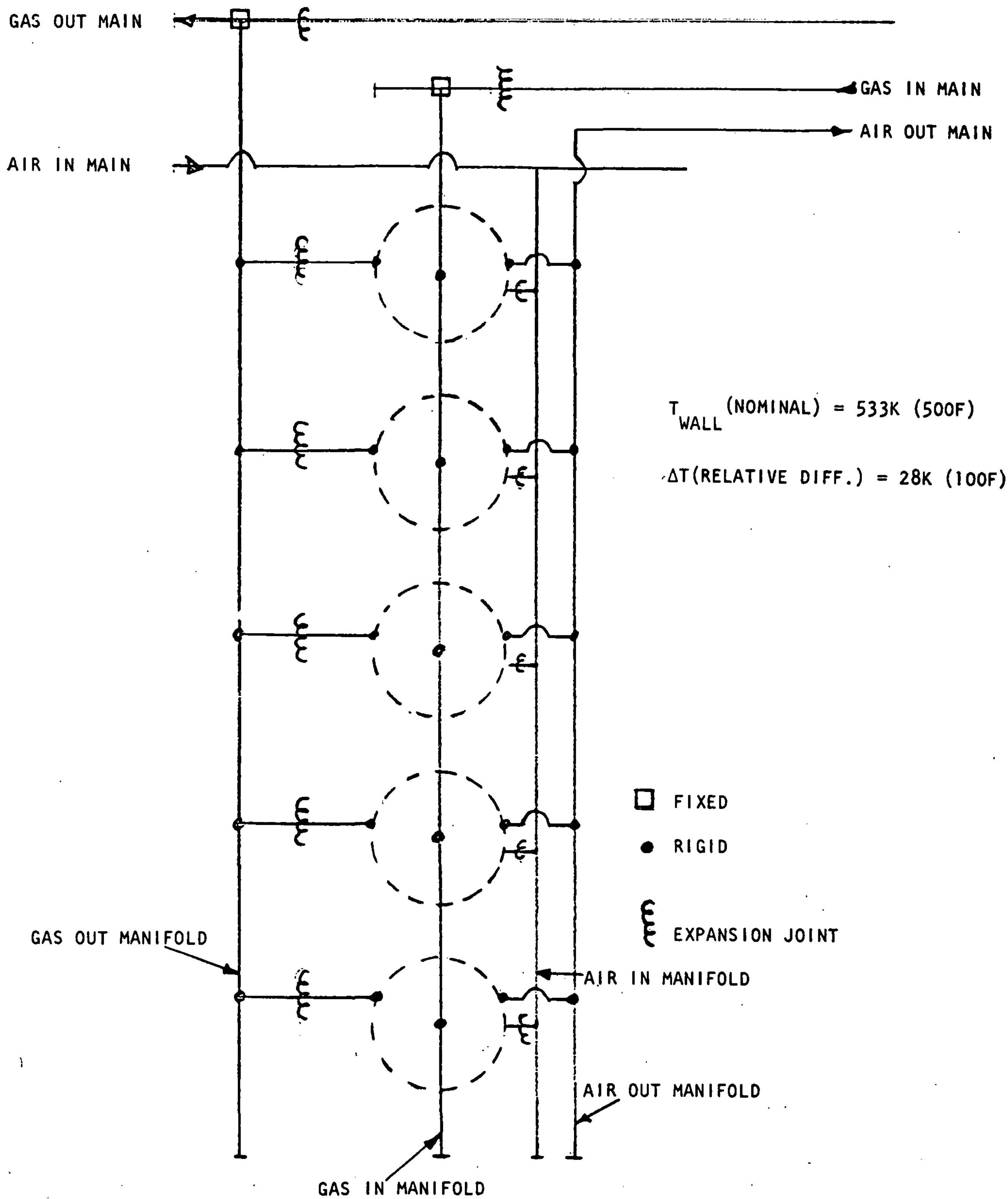

FIGURE 8. TYPICAL HEATER ROW SHOWING THERMAL EXPANSION CONCEPT

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-740-145/876