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Very High Temperature Heat Exchange Performance When Firing Low-Grade Fuels

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Energy & Environmental Research Center

Fred Robson, kraftWorks

Presented at the workshop on The Evolution of Combustion Technology to Support National Energy Needs, Orlando, FL

January 14–16, 2002

Goal

Development of a radiant air heat that can provide very high temperature at (~2000°F) using a range of low grade fuels including coal and biomass.

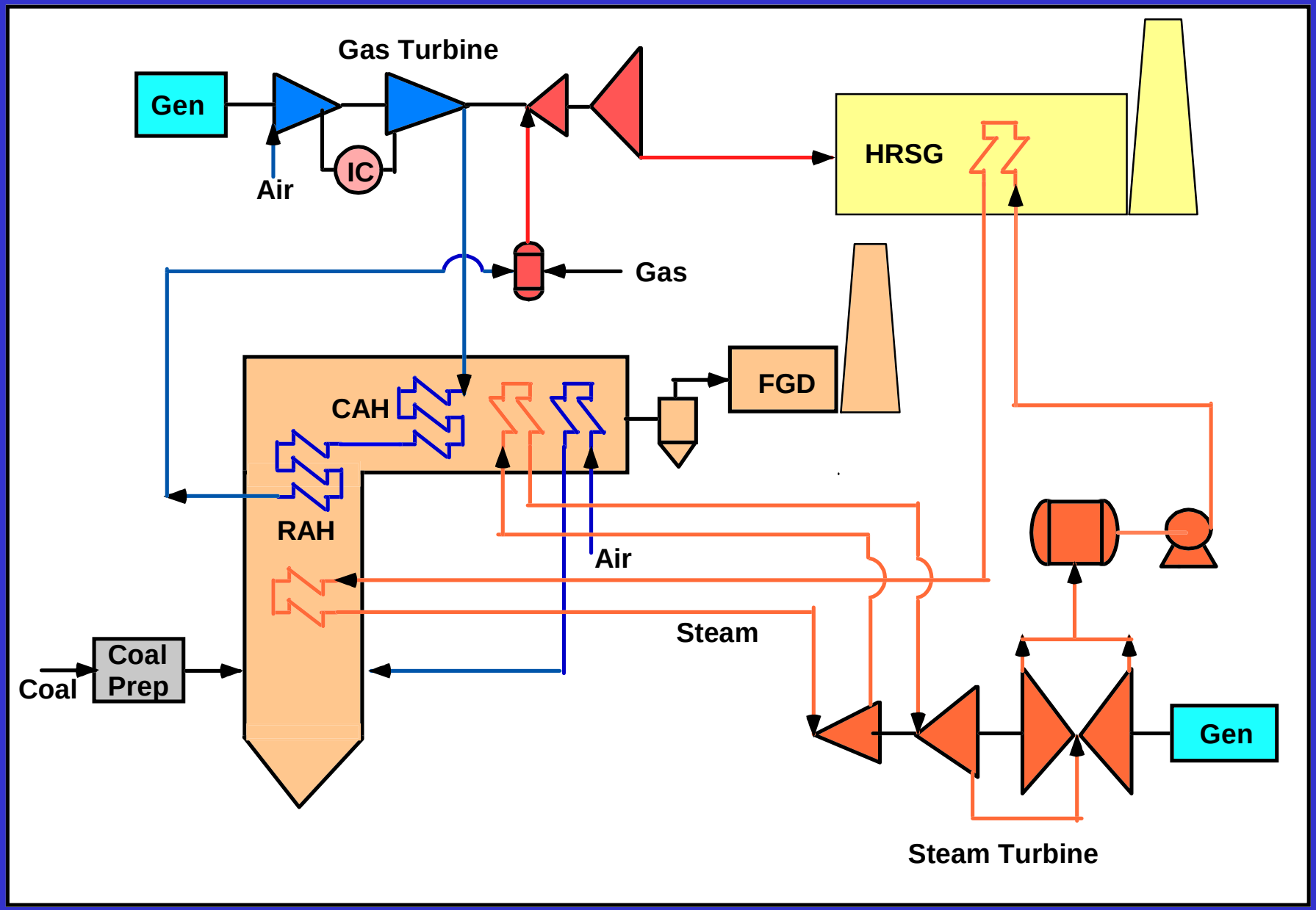
Performance and Economics of HiPPS with Bare Tube HITAF

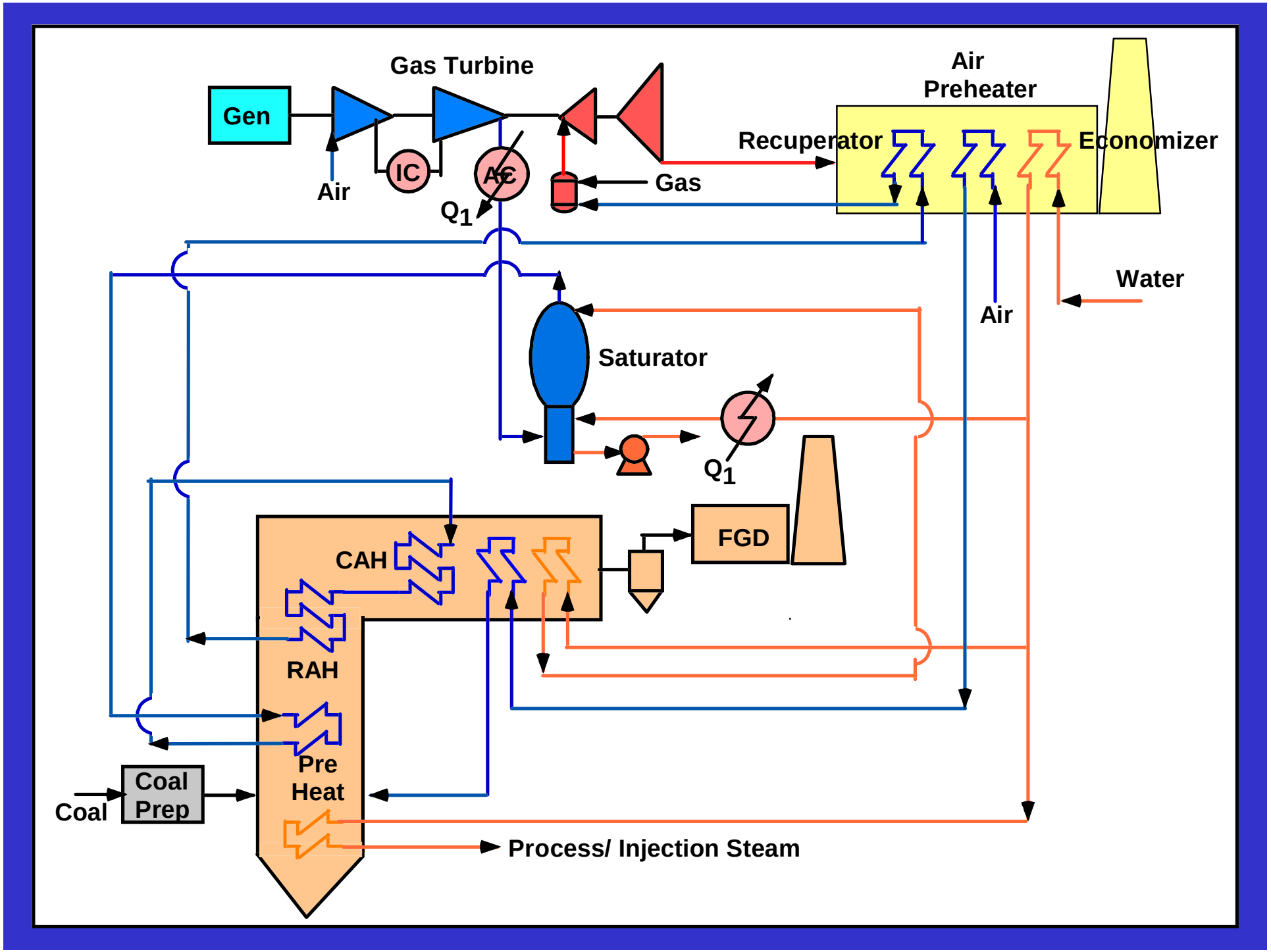
Background

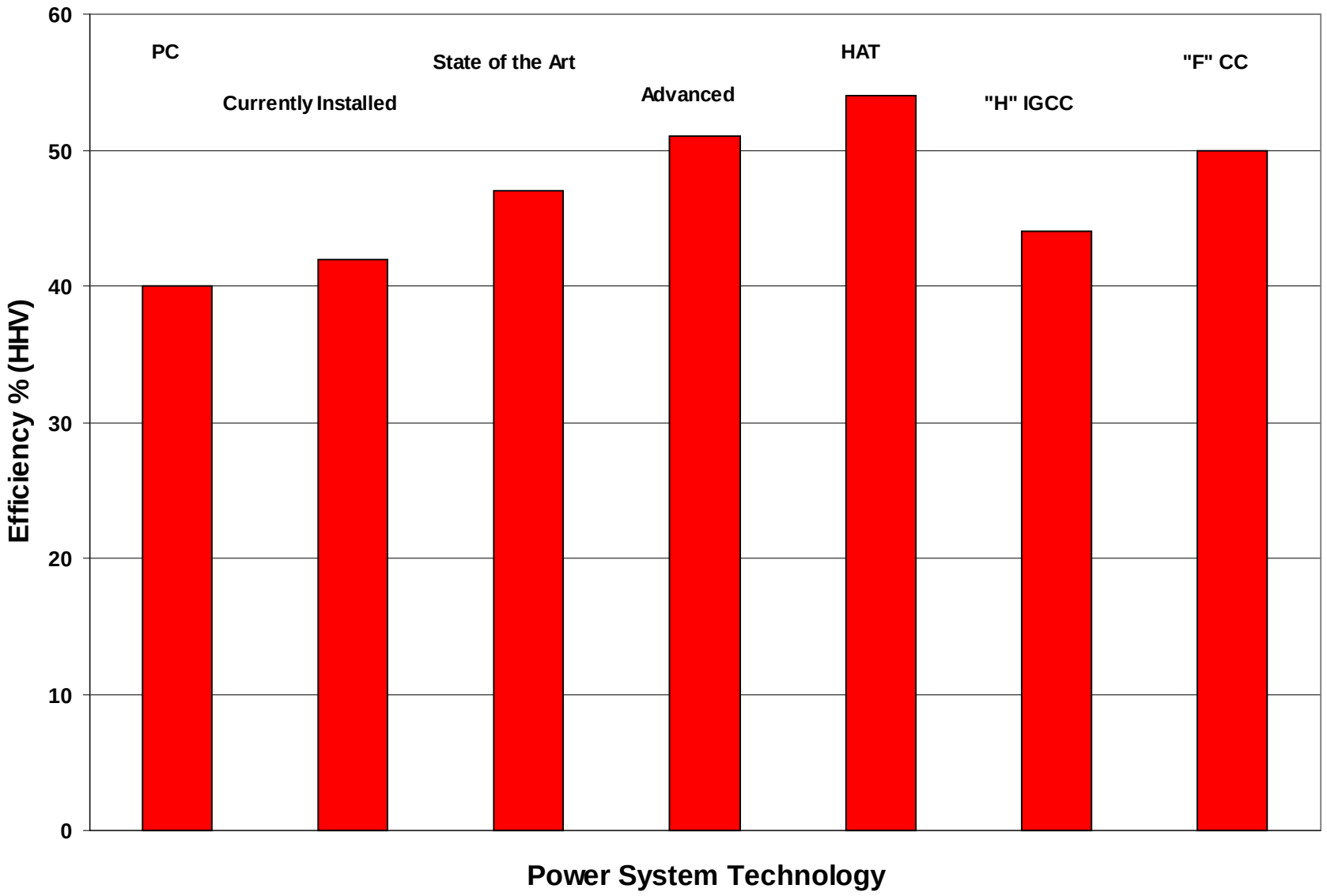
- UTRC HiPPS had refractory protection in RAH
- RAH required approximately 20,000 ft^2 for 300 MW
- Bare tube has five times heat transfer
- Assume 4,000 ft^2 RAH for 300 MW
- HITAF now more closely resembles conventional steam generator

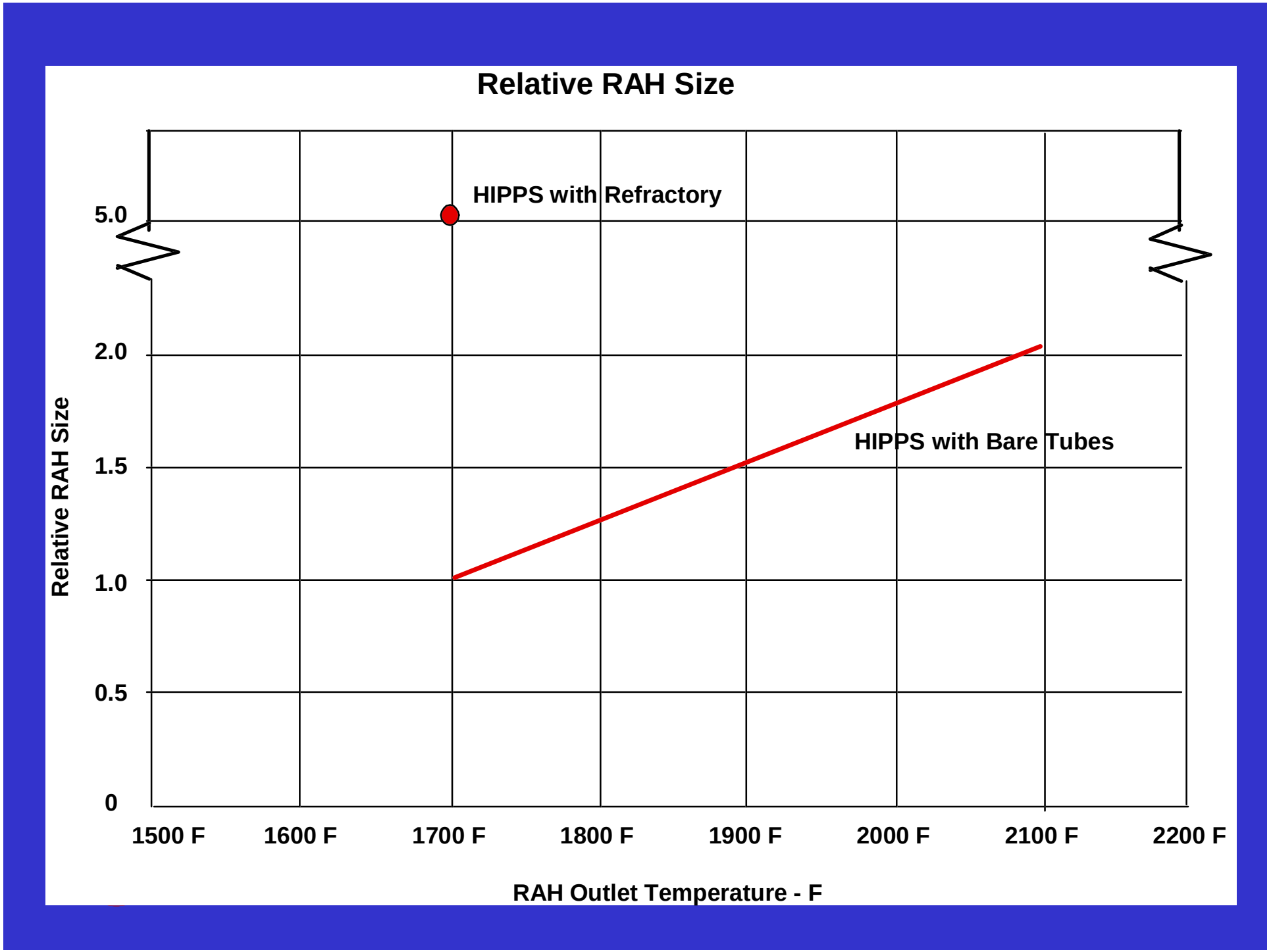
Method of Analysis

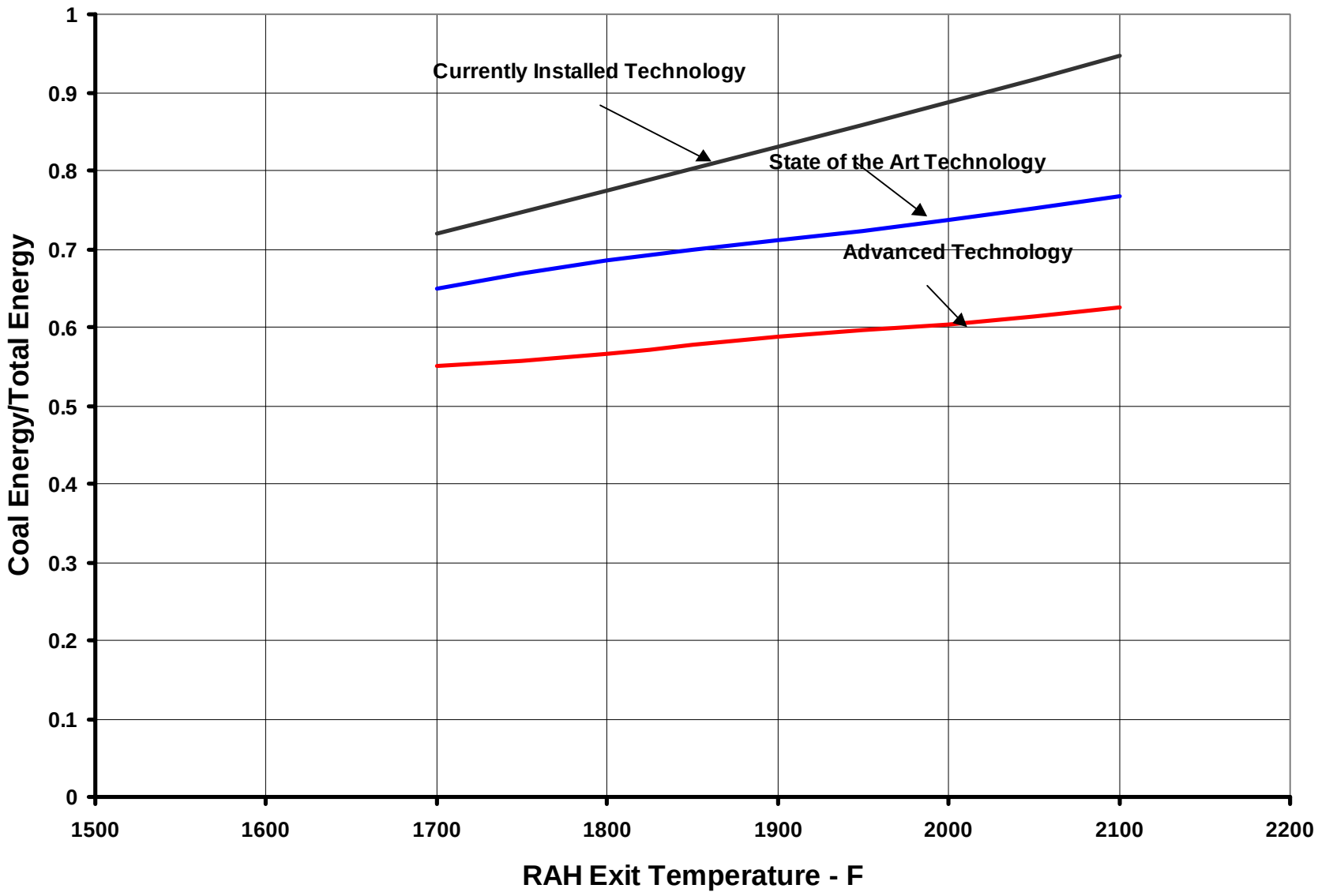
- Performance estimates for 4 HiPPS configurations
- Performance estimates for PC plant, IGCC, and NGCC
- Cost for HiPPS with bare tubes
  - Based on Bechtel/Nexant estimates
- Costs for other systems from literature adjusted to Bechtel/Nexant assumptions


Gas Turbine
Gen
Air
IC
HRSG
Gas
FGD
CAH
RAH
Air
Steam
Coal
Coal Prep
Gen
Steam Turbine

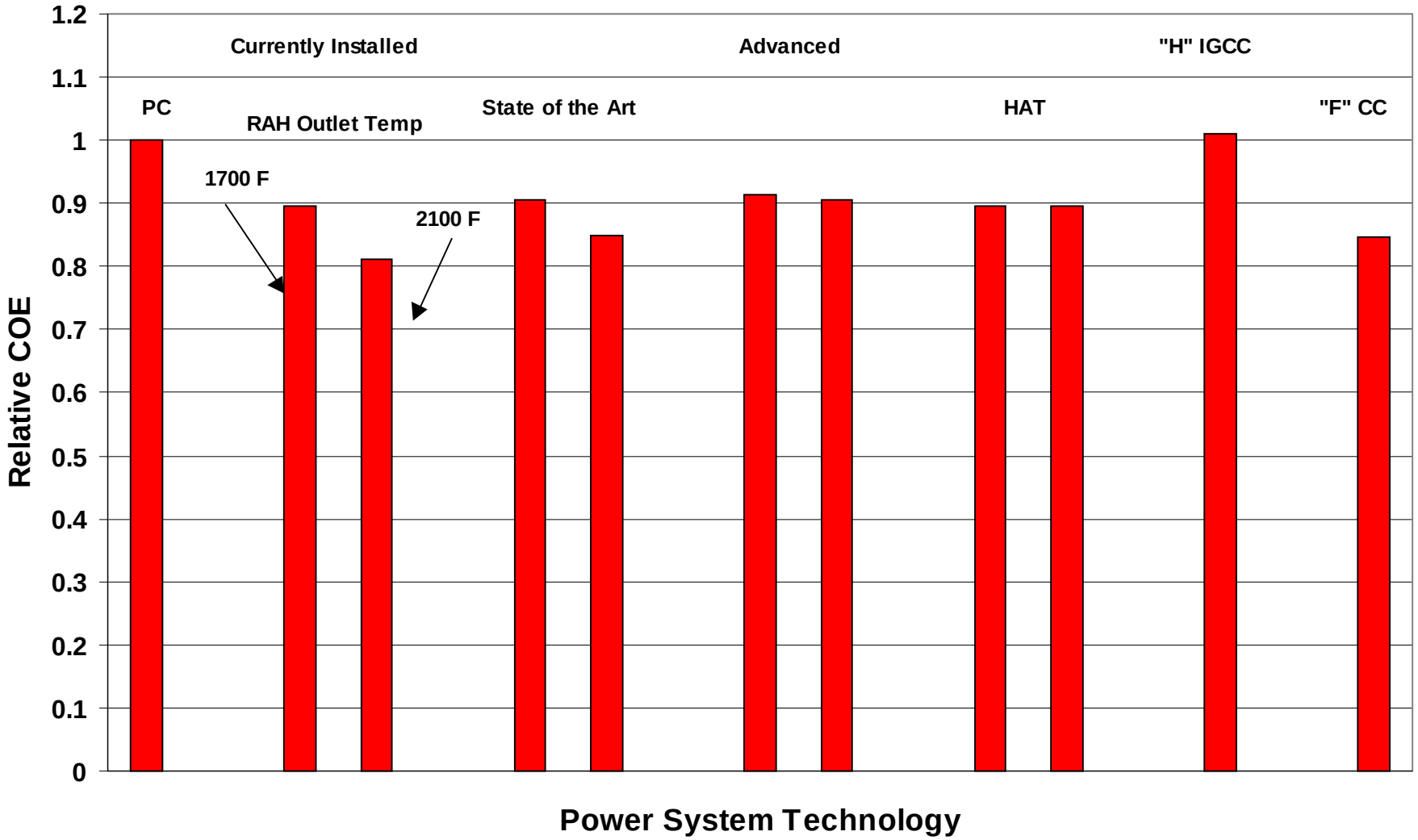

Gas Turbine
Gen
Air
IC
AC
Q_1
Gas
Air
Preheater
Recuperator
Economizer
Water
Air
Saturator
Q_1
FGD
CAH
RAH
Pre
Heat
Coal
Coal
Prep
Process/ Injection Steam

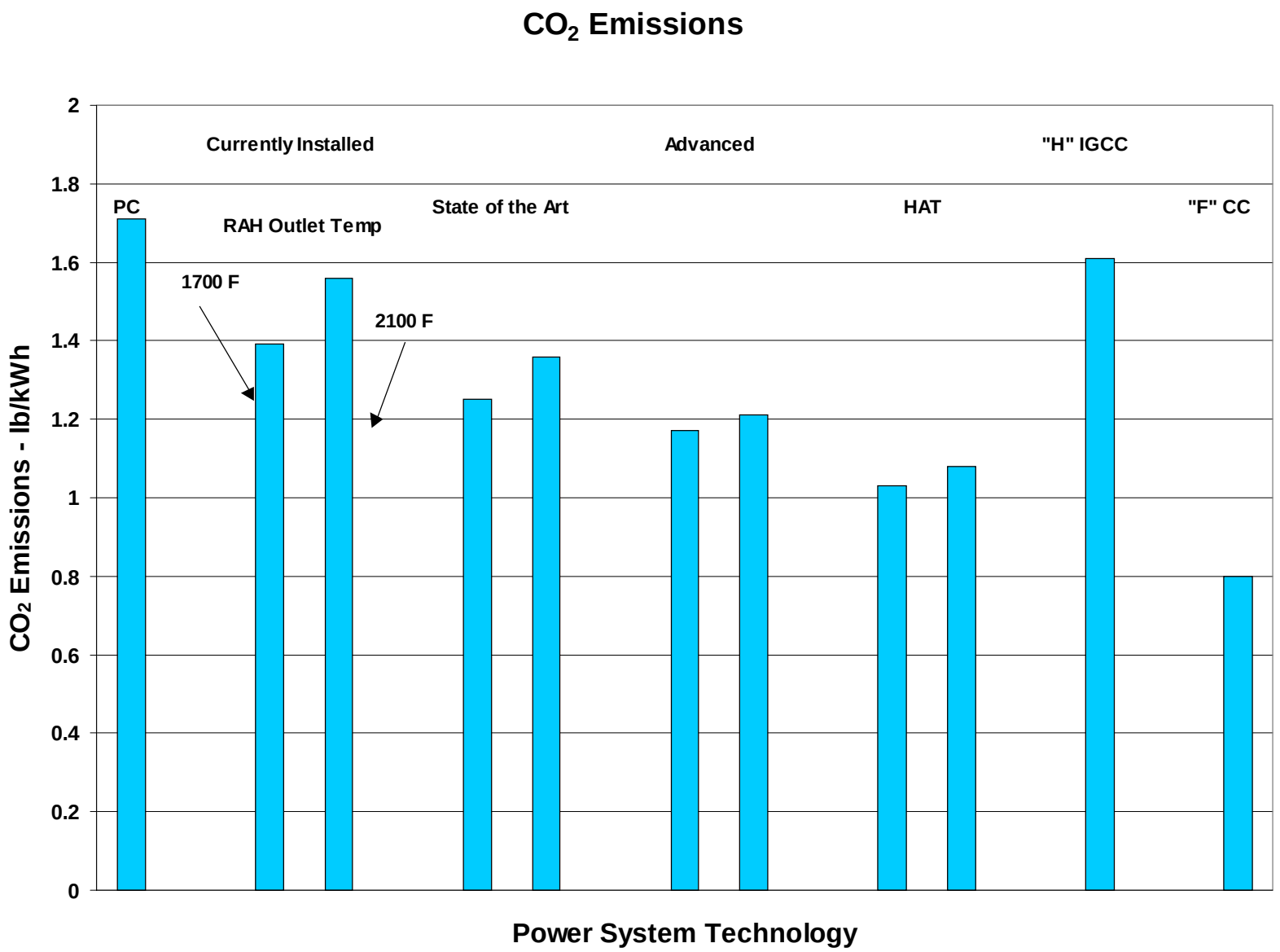

Power System Efficiency
60
50
40
30
20
10
0
Efficiency % (HHV)
PC
Currently Installed
State of the Art
Advanced
HAT
"H" IGCC
"F" CC
Power System Technology


Relative RAH Size
HIPPS with Refractory
HIPPS with Bare Tubes
Relative RAH Size
5.0
2.0
1.5
1.0
0.5
0
1500 F
1600 F
1700 F
1800 F
1900 F
2000 F
2100 F
2200 F
RAH Outlet Temperature - F

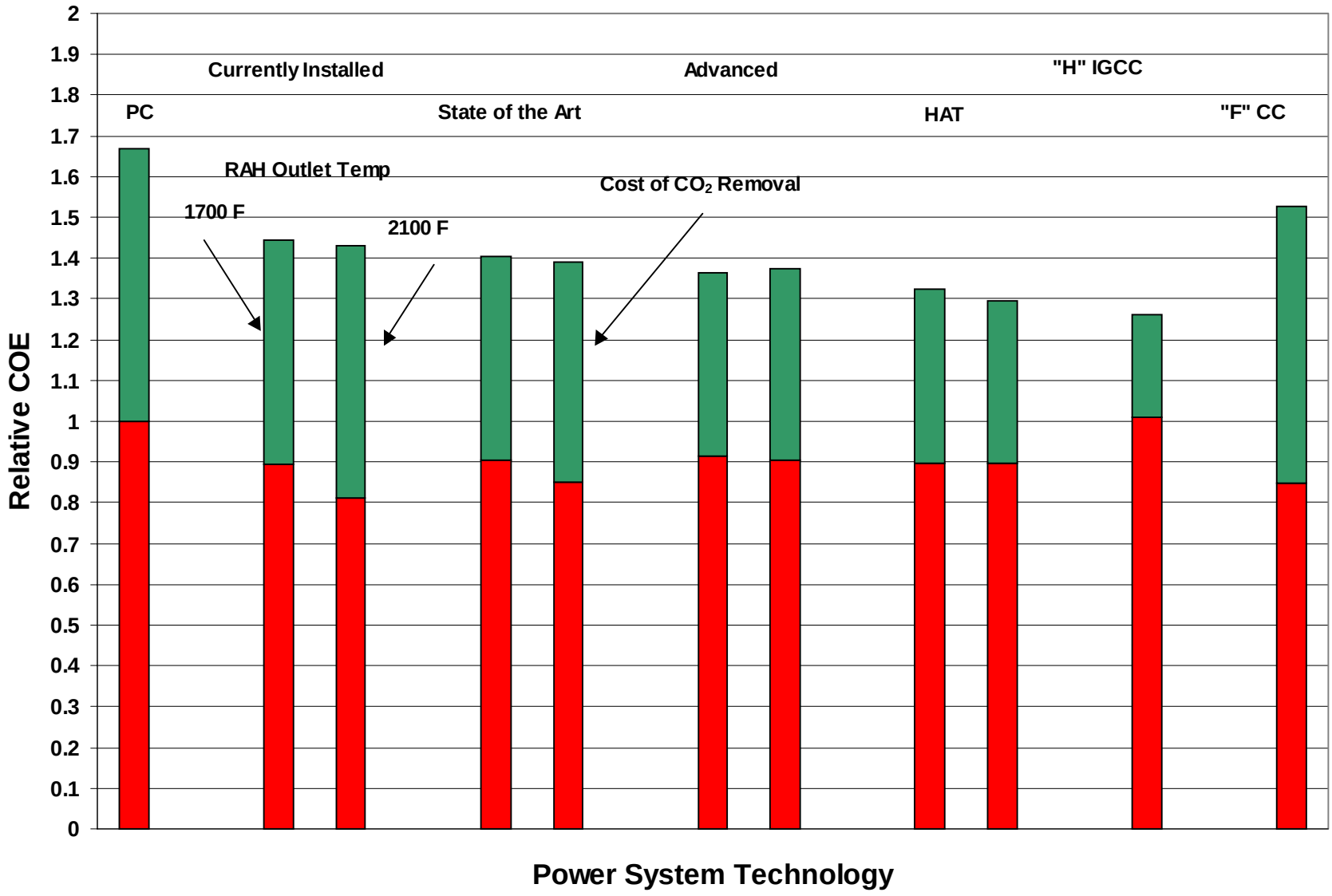

Coal Fraction
Currently Installed Technology
State of the Art Technology
Advanced Technology
Coal Energy/Total Energy
RAH Exit Temperature - F
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1500
1600
1700
1800
1900
2000
2100
2200

Relative Cost of Electricty




CO_2 Emissions
Currently Installed
Advanced
"H" IGCC
PC
State of the Art
HAT
"F" CC
RAH Outlet Temp
1700 F
2100 F
CO_2 Emissions - lb/kWh
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Power System Technology

Relative Cost of Electricity with CO_2 Capture



Summary

- Bare tube HiPPS has advantage over other HiPPS and conventional coal-based systems.
- Nearer term systems are very attractive and potentially could meet market demand for efficient, low cost coal-fired plants in Third World countries

Preliminary Conclusions

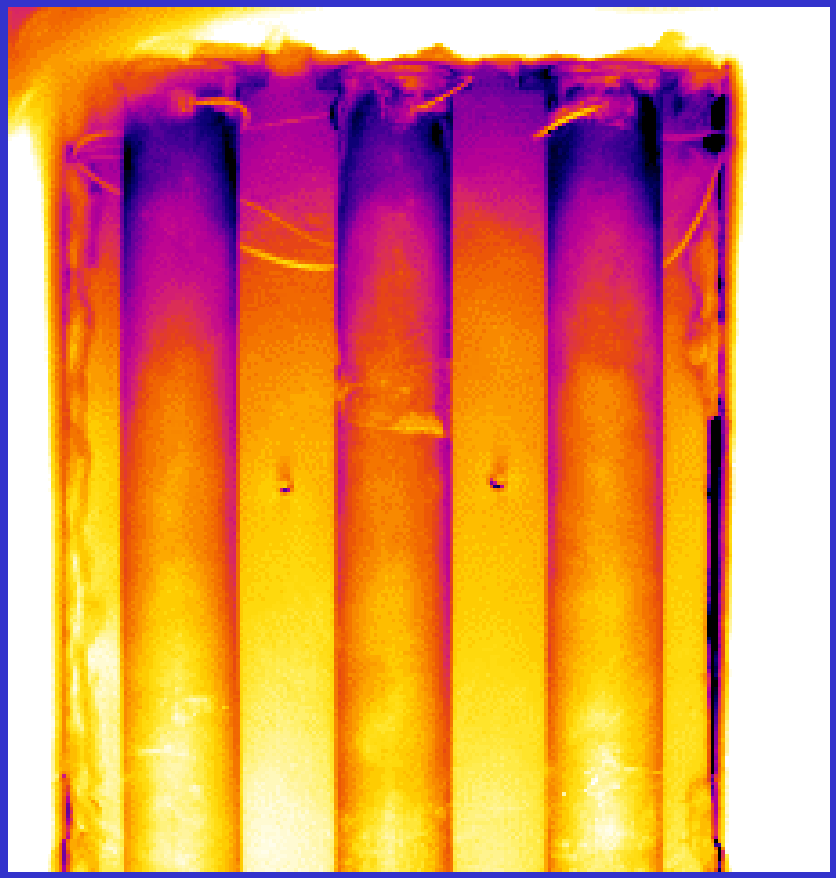
- Heat removal rates are increased by a factor of 4 to 6 by removing the ceramic panels.
- This change will lower the cost of the heat exchanger by a factor of 10 over the UTRC design.
- Initial ash deposit is thin and sintered which protects the tube from rapid corrosion with a minimum of insulation.
- A flowing slag layer is created within a few millimeters of the surface, minimizing insulating value and becoming self-cleaning.
- Most likely industries interested in first trying the technology are fossil-energy intensive industries, not the power sector.

Future Work

- With much lower levels of funding, pilot testing will not be possible.
- Corrosion testing of alloys with different flowing slags and temperatures will continue.
- Laboratory tests of joining MA 956 alloy.
- Construction of six foot tall, three tube heat exchanger using MA 956 alloy.

Infrared Image of RAH Tubes Before Coal-Fire – August 2001

Upper Portion



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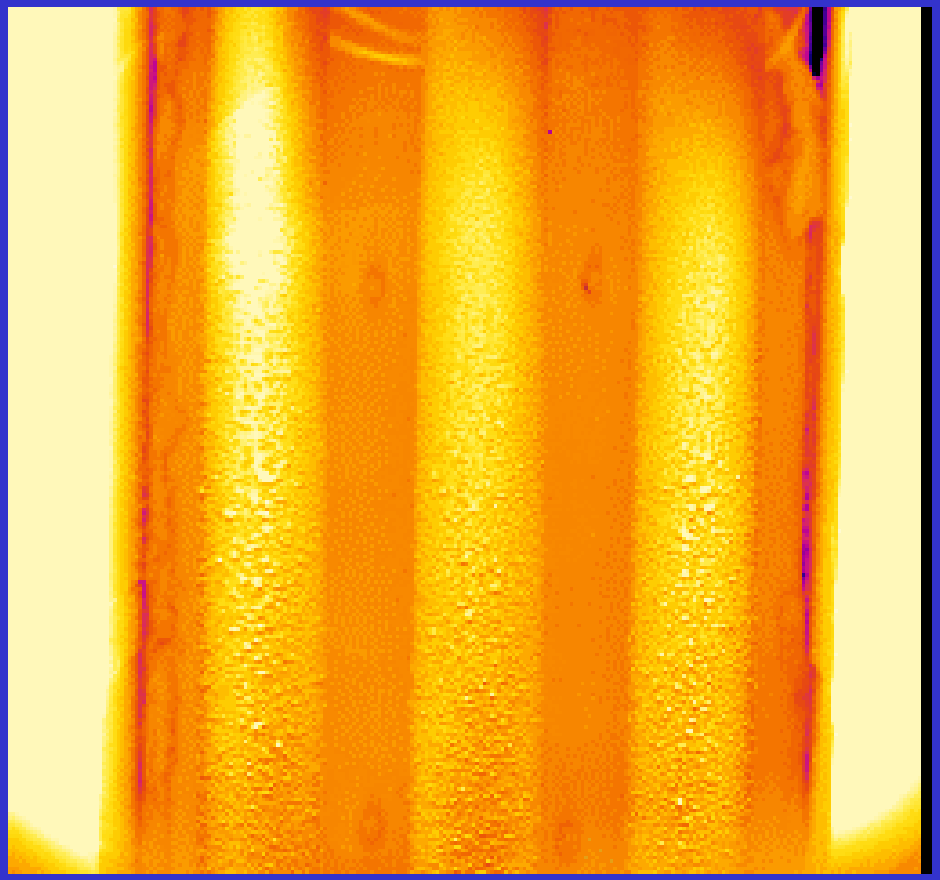
Infrared Image of RAH Tubes After 24 hr on Coal-Fire – August 2001



RAH Exchanger Tubes

Before August 2001 Test

After August 2001 Test

RAH Exchanger Tubes After August 2001 Test

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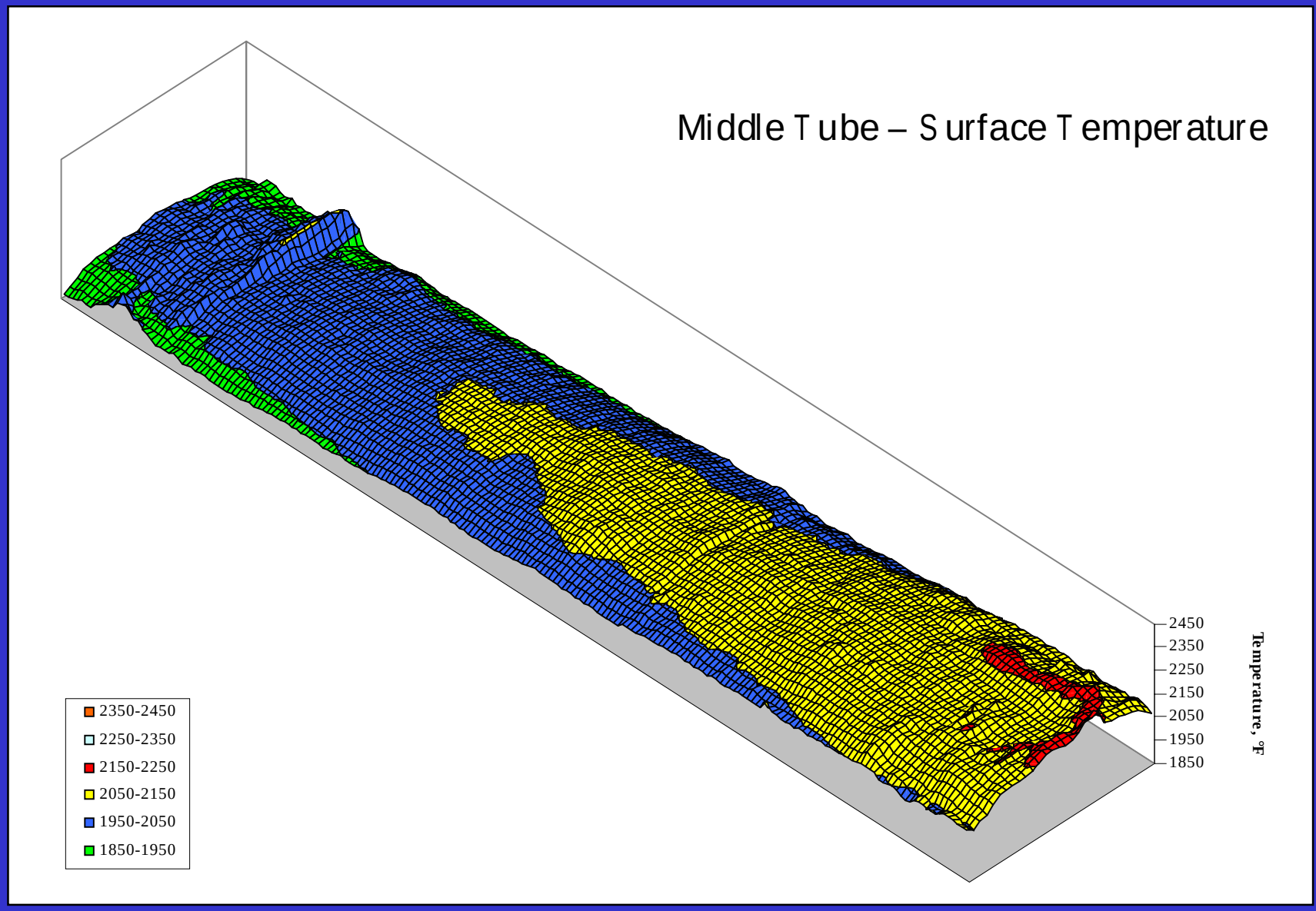
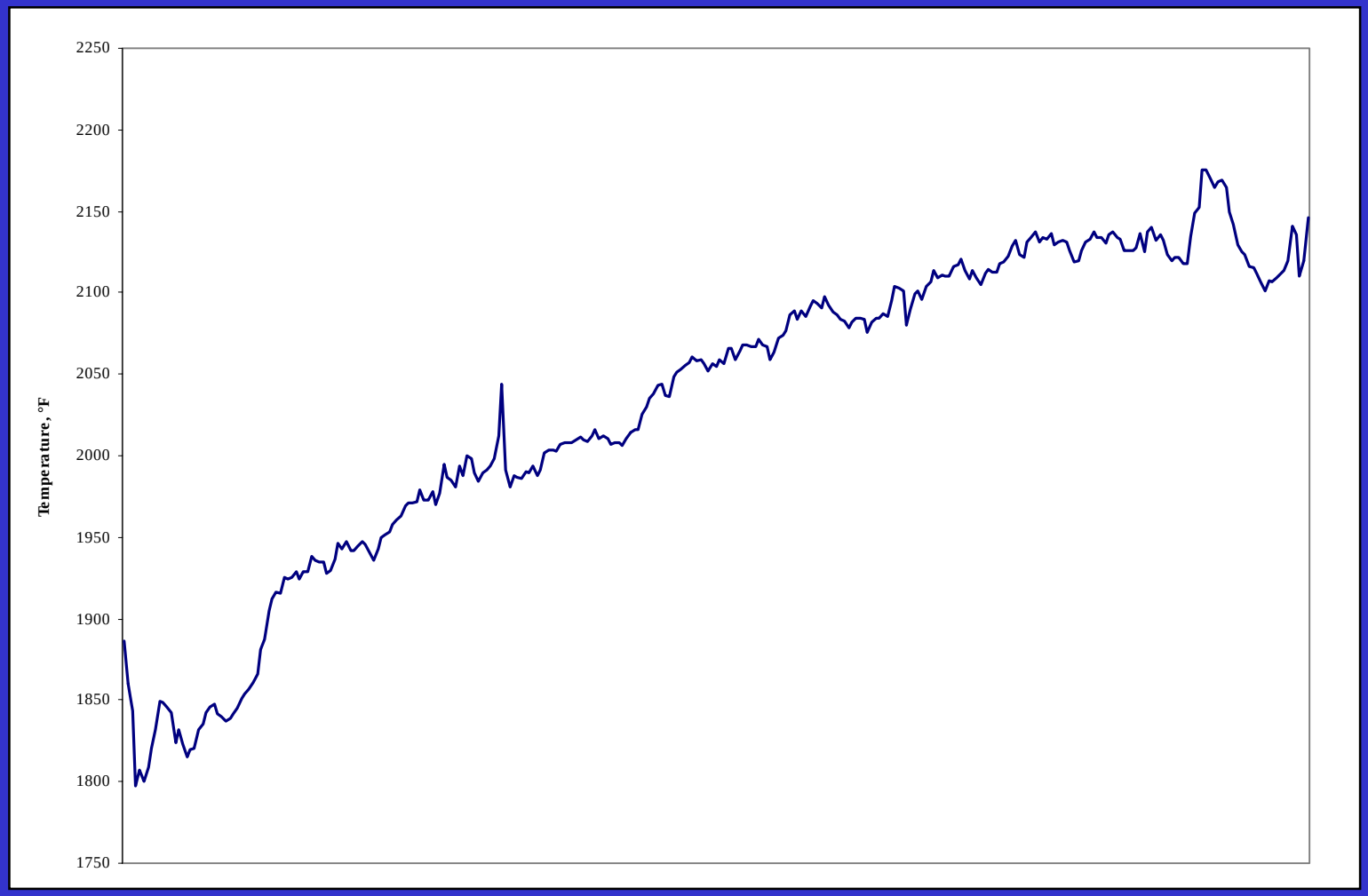
AM Images 02-04 Test 6
Before Coal-Fire – August 29, 2001



AM Images 02-04 Test 6
Before Coal-Fire – August 29, 2001

Middle Tube – Centerline Temperature



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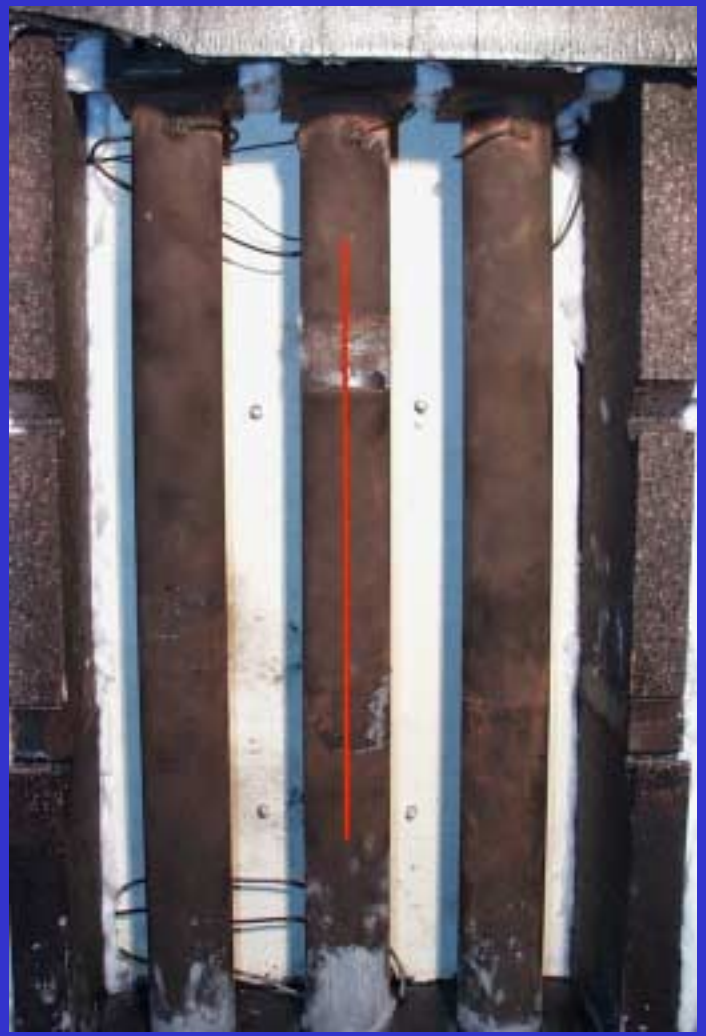
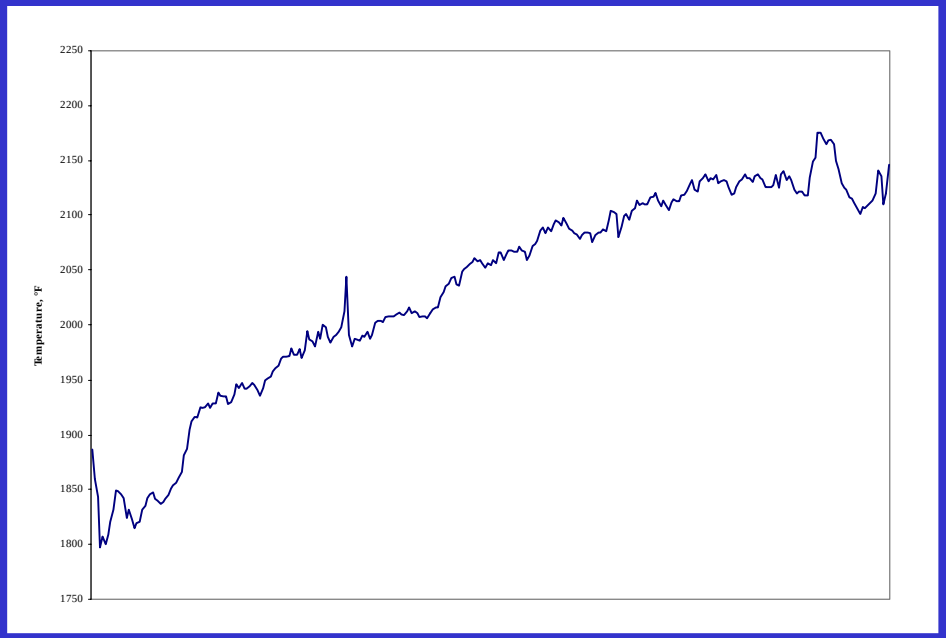
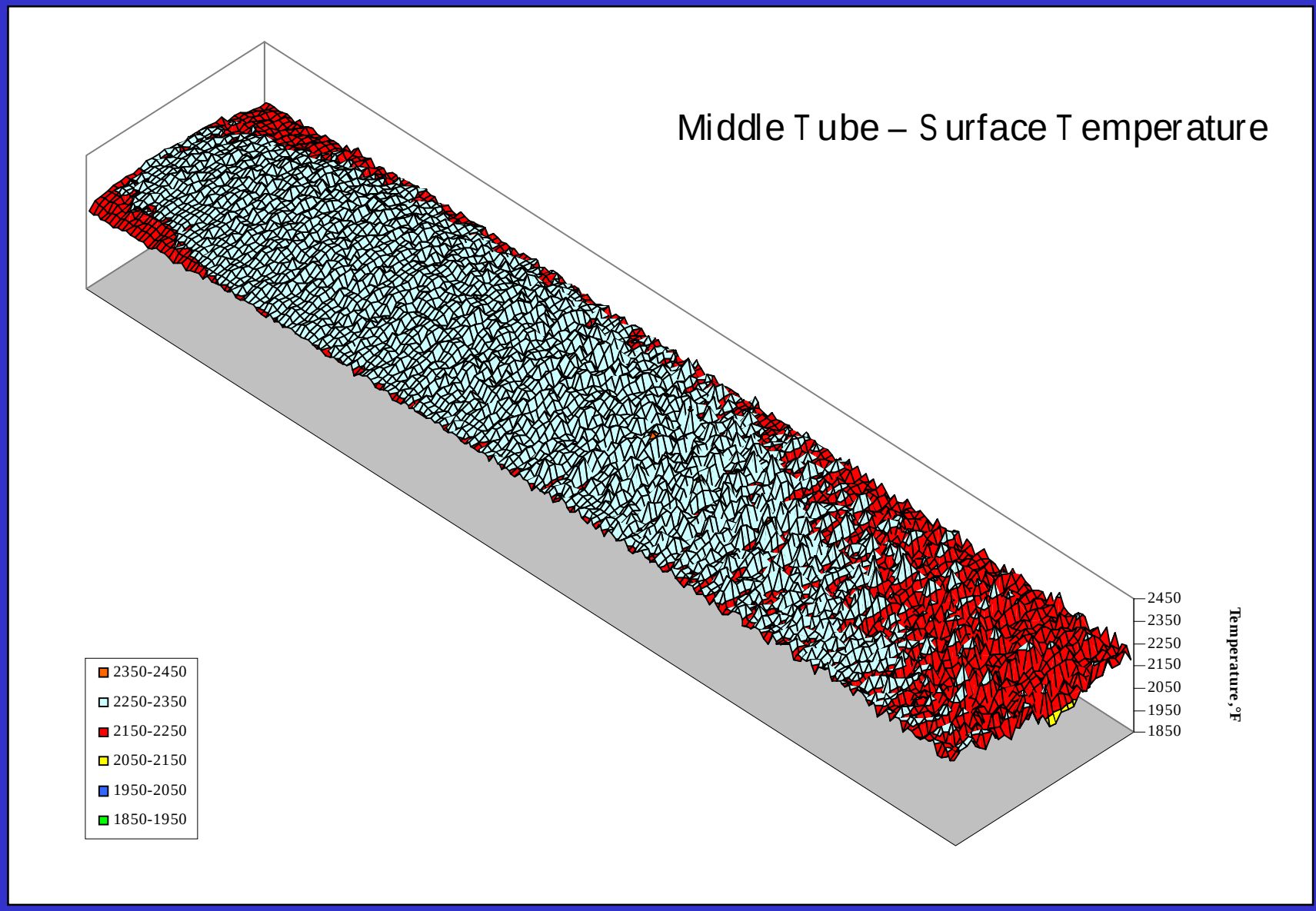


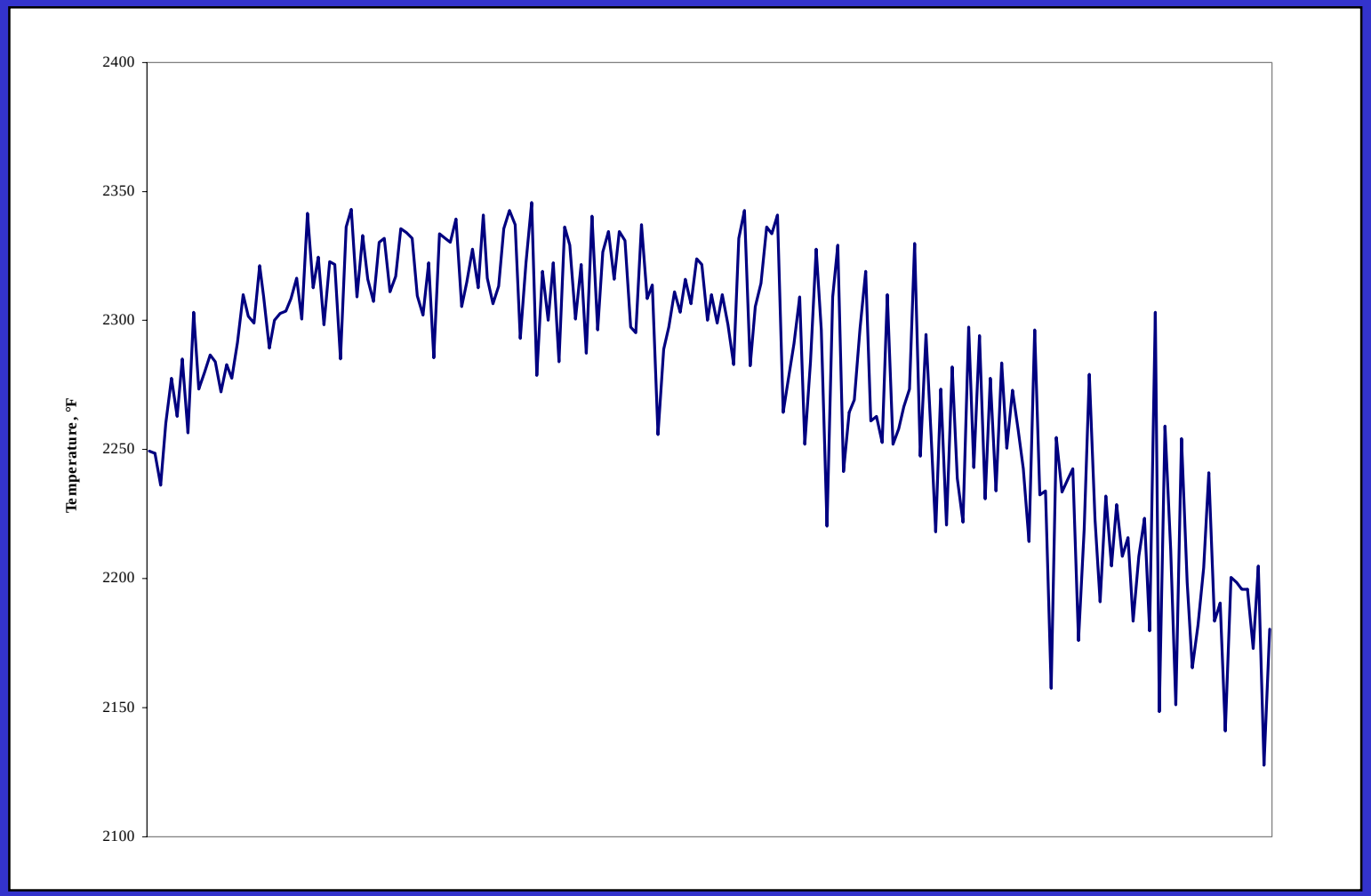


4PM Image 03 Test 7
After Coal-Fire – August 30, 2001



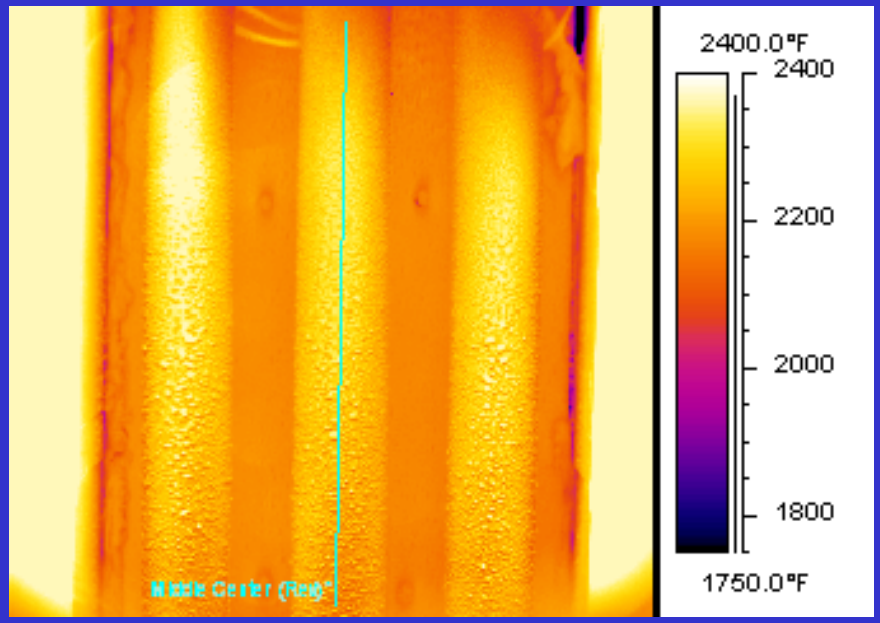
4PM Image 03 Test 7
After Coal-Fire – August 30, 2001

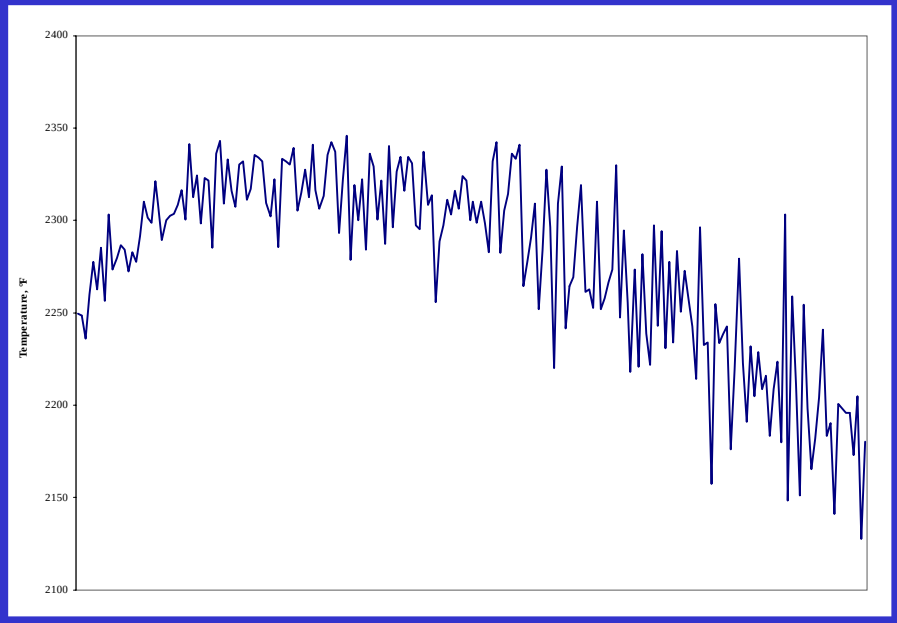
Middle Tube – Centerline Temperature



4PM Image 03 Test 7
After Coal-Fire – August 30, 2001

Middle Tube – Centerline Temperature





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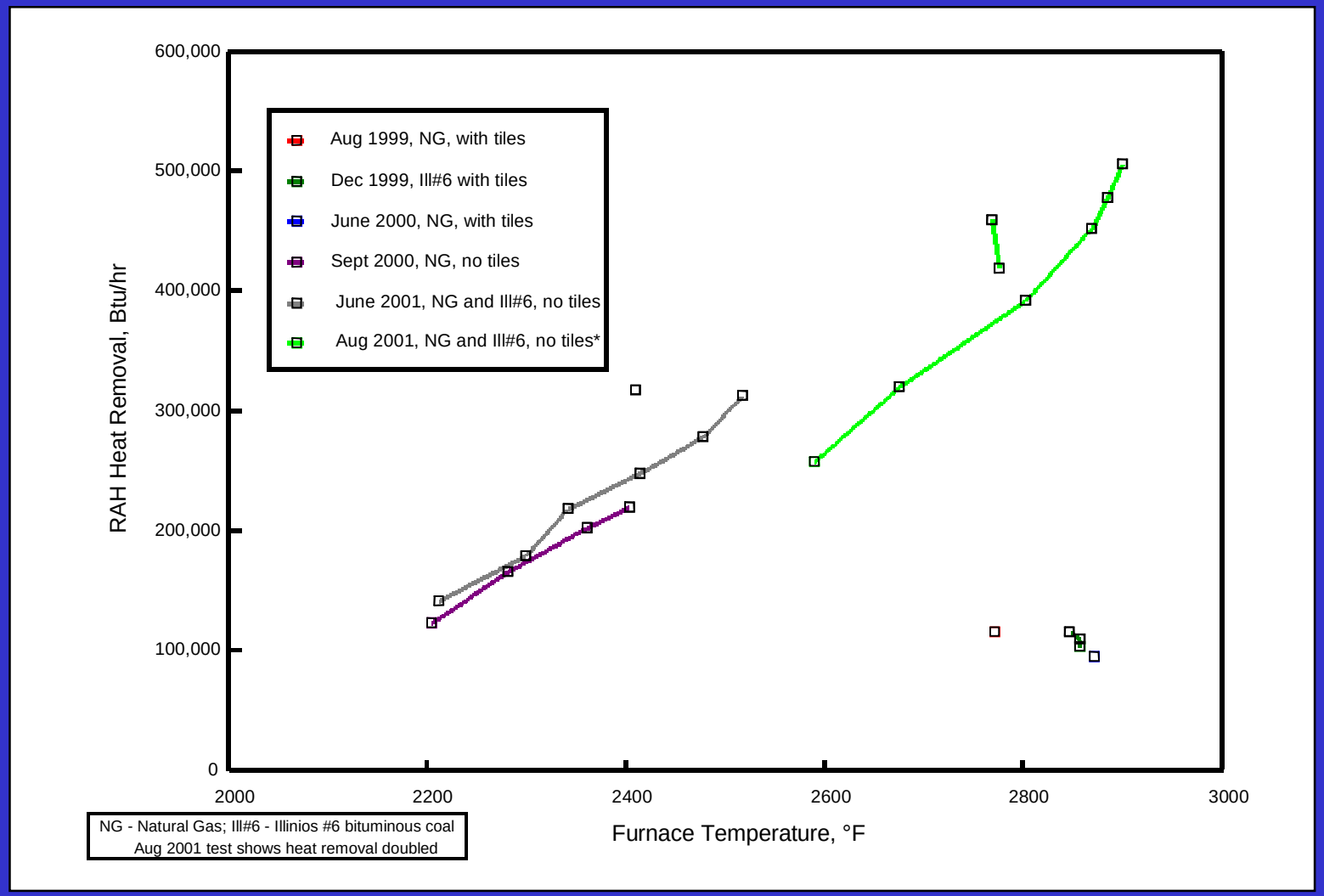
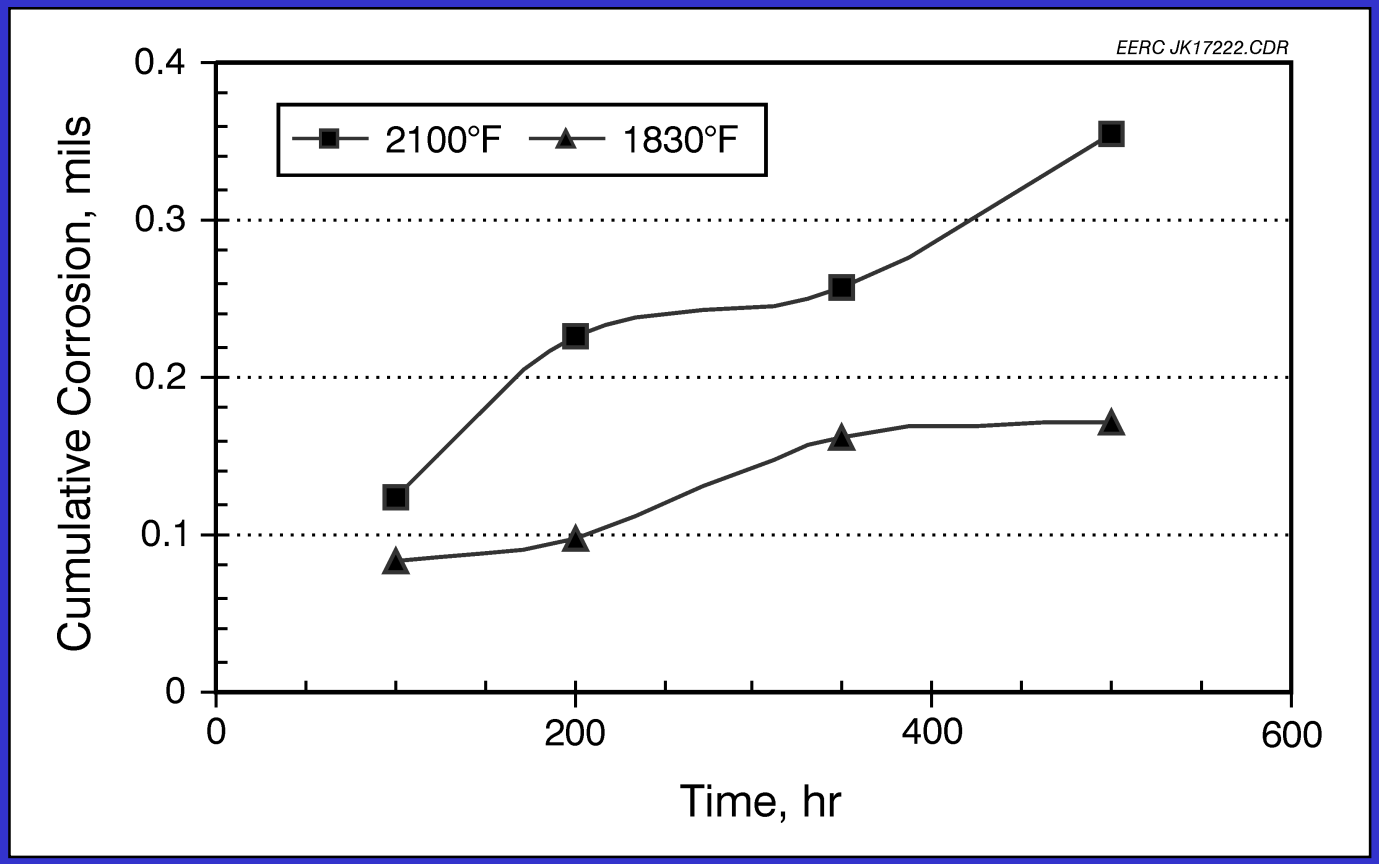
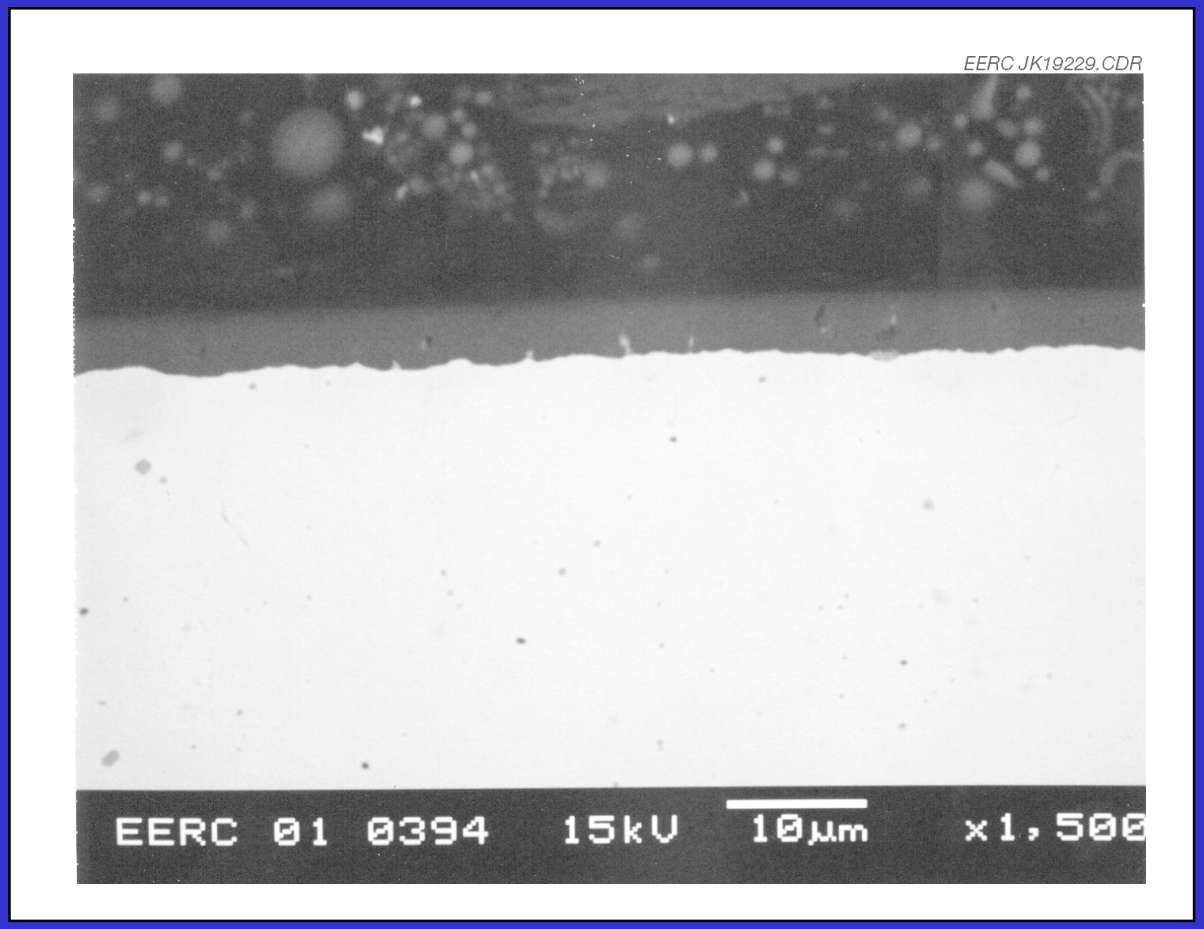
Heat Removal and Air Flow Rates September 2000 and June 2001 SFS Tests



Corrosion of MA754 Under Coal Combustion Conditions



Protective Alumina Layer on MA956



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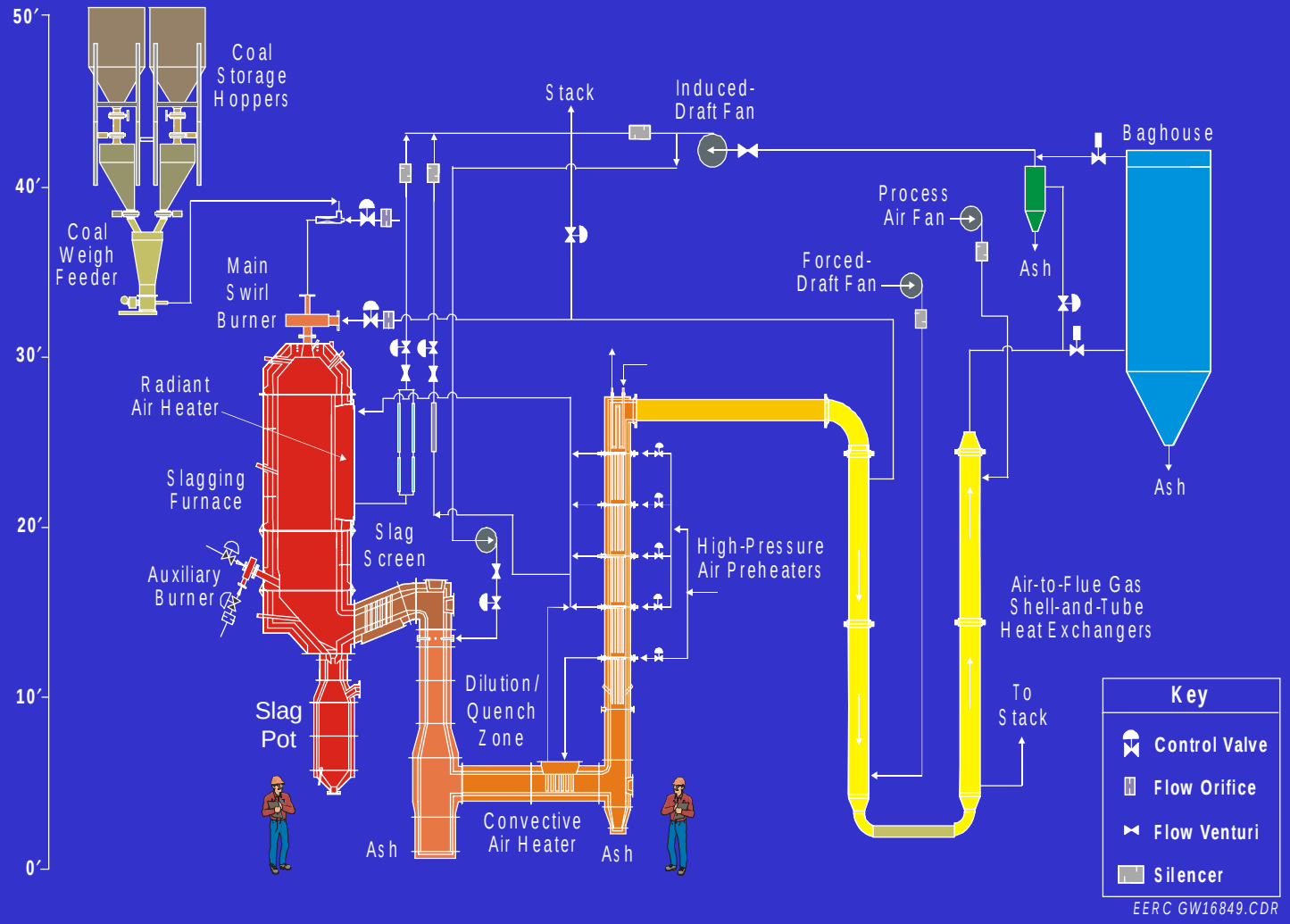
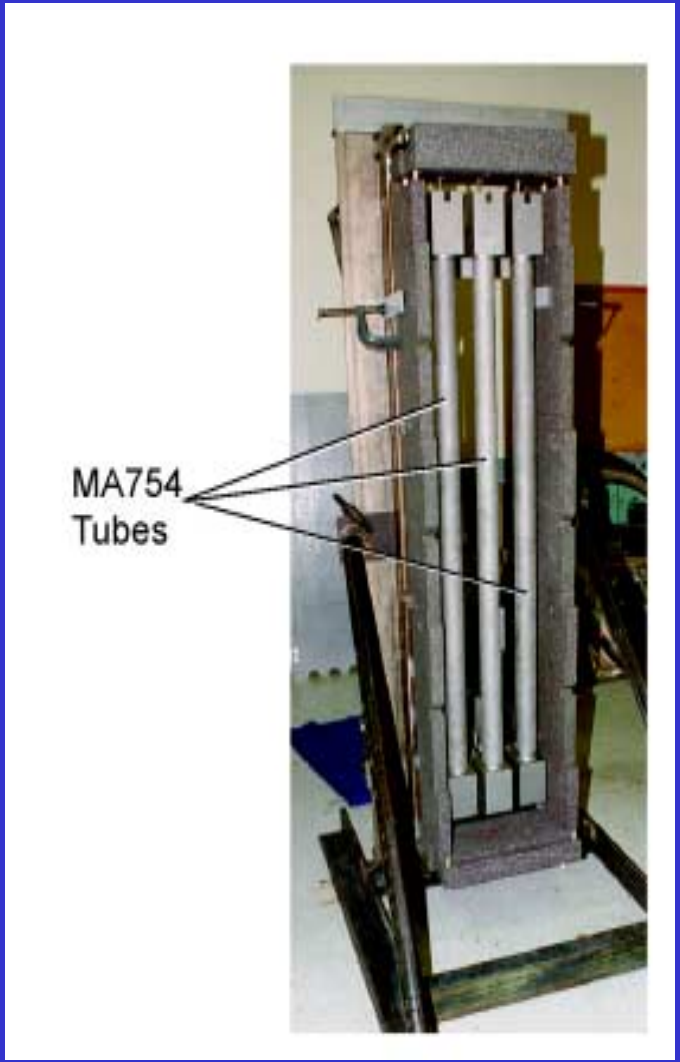
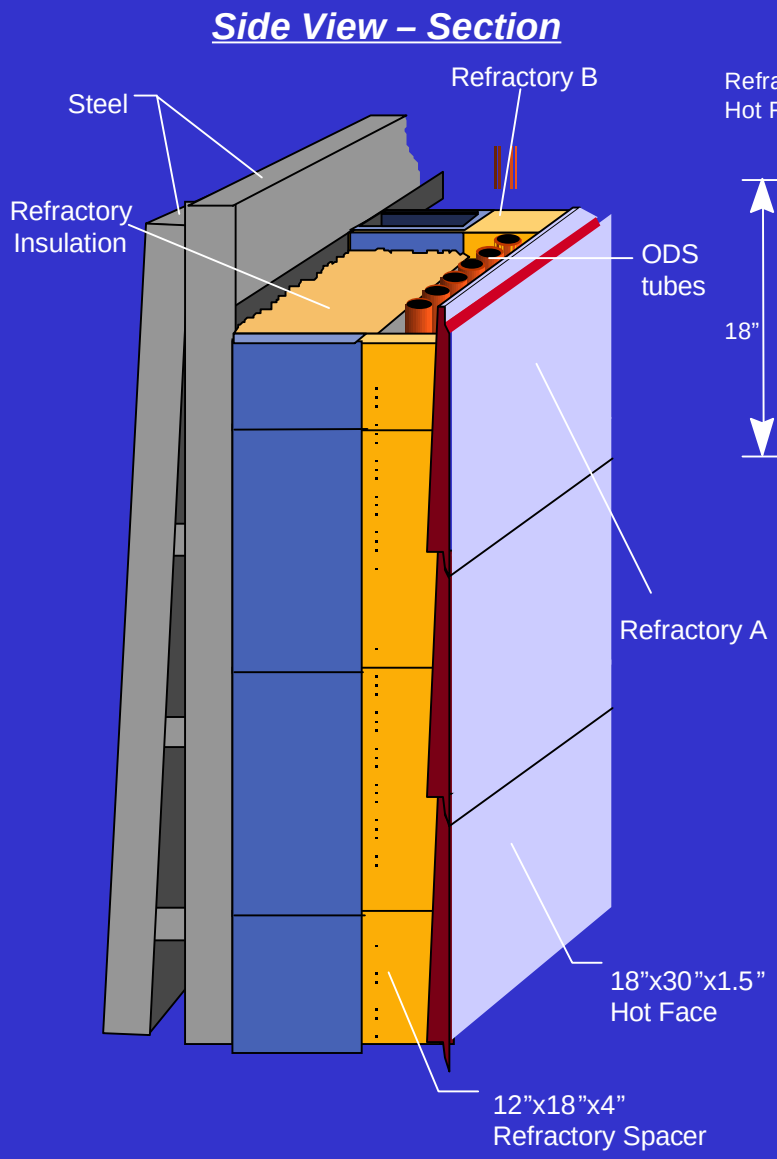
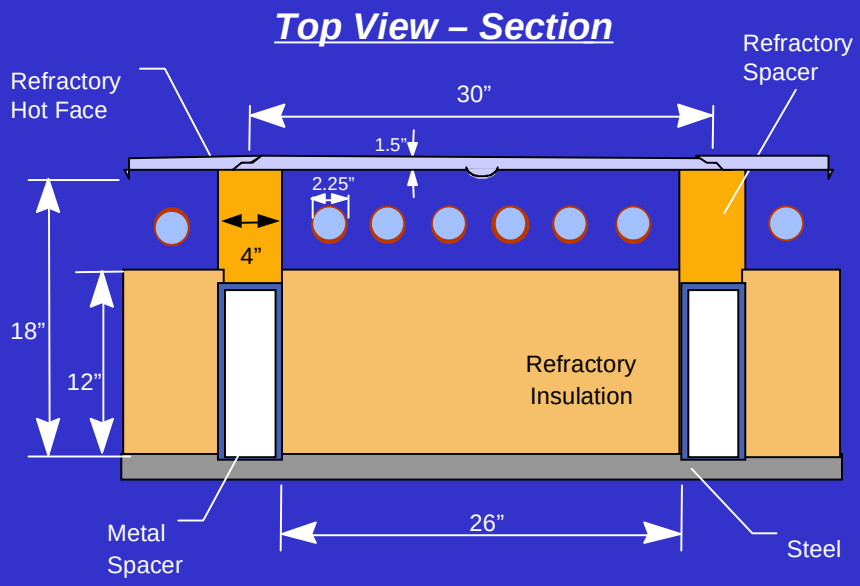
Combustion 2000 Slagging Furnace



Open View of RAH Test Panel







Hot Sections of Radiant Air Heater

Summary of Operating Experience

RAH Operation

- Heat transfer meets design criteria with Monofrax tiles.
- Standard process air 1750°F and 150 psig.
- 2000°F process air reached for short time at 100 psi.
- Slag layer less than 1 mm thick on panels.
- Thermal shock is biggest problem for ceramic panels.
- Corrosion of panels is secondary issue.
  - Additives may substantially reduce corrosion.
  - Prevent dripping to prevent channeling of slag.

Goals of HiPPS

- < 47% efficiency
- 1/10 emissions of particulates, SO_x, and NO_x
- 10% reduction in cost of electricity
- Efficiency to 55% with Illinois Basin coal–75% gas
- 2% less efficiency with high-moisture lignite

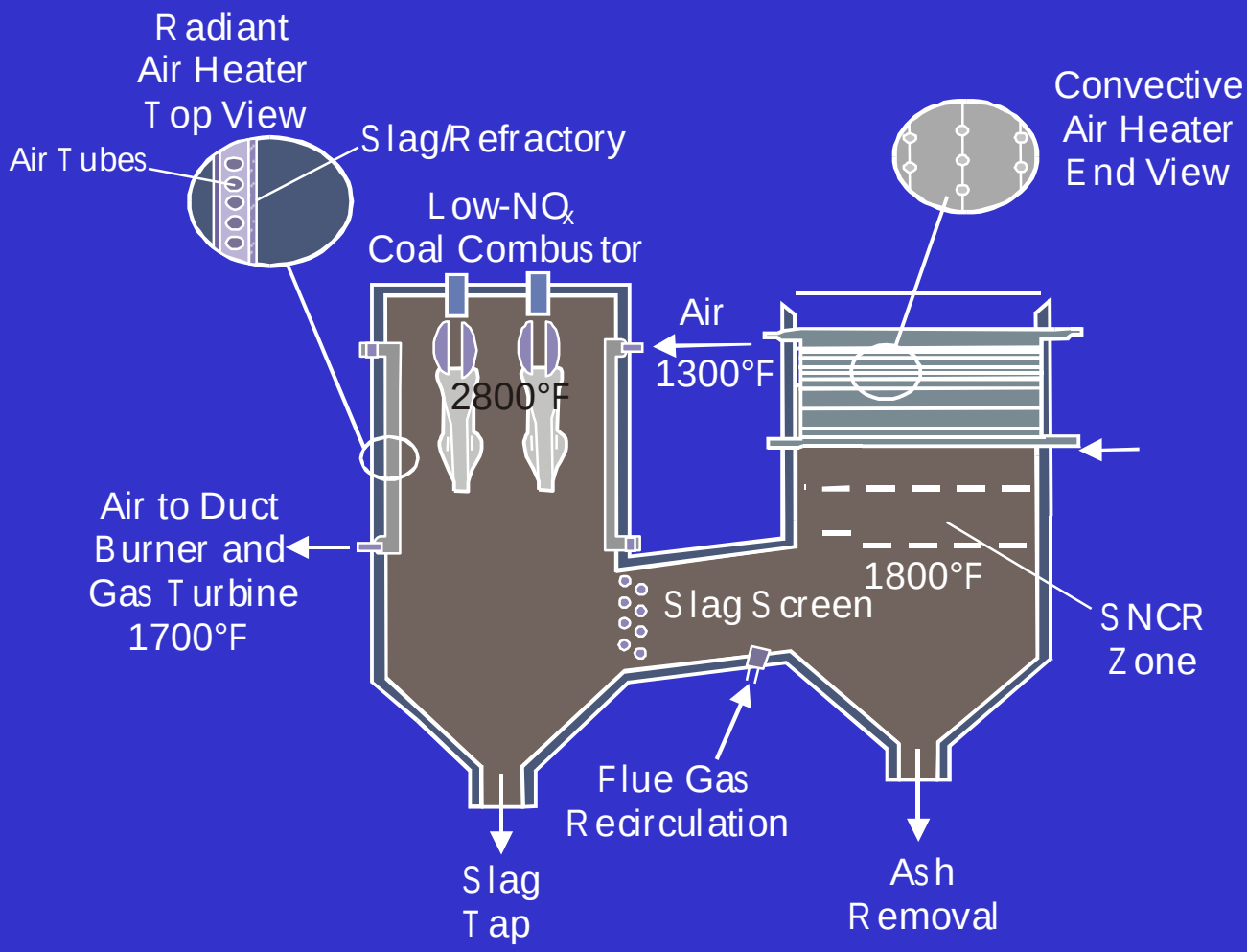
Pilot-Scale System

- Slagging furnace
- Slag screen
- Dilution-quench zone
- Process air preheater
- Convective air heater
- Radiant air heater
- Tube and shell heat exchangers

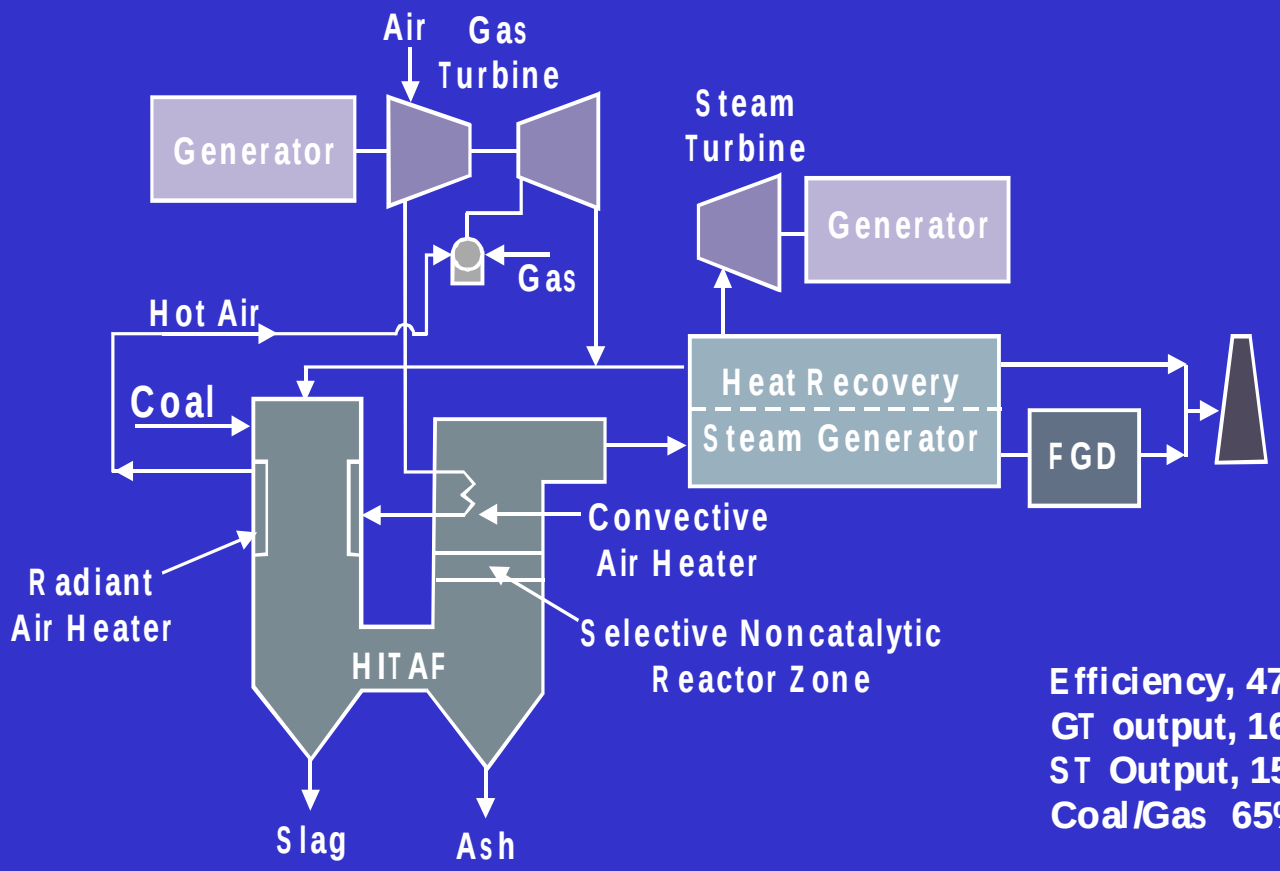
Slagging Furnace

- Maximum temperatures 2700°F–2900°F
- 2.5 MMBtu/air
- Residence time ~ 3.5 sec (Illinois Basin)
  2.6 sec (Powder River Basin)
- Down-fired
- Data acquisition system

Conceptual Design of HITAF



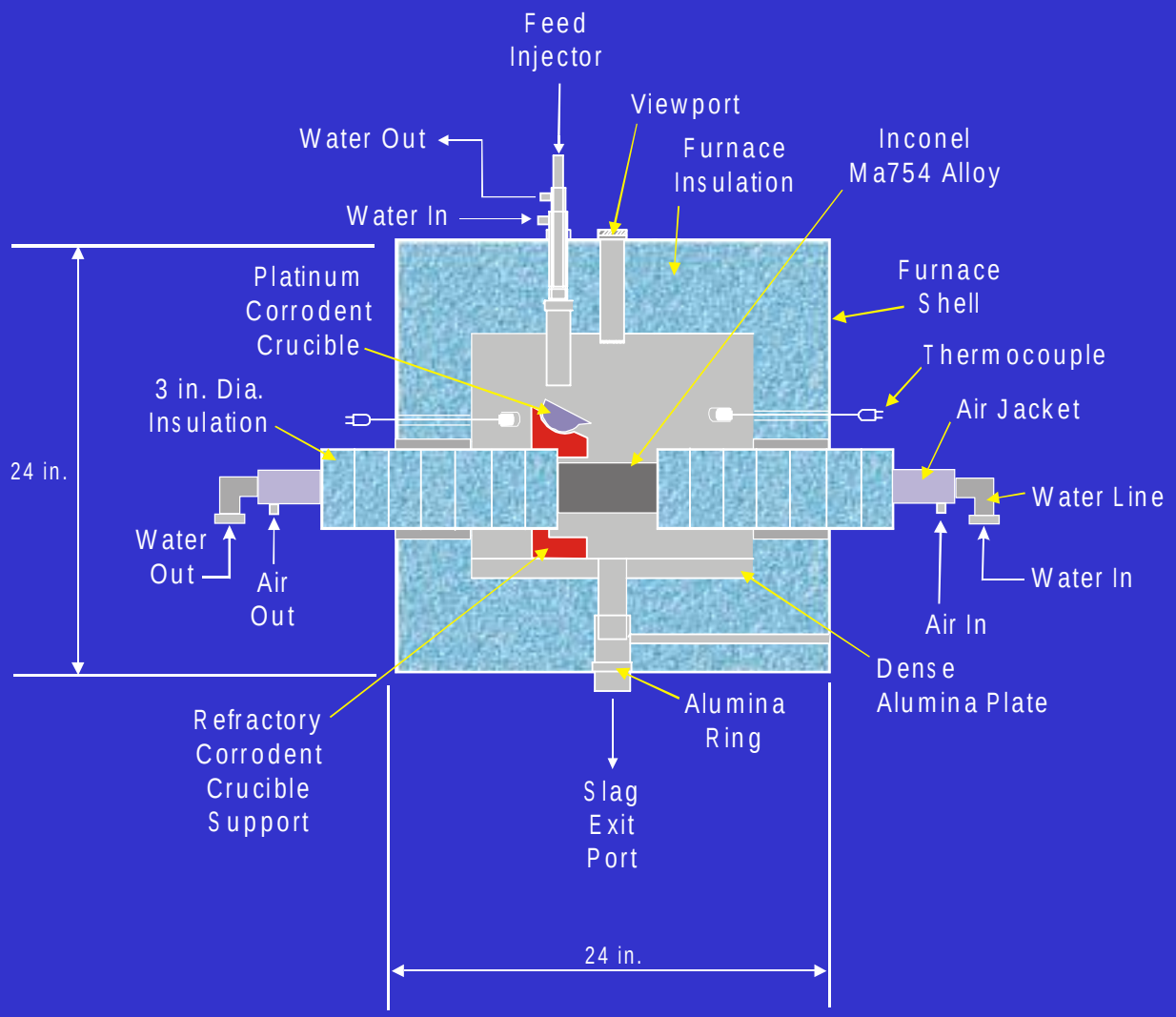
HiPPS Schematic



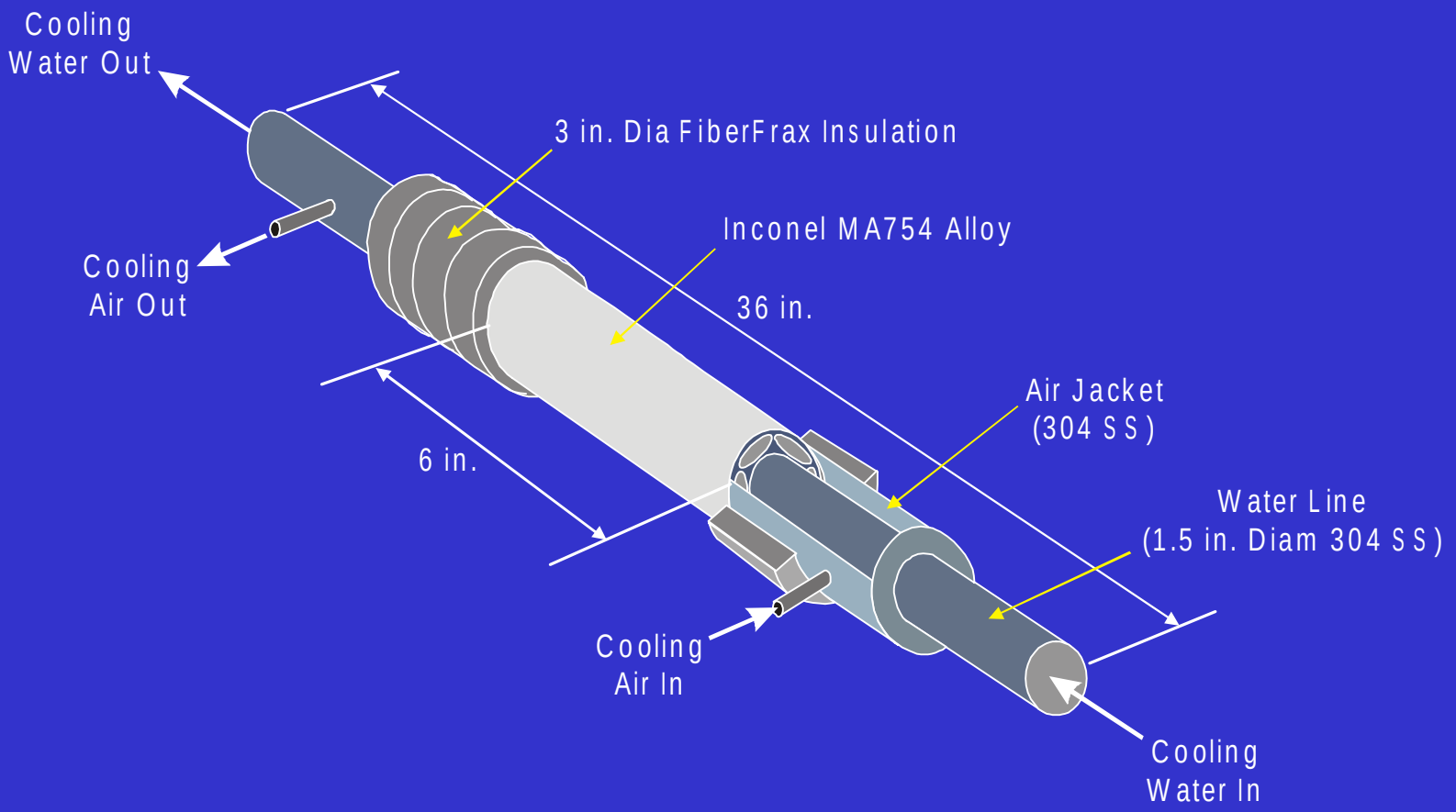
Efficiency, 47.3%
GT output, 161 MW
ST Output, 150 MW
Coal/Gas 65%/35%

(Robson, et al., 1994(

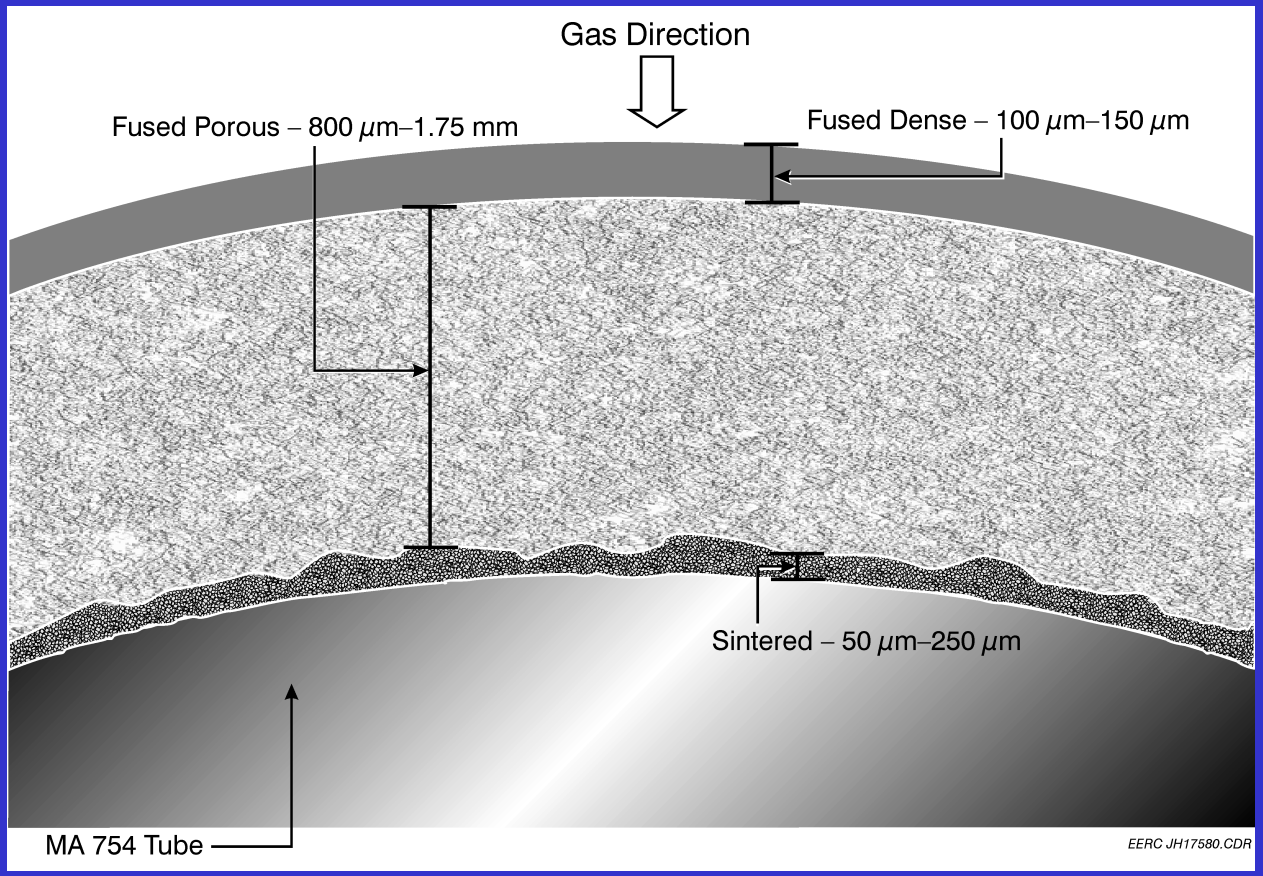
DSAF Modified For Alloy Testing



Alloy Cooling Schematic



MA 754 Direct Exposure



- Surface cooled to 2000°F
- 1.5 mm thick detached slag layer developed on surface
- No nickel or chrome in the detached slag layer
- 20 micron thick attached slag layer
- 10 micron chromia corrosion layer under attached slag
- Surface recession average 2.2 mil/110 hours or 180 mil/year

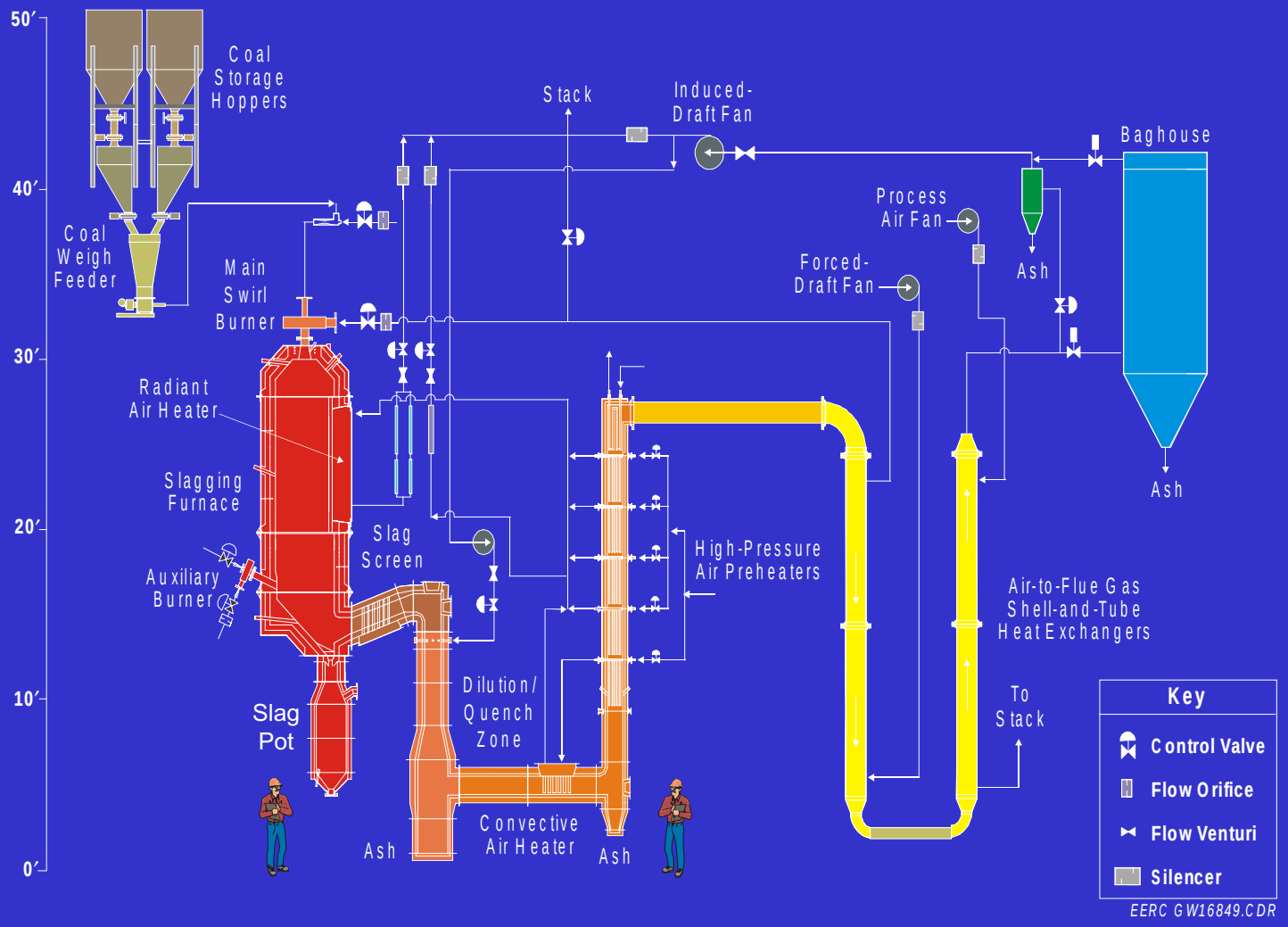
Preliminary Conclusions

- Heat removal rates are increased by a factor of 4 to 6 by removing the ceramic panels.
- This change will lower the cost of the heat exchanger by a factor of 10 over the UTRC design.
- Initial ash deposit is thin and sintered which protects the tube from rapid corrosion with a minimum of insulation.
- A flowing slag layer is created within a few millimeters of the surface, minimizing insulating value and becoming self-cleaning.
- Most likely industries interested in first trying the technology are fossil-energy intensive industries, not the power sector.

Conclusions

- Bare tube HiPPS using MA 956 has very low corrosion rates
- Heat transfer rates ~5 times heat transfer rates for the heat exchanger in the box (does not drop off with time as ash layer build)
- Cost of radiant heat exchange surface reduced by factor of 10
- Bare tube HiPPS has advantage over other HiPPS and conventional coal-based systems

Combustion 2000 Slagging Furnace



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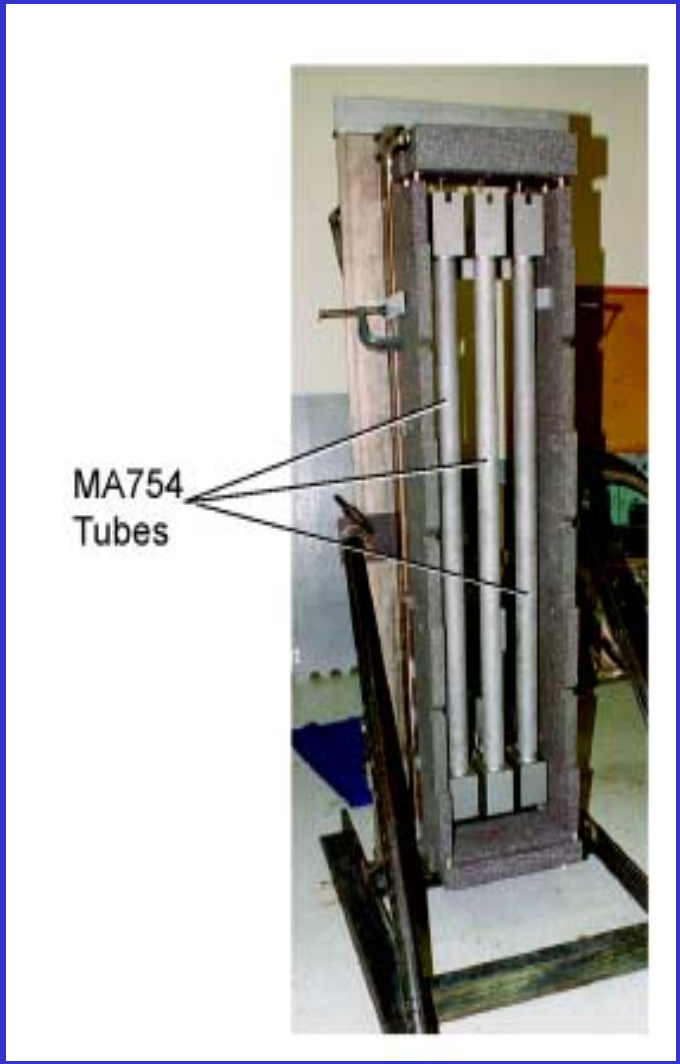

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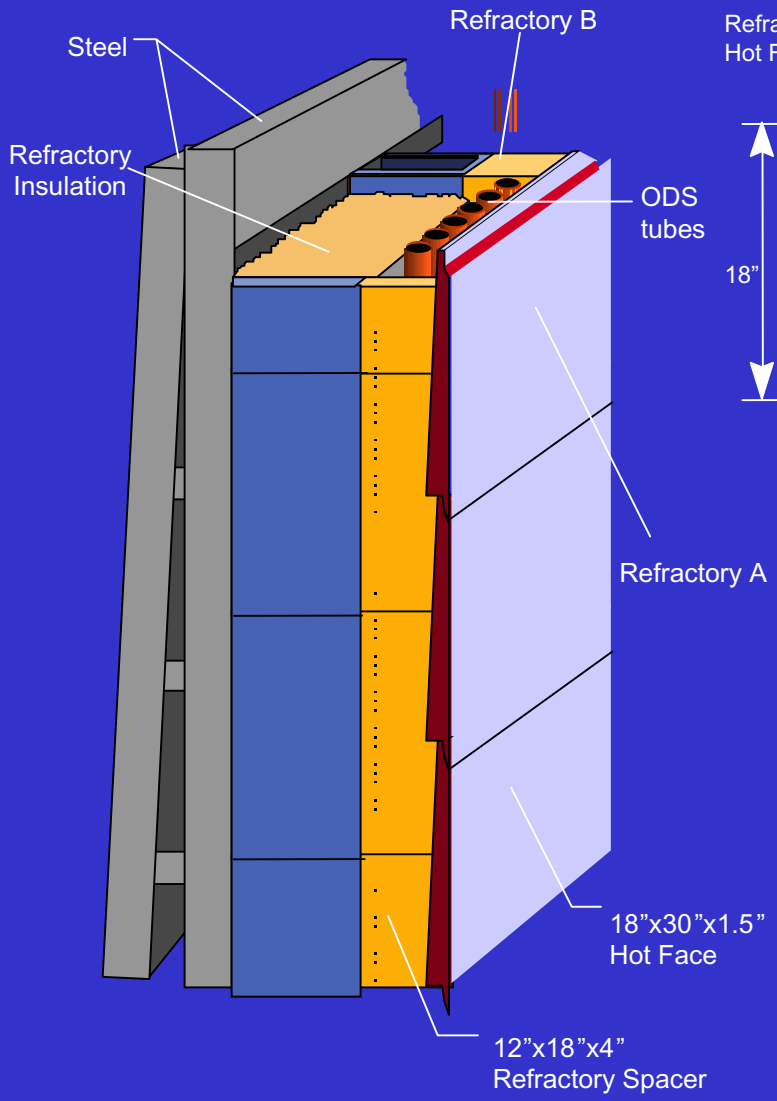
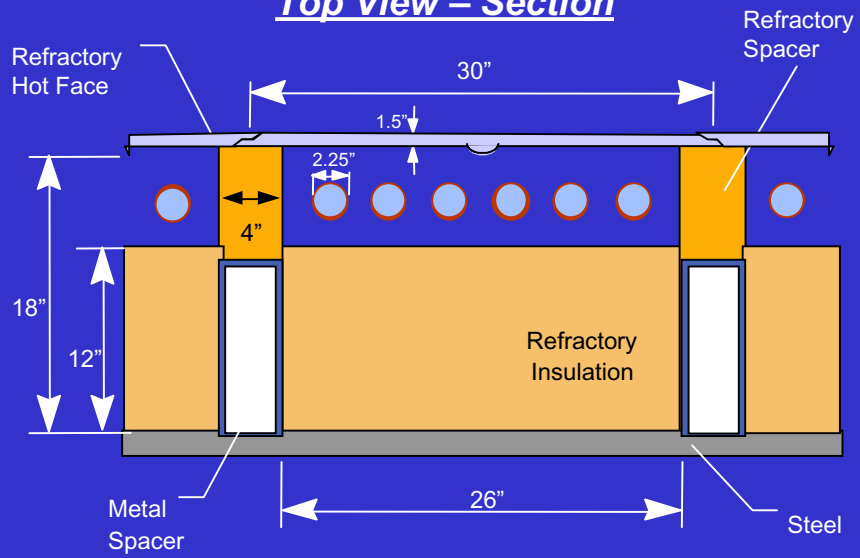
Side View – Section



Top View – Section



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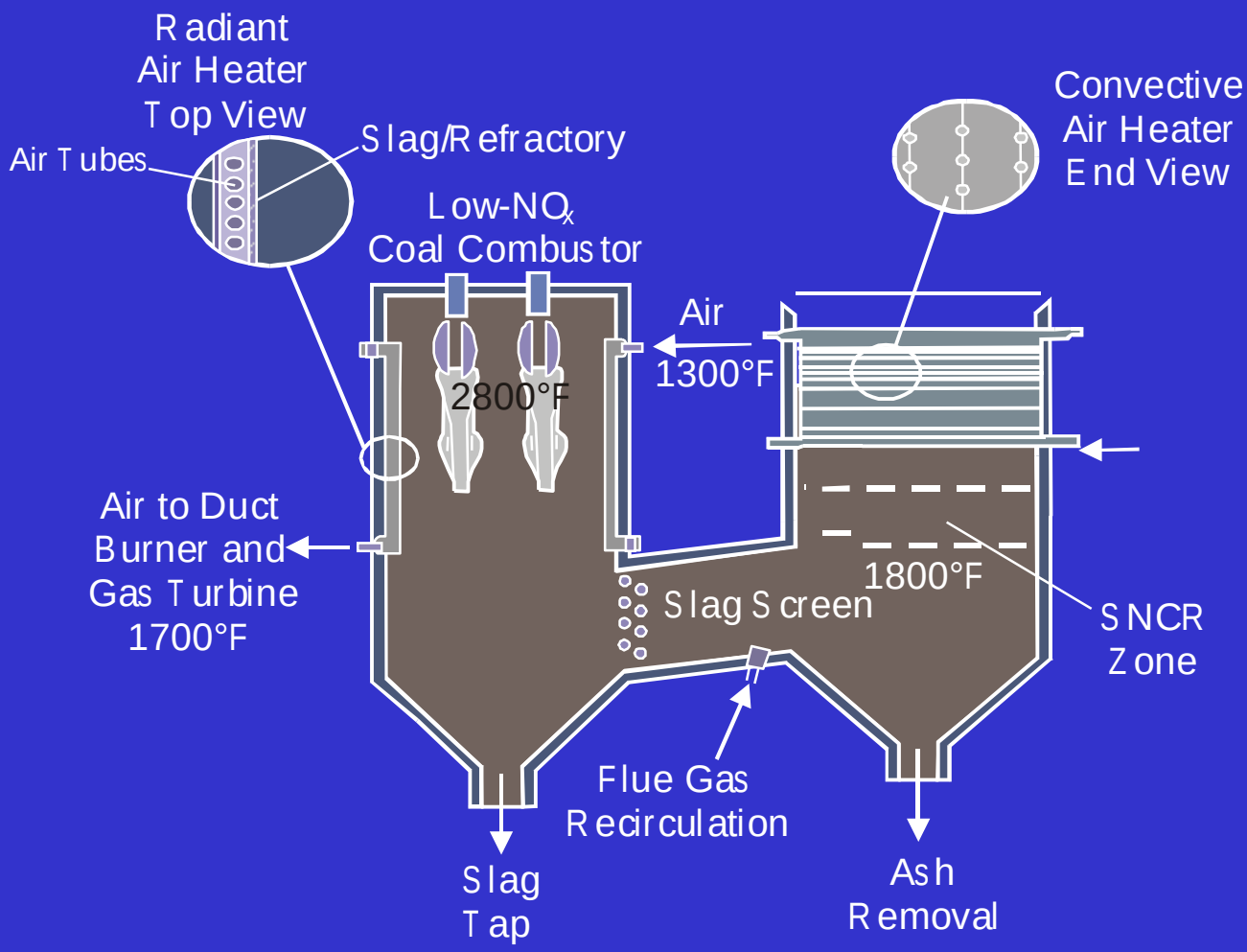
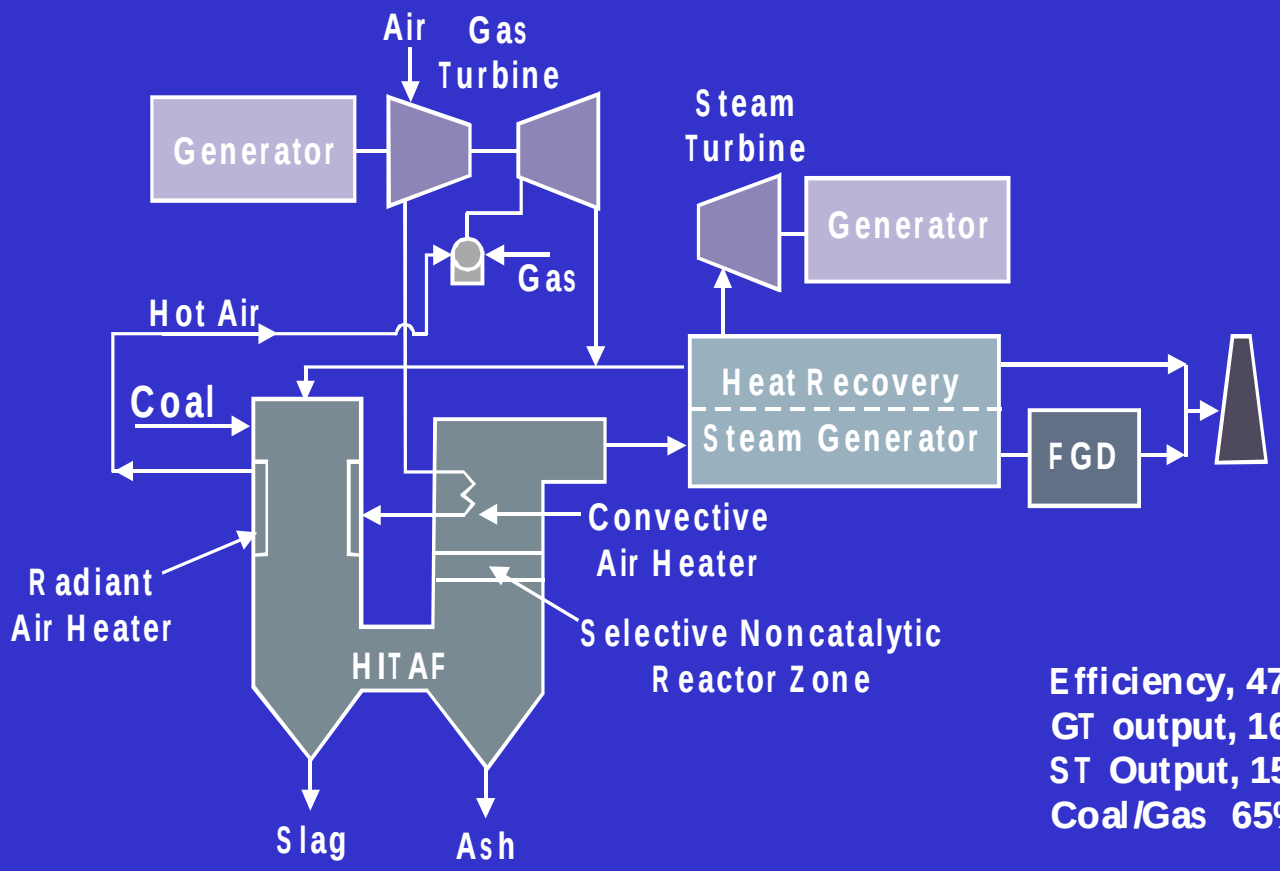


HiPPS Schematic



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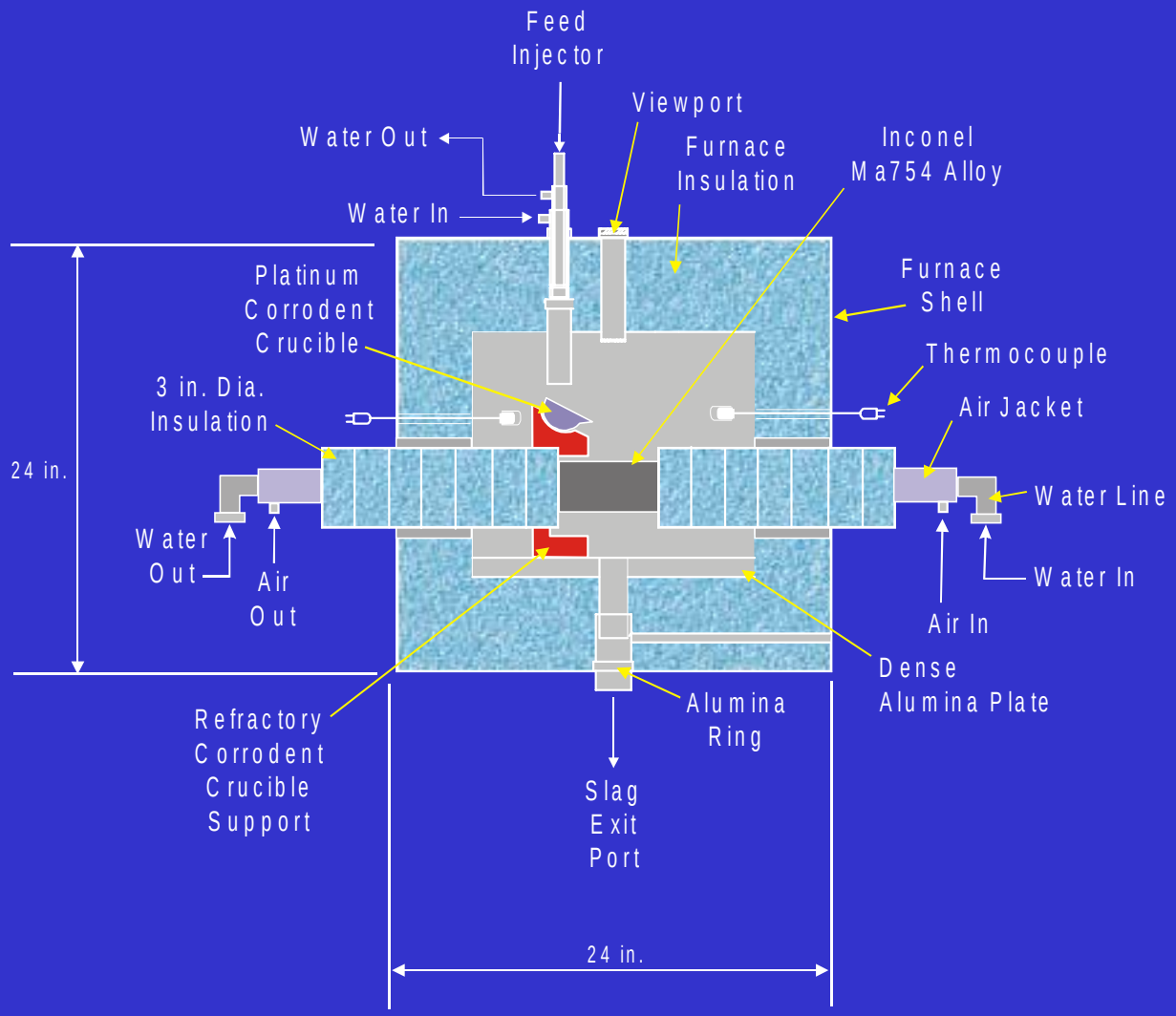

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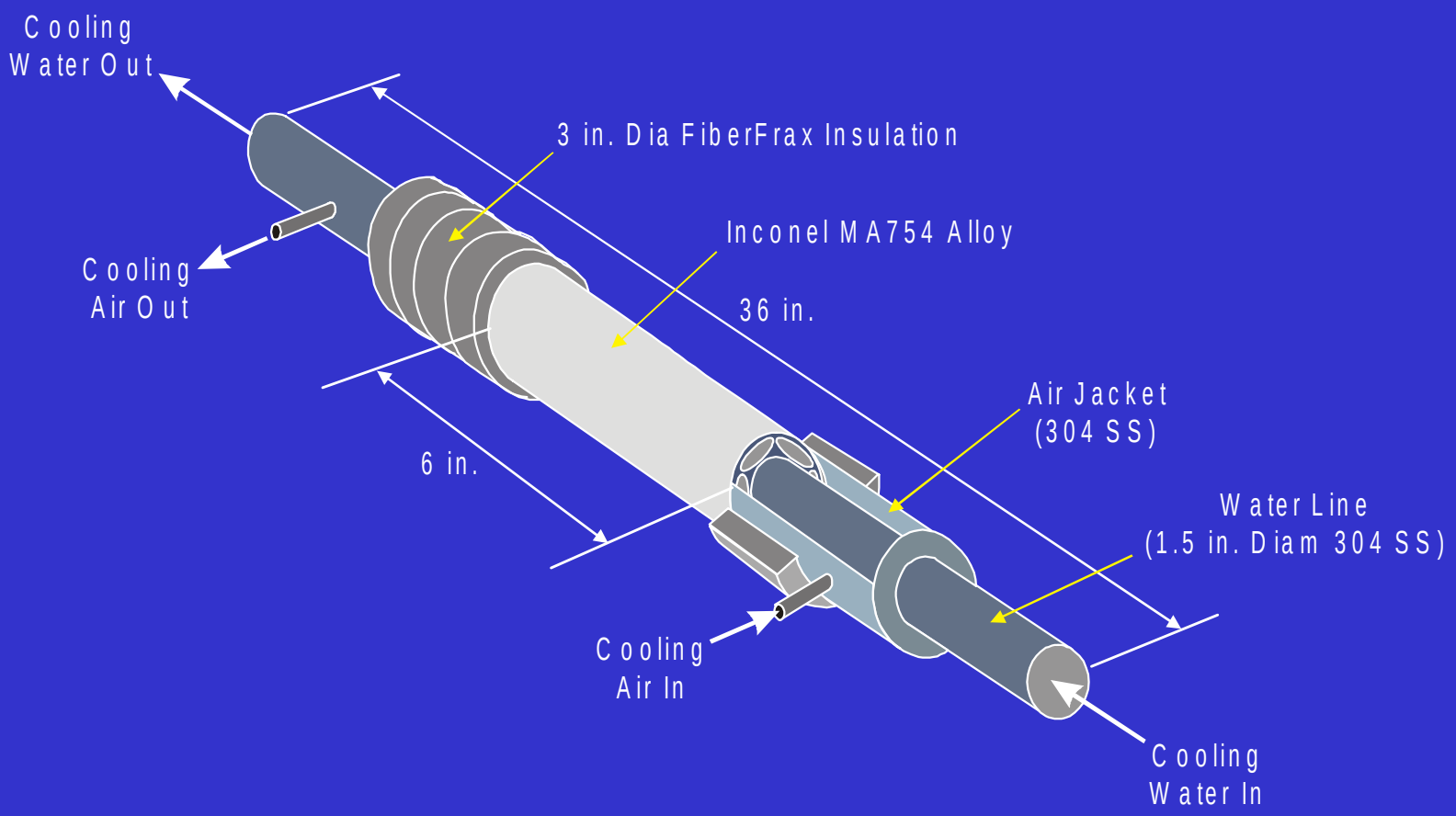

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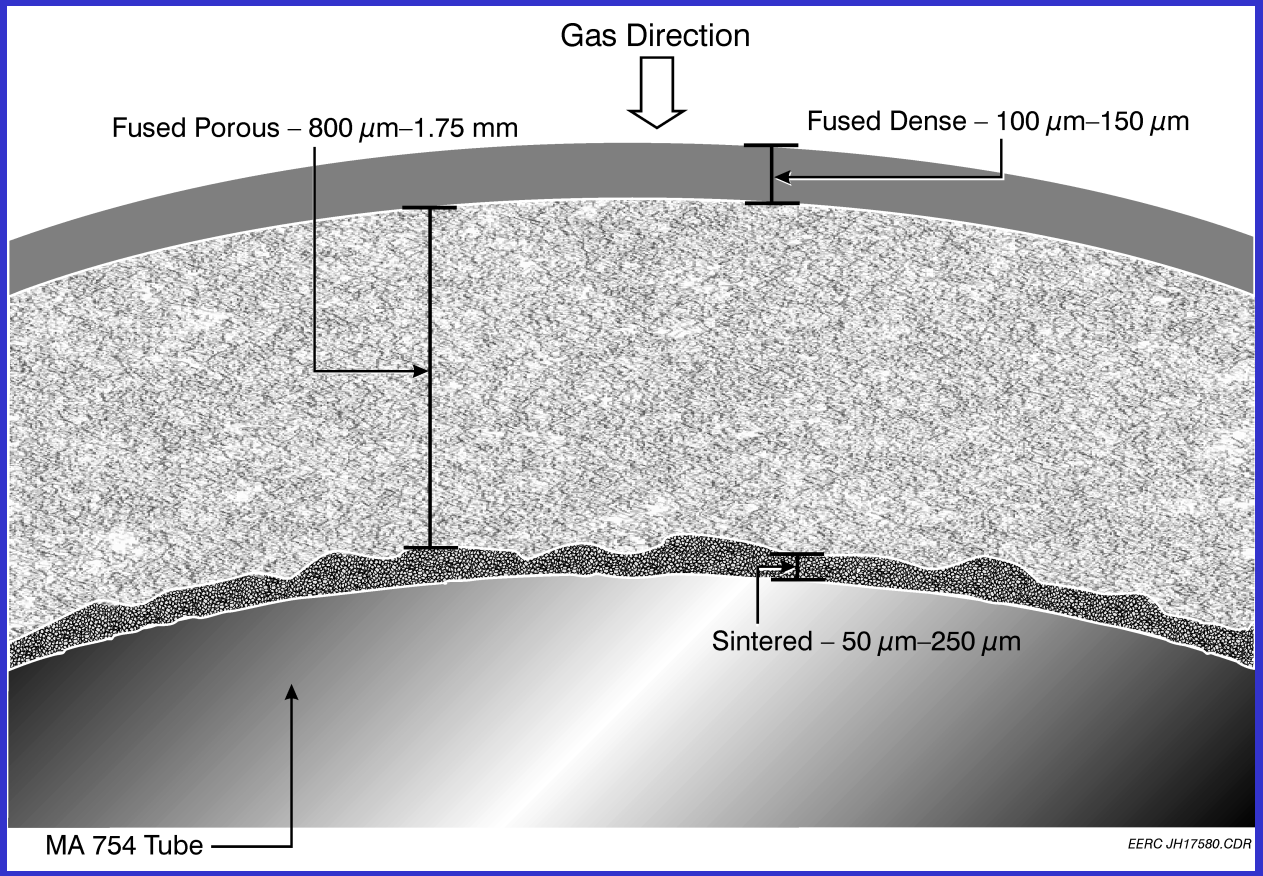

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RAH Exchanger Tubes After August 2001 Test

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