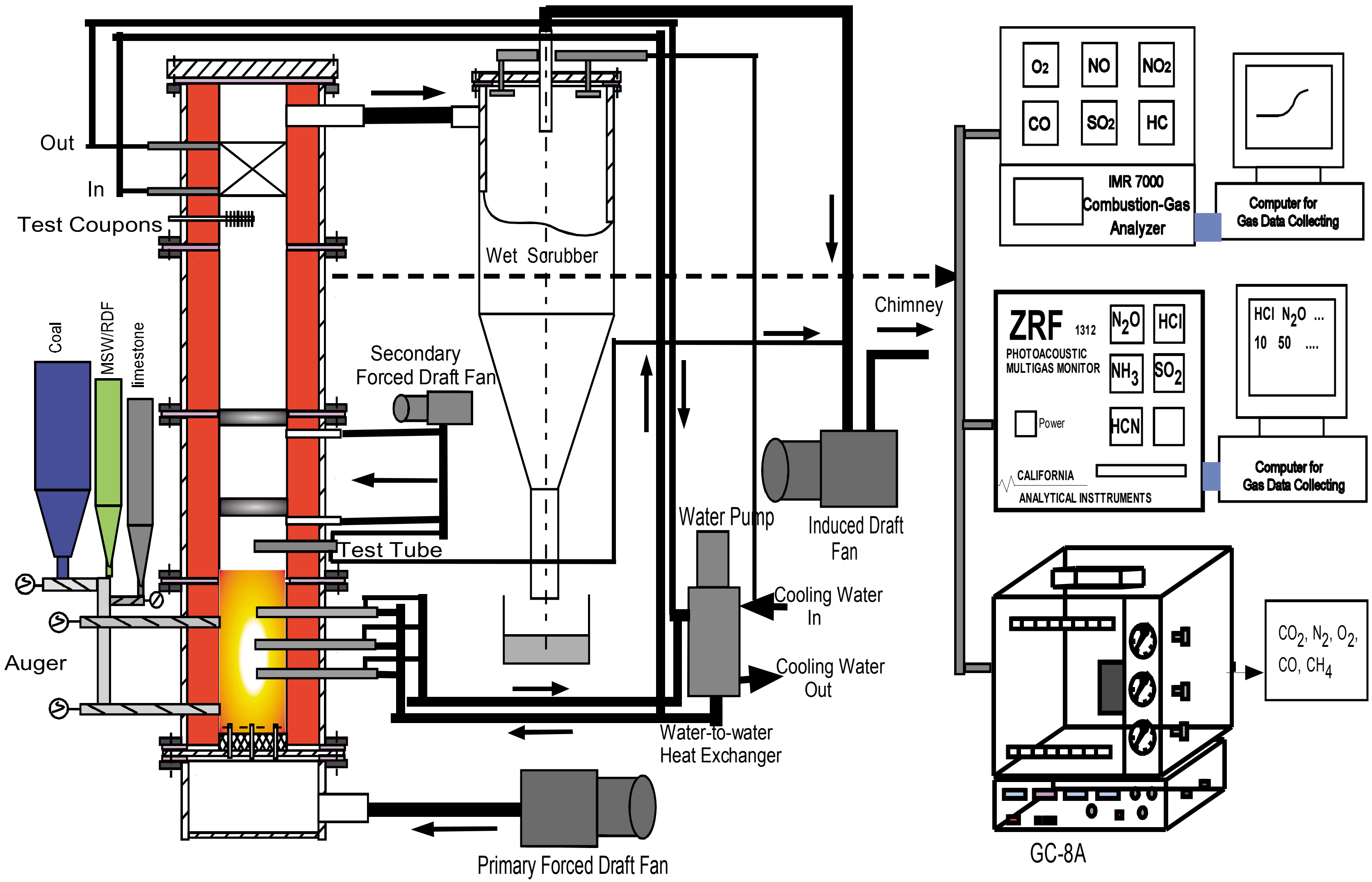
ESTABLISHMENT OF AN ENVIRONMENTAL CONTROL TECHNOLOGY LABORATORY WITH A CIRCULATING FLUIDIZED BED COMBUSTION SYSTEM

Materials Characterization Center

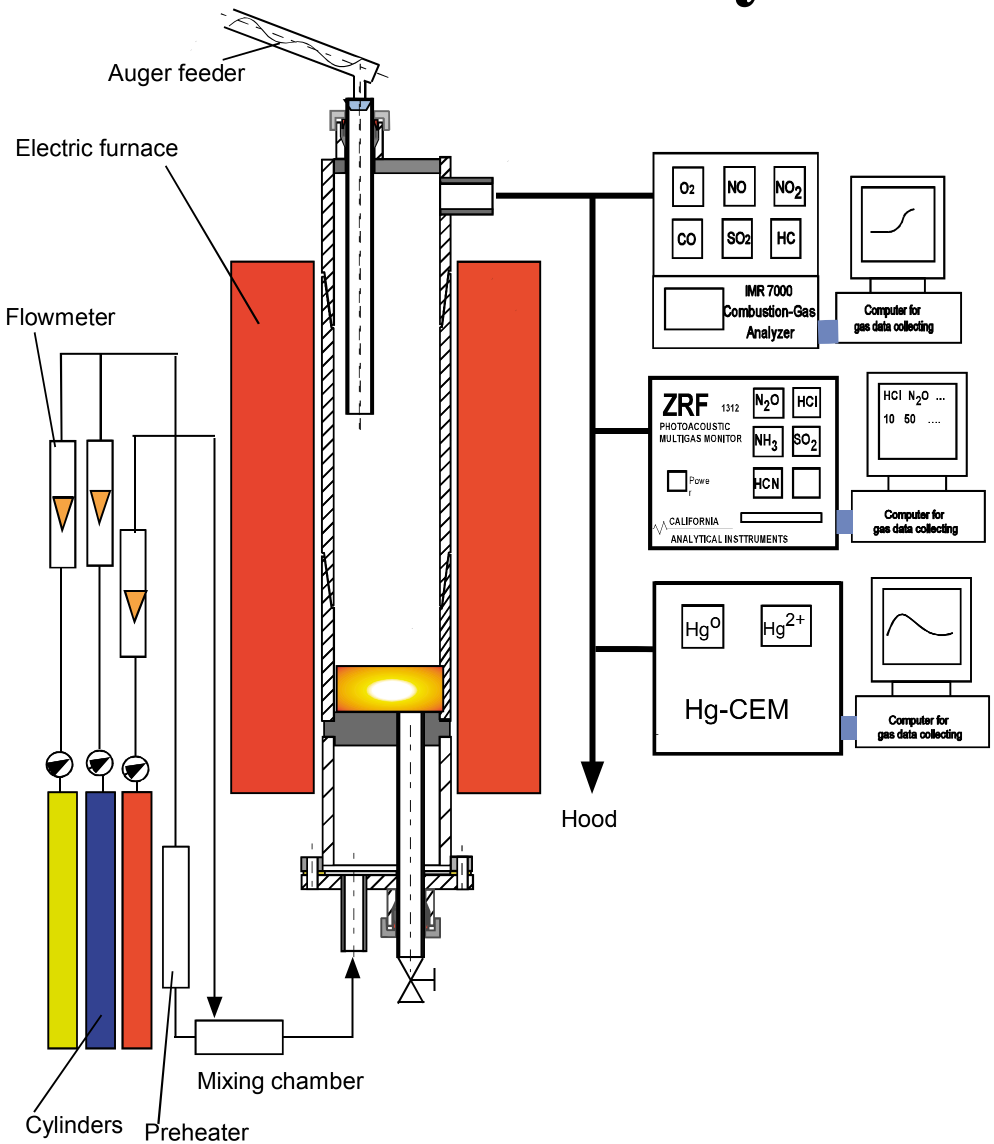
Western Kentucky University

Bowling Green, KY 42101

Schematic Diagram of WKU Combustion FBC System



Schematic Diagram of Drop-Tube Furnace System



Main Parameters of Combustors

- **Combustor Size:**
  - 12" I.D. and 24" O.D. with 15 ft height
- **Capacity:**
  - 20-30 lb/h coal, 4 lb/min air
- **Sample Location:**
  - Alloy specimen -- 10 ft above distributor
  - A210-C -- 5.3 ft above distributor
- **Identified Components in Flue Gas:**
  - SO_2, HCl, O_2, CO_2, H_2O and CO

Identified Components in Flue Gas

- Inorganic:
  - SO_2, HCl, nitrogen compounds (NO, NO_2, N_2O, HCN, NH_3)
- Organic:
  - PAHs (polycyclic aromatic hydrocarbons)
  - PCDD/Fs (polychlorinated dibenzo-p-dioxins/ dibenzofurans)

Recent Research Projects Conducted with the 0.1 MW_{th} FBC

- Emission Studies:
  - Behavior of Nitrogen Compounds in NOx Selective Catalytic Reduction (SCR) Systems, Tennessee Valley Authority. Project No. 98PPW-242520
  - Co-Firing High Sulfur Coal with Refuse Derived Fuels. DOE Project No. DE-FG-94PC-94211
- Corrosion Research:
  - A Study of Chlorine in High Temperature Corrosion of Alloys in an AFBC System. Project No. ICCI-97-06
  - Behavior of Chlorine during Coal Combustion in AFBC System. EPRI Project No. WO9002-13

Analytical Values[A] for the Coals Used in the Study

	Phase 0 (1995-1997)		Phase I (1998-1999)			Phase II (1999)	
	95011	95031	97025	98011	98111	99426	99626
Proximate Analysis							
% Moisture	10.07	8.32	4.56	10.63	10.25	2.33	6.96
% Ash	9.37	10.78	10.97	10.10	9.67	8.70	13.81
% Volatile Matter	43.34	37.21	36.25	34.03	34.84	36.98	34.14
% Fixed Carbon	47.29	52.02	52.78	55.87	55.49	54.32	52.05
Ultimate Analysis							
% Ash	**9.37**	**10.78**	**10.79**	**10.10**	**9.67**	**8.70**	**13.81**
% Carbon	74.08	72.16	74.69	75.59	74.18	76.25	69.53
% Hydrogen	5.08	4.82	4.95	4.52	4.73	4.89	4.49
% Nitrogen	1.54	1.54	1.63	1.51	1.59	1.79	1.55
% Sulfur	**3.2**	**2.38**	**3.06**	**1.09**	**1.68**	**0.97**	**4.48**
% Oxygen	6.72	7.57	4.50	6.73	7.72	7.37	5.73
Miscellaneous Analysis							
Chlorine (%)	**0.012**	**0.31**	**0.21**	**0.47**	**0.42**	**0.026**	**0.41**
BTU/pound	13203	12842	13152	13017	13226	13655	12406

[A] Moisture is as-received, all other values are reported on a dry basis

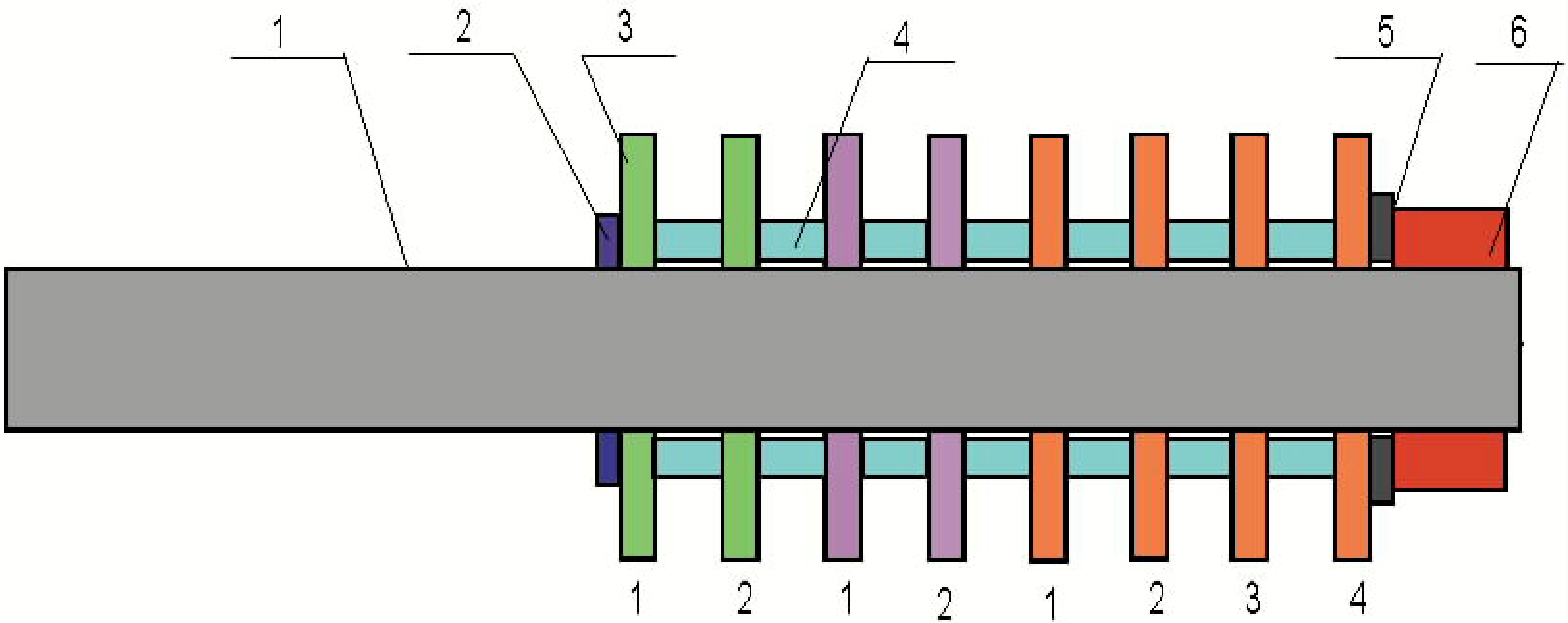
Analysis of Ashes Prepared from the Coals Used in the Study

Metal Oxides	95011	95031	97025	98011	98111	99426	99626
SiO_2	49.22	47.32	38.51	54.66	49.03	52.47	31.36
P_2O_5	3.36	4.46	0.785	1.87	4.49	2.52	3.21
CaO	1.86	1.62	3.75	1.96	2.63	3.27	6.13
K_2O	**4.14**	**5.03**	**1.48**	**2.91**	**2.87**	**1.92**	**1.39**
TiO_2	1.11	1.14	1.00	1.23	1.17	1.71	0.67
Fe_2O_3	19.90	17.04	26.98	9.01	15.44	5.35	36.41
Na_2O	**0.58**	**1.90**	**0.41**	**1.60**	**1.13**	**0.38**	**0.98**
MgO	0.70	0.80	0.92	1.08	0.65	0.82	1.42
Al_2O_3	17.12	18.18	19.52	23.76	23.33	27.90	12.73
MnO_2	0.02	0.02	0.01	0.03	0.03	0.023	0.06
Total Alkali	**4.72**	**6.93**	**1.89**	**4.51**	**4.00**	**2.30**	**2.73**

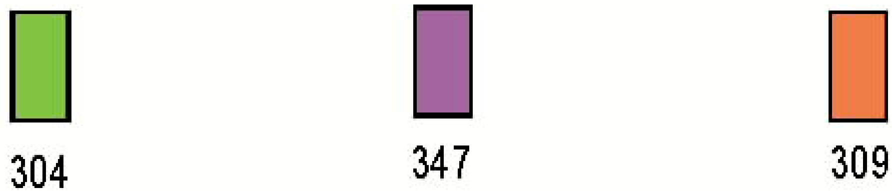
Corrosion Test Alloys

- Alloy Specimens
  - SS304 (18-20% Cr, 8-10% Ni), SS347 (17-20% Cr, 8-12% Ni), SS309 (22-26% Cr, 12-14% Ni)
- Cooled and Uncooled Tubes
  - Evaporating Tubes in FBC boiler from TVA
  - A210-C

The Set-up for Test Coupons



1. stainless steel rod, 2. ceramic washer,3. test coupons, 4.spacer,
5. ceramic washer, 6. nut



Test Conditions

- FBC Operating Parameters:
  - Temperature: 850^{o}C
  - Fluidizing Velocity: 1.25 m/s
  - Excess Air Ratio (α): 1.25
  - Ca/S Molar Ratio: 3-3.5
  - Bed Height: 0.6 meter (static)
  - Limestone as bed material
- Coupon Conditions:
  - SS304 (18-20% Cr, 8-10% Ni), SS347 (17-20% Cr, 8-12% Ni), SS309 (22-26% Cr, 12-14% Ni)
  - Location: 3.1 meter above distributor
  - Surface and surrounding temperature: 500-550^{o}C
- A210-C Cooled Tube (I.D. $1^1/_2$", O.D. 2")
  - Location: 1.6 meters above distributor
  - Surface temperature: 380-400^{o}C (air coolant)
  - Surrounding temperature: 850^{o}C

Summary of Steady-State Run Conditions

	Runs						
	1st	2nd	3rd	4th	5th	6th	7th
Fuel feed rate (kg/h)	8.41	10.44	7.50	7.95	8.21	8.16	7.26
Limestone rate (kg/h)	2.21	2.21	1.61	1.02	1.43	2.72	3.22
Ca/(S+Cl) molar ratio	3.10	3.10	2.88	3.15	3.19	9.21	3.05
Temperature (K)							
At 0.56 meter*		1108	1168	1218			
At 1.90 meter		943	1013	1078			
At 3.30 meter		843	923	978			
SO_2 Concentration (ppm)							
Coupon	250	190	245	174	114	53	282
A210-C tube	270	210	260	220	137	68	286
HCl Concentration (ppm)							
Coupon	1.5	38.5	44.3	65.7	55.3	2.8	55.1
A210-C tube	10	46.7	56.8	84.8	68.2	13.0	85.4
CO Concentration (ppm)							
Coupon	140	160	156	214	156	113	173
A210-C tube	155	165	170	222	187	164	244

Final Metal Loss after 1,000 Hours Exposure in 0.1 MWth WKU-FBC System

	Phase 0 (1995-1997)		Phase I (1998-1999)			Phase II (1999)	
	95011	95031	97025	98011	98111	99426	99626
Ultimate Analysis							
% Ash	**9.37**	**10.78**	**10.79**	**10.10**	**9.67**	**8.70**	**13.81**
% Sulfur	**3.2**	**2.38**	**3.06**	**1.09**	**1.68**	**0.97**	**4.48**
% Chlorine	**0.012**	**0.31**	**0.21**	**0.47**	**0.42**	**0.026**	**0.41**
% Alkali	**4.72**	**6.93**	**1.89**	**4.51**	**4.00**	**2.30**	**2.73**
Thickness of coupon (mils)							
Alloy **304**: *Initial*	91.535	103.150	106.142	107.283	108.464	114.370	113.228
After 1,000 hours	90.945	102.480	105.512	106.929	107.874	114.213	112.638
Loss per year* (mils)	**2.586**	**2.931**	**2.759**	**1.552**	**2.586**	**0.689**	**2.587**
Alloy **309**: *Initial*	103.346	134.291	128.150	127.165	101.614	128.583	130.118
After 1,000 hours	103.150	134.095	127.992	127.047	101.457	128.504	129.646
Loss per year(mils)	**0.862**	**0.862**	**0.670**	**0.517**	**0.670**	**0.345**	**2.069**
Alloy **347**: *Initial*	92.244	123.661	115.196	114.213	114.213	119.724	122.441
After 1,000 hours	91.772	123.032	114.606	114.016	114.016	119.606	121.811
Loss per year(mils)	**2.069**	**2.759**	**2.586**	**0.862**	**1.207**	**0.517**	**2.759**

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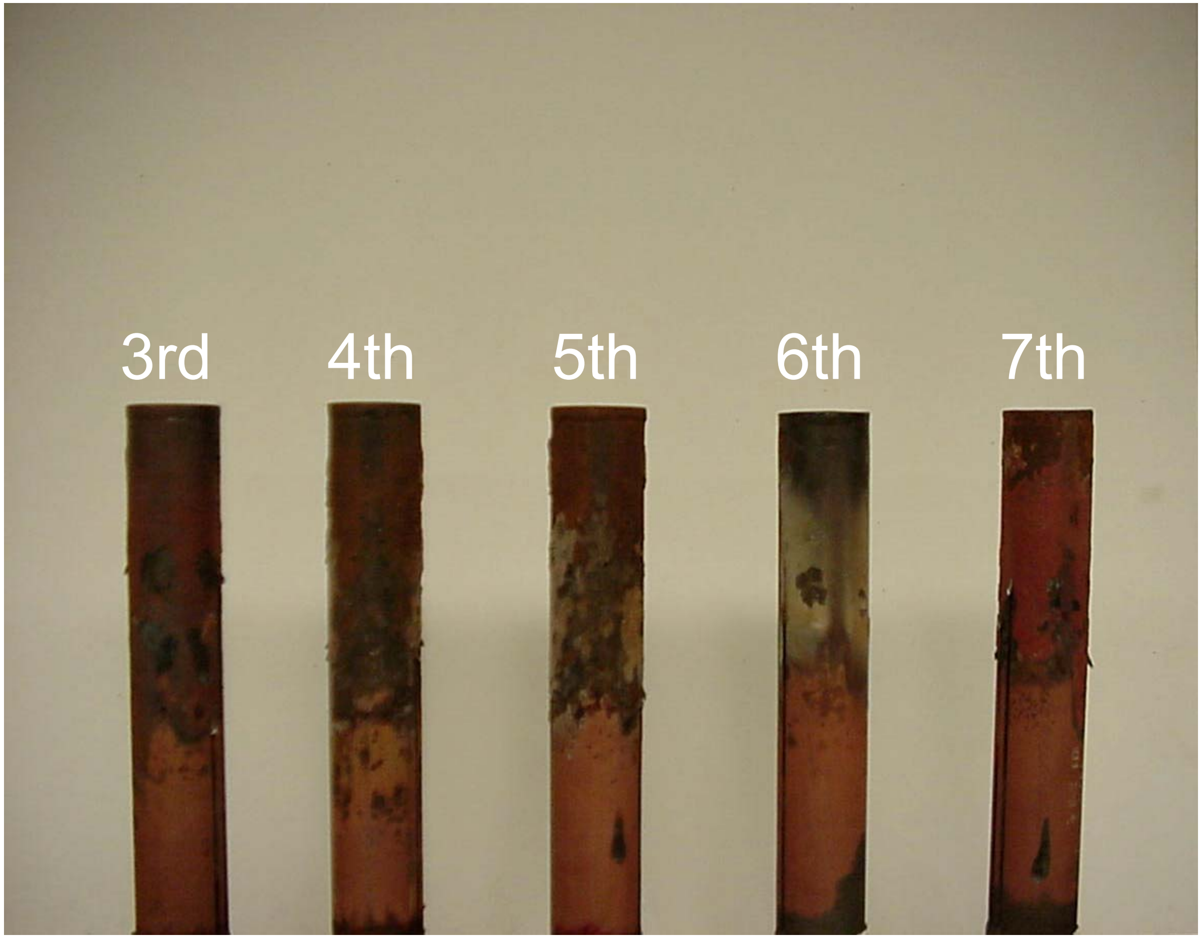
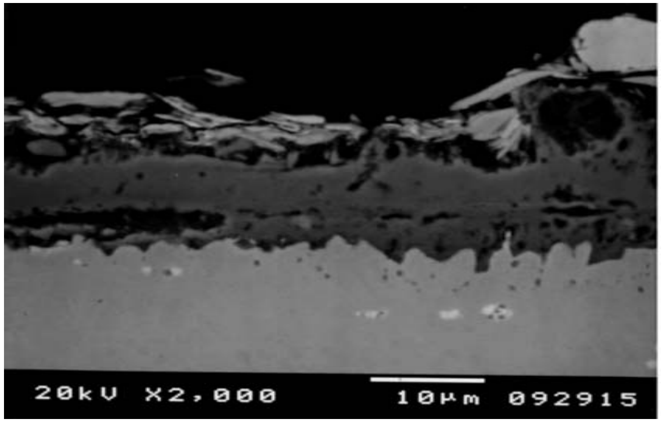
*Based on full time run (8760 hours/year)

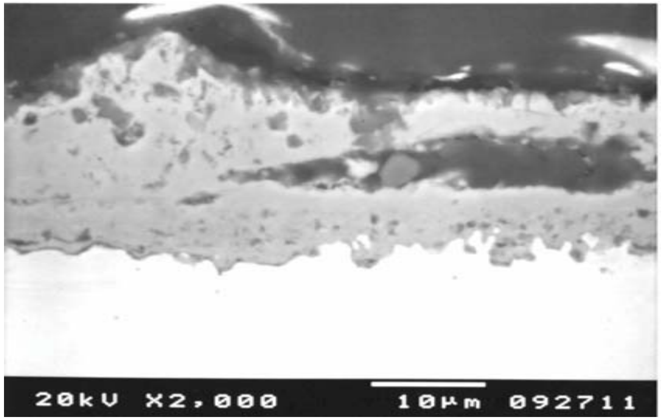
Overview of Five Test Tubes



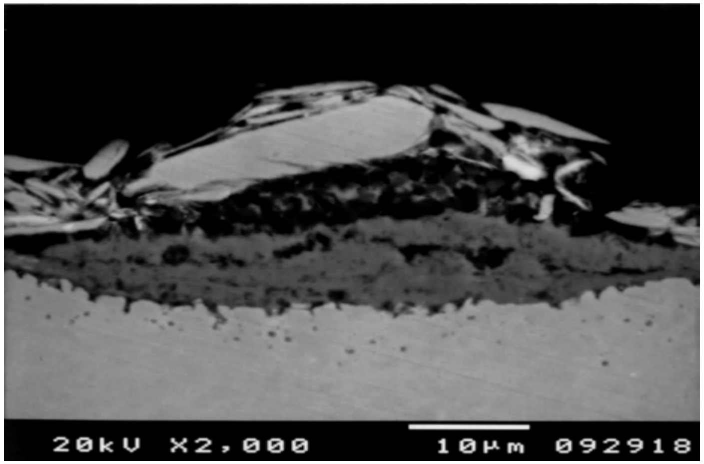
Effect of Ash Deposits on Tubes: SEM Photos at Four Positions



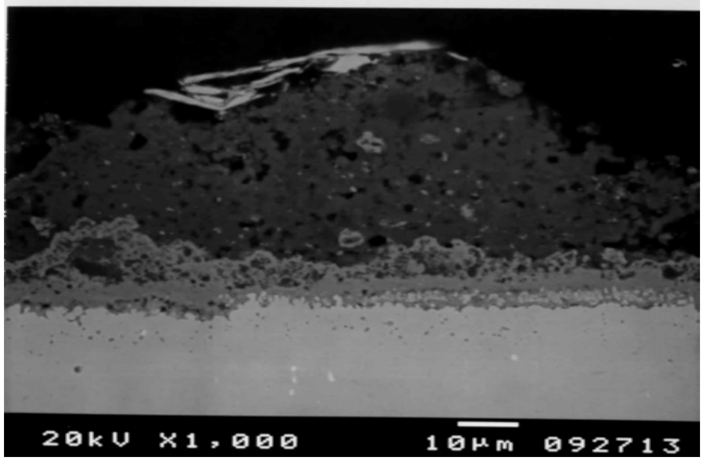
Surface of 12'O position



Surface of 6'O position

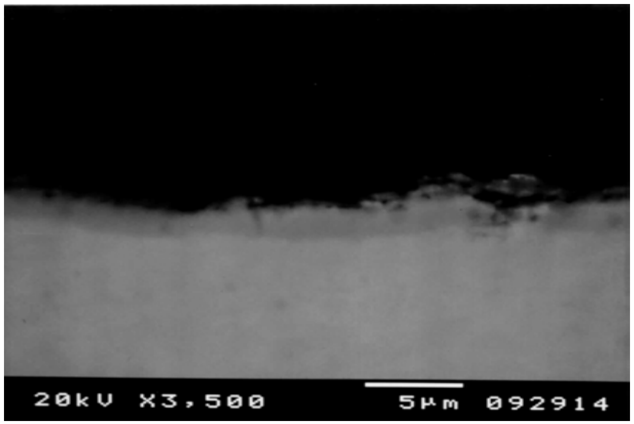


Outer edge of 12'O position

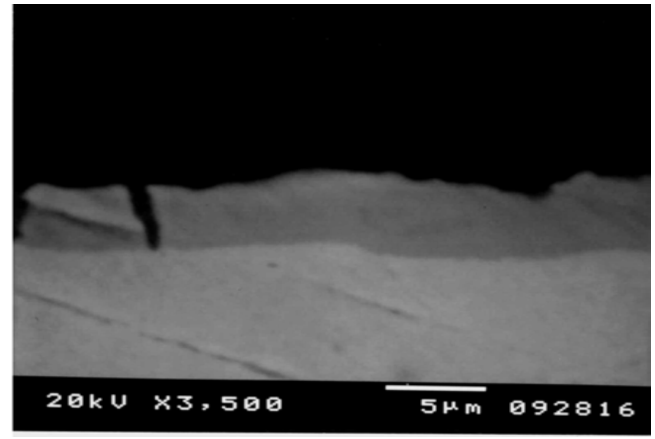


Outer edge of 6'O position

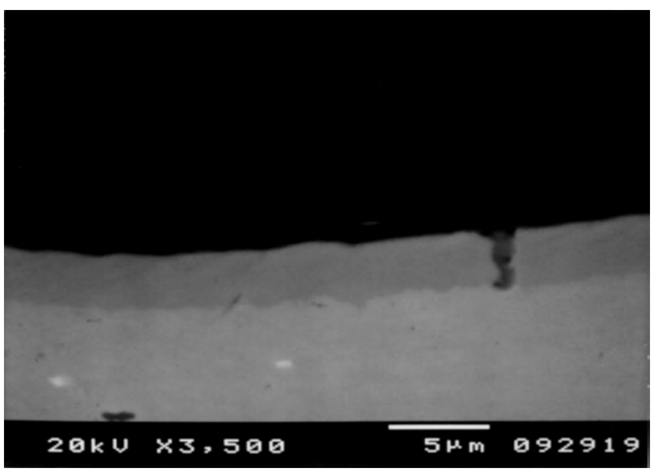
Results from SEM-EDX Analysis of the Inner Edge of Coupons



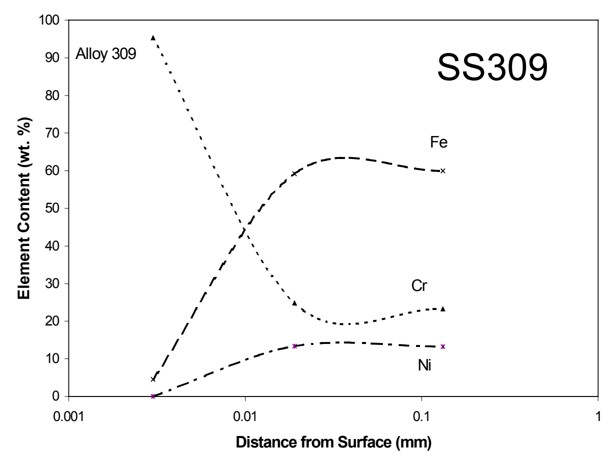
SS304



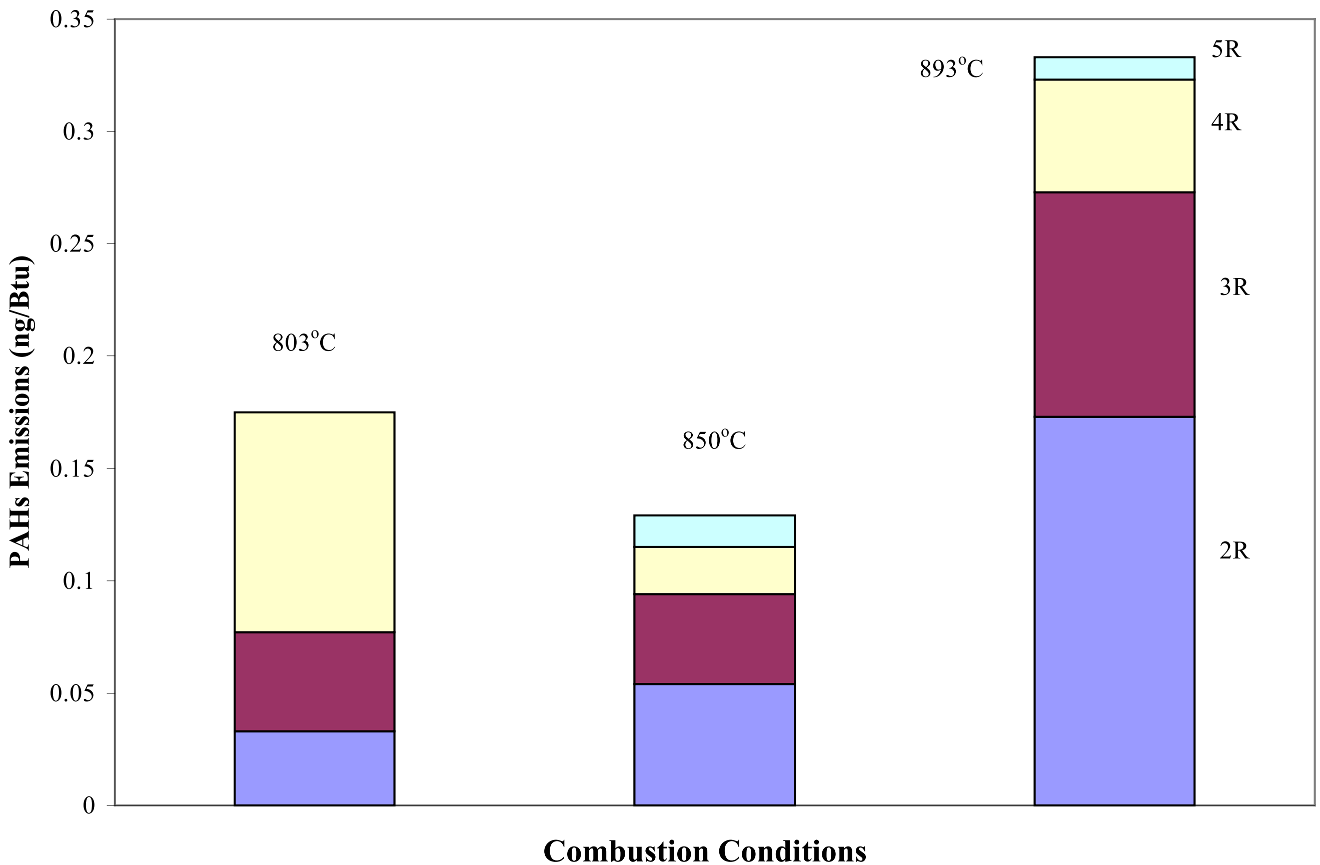
SS309



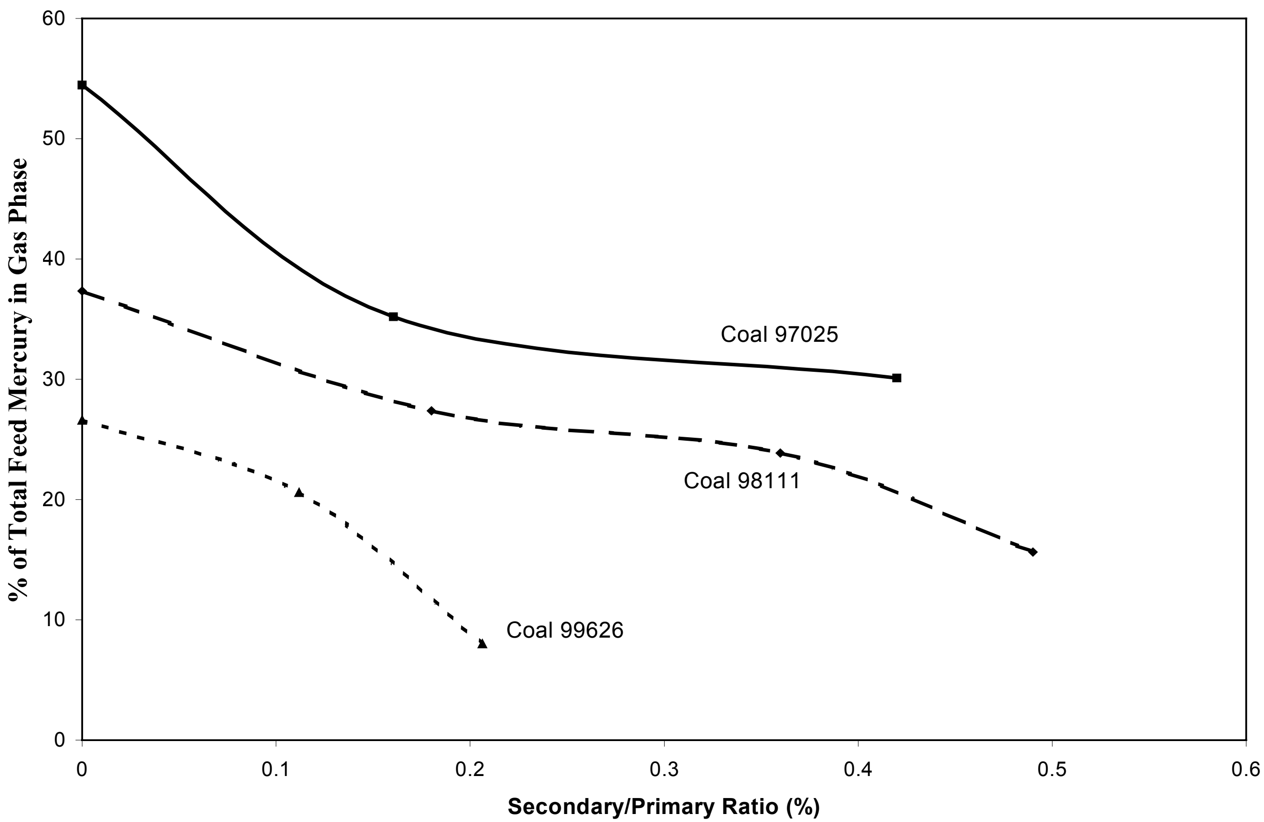
SS347



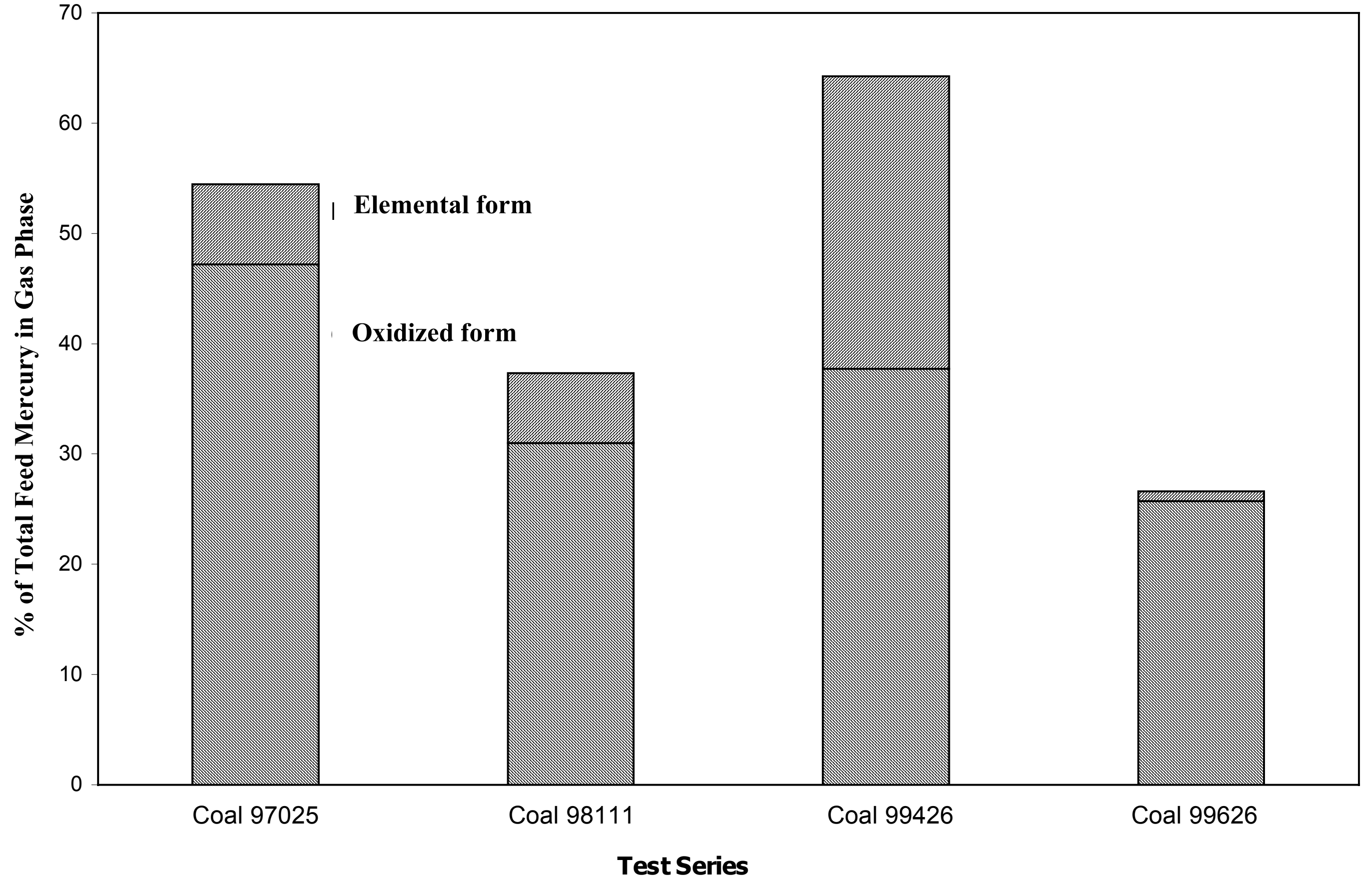
Effect of Combustion Temperature on the Emissions of PAHs in the Flue Gas



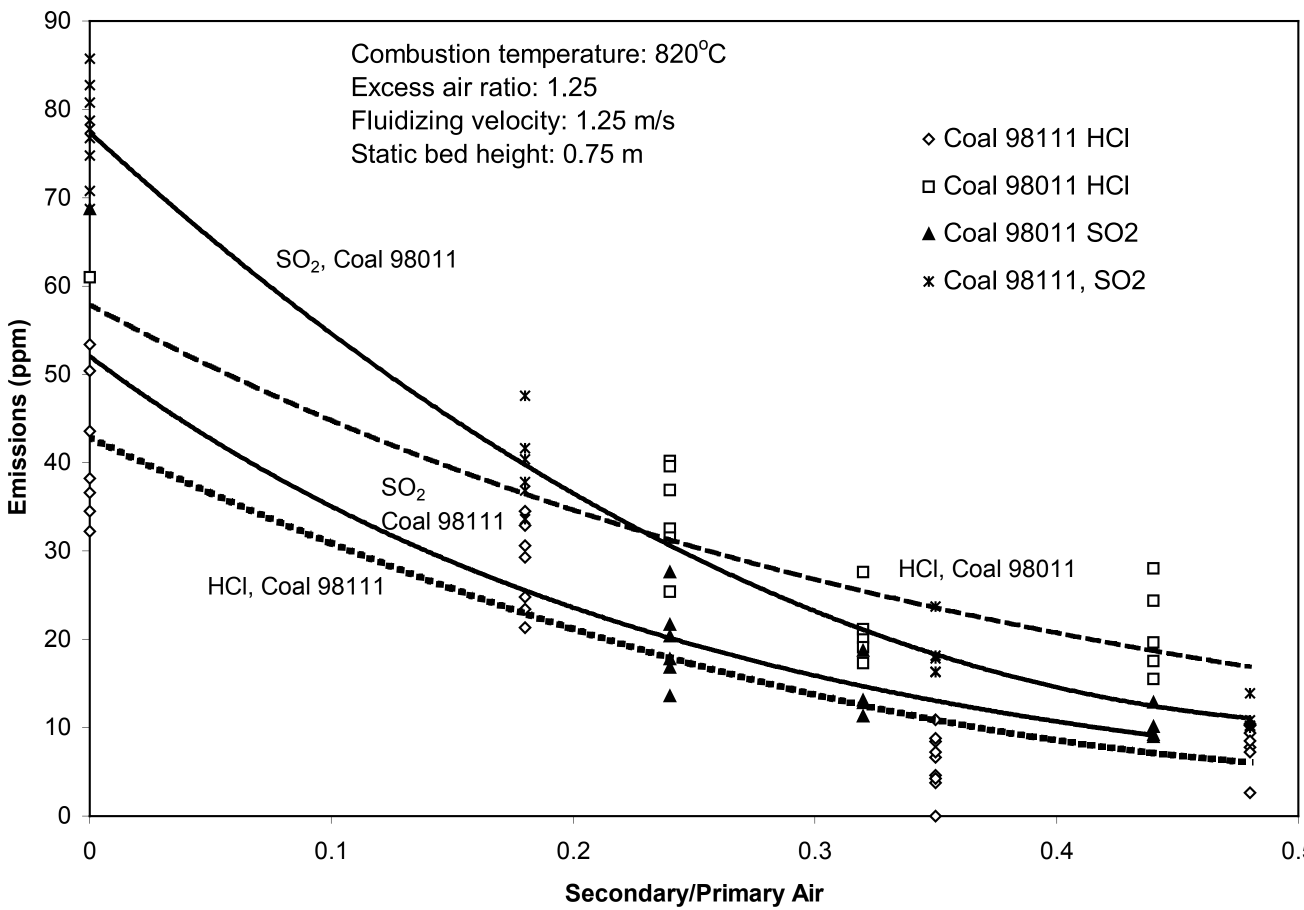
Effect of Coal Types on the Emissions of Mercury in the Flue Gas



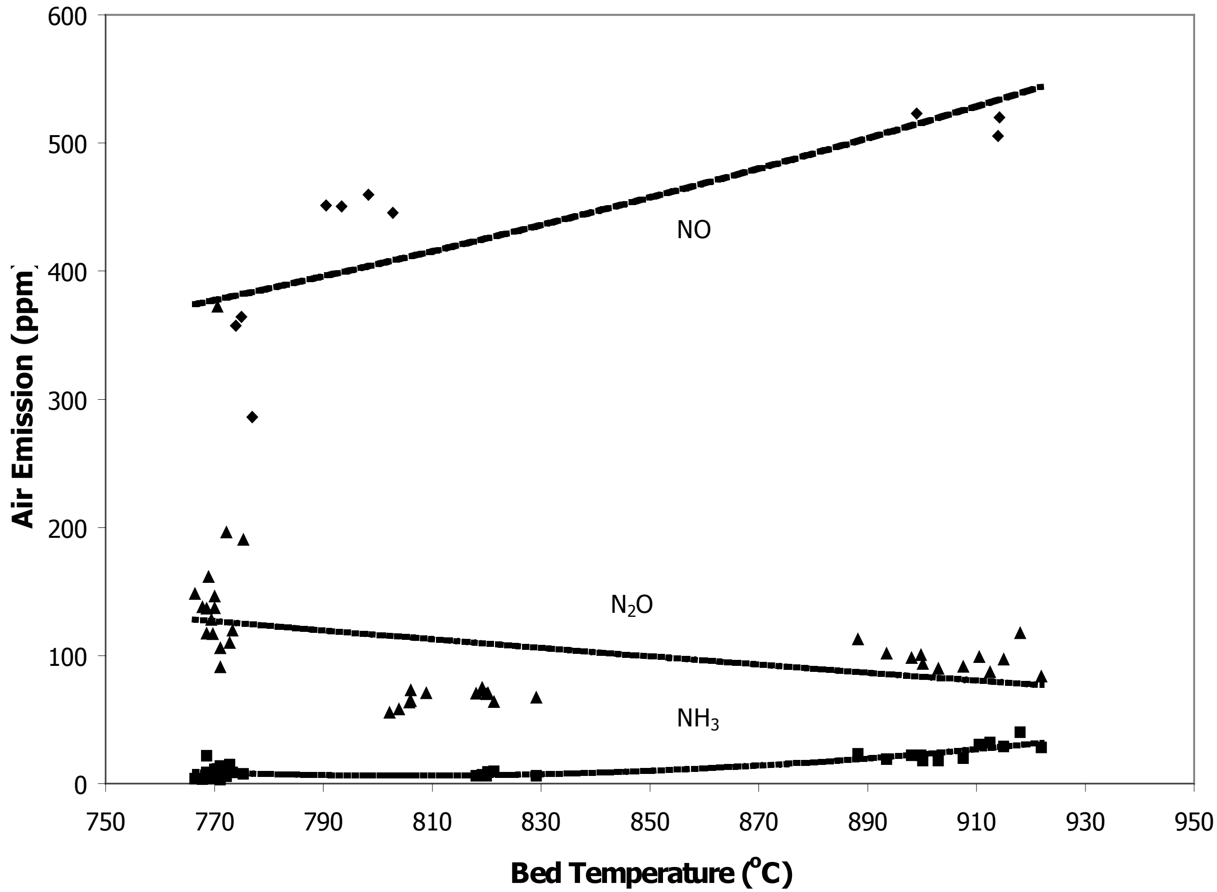
Effect of Coal Types on Mercury Species Emission in Flue Gas



Effect of Coal Types on the Emissions of HCl and SOx in the Flue Gas



Effect of Combustion Temperature on Nitrogen Compound Emissions



Advantages of Co-firing MSW/RDF or Biomass with High Sulfur Coals

- Energy recovery
- Sulfur dioxide in combustion gases minimizes production of molecular chlorine to control the formation of polychlorinated organics.
- Convert elemental mercury to oxidized mercury in the presence of HCl and fly ash acting as catalysts in the upper combustion area of a utility boiler
- Reduce CO_2 emission.

Benefits

- Reduction in landfill costs, in carbon dioxide emissions, in chlorinated organic and PAH compound emissions, and in heavy metal and other greenhouse gases emissions

- Energy recovery from waste

- Open new markets for processed MSW/RDF, biomass and Western Kentucky, Illinois, and Ohio high sulfur coals.

3D views of CFBC Layout

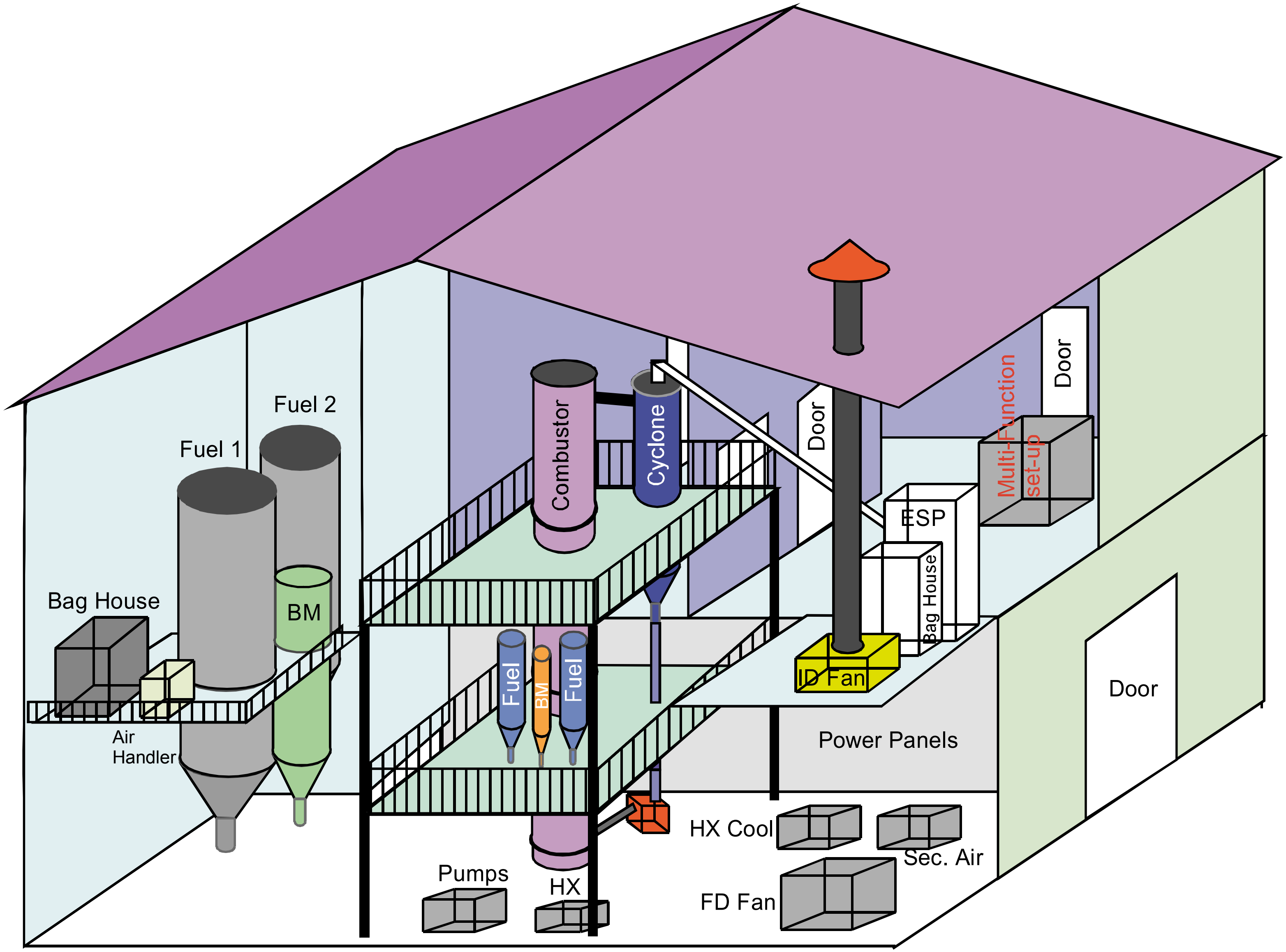
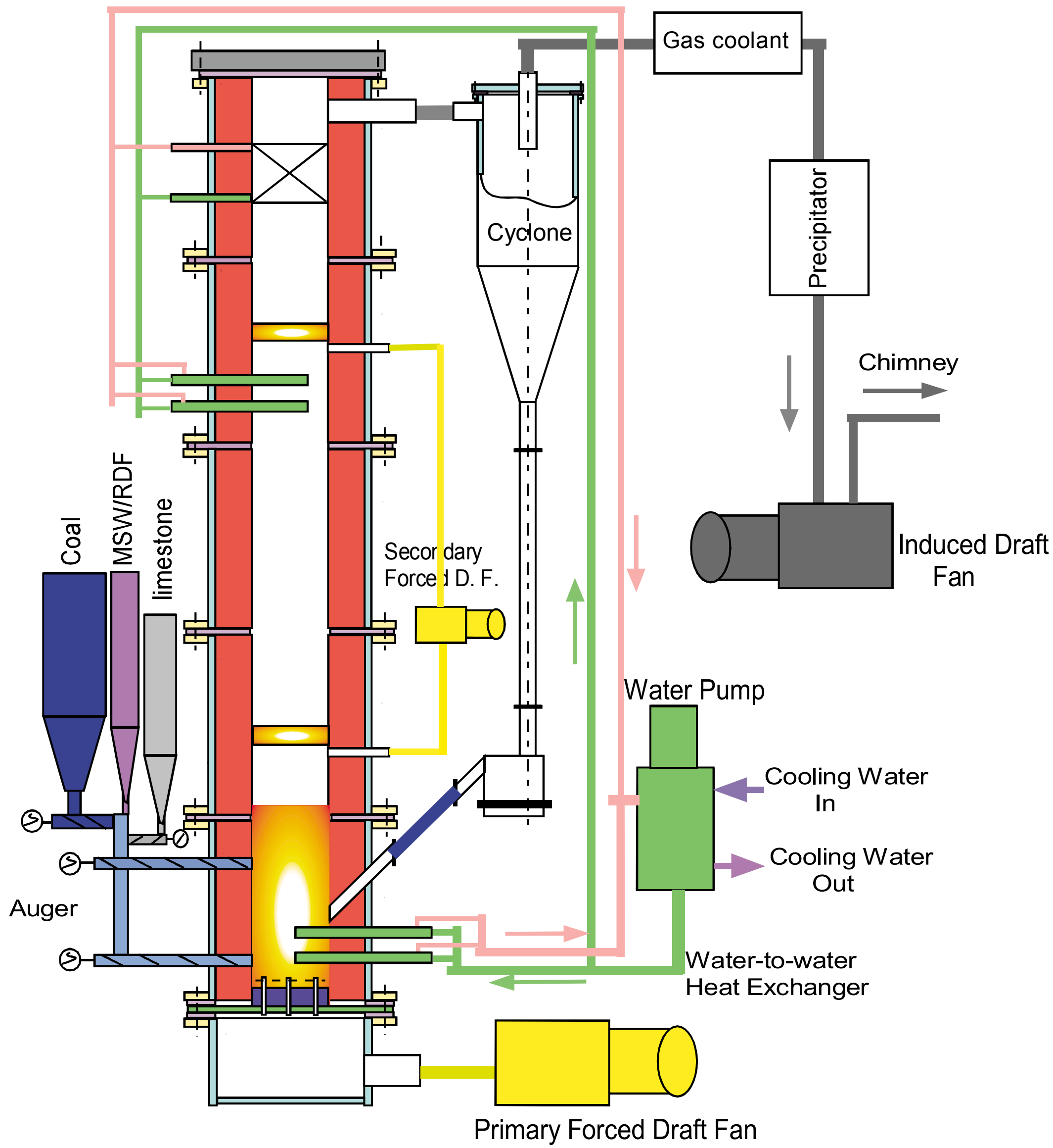
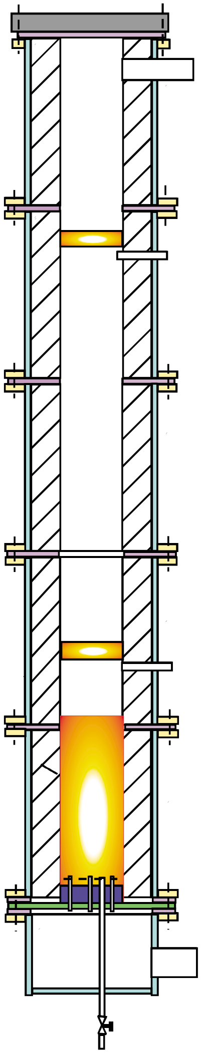


Diagram of 0.6 MWth CFBC System



Brief Design Parameters of 0.6 MWth CFBC System



The major parameters:

If inside diameter is chosen as 0.3 meter, 16-20 meters effective height
and fluidizing velocity: 5 m/s (maximum)
and combustion temperature: 850 ^oC

and coal feeding rate: 45-55 kg/h (~0.6 MWe)

Then, the capacity of F.D.F:
Flow rate: 20 lb/min (minimum) (15 lb/min request)
Pressure: 2500 mmH_2O (99 inch WC) (max.)

the capacity of I.D.F.:
If we choose water exchange tube for flue gas cooling
Flowrate: 25 lb/min (minimum)
Pressure: 500 mmH_2O (20 inch WC) (max.)

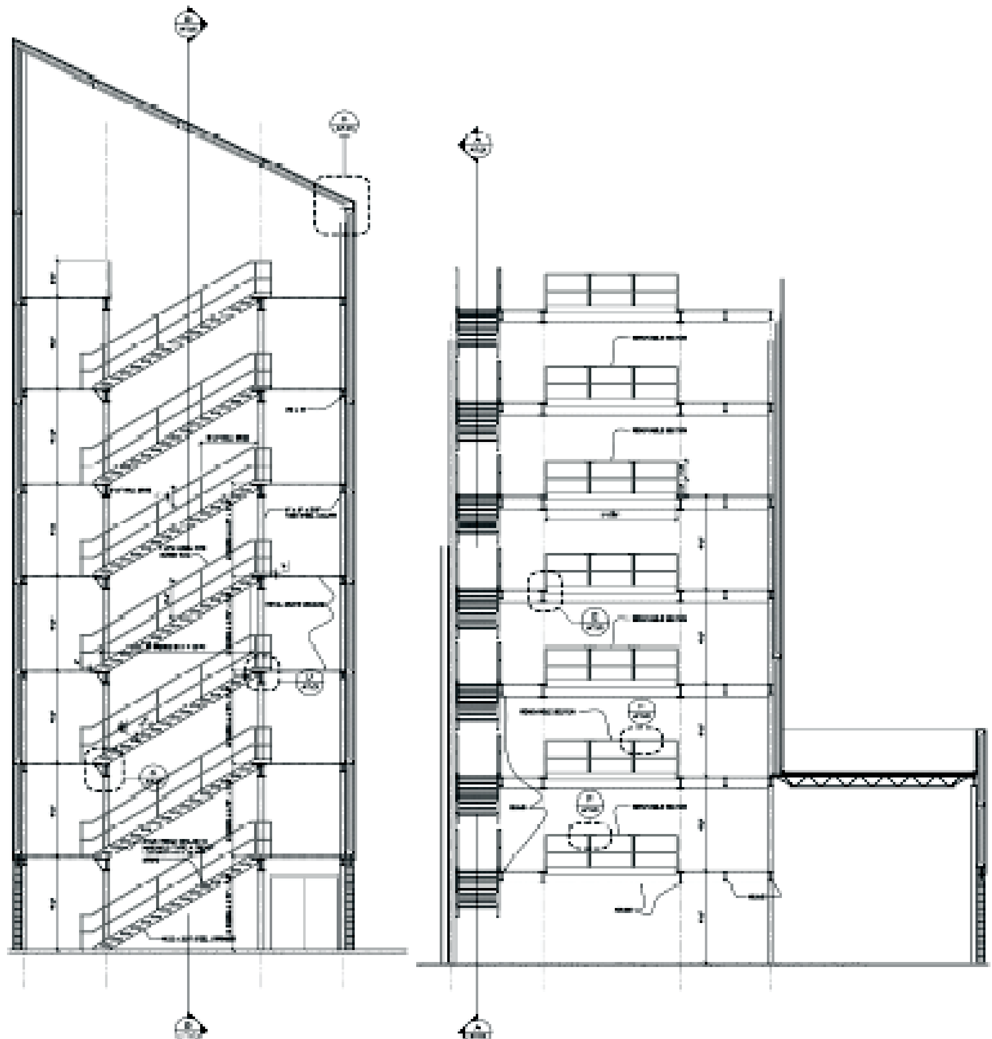
If we use cold air to mix with hot gas for flue gas cooling
Flowrate and Pressure will depend on the temperature at outlet of cyclone and the maximum temperature of baghouse.

the capacity of secondary F.D.F.:
Flowrate: 9 lb/min
Pressure: 1000 mmH_2O (40 inch WC) (max.)

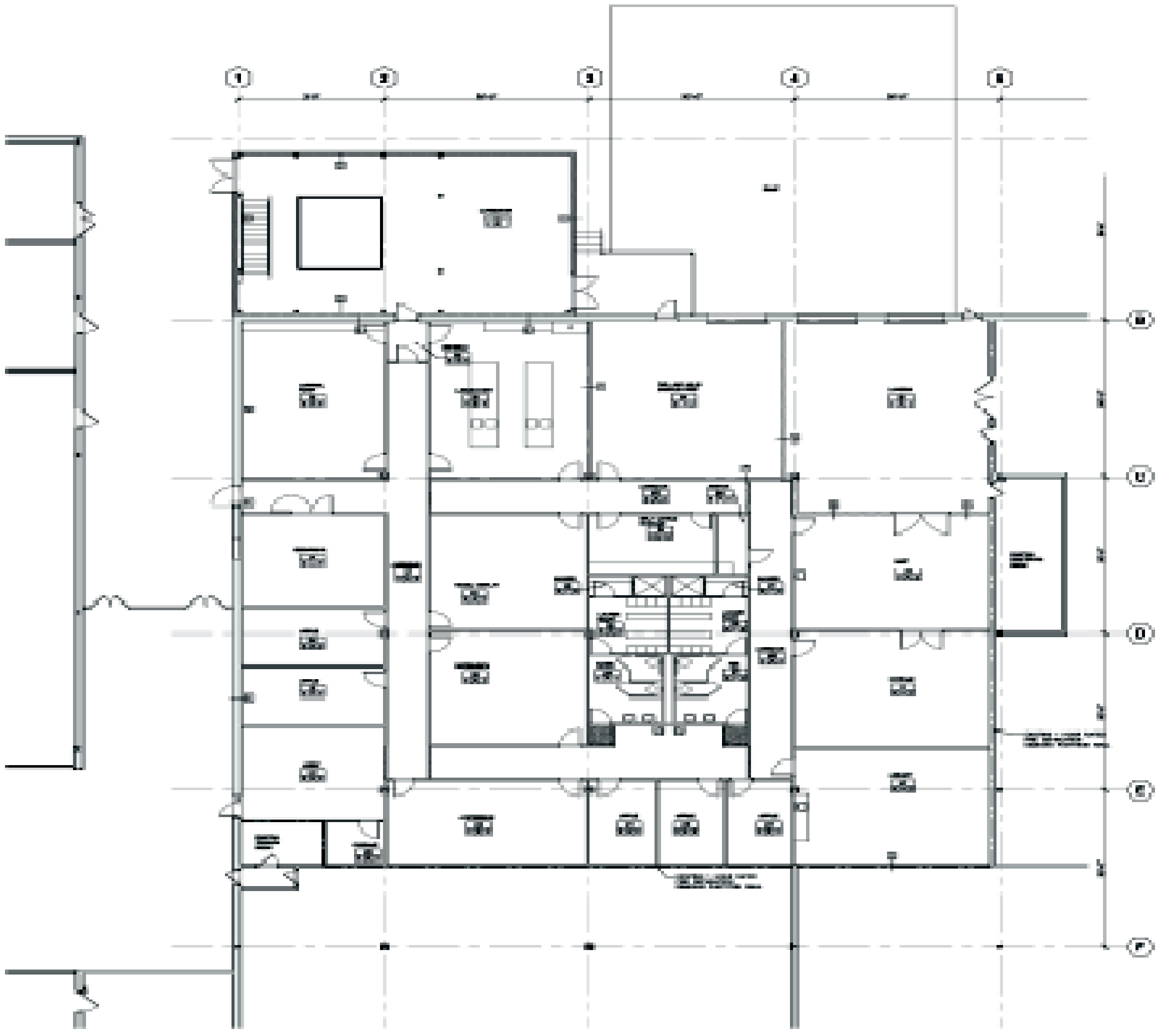
the set-plate:
Pressure drop: 150--250 mmH_2O (6--10 inch WC)

Estimated weight:
Combustor: 12,000 lbs
Cyclone: 2,000 lbs
Coal and limestone system: 2,000 lbs
Heat exchange tubes: 1,000 lbs
Platform: 2,000 lbs
Another accessories: 3,000 lbs

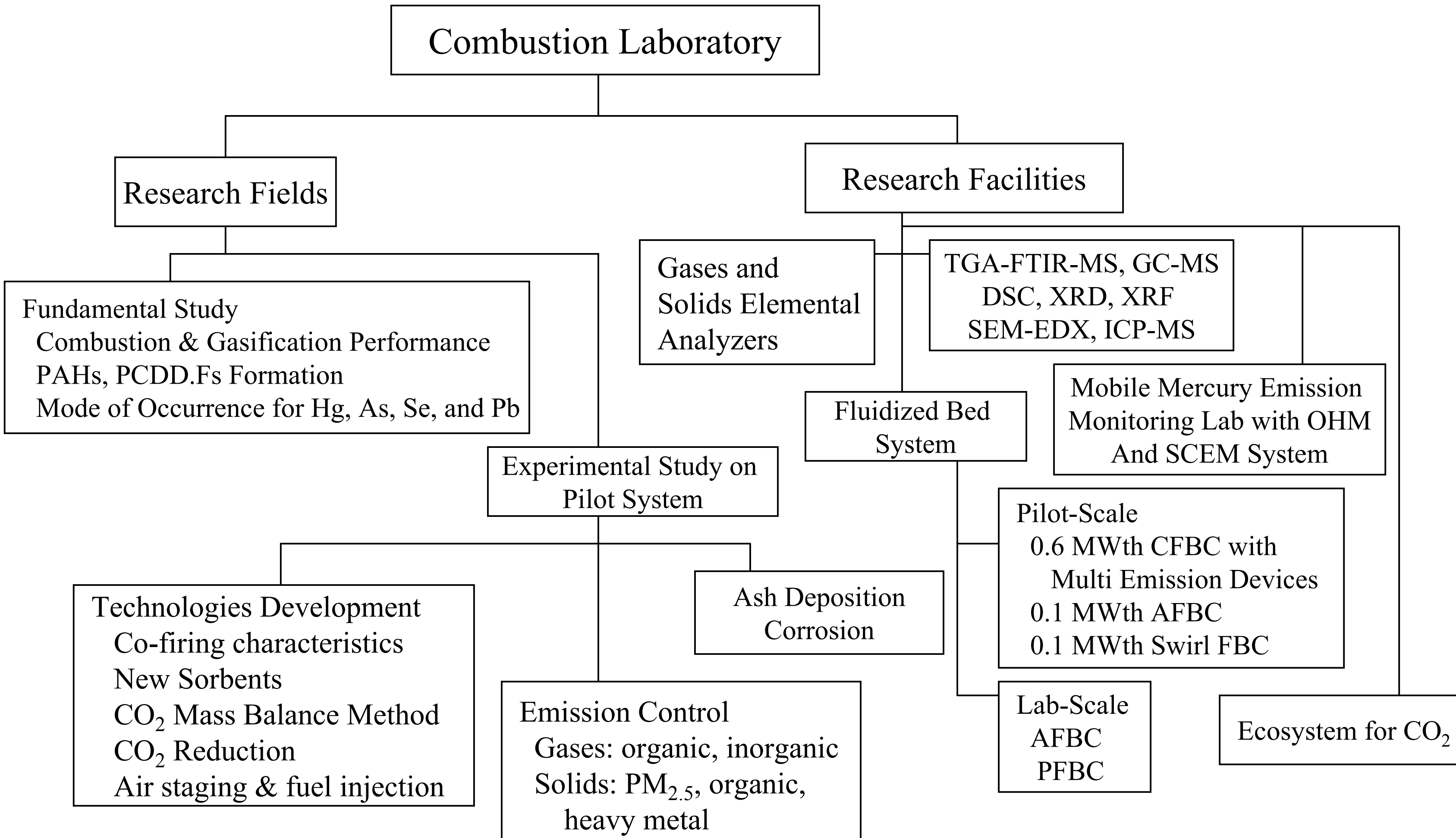
Building for CFBC



Combustion Laboratory and CFBC Facility

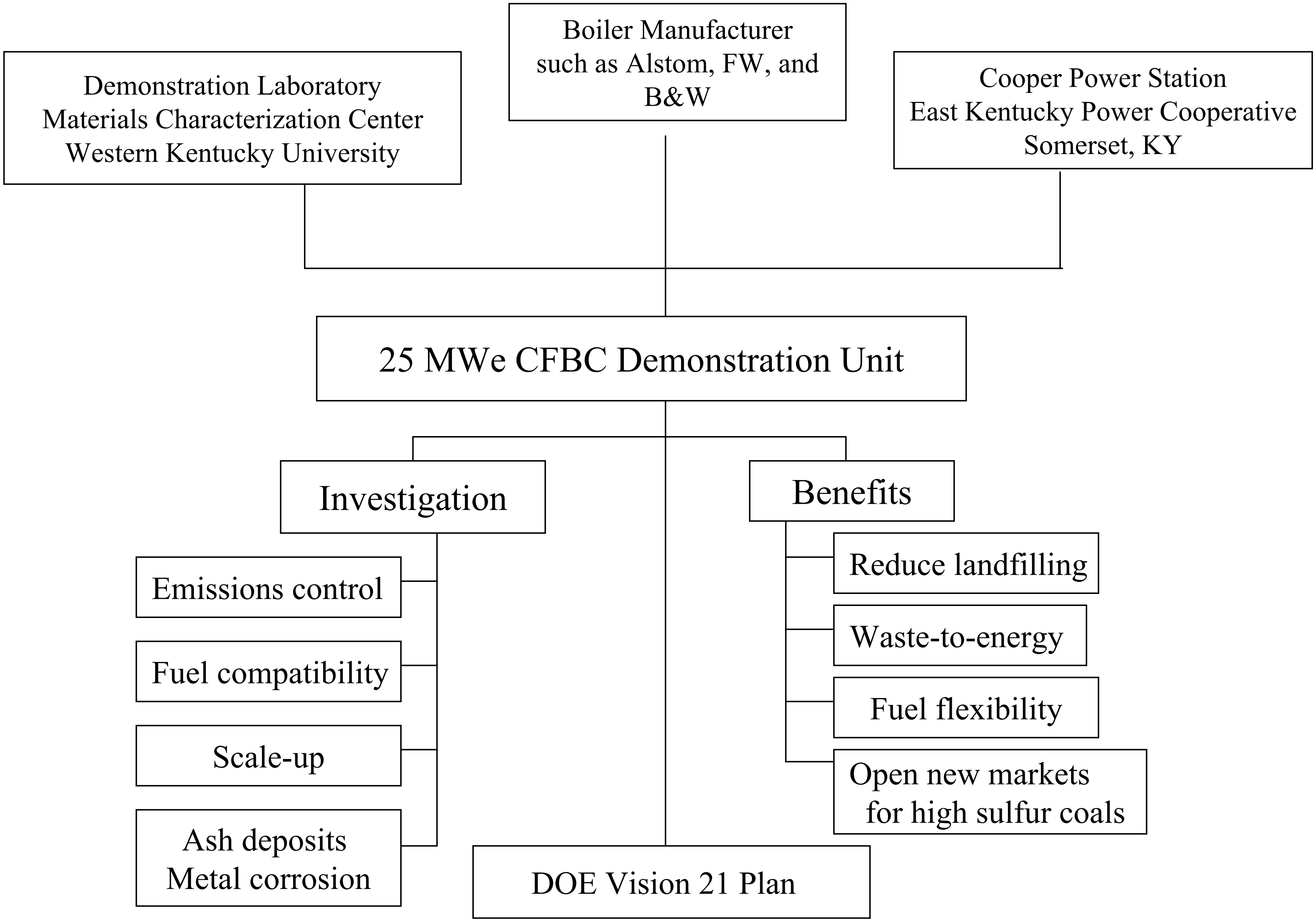


Establishment of a Demonstration Laboratory for Co-firing Refuse Derived Fuels with High Sulfur Coals



Future Work

- Transfer Co-firing RDF with high sulfur coal technology to a utility boiler.
- Use new sorbents to retrofit a boiler to capture SO_x, HCl and Hg with low operating cost.
- Study the performance of partial gasification of co-firing RDF with high sulfur coal in CFB and PFB systems.
- Build a relationship with Kentucky Pioneer Energy Project


Boiler Manufacturer such as Alstom, FW, and B&W
Demonstration Laboratory Materials Characterization Center Western Kentucky University
Cooper Power Station East Kentucky Power Cooperative Somerset, KY
25 MWe CFBC Demonstration Unit
Investigation
Benefits
Emissions control
Fuel compatibility
Scale-up
Ash deposits Metal corrosion
Reduce landfilling
Waste-to-energy
Fuel flexibility
Open new markets for high sulfur coals
DOE Vision 21 Plan