MASTER

IDENTIFICATION OF HAZARDS
IN
NON-NUCLEAR POWER PLANTS

VOLUME II: PHASE II

CONSULTANT REPORT

AUGUST 1979

CALIFORNIA ENERGY COMMISSION

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NUS-3360

IDENTIFICATION OF HAZARDS
IN NON-NUCLEAR POWER PLANTS
PHASE II

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California Energy Resources
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Electric generating stations can impose on and expose the general public and environment to adverse demands and emissions that may be considered detrimental or degrading. For example, a conventional coal fired plant demands coal as its fuel which, in turn, creates a demand for coal mining and coal transportation systems that may degrade the environment. In addition, the emissions from the coal plant (sulfur dioxide, ash, and other waste products), if not managed and controlled properly, might lead to a diminution in public health. These environmental and public "hazards" have been qualitatively ranked for a modern conventional coal fired power plant in the Phase I study, Identification of Hazards In Non-Nuclear Power Plants, for the California Energy Resources Conservation and Development Commission dated January 1978.* The purpose for this Phase II study is two fold. First, this study extends the Phase I study to also include a "hazards" evaluation for two new emerging coal power plant technologies: coal fired atmospheric fluidized bed and pressurized fluidized bed power generating systems. Second, this study considers the sensitivity of the hazards ranking for all the non-nuclear power plants to the effects of population density, mode of plant operation, technical changes, location and environmental (temperature) effects.

*Issued by California Energy Commission as "Hazards in Non-Nuclear Power Plants" CAEC-009, July 1978

Coal fired power plants supply a major portion of the electricity needs in the United States. If all the coal could be utilized, the recoverable coal reserves in the U.S. could generate all of the electric energy needs in the U.S. for approximately 400 years. However, because coal contains sulfur and other impurities, to protect environment and public health, it is necessary to employ systems to remove sulfur and waste products and dispose of these waste materials in an acceptable manner. Modern conventional coal fired plants burning high sulfur coals (greater than 1% by weight) generally remove the sulfur (in the sulfur dioxide phase) from the flue gases before entering the exhaust stack using either wet or dry chemical flue gas desulfurizing systems.

An emerging technology for burning high sulfur coals which eliminates the need for flue gas desulfurization is fluidized bed coal combustion. In this process, calcium carbonate is mixed with coal, suspended in a turbulent fluidized condition by the drag forces of combustion air rising up through the bed. During combustion of the coal, the heat released decomposes the calcium carbonate to calcium oxide and carbon dioxide. Then the calcium oxide reacts with any gaseous sulfur dioxide present to form a solid calcium sulfate which can then be removed with the solid combustion residues. Another advantage of the fluidized bed boiler is high convective heat transfer coefficients within the hot fluid bed. This characteristic makes the fluid bed boiler smaller than a conventional boiler delivering the same thermal demands.

Preliminary design studies for coal fired fluidized bed power plants have been performed by the following architect engineering and boiler vendor firms; their designs have been the basis for this "hazards" evaluation report:

Combustion Engineering, "Preliminary Design For A Fluidized Bed Demonstration Unit," June 1978.

Stone and Webster, "Technical Notes for the Conceptual Design For An Atmospheric Fluidized Bed Direct Combustion Power Generating Plant," April 1978.

Burns and Roe/Combustion Engineering, "Conceptual Design of An Atmospheric Fluidized Bed Combustion Electric Power Generating Plant," April 1978.

Babcock and Wilcox, "Conceptual Studies and Preliminary Design of A Fluid Bed Fired Boiler for Service in An Electric Utility," April 1978.

Fluidized Combustion Company, "Preliminary Design and Cost Estimate for An Atmospheric Fluidized Bed Steam Generator," April 1978.

Burns and Roe/Babcock and Wilcox/United Technologies, "Evaluation of A Pressurized Fluidized Bed Combustion (PFBC) Combined Cycle Power Plant," June 1978.

The Combustion Engineering Design has been selected as the representative Atmospheric Fluidized Bed Boiler (AFBB) thermal plant. The Burns and Roe/Babcock and Wilcox/United Technologies design has been selected as the representative pressurized fluidized bed combustion combined cycle (PFBC) power plant.

These plant preliminary designs have been reviewed to identify the potential hazards they might impose on the general public and environment.

Because the steam cycle of the power plants are similar to conventional coal fired power plants, hazards associated with the steam side of power generation have already been done in the Phase 1 study. Therefore, this part of the Phase 2 study only considers the characteristics of the fluidized bed energy conversion systems.

3.0 ENVIRONMENTAL AND PUBLIC HEALTH CONCERNS ASSOCIATED WITH FLUIDIZED BED COMBUSTION POWER PLANTS

3.1 Particulate Emissions

As described in Section 4, due to the nature of the fluidized bed combustion sulfur removal process, large quantities of particulates are generated that must be removed from the flue gases. It is possible that considerable amounts of these particulates could be released to the atmosphere due to reduced collection efficiency in the small particule size range. These fine particules may have an impact on air quality and health since a greater quantity of toxic and possibly carcinogenic elements and compounds are deposited and absorbed on these particulates than for particulates emitted from a conventional coal fired power station.

The trace elements typically found in coal are listed in Table 3-1. This table shows, as a whole, that a greater percentage of trace elements is emitted from the stack for a conventional coal plant than for fluidized bed boilers. For a conventional coal fired plant, most of these elements would vaporize at the combustion phase due to the high flame temperatures. A fraction of these vaporized elements as compounds will remain in the gaseous phase and will be discharged to the environment at the exhaust stack while the balance will solidify as the combustion gases cool through the boiler and coalesce with the fly ash and bottom ash to be disposed of by the ash removal and handling systems. But, in the fluidized bed boiler, the significantly lower combustion temperature (1600°F vs 2700°F) prevents vaporization of some of these trace elements. Consequently, because these elements are still in the solid phase, more trace elements deposit and absorb onto particulates and ash products than would occur in a conventional coal fired boiler. Thus, emitted and collected particulates from the fluidized bed boiler plants will

TABLE 3-1

PROJECTED STACK EMISSIONS OF SELECTED TRACE
ELEMENTS FROM CONVENTIONAL AND FLUIDIZED-BED
COMBUSTORS EXPRESSED AS A PERCENTAGE OF THE
ELEMENT ENTERING THE SYSTEM

Element	Conventional Combustion ^(a)	Fluidized-Bed Combustion		
		ANL ^(a)	Exxon ^(b)	BCL ^(c)
Mercury	90	80	No Data	75
Fluorine	90-100 (estimated)	40	No Data	98
Bromine	100 (estimated)	65-82	79	90
Arsenic	50-60	15	14	59
Lead	0-60	0-20	No Data	21
Beryllium	No Data	20-40	No Data	98
Scandium	10	0-3	15	0
Chromium	0	25	0	(d)
Cobalt	10-20	0-20	No Data	(d)
Sodium	20	4-5	12	(d)
Potassium	30	0-10	25	25-54
Iron	0	0	20	(d)
Manganese	0	0	4	(d)

(a) Source: Argonne National Laboratories

(b) Source: Exxon Research and Engineering

(c) Source: Battelle-Columbus Laboratories

Spark Source Mass Spectrometer Data (SSMS)

(d) Data Suspect Due to Accuracy Limitations of SSMS

contain greater concentrations of toxic elements than would be expected for a conventional coal fired plant.⁽¹⁾

The control technology proposed to keep the particulate emissions within acceptable EPA standards consists of utilizing cyclones, electrostatic precipitators, and baghouses. All three of these systems are subject to degradation in particulate removal inefficiencies when the particulates are small in the respirable size range. In addition, the high resistivity of the particulates tends to make electrostatic precipitators ineffective at conventional flue gas exhaust temperatures (200 - 300°F) and the high particulate loading, hygroscopic nature of some of the dust particles (CaO), and potential high exhaust temperatures may limit the practicality of fabric filters.

Combustion Engineers in their study estimated that particulate removal efficiencies must be greater than 99% to achieve the current EPA standard of 0.1 lb/10⁶ Btu. However, a particulate removal efficiency of greater than 99.9% would be required to meet the Proposed EPA new Source Performance Standards of 0.03 lb/10⁶ Btu particulate emissions. Filtration systems must be employed in series in order to be able to achieve these high removal efficiencies.

3.2 Sulfur Dioxide (SO₂) Emissions

Present fluidized bed combustion facilities will capture approximately 85% of the generated sulfur dioxide. The amount emitted will be approximately

(1) It is noted that a conventional coal fired plant with a wet flue gas SO₂ removal system will also absorb most of these vaporized elements. Therefore, the collected ash and sludge waste from this system will most likely contain equivalent amounts of toxic metal oxide as is collected in the solid waste of the fluidized bed boiler. Nevertheless, the airborne particulates leaving the AFBB or PFBC will probably contain higher percentages of potentially toxic metallic oxide than for particulates emitted from a conventional power plant.

50% greater than for a conventional coal fired boiler with a 90% SO₂ removal flue gas scrubbing system. The EPA proposed new source performance standards for sulfur dioxide removal efficiencies of 85% and SO₂ discharge limits of less than 1.2 lb/10⁶ Btu are achievable for the AFBB.

3.3 Nitric Oxide (NO_x) Emissions

Emissions of nitrous oxide (NO_x) will occur from fluidized bed combustion systems, but will be lower than NO_x emitted by conventional coal fired plants. The lower NO_x emissions are a direct result of the lower combustion temperatures experienced in the fluidized bed combustion process. Present experimental data supports the conclusions that the NO_x emissions will meet the current EPA standards of 0.7 lb/10⁶ Btu and the proposed EPA New Source Performance Standards for NO_x emission of 0.5 and 0.6 lb/10⁶ Btu for Western and Eastern coals, respectively.

3.4 Disposal of Solid Waste

The production of solid waste from the combustion of coal is a problem generic to all coal fired electric generating systems. However, because the FBC systems require greater quantities of limestone than do the conventional plant with FGD systems, and because of the trace element loading on the collected solid material, the FBC systems generate greater quantities of solid waste products with possibilities for high concentrations of potentially toxic materials. Disposal of this spent sorbent and ash residue will require large amounts of land. These solid residues may contribute to degradation of ground water and surface water quality due to leaching and run-off. Migration of trace elements from the disposal site may cause violation of water quality standards and endanger health and environmental quality.

A number of trace metals are likely to leach out of this material such as arsenic, cadmium, mercury, lead, and vanadium. The alkaline nature of the solid waste product matrix should tend to reduce the mobility of many of these elements. Control technologies employing landfills and settling ponds should be properly designed to capture the leachate and surface runoff. Existing technologies should be capable of meeting the appropriate standards set by "Clean Water Act" for bottom ash and blowdown and the "Resource Conservation and Recovery Act" for spent sorbent from limestone, calcium sulfate, fly and bottom ash, and trace metals and organics.

Other factors of concern associated with the disposition of solid waste are potential adverse influences or socioeconomic and demographic conditions. Disposal will consume land which could be used for other purposes. There is data to support the possibility that some of this material, due to its solid structural and cementous characteristics, may find an alternative use such as road bed substrats or additive with cement and gypsum. If there are no significant alternate uses for the solid waste products, the hydrological, socioeconomic and environmental considerations may be a limiting factor to the fluidized bed combustion systems.

3.5 Plant Systems Hazards Identification

Table 3-2 identifies in general the plant systems and associated hazards for the atmospheric fluidized bed boiler and pressurized fluidized bed combined cycle power plants. The details for system failures and associated hazards for the AFBB and PFBCC are contained in Sections 4.2 and 5.2, respectively.

TABLE 3-2
PLANT SYSTEMS HAZARDS IDENTIFICATION
FOR FLUIDIZED BED COMBUSTION POWER PLANTS

<u>Hazard</u>	<u>Initiating Event</u>	<u>Hazard Source</u>	<u>Increasing Hazard</u>	<u>Monitoring Hazard</u>	<u>Mitigation</u>	<u>Remarks</u>
SO ₂	Normal Operation	Coal Combustion		In Stack SO ₂ Detection	In-Situ SO ₂ Absorbtion	
	Startup	Oil Combustion				
	Fire	Coal Bunker		Fire Protection		
		Coal Pile			Water Spray	
		Coal Handling	Methane Foreign Matter			
		Fuel Oil			Tank Berm	
		Oil Filled Transformers				
		Turbine	Lube and Seal Oil, H ₂	Fire Protection	Sprinkler	
		Airplane Crash Landslide Lightning Earthquake	(See above fire events)			
NO _x	Normal Operation	Coal Combustion		In Stack NO _x Detection	Low Combustion Temperatures	
	Startup	Oil Combustion				
	Fire	Coal Bunker		Fire Protection		
		Coal Pile			Water Spray	
		Coal Handling	Methane Foreign Matter			
		Fuel Oil			Tank Berm	
		Oil Filled Transformers				
		Turbine	Lube and Seal Oil, H ₂	Fire Protection	Sprinkler	
		Airplane Crash Landslide Lightning Earthquake	(See above fire events)			
Particulates	Normal Operation	Coal Combustion	Trace Toxic Elements and Radium, Thorium	Dust Sampling At Stack	Cyclones, Electrostatic Precipitators, and Baghouse Fabric Filters	Loaded filter handling may be hazardous & require proper disposal techniques
		Cooling Tower Emissions			Blowdown	
		Coal Pile			Dust Suppression	
		Limestone Pile			Dust Suppression	
		Ash and Solid Waste Pond			Wet Ash System	
		Startup				
		Oil Combustion				
	Fire	Coal Handling	Methane Foreign Matter			
		Fuel Oil			Tank Berm	
		Oil Filled Transformers				
		Turbine	Lube and Seal Oil, H ₂	Fire Protection	Sprinkler	
		Airplane Crash Landslide Lightning Earthquake	(See above fire events)			

TABLE 3-2 (cont.)

<u>Hazard</u>	<u>Initiating Event</u>	<u>Hazard Source</u>	<u>Increasing Hazard</u>	<u>Monitoring Hazard</u>	<u>Mitigation</u>	<u>Remarks</u>
Hydrocarbons	Normal Operation	Coal Combustion				
		Fuel Oil Tanks				
		Oil Combustion				
	Startup	Coal Bunker				
		Coal Pile			Water Spray	
	Fire	Coal Handling	Methane Foreign Matter			
		Fuel Oil Tanks			Tank Berm	
		Oil Filled Transformers				
		Turbine	Lube and Seal Oil, H ₂	Fire Protection		
		Airplane Crash	(See above fire events)			
		Landslide				
		Lightning				
		Earthquake				
	Pipe or Tank Rupture	Fuel Oil System				
CO	Normal Operation	Coal Combustion				
	Startup	Oil Combustion				
Water Pollution	Normal Operation	Cooling Tower Blowdown	Trace Metals			Used SO ₂ removal makeup water
		Boiler Blowdown				Used for coal pile dust suppression
		Coal Pile			Clay lined, Re-cycle to Ash Pond	
	Flood Earthquakes Landslides Airplane Crash	Ash and Solid Waste Pond	Trace Metals		Clay lined	
		Fuel Oil Tanks			Tank Berm	
		Water Storage Tanks				
Land Effects	Normal Operation	Ash Pond				
		Coal Pile				
Plume, Drift, Fog, Icing	Normal Operation	Waste Disposal				
		Cooling Tower Vapor				
Missiles	Fire	Lube Oil	Turbine Blades	Fire Protection	Sprinkler	
	Mechanical Failure	Turbine	Turbine Blades			
	Earthquake	Turbine	Turbine Blades			
	Landslide					
	Airplane Crash					
Overpressurization	Explosion	Fuel Oil Tanks			Low Volatility of Oil	
		AFBB				
		PFBCC				
		H ₂ Storage Tanks				
		Fuel Oil Tanks				
		H ₂ Storage Tank				
		AFBB				
		PFBCC				

TABLE 3-2 (cont.)

<u>Hazard</u>	<u>Initiating Event</u>	<u>Hazard Source</u>	<u>Increasing Hazard</u>	<u>Monitoring Hazard</u>	<u>Mitigation</u>	<u>Remarks</u>
Noise	Normal Operation	Bulldozers , Coal Car Shakers , Cooling Towers , Fans				
Fire	Fire	Fuel Oil Coal Pile Coal Bunker	Combustible Materials Near Plant	Fire Protection	Tank Berm	
	Explosion	Fuel Oil, H ₂ Storage Tank	Combustible Materials Near Plant			
Burns	Fire	Fuel Oil H ₂ Storage Tank				
Chlorine	Airplane Crash Landslide Flood Earthquake Fire	Chlorine Tank Car		Chlorine Detectors		

4.0 DESCRIPTION OF A CONCEPTUAL ATMOSPHERIC FLUIDIZED BED POWER PLANT

4.1 System Description

Figures 4-1 and 4-2 illustrate the coal combustion side of a 200 MWe atmospheric fluidized bed boiler power plant. The steam electric generation side not shown consists of conventional components such as the steam turbine, electric generator, condensate pumps, condensate reheaters, and heat rejection condenser. Because the "hazards" associated with the steam side of the atmospheric fluidized bed boiler system are similar to the steam side of conventional coal power plants, no further study is given to the steam side of the atmospheric fluidized bed boiler.

The following systems refer only to the coal combustion side of the atmospheric fluidized bed boiler systems. These systems are:

- Coal and limestone mixing and feeding system
- Fluidized bed boiler system
- Bed material cooler system
- Carbon burnup cell system
- Cyclone particulate removal system
- Combustion air heater system
- Baghouse particulate filtration system
- Solid waste disposal landfill system

LOCATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
TEMPERATURE °F	100	100	668	668	668	700	700	800	800	711	230	230	268	80	80	104	1,330	250	700	700	421	800	238
PRESSURE IN. WG	+34	+33	+49	+47	+47	-3	-7	-4	-7	-9	-17	-21	+1	0	0	+354	+30	0	0	0	+354	0	0
SOLID COMPONENT FLOWS lbm/hr																							
COAL															768,326	768,326							
LIMESTONE														461,041	461,041								
CO ₂						44,922	2,245	42,678	2,133	4,378	4,378	22	22				67,385	67,385		42,678	42,678	40,545	4,355
CO						69,738	3,488	66,250	3,315	6,803	6,803	39	39				104,841	104,841		66,270	66,270	62,933	6,768
CARBON						36,652	2,833	33,819	270	3,103	3,103	18	18				2,985	2,985		33,801	33,801	3,112	3,085
ASH						110,439	5,533	105,120	5,254	10,787	10,787	53	53				0	0		105,120	105,120	99,866	10,734
OTHER						18,440	921	17,519	876	1,797	1,797	9	9				27,640	27,640		17,519	17,519	16,643	1,788
TOTAL SOLIDS FLOW	0	0	0	0	0	300,411	15,022	285,389	11,848	26,868	26,868	137	137	461,041	768,326	1,229,367	202,669	202,669	0	285,389	285,389	225,121	26,730
GASEOUS COMPONENT FLOWS lbm/hr																							
AIR	8,111,030	8,111,030	7,345,030	649,374	6,715,476		420,275			420,275	1,146,275	1,146,275	1,146,275			245,875			420,275		37,077		0
CO ₂						1,643,717	1,463,717	177,525	177,525	1,841,243	1,841,243	1,841,243	1,841,243										
CO						10,087	10,087	0	0	10,087	10,087	10,087	10,087										
H ₂						5,287,873	5,287,873	534,138	534,138	5,822,033	5,822,033	5,822,033	5,822,033										
O ₂						243,302	243,302	34,202	34,202	297,503	297,503	297,503	297,503										
H ₂ O						462,640	462,640	9,183	9,183	471,846	471,846	471,846	471,846										
TOTAL GAS FLOW	8,111,030	8,111,030	7,345,030	649,374	6,715,476	7,487,639	8,107,914	735,070	735,070	8,842,987	9,608,987	9,608,987	9,608,987	0	0	245,875	0	0	420,275	0	37,077	0	0
TOTAL MASS FLOW	8,111,030	8,111,030	7,345,030	649,374	6,715,476	7,988,050	8,122,934	792,039	746,918	8,889,854	9,635,854	9,609,124	9,609,124	461,041	768,326	1,475,242	202,669	202,669	420,275	285,389	342,463	225,121	26,730

MAJOR COMPONENT
 - - - - - AIR
 - - - - - GAS
 - - - - - SOLID

FIGURE 4-1

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TVA 800 MW FLUIDIZED BED
 COMMERCIAL UNIT
 MATERIAL AND ENERGY BALANCE
 100% MCR

SCALE NONE DWS
 NO. NE-774799-00

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<p>DRAWN BY: <u>G.W. FRANCHI</u> CHECKED: _____ DATE: <u>1/6/78</u> APPROVED: <u>SLD</u></p>		<p>SCALE: NONE BOX NO: NE-774826-0</p>

4.1.1 Coal and Limestone Mixing and Feeding System

Atmospheric fluidized bed boilers require a Ca/S mole ratio of approximately 4:1 to obtain 85% sulfur dioxide removed efficiencies. This requires approximately 5 lbs. of calcium to every 1 lb. of sulfur in the coal. Typical limestone contains approximately 86% calcium carbonate, CaCO_3 . Therefore, approximately 40% by weight of the CaCO_3 is calcium or approximately 34.4% by weight of the limestone is calcium. Consequently, approximately 14.5 lbs. of limestone are required per 1 lb of sulfur in the coal. For a high sulfur coal at 4% by weight sulfur, approximately 1 ton of limestone is required for every 1.7 tons of coal burned.

4.1.1.1 Fuel Preparation (see Figure 4-3)

The coal and limestone preparation equipment must be designed to dry and size the raw coal and limestone received from the open storage conveyors and transport the prepared material to the live storage silos supplying the feed equipment.

To insure positive control of the preparation and the mixture rates of the coal and limestone delivered to the fluidized beds, as well as to preclude segregation that may very well take place in a common bunkering system, separate preparation, conveying and bunkering are provided for the coal and for the limestone. Individual feeders are provided that will meter the coal and the limestone to each of the independent feed systems.

The coal and the limestone preparation systems are each designed with sufficient capacity to supply a 24 hour demand from the live silos supplying the fluidized bed feed systems during an 8 hour operating day.

The fuel preparation equipment is shown schematically in Figure 4-4.

FIGURE 4-3 COAL & LIMESTONE PREPARATION & TRANSPORT SYSTEM
SCHEMATIC DIAGRAM
200 MW DEMO UNIT

COAL PREPARATION

LIMESTONE PREPARATION

FIGURE 4-4

4.1.1.2 Coal Preparation

The raw coal received from the outdoor conveyor will contain approximately 9% total moisture and will have been passed through a breaker, sized to a nominal 3" x 0" (maximum size 3" - minimum size 0", or dust). This raw feed will be received in a surge hopper.

The surge hopper bottom will be furnished with a Vibra-Screw bin activator to insure a continuous free flow. The bin activator will discharge to a diverter valve (to by-pass the dryers) and then to a vibrating feeder and a diverting hopper (to feed two dryers) to the dryers. Two rotary dryers are required to handle the large coal volume. These are oil-fired dryers and can be operated individually or in parallel, depending on the coal flow rate. The dryers have been located upstream of the final screen sizing operation to ensure a more reliable screening operation and preclude possible moisture binding of the screens.

A dryer by-pass conveyor will be provided to handle very dry coal, and be available in the event test operation of the coal-limestone fluidized bed feed systems prove the feed system design can satisfactorily handle coals with greater than 2% surface moisture.

In either case, the total raw coal feed will be conveyed from the dryer outlets or the by-pass conveyor discharge to the vibrating screen coal sizing operation. An enclosed bucket elevator will lift the coal to the vibrating screen inlet.

The coal particle sizing operation is actually a screener impactor crusher loop with the crusher in closed circuit with the screen. This operating arrangement increases the loading of the screen in excess of the required unit material rate; however, it is deemed the most desirable arrangement for efficient processing of 1/4" top size material.

The final sized coal from the screen loop will discharge to a belt conveyor and then to a bucket elevator. This elevator will lift the prepared coal to the silo feed belt conveyor.

The entire coal preparation system will be enclosed in a building and equipped with dust suppression (for example a water or chemical spray) and dust collection (for example ventilation and filtration) equipment.

4.1.1.3 Limestone Preparation

The raw limestone received from the outdoor storage conveyor may contain approximately 4-1/2% moisture, and sized to 3" x 1".

The limestone feed will be received in a surge hopper. The hopper bottom will be furnished with a Vibra-Screw bin actuator to insure a continuous free flow of material. The bin actuator will discharge to a diverter valve (to bypass the dryer) and then to a vibrating feeder to the dryer.

Normally, the diverter valve will direct the limestone feed stock to the oil fired dryer; however, a dryer by-pass conveyor is provided for very dry limestone conditions or in the event test operation of the coal-limestone bed feed systems prove the feed system can satisfactorily handle feeds with greater than 1% moisture.

One oil fired rotary dryer is required for limestone drying. The drying equipment should be capable to dry limestone of up to 8.5% moisture, (anticipating higher moisture than specified in consideration of the outdoor storage and possible occasional winter ice or snow conditions) down to 1% moisture.

The limestone crushing equipment should deliver a final product 1/8" x 0". Since the feed will be 3" x 1", the limestone has a slightly different crusher-screen closed loop from the coal system in that all the new feed will be passed to the crusher first, the total crusher load being the total new feed plus the recirculated load of the screen oversize. This total tonnage will also be seen by the screen following the crusher.

The final dried and sized preparation limestone from the screen will discharge to a belt conveyor, and then to a bucket elevator. This elevator will lift the prepared limestone to the silo feed belt conveyor.

The entire system is enclosed and equipped with dust suppression and dust collection equipment.

4.1.1.4 Silos

To accommodate the fuel feed equipment, there should be sufficient silos for the prepared coal feed and the prepared limestone feed. Each silo will be designed with four discharge outlets.

4.1.1.5 Fuel Feed

The coal and limestone feed system will meter and ratio the required quantities of limestone to coal and deliver the controlled solid mixture to approximately one hundred separate feed points in the main beds, and to approximately eighteen separate feed points in the CBC beds, if required. A proposed feed system is described as follows:

4.1.1.6 Fuller Feed System

Figure 4-5 illustrates the Fuller Fluidized Bed boiler feed system. The Fuller design concept appears technically feasible and uses proven components wherever possible. Laboratory testing indicated the multi-splitter design for dividing one transport line into ten separate feed lines should perform satisfactorily. These recently completed tests were conducted using crushed coal and limestone with varying moisture content and a four-to-one splitter. Individual lines were blocked and back pressures varied, and the solids product distribution was within an acceptable $\pm 10\%$.

The proposed Fuller System is shown schematically in Figure 4-6. The total system consists of twelve independent sub-loop feed systems, ten sub-loops for the main beds, and two sub-loops for the CBC beds. These systems will transport the total required solids from the storage silos to individual feed nozzles in the fluidized beds. Approximately one hundred individual feed nozzles are provided in the main beds or approximately one feed nozzle for each 18 ft^2 of bed.

Three pairs of main storage silos will be provided for bunkering the limestone and coal, which feed the Fuller sub-loops. Each silo will have four discharge outlets and each outlet will discharge to a sub-loop metering screw feeder.

FIGURE 4-5
FEED SYSTEM CONCEPT INVESTIGATED

4-12

TYPICAL
OF 12

FIGURE 4-6 COAL AND LIMESTONE
FEED SYSTEM
200 Mw DEMONSTRATION UNIT

Thus, each of the twelve sub-loops will have independent metering of the coal and the limestone to the sub-loop. The screw feeders will discharge into the inlet hopper of the Fuller-Kinyon (F-K) screw pump.

The pump will blend and maintain the necessary feed flow to provide the desired firing rates and provide a material seal for injecting the solids into the pressurized transport system.

Turndown of the pump is accomplished by reducing the solids flow to the pump at constant pump speed (100% to 50% solids flow), and then by reducing pump speed with a further reduction in solids flow (50% to 25% solids flow). The pumps for the demonstration unit are equipped with variable speed motor drives for this purpose.

One air compressor is provided for each pump for solid transport. The compressors are the Fuller C-270 constant flow rotary compressors. The amount of conveying air required is 1 lb air per 5 lbs solids. Note that while the flow of solids in the pump is reduced, the amount of transport air remains constant to maintain line velocities at 2200 ft/min minimum.

In-line splitters are provided which split the flow from each pump into ten separate lines for the main beds, and nine separate lines for the CBC beds. For proper splitting action, 10'-15' of straight vertical pipe run must be provided in the line entering the splitter. Shut-off valves are provided in the lines leaving the splitters, so that solids flow to selected bed zones may be shut-off. As many as seven out of ten lines from the splitter may be shut off, with the pump still above its minimum flow.

4.1.2 Atmospheric Fluidized Bed Boiler System

The Combustion Engineering proposed design for an Atmospheric Fluidized Bed Boiler is illustrated in Figure 4-7 . This design shows a single elevation of beds. Preheated air enters the plenum chamber under each bed from an air duct at the end of each bed; air enters the beds along the side walls of the lower furnace area. The air velocity, approximately 12 ft./sec. for the CE design, is sufficient to lift and suspend the coal/limestone bed mixture in a fluidized state. In the fluidized condition, the energy and momentum exchanges for the moving particles are large and rapid leading to high average convective heat transfer coefficients of approximately $45 \text{ Btu/hr. ft.}^2 \text{ } ^\circ\text{F}$ for horizontal tubes passing through the bed. Approximately 85% of the total combustion heat released occurs within the fluidized suspension as the solid combustible products react with the air. The remaining 15% of the heat released occurs above the fluidized bed due to combustion of volatiles in the coal and CO formed within the bed.

The limestone (CaCO_3) fluidized within the bed absorbs heat and calcines to form lime (CaO) and carbon dioxide (CO_2). Approximately 2.6% of the energy content in the coal is lost in the calcination process. The CaO then reacts with the SO_2 and additional oxygen to form a solid calcium sulfate (CaSO_4).

The capture of sulfur dioxide within the fluidized bed is sensitive to the operating temperature of the bed. The bed temperature must be greater

FIGURE 4-7

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DRAWN BY: <u>W. J. LACE</u> DATE: <u>5-17-77</u>	CHECKED: _____ APPROVED: _____	SCALE: <u>6"=10'</u>	SHEET NO. <u>317-0</u>

than 1400°F in order to calcine the limestone to form CaO. On the other hand, at atmospheric pressures, bed temperature greater than 1600°F discourages the formation of the desired product, CaSO₄. Therefore, the bed temperature should be maintained at approximately 1550°F.

Bed temperature is controlled primarily by the heat absorbed by the steam and water flow through the submerged horizontal tubes within the fluidized bed, and also by the air flow through the bed. Excessive steam flows would lower the bed temperature, and loss or reduced steam flow would raise the bed temperature. On the other hand, because the heat release rate is directly proportional to air flow, reduced air flows would lower the bed temperature and increased air flows would increase the bed temperature.

Because bed temperature affects the sulfur removal, the subsystems that control operation to maintain the bed temperature at approximately 1550°F are necessary to minimize the hazards resulting from SO₂ emissions.

The combustion gases leaving the main beds (1550°F) continue to burn above the bed in a region called the freeboard. The temperature of the gases after combustion leaving the freeboard is approximately 1850°F. These flue gases then increase in velocity as they pass up through a water cooled hood where they cool down to about 1650°F (by radiation losses) and enter the convection pass boiler section containing pendant heating surfaces. The decrease in area of the convective pass section increases the gas velocity which results in higher heat transfer and higher entering temperatures in the convective pass.

The hot gases then pass over steam super heat, steam reheat, evaporator and economizer convective heat transfer tube bundles in the convective pass section. The temperature of the gases as they leave the economizer section is approximately 600-700°F. These gases then proceed to the main bed cyclone.

Some of the heavier elutriated material from the main bed will drop out while passing through the convective pass section and is collected in a hopper at the bottom of the economizer section. This carbon/ash material is fed to the carbon burnup cell.

4.1.3 Bed Material Cooler and Collection System

To maintain the proper inventory of material in the beds, a bed drain material handling system is used. The equipment included in this system consists of drain lines, feeder/air-lock valves, air cooler, solids coolers, and a cooled solids conveying system. Figure 4-8 illustrates the bed drain system. Six inch drain lines are provided, with one drain per every 100 ft² of bed area, centrally located. The lines are stainless steel and lined with refractory for wear resistance. The lines penetrate the air plenum and grid plate, and are welded into the grid plate flush with the plate. The lines run nearly vertical (angles 60° or greater from horizontal) and will convey hot bed material to the solids coolers by gravity.

Feeder/air-lock valves are located in each drain line to isolate the solids coolers, which run at 0" w.g. internal pressure, from the +30" w.g. pressure at the base of the beds. The valves are equipped with variable speed motor drives.

The air-cooled solids coolers are located under each bed module. Five coolers are provided for the main beds, with one cooler for each 44' long section of bed; each cooler cools the material from four drain lines. Compressed air is passed through the hot bed material and cools the material from 1550°F to 250°F, while it, in turn, heats up from ambient to 700°F; each cooler is sized to cool 10,000 #/hr of material. A fan is used to provide the fluidizing/cooling air to each cooler.

FIGURE 4-8

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The hot air from the coolers is then ducted to the gas stream ahead of the main bed cyclone. This method for recovering heat from the bed material drain flow is relatively simple and eliminates potential problems in obtaining and/or operating a hot booster fan which would be required if the hot air were to be injected into the secondary air flow to the beds. The heat recovered by this system is approximately equal to 0.5% of the heat input.

The CBC (Carbon Burnup Cell) employs a similar system, but cools the material with water instead of air. CBC beds, where the steady-state solids drain flow is small, a water-cooled screw conveyor is provided to cool the material from the drain lines and convey it to a main conveyor for transport to a disposal site. One screw conveyor is provided for the CBC bed. It is not planned to recover the heat in the CBC bed drain material.

The cooled solids leaving the coolers are dumped to a screw conveyor, which collects the material from all the coolers. The conveyor moves the material toward the rear of the boiler to a bucket elevator which discharges into a 125 ft³ surge bin. The surge bin empties into a 100 ft³ blow tank which pneumatically conveys the bed material through an 8" diameter wear resistant pipe to a storage silo.

4.1.4 Carbon Burnup Cell (CBC) System

The purpose for the Carbon Burnup Cell (CBC) is to burn the elutreated carbon ejected from the main fluidized beds and collected in the cyclone separators and the ash hopper of the main fluidized bed boiler. The unburned carbon/ash material is transported from these collection areas via the material feed pump to the primary air flow. The primary air flow carries the small particles of unburned carbon/ash into the fluidized bed section of the carbon burnup cell where it undergoes combustion. The temperature of the fluidized bed in the CBC is maintained at approximately 2000°F by the steam evaporator

horizontal tubes buried within the bed of the CBC module. Above the fluidized bed are additional horizontal tube bundles that are used for economizer duty. These tube bundles cool the combustion gases down to approximately 800°F. Figure 4-9 illustrates a proposed fluidized bed carbon burnup cell.

In addition to the carbon/ash recycle feed lines, coal/limestone feed lines also supply fuel to the bed in the CBC module. Bed drain lines are also provided to discharge the solid waste material to the CBC material bed cooler (discussed in Section 4.1.3). Startup of the carbon burnup cell is accomplished by using startup oil ignitors.

4.1.5 Particulate Removal Systems

The particulate removal equipment includes the main bed cyclones, CBC bed cyclones, and the bag filter.

4.1.5.1 Main Bed Cyclone

The purpose of the main bed cyclone is to recover the carbon-containing material elutriated from the main beds for recycle to the CBC beds, providing for minimum overall system carbon loss.

Considerations of the inlet dust loading, pressure drop, required efficiency and cost dictated the use of a multi-tube cyclone collector.

Because the size of the particles elutriated from the main beds (98% >10 microns) is larger than for the particulates leaving a pulverized coal fired boiler (70% >10 microns), the main bed cyclone efficiency should be much higher than has been experienced with cyclones installed on pulverized coal fired units. Also, because of the low combustion temperatures in the main beds the coal ash is not fused, and the particles entering the main bed cyclone should be less abrasive than those from a pulverized coal-fired

FIGURE 4-9

TYP. PRODUCTION SHOWN ON THE PLACEMENT OF C-E POWER SYSTEMS CONSTRUCTION INC.-WESTING HOUSE DIVISION DRAWN BY: <u>W. J. KATZ</u> CHECKED BY: <u>W. J. KATZ</u> DATE: <u>1-3-78</u> APPROVED: <u>W. J. KATZ</u>		TYP. CBC MODULE FOR TENNESSEE VALLEY AUTHORITY SCALE: <u>1" = 4'-0"</u> FILE NO: <u>NE 774-825-00</u>	
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boiler. Therefore, the cyclone efficiency should remain high during the life of the unit. However, a second cyclone can be added should the performance of the first unit be below expected performance.

4.1.5.2 CBC Bed Cyclone

The purpose of the CBC bed cyclone is to reduce the amount of particulates entering the air heater. This will decrease wear of the air heater elements and also decreases the amount of particulates which are carried over from the gas side of the air heater into the air side.

Consideration of the high inlet dust loading dictated the use of cyclones with large diameter cyclone barrels with refractory lining for wear resistance.

Space should be made available for the addition of a second CBC bed cyclone in series with the first, should the performance of the first unit be below the guaranteed performance.

4.1.5.3 Bag Filter

A bag filter is used for final particulate emission control. While a properly designed precipitator could most likely attain the required efficiency, the information required for proper precipitator design (dust resistivity, particle composition, particle size distribution, etc.) is not yet available.

The major factor affecting precipitator performance is the low sulfur content of the flue gas. The low sulfur content in the gas generally indicates the dust will have a relatively high resistivity, hence the precipitator must be designed with low velocities and large collecting areas, resulting in a high cost. This is the situation encountered in conventional units having low sulfur Western coal. While chemical conditioning agents have been used in some precipitator installations to reduce the ash resistivity, initial indications

are that the dust composition (specifically the CaO present) would render the normal conditioning agents ineffective.

The performance of a bag filter essentially is independent of the particle resistivity, composition, and size distribution. Also, for low sulfur coals the cost of a bag filter is comparable to the cost of a hot or cold precipitator. For these reasons, a bag filter was selected for the demonstration unit.

A commercial bag filter considered collects the dust on the outside of the filter bags permitting a higher air-to-cloth ratio. The unit selected uses felted acrylic bags (good to 295°F gas temperature) stiffened with an internal wire mesh, and has a low pressure pulsed air cleaning system.

Bag filters of the design considered here have been operating successfully on commercial-size boilers in Australia for the past four years with relatively low maintenance. These units have high air-to-cloth ratios (6.7:1) and are operated on low sulfur coal with relatively low stack gas temperatures (230°F).

4.1.6 Combustion Air Heater System

A regenerative air heater (heat wheel) provides for transfer of heat from the flue gas stream to the combustion air flow prior to entering the beds. The proposed design conditions for the air heater are as follows: air enter on the air side at 100°F and leaves at 668°F while flue gas enters on the gas side at 711°F and cools down to 250°F before entering the baghouses.

It is pointed out here that a potential particulate emission can be initiated by failure of the regenerative air heater. If, for example, the power to the heat wheel stops, then the temperature of the flue gases entering the bag filters would be 700°F exceeding the normal operating temperature of 250°F

for the filters. Consequently, the structural integrity of the filters could be degraded and releases of particulates could occur.

4.1.7 Solid Waste Disposal Landfill System

The composition of the solid waste generated is primarily calcium sulfate (33.3%), calcium oxide (51.6%), inert material (15.6%), and carbon (1.5%). Trace elements will also be present. Due to the low bed operating temperatures, the bed material does not melt and fuse, but is discharged as a dry granular waste material. The calcium oxide and calcium sulfate contained in the waste material develop cementitious properties that tend to hold the material together when placed in a landfill.

An important consideration for the design of the solid waste landfill is that it must prevent leachate from percolating into uncontrolled groundwaters. This is because the leachate that can be generated in the disposal pile may contain trace toxic elements. As a consequence of the lower combustion temperatures experienced in FBC units, vaporization of some trace elements does not occur. Therefore, these trace elements that would normally be carried through the boiler in the gaseous phase coalesce and attach with the dry solid residues.

The landfills that are designed to collect leachate should contain a clay liner or other liner type impervious to leachate and runoff. The liner may contain the leachate only or direct it to a low point sump pump where it is pumped to storage tanks for processing or disposal.

4.2 Summary of Hazards Associated With Atmospheric Fluidized Bed Boilers

The principal hazards associated with atmospheric fluidized bed boilers have been discussed in Section 3 and are listed below:

- Particulate emission
- SO_2 and NO_x emission
- Solid waste disposal pollution

These hazards are generally associated with normal operation. However, abnormal operation and mechanical failures can temporarily create higher hazardous conditions and also create other hazards (such as fires, explosions, and missile generation) which are considered infrequent occurrences.

Table 4-1 lists system failures and hazards caused. The hazards event tree for the AFBB is shown in Figure 4-10.

TABLE 4-1

AFB SYSTEM FAILURE AND ASSOCIATED HAZARD

<u>Systems Failure</u>	<u>Failure Description</u>	<u>Hazard</u>
Coal/Limestone Mixing System	Lower Ca/S than required	Higher SO ₂ emissions
Fluidizer Combustion Air Fans	Higher fluidizing velocities than normal	Higher SO ₂ emission Higher particulate emission
Heat exchanger tubes within bed	Loss of steam or water flow within tubes - results in higher bed temperature	Higher SO ₂ emission
Rupture of heat exchanger tubes within bed	Erosion of heat exchanger tubes by turbulent fluid bed	Carbon monoxide generation Hydrogen generation Higher SO ₂ emission Potential for structural damage of AFBB
Cyclone Particulate Removal	Reduction in particulate removal efficiency with age	Higher loading of bag filter Higher particulate emission
Air Preheater	Heat wheel stops due to loss of motor power	High gas temperatures entering bag house, bag filters degradation, higher particulate emissions
Bag House Filter System	Rupture of fabric filter	High particulate emission
Solid Waste Disposal System (If off site)	Transportation accidents releasing solid waste residue to ground surface	Potential for some uncontrolled toxic elements to enter ground waters by surface runoff
Landfill System	Rupture of landfill liner or no liner at all	Potential for leachate containing toxic elements to enter water supply

TABLE 4-1 (cont.)

<u>Systems</u> <u>Failure</u>	<u>Failure</u> <u>Description</u>	<u>Hazard</u>
Fluid Bed Boiler	Coal Dust Explosion	SO ₂ , NO _x , particulate hydro- carbon and CO emissions; missile generation; noise; overpressure
Fluid Bed Boiler Vessel	Excessive thermal and cyclic stresses on hot spots leading to boiler tube failure	Same as above
Coal Handling/ Bunker System	Fire	SO ₂ , NO _x , hydrocarbon, CO emissions
Coal Pile	Fire	SO ₂ , NO _x , hydrocarbon, CO emissions
Bunker System	Coal Dust Explosion	SO ₂ , NO _x , hydrocarbon, CO emission; overpressure; missiles

HAZARDS EVENT TREE FOR ATMOSPHERIC FLUIDIZED BED BOILER

5.0 PRESSURIZED FLUIDIZED BED COMBUSTION COMBINED CYCLE (PFBC) POWER PLANT

5.1 System Description

Figure 5-1 illustrates the Burns and Roe/Babcock and Wilcox/ United Technologies design for a 592 MWe gross Pressurized Fluidized Bed Combustion Combined Cycle (PFBC) power plant. In summary, pressurized air supplied by two turbine air compressors is heated up to high temperatures as it passes through four pressurized fluidized bed reactor vessels burning a mixture of coal and dolomite. The hot air and combustion products then pass through a cyclone particulate removal stage and then expand in two 63.6 MWe gas turbines producing mechanical power that drives two electric generators and the two air compressors. The exhaust gases from the gas turbines (still very hot and rich in oxygen) then pass up through a single atmospheric fluidized bed boiler (AFBB) where the fluidized coal burns releasing heat for steam generation (the steam drives a single 465 MWe conventional steam turbine electric generator cycle). The hot combustion gases give up heat as they pass through the convection sections of the AFBB. The gases leave the boiler at about 700°F, pass through cyclone particulate removal systems, through a hot electrostatic precipitator, then through an economizer for final energy recovery before discharged out the plant stack. The expected electric generation efficiency is approximately 40% which is comparable to that obtained from oil fired or coal fired conventional boilers and power conversion systems.

In the pressurized section, dolomite (CaCO_3 and MgCO_3) is the additive employed to remove the SO_2 from the combustion products whereas limestone (CaCO_3) is the additive to remove SO_2 in the atmospheric section.

Because the "hazards" associated with the steam cycle are similar to the steam side of conventional coal fired power plants, no further consideration

SCHEMATIC OF PLANT

is given to the steam loop of this combined cycle plant. The following systems refer only to the coal combustion and associated gas energy conversion cycles:

- Coal/dolomite and coal/limestone feed systems
- Pressurized fluidized bed combustion vessel
- Gas turbine generator and air compressor
- Atmospheric fluidized bed boiler
- Cyclone/precipitator particulate removal

5.1.1 Coal Dolomite and Coal Limestone Feed Systems

It has been found experimentally that for the maximum removal of SO_2 in a pressurized environment, dolomite, a mixture of calcium carbonate and magnesium carbonate, should be used instead of pure limestone (calcium carbonate) for the sorbent material. It is estimated at a Ca/S mole feed ratio of 1.5 is required for a 90% sulfur capture in the pressurized section. Since approximately 53.9% of the dolomite is CaCO_3 , approximately 8.7 lb. of dolomite are required per 1 lb. of sulfur in the coal. For a typical Illinois coal of 3.43% by weight sulfur, the dolomite feed requirement is approximately 0.3 tons of dolomite per ton of coal.

Figure 5-2 illustrates the coal/dolomite feed systems.

For the atmospheric fluidized bed section, the sorbent, limestone, is added at a Ca/S mole feed ratio of approximately 3.4. Since limestone is approximately 97% CaCO_3 , about 0.37 ton of limestone per ton of coal is required for a coal containing 3.43% sulfur by weight.

5.1.1.1 Pressurized Fluidized Bed Feed Systems

The coal and sorbent feed systems for the PFB combustors are pneumatic transport systems which incorporate lock hoppers to provide pressurization of the coal and dolomite. To provide rapid control of the Ca/S feed ratio and to eliminate the concern for solids segregation in the lock hoppers and feed tanks, separate feed systems are used for the dolomite and coal. One coal feed system and one dolomite feed system are provided for each of the PFB combustors.

The dried, crushed coal free falls from the coal silo into one of the two lock hoppers. Two full capacity lock hoppers are used to provide redundancy and thereby increase availability of the lock hopper system (particularly the knife-gate valves used for lock hopper sealing during pressurization and depressurization). The two knife-gate valves before and after each lock hopper are remotely operated to shutoff the passage of the solid material to and from the lock hoppers and to provide a seal during pressurization and depressurization. The lock hoppers are equipped with load cells and transmitters for monitoring the filling and dump cycles. Pressure transmitters on the lock hoppers and the pressurizing lines provide control of the rate of pressurization and thus minimize transient effects on the transport air system. Equalizing lines connect the lock hoppers to the respective feed tanks so that no differential pressure exists between the lock hopper and feed tank during the lock hopper dump cycle. Vent lines, with remote operated control valves, depressurize the lock hoppers by venting to the bunkers. The coal in the bunker acts as a natural filter to remove the solids entrained in the vent air.

The operating cycle for the lock hoppers consist of four steps:

1. Filling - The knife-gate valves between the bunker and lock hopper are opened while those between the lock hopper and feed tank remain closed. Solid materials free falls from bunker to lock hopper. When the lock hopper is filled, the knife-gate valve closest to the bunker is closed and then the other knife-gate valve is closed.
2. Pressurizing - All valves are closed; the pressure differential controll valves are opened allowing the lock hopper to pressurize at a constant flow rate. When the lock hopper has been pressurized, the pressurizing air flow control vlave is closed and the pressure equalizing line to the feed tank is opened.
3. Dumping - The knife-gate valves between the lock hopper and feed tank are opened (valve closest to the lock hopper is opened first) and the coal free falls into the feed tank. After the lock hopper has been emptied, the knife-gate valves are closed. The pressure equalizing line is then closed.
4. Depressurizing - All valves are closed. The depressurizing (vent) line to the bunker is opened and the lock hopper is depressurized.

In normal operation the two lock hoppers would be operated sequentially thereby extending the time between cycles for each hopper.

The coal free falls from the feed tank into an "air swept" rotary feeder. This feeder controls the solids flow rate and provides for the introduction of the transport air into the solids stream. The transport air is introduced into each pocket of the rotary feeder as the pockets pass the air inlet point; the air is mixed with the solids in the pocket and the air-solids mixture is introduced

into the transport system at the feeder outlet. A pressure equalizing line between the transport air line and the feed tank minimizes the pressure differential across the feeder so that the feeder is not required to function as a pressure seal. The feed tank is equipped with load cells and transmitters to monitor the coal storage and initiate filling from the lock hoppers. The signal from these weight transmitters also provides a measure of the coal flow rate.

The system design is based on the use of air for both transport of the solids and pressurizing the lock hoppers and feed tanks. Based on experience with pressurized feeding of pulverized coal to blast furnaces, there is a concern for the safety aspects of pressurized storage of crushed coal in the lock hoppers and feed tanks. A literature survey was conducted to determine if data were available related to the spontaneous combustion and/or explosion potential of crushed coal in a pressurized air environment. The survey was inconclusive but did not indicate that air could not be used. The alternate, if air should prove unsafe for pressurized storage in the lock hoppers and feed tanks, is to use an inert gas. The inert gas can be generated by burning a fuel in air to lower the oxygen content to 2 to 3% and then cleaning the combustion gas. While this is readily accomplished with a clean fuel, the use of coal to generate the inert gas adds considerable complications.

The source of air for the pressurizing and transport system is the gas turbine compressor discharge. The pressurizing and transport air is cooled from the 595^oF compressor discharge temperature to 125^oF and is passed through a booster compressor to provide the required pressure for the system. By cooling to 125^oF the booster compressor power is minimized and the discharge air temperature is the desired 150^oF for the transport system.

A single transport line is used from the "air-swept" rotary feeder to a feed distributor located below the PFB combustor. At the distributor the coal/air mixture is divided evenly among the 24 individual lines that feed coal to the PFB combustor (four individual lines for the dolomite feed system).

The system controls are based on maintaining a constant transport air volume flow rate in the transport lines. The solids flow turndown is accomplished by speed variation of the "air-swept" feeder. This design permits operation of the transport system at low velocity to minimize erosion and yet provides for a wide range of solids flow turndown with the system turndown range limited by the feeder characteristics.

5.1.1.2 Atmospheric Fluidized Bed (AFB) Feed Systems

5.1.1.2.1 Main Fluid Bed (MFB) Feed System

The arrangement of the coal and limestone feed system for the Main Fluid Bed unit is shown on Figures 5-3 and 5-4.

Sixteen full sized feed systems, one for each of the MFB operating compartments are provided. Six quarter sized systems are used to feed limestone to the Carbon Burn-up Bed (CBB) as required to maintain the bed level, and to feed coal to the CBB if required to maintain bed temperature. Of these six quarter sized systems, four are arranged to provide coal and limestone feed to the start-up compartments of the MFB.

Separate bunkers are provided for the coal and limestone. A pair of gravimetric feeders, one for coal and one for limestone, are provided for each feed system. These feeders provide the flow control for the solids and permit variation in the Ca/S feed ratio. The feeders are arranged to discharge into a common hopper providing the initial mixing of the coal and limestone. The

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AFB FEED SYSTEM

FIGURE: 5-3

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mixture flows by gravity through a rotary seal which minimizes the leakage of transport air into the feeders and bunkers. The mixture continues to free fall into a mixing bustle where the transport air is introduced. The mixture is pneumatically transported in a single line to the vicinity of the bed compartment being fed where it is split into 40 streams using a distributor similar to that used in the PFB system. Maintaining proper Ca/S feed ratio is important to minimize SO₂ emissions.

The transport air is provided by a pair of atmospheric suction, primary air fans that service all twenty-two feed systems. The air flow to each feed system is controlled to maintain constant velocity in the feed system with the solids flow rate being controlled by the gravimetric feeders. This permits designing the transport system for a low velocity to minimize the erosion in the feed lines.

5.1.1.2.2 Carbon Burn-up Bed (CBB) Feed System

In addition to the coal and limestone feeders to the CBB, a feed system is provided for feeding the char, ash and partially sulfated limestone collected in the MFB dust collectors.

This system, shown in Figure 5-5, includes a vacuum transport system to convey the material from the dust collector hoppers to the CBB feed tank. Six rotary feeders, one for each CBB compartment, control the feed rate of the solids to mix bustles where the transport air is introduced. The solids are then pneumatically conveyed through a single pipe, one for each compartment, to a distributor near the CBB where the flow is split among the 20 individual lines which feed each compartment.

Figure 5-5

5.1.2 Pressurized Fluidized Bed (PFB) Combustor

Figure 5-6 illustrates the pressurized fluidized bed combustor. Pressurized air at about 150 Psia and 595^oF (supplied by the turbine compressor) enters the lower end of the PFB pressure vessel. Approximately 25% of this incoming air flows upward through the bubble caps in the distributor plate and fluidizes the coal/dolomite mixture and also supplies oxygen for combustion. The remaining 75% of the incoming air flows through heat exchanger tubes buried within the fluidized bed. Load following is accomplished by by-passing the heat exchanger air flow to the discharge of the fluidized combustor air flow. This concept provides turn down control while permitting the combustor to operate at constant fluidizing velocity and bed level.

The bed fluidizing velocity is approximately 2 ft./sec to 3 ft./sec and is at a flow rate equivalent to 15% excess air for combustion. The sulfur capture in this section is approximately 78% for 3.43% sulfur in coal. The low fluidizing velocity improves combustion efficiency, sulfur removal, and reduces elutriation of the bed material. Particulate removal from the combustion gases is achieved by the cyclone filtration system.

5.1.2.1 Pressurized FBC Hazards

The hazards associated with this pressurized combustor are pressurized rupture, sudden depressurization, and high gas temperatures resulting from loss of clean air flow.

5.1.2.1.1 Pressure Vessel Rupture

The pressure vessel and associated piping operate at approximately a pressure of 150 psia. Even though the temperature of the fluidized bed and combustion gases are at 1650^oF, because there is refractory lining adjacent

Schematic - Split Air Flow PFB Combustor

FIGURE: 5-6

to the pressure vessel walls, the temperature of the pressure vessel is less than 250°F. These design conditions for a pressure vessel are not severe and the pressure vessel should operate safely. However, if in the unlikely event that the pressure vessel should rupture due to the high pressure temperature conditions, the only hazards to the general public would be an inconsequential release of SO₂, NO_x, coal, dolomite, calcium sulfate, and particulates to the environment in addition to a loud noise and possible missile generation.

5.1.2.1.2 Sudden Depressurization

If a break occurs in the discharge piping or particulate removal system, then there would be a sudden depressurization of the fluidized bed combustor. The hazard of this accident would be an inconsequential release of SO₂, NO_x, elutriated coal, dolomite, and calcium sulfate in addition to unusual noise generation.

5.1.2.1.3 High Gas Temperatures

Part of the heat removal mechanism for extracting heat from the fluidized bed is the clean air cooling header that is buried within the fluidized bed at full load, 75% of the total air flow passes through this header to remove the fluidized bed combustion heat which maintains the bed temperature at approximately 1650°F. Loss of this air without any additional corrective action would result in fluidized bed and combustion gas temperatures significantly higher than the design of 1650°F. The hazards associated with this situation would be higher than normal releases of SO₂ and NO_x. Also, structural damage could occur to the clean air cooling manifold and distributor/support plate if the bed temperature exceeded 1700°F for a sufficient length of time.

5.1.3 Gas Turbine/Air Compressor

Hot clean combustion gases leaving the cyclone particulate removal system mixed with hot clean air from the air cooling manifold expand through a back pressure gas turbine producing mechanical shaft horsepower. The same shaft is coupled to the air compressor supplying the pressurized air to the pressurized fluidized bed combustor. Also connected to the turbine shaft is a 20 MWe electric generator delivering electric power to electric loads. The pressure and temperature of the gases discharging from the turbine is approximately 1-2 psig (15.7-16.7 psia) and 750 to 850^oF. These hot gases then pass into the atmospheric fluidized bed boiler.

The air compressor stage compresses inlet air to a pressure of about 150 psig and a temperature of about 595^oF. Most of this air flow goes directly to the pressurized fluidized bed combustor. However, part of the compressor air flow is diverted and used as a transport medium which receives the fuel mixture from the pressurized lock hoppers and carries the coal/dolomite into the fluidized bed compartment of the PFBC.

The hazard that results from failure of the gas turbine/air compressor are missile generation due to failure of the turbine blades. This hazard can occur if the turbine overspeeds as a result of a sudden loss in electric generator load coupled with control system malfunction.

Another hazard associated with a loss of electric generator load is the potential overpressurization of the atmospheric fluidized bed boiler. With a sudden loss in electric generator load, and assuming a failure in safety control systems, the turbine will overspeed and the turbine discharge pressure and temperature will be significantly higher than normal. This condition would lead to a possible overpressurization of the atmospheric fluidized bed boiler and/or significantly higher gas velocities through the AFBB. An

overpressurization of the AFBB could rupture the walls of the boiler and the high gas velocities would result in higher than normal SO_2 and particulate emissions for a short time period.

5.1.4 Atmospheric Fluidized Bed Boiler (AFBB) System of The PFBCC

The exhaust gases from the gas turbines (rich in oxygen) are routed to the atmospheric fluid bed boiler system for combustion of additional coal and generation of steam for a steam turbine power cycle. The AFB system is composed of a main fluid bed boiler (MFBB) where coal is burned in the presence of limestone to capture the sulfur, and a carbon burnup bed for final combustion of the char elutriated from the MFBB.

The design of the main fluid bed boiler and the carbon burnup bed are similar to the design description provided in the atmospheric fluidized bed boiler, Section 4, of this study. Figure 5-4 illustrates the basic design of the AFBB for the PFBCC.

The hazards associated with the AFBB system are the same as those mentioned in Section 4. These are summarized below:

- SO_2 releases due to out of control operating conditions such as high fluidized bed gas velocities, low Ca/S feed ratio, high bed temperatures due to sudden loss in steam flow.
- High particulate releases due to high fluidized bed gas velocities, failure of filtration system, particle sizes for the coal and limestone feed stock are smaller than design feed conditions.
- NO_x releases due to high bed temperatures.
- Hydrocarbon and carbon monoxide releases due to incomplete combustion.

5.1.5 Particulate Removal Systems

5.1.5.1 Pressurized Fluid Bed Particulate Removal System

The combustion gases leaving the PFB are filtered by a 2-stage cyclone particulate removal system. Based on limited data, it appears that gas turbine particulate load size of greater than 10 microns will give unsatisfactory turbine life, particulates less than 2 microns in size will have negligible effects on turbine life and that some limited amount of particulates of 0.0100 grains/Scf in the 2-10 micron size can be tolerated within the gas turbine. Therefore, the performance requirements for the 2-stage cyclone filtration system are then to provide a gas outlet with a dust loading meeting the above size conditions (i.e., zero greater than 10 microns, no limit less than 2 microns, and 0.0100 grains/scf between 2-10 microns).

The hazards associated with the PFB cyclone filtration system are:

- 1) Degradation of particulate removal efficiency will result in higher dust loading entering the turbine. The high dust loading will erode the turbine blades causing an unbalanced condition which may eventually lead to blade vibration and missile generation. Also, lower turbine power conversion efficiencies will result and higher turbine discharge temperatures, pressure, and velocities which will create abnormal operating conditions for the AFBB.
- 2) The cyclones operate at high temperature (1650°F) and high pressure, 150 psig. Even though the probability is considered very low, rupture of the cyclone would generate missiles and release large quantities of particulates to the environment.

5.1.5.2 Atmospheric Fluidized Bed Particulate Removal Systems

5.1.5.2.1 AFB System Dust Collectors

Two dust collector systems are incorporated into the AFB system, one for the

Main Fluid Bed Unit (MFB) and one for the Carbon Burn-up Bed Unit (CBB).

The primary function of the dust collectors following the MFB is to capture the char (unburned coal) elutriated from the MFB unit. This captured char is combusted in the CBB to improve the system combustion efficiency. The primary function of the dust collector following the CBB is to reduce the total solids loading of the gases entering the hot electrostatic precipitator which is used for final particulate removal to comply with environmental requirements.

Conventional multiclone dust collectors are used for both systems. To achieve a high char collection efficiency for the MFB dust collector, a collector utilizing 6" diameter tubes is selected. The projected char collection efficiency is 90% while the corresponding efficiency for the spent sorbent and coal ash are 99+% and 75%, respectively. The same high collection efficiency is not required for the CBB dust collector; therefore, a less expensive collector utilizing 10" diameter tubes is selected. The collection efficiencies for the char, spent sorbent and coal ash are projected to be 80%, 99+%, and 75%, respectively.

5.1.5.2.2 Final Particulate Collection Device

5.1.5.2.2.1 General

The flue gas from the AFB boiler has to be cleaned of most of the particulates to meet the EPA emission limits. A bag house or an electrostatic precipitator (EP) is normally employed as the final collecting device for particulates. Because the flue gas is normally low in sulfur dioxide and moisture, an electrostatic precipitator is not an efficient collecting device at normal stack temperatures (i.e., 250°F - 400°F range) but is expected to work acceptably at temperatures greater than 650°F.

During some part load operation the stack temperature might reach 620°F. At that temperature, it is questionable whether a bag-house could tolerate 620°F for an extended period. Therefore, a high temperature Electrostatic Precipitator upstream of the economizer where the fuel gases are approximately 700°F is employed for final particulate control.

5.1.5.2.2.2 High Temperature Electrostatic Precipitator

The flue gas from the AFB boiler after passing through high efficiency multiclones goes through a high temperature electrostatic precipitator (EP).

The electrostatic precipitator is designed for a maximum temperature of 800°F. The EP has four electric fields in series. The total particulates emission is estimated to be less than 0.09 lb. per million Btu of heat input.

5.1.5.2.3 Hazards Associated With the AFBB Particulate Removal System

The only hazard to the general public due to malfunction of the electrostatic precipitator or upstream cyclones is high particulate emissions. The concern on particulate emission from fluid bed combustors has been discussed in Section 3.

5.1.6 Pressurized Fluid Bed Combined Cycle Solid Waste Handling System

5.1.6.1 PFB Combustor Spent Bed Material Let Down System

Two solids drains are provided on the PFB combustor. The upper drain is a standpipe arrangement at the side of the pressure vessel at the normal bed operating level. This drain is used for level control during normal operation of the combustor. The lower drain at the distributor plate is to provide for

low bed level control during start-up and as a means of lowering the bed level during the unit shutdown.

Since the spent material is withdrawn from the beds under pressure, a lock hopper system is provided for depressurization and dumping the solids to the solids cooler. The lock hopper system consists of two parallel lock hoppers per combustor. The lock hopper size is elected so that one hopper alone, operating on a batch basis, can provide the system level control, thus providing system redundancy to increase system reliability. During normal operation, however, the hoppers are operated sequentially to provide continuous level control. Figure 5-7 illustrates the lock hopper system.

A pair of knife-gate valves before and after each lock hopper provides the seal during pressurization and depressurization of the lock hoppers as well as providing on-off control of the flow of solid material to and from the lock hoppers. Each lock hopper is equipped with load cells and transmitters for monitoring solids flow rate. Pressure transmitters on the lock hoppers provide pressure indication and signal the pressure controllers that control the valves in the pressurizing lines. Equalizing lines with remote operated control valves connect the lock hopper to the pressurized fluidized beds (PFB) so that no differential pressure exists between the lock hopper and the PFB upon filling.

Depressurizing lines, with remote operated control valves, depressurize the lock hoppers by venting to the solids cooler before dumping.

The operating cycle for the lock hoppers consists of four steps:

- 1) Pressurizing - All valves are closed except the pressure control valves which allow the lock hopper to pressurize. When the lock hopper is pressurized, the control valve is closed and the equalizing line is opened.

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PFB-COMBUSTOR ASH LETDOWN SYSTEM

FIGURE: 5-7.

* 20" SCH. 80 C.S. PIPE, REFRACTORY LINED TO GIVE 6" FLOW ID.

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P&ID PFB ASH
LET DOWN SYSTEM

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- 2) Filling - All valves are closed except the knifegate valve between the PFB and one of its associated lock hoppers. Solid material free falls from the PFB to the active lock hopper. The weight transmitter indicates when the desired capacity is achieved. At this point, the knife-gate valves are manipulated so that the solids flow is diverted to the second lock hopper and shut-off to the first.
- 3) Depressurizing - All valves are closed except that in the depressurizing line to the solids cooler which is opened to reduce the tank pressure to atmospheric.
- 4) Dumping - The valves below the lock hopper are opened. Solid material free falls from the lock hopper into the solids cooler. After the lock hopper is emptied, the knife-gate valve closest to the lock hopper is closed and then the second knife-gate valve is closed. Depressurizing lines are closed.

5.1.6.2 PFB Cyclone Ash Handling System

The ash captured in the particulate removal system following the PFB combustor is removed from the system under pressure. Lock hoppers are required for depressurization so the solids may be dumped to the solids cooler. The systems arrangement is illustrated in Figure 5-8.

For the primary cyclone, holding tanks are provided for both the first stage and second stage cyclone drains. The drains from the holding tanks are arranged so they can deposit solids into either of the two full sized lock hoppers. The lock hopper sizing provides redundancy for improved reliability since one lock hopper can provide the ash let down function based on the maximum expected solids flow rate. Normal operation would be to use the two lock hoppers sequentially to provide more continuous flow of solids to the solids cooler.

PRIMARY CYCLONE

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* 20" SCH. 80 C.S. PIPE, REFRACTORY LINED TO GIVE 6" FLOW I.D.

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ASH LET DOWN SYSTEM

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Because of the pressure differential that exists between the first and second cyclone stages, the holding tanks must be sequentially emptied into the lock hoppers. Load cells and transmitters are provided on the holding tanks to provide indication for tank dumping.

The lock hoppers are equipped with load cells and transmitters for monitoring the operation sequence and for monitoring solids flow. Pressure transmitters on the lock hoppers give pressure indication to panel board instruments and provide signals to controllers that operate the valves in the pressurizing lines. Equalizing lines, with remote operated control valves, connect the lock hoppers to both the holding tanks, so that no differential pressure exists between the lock hopper and the holding tank upon filling. Depressurizing lines, with remote operated control valves, connect the lock hoppers to both the holding tanks, so that no differential pressure exists between the lock hopper and the holding tank upon filling. Depressurizing lines, with remote operated control valves, depressurize the lock hoppers by venting to the solids cooler before dumping.

The operating sequence of the lock hopper parallels that of the lock hopper for the PFB combustor solids letdown system. The lock hopper operating cycle time at the maximum expected solids loading also parallels that of the PFB combustor solids let-down system.

5.1.6.3 AFB Bed Material Let Down System

The bed material let down system for both the Main Fluid Bed and the Carbon Burn-up Bed is based on the use of one drain line per bed compartment. This results in 20 drains for the MFB and 6 for the CBB. Each of the drain lines includes a high temperature rotary feed for control of the solids flow rate so that the bed level may be maintained. This system is similar to the bed material cooler and collection system described for the AFBB in Section 4.1.3.

5.1.6.4 PFBCC Solid Waste Cooling and Disposal

The solid waste handling system encompasses three basic subsystems:

- 1) Cooling
- 2) Positive pressure pneumatic transport
- 3) Storage and shipping

The cooling subsystem is designed to cool the solid wastes from 1600°F to 200°F. The positive pressure pneumatic system is designed to transport the solids from the coolers to the storage silos. The storage system is designed to hold the collected solid wastes and to load them into railroad cars or trucks for shipment to a disposal area off-site.

5.1.6.4.1 Cooling System

The solid wastes flow from the PFB and AFB units to the coolers by gravity. The cooling system includes eight separate coolers with water cooled coils.

Waste material is introduced to the cooler through a feed inlet. Air from a rotary blower passes through an inlet manifold at the bottom of the cooler and is distributed by means of a grid plate. This air fluidizes the material to be cooled. The inherent agitation of the material in the fluidized state ensures excellent contact with the cooling surface and thus results in maximum heat transfer.

In order to recover some of the sensible heat from the waste material, condensate from the Main Condenser is passed through the cooling coils at 101°F and leaves at 190°F. The condensate from the cooling coils is then sent to the deaerator.

Each cooler has a separate air blower. Four spare blowers are provided. The heated fluidizing air leaves the coolers at 600°F. This air containing entrained solids is sent to the main electrostatic precipitator for dust removal, and then to the low-level economizer for further heat recovery.

The solids from the coolers are dropped into transfer hoppers and then pneumatically conveyed to the storage silos.

Each cooler system is equipped with a separate control system.

5.1.6.4.2 Pneumatic Transport System

The pneumatic transport system consists of eight independent conveying systems as follows:

- 1) Four 5" conveying pipe lines conveying 20,000 lb/h (each) from the PFB coolers to the storage silos.
- 2) One 6" pipe line conveying 60,000 lb/h from the CBB multi-cyclone cooler to the storage silos.
- 3) Two 6" pipe lines conveying 40,000 lb/h (each) from the AFB coolers to the silos.
- 4) One 5" pipe line conveying 20,000 lb/h from CBB and fly-ash coolers to the silos.

Each of the above systems is equipped with transfer hoppers, Single Stage Rotary Compressors, and a control panel. In addition, a separate system has been provided to collect the fly-ash from the electrostatic precipitator hoppers and transfer the material to the ash cooler unit near the CBB area. This system is equipped with two rotary single-stage compressors, and a separate control panel. It is designed to operate on a timed cycle basis.

5.1.6.4.3 Storage and Shipping

The solid wastes are collected and stored in four concrete silos (55' diameter, total height 90', total volume 137,000 cu. ft. each).

Each silo is equipped with a separate dust collection system, and with a dry unloading system for the purpose of transferring the solids from the silos into railroad cars and trucks for shipment to an off-site disposal area.

Each unloader has a rated capacity of 100 tons/h continuous flow, and can be remotely controlled from grade level.

5.1.6.5 Hazards Associated With The PFBCC Solid Waste Handling System

The hazards of the solid waste residues from fluidized bed combustors has been discussed in Section 3.4. Failure of any of the solid waste handling components for the PFBCC system would not create any additional hazard. The ultimate disposition of the solid waste will probably be in landfills. Section 4.1.7 discusses the environmental hazards associated with landfill disposal of fluid bed solid waste.

5.2 Pressurized Fluidized Bed Combined Cycle System Failures
and Associated Hazards

The hazards associated with coal fired fluidized bed combustion processes have been discussed in Section 3. Table 5-1 lists the systems failures for the PFBCC and the associated hazards. A hazards event tree is shown in Figures 5-9A and 5-9B.

TABLE 5-1

SYSTEM FAILURES FOR PFBCC AND ASSOCIATED HAZARD

<u>Systems Failure</u>	<u>Description of Failure</u>	<u>Hazard</u>
Coal/dolomite feed system	Lower Ca/S feed ratios than required	Higher SO ₂ concentration to be removed by AFBB leading to potentially higher SO ₂ emission at stack
Coal/limestone feed system	Lower Ca/S feed ratio than required	Higher SO ₂ emission
Pressurized fluid bed combustor	Loss of air flow through heat exchanger	Higher than normal combustion. Temperature potentially leading to higher SO ₂ concentrations to be removed by AFBB which could result in higher than normal SO ₂ emissions at stack
Pressurized fluid bed combustor	Internal Explosion leading to rupture of pressure vessel	SO ₂ and particulate released to environment; missile generation; overpressure
Turbine Generator	Loss of electric load without immediate corrective action	Turbine generator overspeed causing missile generation
Atmospheric fluid bed boiler (over pressurization)	Loss of turbine load without corrective action	High pressure in AFBB possibly causing rupture of walls and/or high fluidizing gas velocities causing high particulate and SO ₂ emissions for a short period ² of time.
Dolomite feed system	Limestone accidentally placed in dolomite feed.	Potential for higher SO ₂ emission from AFBB
Limestone feed system	Dolomite accidentally placed in limestone feed	Higher SO ₂ emission from AFBB

TABLE 5-1 (cont.)

<u>System Failure</u>	<u>Description of Failure</u>	<u>Hazard</u>
PFB cyclone particulate removal	Reduction in particulate removed efficiency with age/wear	Potential for turbine blade erosion leading to blade failure and missile generation; loss of power conversion; higher pressure and gas velocities in AFBB leading to higher SO ₂ and particulate emissions
Pressurized piping	Rupture of pressurized piping	Potential for high particulate and SO ₂ released to environment while PFB combustor depressurizes
AFBB cyclone particulate removed	Reduction in particulate removal efficiency with age/wear	Higher particulate loading to electrostatic precipitator leading to higher particulate emissions
Hot electrostatic precipitator	Loss of electric field voltage with no corrective action or EP will not work efficiently because of high gas resistivity	High particulate emissions
Solid Waste disposal systems (off site disposal)	Transportation spills	Potential contaminants of ground water with toxic elements
Solid waste landfill	Rupture of lining or no lining at all	Potential for ground water contaminants with toxic elements due to leachate percolation
Coal Feed Bunkers and hoppers	Coal fire	SO ₂ , NO _x , particulate releases
Coal Feed Bunkers and hoppers	Coal dust explosion	SO ₂ , NO _x , particulates releases; overpressure; missile generation

TABLE 5-1 (cont.)

<u>System Failure</u>	<u>Description of Failure</u>	<u>Hazard</u>
Pressurized fluid bed combustor	Mechanical failure due to excessive thermal and cyclic stresses or hot spots	SO ₂ and particulate released to environment; missile generation; overpressure
AFBB rupture of heat exchanger tubes within bed	Failure of steam tubes due to thermal stresses and erosion	Carbon monoxide and hydrogen generation, higher SO ₂ emissions, potential for structural damage of AFBB, and missile generation

FIGURE 5-9A

HAZARDS EVENT TREE FOR PRESSURIZED FLUIDIZED BED COMBINED CYCLE POWER PLANT

PRESSURIZED SECTION

FIGURE 5-9B

HAZARDS EVENT TREE FOR PRESSURIZED FLUIDIZED BED COMBINED CYCLE POWER PLANT

ATMOSPHERIC SECTION

6.0 HAZARD RANKING AND RISK ASSESSMENT FOR NON-NUCLEAR POWER PLANTS

6.1 Hazard Ranking

A hazard ranking methodology was used to rate the adverse health effects due to the hazards identified for each of the two types of fluidized bed boiler plants and the five other plants studied in the Phase 1 study. A questionnaire was prepared identifying ninety plant hazards to be evaluated in accordance to the criteria developed in Section 3.4 of the Phase 1 study. Potential plant hazards were initially divided into two major classifications, normal operations and abnormal occurrences. Each participant in the survey ranked the hazard on a 1 to 9 scale with respect to the evaluation criteria. The six factors in the evaluation criteria were the following:

1. area/population exposed (AP)
2. duration (DU)
3. mitigation (MI)
4. quantity to toxicity ratio (QT)
5. nature of health effect (HE)
6. public attitude (PA)

For each hazard, the results of the questionnaire were analyzed to obtain a single value for each of the six factors before applying the weighting factor. The highest possible weighted score is 9 with the lowest score being 1. Tables 6-1 through 6-7 give the results of the hazard ratings for each plant. Hazards with the highest ratings are the ones that were determined to have the most adverse potential effect on public health and safety.

Tables 6-2 and 6-3 are hazards rating for the two additional fluidized bed power plants.

TABLE 6-1

COAL-FIRED PLANT HAZARDS EVALUATION

<u>Normal Operations</u>	AP	DU	MI	QT	HE	PA	Weighted Rating
SO ₂ (Coal & Oil)	8	9	9	7	3.5	6	7.1
NO _x (Coal & Oil)	8	9	9	7	3.5	5.5	7.1
CO (Coal & Oil)	5	9	9	5	1.5	5	5.4
Hydrocarbons	6	9	9	5	2.5	5	5.9
Particulates	7	9	9	5	3	6.5	6.4
Noise	3	9	9	2.5	1	5	4.3
Fog, Plume Drift, Icing	3	5	8	3	2	4.5	4.1
Water Pollution (Blowdowns)	2.5	7	8.5	2	2	4.5	4.2
Water Pollution (Coal and Ash Runoff)	3	6.5	7.5	4	2	6	4.3
Ash & Sludge Disposal	4	7	7.5	4	2	6.5	4.7
Acid Rain	3	4	8	4	2	5.5	4.2
<u>Abnormal Occurrences</u>							
SO ₂ (Fire)	5	2	4	4	2.5	5	3.9
NO _x (Fire)	5	2	4	4	2.5	5	3.9
Hydrocarbons (Fire and Oil Releases)	5	2	4	3	2.5	5	3.8
Particulates (Fire)	4.5	2	4	3.5	2.5	6.5	3.8
Missiles	1	1	7.5	1	7	4.5	3.7
Fire (Offsite)	3	2	4	3.5	7	6	4.2
Oil, Ash, Coal Runoffs	3	2.5	4	3	2.5	6	3.3
Cooling Water Release	3	2	4	3	2	4	3.0
Chlorine Leakage	3	2	3	5	7	7	4.3
Chlorine Tank Rupture	4	2.5	2	7	7	7	4.7

TABLE 6-2
ATMOSPHERIC FLUIDIZED BED HAZARDS EVALUATION

<u>Normal Operations</u>	<u>AP</u>	<u>DU</u>	<u>MI</u>	<u>QT</u>	<u>HE</u>	<u>PA</u>	<u>Weighted Rating</u>
SO ₂ (coal)	8	9	9	7.5	3.5	6	7.2
NO _x (coal)	8	9	9	5	3.5	5.5	6.8
CO (coal)	5	9	9	6	1.5	5	5.6
Hydrocarbons	6	9	9	5.5	2.5	5	6.0
Particulates	7	9	9	6	3	6.5	6.6
Noise	3	9	9	2.5	1	5	4.3
Fog, Plume Drift	3	5	8	3	2	4.5	4.1
Water Pollution (blowdown)	2.5	7	8.5	2	2	4.5	4.0
Water Pollution	3	6.5	7.5	4	2	6	4.3
Solid Waste	4.5	7	7.5	5	2	6.5	5.0
Acid Rain	3	4	8	4	2	5.5	4.2
<u>Abnormal Occurrences</u>							
SO ₂ (fire)	5	2	4	4	2.5	5	3.9
NO _x (fire)	5	2	4	4	2.5	4.5	3.9
Hydrocarbons (fire)	5	2	4	3	2.5	5	3.8
Particulates (fire)	4.5	2	4	4	2.5	6.5	3.9
Missiles	1	1	7.5	1	7	4.5	3.7
Fire (offsite)	3	2	4	4	7	6	4.3
Oil, Ash, Coal Runoff	3	2.5	4	3	2.5	6	3.3
Cooling Water Release	3	2	4	3	2	4	3.0
Chlorine Leakage	3	2	3	5	7	7	4.3
Chlorine Tank Rupture	4	2.5	2	7	7	7	4.7
Explosions (overpressurization)	1	1	8	3	4	5	3.4

TABLE 6-3
PRESSURIZED FLUIDIZED BED COMBINED CYCLE
HAZARDS EVALUATION

<u>Normal Operations</u>	<u>AP</u>	<u>DU</u>	<u>MI</u>	<u>QT</u>	<u>HE</u>	<u>PA</u>	<u>Weighted Rating</u>
SO ₂ (coal)	8	9	9	7	3.5	6	7.1
NO _x (coal)	8	9	9	4.5	3.5	5.5	6.7
CO (coal)	5.5	9	9	6	1.5	5	5.7
Hydrocarbons	6	9	9	5.5	2.5	5	6.0
Particulates	7.5	9	9	5.5	3	6.5	6.6
Noise	3.5	9	9	3	1	5	4.6
Fog, Plume Drift	3	5	8	3	2	4.5	4.1
Water Pollution (blowdown)	2.5	7	8.5	2	2	4.5	4.0
Water Pollution (coal & ash runoff)	3	6.5	7.5	4.5	2	6	4.4
Solid Waste Disposal	4.5	7.5	7.5	4.5	2	6.5	5.0
Acid Rain	3	4	8	4	2	5.5	4.2
<u>Abnormal Occurrences</u>							
SO ₂ (fire)	5	2.5	4.5	4.5	2.5	5	4.1
NO _x (fire)	5	2.5	4.5	4	2.5	4.5	4.0
Hydrocarbons (fire and oil release)	5	2.5	4.5	3	2.5	5	3.9
Particulates (fire)	4.5	2.5	4.5	3.5	2.5	6.5	3.9
Missiles	1	1	7.5	1.5	7	4.5	3.8
Fire (offsite)	3	2	4	3.5	7	6	4.2
Oil, Ash, Coal Runoff	3	2.5	4	3	2.5	6	3.3
Cooling Water Release	2.5	2	4	3	2	4	2.8
Chlorine Leakage	2.5	2	3	5	7	7	4.1
Chlorine Tank Rupture	3.5	2.5	2	7	7	7	4.6
Explosions (overpressure)	2	1	8	3	3	5	3.7

TABLE 6-4

OIL-FIRED PLANT HAZARDS EVALUATION

<u>Normal Operations</u>	AP	DU	MI	OT	HE	PA	Weighted Rating
SO ₂	7	9	9	7	3.5	5.5	6.8
NO _x	7	9	9	7	3.5	5	6.7
CO	5	9	9	5	1.5	4	5.3
Hydrocarbons	5.5	9	9	5	2	4	5.6
Particulates	5.5	9	9	6	2	5.5	5.9
Noise	2.5	9	9	2	1	4	4.0
Ground Fog	1	1	8	1.5	1.5	3.5	2.7
Water Pollution (Once through Cooling)	1.5	9	9	3	1	5	4.0
<u>Abnormal Occurrences</u>							
SO ₂ (Fire)	5	1.5	5	5	2.5	5	4.2
NO _x (Fire)	5	1.5	5	5	2.5	5	4.2
Hydrocarbons (Fire and Oil Releases)	5	1.5	5	4	2.5	5	4.1
Particulates (Fire)	5	1.5	5	4	2.5	5.5	4.1
Water Pollution (Oil)	3	1.5	5	2.5	4	6.5	3.6
Missiles	1	1	7	1	8	4.5	3.8
Fire (Offsite)	3	2	6	4.5	8	5	4.9
Explosion (Overpressurization)	2	2	7	5	7	5.5	4.7
Chlorine Leakage	2.5	2	3	3.5	7	7	3.9
Chlorine Tank Rupture	4	2.5	2	5	7	7	4.4

TABLE 6-5
COMBINED-CYCLE PLANT HAZARDS EVALUATION

<u>Normal Operations</u>	AP	DU	MI	QT	HE	PA	Weighted Rating
SO ₂	7	9	9	7	3.5	5.5	6.8
NO _x	7	9	9	7	3.5	5	6.7
CO	4.5	9	9	5	1.5	5	5.2
Hydrocarbons	4.5	9	9	5	2	5	5.3
Particulates	5	9	9	5	2	6	5.5
Noise	3	9	9	3	1	6	4.5
Water Pollution (Blowdowns)	2.5	6	8	3	2	4.5	4.0
Fog, Plume Drift, Icing	2	6	8	3	2	4.5	3.8
Acid Rain	3	4	8	3	1.5	5	3.9
<u>Abnormal Occurrences</u>							
SO ₂ (Fire)	5	1.5	5	5	2.5	5	4.2
NO _x (Fire)	5	1.5	5	5	2.5	5	4.2
Hydrocarbons (Fire and Oil Releases)	5	1.5	5	4	2.5	4.5	4.0
Particulates (Fire)	5	1.5	5	4	2.5	5.5	4.1
Water Pollution (Oil Release)	4	2	5	3	3	4.5	3.7
Missiles	1	1	6.5	1.5	8	5	3.9
Fire (Offsite)	3	2	4.5	3	7.5	5.5	4.3
Explosions (Overpressurization)	2	1.5	6.5	4	7	5	4.4
Cooling Water Release	2	1	4	2.5	2	4	2.5
Chlorine Leakage	2.5	2	3	4	7	7	4.0
Chlorine Tank Rupture	4	2.5	2	5	7	7	4.4

TABLE 6-6

COMBUSTION TURBINE HAZARDS EVALUATION

<u>Normal Operations</u>	AP	DU	MI	QT	HE	PA	Weighted Rating
SO ₂	6	9	9	6	3.5	5.5	6.5
NO _x	6	9	9	6	3.5	5	6.4
CO	5	9	9	5.5	1.5	5	5.3
Hydrocarbons	4.5	9	9	5	2	5	5.3
Particulates	4.5	9	9	5.5	2	5.5	5.4
Noise	3	9	9	2.5	1	6	4.4
<u>Abnormal Occurrences</u>							
SO ₂ (Fire)	5	1.5	5	4	2.5	5	4.1
NO _x (Fire)	5	1.5	5	4	2.5	5	4.1
Hydrocarbons (Fire and Oil Releases)	5	1.5	5	3.5	2.5	4	3.9
Particulates (Fire)	4.5	1.5	5	3	2.5	5.5	3.8
Fire (Offsite)	3	1.5	4	4.5	7	5	4.2
Water Pollution (Oil Release)	3	2	5	2	3	6	3.4
Missiles	1	1	6.5	1.5	8	4.5	3.8
Explosions (Overpressurization)	2	1.5	6	5	7	5	3.2
Cooling Water Release	1	1.5	4	2	2	4	2.2

TABLE 6-7

GEOTHERMAL PLANT HAZARDS EVALUATION

<u>Normal Operations</u>	AP	DU	MI	OT	HE	PA	Weighted Rating
Hydrogen Sulfide	6	9	9	7.5	5	6	6.9
Other Air Pollutants	5	9	9	6.5	4	5	6.1
Fog, Plume Drift, Icing	3	8	6	2	2	4	3.7
Acid Rain	3	5	8	3	2	5	4.1
Subsidence	2	2	6	4	4	6.5	3.2
Noise	2	9	9	2	1	6	4.0

Abnormal Occurrences

Inducing Earthquakes	5	1.5	6	7	8	6.5	5.9
Air Pollutants (Fire)	3	2	3	3	4	5	3.3
Steam Ruptures (H ₂ S)	5	2	7	4.5	3	5	4.7
Cooling Water Release	3	2	4	4	2	4	3.1
Missiles	1	1	6.5	1	8	4.5	3.7
Burns	1	1.5	5	2.5	5	5	3.1
Well Blowout (H ₂ S)	5	2	4.5	5	4	5.5	4.5
Noise (Well Blowout)	3	2	5	3	1	7	3.2

Results of the analyses showed that air pollutants generally received the highest weighted rating for each plant type. Aside from the obvious importance of these types of hazards, an examination of the results in the tables showed that air pollutants consistently received high ratings in three categories: area/population exposed, duration and mitigation. These high ratings were justified since air pollutants are continuous during plant operations, are transported large distances in the atmosphere and evacuation of nearby population is an impractical method for mitigating the health hazard. The weightings used for three categories comprised 58% of the overall hazard rating. Combining the high scores in these categories with their high weightings resulted in overall high ratings for the air pollutants. The ratings from the individual plants are combined into an overall risk assessment described in the next section.

6.2 Risk Assessment

Each of the plant hazards were placed in one of three categories: frequent, infrequent, and hypothetical. Frequent events are those that occur or are expected to occur between once a year and once every twenty years, while hypothetical events are those whose probability of occurrence is less than once every twenty years. Tables 6-8 through 6-10 rank the hazards numerically in these three categories.

One interesting result was that the highest rated hazards were those that occurred frequently which are the plant air pollutants. Except for geothermally induced earthquakes, all of the infrequent and hypothetical accidents had an overall rating of less than 5 while sulfur dioxide and nitrogen oxide emissions ranged between 6 and 7. This is due in part to

TABLE 6-8

RATING OF FREQUENTLY OCCURRING HAZARDS

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
SO ₂ Emission	Atmospheric Fluidized Bed Boiler	7.2
	Pressurized Fluidized Bed Combined Cycle	7.1
	Conventional Coal with FGD	7.1
	Oil	6.8
	Combined Cycle	6.8
	Combustion Turbine	6.5
NO _x Emission	Coal	7.1
	AFBB	6.8
	Oil	6.7
	Combined Cycle	6.7
	PFBCC	6.7
	Combustion Turbine	6.4
Particulate	PFBCC	6.6
	AFBB	6.6
	Coal with EP & FGD	6.4
	Oil	5.9
	Combined Cycle	5.5
	Combustion Turbine	5.4
Other Air Pollutants (H ₂ S)	Geothermal	6.9
Hydrocarbon Emission	AFBB	6.0
	PFBCC	6.0

TABLE 6-8 (cont.)

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
CO Emission	Coal (conventional)	5.9
	Combined Cycle	5.3
	Combustion Turbine	5.3
	PFBB	5.7
	AFBB	5.6
	Conventional Coal	5.4
	Oil	5.3
	Combustion Turbine	5.3
	Combined Cycle	5.2
Ash and Sludge and Solid Waste Disposal	AFBB	5.0
	PFBB	5.0
	Conventional Coal	4.7
Noise	PFBCC	4.6
	Combined Cycle	4.5
	Combustion Turbine	4.4
	AFBB	4.3
	Coal (conventional)	4.3
	Oil	4.0
	Geothermal	4.0
	Geothermal (steam venting)	3.8
Water Pollution (coal, ash/solid waste/ sludge runoff)	PFBCC	4.4
	AFBB	4.3
	Coal/Conventional	4.3

TABLE 6-8 (cont.)

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
Water Pollution (steam generator blow down)	Coal/Conventional	4.2
	AFBB	4.0
	PFBB	4.0
	Combined Cycle	4.0
	Oil	4.0
Acid Rain	PFBCC	4.2
	AFBB	4.2
	Coal (conventional)	4.2
	Geothermal	4.1
	Combined Cycle	3.9
Fog, Plume Drift, Icing	AFBB	4.1
	Coal (conventional)	4.1
	PFBCC	4.1
	Combined Cycle	3.8
	Geothermal	3.7
	Oil	2.7

TABLE 6-9

RATING OF INFREQUENTLY OCCURRING HAZARDS

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
Induced Earthquakes	Geothermal	5.9
H ₂ S (steam line rupture)	Geothermal	4.7
H ₂ S (well blow out)	Geothermal	4.5
Chlorine Leakage	Coal (conventional)	4.3
	AFBB	4.3
	PFBCC	
	Combined Cycle	4.0
	Oil	3.9
SO ₂ (fire)	Oil	4.2
	Combined Cycle	4.2
	PFBCC	4.1
	Combustion Turbine	4.1
	Coal (conventional)	3.9
	AFBB	3.9
NO _x (fire)	Oil	4.2
	Combined Cycle	4.2
	Combustion Turbine	4.1
	PFBCC	4.0
	Coal (conventional)	3.9
	AFBB	3.9

TABLE 6-9 (cont.)

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
Particulates (fire)	Oil	4.1
	Combined Cycle	4.1
	PFBCC	3.9
	AFBB	3.9
	Combustion Turbine	3.8
	Coal (conventional)	3.8
Hydrocarbon (fire and oil releases)	Oil	4.1
	Combined Cycle	4.0
	Combustion Turbine	3.9
	PFBCC	3.9
	Coal (conventional)	3.8
	AFBB	3.8
Subsidence	Geothermal	3.8
Water Pollution (oil release)	Combined Cycle	3.7
	Oil	3.6
	Combustion Turbine	3.4
Leachate of Toxic Elements to Subsurface Ground Water	PFBCC	3.3
	AFBB	3.3
	Coal (conventional)	3.3
Noise (geothermal well blow out)	Geothermal	3.2
Burns (steamline)	Geothermal	3.1

TABLE 6-10

RATING OF HYPOTHETICALLY OCCURRING HAZARDS

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
Fire (offsite)	Oil	4.3
	Combined Cycle	4.3
	Combustion Turbine	4.2
	AFBB	4.3
	Coal (conventional)	4.2
	PFBCC	4.2
Explosion	Oil	4.7
	Combined Cycle	4.4
	PFBCC	3.9
	AFBB	3.9
	Combustion Turbine	3.2
Chlorine Tank Rupture	Coal	4.7
	AFBB	4.7
	PFBCC	4.6
	Combined Cycle	4.4
	Oil	4.4
Missiles	Combined Cycle	3.9
	Oil	3.9
	PFBCC	3.8
	Combustion Turbine	3.8
	Coal (conventional)	3.7
	AFBB	3.7
	Geothermal	3.7

an implied frequency in the evaluation criteria. Duration and mitigation categories have implicit in their definitions that a continuously occurring event will receive a higher rating than an event that occurs rarely. Due to this implied frequency effect in certain factors of the evaluation criteria, it would be necessary to reevaluate a hazard if its frequency of occurrence changed.

It is important to point out that the ratings for the hazards should not be used in an absolute sense. For example, SO_2 emissions in oil plants should not be considered a greater hazard than NO_x emissions because SO_2 had a 6.8 rating versus 6.7 for NO_x . Similarly, SO_2 emissions in coal plants should also not be considered a greater hazard than SO_2 emissions in other plants that have lower ratings. No attempt has been made to determine how large a difference in ratings between two hazards would be considered significant.

Even though ninety hazards were identified for the seven plants analyzed, the large majority of hazards were similar for each plant. Water pollution, cooling tower effects, and noise received relatively low ratings. The list of hazards generated by abnormal occurrences either inside the plant or due to external forces, such as earthquakes, is short because most of the hazards in the plant do not affect the general public. Even those abnormal plant occurrences that can affect the public received relatively low scores in the overall risk assessment. The highest rated of this infrequent or hypothetical event were the hazards associated with potential fires, explosions and chlorine releases at the plant. Hazards associated with major cooling water releases, water pollution and missiles received the lowest ratings.

Due to the importance of the air pollutants, an additional analysis was performed to compare the relative amounts of pollutants emitted from each reference plant. The results of this analysis are given in the next section.

An additional assessment of air and solid waste pollutant hazards was made by comparing the emission rates for the seven types of plants considered in the project. In order to make a comparison of these types of various plants and operating conditions, a normalized plant size of 1000 MWe was chosen which had an annual operating capacity of 75%. The results of this analysis is shown in Table 6-11. For the geothermal plants, it was assumed that the hydrogen sulfide (H_2S) emissions were converted to sulfur dioxide (SO_2).

SO_2 and particulate emissions from the coal plant are relatively low due to the fact that scrubbers and precipitators were used on the plant. Nitrogen oxide (NO_x) emissions from the combustion turbine are higher than the combined cycle due to the differences in the NO_x abatement techniques used on the gas turbines.

The results of this analysis show that emission levels for various plant types for most cases have the same order of magnitude but are greatly dependent on the type of abatement systems that are employed in the plant.

TABLE 6-11
ANNUAL PLANT POLLUTANT EMISSIONS (TONS)
1000 MWe Plant

	<u>Coal</u> ⁽¹⁾	<u>AFBB</u> ⁽²⁾	<u>PFBCC</u> ⁽²⁾	<u>Oil</u>	<u>Combined Cycle</u>	<u>Combustion Turbine</u>	<u>Geothermal</u>
Sulfur Dioxide	15,998	23,400	20,472	17,800	13,400	25,600	5,580
Nitrogen Oxide	22,800	19,218	16,812	23,500	8,260	16,800	--
Hydrocarbon	391	See Carbon Monoxide	See Carbon Monoxide	65.7	4,270	8,760	1,210 ⁽³⁾
Particulate	905 ⁽⁴⁾	3,200/ 960 ⁽⁵⁾	2,802/ 840 ⁽⁵⁾	1,750	820	1,460	--
Carbon Monoxide	1,250	3,412 ⁽⁶⁾	2,985 ⁽⁶⁾	9	2,790	45,300	--
Ash/Sludge/ Solid Waste	9.4 x 10 ⁵⁽⁷⁾	1.4 x 10 ⁶	9.5 x 10 ⁵				

-
- (1) Coal feed is same for coal/AFBB/PFBCC plants (3% sulfur, 8.5% ash).
- (2) Heat rate for coal and AFBB plants is 9750 Btu/kWh; heat rate for PFBCC plant is 8530 Btu/kWh.
- (3) Methane gas.
- (4) Electrostatic precipitator with 99.5% removal efficiency.
- (5) Based on particulate emissions meeting present/proposed EPA limits of .1/.03 lb. per million Btu. Requires particulate removal efficiencies of approximately 99.7+/99.9+% respectively.
- (6) Carbon monoxide and hydrocarbons together.
- (7) Assumes the ash/sludge from conventional coal plants contains 50% by weight water.

7.0 HAZARDS SENSITIVITY ANALYSIS

7.1 Background and General Methodology

A sensitivity analysis is presented on the hazards for all non-nuclear plant types considered in the Phase I and Phase II study as they relate to population density, changes in plant operating conditions, and technological changes. The effects of location and environmental conditions (temperature) are also discussed. The procedure developed is to adjust the hazards results from the Phase I study to reflect the effects of these variables as briefly described below:

The hazards results of the Phase I study were based on the hazards ranking formula:

$$OR_{ik} = \sum_{j=1}^n C_j H_{kij} = \begin{bmatrix} C_1 & \dots & C_n \end{bmatrix} \begin{bmatrix} H_{kil} \\ \vdots \\ H_{kin} \end{bmatrix}$$

where OR_{ik} is the overall plant hazard ranking for plant type i on hazard type k.

The hazard vector H_{kij} is the hazard level for hazard type k, due to plant type i relative to criteria j.

The vector $\overline{C}_j = C_1 \dots C_n$ is the original weighting factor vector that specified the relative importance of a hazard H_{kij} as it relates to predetermined hazard criteria. The hazard criteria established in the Phase I study considered six characteristics: Area/Population, Quantity to Toxicity, Health effects, Ability to mitigate hazard effects, Duration, and Public attitude. The Phase I study judged that the weighting factor vector, $\overline{C}_j$, determined for the Phase I analyses, be held constant for the entire analysis.

The sensitivity analysis procedure developed is to modify the present hazards vector H_{ijk} by using a modifier vector, M_m , producing a new modified hazards vector:

$$H_{kijm} = \begin{bmatrix} H_{kij} \\ \vdots \\ H_{kin} \end{bmatrix} \begin{bmatrix} M_m & \dots & M_n \end{bmatrix} = \begin{bmatrix} H_{kijm} & \dots & H_{kijn} \\ \vdots & \ddots & \vdots \\ H_{kinm} & \dots & H_{kinn} \end{bmatrix}$$

The modified hazard vector H_{kijm} is the hazard level for hazard type k, due to plant type i, relative to criteria j, modified by sensitivity m.

7.2 Population Density Modifier Vector

The above relationship is used to determine the modified hazard vector for the sensitivity analysis for population density. Population density affects only three of the six criteria, Population/Area, Mitigation, and Public Attitude. The modified hazard vectors developed for each criteria are presented in Table 7-1. Population density was divided into high, medium, and low categories which correspond closely to the classifications of urban, semi-urban and rural. Urban is defined as greater than 2500 people per square mile; rural is defined as less than or equal to 25 people per square mile; and semi-urban is in between these two values, at about 1200 people per square mile.

The values of the modifier vector for the Population/Area criteria correspond directly with population density since the number of the population exposed is directly related to the degree of hazard. The ratio of the population exposed per unit area could easily vary over a spectrum of 1.0 to 0.01. This spectrum is used for the extreme values of the modifier.

The values of the modifier vectors for the Mitigation criteria are developed in a different manner due to its definition. This caused the use of dual values for the modifier vector. When Mitigation is classified as not possible, then population density has no effect and the values of the modification

TABLE 7-1

SENSITIVITY TABLE FOR HAZARDS CRITERIA
EFFECTED BY CHANGES IN POPULATION DENSITY

Criteria (people/sq.mi)	Population Density		
	High 2500	Medium 1200	Low 25
Area/Population (AP)	1.0	0.5	0.01
Quantity Toxicity (QT)	1.0	1.0	1.0
Mitigation* (MI)	1.0	0.8	0.6
Duration (DU)	1.0	1.0	1.0
Health Effects (HE)	1.0	1.0	1.0
Public Attitude (PA)	1.0	0.7	1.0

* If an original hazard ranking for mitigation is 9 (no mitigation possible), then the adjustment factors for high/medium/low population densities are all 1.0.

vector are all unity. However, when Mitigation is classified as possible the values of the modification vector decrease with reduction in population density. The rationale for this approach being, the smaller number of people to be displaced would make evacuation easier.

The values of the modifier vector for Public Attitude are developed using the rationale that the more people affected, the better chance of a hostile attitude developing which is shown in its respective values for the high and medium category. However, because low population density areas are associated with pristine areas, hazards from a power plant will most probably be viewed with greater hostility and the value of its modifier vector is adjusted accordingly.

7.3 Operational Changes

The hazards ranking for a given plant may be influenced by how the plant is operated. For example, a 500 MWe base load conventional coal fired plant will emit more SO_2 over a year's time than if the same plant were operated in a load following mode; thus, because of the greater SO_2 emitted, the same plant is more hazardous operating in the base load mode than in the load following mode.

The procedure that is followed to ascertain the hazards sensitivity relative to plant operating modes is as follows:

- Four modes of plant operation are considered: base load, load follow, load peaking, and 70% derated base load.
- These above modes of plant operation affect hazards that are directly proportional to energy released (such as SO_2 emissions) and hazards that are influenced by operating

time (such as SO_2 released and missile generation). The hazards criteria influenced by energy released and time of operation are "Quantity Toxicity" (QT) and "Duration." The other criteria (such as area/population, mitigation, public attitude, and health effects) are not affected.

- A sensitivity matrix as shown in Table 7-2 is used to adjust the original values for QT and Duration identified and ranked in the Phase I study. All plants considered in the Phase I study (except for the gas turbine peaking unit) are treated as "base load" plants. Therefore, there is no change from the original hazards ranking for the base load operating mode.

If the power plant is operated in the "load following" mode, it will operate 100% of its scheduled time (same as base load), but the output power will vary between 0 to 100% of the base load output power. Consequently, during high load seasons (summer and winter) the output power will approach the base load level. During these seasons, the hazardous conditions will approach those for the base load plant. On the other hand, during low load seasons (spring and fall) the output power generated will be lower than the base load plant and accordingly there will be a relative reduction in hazardous conditions from the base load operation. It is conservatively assumed that over a year's cycle the load following plant will deliver approximately 70% of the base load energy.

For this mode of operation the reduction in hazards is not considered entirely proportional to the reduction in energy

TABLE 7-2
SENSITIVITY TABLE FOR HAZARDS CRITERIA
AFFECTED BY ENERGY GENERATED AND OPERATING TIME

<u>Criteria</u>	<u>Base Load</u> ⁽¹⁾	<u>Load Follow</u> ⁽¹⁾	<u>Peaking Operation</u> ^(1,2)	<u>70% Base Load (Derated)</u> ⁽¹⁾
Area/Population	1	1	1	1
Quantity Toxicity	1	0.8	0.2	0.7
Mitigation	1	1	1	1
Duration	1	0.8	0.2	0.7
Health Effects *	1	1	1	1
Public Attitude	1	1	1	1

(1) Hazards influenced by quantity of energy generated are SO₂, NO_x, waste disposal, blowdown, particulate emissions, fog generation, and H₂S emissions.

(2) In addition to reducing the hazards identified in (1), peaking operation also reduces the hazards sensitive to operating time such as noise.

NOTE: Some hazards are not influenced at all by energy generated and operating time. These hazards are coal pile fires, and oil storage fires.

* This criterion pertains to the nature of the health effect, see Section 3.4 of Phase I report.

generated. Because of the near base load conditions during high load seasons, the hazards effects are similar to the base load mode of operation during summer and winter. Accordingly, it is considered that for a one year cycle the overall reduction in hazards effects for a load following plant is 80% of the base load hazards ranking.

If the power plant is operated as a "peaking unit," then the total energy delivered in one year will be approximately 20% of the base load condition, and the time of operation may be only 20% of the base load operating time. Thus, the QT and Duration criteria ranking for the hazards sensitive to energy generated are reduced to 20% of the base load values. In addition, because a peaking plant runs only a fraction of a year, the hazards sensitive only to operating time will have their QT and Duration ranking reduced to 20% of the base load values.

The fourth operating mode is a base load plant derated and running at a lower output power level. It is assumed that the base loaded plant will be reduced to 70% of its original design output. For this condition, both the output power and total yearly energy are reduced to 70% of the base load conditions. Consequently, the associated energy related hazards are reduced to 70% of the base load values.

7.4 Sensitivity Analysis Results

Tables 7-3 through 7-9 show how the hazards rating change with changes in population density and mode of plant operations. In general for population density, all hazards for all plants decreased as the population density decreased. Changes in plant operational modes, in general, resulted in a hazards rating (starting from the highest to lowest rating) in the following order: Base Load, Load Follow, 70% Base Load Derate, and Peaking Operation.

As an example of the development of these ratings, the SO₂ hazard ranking for the coal fired plant in the low population zone is

$$\begin{aligned} &0.30 \times 8 \times 0.01 + 0.08 \times 9 \times 1.0 + 0.20 \times 9 \times 1.0 \\ &+ 0.15 \times 7 \times 1.0 + 0.20 \times 3.5 \times 1.0 + 0.07 \times 6 \times 1.0 \\ &= 4.7 \end{aligned}$$

The first number in each term is the weighting factor from Table 3-1 of the Phase I report. The second number is the original hazard ranking for each criteria (from Table 6-1 for this example) and the third number is the sensitivity factor (from Table 7-1 for this example).

TABLE 7-3
SENSITIVITY ANALYSIS FOR
COAL-FIRED PLANT HAZARDS EVALUATION

		Population Density		Mode of Plant Operation		
Normal Operation	Base ⁽¹⁾	Medium	Low	Load Follow	Peaking Operation	70% Base Load (Derated)
SO ₂ (coal & oil)	7.1	5.8	4.7	6.7	5.7	6.6
NO ₂ (coal & oil)	7.1	5.7	4.7	6.7	5.6	6.5
CO ^x (coal & oil)	5.4	4.6	3.9	5.1	4.2	5.0
Hydrocarbon	5.9	4.9	4.1	5.6	4.7	5.5
Particulates	6.4	5.2	4.3	6.1	5.2	6.0
Noise	4.3	3.8	3.4	4.1	3.5	4.0
Fog, Plume Drift, Icing	4.1	3.2	2.5	3.9	3.4	3.8
Water Pollution (blowdowns)	4.2	3.2	2.6	3.8	3.3	3.8
Water Pollution (coal and ash runoff)	4.3	3.5	2.8	4.1	3.4	4.0
Ash & Sludge Disposal	4.7	3.7	2.9	4.5	3.8	4.4
Acid Rain	4.2	3.3	2.7	4.0	3.5	3.9
<u>Abnormal Occurrences</u>						
SO ₂ (fire)	3.9	2.9	2.1	3.9	3.9	3.9
NO ₂ (fire)	3.9	2.9	2.1	3.9	3.9	3.9
Hydrocarbons (fire and oil releases)	3.8	2.7	2.0	3.8	3.8	3.8
Particulates (fire)	3.8	2.8	2.1	3.8	3.8	3.8
Missiles	3.7	3.2	2.8	3.7	3.7	3.7
Fire (offsite)	4.2	3.5	3.0	4.2	4.2	4.2
Oil, Ash, Coal Runoffs	3.3	2.5	2.1	3.3	3.3	3.3
Cooling Water Release	3.0	2.3	1.8	3.0	3.0	3.0
Chlorine Leakage	4.3	3.6	3.2	4.3	4.3	4.3
Chlorine Tank Rupture	4.7	3.9	3.4	4.7	4.7	4.7

(1) Base Case: A base loaded plant in a high population density zone.

TABLE 7-4
SENSITIVITY ANALYSIS FOR
ATMOSPHERIC FLUIDIZED BED

		Population Density		Mode of Plant Operation			
		Base ⁽¹⁾	Medium	Low	Load Follow	Peaking Operation	70% Base Load (Derated)
<u>Normal Operation</u>							
SO ₂ (coal & oil)	7.2	5.8	4.8	6.8	5.7	6.6	
NO ₂ (coal & oil)	6.8	5.4	3.4	6.5	5.6	6.3	
CO _x (coal & oil)	5.6	5.7	4.1	5.2	4.3	5.1	
Hydrocarbons	6.0	5.0	4.2	5.7	4.8	5.5	
Particulates	6.6	5.4	4.5	6.2	5.3	6.1	
Noise	4.3	3.8	3.4	4.1	3.5	4.0	
Fog, Plume Drift, Icing	4.1	3.4	2.5	3.9	3.4	3.8	
Water Pollution (blowdowns)	4.0	3.2	2.6	3.8	3.3	3.8	
Water Pollution (coal, sludge, & ash runoff)	4.3	3.5	2.8	4.1	3.4	4.0	
Ash & Sludge & Solid Waste Disposal	5.0	3.9	3.1	4.7	4.0	4.6	
Acid Rain	4.2	3.5	2.7	4.0	3.5	3.9	
<u>Abnormal Occurrences</u>							
SO ₂ (fire)	3.9	2.9	2.1	3.9	3.9	3.9	
NO ₂ (fire)	3.9	2.9	2.1	3.9	3.9	3.9	
Hydrocarbons (fire and oil releases)	3.8	2.7	2.0	3.8	3.8	3.8	
Particulates (fire)	3.9	2.9	2.2	3.9	3.9	3.9	
Missiles	3.7	3.2	2.8	3.7	3.7	3.7	
Fire (offsite)	4.3	3.5	3.1	4.3	4.3	4.3	
Oil, Ash, Coal Runoffs	3.3	2.5	2.1	3.3	3.3	3.3	
Cooling Water Release	3.0	2.3	1.8	3.0	3.0	3.0	
Chlorine Leakage	4.3	3.6	3.2	4.3	4.3	4.3	
Chlorine Tank Rupture	4.7	3.9	3.4	4.7	4.7	4.7	
Explosions	3.9	3.5	2.9	3.9	3.9	3.9	

(1) Base Case: A base loaded plant in a high population density zone.

TABLE 7-5
SENSITIVITY ANALYSIS FOR
PRESSURIZED FLUIDIZED BED COMBINED CYCLE

		Population Density		Mode of Plant Operation		
		Medium	Low	Load Follow	Peaking Operations	70% Base Load (Derated)
<u>Normal Operations</u>	⁽¹⁾ Base					
SO ₂ (coal & oil)	7.1	5.8	4.7	6.7	5.7	6.6
NO ₂ (coal & oil)	6.7	5.4	4.3	6.4	5.6	6.3
CO ^x (coal & oil)	5.7	4.8	4.1	5.4	4.4	5.2
Hydrocarbons	6.0	5.0	4.2	5.7	4.8	5.5
Particulates	6.6	5.4	4.4	6.3	5.4	6.2
Noise	4.6	3.9	3.5	4.3	3.6	4.2
Fog, Plume Drift, Icing	4.1	3.2	2.5	3.9	3.4	3.8
Water Pollution (blowdowns)	4.0	3.2	2.6	3.8	3.3	3.8
Water Pollution (coal, sludge, & ash runoff)	4.4	3.5	2.9	4.2	3.5	4.1
Ash, Sludge & Solid Waste Disposal	5.0	3.9	3.0	4.7	4.0	4.6
Acid Rain	4.2	3.3	2.7	4.0	3.5	3.9
<u>Abnormal Occurrences</u>						
SO ₂ (fire)	4.1	2.8	2.3	4.1	4.1	4.1
NO ₂ (fire)	4.0	2.7	2.2	4.0	4.0	4.0
Hydrocarbons (fire & oil releases)	3.9	2.6	2.1	3.9	3.9	3.9
Particulates (fire)	3.9	2.9	2.2	3.9	3.9	3.9
Missiles	3.8	3.3	2.9	3.8	3.8	3.8
Fire (offsite)	4.2	3.5	3.0	4.2	4.2	4.2
Oil, Ash, Coal Runoffs	3.3	2.5	2.1	3.3	3.3	3.3
Cooling Water Release	2.8	2.2	1.8	2.8	2.8	2.8
Chlorine Leakage	4.1	3.5	3.2	4.1	4.1	4.1
Chlorine Tank Rupture	4.6	3.8	3.4	4.6	4.6	4.6
Explosions	3.9	4.5	2.9	3.9	3.9	3.9

(1) Base Case: A base loaded plant in a high population density zone.

TABLE 7-6
SENSITIVITY ANALYSIS FOR
OIL-FIRED PLANT HAZARDS EVALUATION

<u>Normal Operations</u>	<u>Base</u> ⁽¹⁾	<u>Population Density</u>		<u>Mode of Plant Operation</u>		
		<u>Medium</u>	<u>Low</u>	<u>Load Follow</u>	<u>Peaking Operation</u>	<u>70% Base Load (Derated)</u>
SO ₂	6.8	5.6	4.7	6.4	5.3	6.2
NO ₂	6.7	5.6	4.6	6.4	5.3	6.2
CO ^x	5.3	4.5	3.9	5.1	4.2	4.9
Hydrocarbons	5.6	4.7	4.0	5.3	4.4	5.2
Particulates	5.9	4.9	4.2	5.5	4.6	5.4
Noise	4.0	4.0	3.3	3.8	3.2	3.7
Ground Fog	2.7	2.2	1.8	2.7	2.5	2.7
Water Pollution (once through cooling)	4.0	3.6	3.5	3.7	3.0	3.6
<u>Abnormal Occurrences</u>						
SO ₂ (fire)	4.2	3.2	2.3	4.2	4.2	4.2
NO ₂ (fire)	4.2	3.2	2.3	4.2	4.2	4.2
Hydrocarbons (fire and oil releases)	4.1	3.0	2.2	4.1	4.1	4.1
Particulates (fire)	4.1	3.0	2.2	4.1	4.1	4.1
Water Pollution (oil)	3.6	2.9	2.7	3.6	3.6	3.6
Missiles	3.8	3.3	3.0	3.8	3.8	3.8
Fire (offsite)	4.9	4.1	3.5	4.9	4.9	4.9
Explosion (over-pressurization)	4.7	4.0	3.5	4.7	4.7	4.7
Chlorine Leakage	3.9	3.3	2.9	3.9	3.9	3.9
Chlorine Tank Rupture	4.4	3.6	3.1	4.4	4.4	4.4

(1) Base Case: A base loaded plant in a high population density zone.

TABLE 7-7
SENSITIVITY ANALYSIS FOR
COMBINED-CYCLE PLANT HAZARDS EVALUATION

		Population Density		Mode of Plant Operation		
<u>Normal Operations</u>	Base ⁽¹⁾	<u>Medium</u>	<u>Low</u>	<u>Load Follow</u>	<u>Peaking Operation</u>	70% <u>Base Load (Derated)</u>
SO ₂	6.8	5.6	4.7	6.4	5.3	6.2
NO ₂	6.7	5.6	4.6	6.4	5.3	6.2
CO ^x	5.2	4.5	3.9	5.0	4.1	4.8
Hydrocarbons	5.3	4.6	4.0	5.1	4.2	4.9
Particulates	5.5	4.7	4.1	5.3	4.4	5.2
Noise	4.5	3.9	3.6	4.3	3.5	4.1
Water Pollution (blowdowns)	4.0	3.2	2.6	3.8	3.2	3.7
Fog, Plume Drift, Icing	3.8	3.1	2.6	3.7	3.1	3.6
Acid Rain	3.9	3.0	2.4	3.8	3.3	3.7
<u>Abnormal Occurrences</u>						
SO ₂ (fire)	4.2	3.2	2.3	4.2	4.2	4.2
NO ₂ (fire)	4.2	3.2	2.3	4.2	4.2	4.2
Hydrocarbons (fire and oil releases)	4.0	3.0	2.1	4.0	4.0	4.0
Particulates (fire)	4.1	3.0	2.2	4.1	4.1	4.1
Water Pollution (oil release)	3.7	2.8	2.1	3.7	3.7	3.7
Missiles	3.9	3.3	3.0	3.9	3.9	3.9
Fire (offsites)	4.3	3.5	3.0	4.3	4.3	4.3
Explosions (over- pressurization)	4.4	3.7	3.3	4.4	4.4	4.4
Cooling Water Release	2.5	1.9	1.6	2.5	2.5	2.5
Chlorine Leakage	4.0	3.4	3.0	4.0	4.0	4.0
Chlorine Tank Rupture	4.4	3.6	3.1	4.4	4.4	4.4

(1) Base Case: A base loaded plant in a high population density zone.

TABLE 7-8
SENSITIVITY ANALYSIS FOR
COMBUSTION TURBINE HAZARDS EVALUATION

Normal Operations	Base ⁽¹⁾	Population Density		Mode of Plant Operation		
		Medium	Low	Load Follow	Peaking Operating	70% Base Load (Derated)
SO ₂	6.5	5.3	4.5	n/a	6.5	n/a
NO ₂	6.4	5.3	4.5	n/a	6.4	n/a
CO ^x	5.3	4.6	4.0	n/a	5.3	n/a
Hydrocarbons	5.3	4.6	4.0	n/a	5.3	n/a
Particulates	5.4	4.7	4.1	n/a	5.4	n/a
Noise	4.4	3.8	3.5	n/a	4.4	n/a
<u>Abnormal Occurrences</u>						
SO ₂ (fire)	4.1	3.0	2.2	n/a	4.1	n/a
NO ₂ (fire)	4.1	3.0	2.2	n/a	4.1	n/a
Hydrocarbons (fire and oil releases)	3.9	2.9	2.0	n/a	3.9	n/a
Particulates (fire)	3.8	2.8	2.1	n/a	3.8	n/a
Fire (offsite)	4.2	3.5	3.0	n/a	4.2	n/a
Water Pollution (oil release)	3.4	2.6	2.1	n/a	3.4	n/a
Missiles	3.8	3.3	3.0	n/a	3.8	n/a
Explosions (over-pressurization)	3.2	3.8	3.3	n/a	3.16	n/a
Cooling water Release	2.2	1.8	1.6	n/a	2.2	n/a

(1) Base Case: A peaking plant in a high population density zone. Combustion turbines are not generally employed for load follow base load operations.

TABLE 7-9
SENSITIVITY ANALYSIS FOR
GEOTHERMAL PLANT HAZARDS EVALUATION

		Population Density		Mode of Plant Operation		
						70%
<u>Normal Operations</u>	Base ⁽¹⁾	<u>Medium</u>	<u>Low</u>	<u>Load Follow</u>	<u>Peaking Operation</u>	<u>Base Load (Derated)</u>
Hydrogen Sulfide	6.9	5.8	5.1	6.5	5.4	6.3
Other Air Pollutants	6.1	5.3	4.7	5.8	4.8	5.6
Fog, Plume Drift, Icing	3.7	2.9	2.3	3.5	3.0	3.4
Acid Rain	4.1	3.2	2.6	3.9	3.4	3.8
Subsidence	3.8	3.1	2.7	3.7	3.2	3.6
Noise	4.0	3.6	3.4	3.8	3.2	3.7
Inducing Earthquakes	5.9	4.8	4.0	5.7	5.0	5.6
<u>Abnormal Occurrences</u>						
Steam Venting (H ₂ S)	6.1	4.7	3.6	6.1	6.1	6.1
Noise (steam venting)	3.8	2.9	2.3	3.8	3.8	3.8
Air Pollutants (fire)	3.3	2.6	2.1	3.3	3.3	3.3
Steam Ruptures (H ₂ S)	4.7	3.5	2.6	4.7	4.7	4.7
Cooling Water Release	3.1	2.8	1.9	3.1	3.1	3.1
Missiles	3.7	3.2	2.9	3.7	3.7	3.7
Burns	3.1	2.7	2.4	3.1	3.1	3.1
Well Blowout (H ₂ S)	4.5	3.4	2.6	4.5	4.5	4.5
Noise (well blowout)	3.2	2.4	1.9	3.2	3.2	3.2

(1) Base Case: A base loaded plant in a high population density zone.

Power generation plants designed under today's regulations must meet a variety of state and Federal regulations. Some of the major regulations are: Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act, Safe Drinking Water Act, Toxic Substance Control Act, and Operational Safety and Health Act. All of these regulations require some degree of control on pollutants emitted to the environment. Consequently, pollution control systems (water, air and land) must be incorporated into the power plant design.

Technology changes in power plant design appear as a result for the need to utilize fuels that could normally not be used in conventional power plants, or as a result of changes in state and Federal regulations, or as a result of changing economic plant performances.

The emphasis on new technologies today is aimed at utilizing high sulfur coals and maintaining clean air and water. The technical solutions for acceptably burning high sulfur coals are sulfur removal systems at the exhaust stack (flue gas desulfurizing systems); sulfur removal systems before burning the coal (solvent refined coal); and removing the sulfur during combustion (fluidized bed combustion systems).

The Phase I study performed a hazards ranking on a conventional coal fired power plant with flue gas desulfurizing system, that would meet the current and proposed Federal and state pollution control regulations. A hazards sensitivity on this coal fired base plant versus other coal fired plant technologies is revealed in the following characteristics:

- The hazards analysis for fluidized bed boilers is assessed and compared with the conventional coal fired plant in Section 6.

- Solvent refined coal contains very little sulfur and ash content and can be burned in boilers. Under current regulations, if solvent refined coal is low enough in sulfur, no flue gas desulfurizing system is required. A plant burning solvent refined coal will then be similar to an oil fired plant because very little ash or sulfur dioxide is produced. Therefore, the hazards for a plant burning solvent refined coal will be similar to an oil fired plant of the same output capacity.
-

- Some power plant hazards are slightly affected by heat rejection technologies. All types of power plants reject heat into the environment. The conventional heat rejection systems employed in major steam turbine power stations are "once through" river/lake main condenser cooling systems or evaporative cooling tower main condenser cooling systems. In areas where water is scarce, dry cooling towers can be employed.

The power plant efficiency is affected by the cooling system employed. In general, a plant will be slightly more efficient utilizing a once through cooling system instead of cooling towers and considerably more efficient than a dry cooling tower system. The hazards sensitivity from changing from one cooling system to the other is qualitatively presented by the following characteristics:

- Lower plant efficiency means greater emissions of SO_2 , NO_x , particulates, solid waste material, CO_2 , CO, and ozone.
- Lower power plant efficiency means greater heat rejection to the environment.

- Cooling towers reject heat to the air mixture primarily by water evaporation. Consequently, fog plumes can be created by cooling tower systems that would not have been created by once through cooling systems.
- Once through cooling systems reject heat directly into rivers or lake waters which could potentially cause damaging effects to fish and other marine biota.

It is difficult to assess the hazards effects of utilizing once through cooling or cooling towers. In the first case, the reject heat may be hazardous to marine life but results in less reject heat, air, and water pollutants into the environment than with cooling towers, in addition to lowering the demand for fuel. Cooling towers have the opposite effect of protecting marine life, but adding more reject heat, air, and water pollutants to the environment than for once through cooling. Which system is more hazardous is related to subjective personal values. Because the dry cooling tower system results in significantly lower electric generation efficiencies, greater quantities of air and water and thermal pollutants are created for a plant delivering the same amount of power as one with a once through or cooling tower system. Because of this fact, it is considered that a plant employing a dry cooling system is more hazardous to the environment and general public than for the conventional once through or cooling tower system.

- Wet and Dry SO_2 Scrubber Systems--For removing SO_2 from conventional coal fired plants, two types of flue gas scrubber systems can be employed. These are wet and dry SO_2 absorption systems.

The wet scrubber system works on the principle that a slurry of water, lime, or limestone is sprayed through cooled flue gases containing the SO_2 . The low flue gas temperature promotes the SO_2 absorption into the solution. The reactions that take place form (in time) hydrated calcium sulfate and calcium sulfite crystals which precipitate out of solution. The calcium sulfate/calcium sulfite crystals are then bled off to a lined holding pond in the form of a sludge.

The dry flue gas SO_2 scrubber process works on the principle that a water slurry of lime (CaO) or soda (NaCO_3) is atomized into the hot flue gas containing the SO_2 molecules. The hot gas temperatures promote high molecules velocities and accordingly there is high probability of SO_2 interaction with the atomized slurry mist. When the SO_2 molecules come in contact with the atomized slurry, it is absorbed by the droplet.

When lime (CaO) is dissolved in water, it forms calcium hydroxide or quicklime Ca(OH)_2 . The atomized droplet containing calcium hydroxide reacts with the absorbed SO_2 to form a mixture of calcium sulfite, calcium sulfate and water. As the droplet remains suspended in the hot flue gas, the sensible heat of the hot gases evaporate the free water, leaving a dry powdery mixture of sulfite/sulfate. This product is then filtered out with flyash as the flue gas passes through fabric filters.

The main differences in hazards effects for wet and dry scrubbers is primarily in the means for solid waste disposal. Whereas in a wet scrubbing process the wet sludges may represent a materials handling problem, the residue from the dry absorption system is a dried, free-flowing powder which can be disposed of in a manner similar to normal flyash disposal. It is not necessary to provide any further treatment to these wastes and the volume of material which must be disposed of is substantially less than that produced by a wet scrubber. Also, since there is no further treatment of the wastes, equipment such as thickeners, centrifuges, and filters can be eliminated which reduces the amount of land necessary for a pollution control system. Thus, from a solid waste disposal point of view, dry SO₂ scrubber systems probably impose less of a demand on disposal sites than for a wet scrubber system.

The sensitivity analysis, using the modifier vector has not been conducted for the variables of ambient temperature and site location. The variable of extremes in ambient temperature has such a minimal effect on the hazards due to operation of a power plant that a sensitivity analysis would be meaningless. Site location has two principal effects on hazards; population and transportation hazards. Population is considered in the sensitivity analysis. Since hazards of activities offsite were not included in the previous hazards analysis, the sensitivity study cannot be done.

Ambient temperature does have an effect on the operations of a fossil fueled power plant. Its most direct effect would be to increase or decrease the efficiency of the cooling system for the condensers. At extremely high ambient temperatures, overall plant efficiency will decrease more rapidly as the cooling system fluid exceeds design temperatures. A similar reduction in overall plant efficiency would also occur if the temperature of the air entering the air pre-heaters was below design limits. However, these changes in efficiency are minor and do not have any effect on the designated hazard ranking or risk assessment. Temperature extremes also would affect the probability of the occurrence of cooling tower fogging and icing and at its extremes would increase the probability of equipment failure that would then increase the probability of occurrence for the identified abnormal hazards. Atmospheric temperature per se does not have a significant direct effect on atmospheric dispersion of emissions. While differences in dispersion do occur from site to site factors other than temperature are more important. Such things as terrain, distance to large bodies of water must be considered. In reality, site measurements are necessary to accurately model atmospheric dispersion.

The hazards due to transportation requirement of power plants comes primarily from accidents. There are other non-accident or operational hazards involved, mainly from air pollutants from fuel burned by the different transportation modes. Transportation modes that have been identified are: unit train for coal, pipeline for larger volumes of oil, rail tank car or tank truck for smaller volumes of oil. Air pollutants would originate from the diesel emissions of the train engines, compressors and heating units of pipeline pumping stations and truck engines. These emissions would be small in magnitude and would be transient in nature except for the stationary pumping station emissions. The hazard would be those identified for normal operations: emissions of sulfur oxides, nitric oxides, carbon monoxides, hydrocarbons, particulates and noise. The hazards identified for abnormal occurrences are accidental occurrences, derailment, collision, pipeline rupture and their possible resultant fires and explosions (over pressure). The occurrence of fire or explosions for coal or residual fuel oil are very low since neither is explosive and ignition for both is difficult. The transport of distillate fuel oil via truck would involve risks associated with heavy truck operations. Distillate fuel is not explosive but its ignition is easier than for residual fuel oil, so fire is a more present danger. The overall hazard to the public while low on a per truck or train mile basis is actually high compared to other hazards because of the volume of material to be transported. Transportation hazards should be further evaluated.

BIBLIOGRAPHY

1. Final Report to the Tennessee Valley Authority, "Preliminary Design Study For A Fluidized Bed Demonstration Unit," prepared by Combustion Engineering, Inc., dated June 1, 1978.
2. Evaluation of A Pressurized Fluidized Bed Combustion (PFBC) Combined Cycle Power Plant, prepared for the United States Department of Energy by Burns and Roe/Babcock and Wilcox/United Technologies Corporation, Dated June 1978.
3. Conceptual Studies and Preliminary Design of A Fluid Bed Fired Boiler For Service In An Electric Utility, prepared for the Tennessee Valley Authority by Babcock and Wilcox, dated April 28, 1978.
4. Conceptual Design of An Atmospheric Fluidized Bed Combustion Electric Power Generating Plant, prepared for the United States Department of Energy by Burns and Roe, Inc., dated April 1978.
5. Technical Notes for the Conceptual Design For An Atmospheric Fluidized Bed Direct Combustion Power Generating Plant, prepared for the United States Department of Energy by Stone and Webster Engineering Corporation, dated April 1978.
6. Preliminary Design and Cost Estimate for An Atmospheric Fluidized Bed Steam Generator, prepared for the Tennessee Valley Authority by Fluidized Combustion Company dated April 1978.
7. Environmental Readiness Document, "Small Atmospheric Fluidized Bed Combustion," Commercialization Phase III Planning, prepared by the U.S. Department of Energy, dated September 1978.
8. "Fluidized Bed Combustion Industrial Application Demonstration Projects, Multi-Solids Fluidized Bed Combustion," Quarterly Technical Progress Report prepared for the U.S. Department of Energy by Battelle Columbus Laboratories, dated September 30, 1978.
9. Industrial Application Fluidized Bed Combustion Category III, Indirect Fired Heaters, Quarterly Technical Report No. 9, prepared for the U.S. Department of Energy by Exxon Research and Engineering Co., dated September 1978.
10. "Support Studies In Fluidized Bed Combustion," Quarterly Report dated April-June 1978, prepared for the U.S. Department of Energy by Argonne National Laboratory.