IDENTIFICATION OF HAZARDS IN NON-NUCLEAR POWER PLANTS;

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VOLUME I: SUMMARY REPORT

PHASE I AND PHASE II

CONSULTANT REPORT

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SUMMARY REPORT

IDENTIFICATION OF HAZARDS IN
NON-NUCLEAR POWER PLANTS

PHASE I and PHASE II

Prepared for
California Energy Commission

August 1979

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Rockville, Maryland 20850

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1.0 INTRODUCTION

1.1 Background

This report summarizes the work performed in the first two phases of a study for the California Energy Commission of the public hazards associated with the operation of non-nuclear power plants. The overall goal of the program is to provide the Commission with the procedures and tools to assure itself that public safety is adequately considered in the design, siting and operation of non-nuclear power plants.

The growth and type of electrical power production in California is undergoing a period of significant change. Historically, utilities have relied primarily upon hydroelectric units and oil and gas fueled thermal units for the bulk of their electric generating capacity. With the prime hydroelectric locations being exhausted and the potential unavailability of gas and oil, California utilities are expanding their geothermal plants, proposing coal-fired plants and building combined cycle plants. By law, the California Energy Commission is mandated to insure that all new thermal power plants, which are designed, constructed and operated in California, meet a standard of quality to protect health and safety, and environmental quality.

Within the last fifteen years, there has been a growing recognition by society of the importance to assess the health and safety issues of various technological activities, especially power plants. This recognition was prompted by the concern for the degradation of the environment and recognition of actual and potential hazards in many technologies. The initial impetus for hazard analysis for electric power plants came from the development of nuclear power plants. The operators of these plants are required by law to assess not only the hazards of the plant operations but also the mechanisms by which these hazards develop in the plant and how they are transmitted to the general public.

While the public health and safety risks associated with nuclear power plants have been the object of significant research, non-nuclear power plant hazards have not been, until recently, extensively identified or researched as to their effects on the

general public. In general, research has focused on the health and environmental effects of normal air and water emissions from these plants.

Non-nuclear plants, especially fossil fueled units, are faced with evaluating the short and long term effects of a multitude of hazardous materials released to the environment. Although significant progress has been made in these areas, Dr. Samuel Morris of Brookhaven National Laboratory after completing a major study on the health effects of power plants, indicated that further research was required. Dr. Morris stated that estimates of annual deaths due to coal plant air emissions in the United States ranged from 0.6 to 300 because there is "an incredible lack of knowledge of air pollution effects." Very little effort has been extended in identifying and quantifying hazards associated with abnormal or accidents at non-nuclear power plants.

1.2 Workscope

This report summarizes the first step in an evaluation of the public health and safety hazards associated with non-nuclear plants. This study was limited to hazards which could affect the general public outside the plant boundaries. Occupational hazards were not part of this study even though it is recognized that these hazards can present a danger to operating personnel. Public health and safety hazards have been identified for seven types of power plants: coal-fired conventional boiler, atmospheric fluidized bed boiler, pressurized fluidized bed-combined cycle, oil-fired, oil-fired steam turbine, combined cycle, combustion (gas) turbine, and geothermal. Major plant systems effecting the hazards have been identified and described. Potentially hazardous conditions and events have been identified for normal and abnormal plant operating conditions and for accidents at the plant. A classification of each hazard has been made which identifies the initiating event, the hazard source, equipment or conditions that increase, monitor or mitigate the hazard. An event tree has been developed for each plant which relates the effect on the general public for each hazard and initiating event. A semi-quantitative hazard ranking has been developed that provides a method of comparing the hazards and events at different types of plants. Consideration has been given to the sensitivity of the hazard ranking to population density, changes in operating mode and technology changes.

The work performed for this study is documented in NUS 3099 "Identification of Hazards in Non-Nuclear Power Plants," January 1978 and NUS 3360 "Identification of Hazards in Non-Nuclear Power Plants - Phase II," May 1979.

2.0 DESCRIPTION OF STUDY AND RESULTS

2.1 Reference Plant Designs

To facilitate the analysis of the seven different types of plants, a reference design was chosen for each plant. The selection of the reference designs was based on the plants currently under construction or being proposed in California and reflects the current state-of-the-art technology for the particular types of plants. The reference plant designs were site independent except in cases where certain reference plant equipment was designed for operation at a specific location. For example, the oil-fired plant used a once-through cooling system using seawater for condenser cooling. The reference designs were:

- 2 - 750 MWe Coal-fired Plants
- 1 - 300 MWe Oil-fired Plant
- 1 - 200 MWe Atmospheric Fluidized Bed Power Plant
- 1 - 600 MWe Pressurized Fluidized Bed Combined Cycle Power Plant
- 1 - 400 MWe Combined-cycle Plant
- 1 - 60 MWe Combustion Turbine Plant
- 1 - 110 MWe Geothermal Plant

For each reference plant, the study identified hazards which could affect the general public outside the plant boundaries. A hazard is defined as an event or combination of events which could result in immediate injury to the general public or in degradation to the environment that would have an ultimate adverse effect on the general public. Occupational health and safety hazards involving plant workers are not part of the study. Hazards were determined from those arising from normal plant operations, startup, shutdown, accidents and equipment failures. The initiating events for hazards included all events that could occur inside the plant and certain outside man-caused and natural events. Man-caused events eliminated from the study included sabotage, terrorism, war, spacecraft debris and ballistic missiles. Natural occurring events not discussed were volcanoes, avalanches, and meteors.

The study did not include hazards arising from construction, renovation, or decommissioning of the plant. Also, hazards associated with the non-plant portion of the fuel cycle such as exploration, extraction, processing, transportation and distribution are eliminated from the study. Finally, the effects of the loss of electricity on the general public are not part of the study, nor are such potential generic issues as the effect of large amounts of CO₂ on energy absorption in the atmosphere, i.e., the "greenhouse effect."

2.1.1 Conventional Coal Fired; Twin, Unit, 1500 MWe Electric Generating Station

Coal is delivered by unit train. The coal is crushed, magnetic particles are removed, and then pulverized with hot air suspending the coal and transporting it into the fire box/furnace of the boiler where it is burned with additional air. The air flow is adjusted to maintain the combustion gas temperature below the ash melting temperature (this is to prevent ash slagging on the boiler tubes). Approximately 80% of the ash will be carried with the combustion gases through the boiler where 99.5% of the particulates are collected by electrostatic precipitators. The remaining 20% of the ash will be discharged out the bottom of the furnace and the bottom hopper of the economizer section of the boiler. The sulfur in the coal will be converted to sulfur dioxide during combustion. Approximately 90% of this sulfur dioxide will be removed from the flue gases by a wet sulfur dioxide scrubber system prior to being exhausted up the exhaust stack. The collected ash, sulfur removal sludge, and particulates are transported via water slurry to a disposal settling pond.

The boiler supplies high and intermediate pressure superheated steam to drive the steam turbines. The high pressure superheated steam (at 3630 psi and 1008°F) expands through the high pressure section of the steam turbine. Approximately 92% of this mass flow exhausting from the high pressure section is returned to the boiler at intermediate pressure to be reheated to 1002°F prior to expanding further in the intermediate and low pressure turbine sections. (The other 8% is used to reheat the steam condensate). The steam exhaust from the low pressure turbine section goes into the main steam condenser where it condenses at a vacuum pressure (the condenser pressure is approximately a few inches of mercury above the partial pressure of the cooling water source).

The liquid condensate is pumped from the condenser hot wells, passed through demineralizers to remove impurities, then through a deaerator to preheat the water and remove dissolved gases, and then pumped through a series of feedwater heaters. The feedwater heaters are essentially condensing heat exchangers where steam and high pressure condensate are extracted from the high, intermediate, and low pressure turbine section flows from the high pressure end to the low pressure end of the heat exchanger array transferring heat along the way as it condenses, flashes, and is let down in pressure returning to the liquid condensate. The feedwater pumped back into the boiler is regulated by steam driven boiler feed pumps.

2.1.2 Oil-Fired Electric Generating Stations

The referenced oil-fired electric generating station is a 300 MWe unit using residual oil as the fuel. This fuel is supplied to the plant by pipe line and stored in storage tanks. The oil is heated, atomized, and mixed with pre-heated air as it enters the boiler fire box where it burns. The combustion gases (hotter than for a coal unit) pass through the boiler convective superheater, reheater, and boiler tube sections followed by feedwater preheater and then economizer sections. The exhaust gases then pass through the induced draft fans and out the stack. (Plant emissions at the stack will generally contain NO_x , SO_2 , particulates, CO, and hydrocarbons. Even though the reference plant can meet the present new source performance standards for particulate emissions, some oil fired plants have employed electrostatic precipitators to provide additional reductions in particulate emissions.)

The steam generation and turbine generation systems are similar to the coal fired plant. The only significant difference is the main steam pressure for temperature, and flows for the reference 300 MWe oil-fired plant are different than for the 750 MWe coal plant (i.e., 2000 psi, 1005°F vs. 3630 psi, 1008°F and lower mass flows).

2.1.3 Atmospheric Fluidized Bed Boiler (AFBB) 200 MWe Steam Electric Generating Station

The AFBB generating station requires plant systems that are similar to a conventional coal fired boiler steam electric generating station except for the

following differences:

- o the coal combustion furnace is designed to support a bed of burning coal and limestone that is suspended and fluidized by combustion air passing up through the bed. The limestone decomposes by the heat to lime and in turn the lime combines with the sulfur dioxide released by the burning coal to form a solid calcium sulfate. This solid waste product is disposed by storing it in a landfill. This in-situ sulfur removal combustion process eliminates the need for flue gas sulfur dioxide scrubbing systems employed in conventional coal plants.
- o Coal is mixed with limestone in small solid grains and fed to the boiler through feed lines at the bottom of the bed.
- o Because of the churning/turbulent burning particle transport throughout a fluidized bed, high heat transfer characteristics are obtained by passing some of the boiler heat exchanger tubes through the burning bed of coal. This feature allows for a smaller boiler than is needed for a conventional pulverized coal boiler of the same thermal capacity.
- o Particle flue gas dust loading is significantly higher in the AFBB than for a conventional coal boiler and therefore flue gas particulate removal systems are larger, more complicated, and potentially more troublesome than for a particulate filtration system used in a conventional coal plant.
- o A limestone pile/handling/bunker system is required in addition to the coal pile/handling/bunker system.
- o The forced and induced combustion air draft fans are larger than for a conventional coal boiler (of same thermal capacity) because of the increased pressure drop through the fluidized bed and particulate filtration systems.

2.1.4 Pressurized Fluidized Bed Combustion Combined Cycle (PFBCC) Power Plant

The reference PFBCC power plant is a Burns and Roe/Babcock and Wilcox/United Technologies design for a 592 MWe gross Pressurized Fluidized Bed Combustion Combined Cycle (PFBCC) 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 combustion products then pass through a cyclone particulate removal state, mix with heated pressurized air and then expand in two 63.6 MWe gas turbines producing mechanical power than 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 upheating 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%.

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.

The steam cycle and associated steam electric systems are similar to the steam side of conventional coal fired power plants except for the fact that a forced draft fan has been replaced by the air turbine compressor and expander, the atmospheric fluidized bed boiler and particulate removal systems are similar to the AFBB mentioned in Section 2.3.

2.1.5 Combined-Cycle Plant

The combined cycle plant integrates a group of combustion (gas) turbines with a conventional steam turbine plant to produce electrical power more efficiently.

The combustion turbines are basically rotary engines consisting of a compressor, combustion chambers and turbines. Distillate fuel oil is supplied to the turbines from two fuel oil storage tanks by the fuel oil handling system. The four combustion turbines supply 70% of the total plant output.

Air is drawn through a duct system into the multi-stage turbine driven compressor where it is compressed and then mixed with the fuel oil for ignition in the combustion chamber. Only 20% of the air mixes with the fuel, the remainder is used for cooling the exhaust gases. Water is injected into the combustion chamber to reduce the flame temperature and emissions of nitrogen oxides. The gases leaving the combustion chamber expand through the turbine section and turn the turbine shaft. Each turbine is directly connected to its own electrical generator which produces 70 MWe and drives the turbine compressor.

The exhaust gases from the turbines are ducted to four heat recovery steam generators (HRSG). In the HRSG, the hot gases heat water to produce steam at 950 psig and 845°F. The gases are exhausted to the atmosphere after passing through the HRSG. Steam flow from each of the four HRSGs is combined in the main steam header and is directed to the 120 MWe capacity steam turbine. A portion of the steam is diverted for use in the condensate deaerator, turbine water wash system, fuel oil heating system, steam turbine seals and soot blower. Aside from being smaller in electric generating capacity, the steam electric cycle and associated systems are similar to the steam electric cycle of the conventional coal plant.

2.1.6 Combustion Turbine Plant

The reference design combustion (gas) turbine plant is a nominal 60 MWe plant using No. 2 diesel oil as the primary fuel. This type of plant is typically used for peaking operation. It is similar to the combined cycle plant except that it does not utilize a heat recovery boiler. Air is drawn into the multi-stage compressor through a duct system which is equipped with filters and silencers to alleviate the noise. Depending on the system, some of this compressed air can be preheated by the turbine exhaust gases to improve efficiency. Approximately 20% of the air is mixed with the fuel oil and ignited in the combustion chamber. The remaining air is used to dilute and cool the combustion gases. The fuel oil is premixed and

prevaporized prior to combustion to reduce emissions of nitrogen oxides. The hot gases then expand through a multi-stage turbine developing shaft horsepower which drives the turbine compressor and a 60 MWe generator. The hot gases exhausting from the turbine can then be directly exhausted to the atmosphere or diverted to an economizer where some of the exhaust heat is recovered by preheating the compressed air prior to entering the combustion chamber.

2.1.7 Geothermal Plant

The reference design geothermal plant is a nominal 110 MWe net unit which is similar in design to the Geysers plant. Steam from twelve (12) to fifteen (15) geothermal wells is piped through the main steam system to the plant. The main steam system includes the piping from the wells to the plant's steam turbines and also the valves that isolate and control the steam flow. A portion (approximately 5%) of the main steam flow is diverted to the auxiliary steam system which supplies the necessary steam for the condenser gas ejectors, turbine steam seal system and hydrogen sulfide abatement system.

The geothermal steam expands through the turbine which drives an electrical generator. After the steam passes through the turbine, it is exhausted to the condenser where it is cooled and forms water (condensate). The turbine generator is equipped with a lubricating oil system which provides lubrication to the bearings in the turbine and the generator. A hydrogen gas system provides cooling to the generator components.

Since the amount of steam from the wells exceeds the amount of water vapor released by the cooling towers, the amount of water in the cooling system increases during plant operations. To maintain a constant amount of cooling water in the plant, a portion of the cooling water is piped and reinjected into the geothermal wells.

Hydrogen sulfide and other non-condensable gases in the incoming stream are removed from the condenser by the gas ejectors. These gases are transported to a hydrogen sulfide abatement system, which removes the sulfur from the gas by a series of chemical reactions. The sulfur obtained from the process is initially stored at the plant and then it is trucked offsite for disposal. The treated gas is

returned to the cooling tower where it is released to the atmosphere. Also, any water and salts which are removed by the process are returned to the cooling towers for reinjection into the wells.

2.2 Hazards Identification

As part of the hazards identification, a comprehensive literature survey in the areas of non-nuclear plant hazards was performed. This literature survey included data bases from data management firms (such as NTIS), Government information centers (such as Oak Ridge National Laboratory), environmental impact reports for similar plant designs, various Government offices (such as Environmental Protection Agency, and National Institute for Occupational Safety and Health), insurance companies (such as Hartford Steam Boiler Insurance), and technical descriptions of power plants (such as Combustion Engineering design for Atmospheric Fluidized Bed Boilers).

The results of the hazards identification is summarized in Table 1. This table presents the power plant types, power plant systems, and associated hazards for both normal and abnormal operating conditions.

2.3 Hazard Ranking

2.3.1 Ranking Methodology

A hazard ranking methodology was developed to provide a numerical rating for each hazard that might have adverse human health or safety effects. By ranking the hazards numerically, one would be able to quickly compare different hazards from various types of power plants. Secondly, the rankings would provide a basis for determining which hazards have the greatest potential effect on the general public. Thus, the ranking identifies the hazards which require further study and development of techniques to mitigate these hazards.

The hazard ranking consisted of rating each identified hazard numerically on a 1 to 9 scale with respect to a set of criteria having a bearing on the significance of the hazard. The criteria used in this analysis were:

TABLE 1
NON-NUCLEAR POWER PLANT HAZARDS

Power Plant Systems	Power Plant Types							Abnormal Operating Hazards	Normal Operating Hazards
	Geothermal	Combustion Turbine	Oil Fired Combined Cycle	Oil	Pressurized Fluid Bed Combined Cycle (PFBC)	Atmospheric Fluidized Bed Boiler (AFBB)	Coal (Conventional)		
Steam Generator Boiler			X	X	X	X	X	Steam Side Boiler Explosion Leading to Missile Generation, Fire Endangering People	
High Pressure Steam Piping	X		X	X	X note 4	X note 4	X	For AFBB/PFBC, SO ₂ , Particulate, CO, H ₂ , Missile Generation; Geothermal SO ₂ and H ₂ S Emission	
Coal Pile and Coal Handling System; Coal Bunkers					X	X	X	Fire Leading to SO ₂ , NO _x , Particulate Emissions; Potential for Offsite Fires	Rainwater Acid Runoff, Noise
Limestone/Dolomite Handling/Burner/Mixing System					X	X	X	Abnormal Control Leading to Higher SO ₂ Emissions	Noise
SO ₂ Flue Gas Scrubbing System							X	Reduced Efficiency or Failure of System Leading to Higher SO ₂ Emissions	Some SO ₂ Still Emitted To Environment, Leading To Acid Rain
Flue Gas Particulate Removal System				note 5	X	X	X	Reduced Efficiency or Abnormal Operation or Failure Leads to Higher Particulate Emissions	Some Particulates Emitted To Environment
Ash/Sludge/Solid Waste/Water Accumulation Disposal/Landfill	X				X	X	X	Potentials for Water Runoff or Leachate Containing Toxic Materials; Land Consumption	Land Consumption, Waste Transportation Related Accidents & Spills
Fuel Oil Storage, Handling, and Pumping Systems		X	X	X	X minor	X minor	X minor	Fire Generating NO _x , Carbon, SO ₂ , CO, Hydrocarbons; Explosions/Missiles; Offsite Fires	
High Pressure Gas/Combustion Turbine Generator System		X	X		X note 1			Failure of Turbine Blade Structural Integrity Leading to Missile Generation	Noise
Steam Turbine Generation System			X	X	X	X	X	Failure of Turbine Blade Structural Integrity Leading to Missile Generation	
Combustion Air Draft Fans System			X at stack	X	X note 3	X note 2	X	Abnormal Operations Can Lead to Greater NO _x , CO, hydrocarbon emissions; cause Furnace Explosions Generating Missiles	
H ₂ S Abatement	X							Failure Leads to Hydrogen Sulfide Emissions to Environment	Some H ₂ S and SO ₂ Is Emitted
Main Condenser Cooling Water System	X		X	X	X	X	X	Cooling Towers Lead to Potential Ground Fogging and Greater Emissions of Pollutants and Reject Heat; Once-Through Cooling Can Endanger Marine Life	Cooling Towers Fogging, Noise
Condenser Cooling Water Chlorination System	X		X	X	X	X	X	Accidental Release of Chlorine Gas to Environment	
Electric Generator H ₂ Cooling System	X if lg. enough		X	X	X	X	X	Accidental Ignition Leading to H ₂ Fire or Explosion Generating Missiles	
Fire Protection System	X	X	X	X	X	X	X	Failure or Absence Can Lead to Plant Fires or Explosions	
Steam Generator Blowdown System			X	X	X	X	X	Uncontrolled Discharges Can Potentially Pollute Groundwaters	Water Containing Dissolved Solids
Fossil Fuel Combustion Vessel/Furnace/Controls			X	X	X	X	X	Failure of Combustion Controls or Abnormal Operation Could Lead to Explosions Generating Missiles; Higher NO _x , CO, Hydrocarbon, SO ₂ , Particulate Emissions	NO _x , SO ₂ , CO, Hydrocarbon Particulate Emissions

NOTES FOR TABLE 1

- 1) Loss of turbine load may cause overpressurization and/or high gas velocities in the Atmospheric Fluidized Bed Boiler section of the PFBCC. This condition could then lead to higher SO_2 and particulate releases in addition to possible rupture of the AFBB section.
- 2) Higher than normal combustion air flows in the AFBB can cause higher than normal SO_2 , NO_x , and possibly particulate emissions.
- 3) Combustion air for the Atmospheric Fluid Bed Boiler section of the PFBCC is supplied by the exhaust flow leaving the gas turbine. Abnormal operation of the gas turbines can cause hotter combustion air and higher gas velocities through the AFBB section resulting in higher SO_2 , NO_x , and potentially higher particulate emission.
- 4) The AFBB and the atmospheric section of the PFBCC contain high pressure steam piping within the fluidized bed. Rupture of these tubes due to erosion can cause greater SO_2 , particulates, CO, H_2 emission and potentially overpressure and lead to missile generation.
- 5) The reference residual fuel oil fired boiler does not have a particulate removal system. However, as a measure to keep particulates emission down, particulate removal systems can be used on oil fired boilers.

<u>Criteria</u>	<u>Weighting Factor</u>
1) area/population exposed,	0.30
2) duration,	0.08
3) mitigation	0.20
4) quantity to toxicity ratio,	0.15
5) nature of health effects, and	0.20
6) public attitude	0.07

Weighting factors were preassigned to each of the criteria in relation to the relative importance of the criterion to the overall risk assessment. The ultimate rating of a hazard is the sum of the products of the individual weighting factor and the hazard criterion value. The hazard criterion value for each hazard was set by a composite survey of NUS staff members with public health and safety experience.

When quantitatively evaluating any phenomena, there are a number of pros and cons in the methodology employed to obtain the numerical rating. The methods used in this analysis are believed to be consistent with the currently available understanding and knowledge of the potential hazards associated with non-nuclear power plants. The six criteria with their associated weighting factors were selected as being the most significant factors in a hazards evaluation. Additional factors were determined to have an insignificant effect on the overall rating of a hazard. The selected criteria provided an evaluation of not only the nature of the hazard but also the hazard's impact on the public and the public's acceptability of the hazard. It is recognized as further research clarifies the health and safety effects of each hazard, the evaluation criteria and weighting factors will change to reflect this further knowledge.

One important factor that is not directly addressed in the hazard ranking is the determination of the frequency of occurrence for each hazard. Obviously a hazard that occurs continuously is more important than a hazard with the same potential consequence that occurs only infrequently. Three broad classes of frequency have been defined: frequent, infrequent and hypothetical. Frequent events are those that occur continuously or are expected to occur at least once a year on the average at a plant. Infrequent occurrences are those that are expected to occur between once a year and once every twenty years at a plant. Hypothetical events

or accidents are those whose probability of occurrence are estimated at less than once every twenty years. An overall numerical ranking of each hazard is then established within these three classifications to determine the overall risk assessment for all types of plants considered in this analysis.

2.3.2 Results of Hazard Ranking

The results of the hazard ranking is summarized in Tables 2, 3 and 4 for frequent, infrequent and hypothetical hazards and in a condensed generic way in Table 5.

In considering the results of the hazard ranking several factors must be kept in mind. First, the numerical value has no meaning in an absolute sense. The results are significant only in relating one hazard to another. The higher the rating the greater the hazard. Ratings above 5 are probably significant while ratings below 3 probably are not. Small differences in rating are not significant. While no specific effort has been made to determine the difference in rating that is significant it appears that a difference of 0.5 is probably meaningful while a difference of 0.2 is probably not.

Results of the analyses showed that air pollutants generally received the highest weighted rating for each plant type. An examination of the detailed results 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. 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.

An additional assessment of air 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

TABLE 2

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 2 (cont.)

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
	Coal (conventional)	5.9
	Combined Cycle	5.3
	Combustion Turbine	5.3
CO Emission	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	PFBC	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)	PFBC	4.4
	AFBB	4.3
	Coal/Conventional	4.3

TABLE 2 (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 3

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 3 (cont.)

<u>Hazard</u>	<u>Plant</u>	<u>Rating</u>
Particulates (fire)	Oil	4.1
	Combined Cycle	4.1
	PFBC	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
	PFBC	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	PFBC	3.3
	AFBB	3.3
	Coal (conventional)	3.3
Noise (geothermal well blow out)	Geothermal	3.2
Burns (steamline)	Geothermal	3.1

TABLE 4

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	3.3
	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

TABLE 5

SUMMARY OF COMPARISON OF HAZARD RANKING

<u>Approximate Range of Hazard Ranking</u>	<u>Frequent</u>	<u>Infrequent</u>	<u>Hypothetical</u>
7.0-7.2	All coal fired - SO ₂ Conventional coal fired - NO _x	-	-
6.5-7.0	Oil fired - SO ₂ Geothermal - H ₂ S Other - NO _x Coal fired - particulate	-	-
6.0-6.5	Geothermal - HC Coal - HC	-	-
5.5-6.0	Oil fired - particulate	Geothermal - induced earthquake	-
5.0-5.5	Oil - CO Oil fired - HC	-	-
4.5-5.0	-	Geothermal - blowout - H ₂ S Geothermal - pipe failure - H ₂ S	all-large chlorine release oil - explosions - overpressure
4.0-4.5	all - noise all - blowdown water pollution	all-chlorine leakage all - fire - SO ₂ /NO _x	all-fire-burns all-fire-burns
3.5-4.0	all - closed cycle cooling-fog, plume drift	all - fire - particulate/HC Geothermal - subsidence oil - spills - water pollution	coal-explosions-overpressure all - missiles
2.5-3.5	oil-once thru cooling - fog	all-solid waste spills - water pollution Geothermal-well blowout-noise Geothermal-steamline - burns	all-cooling water releases - flooding

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. 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.

2.4 Sensitivity Study

A sensitivity study was performed to assess the effect of population density, mode of plant operation, and technology changes on the hazard ranking.

The population density assessment was made by adjusting the numerical ratings for those criteria affected by population density by a factor accounting for population density changes. Three population densities were considered, urban (base case with a population density of approximately 2500 people per square mile or more), semi-urban (approximately 1200 people per square mile), and rural (approximately 25 people per square mile) with relative densities of 1.0, 0.5, and 0.01. The effect on hazard rating is shown in Table 7 and 8. As expected the rating of all hazards decrease significantly as the population density decreases. For a low population density the ratings of a few of the frequent hazards and a greater number of the infrequent and hypothetical hazards are reduced to values less than 3 and are of little significance.

Four different modes of plant operation were considered: base load, load follow, peaking and derated base loaded. The principal effect of these different modes of operation on hazards is in the quantity of normal emissions. The quantity toxicity ratio and duration criteria were reduced by factors considered typical of the modes

TABLE 6

**ANNUAL PLANT POLLUTANT EMISSIONS (TONS)
1000 MWe Plant**

	<u>Coal</u> ⁽¹⁾	<u>AFBB</u> ⁽²⁾	<u>PFBC</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.

TABLE 7

SUMMARY RESULTS OF SENSITIVITY STUDY
FREQUENTLY OCCURRING HAZARDS

Approximate Range of Hazard Ranking	High Population Density Urban	Low Population Density Rural	Peaking Operation
7.0-7.2	All coal fired - SO ₂ Conventional Coal fired - NO _x	-	-
6.5-7.0	Oil fired - SO ₂ Geothermal - H ₂ S Other - NO _x Coal fired - particulate	-	Combustion Turb. - SO ₂ /NO _x
6.0-6.5	Geothermal - HC Coal - HC	-	-
5.5-6.0	Oil fired - particulate	-	Coal - SO ₂ /NO _x
-25- 5.0-5.5	Oil - CO Oil fired - HC	-	Combustion Turb. - particulate/HC Conventional Oil - SO ₂ /NO _x Geothermal - H ₂ S Coal - particulate
4.5-5.0	-	Geothermal - H ₂ S All coal fired - SO ₂ Conventional Coal fired - NO _x Oil fired - SO ₂ Geothermal - HC Other - NO _x	Remaining air pollutants
4.0-4.5	all - noise all - blowdown water pollution all - acid rain	Coal fired - particulate Coal - HC Oil fired - particulate Oil - CO Oil fired - HC	Combustion turbine - noise
3.5-4.0	all - closed cycle cooling - fog plume drift	-	-
2.5-3.5	oil - once thru cooling - fog	all - noise all - blowdown water pollution all - acid rain all - closed cycle cooling fog plume drift	other - noise all - closed cycle cooling - fog plume drift all - acid rain all - blowdown water pollution
<2.5	-	oil - once thru cooling - fog	oil - once thru cooling - fog

TABLE 8
SUMMARY RESULTS OF SENSITIVITY STUDY
INFREQUENT AND HYPOTHETICAL HAZARDS

Approximate Range of Hazard Ranking	<u>Infrequent Hazards</u>		<u>Hypothetical Hazards</u>	
	<u>High Population Density</u>	<u>Low Population Density</u>	<u>High Population Density</u>	<u>Low Population Density</u>
7.0-7.2	-	-	-	-
6.5-7.0	-	-	-	-
6.0-6.5	-	-	-	-
5.5-6.0	Geothermal - induced earthquake	-	-	-
-26- 5.0-5.5	-	-	-	-
4.5-5.0	Geothermal-blowout-H ₂ S Geothermal-pipe failure-H ₂ S	-	all-large chlorine release oil-explosions-overpressure	-
4.0-4.5	all-chlorine leakage	Geothermal-induced earthquake	all-fire-burns	-
3.5-4.0	all-fire-particulate/H ₂ C Geothermal-subsidence oil-spills-water pollution	-	coal-explosions-overpressure all-missiles	-
2.5-3.5	all-solid waste spills- water pollution Geothermal-well blowout-noise Geothermal-steamline-burns	all-chlorine leakage Geothermal-subsidence Geothermal-blowout-H ₂ S Geothermal-pipe failure-H ₂ S	all-cooling water releases flooding	all-large chlorine release oil-explosions-overpressure all-fire-burns coal-explosions-overpressure all-missiles
<2.5	-	others	-	all-cooling water releases flooding

of operation. Only frequently occurring (normal operation) hazards are effected. Infrequent or hypothetical hazards are essentially unchanged by mode of operation. The results of going from the base case to peaking operation is shown in Table 7.

While there is substantial reduction in hazard ranking, it is not as significant as the effect of a low population density site. The combustion turbine plant hazards remain unchanged since the reference design is a peaking unit.

The plants considered in this study represent a range of power generation techniques. The detailed hazard ranking given in Tables 2, 3 and 4 indicating the effect of technology changes on hazards is generally rather small. This is the result of a number of factors. One major goal of new technologies is to permit the use of high sulfur coals and still stay within emission limits. For example fluidized bed technology permits the burning of high sulfur coal without flue gas desulfurizing systems (the desulfurization being carried out in the boiler). The net effect is that there is no real substantial change in overall emission and no significant change in other hazards. Heat rejection techniques has a small effect on hazard since ultimately the heat must get dispersed in the atmosphere. Once thru cooling has a reduced potential for causing fogs than a closed cycle cooling and is of a lesser hazard from that standpoint. The closed cycle cooling will probably have a lower efficiency which means more combustion product emissions. The fog potential can be reduced by dry cooling towers but at the expense of an even greater efficiency reduction and more emissions. Hence a reduction in one hazard increases another.

3.0 CONCLUSIONS AND RECOMMENDATIONS

As indicated earlier, this report summarizes the work done in the first two phases of the hazard identification and assessment study. The work in these two phases has concentrated primarily on the identification of hazard and on the semiquantitative ranking of them. More thorough quantitative assessments and recommendations for CEC action are part of the follow on work. The conclusions and recommendations from work done to date are given below.

3.1 Specific Conclusions Relative to Hazards

- o There are numerous potential public health and safety hazards associated with the operation of non-nuclear power plants.
- o Normal operating emissions are more significant hazards than those associated with most accidents.
- o Current and proposed plant designs generally recognize the potential hazards and provide systems to prevent, reduce or mitigate the hazards.
- o No new unrecognized hazards were identified.
- o There is no significant difference between fossil fuel plant types other than those caused by plant size and specific pollution control equipment included in the design. Coal plant hazards were ranked highest primarily because of plant size.
- o Normal operating geothermal plant hazards are not much different than those for fossil fuel plants, however, potential hazards from infrequent-accident occurrences may be more significant.
- o The most significant infrequent or hypothetical occurrences are potential geologic effects associated with geothermal plants, acute air pollution associated with geothermal system failures or fossil plant fires and inadvertent releases of toxic chemicals.

- o Locating the plant in a low population density area reduces all hazards significantly.
- o Changing plant operating mode (base load, load follow, peaking and derating) reduces normal operating hazards somewhat, but does not affect accident hazards.

3.2 Conclusions Relative to the Program

- o An integrated coordinated identification and ranking of potential hazards provides a useful reference tool.
- o For new technologies without any commercial scale experience a thorough detailed safety review is necessary.
- o The hazard ranking scheme developed provides a useful general comparison of hazards; however, because of its subjectivity, it provides only a coarse discrimination between plant and hazard types.
- o While some changes in hazard ranking methodology and of the assigned hazard ranking would produce a better result, there would be no essential change in the conclusions.
- o A more definitive ranking of hazards requires detailed quantification of public injuries and mortalities for specific site and plant conditions and of the probability of accidents and abnormal conditions. For a significant number of the hazards, particularly the normal emissions, insufficient technical data is available to do this with much confidence.

3.3 Recommendations

- o Continue support of wide efforts to more fully understand and quantify public health hazards from normal plant emissions.

- o Extend the hazard identification and ranking to front end fuel processing systems in order to add to the assessment any hazardous effect of these systems so that the hazards can be weighed against the benefits.
- o Add to the assessment those local hazards resulting from transportation of fuel and other consummables to the plants and of wastes from the plants.
- o Combine the ranking of safety hazards with available information on probability and consequences of accidents.
- o Integrate all of the foregoing work and produce review guidelines for ensuring that public safety is adequately considered in plant design and siting.