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U. S. DEPARTMENT OF THE INTERIOR, DEFENSE ELECTRIC POWER ADMINISTRATION
WASHINGTON, D. C.

ELECTRIC POWER SYSTEMS
VULNERABILITY METHODOLOGY

FINAL REPORT

BRIAN K. LAMBERT

AUGUST, 1976

PREPARED FOR U. S. DEPARTMENT OF DEFENSE, DEFENSE CIVIL PREPAREDNESS AGENCY, WASHINGTON, D. C. WORK UNIT 4334B, WORK ORDER OCD-PS-66-92

DETACHABLE SUMMARY

This report contains basic planning information for nuclear weapons effects damage estimating procedures in the electric power industry. Initial sections of the report include a comprehensive state-of-the-art summary and a general description of electric power systems. Initial planning steps concerning necessary information pertaining to generation, transmission, distribution and associated components are outlined.

Based upon discussion with electric power system engineers and operating personnel as well as civil defense planners, expanded and updated overpressure versus damage estimates are provided for major electric power system components. The report also includes discussions concerning electromagnetic pulse and potential thermal damage, and estimated repair times for selected components subjected to various overpressures.

Final sections of the report contain major conclusions and recommendations for damage estimating procedures. The principal conclusions in these discussions are: (1) electric power systems face the problem of complexity in design and operation and disruption of service at relatively low overpressures due to control system failures, (2) at moderate overpressure values (3 to 4 psi) considerable damage occurs to distribution systems requiring large repair efforts, (3) overpressures in the 5 to 6 psi range cause extensive damage to most parts of the system and supporting service systems, necessitating massive repair efforts, and (4) repair or replacement of components will pose a major post-attack problem due to the high cost and the specialized nature of many large components.

Appendixes include a selected annotated bibliography, overpressure versus distance values, and overpressure versus damage descriptions for major electric power system components.

U. S. DEPARTMENT OF THE INTERIOR
DEFENSE ELECTRIC POWER ADMINISTRATION
Washington, D. C. 20240

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Final Report

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Washington, D. C. 20301

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This report has been reviewed in the Defense Civil Preparedness Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Defense Civil Preparedness Agency.

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The data contained in the report can provide planners with the necessary information to identify critical components in an electric power system, estimate potential damage, establish priorities for →

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Analysis and evaluation of the data reveals that due to the complexity of an electric power system and because many major components would be exposed to direct weapons effects, system disruption could occur at relatively low levels of overpressure. Also, as overpressure values increase, massive restoration efforts will be required. In addition, complex spare parts are not readily available and, as a result, will pose a major post-attack problem.

The report also contains a state-of-the-art discussion, a description of major components and their relationship to the functioning of the overall system, and an annotated bibliography.

FOREWORD

Work reported herein was performed by the Defense Electric Power Administration, Department of the Interior, under Defense Civil Preparedness Agency Project Order OCD-PS-66-92. Mr. George F. Divine served as contract monitor for the Emergency Operations Systems Division (Research) within DCPA. Mr. George W. Penebaker served as project director for DEPA. The principal technical investigator was Dr. Brian K. Lambert, DEPA Representative, Lubbock, Texas. He was assisted by the DEPA staff -- Mrs. Lori O'Neill and Mr. Phillip Swart. Work was conducted as DCPA Work Unit 4334 B.

Penebaker

G. W. Penebaker
Administrator

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Much of the technical data, systems information, and advice was provided by personnel in the electric power industry. Although too numerous to mention here, their cooperation and generous use of valuable time is greatly appreciated.

ABSTRACT

This report presents expanded and updated overpressure versus damage estimates for major electric power system components and fundamental planning guidelines for damage estimation procedures.

The data contained in the report can provide planners with the necessary information to identify critical components in an electric power system, estimate potential damage, establish priorities for resource allocation and management in the event of system disruption, and make tentative repair effort estimates.

Analysis and evaluation of the data reveals that due to the complexity of an electric power system and because many major components would be exposed to direct weapons effects, system disruption could occur at relatively low levels of overpressure. Also, as overpressure values increase, massive restoration efforts will be required. In addition, complex spare parts are not readily available and, as a result, will pose a major post-attack problem.

The report also contains a state-of-the-art discussion, a description of major components and their relationship to the functioning of the overall system, and an annotated bibliography.

SUMMARY

ELECTRIC POWER SYSTEMS VULNERABILITY METHODOLOGY

Brian K. Lambert

U.S. DEPARTMENT OF THE INTERIOR
DEFENSE ELECTRIC POWER ADMINISTRATION

prepared for

U.S. DEPARTMENT OF DEFENSE
DEFENSE CIVIL PREPAREDNESS AGENCY

(DCPA Project Order No. OCD-PS-66-92, Work Unit 4334B)

This report contains basic planning information for nuclear weapons effects damage estimating procedures in the electric power industry. Initial sections of the report include a comprehensive state-of-the-art summary and a general description of electric power systems. Initial planning steps concerning necessary information pertaining to generation, transmission, distribution and associated components are outlined.

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these discussions are: (1) electric power systems face the problem of complexity in design and operation and disruption of service at relatively low overpressures due to control system failures, (2) at moderate overpressure values (3 to 4 psi) considerable damage occurs to distribution systems requiring large repair efforts, (3) overpressures in the 5 to 6 psi range cause extensive damage to most parts of the system and supporting service systems, necessitating massive repair efforts, and (4) repair or replacement of components will pose a major post-attack problem due to the high cost and the specialized nature of many large components.

Appendixes include a selected annotated bibliography, overpressure versus distance values, and overpressure versus damage descriptions for major electric power system components.

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I. INTRODUCTION

The purpose of a damage estimating procedure is to provide information regarding the amounts and locations of the resources which remain after a disruption to the system has been considered. Damage estimates provide the basic input data to decision-makers who must allocate and manage the remaining resources for the survival and recovery of the Nation. Reliable damage estimates are also necessary for determining the level of repair effort needed to restore a system to a given operating condition. Knowledge of the state of a system will enable planners to effectively utilize available repair resources in order to respond to predetermined priorities.

Post-attack inventories of damage can be done eventually by using on-site surveys of the actual situation. However, many months might be required to perform a complete post-attack analysis of remaining resources by conventional survey methods. Many decisions regarding resource allocation and utilization cannot wait for the completion of a detailed survey and analysis of the findings. Consequently, rapid estimating procedures are necessary to provide information on emergency problems in a nuclear attack situation. Equally important is the idea that damage estimating procedures are required prior to attack for use in developing plans and preparations for emergency situations.

With the importance of reliable damage estimates in mind and the obvious importance of the electric power industry to the survival and recovery of the Nation in the event of nuclear attack, the Defense Civil Preparedness Agency working with the Defense Electric Power Administration made the decision to update and expand damage estimating procedures for the electric power industry. These procedures are intended to provide a meaningful basis upon which realistic estimates of damage to electric power systems can be made.

Based on updated overpressure damage estimates, the report contains procedures that will enable civil preparedness planners in government and the electric power industry to manually perform real time nuclear weapon overpressure damage estimates on key components, nodes and links of the electric power system. Because the report encompasses many previously published works, it is especially important that the presentation contain a comprehensive "state-of-the-art" discussion. Hence, Section II contains summaries of completed research pertaining to damage estimates in the electric power industry. Section III presents a description of the major components in an electric power system and a discussion of how the components interact to make the system function. Section IV presents information regarding overpressure and the estimated damage to major electric power system components. Also presented is some information regarding the level of repair efforts needed to restore a system to operation. Section V contains major conclusions and identifies areas where additional research may merit consideration. References, supporting data and an annotated bibliography complete the report.

II. ELECTRIC POWER SYSTEMS DAMAGE ESTIMATION STATE-OF-THE-ART

One of the earliest reports concerning the effects of nuclear weapons on electric power systems was published by the Defense Electric Power Administration (DEPA) in 1963 (DEPA, 1962).* The report includes a listing of certain electric power system equipment and the overpressure required for equipment failure. The overpressure - damage relationships were derived from an Atomic Energy Commission (AEC) publication on the effects of nuclear weapons and are based on 1, 5, and 10 megaton weapons (AEC, 1962). A summary of the results of this study is presented in Tables I and II.

A study conducted by the National Engineering Science Company in 1963 provided some additional information regarding overpressure vs. damage to electric power components (Chenoweth, 1963). The overpressure - damage relationships presented in this study were developed primarily from the AEC publication, "The Effects of Nuclear Weapons." For generating stations, the components considered were: (1) air and flue gas systems, (2) feed water and steam systems, (3) circulating water systems, and (4) electrical systems. Based on the effects of small nuclear weapons (20 to 30 KT) the recommended damage criterion for a plant as a whole was 3 psi.

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* References may be located in the list of References by referring first to author name and then to publication date.

TABLE I

CRITICAL OVERPRESSURES FROM NUCLEAR BLASTS
FROM (DEPA, 1962)

Equipment	Avg. Overpressures (psi)	Description of Failure
Breaker and supporting frame, 69KV	10	Collapse of support frame
Reactor, 350 amp, single phase, oil immersed, self-cooled	23	Overturned
Regulating transformer, 2222 KVA	36	Overturned
Power transformer, No. 1, 12-69 KVA 20,000-25,000 KVA	25-35	Overturned
Turbo-generator units, 107,000 KW	30	None
Breaker terminals, BENTS	7	Collapse
Potential transformer, BENTS	8	Collapse
Transformer fire walls	4	Partial collapse
Station battery	20	None
Electric control panels	10	Overturned
Boiler side walls	2	Upper walls, cave-in
Stack breeching	3.5 to 6	Walls, cave-in
Air preheater walls	3	Walls, cave-in
Economizer walls	3	Walls, cave-in
Boiler stack	4-6	Overturned
Outside coal conveyor	7	Collapsed
Main building structures steam generators	10	Partial collapse
Main building structures steam generators	15	Complete collapse
69 KV disconnecting switches	2 to 10	Severe damage

TABLE I

(continued)

Equipment	Avg. Overpressures (psi)	Description of Failure
Induced draft fan	3.5	Severe damage
Battery	3.5	Severe damage
Insulators	3.5	Severe damage
Power transformers	3.5 to 10	Severe damage
Generators, steam	10	Severe damage

TABLE II

BOMB DAMAGE SUMMARY
SUMMARIZED FROM (DEPA, 1962)

AIR BURST

Feature	Damage Radii (Mi) 1 MT	5 MT	10 MT	Type & Extent of Damage
Transmission line radial orientation	3.7	6.3	8.0	Inside damage zone, lines are broken and down--not operating. Outside zone line is easily repaired.
Transmission line transverse orientation	5.0	8.6	10.8	More severe damage than radially oriented. Difficult to repair.
Transmission line underground	8.2	17.7	22.3	Less severe than to surface lines. Damaged by secondary effects. Many still usable.
Buildings used to house generating facilities	3.7	6.3	8.6	Building damage occurs but equipment inside is generally undamaged although possibly inoperable.
Distribution transformers, outside	4.0	6.8	8.6	Usually undamaged up to 5 psi. At over 5 they are overturned and damaged.
Fire zone	4.5	7.7	9.7	Widespread fires in these areas. Poles may be destroyed and repair operations delayed.

The elements considered for transmission and distribution systems were: (1) wood pole transmission lines, (2) steel tower transmission lines, (3) cables and wires, and (4) substations. Again using small nuclear weapons in the 20 to 30 KT range, the general recommended overpressure - damage criteria were stated as:

(1) Transmission lines - 4 psi

(2) Substations - 4 psi

(3) Distribution lines - 2 psi

Also in 1963, the Defense Electric Power Administration published a report entitled, "Vulnerability of Electric Utilities to Nuclear Attack," (DEPA, 1963). No overpressure versus damage data were used for damage assessment; instead, blast effects were measured in terms of severe, moderate, or light. Severe damage was considered to mean that a facility was permanently destroyed or damaged beyond repair; moderate damage implied that extensive repairs were necessary (over 120 days) until the facility could be placed back into service; light damage meant that the facility would be out of service a short time but operable with minor repairs. The damage category in which a facility was placed was determined by the weapon size and distance in miles from ground zero, and is given as follows:

Weapon Size	Severe	Moderate	Light
1 MT	1 mile	2 miles	7 miles
5 MT	2 miles	3 miles	9 miles
10 MT	3 miles	4 miles	12 miles

The Edison Electric Institute conducted a study based on data gathered at the Nevada Test Site in 1955 (Wood, 1965). Various types of transmission, substation, and distribution equipment were subjected to the detonation of a 30 KT weapon. The equipment was placed 4700 feet and 10,500 feet from ground zero. The estimated overpressure at the 4700 foot line was approximately 5 psi and at the 10,500 foot line the overpressure was estimated to be 2 psi. All of the damage reported occurred at the 4700 foot installations with none being incurred at the 10,500 foot installations. The report states:

> "The damage to the electric system at the 4700 ft. line was moderate. The type of damage appeared similar to that caused by severe windstorms and was due to the blast effect and missiles rather than to the thermal or radiations effects of the explosion" (Wood, 1965).

All of the damage reported at an estimated 5 psi overpressure was considered repairable in a reasonably short time with materials normally carried in stock by utility companies.

Stanford Research Institute published a report in 1966 entitled, "Methods for Evaluating the Effects of Nuclear Attack on the Ability of Power Systems to Meet Estimated Postattack Demands," (Doll, 1966). The report includes damage categories and approximate overpressures based on a one megaton weapon for various electric power system components. The overpressure - damage values were derived from the U.S. Air Force Nuclear Weapons Employment Handbook. The approximate mean lethal overpressure values used in this study are summarized in Table III.

A report by the URS Corporation in July, 1967 presented the results on the relationship between weapons effects, system damage, and repair

TABLE III

DAMAGE - OVERPRESSURE VALUES SUMMARIZED FROM (DOLL, 1966)

Damage Description	Approximate Mean Lethal Overpressure (psi)
Severe structural damage to power plants	14.0
Moderate structural damage to power plants	7.5
Collapse of switchyard frames. Severe damage to switches and circuit breakers and to bushings and insulators on transformers. Interior control panels overturned.	5.5
Transformers overturned	9.5
Transmission lines down	4.4
Crushing of boiler walls, stack breachings, and fan housings. Some rupturing of piping.	7.8
Miscellaneous light damage - glass breakage, cracks, dust and debris damage	2.0

requirements (URS, 1967). A megaton - range weapon size was assumed and the worst effects of both air burst and ground burst weapon detonation location were considered while preparing damage predictions.

Beginning in 1967 a series of three reports pertaining to the "Five City Study" were published by the Defense Electric Power Administration (DEPA, 1967; DEPA, 1969; DEPA, 1970). Included in each of these reports is a list of failure pressures for certain transmission and distribution components. This list is presented in Table IV. The failure pressures given are based on a weapon size of one megaton or larger and are classified as to whether the installations are in an open area or in a building. The failure pressure as specified for installations in the open is for widely cleared areas. For open type installations in wooded or in built-up areas, the failure pressure is assumed to approximate that of installations in buildings.

A paper entitled, "Effects of Nuclear Blasts on Utilities," published in 1971 (Sisson, 1971) presents some general information pertaining to overpressure damage relationships for electric, gas, water, sewerage, and communications systems. The data on electric power systems is given as an overpressure range and a general damage description. The report also states:

> "The vulnerable portions of electric power transmission and distribution systems are the above ground portion - power lines, poles, transformers, substations, etc. Most of these features are 'drag sensitive,' i.e., they will be most sensitive to the high wind forces (dynamic pressure) following the shock front. Others may be relatively insensitive to both overpressure and dynamic pressure but may be damaged by flying tree branches or by the debris created by the collapse of the enclosing structures" (Sisson, 1971).

TABLE IV

VULNERABILITY OF TRANSMISSION AND DISTRIBUTION EQUIPMENT
FROM (DEPA, 1967)

Itemized Electrical Equipment	Failure Pressure - Psi: Installations in Open	Failure Pressure - Psi: Installations in Buildings
1. Power transformers (w/radiators)	10	4
2. Power transformers (w/o/radiators)	10	4
3. Bushings and insulators	10	4
4. Regulators	5	4
5. Capacitors	7	4
6. Oil Switches	7	4
7. Reclosers	7	3
8. Sectionalizers	4	3
9. Radio transmitters, receivers	4	4
10. Street light relays	4	4
11. Breakers, terminals	5	3
12. Electric control panels	4	3
13. Reactors, 350 amp, oil emersed	10	4

Itemized Equipment of Stations	Installations in Open	Installations in Buildings
1. Switch, disconnect, manual	5	3
2. Coupling capacitor	7	4
3. Synchronous condenser	10	4
4. Oil circuit breaker	5	4
5. Air circuit breaker	3	3
6. Vacuum circuit breaker	3	3
7. Recloser, oil	7	3
8. Recloser, vacuum	7	3
9. Capacitor banks	7	4
10. Fuse	5	3
11. Fuse, cutoff	5	3
12. Regulator	6	4
13. Battery	3	3
14. Battery, charger	4	4

In addition to the studies relating directly to damage assessment in the electric power industry, the Defense Civil Preparedness Agency and the Defense Electric Power Administration have conducted research focused on evaluating the total vulnerability of electric power systems. The results of such system evaluation studies are presented in two reports, "Vulnerability of Regional Electric Power Systems to Nuclear Weapons Effects" (Lambert and Minor, 1973), and "Regional Manufacturing Systems: Nuclear Weapons Effects and Civil Defense Actions" (Lambert and Minor, 1975).

Considerable research has been done in the area of damage assessment. For example, the Department of Housing and Urban Development published a damage assessment manual for personnel in the HUD organization (HUD, 1966). In addition the Department of Transportation developed a report on manual damage assessment procedures for the civil transportation system of the United States (DOT, 1968). Other damage assessment methods have been developed by the Defense Civil Preparedness Agency and the Federal Preparedness Agency.

To be complete, the technical status summary must include the potential effects of nuclear electromagnetic pulse (EMP) on electric power systems. This phenomenon will have an effect on the functioning of an electric power system - the total extent of the potential disruption has not yet been determined but partial information is available and considerable research is currently being done in the area. One report concerned countering the effects of EMP in commercial power systems (Nelson, 1971) and discusses problems associated with electromagnetic phenomena resulting from high altitude nuclear detonations. Also included in the study were discussions of coupling methods, estimates of induced surge magnitude on transmission lines and control cables, and comparisons with direct lightning strikes and switching surges. The report considers the type and probability of damage or malfunction from EMP effects, and counter measures to reduce disruption and to harden electric power systems. A study of EMP effects on a distribution network has been completed (Marable, et. al., 1973) through an analysis of a power distribution substation. Other studies presently underway include an evaluation of the effects of EMP on power system monitoring and control equipment, and EMP effects on a typical interconnected power pool.

Considerable progress has been made towards developing suitable procedures as evidenced by the previous paragraphs describing the progress of research concerning damage assessment in the electric power industry. However, despite these advancements several areas need additional work. These deficiencies are discussed as follows.

Observations made of the data pertaining to overpressure - damage relationships for electric power system components indicate an extremely wide range of overpressure values presented by different sources for similar types of equipment. Consequently, a more complete and updated, comprehensive listing of specific generation, transmission and distribution components along with specific critical overpressure versus damage values is needed. Additionally, the current state-of-the-art indicates the need to develop a methodology for use in the field by electric power system planners (both private and governmental) which would assist in the preparation of realistic damage assessments based upon real or assumed nuclear attacks. It is these deficiencies which are considered in this study.

In addition to the previous research efforts discussed here, other work in related areas is briefly described in the Annotated Bibliography presented in Appendix A.

III. SYSTEM DESCRIPTION

A. Introduction

Prior to a discussion of the physical vulnerability of electric power systems it is necessary to identify and describe the major components of the system. To estimate damage to the system and identify critical points, the analyst must have a knowledge of the operation of the major components and how these components interact in performing the functions of the system. A discussion of the major components of an electric power system and a general description of how these components function within the overall system is contained in the following paragraphs.

One category of equipment within an electric power system is the generating components. A main portion of this group is generating stations which may be thermal stations using various types of fuel such as coal, oil, or gas; or they may be hydroelectric stations or nuclear power plants. Associated with the power station is a switchyard. When the power station is near a load center the yard will contain relatively low voltage distribution or subtransmission equipment. However, if the generating station is some distance from the load center, then the switchyard will contain transformers to adjust the voltage to a suitable transmission value. In addition, the switchyard contains circuit breakers and certain control equipment.

The second major category of components consists of transmission lines and transmission substations. The substations are comprised of transformers for reducing the high voltage of transmission to medium voltage to supply the feeders at the required voltage of the primary distribution network and the necessary circuit breakers and control equipment. The transmission line consists of the conductor itself, poles, towers, and associated hardware.

The third category of equipment within an electric power system is the distribution components. Contained in this group are the distribution substations which have transformers to step down the voltage of the primary distribution network in order to supply pole mounted transformers or transformers in vaults for general distribution to customers. Other components include the distribution lines, poles, hardware, and control circuitry. Also, some systems may have substations designed to give service to large industrial customers at transmission voltage, at subtransmission voltage, or at distribution voltage depending on the size and location of the customer.

In addition to the generating, transmission and distribution categories, additional components are involved in the functioning of an electric power system. These additional components include maintenance equipment, communications equipment, fuel supply systems, inventories of spare parts, etc.

The following paragraphs of this section contain more detailed descriptions of the major components of the groups discussed above.

B. Generating Stations

An electric power station is, in essence, an entity for converting energy from one form or another into electrical energy. In a conventional thermal station the energy is first found in the form of heat in the fuel. Generally, the fuel is coal, gas, or oil. The heat is freed from the fuel by combustion and is used to convert water into steam. The energy contained in the steam is then converted into mechanical energy and then to electrical energy by means of a generator. Nuclear power plants utilize atomic energy in the form of heat in the reactor to convert water into steam. A nuclear station, excluding the extensive control systems, is relatively similar to a thermal station except that it utilizes a reactor rather than a boiler. A hydroelectric station converts the potential energy of water stored at a height into mechanical energy by the use of a water turbine. The turbine is coupled to a generator for conversion to electrical energy.

The major components of each of these generating station types are discussed as follows.

1. <u>Steam Stations</u>

A modern steam station utilizing coal as the fuel consists of the following major equipment:

1. Boiler plant

   Coal bunker

   Stokers

   Coal pulverizers

   Air preheaters

   Economizer

   Feedwater heaters

   Deaerator

   Boiler feed pump

   Forced draft fan

   Induced draft fan

2. Turbine generators

   Governor

   Generator cooling system

3. Condenser

   Condensate pump

   Circulating pump

4. Switchgear for generator control

5. Switchgear for auxiliary control

A more comprehensive breakdown of components is given in Table V.

Using a coal station as an example, the fuel is usually brought to the site by means of rail or barge. The coal is crushed or pulverized and transferred by conveyor to the bunkers. The coal is fed to the boiler furnace in a slanting hopper coming down from the bunker. The fuel is burned in the furnace of the boiler system and for efficient combustion enough air must be supplied. Natural draft is provided by a chimney and additional draft is supplied by induced draft fans or forced draft fans. The heat produced in the furnace is used to convert water in the boiler into steam at the required pressure and temperature. The heat is also used for the superheater which improves the economy of the heat cycle by increasing the Btu content of the steam and reducing its moisture content. To utilize the remaining heat the gases may pass through an economizer to heat the feedwater in the economizer tubes. Also, an air preheater is used to initially heat air going to the furnace. The residue of the burnt fuel goes down the chain grate as ash to a channel where it mixes with water

TABLE V

GENERATING STATION COMPONENTS
(COAL FIRED)

A. Turbine-generator

B. Turbine auxiliaries

1. condenser
2. circulating water pumps
3. waterside vacuum pumps
4. steamside vacuum pumps
5. condenser cleaning system
6. turbine oil conditioning equip.

C. Feedwater system

1. boiler feed pumps
2. hotwell pumps
3. feedwater heaters

D. Turbine room crane

E. Steam generating system

1. boiler
   a. furnace
   b. superheater
   c. reheater
   d. economizer
   e. circulation pumps
2. pulverizers
3. burners
4. soot blowers

F. Draft system

1. forced draft fans
2. air heater
3. hot water air heating coils
4. precipitator
5. stack
6. induced draft fans

G. Ash handling system

1. ash hopper
2. crusher feeders
3. storage hopper
4. pumps

H. Coal handling system

1. unitrain
2. receiving hopper
3. vibrating feeders
4. collecting belt conveyor
5. inclined belt conveyor
6. stacker tower
7. movable boom conveyor
8. coal silos

I. Instruments and computer

1. load dispatching computer
2. alarm system
3. sampling system

J. Water treatment system

1. clarifiers
2. filters
3. water tanks
4. demineralizers
5. exchangers
6. condensate storage tanks

K. Fuel oil system

L. Auxiliary boiler

M. Compressed air system

TABLE V

(continued)

N. Major piping

1. main steam piping
2. cold reheat piping
3. hot reheat piping
4. high pressure boiler feed piping

O. Major electrical equipment

1. generator transformers
2. main generator leads
3. high voltage transformer leads

P. Switchyard equipment

1. load interrupter switch
2. grounding switch
3. circuit breakers
4. bus ties
5. generators
6. disconnecting switches
7. relays

Q. Auxiliary electrical equipment

R. Start up transformers

and the mixture is then taken to a sump for removal.

The steam from the boiler system is transmitted to the turbine which may be either an impulse or reaction type or some combination. The turbine converts the energy in the steam into mechanical energy in the form of a rotating shaft. This mechanical energy is then converted to electrical energy by means of a generator which is coupled to the turbine.

After passing through the turbine the steam goes to a condenser. The condensers are usually a surface type in which the steam enters a cylindrical vessel from the turbine exhaust and passes over the surface of brass-alloy tubes through which cold water is circulated. The condensed steam falls into the hotwell in which the condensate is collected and from which it is pumped by the condensate pump into the first stage heater. Some water may be lost owing to leakage through steam traps, etc., so water is added in the feedwater system as make-up water. Raw water is passed through the evaporator, heated to steam and condensed into water in the evaporator and then passes through the feedwater pump into the feedwater system in the boiler. A schematic representation of such a system is presented in Figure 1, and Figure 2 shows a flow chart for a typical coal fired thermal station.

2. Hydroelectric Stations

Water power systems can be classified into three basic types: (1) those which dam the water and have spillway, control gates, and powerhouse in a somewhat integrated unit; (2) those which short circuit a part of the river fall by means of a pipeline, tunnel or canal; the dam and the

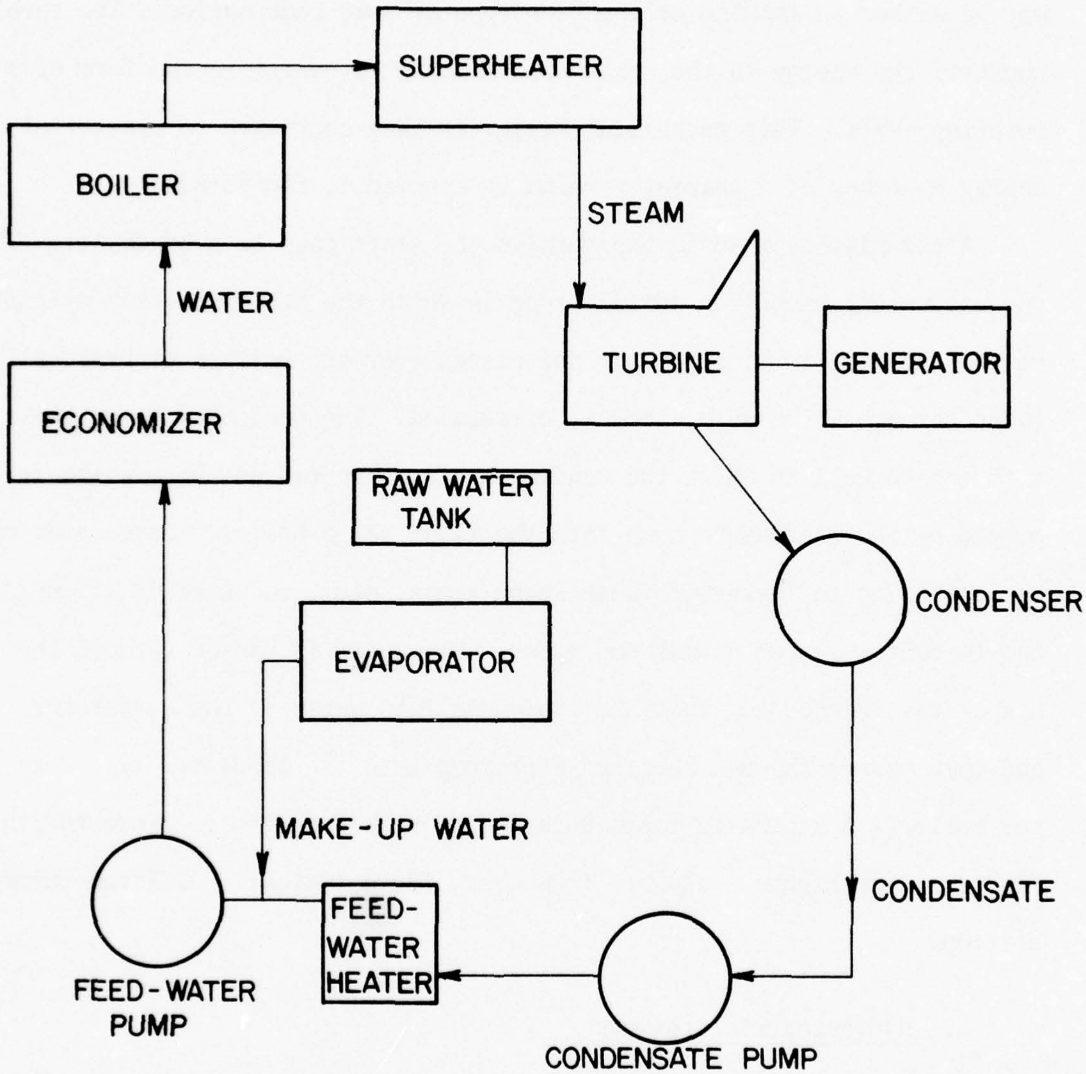

Figure 1. Major Components for a Thermal Unit

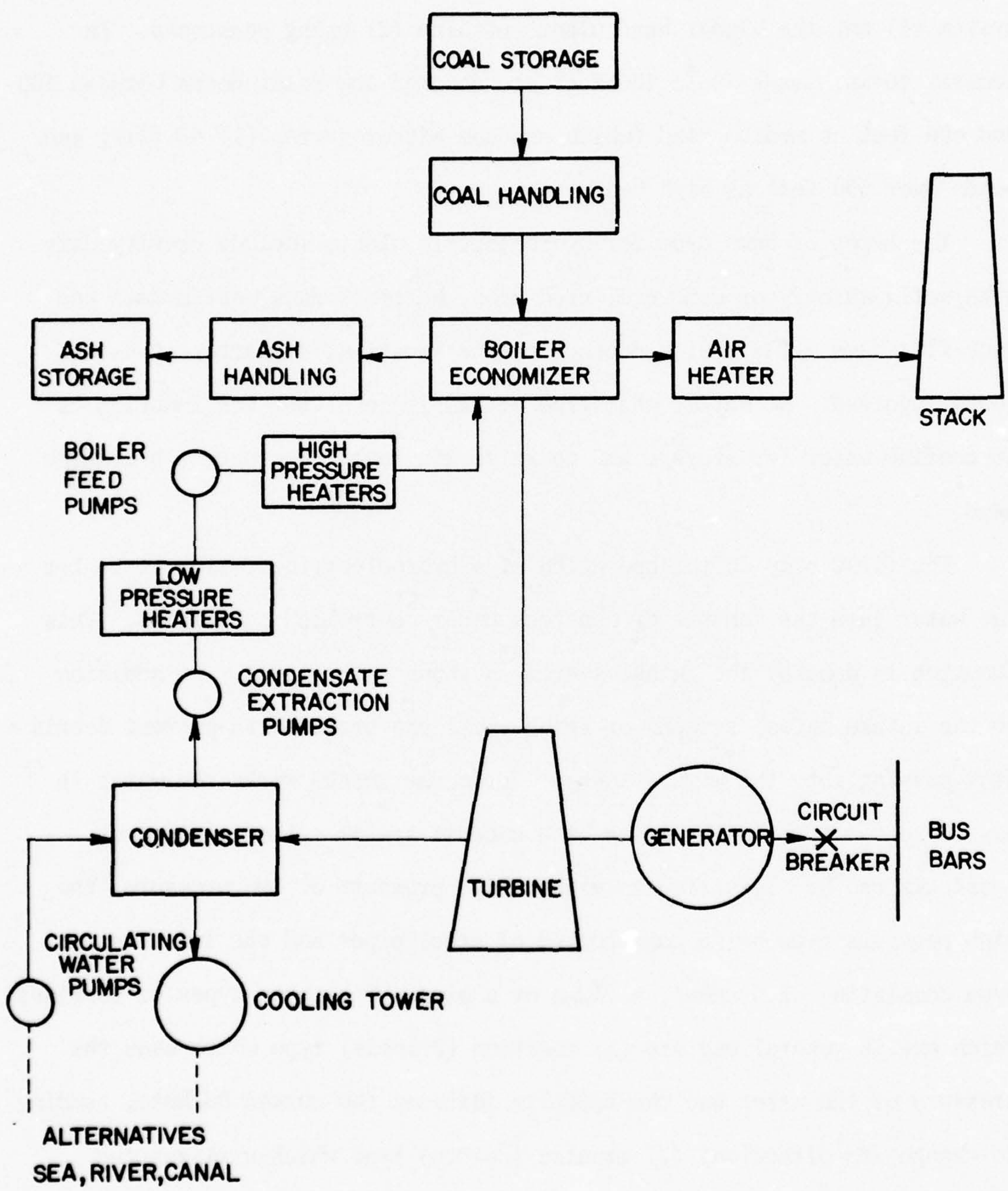

Figure 2. Block Diagram of Coal Thermal Station

spillway may be at some distance from the powerhouse which is usually at the bottom end of a penstock which brings water down from the pipeline, tunnel or canal; and (3) pump storage installations. Low head plants usually use system (1) and the higher head plants utilize (2) using penstocks. In general terms, heads 20 to 100 feet are denoted low head; heads between 100 and 600 feet as medium head (which can use either system (1) or (2)); and heads over 600 feet as high head.

The types of dams used for hydroelectric plants include gravity dams with solid masonry or concrete, arch dams, buttress dams, earth dams and rock-fill dams. The choice depends on the location, characteristics and costs involved. No matter what type of dam is involved, its function is to confine water for storage and to raise its level to create a hydraulic head.

The first step in the operation of a hydroelectric station is to let the water into the conduit or penstock under controlled conditions. This function is done by the intake system as shown in Figure 3. In addition to the intake gates, screens or trash racks are provided to prevent debris from passing into the water passage. From the intake works the water is passed to the turbines by means of a conduit system called a penstock. Penstocks can be classified as either high pressure or low pressure; the high pressure type being constructed of steel pipes and the low pressure type consisting of a canal, a flume or a pipe. The three types of turbines which are in general use are (1) reaction (Francis) type which uses the pressure of the water and the reactive force on the curved buckets, tending to change its direction; (2) impulse (Pelton) type which utilizes the

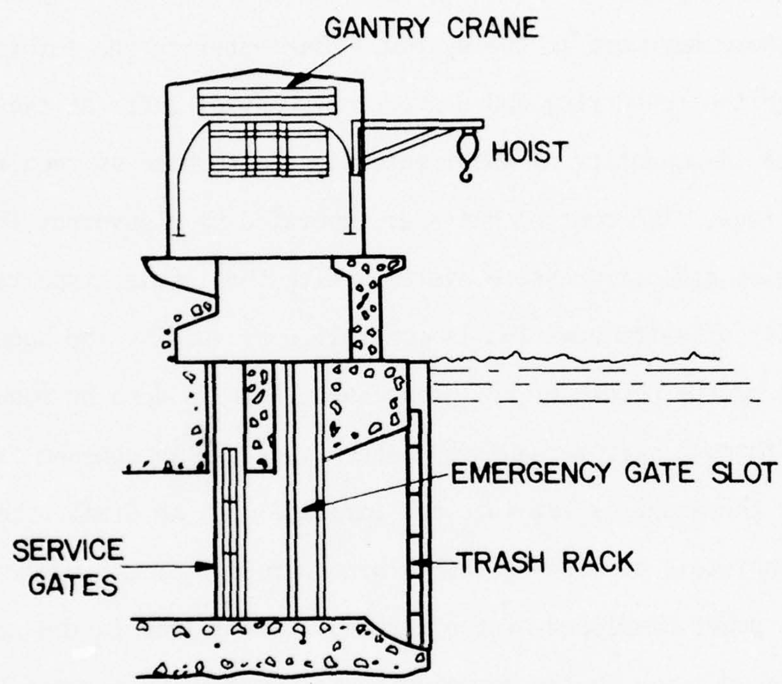

Figure 3. Intake System-Hydroelectric Plant

velocity and impact of a jet of water against buckets arranged around the periphery of a wheel and (3) propeller (Kaplan) type which is actually a reaction type turbine of special design utilizing the axial flow principle. In general, propeller types are used for heads up to 100 feet, reaction types for heads between 70 and 1000 feet, and impulse types for heads between 300 and 3000 feet. In a reaction turbine the water is let out through a draft tube into the tail-race without loss of pressure to the atmosphere anywhere in the system. When entering the turbine water passes through the speed ring and a number of control gates at the speed ring control the quantity of water entering the turbine as required by the load conditions. The control gates are operated by a governor through a servo-mechanism and oil pressure system. With the impulse type turbine the quantity of water admitted is controlled by varying the opening of the nozzle by the needle or by throttling. This is done by means of a governor, again through servomechanisms. After the work is done on the turbine runner the water is let into the tailrace with no draft tube being required. The generators coupled to the turbines produce electric power corresponding to the power developed by the turbines less losses in the system.

In addition to the components discussed above a surge tank is necessary to handle water hammer. When the gates admitting water to the turbines are suddenly closed by the action of the governor when the load on the generator is suddenly reduced there is a change in pressure in the penstock pipes. This sudden pressure change is known as water hammer. To provide better regulation of water pressure in the system under water hammer conditions a surge tank is provided as illustrated in Figure 4.

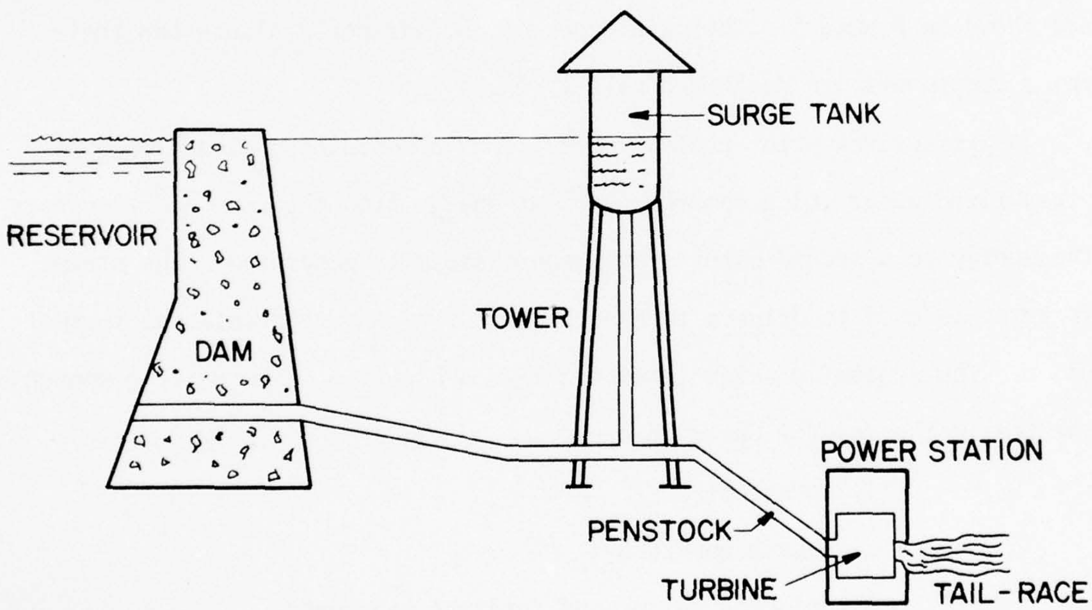

Figure 4. Water Hammer Compensation

3. Nuclear Power Plants

Conventional thermal power stations use oil, coal or gas as the energy source. In a nuclear power station instead of a furnace a nuclear reactor is used to generate heat. A cooling medium takes this heat and delivers it to a heat exchanger where steam for the turbine is produced. Thus, the reactor and heat exchanger are equivalent to the furnace and boiler in a conventional steam plant. The remainder of a nuclear power plant, other than special controls, shielding, waste disposal, etc., is similar to a conventional thermal plant. The basic components of a nuclear power plant are shown in Figure 5. The main types of nuclear power plants and their major components are described as follows.

A pressurized water nuclear power station contains a closed loop of pressurized water which removes the heat energy from the core and transfers the energy to a second water system where steam is generated. The steam, in turn, is used to drive a turbine generator as in a conventional thermal plant. The system is shown schematically in Figure 6. The major components located in the reactor building are:

1) pressurizer
2) steam generators
3) reactor vessel and internal components
4) reactor core
5) drive mechanisms
6) fuel transfer equipment
7) control rods
8) primary pump
9) associated hardware

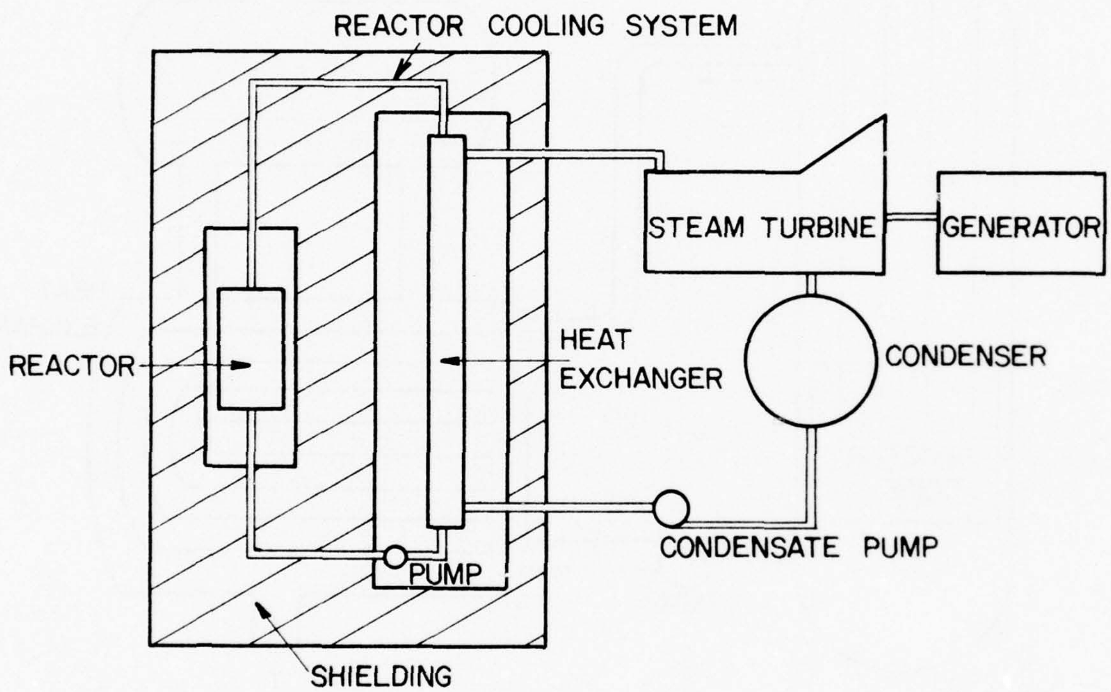

Figure 5. Nuclear Power Plant-Major Components

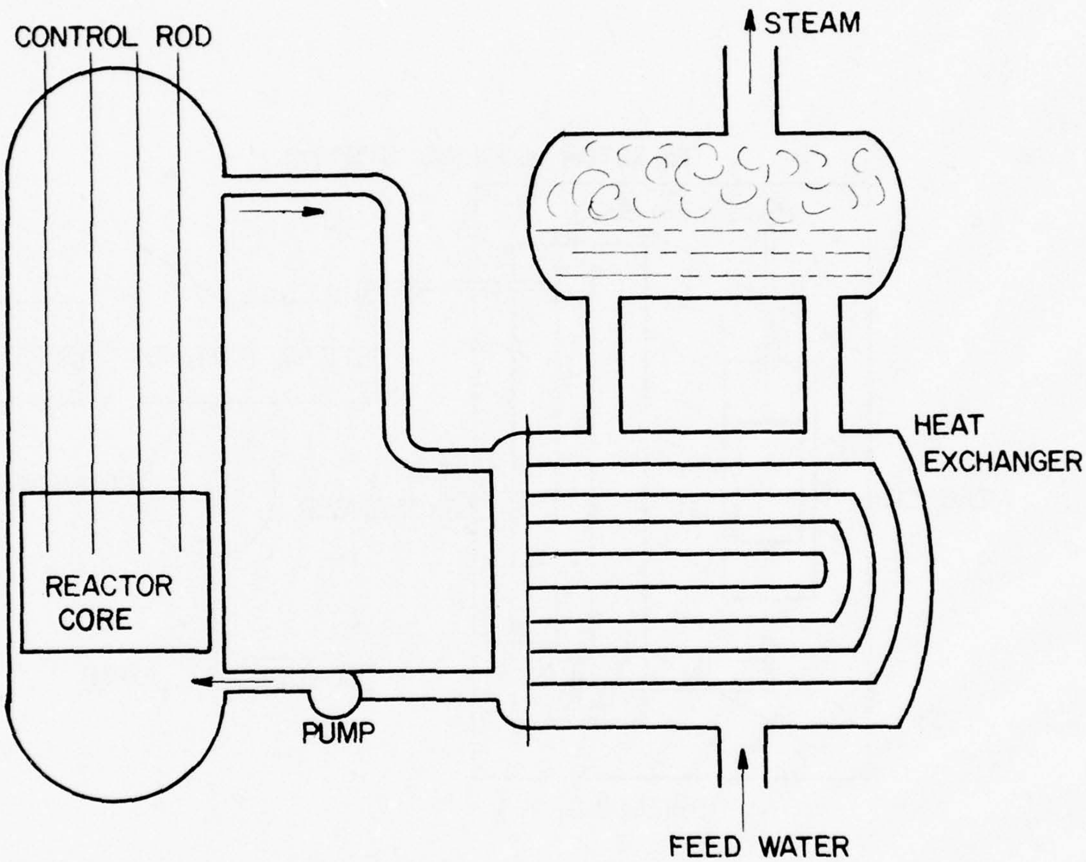

Figure 6. Pressurized Water Reactor Components

In addition to the reactor building, the fuel handling building contains the spent fuel storage pool, bridge crane and all of the spent fuel cooling system equipment. This building is connected to the reactor building by the fuel transfer tube. The auxiliary building houses the residual heat removal system, the chemical and volume control system, safety injection system, radioactive waste system, closed loop cooling system, plus any air handling equipment required. In addition, there is a control building, or wing, containing the central control room as well as the relay room.

A second type of nuclear power plant is called a boiling water reactor system and is a direct cycle steam generating system as shown in Figure 7. Water is boiled by the core in the reactor vessel and the wet steam passes up through moisture separators and steam dryers and goes to the turbine.

The reactor building entirely surrounds the containment and has four or five stories. The top floor has a spent fuel storage pool, refueling equipment and a service crane of at least 100 ton capacity. The remainder of the building houses the following: (1) control rod drive hydraulic system, (2) reactor water cleanup system, (3) standby liquid control system, (4) high and low pressure core spray systems, (5) automatic blowdown system, (6) residual heat removal system, (7) reactor core isolation system, (8) spent fuel cooling system, (9) closed loop cooling system, (10) standby gas treatment system, and (11) ventilation system.

The "radwaste" building houses the radioactive waste system and all necessary ventilation equipment. The control building contains control consoles, relay racks, instrument panels, battery sets, D.C. motor generator

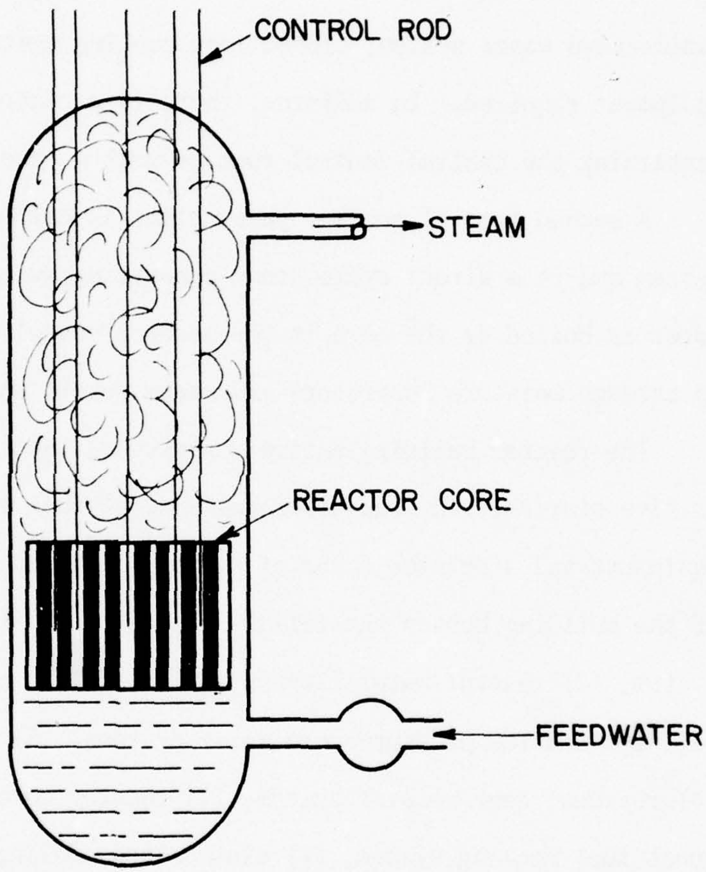

Figure 7. Boiling Water Reactor Components

set, instrument air compression and storage system, plus the regular air conditioning and ventilating equipment for the building.

Sodium-graphite reactors constitute a third type of nuclear power plants. In this type, graphite is used as the moderator, and liquid sodium as the coolant. An intermediate heat exchanger is necessary between the reactor and the boiler. This intermediate exchanger utilizes liquid NaK, an alloy of sodium and potassium, to carry heat to the boiler.

One other type of nuclear plant utilizes a fast breeder reactor. When U-235 is fissioned it produces heat and also additional neutrons. If U-238 is contained in the same reactor, some of the additional neutrons available after reacting with U-235 convert U-238 into plutonium which is fissile. Thus the reactor produces heat and, at the same time, can be used to generate more fissile material. If the process is efficient more fissile material is produced than can be consumed. This process is known as breeding. A fast breeder reactor is a vessel which contains the required amount of enriched uranium or plutonium. Surrounding the vessel is a blanket of depleted uranium which can absorb the neutrons and converts the fertile material into fissile material. The reactor core is cooled by liquid metal and neutron shielding is provided by utilizing boron, light water, oil, or graphite. Also, gamma ray shielding is done via lead, concrete, or concrete with added barium or magnetite.

4. Generating Station Auxiliary Equipment

As stated earlier the purpose of the generating station is to convert a given form of energy into electrical energy. This conversion process depends to a large extent on many auxiliary pieces of equipment. The auxiliary equipment can be considered to consist of:

1) A low voltage supply for auxiliary power
2) Fans for combustion purposes
3) Pumps for feedwater and condensate
4) Pumps for condensing water
5) Miscellaneous equipment

The auxiliary power requirement in most generating stations amounts to approximately six to eight percent of the station output and this supply voltage is usually 440 and/or 2400 volts. Because reliability of supply is extremely important it is usual to provide two sources one normal and a stand-by system. In some situations only the essential auxiliaries are connected to the regular supply bus and transfer relays are arranged to change over automatically from the regular to the stand-by supply in case of loss of voltage in the normal supply. In other cases, two supplies are operated in parallel and provision is made to eliminate one in case of failure. The principal methods of normal supply include: (1) transformers connected to the station bus, (2) transformers connected to the generator leads, (3) one or more house turbine-generators, (4) auxiliary generators coupled to the main generators, and (5) supply from another station through transformers.

There are two major fans required for boiler operations in thermal plants: (1) the forced draft fan used to supply air required for combustion, and (2) induced draft fan for blowing products of combustion up the stack. Speed control of fans is done by means of adjustable speed motors or constant speed motors and slip couplings. Damper control involves the throttling of air flow in the fan outlet circuit and vane control involves a system where the air to the fan is controlled by adjustable vanes in the fan inlet.

The numerous pumps in a station constitute a considerable part of the load on the auxiliary system. Generally, they can be classified into three groups: (1) the boiler pumps comprising the condensate and feedwater pumps with booster and recirculating pumps, if used; (2) the circulating pumps for the condenser; and (3) a large number of miscellaneous pumps for feedwater makeup, ash sluicing, fire protection, sumps, etc. Many of the pumps are essential to the continuity of service. For example, to maintain a flow of steam to the turbine, a flow of water must be maintained to the boiler. The flow of boiler feedwater is dependent upon the condensate pump, the booster pump (if used) and the boiler feed pump. Certain nonessential pumps can be out for long periods of time without causing a drastic effect on service. For example, the pumps in the feedwater makeup system may be out as long as there is water in the storage tank.

Generally, the auxiliary problem in hydroelectric stations is not quite as complicated as that occurring in steam plants. The portions of the hydroelectric station used for the production of mechanical power are relatively simple. Because of this there are usually not so many normally running auxiliaries nor are there so many of the type from which an uninterrupted operation is required to avoid shutdown caused by failure of the service alone. However, there are some problems peculiar to hydroelectric auxiliary systems. Because many hydroelectric stations are relatively isolated, these should be capable of independent starting and operation under emergency situations especially in the event of possible failure of ties to other stations.

C. Transmission Components

Stations which transmit power at voltages above that of the generator have a switchyard where the high voltage equipment is located. This facility consists of stepup transformers, breakers, isolating switches, lightning arresters, buses, etc. At the other end of the transmission line the equipment used is essentially the same but in the stepdown mode. In between is the line itself: the conductors, insulators, towers or poles, protective devices, and all other associated equipment. The various pieces of equipment which constitute the transmission system are discussed as follows.

1. Transformers

Transformers, either stepup or stepdown used in transmission systems are of two general types: core and shell. In the core type the steel punchings are arranged to form a single magnetic circuit consisting of legs over which the windings are mounted and a top and bottom yoke. The shell type unit has a single set of windings with two magnetic circuits encircling each side of the coils.

Several methods are used for cooling transformers and the methods used can affect their rating and size. Self-oil-cooled transformers employ a cooling surface which is provided by radiators through which oil circulates by natural convection. By blowing air over the radiator surface by fans the rate of heat dissipation can be increased - resulting in the forced are cooled type transformer. Further increases in capacity can be achieved by forced oil cooling which involves circulating oil through the radiators with pumps in addition to blowing air over the radiation.

As implied by the name, self-oil-cooled transformers do not require external equipment and are self contained. Forced air cooling and forced oil cooling transformers, however, require auxiliary power supplies for fans and pumps. In situations where large power transformers are located near hydroelectric stations water may be used for cooling the radiator oil in a separate heat exchanger. Steam stations may also utilize this method if the water supply is available. However, this method needs pumping equipment and a reliable source of power. With respect to size, self-oil-cooled transformers have the largest weights and dimensional sizes compared to forced air cooled and forced oil cooled units.

2. Circuit Breakers

A circuit breaker may be defined as a device for interrupting a circuit between separable contacts. Generally, they are required to function infrequently. Breakers operate to close and open circuits under load when conditions are normal and to interrupt circuits during abnormal conditions.

Circuit breakers may be classified into two broad categories: air and oil types. In air break circuit breakers the arc is initiated and extinguished in basically static air in which the arc moves. Air blast breakers utilize a blast of air to convert the arc path into an insulator. In oil breaker types, oil plays a primary role in the interrupting process.

Air break circuit breakers are generally used for low voltages up to 15 kv and interrupting capacities of 500 MVA. The main contacts for carrying currents permanently are of copper. A pair of contacts of tungsten or similar material is used to carry the total current only during the process of interruption. Air blast breakers utilize compressed air stored in a tank and released through a nozzle to produce a high velocity jet which is used to extinguish the arc. Such breakers may be either axial blast or cross blast. Air blast breakers are used primarily for indoor service in the medium - high voltage field and medium interrupting capacity - usually up to voltages of 15 kv and capacities of 2500 MVA.

The oil circuit breakers are the most common type utilized in power stations and transmission lines. Common ratings are from 25 MVA at 2.5 kv to 5000 MVA at 230 kv. Plain tank type oil breakers operate satisfactorily when the current under interruption is neither too large or too small. Such breakers have their stationary contacts and arc enclosing devices arranged in large oil filled steel tanks with the tank at earth potential and the oil insulating all live parts of the breaker from the earth. These breakers require relatively large tanks and a large volume of oil which increase in proportion to the voltage rating of the breaker.

Another type of oil breaker is the oil impulse breaker. This type employs an arc-extinguishing oil jet produced by a piston pump. The pump is externally activated by means of a spring or compressed air. The jet of oil is aimed at the gap formed between the separating contacts of the breaker to extinguish the arc.

3. Switchboards

Commonly, switchboards are self-supporting duplex boards with front and rear vertical panels both of which carry various instruments and relays. Often metal enclosed switchgear is used with completely enclosed breakers, instrument transformers, buses and connections and provision is made for disconnecting live components when it is necessary to gain interior access. Control power to activate switchgear in generating stations and major substations is often provided from storage batteries with the larger batteries charged by motor generator sets. Supervisory control equipment provides remote control of substations or power plants. Such control includes such operations as closing or tripping circuit breakers, starting or stopping generators, adjusting the loading and voltage of generators, etc., and may be accomplished remotely either by manual means or by computer control.

4. Relays

A basic definition of a relay is that it is a mechanism which reacts to some condition to cause the operation of some other device. In power systems relays receive energy for operation from potential and current transformers connected to the circuit being considered. These transformers are generally referred to as instrument transformers. The major types of relays are: (1) overcurrent relays which are primarily used for protection of circuits and equipment; (2) differential relays which are generally used for removing faulty transformers or generators from the circuit; (3) directional relays which are used in applications where the current can flow to a fault from two directions and it is necessary to give the relay a sense of direction if the loss of circuits is to be contained to the faulty section; and (4) distance relays which measure either the impedance or reactance of the circuit between the relay and the point of fault as a measure of distance by balancing the voltage drop in the faulted circuit against the current of the faulted circuit.

D. Distribution Components

In general, the customers of an electric power system can be categorized as residential commercial, or industrial. Most industrial and commercial customers are supplied at distribution voltages. The distribution system can be divided into three major parts: (1) the subtransmission circuits and distribution substations, (2) the primary distribution circuits, and (3) the distribution transformers and secondary circuits.

The subtransmission system brings power from the bulk supply stations to the distribution substations. Usually the voltage of these systems varies from 1,200 to 69,000 volts and the circuits may be open wire on wood poles or cable in underground ducts. The major circuit arrangements are radial, loop, and grid with possible combinations and modifications dependeing on the transmission system and the nature of the area served.

With a radial system the circuits to the distribution substations radiate from the bulk power source. Generally there are two circuits in order to ensure supply to the substation in the event of a line fault. In the loop arrangement, a single circuit beginning at one of the bulk power stations passes through a number of substations and returns to the same station. In a grid system no attempt is made to restrict the supply of any substation to a single bulk power station. The stations are tied together as in a loop system but the subtransmission circuits may begin at one bulk source and terminate at another.

The subtransmission lines are generally wood pole construction with pin type and post type insulators on wood cross arms. In the case where a ground wire is unnecessary a common arrangement is a single cross arm with the middle phase insulator on top of the pole. The specific type of construction used varies throughout the country depending upon the isokeraunic level.

Large substations (on the order of 10,000 to 40,000 kva) usually have a high voltage bus and several banks of transformers supplying the low level bus. The high voltage bus is sectionalized with the sections connected by automatic breakers. The smaller substations (on the order of 1500 to 7500 kva) are spaced closer together and can be factory built.

The primary distribution system is that part of the distribution system between the substation and the distribution transformers. The circuits from the substations are usually referred to as mains and the branches from the mains as laterals. In congested and heavy load areas, underground primary feeders are used rather than overhead lines.

The secondary system consists of the distribution transformers and wires to the service entrance of the consumer. The pole mounted transformers are usually provided with an automatic breaker and lightning arrester to make it self-protecting. The circuit breaker will open and disconnect the transformer from the system in the event of overloads and secondary circuit faults.

IV. ELECTRIC POWER SYSTEM COMPONENTS - DAMAGE ESTIMATION

A. Introduction

As previously pointed out reliable damage estimates are important for determining the status of a resource system so that decisions can be made regarding the allocation and management of remaining resources and for determining the level of repair effort needed to restore a system to a given operating level. This research effort was aimed at expanding and updating overpressure values and the resulting expected damage to major electric power system components. Thus, the effects of thermal radiation, nuclear radiation, ground motion, and electromagnetic pulse were not examined in detail since they were considered beyond the scope of this study.

The overpressure values and corresponding damage estimates presented in this section were developed by examination of previous studies, discussions and analysis with electric power industry engineers and operating personnel, discussions with Defense Civil Preparedness Agency personnel and, in some cases, by calculations. Unfortunately, very little experimental data pertaining to electric power system equipment is available; consequently, considerable reliance was placed on the judgement of qualified people in the industry and in civil defense personnel well acquainted with damage estimating methods.

B. Damage Estimation Planning

Pre-attack planning is an essential element of a successful damage estimation program. Of primary importance in such a planning program is the specification of the location and characteristics of major electric power system components. Also of high importance is the identification of specific critical components of the system. Since each individual electrical power system has its own particular characteristics a person or group knowledgeable about the system should be responsible for specifying the facility characteristics and associated component criticality. The following discussion will provide guidelines for such pre-disruption information necessary for planning.

1. Generating Components

Information necessary for damage estimation pertaining to generation components is listed as follows:

a) Plot the location of each generating station in the system by latitude and longitude on a system map for damage estimation purposes.

b) Specify the type of generating plant: steam, hydroelectric, nuclear, or internal combustion.

c) State the capacity of each plant (preferably each generating unit).

d) Specify the primary and secondary fuel types including the amount of reserve fuel supply at each station. The reserve fuel supply should be stated in terms of number of operating hours or days possible when the reserve fuel is used.

e) State the method by which fuel is supplied as well as potential or existing alternative methods. For example, a coal fired thermal plant might receive coal by rail and/or barge depending on location.

f) Simple site plans should be available for each generating station.

These plans should include (as a minimum) the location of major components both inside and outside of structures. Also, state the type of structures of each station, i.e., reinforced concrete, brick, steel frame, etc.

2. Transmission Components

a) Plot transmission lines with capacity and the number of circuits on each line.

b) Identify lines as to type: underground, aerial, etc., and type of conductor.

c) Identify pole or tower types. Also, note design loadings of typical lines of various capacities.

d) Plot substations and indicate capacity.

e) Simple site plans should be available for each substation. The plans should indicate the location of major components both inside and outside of structures. The type of structures on the site should be given. The substation should be identified as attended or unattended and the type of control stated.

3. Distribution Components

a) Plot the primary distribution lines showing the capacity and the number of circuits.

b) Lines should be specified as to type and kinds of poles utilized with typical design loadings.

c) Locations, capacities and simple site plans of distribution substations should be available. Also, distribution circuits should be identified as to the type of service: industrial, commercial, residential or some combination.

4. Other Information

a) Specify the locations of maintenance facilities, storage yards, and engineering facilities by latitude and longitude. Simple site plans of these facilities should be available and the type of structure noted.

b) An inventory of major repair parts such as poles, transformers, conductors, breakers, etc. should be available.

c) List the major repair equipment such as trucks, bulldozers, etc..

d) Describe and list an inventory of communication systems and equipment.

When the above planning information has been compiled, identify those components which are essential to the operation of the system. This effort should be undertaken by an individual or group highly knowledgeable about their particular system. This effort is very important with respect to the allocation of repair effort: manpower, equipment, and parts. By identifying essential components, realistic priorities for repairs can be established. With such information the reapir of components that do not make significant contributions to the functioning of the system can be delayed and time and effort can be allocated to more important components.

For example, major components could be classified as highly essential, essential, and nonessential. An item classified as highly essential would be one where damage to the item results in significant loss in capacity or operation of the system. An essential component would be one where damage to the component causes a loss in capacity or efficiency or a drop in the reliability or safety of the system. A nonessential component is considered one that, if damaged, would cause only minor losses in safety and/or reliability and little loss in system capacity. An example of such a scheme is presented in Table VI.

C. Damage Estimates

As previously mentioned the primary scope of this research effort was to develop updated and expanded overpressure versus damage estimates for major electric power system components. The initial step in this effort was the identification of major components for various system types as described in Section III. The overpressure - damage information was derived from literature surveys, discussion with power engineers and operating personnel, and civil preparedness personnel having expertise in damage estimation.

1. Overpressure Damage

The blast damage sustained by a particular facility is a function of the size of the weapon detonated, the type of burst, the distance the facility is from the location of the detonation, and the physical characteristics. For convenience, distance versus overpressure values for various weapon sizes, ranging from 1 MT to 20 MT, are given in Appendix B. Thus, by using the planning information gathered as discussed in Part B of this section, an estimate of the overpressure at a given facility can be determined.

A listing of major electric power system components and related equipment and the damage incurred at various overpressure ranges is presented

TABLE VI

EXAMPLE OF COMPONENT CLASSIFICATION

Example System	Example Components	Rating
Turbine - Generator	Major assembly	HE*
	Cooling components	HE
	Oil conditioning equipment	HE
Boiler System	Boiler structure	HE
	Air heaters	E
	Feedwater pumps	HE
	Soot blower	E
Coal Handling System	Conveyors	HE
	Pulverizers	HE
	Unitrain	E
Transmission System	Line and towers	HE
	Circuit breaker	E
	Control system	NE

*HE = highly essential

E = essential

NE = nonessential

in Appendix C. The equipment has been categorized into generating components, transmission and distribution components, and related equipment. The damage for a given overpressure range has been classified as light, moderate, and severe. Light damage implies that the component has suffered minor damage but is still functional and can be used while undergoing light repair. Moderate damage means that the component requires extensive repair and has a good probability of being out of operation or is operating well below capacity. Severe damage is interpreted as meaning that the component is severely damaged or totally destroyed, and that complete reconstruction or replacement is necessary. Ranges on the overpressures that cause light, moderate, or severe damage are necessary because of the extensive number of unknown or partially known variables that can affect the situation. Some of these variables include such things as orientation of the component to the blast, proximity to other components, probability of a missile striking the equipment, weather conditions, terrain, etc. To enumerate all these variables and incorporate them into a manual damage estimation procedure would require considerable time and effort on the part of the estimator and would defeat the purpose of obtaining initial, rapid estimates of the status of a system.

As an example of the use of the data in Appendixes B and C, suppose a 5 MT surface burst is imposed on a given system. Examination of the locations of various facilities reveals that a coal fired thermal station is located 7 miles from ground zero. From Appendix B, the overpressure at the station location is found to be approximately 3 psi. Then, using

Appendix C the damage estimator could determine the extent of damage to various components. For example, the damage would include probable collapse of the stack, broken meters, housing damage to conveyors, surface damage to pumps, slight deformation of the pulverizers, etc. By knowing the overall system being considered the estimator could then determine the probable functioning level of the plant. Also, if the list of essential equipment had been properly developed (as described in Part B of this section), then preliminary decisions can be made regarding repair priorities and allocation of spare parts can be made.

Examination of the data in Appendix C indicates that many of the large equipment types have considerable blast resistance and can remain functional or repairable after being exposed to relatively high overpressure values. However, many of the smaller components will fail at much lower overpressure values and, as a result, may make the system inoperable until repair or replacement can take place.

2. Electromagnetic Pulse Damage

The concept that the electromagnetic pulse (EMP) phenomena caused by nuclear weapons can disrupt electric power systems has been well established. Several studies have been completed to determine the specific effects of EMP on electric power system components and the protective measures which can be applied to attenuate these effects (Marable, et. al., 1975; DCPA, 1972). This research effort was not intended to provide a detailed analysis of EMP effects; however, some discussion regarding such effects is considered necessary for a damage estimation procedure to be complete. The following discussion is based on previous research studies, discussions with electric power engineers, research engineers engaged in EMP studies, and engineering judgement.

Electric power systems which are exposed to EMP can undergo disruption due to either damage to a specific component or some type of operational malfunction. The disruption which is incurred is dependent on both the magnitude of the impulse and the type of equipment exposed. For example, EMP could cause a transistor to burn out, i.e., functional damage. An operational malfunction example would be the loss of core memory on a computer.

There are numerous types of equipment which can act as collectors of EMP such as long cable runs, conduit, wire runs, overhead power lines, telephone lines, large antennas, etc. For the purposes of this study it is sufficient to point out those components which are sensitive to EMP. These components are listed in Table VII.

From the information presented in Table VII it appears that control circuit damage is quite likely in the event of exposure to EMP. The occurrence of large surge voltages and currents in power system control circuits and communication networks can cause malfunctions in logic circuits resulting in incorrect breaker operation, false telemetry of data and a general disruption of control. Damage by EMP to electric power system equipment is less likely to occur than damage to control systems; however, certain components such as transformer windings, bushings, etc., may sustain some damage. Also, surges in power lines can enter consumer equipment and cause damage or malfunction.

TABLE VII

COMPONENTS SUSCEPTIBLE TO EMP EFFECTS
Adapted from (DCPA, 1972)

Components Highly Susceptible to Damage

- microwave semi-conductor diodes
- field effect transistors
- audio transistors
- silicon rectifiers
- power rectifier semi-conductor diodes
- vacuum tubes

Components Highly Susceptible to Operational Malfunction

- computers
- computer power supplies
- transistorized power supplies
- semiconductor devices terminating in long cable runs
- alarm systems
- intercom systems
- transistorized receivers and transmitters
- transistorized converters
- transistorized control systems
- power systems control

Components Moderately Susceptible to Operational Malfunction

Vacuum tube equipment such as:

transmitters	intercoms
receivers	teletype-telephone
alarm systems	power supplies

Equipment with low current switches, relays, meters, such as:

- alarms
- power system control panels
- panel indicators
- status boards
- process controls

Other equipment:

- long power cables
- high energy storage capacitors or inductors

Components Least Susceptible to Operational Malfunction

High voltage 60 cps equipment:

transformers	heavy duty relays
motors	circuit breakers
heaters	air insulated cables
rotary converters	

3. Thermal Damage

A nuclear explosion can cause fires in two ways: ignition of materials as a result of the absorption of thermal radiation and by damage caused by the blast wave which can result in short-circuits, broken gas lines, broken furnaces, etc. The estimation of thermal damage to electric power systems is difficult and complex due to uncertainties regarding the location and amount of materials subject to ignition and uncertainties in the location of secondary fires. Consequently, only some general observations will be made here based on discussions with electric power engineers and operating personnel.

A general opinion seems to be that the thermal effects of a nuclear explosion do not present a major hazard to electric power system components as compared to the blast effects. Most electric power facilities are relatively fireproof and considerable attention is given to the proper storage of combustible material and precautions are taken to eliminate potential fire hazards. Secondary fires caused by structural damage such as short-circuits, broken fuel lines sparking, etc. are, of course, a possibility; however, these are so unpredictable that estimation of damage to components is difficult if not impossible.

Two major groups of components which might undergo major thermal damage are wooden transmission poles and certain control components. Experience with forest fires indicates that the wooden poles that support 16 KV lines and smaller can suffer extensive damage. Steel towers which carry larger lines are generally not damaged by forest fires. Thus, lines carried on wooden poles could suffer thermal damage if the surrounding area is on fire. Highly sensitive control mechanisms which are not necessarily flammable may, however, be sensitive to heat. Certain portions of computer systems, for example, may be susceptible to operational malfunctions when exposed to some critical level of heat.

4. Radiation Effects

The initial radiation does rates which could conceivably damage electric power system components are very high and would occur only in regions of extremely high peak overpressures. The blast damage effects extend much further from the detonation location than do any damage effects due to prompt radiation (Battelle, 1961; Saur, 1962). Thus, it can be assumed that prompt radiation will have a negligible effect on electric power system components, especially when compared to the blast effects.

With respect to residual radiation, it can be expected that no damage to equipment will occur. The biggest problem to be faced will be the effects of residual radiation on operating and repair personnel. To perform the necessary repair efforts on damaged components, it will be necessary to determine the permissible length of exposure which is compatible with the allowable accumulated dose. Numerous references on determining radiation levels are available (see for example, The Effects of Nuclear Weapons). The planner is advised to see local civil preparedness personnel regarding radiation levels.

D. Repair Considerations

An important aspect of damage estimation is to allow planners to determine priorities for the restoration of a system as well as allocating remaining resources. Of interest to this study is determining the level of effort required to repair or replace damaged components of electric power systems. One previous study in this area (URS, 1967) attempted to relate overpressure to repair time of gas and electric systems. The results of this study provide some reasonably good repair time estimates and are summarized in Table VIII. In the table, the level of damage is described in Section IV-C. The repair effort is based on qualified workers operating an 8-hour day and does not include travel to the site. It is also assumed that the major portion of debris removal has been done.

TABLE VIII

ESTIMATED REPAIR TIME FOR SELECTED COMPONENTS
Adapted from (URS, 1967)

Component	Damage Level	Repair Effort (man days)	Equipment	Supplies	Spare Parts
Coal conveyor	M*	60	crane welding equipment	metal siding belt	rollers
	S	600	crane welding equipment		new belt & all necessary equip.
Coal pulverizer	M	300	hoist, welder, flame cutter	steel pipe insulation	
Air heater	M	350	hoist, welder, flame cutter	steel plate angle iron insulation	
Hot air duct and flues	M	2800	hoist, welder, flamer cutter	steel plate insulation bolts	
Boiler	M	800	crane, hoist, welder, flame cutter	insulation wall sections	boiler tubes
	S	23,000	crane, hoist, welder, flame cutter	insulation piping	wall sections, drum economizer, reheater, superheater, pipe supports
Forced draft fan	M	60	hoist, welder, flame cutter	plate insulation	
	S	170	crane, hoist, welder, flame cutter	plate insulation angle iron conduit	fan, fan starter

* Damage level values are described in Section IV-C

TABLE VIII

(continued)

Component	Damage Level	Repair Effort (man days)	Equipment	Supplies	Spare Parts
Cooling water intake	M	400	crane, welder	concrete rebar	screen
	S	1700	crane, welder	concrete rebar conduit wire	screen
Condenser and hot well pump	M	65	crane	bolts	tubes
Feedwater pump	M	160	crane, hoist welder flame cutter	piping insulation tubing	
Turbine lubrication system	M	130	welder	small pipe valves	hydrogen storage bottles
	S	250	crane, welder flame cutter	piping valves	oil filter bearings
Exciter and Aux. Bus	M	400	hoist, crane	insulators bus encloser	
Meters and control system	M	2 each	hand tools	meters relays fuses	
	S	20 each	hoist hand tools flame cutter	wire cable connectors fuses	new control cubicles and consoles

TABLE VIII

(continued)

Component	Damage Level	Repair Effort (man days)	Equipment	Supplies	Spare Parts
Circuit breakers & bus structure	M	10 per unit	crane	copper bus tubing insulators bushings oil	
	S	25 per unit	crane welder flame cutter	copper bus tubing insulators	
Substation transformers	M	1	crane oil press	oil nitrogen	
	S	125	crane, oil press, jacks rollers bulldozer	oil nitrogen connectors copper bus	new coil fins
Wood trans-mission lines	M	40/mile	auger compresser crane puller tensioner truck splicer	insulators bolts cable angle iron	poles guys crossarms
Steel tower trans-mission	M	185/mile	trucks tensioner crane	concrete rebar insulators bolts	

V. CONCLUSIONS AND RECOMMENDATIONS

At a relatively early point in an emergency situation many organizations will be required to make operational decisions necessitating analysis and estimation of the requirements, capabilities and overall status of specific system resources. Ideally, the decision-maker desires as much information about the situation as possible which can result in a considerable amount of data manipulation and relatively complex analysis. Unfortunately, time and physical constraints may prevent detailed surveys and analysis in emergency situations. Thus, rapid, uncomplicated but reasonably accurate procedures are required for damage estimation so that decisions can be made regarding resource management. It was the intent of this research effort to provide planners with basic information concerning damage estimation in the electric power industry.

A. Conclusions

Several conclusions may be drawn regarding the performance of electric power systems based upon the overpressure - damage relationships presented in this report. Electric power systems, in general, face the problem of complexity in design and operation with many critical components exposed to direct effects. Even at relatively low overpressures (in the 1 to 2 psi range) service could be disrupted until minor repair could be effected such as resetting protective devices, conversion to manual control, etc.

At higher, though relatively moderate, overpressures of 3 to 4 psi, considerable damage to distribution systems would occur due to downed lines, broken poles, missile damage, etc. It can be expected that at this level of overpressure numerous consumers would be without power. With respect to generating components, the primary problem would be caused by control system failures, especially in steam plants.

Distribution and transmission systems subjected to overpressures in the 4 to 6 psi range would be severely damaged, inoperable and would require large amounts of repair efforts. Generating stations would also sustain major damage at this overpressure level and repair efforts would run into many months.

With the overpressure level at 8 psi and above, total rebuilding of distribution and transmission systems would be necessary. Damage to generating components at this level would be severe but repair might still be possible if certain replacement parts were available. At overpressures around 10 psi, the damage incurred by generating facilities would make restoration highly unlikely and new construction would be required.

One other point regarding electric power system components was revealed in discussions with industry personnel and has to do with the availability of spare parts. Although many small parts are kept in stock (small circuit breakers, relays, etc.) for routine maintenance and replacement purposes, there are many of the larger components that are not kept in inventory. For example, large transformers are a high cost item and standby units are kept to a minimum. Also, repair of such units often requires returning it to the manufacturer. Interchangeability of major equipment is generally not possible due to severe matching problems. Thus, repair or replacement of such components will pose a major post-attack problem.

B. Recommendations

Based on the results of this study, several recommendations can be made regarding damage estimation procedures for the electric power industry. One recommendation is that personnel and organizations responsible for damage estimating and civil defense planning undertake the damage estimating planning steps as outlined in Section IV-B of this report. Essentially, such planning entials identifying, locating, and describing the major generation, transmission, distribution, and supporting facilities of a system. Another recommendation is that personnel highly familiar with a given system identify the most critical components in the system so that priorities for repair effort allocation can be established. Also, since control components appear to be one of the most critical segments of an electric power system, it is recommended that in cases where considerable computer control and automation exist that operators be well-trained in converting and operating the system in the manual mode. A final recommendation is that consideration be given to "hardening" systems against electromagnetic pulse effects. Such hardening procedures are relatively inexpensive and easy to institute and are presented and thoroughly described in the following references: (1) Power System EMP Protection (Marable, 1975), and (2) EMP Protection for Emergency Operating Centers (DCPA, 1972).

In addition to the recommendations given above, this research study revealed some areas of future research which warrant additional investigation. One study considered useful would be the development of a composite vulnerability index for electric power system components. Such a composite index could incorporate numerous factors contributing to the overall vulnerability of a component. Some of the factors considered could include: (1) physical damage level (i.e., failure overpressure), (2) replaceability of the component (i.e., availability of the component), (3) substitutability, (4) redundancy, (5) dependence of the system output on the component, (6) skill level required for repair, and others. A ranking procedure similar to that developed for manufacturing systems (Minor, Lambert, and Smith, 1972) could then be performed. The development of a composite vulnerability index would lead to more accurate identification of critical components, the reason for the criticality of the component, and the development of alternative civil defense actions to reduce overall system vulnerability.

Another potential study considered useful would be to determine the sensitivity of electric power system components to various types of damage. That is, to determine the type of effect -- blast, wind, thermal, EMP, etc. -- that a component is most sensitive to. The results of such a study could then be utilized to identify methods for reducing the vulnerability of the component to that particular type of nuclear weapon effect.

LIST OF REFERENCES

1. Battelle Memorial Institute, The Effects of Nuclear Radiation on Lubricants and Hydraulic Fluids, Radiation Effects Information Center, Columbus, Ohio, 1963.

2. Chenoweth, J. M., et al., A Method for Predicting Electrical Power Availability Following a Nuclear Attack, National Engineering Science Company, Pasadena, CA, April, 1963.

3. Defense Civil Preparedness Agency, EMP Protection for Emergency Operating Centers, Report No. TR-61A, July 1972.

4. Defense Electric Power Administration, Vulnerability of Electric Power Systems to Nuclear Weapons - Pilot Study, Region I, October, 1962.

5. __________, Vulnerability Analysis of Electric Power Distribution Facilities, San Jose, CA, Prepared for DCPA, November 1967.

6. __________, Vulnerability Analysis of Electric Power Distribution Systems, Albuquerque, New Mexico, Prepared for DCPA, June 1969.

7. __________, Vulnerability Analysis of Electric Power Distribution Systems, Detroit, MI, Prepared for DCPA, November, 1970.

8. Department of Housing and Urban Development, Damage Assessment: A Manual of Procedures, HUD Staff Document, Operating Instruction No. 8, September, 1966.

9. Department of Transportation, Manual Damage Assessment Procedures for Transportation Systems, DOT publication 1940.3, August, 1968.

10. Doll, J., Borgeson, N., and L. Towle, Methods for Evaluating the Effects of Nuclear Attack on the Ability of Power Systems to Meet Estimated Postattack Demands, Stanford Research Institute, Menlo Park, CA, September, 1966.

11. Lambert, B. K., and J. E. Minor, Regional Manufacturing Systems: Nuclear Weapons Effects and Civil Defense Actions, Texas Tech University Lubbock, TX, Report prepared for DCPA, April, 1975.

12. Lambert, B. K., and J. E. Minor, Vulnerability of Regional Electric Power Systems to Nuclear Weapons Effects, Defense Electric Power Administration, Report prepared for DCPA, May, 1973.

13. Minor, J. E., Lambert, B. K. and M. L. Smith, Vulnerability of Regional Manufacturing Systems to Nuclear Weapons Effects, Texas Tech University, 1972.

14. Nelson, D. B., A Program to Counter the Effects of Nuclear Electromagnetic Pulse in Commercial Power Systems, Report ORNL-TM-3552, Oak Ridge National Laboratory, August, 1971.

15. Saur, A. J., Zack, J. F., and A. Anderman, Transient Radiation Effects in Electronic Materials, Report No. 1, Atomic International, Canoga Park, CA, 1962.

16. Sisson, George N., "Effects of Nuclear Blast on Utilities," Proceedings: Conference on Engineering Utility Tunnels in Urban Areas, New England College, Henniker, NH, August, 1971.

17. United States Atomic Energy Commission, The Effects of Nuclear Weapons, Prepared by U.S. Dept. of Defense, Revised edition, 1962.

18. URS Corporation, Repair and Reclamation of Gas and Electric Utility Systems, prepared for Stanford Research Institute and DCPA, July, 1967.

19. Wood, R., Werden, A., and R. Berg, Effects of Atomic Weapons on Electric Utilities, Edison Electric Institute, New York, NY, 1965.

APPENDIX A

SELECTED ANNOTATED BIBLIOGRAPHY

The following annotated bibliography contains only those references which are considered to be the most pertinent and timely with respect to electric power system damage assessment. Additional annotated bibliographies may be found in Minor and Lambert (1972), Lambert and Minor (1973) and Lambert and Minor (1975).

Ahlers, E. B., Debris Hazards, a Fundamental Study, IITRI, Project No. 8231 for DASA, 1963.
Annotation Statement: Describes collection and analysis of data on various aspects of debris formation and dispersion. Of primary interest to the electric power industry is the information on horizontal displacement of tree limbs which could have a significant effect on transmission and distribution lines.

Ayers, R. W., Methodology for Postattack Research, Hudson Institute, HI-647-RR, New York, OCD Work Unit 3522A (AD639751), 1966.
Annotation Statement: Discussions of the use of models for postattack research as contrasted to scenarios, games, and case histories.

Bear, D. B. T., and P. G. Clark, The Importance of Individual Industries for Defense Planning, Rank P-2093, Santa Monica, CA, 1960.
Annotation Statement: Analysis of individual industries intended as a guide to peacetime defense preparations, plausible supplies, and demands in the U.S. economy after a nuclear war.

Black, R., Guidelines for Generating and Using Electric Power During Prolonged Emergencies, URS Research Company, Report No. URS 7036-4, Sept. 1971.
Annotation Statement: Presents guidelines for developing electric power by expedient means during prolonged failure of commercial power sources. Test results indicate that either engine generator sets or induction motors can be successfully connected to power distribution systems.

Black, R. H. and W. H. Van Horn, Development of Procedures for Assessment of Local Industrial Productive Capacity Following Nuclear Attack, URS Research Co., Report URS 753-6, 1970.
Annotation Statement: Assessment of productive capacity considered in three steps: (1) damage assessment, (2) repair effort estimation, and (3) estimation of potential productive capacity.

Brown, S. L., Industrial Recovery Techniques, SRI Report MU-4949-350, Menlo Park, CA, OCD Work Unit 3331 B (AD 636 947), 1966.
Annotation Statement: Generalized concepts concerning industrial models, industrial vulnerability to nuclear attack, industrial recovery requirements, and industrial recovery procedures.

Chenoweth, J. M., A Method for Predicting Electrical Power Availability Following a Nuclear Attack, National Engineering Science Co., Pasadena, CA, 1963.
Annotation Statement: Considers a general procedure for estimating power supply availability following nuclear attack. The procedure is tested using the electric power system of the state of Maryland.

DCPA, EMP Protection for AM Radio Broadcast Stations, Defense Civil Preparedness Agency, Publication No. TR-61-C, 1972.
Annotation Statement: A description of nuclear electromagnetic pulse effects on AM broadcast stations.

DCPA, EMP Protection for Emergency Operating Centers, Defense Civil Preparedness Agency, Publication No. TR-61A, 1972.
Annotation Statement: A description of a nuclear electromagnetic pulse is presented and a guide is provided for incorporating EMP protection into emergency operation centers.

DCPA, EMP Protective Systems, Defense Civil Preparedness Agency, Publication No. TR-61-B, July 1972.
Annotation Statement: Provides a description of representative problems and solutions for providing protection against nuclear electromagnetic pulse.

DCPA, EMP Threat and Protective Measures, Defense Civil Preparedness Agency, Publication No. TR-61, 1970.
Annotation Statement: A technical report presenting a description of a nuclear electromagnetic pulse effect on civil defense activities.

DCPA, Reducing the Vulnerability of Industrial Plants to the Effects of Nuclear Weapons, Defense Civil Preparedness Agency, PSD-PG-80-8, 1963, Professional Guide Series.
Annotation Statement: Guide to assist architects and engineers in developing constructive measures for protection of industrial plants against the effects of nuclear attack.

DEPA, Civil Defense Preparedness in the Electric Power Industry, Defense Electric Power Administration, March 1966.
Annotation Statement: Management guide covering (1) CD planning for the power industry, (2) government organization and planning for protection and restoration of the power industry, (3) essentials of electric power industry preparation and readiness, and (4) CD preparedness and readiness check lists for the power industry.

DEPA, Civilian Defense and Emergency Operation Plan, Defense Electric Power Administration, 1961.
Annotation Statement: A proposed plan by which to promote continuity of community services during emergency conditions.

DEPA, Electric Power Emergency Operations Handbook, Department of the Interior, DEPA; DEPA Report (no number), June 1967.
Annotation Statement: Handbook issued to provide current organizational assignments and operational measures essential to meet electric power needs in a national emergency. Readiness actions and emergency actions by organization are delineated. Basic laws, federal documents, personnel rosters are included. This document represents a translation of systems vulnerability evaluations into a working handbook.

DEPA, Engineering Study of the Vulnerability of Electric Utilities to Nuclear Attack, U.S. Department of the Interior, DEPA, Electric Power Area 12; DEPA Report (no number), October 1, 1963.
Annotation Statement: An examination of the postattack electric power capabilities in Defense Electric Power Area 12 (Texas, Oklahoma, Louisiana, Arkansas, Kansas, and parts of Mississippi, Missouri, Nebraska, and New Mexico) concludes that there will be excess capacity for Area 12 following a national nuclear attack and that auxiliary power for fallout shelters would not be needed.

DEPA, Protection of Electric Power Systems, U.S. Department of the Interior, DEPA; DEPA Research Project No. 4405, June 1962.
Annotation Statement: A survey revealed that in general, companies in the electric power industry have plans and procedures for continuing operation under emergency conditions. Structural hardening, shielding from thermal effects, radiological defense plans, and fallout protection are examples of protection discussed.

DEPA, Recommendations to be Used as a Guide to Assist Electric Utilities in Maintaining Service During and Following a Nuclear Bombing Attack, Defense Electric Power Administration, Power Area 7 - Project 1, 1961.
Annotation Statement: Results of a DEPA committee study to serve as a guide for electric utilities during and following a nuclear attack.

DEPA, Vulnerability Analysis of Electric Power Distribution Systems: Albuquerque, New Mexico, U.S. Department of the Interior, DEPA; DEPA Report 5A-11101-4334B-02 for Office of Civil Defense Work Unit 4334B, June 1969.
Annotation Statement: Second in a series of three Five City Study oriented evaluations of electric power systems. Principally a study of damage to various components of the electric power system of Albuquerque.

DEPA, Vulnerability Analysis of Electric Power Distribution Systems: Detroit, Michigan, U.S. Department of the Interior, DEPA; DEPA Report 5D-111-1-4334-B-03 for Office of Civil Defense Work Unit 4334B, November 1970.
Annotation Statement: Third in a series of three Five City Study oriented evaluations of electric power systems. Excellent systemic analysis as it addresses the people damage problem and raises intersystem questions regarding the financial and physical capability of Detroit Edison Company to restore damaged system.

DEPA, Vulnerability Analysis of Electric Power Distribution Facilities: San Jose, California, U.S. Department of the Interior, DEPA; DEPA Report (no number) for Office of Civil Defense Work Unit 4334B, November, 1967.
Annotation Statement: First in a series of three Five City Study oriented evaluations of electric power systems. A brick by brick evaluation of the response of the San Jose electric power system to a specific attack. Valuable as a detailed analysis of electric power system components and the propensities for weapons effects induced damage.

DEPA, Vulnerability of Electric Power Systems to Nuclear Weapons, U.S. Department of the Interior, DEPA; DEPA Report (no number); 1963.
Annotation Statement: Nationally oriented study directed toward estimating electric power service that would be available under conditions following nuclear attack, with particular emphasis on power for community shelters. Report concludes that electric service can be furnished to surviving population during shelter confinement period.

DEPA, Vulnerability of Electric Power Systems to Nuclear Weapons: Pilot Study - Region 1, U.S. Department of the Interior, DEPA; DEPA Contract No. AT (49-5)-2107 with the Atomic Energy Commission, October 1962.
Annotation Statement: DEPA Region 1 (New Hampshire, Vermont, Maryland, Massachusetts, Rhode Island, Connecticut) is analyzed in detail through three time phases. Concluded that the electric power system can meet drastically reduced postattack requirements.

Doll, John P., Methods for Evaluating the Effects of Nuclear Attack on the Ability of Power Systems to Meet Estimated Postattack Demands, Stanford Research Institute, 1966.
Annotation Statement: Development of three methods for assessing vulnerability including a rapid, qualitative technique, a linear programming method, and a non-computer method for determining the amount of deliverable power and size and location of demand.

DOT, Manual Damage Assessment Procedures for Transportation Systems, Department of Transportation, DOT 1940.3, 1968.
Annotation Statement: Describes policies and procedures for transportation personnel engaged in manual procedures to assess nuclear damage to the physical facilities, equipment and manpower comprising the national transportation resources.

Fitz Simons, Neal, A Geographic Framework for Systems Evaluation, Defense Civil Preparedness Agency, Systems Evaluation Division, Washington, D.C., 1972.
Annotation Statement: Description of the structure and uses of the Geographic Nodal Network.

Foget, Carl R. and W. H. Van Horn, Availability and Use of Emergency Power Sources in the Early Postattack Period, URS Research Co., OCD Work Unit 3311B, 1969.
Annotation Statement: Study concerned with the identification and use of emergency power sources, both conventional and unconventional, in the early postattack period.

FPA, Nuclear Attack Damage Assessment Operating Plan, (Draft), Federal Preparedness Agency, April, 1975.
Annotation Statement: Presents a ratified plan for assessing damage and the residual capabilities of non-military resources. The plan is primarily for FPA and other participating agencies for use at both national and regional levels. Primarily computer oriented input information.

HUD, Damage Assessment: A Manual of Procedures, Department of Housing and Urban Development, 1966.
Annotation Statement: A manual which provides an easy-to-use technique for damage assessment for HUD personnel. Concentrates on hand damage assessment procedures primarily for human casualties and housing facilities.

Lambert, B. K. and J. E. Minor, Regional Manufacturing Systems: Nuclear Weapons Effects and Civil Defense Actions, Texas Tech University, Report prepared for DCPA, Work Unit 4352C, April, 1975.
Annotation Statement: Describes the development and use of a prototype model and analysis method which can be used to assess the vulnerability of regional manufacturing systems. Potential civil defense actions which can reduce system vulnerability are also presented.

Lambert, B. K. and J. E. Minor, Vulnerability of Regional Electric Power Systems to Nuclear Weapons Effects, DEPA, 1973.
Annotation Statement: Describes the development of a conceptual model for assessing power system vulnerability. A constrained network flow structure is utilized. Includes an application to a particular region.

Minor, J. E., Lambert, B. K., and M. L. Smith, Vulnerability of Regional Manufacturing Systems to Nuclear Weapons Effects, Texas Tech University, OCD Work Unit 4352A, 1972.
Annotation Statement: Report contains three major presentations: development of a general model concept for simulating a regional manufacturing system, utilization of the model to simulate a specific economic region, and exercise of the model to demonstrate its usefulness in vulnerability evaluations and other types of systems studies.

Nelson, D. B., A Program to Counter the Effects of Nuclear Electromagnetic Pulse in Commercial Power Systems, Report ORNL-TM-3552, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 1971.
Annotation Statement: This report assesses the possible effects on commercial electric power systems from the electromagnetic pulse (EMP) produced by high altitude nuclear detonations. Included are discussions of coupling methods, estimates of induced surge magnitude on transmission lines and control cables, and comparisons with direct lightning strikes and switching surges. The report then considers the type and probability of damage or malfunction from EMP effects, its significance during and after a nuclear attack, and countermeasures to reduce disruption and to harden electric power systems. The report concludes that the weight of effects from EMP makes likely widespread power failure on a national scale at the very beginning of a nuclear attack. Present design trends may result in future power systems which are more susceptible to damage than present systems. Methods are available to greatly reduce the vulnerability of power system components, but testing is required to determine whether these can be applied economically.

New Brunswick Electric Power Commission, Vulnerability to Nuclear Attack - Electric Power Supply, Province of New Brunswick, May, 1963.
Annotation Statement: Primarily an exercise using a specific attack on the North American Continent. Conclusions of the study include: adequate plant capacity was available to supply the remaining load requirements, interruptions in service occurred due to destroyed or damaged transmission and distribution facilities, repair was hampered by severe fallout. General conclusion was that there was no shortage of electric power for the remaining load and that support could be given to neighboring utilities.

OCDM, Manual Damage Estimation, Executive Office of the President, Office of Civil and Defense Mobilization, 1961.
Annotation Statement: Basic manual which briefly explains the methods to perform a manual estimation of nuclear explosion damage.

OEP, Manual Procedures for Resource Evaluation, Executive Office of the President, Office of Emergency Planning, 1966.
Annotation Statement: Describes various phases of data organization, analysis and presentation which might have to be carried out independently without the benefit of centrally calculated data and analysis during emergency situation. Basically, presents a manual damage assessment procedure.

OEP, Survey of Electric Power Problems, Executive Office of the President, Office of Emergency Preparedness; OEP Report (no number), May 1971.
Annotation Statement: A summary of nonnuclear weapons effects electric power problems. Contains valuable insights into electric power problems related to increasing power demands, summer peaks, and environmental impacts.

Reliability and Adequacy of Electric Power Within the Southwest Power Pool, 1970-1980, A report to the Federal Power Commission, September 1, 1970.
Annotation Statement: Study showing additional capacity planned for the power pool to meet increased load projected for the period 1970 to 1980.

Sisson, George N., "Effects of Nuclear Blast on Utilities," Proceedings: Conference on Engineering Utility Tunnels in Urban Areas, August, 1971.
Annotation Statement: Describes general effects of nuclear weapons on electric power, gas, water, sewerage, and communications systems. Summarizes the description of blast damage to system components as a function of overpressure regions.

Task Groups on the Northeast Power Interruption, Prevention of Power Failures, Vol. II, Prepared for the Federal Power Commission, June 1967.
Annotation Statement: A review and investigation of the problems involved in assuring a reliable supply of bulk power on an area or regional basis.

Task Group on the Northeast Power Interruption, Prevention of Power Failures, Vol. III, Prepared for the Federal Power Commission, June 1967.
Annotation Statement: A summarized analysis of the transient behavior of the Canada-United States Interconnected System during the November 9, 1965, power interruption; an examination of other events which could lead to similar power interruptions, and recommendations to prevent or limit interruptions.

Wickham, G. E., and T. N. Williamson, Operational Planning-Debris Removal, Jacobs Associates, Report prepared for OCD, Work Unit 3325D, July 1971.
Annotation Statement: Report presents procedures for predicting debris environments in urban areas for different nuclear attack situations. The procedures developed include all preattack planning activities, increased readiness requirements and implementation of clearing activities.

Van Horn, W. H., Boyd, G. B., and C. R. Foget, Repair and Reclamation of Gas and Electric Utility Systems, URS Corporation, URS Report 669-6, OCD Work Unit 3311B, 1967.
Annotation Statement: Identifies essential subsystems and components of gas and electric utility systems, estimates damage to critical elements from various weapons effects, and estimates repair requirements. Also presents a mathematical model for repair for a "typical" city.

APPENDIX B

DISTANCE VERSUS OVERPRESSURE

WPN YIELD MT	HOB, FEET	SKY CLARITY
1	0	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
0.60	99.53	999.00
0.80	56.34	679.66
1.00	36.32	434.28
1.20	25.42	301.09
1.40	18.84	220.85
1.60	14.56	168.81
1.80	11.62	133.16
2.00	9.51	107.68
2.20	7.95	88.84
2.40	6.76	74.53
2.60	5.84	63.40
2.80	5.10	54.57
3.00	4.50	47.46
3.20	4.02	41.65
3.40	3.61	36.83
3.60	3.27	32.80
3.80	2.98	29.39
4.00	2.74	26.48
4.20	2.52	23.97
4.40	2.34	21.81
4.60	2.18	19.92
4.80	2.04	18.26
5.00	1.91	16.80
5.20	1.80	15.51
5.40	1.70	14.36
5.60	1.61	13.33
5.80	1.53	12.41
6.00	1.46	11.57
6.20	1.39	10.82
6.40	1.33	10.14
6.60	1.28	9.52
6.80	1.23	8.95
7.00	1.18	8.43
7.20	1.14	7.96
7.40	1.10	7.52
7.60	1.07	7.12
7.80	1.03	6.75
8.00	1.00	6.40
8.20	0.98	6.08
8.40	0.95	5.79
8.60	0.92	5.51
8.80	0.90	5.26
9.00	0.88	5.02
9.20	0.86	4.79
9.40	0.84	4.58
9.60	0.82	4.39
9.80	0.81	4.20
10.00	0.79	4.03
10.20	0.78	3.87
10.40	0.76	3.71

WPN YIELD (MT) = 1 HEIGHT OF BURST (METERS) = 0

WPN YIELD MT	HOB, FEET	SKY CLARITY
1	7400	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
0.30	31.74	421.14
0.50	29.32	390.54
0.70	26.34	352.14
0.90	23.28	311.28
1.10	20.44	271.80
1.30	17.98	235.85
1.50	15.95	204.28
1.70	14.31	177.13
1.90	13.01	154.05
2.10	12.01	134.54
2.30	11.24	118.05
2.50	10.66	104.11
2.70	9.94	92.28
2.90	8.91	82.19
3.10	8.03	73.56
3.30	7.27	66.13
3.50	6.61	59.72
3.70	6.03	54.14
3.90	5.53	49.27
4.10	5.09	45.00
4.30	4.70	41.24
4.50	4.35	37.91
4.70	4.05	34.96
4.90	3.77	32.32
5.10	3.53	29.96
5.30	3.30	27.84
5.50	3.10	25.94
5.70	2.92	24.21
5.90	2.76	22.65
6.10	2.61	21.22
6.30	2.47	19.93
6.50	2.35	18.74
6.70	2.23	17.66
6.90	2.13	16.66
7.10	2.03	15.75
7.30	1.94	14.90
7.50	1.86	14.12
7.70	1.78	13.40
7.90	1.71	12.73
8.10	1.64	12.10
8.30	1.58	11.53
8.50	1.52	10.99
8.70	1.46	10.48
8.90	1.41	10.01
9.10	1.37	9.57
9.30	1.32	9.16
9.50	1.28	8.77
9.70	1.24	8.40
9.90	1.20	8.06
10.10	1.17	7.74

WPN YIELD (MT) =1 HEIGHT OF BURST (METERS) = 2256

2 MT-SURFACE

DISTANCE	OVERPRESSURE	THERMAL RADIATION
1.00	57.23	868.56
1.20	39.97	602.18
1.40	29.54	441.69
1.60	22.76	337.61
1.80	18.11	266.32
2.00	14.78	215.36
2.20	12.31	177.69
2.40	10.43	149.06
2.60	8.97	126.80
2.80	7.80	109.15
3.00	6.86	94.92
3.20	6.09	83.29
3.40	5.45	73.66
3.60	4.92	65.59
3.80	4.46	58.77
4.00	4.07	52.95
4.20	3.74	47.95
4.40	3.45	43.62
4.60	3.19	39.84
4.80	2.97	36.53
5.00	2.77	33.61
5.20	2.60	31.02
5.40	2.44	28.72
5.60	2.30	26.66
5.80	2.17	24.81
6.00	2.06	23.15
6.20	1.96	21.64
6.40	1.86	20.28
6.60	1.78	19.03
6.80	1.70	17.90
7.00	1.63	16.86
7.20	1.56	15.91
7.40	1.50	15.04
7.60	1.45	14.24
7.80	1.40	13.49
8.00	1.35	12.80
8.20	1.30	12.17
8.40	1.26	11.58
8.60	1.22	11.02
8.80	1.19	10.51
9.00	1.15	10.03
9.20	1.12	9.59
9.40	1.09	9.17
9.60	1.06	8.77
9.80	1.04	8.41
10.00	1.01	8.06
10.20	0.99	7.73
10.40	0.97	7.43
10.60	0.95	7.14
10.80	0.93	6.86

WPN YIELD MT	HOB, FEET	SKY CLARITY
2	9322	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
0.60	29.65	495.84
0.80	27.35	458.62
1.00	24.90	418.22
1.20	22.51	377.52
1.40	20.30	338.53
1.60	18.33	302.44
1.80	16.63	269.78
2.00	15.18	240.69
2.20	13.98	215.01
2.40	12.99	192.48
2.60	12.17	172.76
2.80	11.51	155.52
3.00	10.98	140.43
3.20	10.56	127.21
3.40	9.95	115.60
3.60	9.12	105.38
3.80	8.38	96.35
4.00	7.73	88.36
4.20	7.15	81.25
4.40	6.63	74.92
4.60	6.16	69.26
4.80	5.75	64.18
5.00	5.37	59.61
5.20	5.03	55.49
5.40	4.72	51.77
5.60	4.44	48.39
5.80	4.19	45.31
6.00	3.96	42.51
6.20	3.74	39.95
6.40	3.55	37.61
6.60	3.37	35.46
6.80	3.20	33.48
7.00	3.05	31.65
7.20	2.91	29.97
7.40	2.78	28.41
7.60	2.66	26.97
7.80	2.55	25.63
8.00	2.44	24.38
8.20	2.34	23.22
8.40	2.25	22.14
8.60	2.16	21.13
8.80	2.08	20.18
9.00	2.01	19.29
9.20	1.94	18.46
9.40	1.87	17.68
9.60	1.81	16.95
9.80	1.75	16.26
10.00	1.69	15.61
10.20	1.64	15.00
10.40	1.59	14.42

WPN YIELD (MT) =2 HEIGHT OF BURST (METERS) = 2842

3 MT-SURFACE

DISTANCE	OVERPRESSURE	THERMAL RADIATION
1.00	74.75	999.00
1.20	52.15	903.27
1.40	38.50	662.54
1.60	29.63	506.42
1.80	23.55	399.47
2.00	19.19	323.04
2.20	15.96	266.53
2.40	13.50	223.59
2.60	11.59	190.20
2.80	10.06	163.72
3.00	8.83	142.39
3.20	7.83	124.94
3.40	6.99	110.49
3.60	6.29	98.39
3.80	5.70	88.16
4.00	5.19	79.43
4.20	4.75	71.92
4.40	4.37	65.43
4.60	4.04	59.76
4.80	3.75	54.79
5.00	3.49	50.41
5.20	3.26	46.53
5.40	3.06	43.08
5.60	2.88	39.99
5.80	2.71	37.22
6.00	2.56	34.72
6.20	2.43	32.46
6.40	2.31	30.41
6.60	2.20	28.55
6.80	2.09	26.85
7.00	2.00	25.30
7.20	1.92	23.87
7.40	1.84	22.56
7.60	1.76	21.35
7.80	1.70	20.24
8.00	1.63	19.21
8.20	1.58	18.25
8.40	1.52	17.36
8.60	1.47	16.54
8.80	1.42	15.77
9.00	1.38	15.05
9.20	1.34	14.38
9.40	1.30	13.75
9.60	1.26	13.16
9.80	1.23	12.61
10.00	1.20	12.09
10.20	1.17	11.60
10.40	1.14	11.14
10.60	1.11	10.71
10.80	1.09	10.30

WPN YIELD MT	JOB, FEET	SKY CLARITY
3	10670	1

DISTANCE	OVERPRESSURE	THERMAL RADIATION
0.60	30.45	580.78
0.80	28.55	546.07
1.00	26.46	507.08
1.20	24.32	466.33
1.40	22.25	425.84
1.60	20.32	387.01
1.80	18.59	350.71
2.00	17.05	317.38
2.20	15.72	287.17
2.40	14.58	260.01
2.60	13.60	235.73
2.80	12.78	214.10
3.00	12.10	194.85
3.20	11.53	177.74
3.40	11.06	162.51
3.60	10.67	148.95
3.80	10.32	136.85
4.00	9.55	126.04
4.20	8.85	116.35
4.40	8.23	107.65
4.60	7.67	99.82
4.80	7.17	92.76
5.00	6.71	86.38
5.20	6.29	80.59
5.40	5.91	75.34
5.60	5.57	70.55
5.80	5.25	66.18
6.00	4.97	62.19
6.20	4.70	58.53
6.40	4.46	55.17
6.60	4.23	52.07
6.80	4.02	49.22
7.00	3.83	46.59
7.20	3.65	44.15
7.40	3.49	41.89
7.60	3.34	39.80
7.80	3.19	37.85
8.00	3.06	36.03
8.20	2.94	34.34
8.40	2.82	32.76
8.60	2.71	31.28
8.80	2.61	29.90
9.00	2.51	28.60
9.20	2.42	27.38
9.40	2.34	26.24
9.60	2.26	25.16
9.80	2.18	24.15
10.00	2.11	23.19
10.20	2.04	22.29
10.40	1.98	21.43

WPN YIELD (MT) = 3 HEIGHT OF BURST (METERS) = 3253

5 MT-SURFACE

DISTANCE	OVERPRESSURE	THERMAL RADIATION
1.00	104.74	999.00
1.20	72.99	999.00
1.40	53.83	999.00
1.60	41.39	844.03
1.80	32.84	665.79
2.00	26.73	538.40
2.20	22.20	444.22
2.40	18.75	372.65
2.60	16.06	317.00
2.80	13.93	272.87
3.00	12.20	237.31
3.20	10.79	208.23
3.40	9.62	184.14
3.60	8.64	163.98
3.80	7.80	146.93
4.00	7.09	132.38
4.20	6.48	119.87
4.40	5.95	109.04
4.60	5.48	99.60
4.80	5.08	91.32
5.00	4.72	84.02
5.20	4.40	77.55
5.40	4.11	71.80
5.60	3.86	66.65
5.80	3.63	62.03
6.00	3.42	57.86
6.20	3.23	54.10
6.40	3.06	50.69
6.60	2.90	47.58
6.80	2.76	44.75
7.00	2.63	42.16
7.20	2.51	39.78
7.40	2.40	37.60
7.60	2.30	35.59
7.80	2.21	33.73
8.00	2.12	32.01
8.20	2.04	30.42
8.40	1.96	28.94
8.60	1.89	27.56
8.80	1.83	26.28
9.00	1.77	25.08
9.20	1.71	23.96
9.40	1.66	22.92
9.60	1.60	21.94
9.80	1.56	21.01
10.00	1.51	20.15
10.20	1.47	19.33
10.40	1.43	18.57
10.60	1.39	17.84
10.80	1.36	17.16

WPN YIELD MT	HOB, FEET	SKY CLARITY
5	12651	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
1.60	22.76	514.92
1.80	21.09	475.48
2.00	19.54	437.95
2.20	18.14	402.75
2.40	16.88	370.11
2.60	15.76	340.10
2.80	14.78	312.67
3.00	13.92	287.70
3.20	13.18	265.03
3.40	12.54	244.49
3.60	11.99	225.88
3.80	11.51	209.02
4.00	11.11	193.75
4.20	10.77	179.90
4.40	10.48	167.33
4.60	10.00	155.91
4.80	9.37	145.51
5.00	8.80	136.03
5.20	8.27	127.37
5.40	7.80	119.46
5.60	7.36	112.20
5.80	6.95	105.54
6.00	6.58	99.42
6.20	6.24	93.79
6.40	5.92	88.59
6.60	5.63	83.79
6.80	5.35	79.34
7.00	5.10	75.22
7.20	4.87	71.40
7.40	4.65	67.85
7.60	4.44	64.54
7.80	4.26	61.46
8.00	4.08	58.58
8.20	3.91	55.89
8.40	3.76	53.37
8.60	3.61	51.01
8.80	3.47	48.80
9.00	3.34	46.72
9.20	3.22	44.77
9.40	3.11	42.93
9.60	3.00	41.20
9.80	2.90	39.56
10.00	2.80	38.02
10.20	2.71	36.56
10.40	2.62	35.18
10.60	2.54	33.87
10.80	2.46	32.64
11.00	2.39	31.46
11.20	2.32	30.35
11.40	2.25	29.29

WPN YIELD (MT) = 5   HEIGHT OF BURST (METERS) = 3857

WPN YIELD MT	HOB, FEET	SKY CLARITY
20	0	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
3.00	29.86	949.24
3.20	26.32	832.90
3.40	23.38	736.57
3.60	20.92	655.91
3.80	18.84	587.71
4.00	17.06	529.52
4.20	15.53	479.50
4.40	14.20	436.17
4.60	13.04	398.40
4.80	12.02	365.28
5.00	11.12	336.09
5.20	10.32	310.21
5.40	9.61	287.18
5.60	8.97	266.59
5.80	8.40	248.11
6.00	7.88	231.46
6.20	7.41	216.41
6.40	6.99	202.75
6.60	6.60	190.33
6.80	6.25	179.00
7.00	5.92	168.64
7.20	5.63	159.14
7.40	5.35	150.40
7.60	5.10	142.35
7.80	4.87	134.92
8.00	4.65	128.04
8.20	4.45	121.67
8.40	4.26	115.75
8.60	4.09	110.25
8.80	3.92	105.12
9.00	3.77	100.33
9.20	3.63	95.86
9.40	3.50	91.67
9.60	3.37	87.74
9.80	3.25	84.06
10.00	3.14	80.59
10.20	3.04	77.34
10.40	2.94	74.27
10.60	2.85	71.37
10.80	2.76	68.64
11.00	2.68	66.05
11.20	2.60	63.61
11.40	2.52	61.30
11.60	2.45	59.10
11.80	2.39	57.02
12.00	2.32	55.04
12.20	2.26	53.16
12.40	2.20	51.38
12.60	2.15	49.68
12.80	2.09	48.06

WPN YIELD (MT) = 20   HEIGHT OF BURST (METERS) = 0

WPN YIELD MT	HOB, FEET	SKY CLARITY
20	20084	1
DISTANCE	OVERPRESSURE	THERMAL RADIATION
0.60	32.45	999.00
1.00	31.02	999.00
1.40	29.10	999.00
1.80	26.92	954.84
2.20	24.64	874.39
2.60	22.43	793.92
3.00	20.38	716.75
3.40	18.53	644.89
3.80	16.92	579.33
4.20	15.53	520.35
4.60	14.35	467.77
5.00	13.36	421.17
5.40	12.53	379.99
5.80	11.85	343.66
6.20	11.29	311.61
6.60	10.84	283.31
7.00	10.47	258.28
7.40	9.80	236.09
7.80	9.04	216.39
8.20	8.36	198.84
8.60	7.75	183.17
9.00	7.21	169.15
9.40	6.72	156.56
9.80	6.28	145.23
10.20	5.88	135.01
10.60	5.52	125.76
11.00	5.19	117.37
11.40	4.89	109.74
11.80	4.61	102.79
12.20	4.36	96.44
12.60	4.13	90.63
13.00	3.92	85.30
13.40	3.72	80.40
13.80	3.54	75.88
14.20	3.38	71.72
14.60	3.22	67.87
15.00	3.08	64.31
15.40	2.95	61.00
15.80	2.82	57.93
16.20	2.71	55.08
16.60	2.60	52.41
17.00	2.50	49.93
17.40	2.40	47.61
17.80	2.31	45.44
18.20	2.23	43.40
18.60	2.15	41.49
19.00	2.08	39.70
19.40	2.01	38.02
19.80	1.94	36.43
20.20	1.88	34.94

WPN YIELD (MT) = 20   HEIGHT OF BURST (METERS) = 6123

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APPENDIX C

OVERPRESSURE VERSUS DAMAGE RELATIONSHIPS

The following tables present overpressure versus damage for major components of electric power systems. The tables contain a brief component description, overpressure ranges and a brief damage description. The damage and overpressure values have been divided into three categories: L - light damage, meaning the equipment is still functional but might require slight repair; M - moderate damage, implying significant repair and probable outage; S - severe damage, implying extensive repair or total replacement and failure of the component. For convenience the tables are presented by electric power system component classification, namely:

Table C.1: Generating components.

Table C.2: Transmission and distribution components.

Table C.3: Associated equipment.

TABLE C.1

GENERATING COMPONENTS

Component Description	Overpressure Psi	Damage Description
Boiler	0.1-4.5 4.6-9.0 9.1-	L - surface damage, slight cracks, slight distortion M - tubes, ducts, connections fail S - collapse
Boiler feed pumps	0.1-4.5 4.6-7.5 7.6-	L - surface damage M - connections and pipes broken, cracking S - pump failure
Circulating water pumps	0.1-4.0 4.1-6.0 6.1-	L - surface damage only M - cracks, connections fail S - failure
Condensate storage tanks	0.1-2.0 2.1-3.0 3.1-	L - small cracks, slight distortion M - large cracks, buckling, leaks S - failure
Condenser	0.1-7.0 7.1-9.5 9.6-	L - surface damage M - misalignment, connections broken S - failure
Control systems	0.1-2.0 2.1-3.5 3.6-	L - some meters and relays broken M - meters broken, cubicles deformed S - system is out

TABLE C.1 (continued)

Component Description	Overpressure Psi	Damage Description
Conveyors	0.1-3.5 3.5-5.5 5.6-	L - housing damaged M - housing fails, belt rips S - failure
Induced draft fans	0.1-3.5 3.6-6.0 6.1-	L - minor cracks M - buckling, distortion S - crushed
Intake structure	0.1-2.5 2.6-4.5 4.6-	L - some deformation M - screen housing broken, pump damage S - pump misaligned, screen failure
Load dispatch computer	0.1-0.8 0.9-1.5 1.6-	L - connections loose, surface damage M - probable malfunction S - failure
Superheater	0.1-4.0 4.1-5.5 5.6-	L - slight cracking M - distortion, connections broken S - failure
Stack	0.1-0.8 0.9-2.5 2.6-	L - slight cracking M - large cracks, deformation S - collapse
Switchyard frames	0.1-3.0 3.1-4.5 4.6-	L - some bending M - deformation S - collapse

TABLE C.1 (continued)

Component Description	Overpressure Psi	Damage Description
Transformers, generating station	0.1-5.0 5.1-8.7 8.8-	L - slight external damage, possible thermal damage M - connections broken, insulators broken S - failure
Turbine-generator	0.1-8.0 8.1-13 13.1-	L - exterior surface damage M - distortion, cracking S - severe distortion, failure
Water tanks	0.1-2.0 2.1-3.5 3.6-	L - roof damage M - roof collapsed, buckling S - loss of contents
Water treatment plant	0.1-1.0 1.1-2.8 2.9-	L - surface damage M - deformation, cracks, leaks begin S - collapse
Nuclear plant: reactor and control buildings	0.1-18 19.0-22 23.0-	L - no significant damage M - walls crack, slight distortion S - walls shattered, severe distortion
Nuclear plant: fuel building	0.1-15 16.0-19 20.0-	L - no significant damage M - walls crack, distorted S - severe distortion, walls shattered
Nuclear plant: auxiliary building	0.1-8.0 8.1-10 10.1-	L - windows and doors fail M - distorted, walls crack S - collapse

TABLE C.1 (continued)

Component Description	Overpressure Psi	Damage Description
Oil conditioning equipment	0.1-5.0 5.1-7.0 7.1-	L - surface damage M - piping broken S - failure
Oil storage tanks	0.1-4.5 4.6-7.5 7.6-	L - roof damage M - roof collapsed, leakage S - loss of contents
Piping, major	0.0-4.5 4.6-7.0 7.1-	L - slight bending M - connections broken, some cracks S - failure
Pulverizers	0.1-3.0 3.1-4.9 5.0-	L - some deformation M - cracks, connections broken, distorted S - failure
Soot blowers	0.1-4.5 4.5-5.5 5.6-	L - superficial damage M - connections broken, distorted S - failure
Spillway gates	0.1-5.0 5.1-7.0 7.1-	L - negligible damage, possible control problems M - cracks, deformation S - failure

TABLE C.2

TRANSMISSION AND DISTRIBUTION COMPONENTS

Components Description	Overpressure Psi	Damage Description
Batteries	0.1-1.2 1.3-2.7 2.8-	L - surface damage, still functional M - cracking, possible outage S - nonfunctional, must be replaced
Breakers, air	0.1-3.0 3.1-4.5 4.6-	L - surface damage, some deformation M - smaller breakers out S - failure, replacement necessary
Breakers, oil	0.1-3.2 3.2-4.9 5.0-	L - functional M - deformation, smaller breakers fail S - failure
Bushings, transformer	0.1-3.0 3.1-4.5 4.6-	L - unharmed M - cracking, some failure S - failure, replacement necessary
Bus structure	0.1-3.0 3.1-8.0 8.1-	L - minor distortion M - distortion, some failures S - Buckling and failure
Capacitors	0.1-3.5 3.6-4.5 4.6-	L - surface damage M - some failures due to debris S - failure

TABLE C.2 (continued)

Component Description	Overpressure Psi	Damage Description
Control systems	0.1-1.5 1.6-3.5 3.5-	L - some meters and relays broken M - meters and connections break S - failure
Distribution lines	0.1-2.0 2.1-4.3 4.4-	L - poles leaning, cross arms broken M - poles broken, transformers out S - lines down and out
Insulators, transformer	0.1-2.5 2.6-3.5 3.6-	L - surface damage M - cracks, missile damage S - failure
Oil switches	0.1-3.5 3.6-6.0 6.1-	L - surface cracks M - distortion, cracks, possible failure S - destroyed
Reclosers	0.1-2.5 2.6-4.0 4.1-	L - surface damage, functional M - possible failure S - failure
Regulators	0.1-2.5 2.6-3.8 3.9-	L - operable with slight surface damage M - possible failure by distortion S - failure
Sectionalizers	0.1-2.0 2.1-3.0 3.1-	L - surface damage M - possible failure, distortion S - failure

TABLE C.2 (continued)

Component Description	Overpressure Psi	Damage Description
Switches, general	0.1-2.5 2.6-4.0 4.1-	L - slight damage, functional M - deformation, cracking S - destroyed
Transmission lines, wooden	0.1-2.8 2.9-3.5 3.6-	L - cross arms broken M - numerous poles broken S - poles broken, lines down
Transmission lines, steel towers	0.1-2.0 2.1-3.3 3.4-	L - slight buckling M - severe buckling S - collapse
Transformers, substation	0.1-4.0 4.1-6.5 6.6-	L - surface damage M - possible thermal breakdown, insulation damage S - failure
Transformers	0.1-1.5 1.6-2.9 3.0-	L - surface damage M - cracking, thermal breakdown S - failure
Underground lines	0.1-5.0 5.1-10 10.1-	L - undamaged M - overhead connections broken, possible flooding S - disconnected and flooded

TABLE C.3

ASSOCIATED EQUIPMENT

Component Description	Overpressure Psi	Damage Description
Building - reinforced concrete blast resistant design, no windows	0.1-17 18.0-20 21.0-	L - no significant damage M - walls cracked, doors out, slight distortion S - walls shattered, frame severely distorted
Building - reinforced concrete, small window area, multi-story	0.1-6.0 6.1-9.0 9.1-	L - windows and doors blown in, partitions cracked M - distorted, walls cracked, partitions down S - collapse
Building - wall bearing brick, up to three stories	0.1-5.0 5.1-8.0 8.1-	L - doors and windows blown in, partitions cracked M - walls cracked, partitions down S - bearing walls collapse, structure collapses
Building - light steel frame single story, five ton crane capacity	0.1-4.0 4.1-6.9 7.0-	L - windows and doors gone, siding buckled M - frame distorted, crane inoperable S - severe frame distortion
Building - medium steel single story, 20 ton capacity	0.1-7.0 7.1-9.5 9.6-	L - siding ripped, windows and doors gone M - frame distorted, crane inoperable S - severe distortion

TABLE C.3 (continued)

Component Description	Overpressure Psi	Damage Description
Building - heavy steel frame single story, 50 ton crane	0.1-8.0	L - siding buckled or ripped, windows and doors gone
	8.1-10	M - slight frame distortion, crane inoperable
	10.1-	S - severe distortion
Building - multi-story frame, light weight office type	0.1-7.0	L - windows and doors blown in, partitions cracked
	7.1-8.5	M - moderate distortion, partitions down
	8.6-	S - probable collapse
Building - reinforced concrete, multi-story office type	0.1-6.0	L - windows and doors blown in, partitions cracked
	6.1-7.5	M - frame slightly distorted, partitions down
	7.6-	S - frame severely distorted, collapse of floor columns
Microwave antenna	0.1-1.5	L - guy lines slack, but functioning
	1.6-2.5	M - buckling, directional ability lost
	2.6-	S - down
Radios	0.1-3.0	L - surface damage by missile
	3.1-3.9	M - possible failure by movement or missiles
	4.0-	S - failure
Railroad equipment: locomotives end-on orientation	0.1-6.0	L - minor damage, still usable
	6.1-9.0	M - possibly overturned, major repairs needed
	9.1-	S - twisted, probably demolished

TABLE C.3 (continued)

Component Description	Overpressure Psi	Damage Description
Railroad equipment: locomotives side-on orientation	0.1-5.0 5.1-7.5 7.6-	L - minor damage M - probably overturned, major repairs S - demolished
Railroad equipment: rolling stock	0.1-3.5 3.6-4.8 4.9-	L - some body damage M - damaged but movable S - demolished or blown from tracks
Transmitting towers: radio and TV	0.1-2.5 2.6-3.5 3.6-	L - slight damage but functioning M - buckling, probably unable to function S - collapse
Trucks, repair	0.1-3.5 3.5-4.9 5.0-	L - broken glass, body damage, operable M - turned over, major repairs S - destroyed

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