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HEALTH AND SAFETY IMPACTS OF
NUCLEAR, GEOTHERMAL, AND FOSSIL-FUEL
ELECTRIC GENERATION IN CALIFORNIA

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California Energy Resources
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Contract no. 4-0123

Energy and Environment Division

Health and Safety Impacts of Nuclear, Geothermal, and Fossil-Fuel Electric Generation in California: Overview Report

Anthony V. Nero, Jr.

January, 1977

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Energy Research and Development Administration under Contract No. W-7405-ENG-48

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LBL-5924

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HEALTH AND SAFETY IMPACTS OF NUCLEAR, GEOTHERMAL, AND FOSSIL-FUEL ELECTRIC GENERATION IN CALIFORNIA

OVERVIEW REPORT

Anthony V. Nero, Jr.

Volume 1

of

HEALTH AND SAFETY IMPACTS OF

NUCLEAR, GEOTHERMAL, AND FOSSIL-FUEL

ELECTRIC GENERATION IN CALIFORNIA

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

January 1977

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This is one of a series of reports prepared as part of the Lawrence Berkeley Laboratory project, "Health and Safety Impacts of Nuclear, Geothermal, and Fossil-Fuel Electric Generation in California." This project was performed for the State of California Energy Resources Conservation and Development Commission as its "Health and Safety Methodology" project, funded under contract number 4-0123. The reports resulting from this work are listed below. Their relationship to one another is described fully in volume 1, the Overview Report.

Vol. 1: "Health and Safety Impacts of Nuclear, Geothermal, and Fossil-Fuel Electric Generation in California: Overview Report," by the entire staff, Lawrence Berkeley Laboratory Report LBL-5924. Includes "Executive Summary" for the project.

Vol. 2: "Radiological Health and Related Standards for Nuclear Power Plants," by A.V. Nero and Y.C. Wong, Lawrence Berkeley Laboratory Report LBL-5285.

Vol. 3: "A Review of Light-Water Reactor Safety Studies," by A.V. Nero and M.R.K. Farnaam, Lawrence Berkeley Laboratory Report LBL-5286.

Vol. 4: "Radiological Emergency Response Planning for Nuclear Power Plants in California," by W.W.S. Yen, Lawrence Berkeley Laboratory Report LBL-5920.

Vol. 5: "Control of Population Densities Surrounding Nuclear Power Plants," by A.V. Nero, C.H. Schroeder, and W.W.S. Yen, Lawrence Berkeley Laboratory Report LBL-5921.

Vol. 6: "Health Effects and Related Standards for Fossil-Fuel and Geothermal Power Plants," by G.D. Case, T.A. Bertolli, J.C. Bodington, T.A. Choy, and A.V. Nero, Lawrence Berkeley Report LBL-5287.

Vol. 7: "Power Plant Reliability-Availability and State Regulation," by A.V. Nero and I.N.M.N. Bouromand, Lawrence Berkeley Laboratory Report LBL-5922.

Vol. 8: "A Review of Air Quality Modeling Techniques," by L.C. Rosen, Lawrence Berkeley Laboratory Report LBL-5998.

Vol. 9: "Methodologies for Review of the Health and Safety Aspects of Proposed Nuclear, Geothermal, and Fossil-Fuel Sites and Facilities," by A.V. Nero, M.S. Quinby-Hunt, et al., Lawrence Berkeley Laboratory Report LBL-5923.

HEALTH AND SAFETY IMPACTS OF NUCLEAR, GEOTHERMAL, AND FOSSIL-FUEL ELECTRIC GENERATION IN CALIFORNIA

OVERVIEW REPORT

ABSTRACT

This report presents an overview of a project on the health and safety impacts of nuclear, geothermal, and fossil-fuel electric generation in California. In addition to presenting an executive summary of the project, it sets forth the main results of the four tasks of the project: to review the health impacts (and related standards) of these forms of power generation, to review the status of standards related to plant safety (with an emphasis on nuclear power), to consider the role of the California Energy Resources Conservation and Development Commission in selection of standards, and to set forth methodologies whereby that Commission may review the health and safety aspects of proposed sites and facilities. In summarizing the results of the project, this report relies heavily on several more specialized reports resulting from this work.

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SELECTED ABBREVIATIONS

AEC - Atomic Energy Commission

AFC - Application for Certification

ACRS - Advisory Committee on Reactor Safeguards

ANSI - American National Standards Institute

APS - American Physical Society

APCD - Air pollution control district

ARB - Air Resources Board

ASME - American Society of Mechanical Engineers

BEIR - Report of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation

BPVC - Boiler and Pressure Vessel Code

BWR - Boiling water reactor

CAC - California Administrative Code

CFR - Code of Federal Regulations

ECCS - Emergency core cooling system

EEI - Edison Electric Institute

EPA - Environmental Protection Agency

EPRI - Electric Power Research Institute

ERCDC - Energy Resources Conservation and Development Commission

FRC - Federal Radiation Council

ICRP - International Commission on Radiological Protection

LOCA - Loss-of-coolant accident

LWR - Light water reactor

MWe - Megawatts (electric)

NCRP - National Council on Radiation Protection and Measurement

NOI - Notice of Intention

NRC - Nuclear Regulatory Commission

OSHA - Occupational Safety and Health Administration

QA - Quality assurance

PWR - Pressurized water reactor

RG - Regulatory guides

SAR - Safety Analysis Report

SRP - Standard Review Plans

WASH-1400 - Report of the NRC Reactor Safety Study

INTRODUCTION AND SUMMARY (EXECUTIVE SUMMARY)

THE HEALTH AND SAFETY IMPACTS OF NUCLEAR, GEOTHERMAL, AND FOSSIL-FUEL ELECTRIC GENERATION IN CALIFORNIA

Lawrence Berkeley Laboratory

January 1977

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This introduction and summary of the Overview Report for the Lawrence Berkeley Laboratory project, "The Health and Safety Impacts of Nuclear, Geothermal, and Fossil-fuel Electric Generation in California," also serves as an Executive Summary for the project. This project was performed for the State of California Energy Resources Conservation and Development Commission as its "Health and Safety Methodology" project and was funded under contract number 4-0123. In addition to the overview report, a number of other reports were written in the course of this work. These reports and their relationship to one another are indicated in this introduction and summary and, more fully, in the body of the Overview Report.

S1. Purpose of the work

The Warren-Alquist State Energy Resources Conservation and Development Act established a Commission, one of whose major responsibilities is to certify sites and facilities for electric power generation. As part of the certification process, this Energy Resources Conservation and Development Commission (ERCDC) must review the "health and safety" aspects of the sites and facilities which are proposed. This review must constitute a portion of the overall review process, which is divided into two stages, an actual application for certification (AFC) and a preliminary notice of intention (NOI) to apply for certification. The NOI stage requires the submission of three alternative sites, and the acceptability of these sites is determined upon review of the site characteristics, in the light of the type of facilities which will be proposed. The AFC stage is an application to construct a facility on a site which has previously been found to be acceptable at the NOI stage.

The purpose of this work has been to examine the potential health and safety impacts of nuclear, geothermal, and fossil-fuel electric-generating power plants and to identify methodologies whereby the ERCDC may review these health and safety impacts to determine compliance with applicable standards, including those which the ERCDC may adopt "to be met in designing or operating facilities to safeguard the public health and safety." The review conducted by the ERCDC examines areas other than health and safety, but these have not been treated in the present work. Examination of environmental impacts and of detailed facility design has been included to the extent that they have implications for human health and safety.

The first part of the work examined the present state of knowledge about, and standards for, potential health and safety impacts. It has been divided, as a convention, into two areas: a "health" area, deemed to include emissions (into air and water) from the plant site and the manner in which they affect the public, and a "safety" area, deemed to include physical or engineering aspects of the facility and site which may have health and safety implications. For the health area, a review of important studies and of the standards was performed. For the safety area, a preliminary survey of available standards was performed, but analysis was limited to two specific areas: a review of studies of light-water nuclear reactor

safety and a brief examination of historical data on power plant reliability and availability.

The second part of the work examined the tools for ERCDC review, the standards which might be employed and methodologies for the review process. A topic which was examined with particular interest was how the ERCDC might evaluate or develop standards, and related methodologies, for areas where these do not presently exist, but which are judged significant for health and safety.

Facilities for electric power production include both the power plants themselves and the other components of the fuel cycle, such as mines and/or mills, fuel fabrication or processing plants, transportation lines, and waste disposal facilities. Although reference is made to facilities other than the power plants, it is the power plant itself that is the basic focus of this work.

S2. Basic considerations for standards and methodologies for review of proposed sites and facilities

Standards, in the sense of "that which is established as a measure," are the basic tool employed during the regulatory review. The major effort in the development of the review process is the identification, selection, or formulation of standards, and the development of methodologies for their application. The character of these standards strongly affects the nature of the review process.

Basically, standards may be developed either as regulatory requirements or as suggested guidelines. Which is chosen depends on the particular application. Often standards related to air quality carry legal force. In other cases, such as for broad assessment functions and for review of facility design, it is difficult to establish regulatory standards. However, it is possible, as indicated below.

Even an emission standard with legal force is based broadly on possible effects on human health. However, it often serves in lieu of any quantitative evaluation of health impacts. As detailed understanding of these impacts develops, standards more directly based on evaluation of impacts can come into use. As examples of these two stages of development, most air quality standards and associated emission standards are based on an appreciation of the effects of air pollution on human health, but not on quantitative assessment of impacts; on the other hand, although standards for routine radioactive emissions were similarly based until recently, the review of nuclear power

plants by the Nuclear Regulatory Commission is now based directly on cost-benefit considerations coupled with quantitative risk assessment.

Should it be considered desirable to perform assessment functions for areas where the legal standards are not formulated in this way, guidelines for assessment would have to be developed. These would specify how an assessment methodology was to be used. It may be appropriate to begin constructing a framework for assessing health impacts of conventional power plant emissions. Since not enough is known for direct calculation of these impacts, indicators might be used; guidelines would have to be developed for use of such indicators. As another example, if the potential impact of nuclear accidents (as distinguished from routine emissions) is to be considered quantitatively in the review process, guidelines and methodologies for accident analysis will have to be developed.

General design of power plants and other industrial facilities customarily use standards which have no legal standing, but which are effective guidelines. In certain areas, with important implications for the health and safety of workers or the public, these standards may assume regulatory force, either formally or practically. However, the bulk of engineering standards are voluntary.

For any area of review, related either to emissions (routine or accidental) or to plant design, a considerable effort may be devoted to analysis, whether or not the standards are actual legal requirements. However, before the ERCDC could review an area for which there are no regulatory standards, it would have to select or develop standards, requiring a considerable effort in itself. Moreover, it would have to carefully consider possibly overlapping jurisdiction with other public agencies. This possibility must be considered, in fact, for any review area. It is to be expected, though, that the details of coordination in overlapping areas would be developed on the basis of actual experience with the processes of standards development and facility review.

For many aspects of electric power plants relating either to emissions or to facility design, important choices have to be made either of review areas, standards, or methodologies. Ultimately the selection of standards and methodologies for a health and safety review should be based precisely on health and safety impacts. This work has been devoted to an examination of these impacts, to elucidation of review methodologies for meeting standards related to these impacts, and — for areas where regulatory standards do not exist, such as for impact assessment functions or engineering review — to identification of approaches for treatment of these areas during ERCDC review.

S3. Products of the work

The work performed in this project has led to the completion of several products, primarily in the form of Lawrence Berkeley Laboratory reports.

Reviewing the health and safety implications of electric generating facilities involved completion of several reports on "health" effects and related matters. Those primarily related to nuclear power plants are:

"Radiological Health and Related Standards for Nuclear Power Plants," by A. V. Nero and Y. C. Wong, Lawrence Berkeley Laboratory Report LBL-5285.

"Radiological Emergency Response Planning for Nuclear Power Plants in California," by W. W. S. Yen, Lawrence Berkeley Laboratory Report LBL-5920.

"Control of Population Densities Surrounding Nuclear Power Plants," by A. V. Nero, C. H. Schroeder, and W. W. S. Yen, Lawrence Berkeley Laboratory Report LBL-5921.

A major report on fossil-fuel and geothermal plants was completed:

"Health Effects and Related Standards for Fossil-Fuel and Geothermal Power Plants," by G. D. Case, T. A. Bertolli, J. C. Bodington, T. A. Choy, and A. V. Nero, Lawrence Berkeley Laboratory Report LBL-5287.

A brief report on meteorological models provided information on pollutant dispersion, a matter of major interest for review methodologies:

"A Review of Air Quality Modeling Techniques," by L. C. Rosen, Lawrence Berkeley Laboratory Report LBL-5998.

Safety-related aspects of nuclear plants and certain reliability aspects of all plants were treated in:

"A Review of Light-Water Reactor Safety Studies," by A. V. Nero and M. R. K. Farnaam, Lawrence Berkeley Laboratory Report LBL-5286.

"Power Plant Reliability-Availability and State Regulation," by A. V. Nero and I. N. M. N. Bouromand, Lawrence Berkeley Laboratory Report LBL-5922.

Two informal reports, simply listings — without comment — of engineering standards, have been compiled on "Criteria, Regulatory Guides, and Standards Applicable to the Safety Engineering of Light-Water Reactor Power Plants" and on "Generally Applicable Engineering Standards."

All of the above work served as primary input to the methodologies report and, finally, to the Overview Report:

"Methodologies for Review of the Health and Safety Aspects of Proposed Nuclear, Geothermal, and Fossil-Fuel Sites and Facilities," by A. V. Nero, M. S. Quinby-Hunt, and staff, Lawrence Berkeley Laboratory Report LBL-5923.

"Health and Safety Impacts of Nuclear, Geothermal, and Fossil-Fuel Electric Generation in California: Overview Report," by the entire staff, Lawrence Berkeley Laboratory Report LBL-5924.

The Overview Report, together with the other reports listed above, constitute the final report for this project. They serve both as a basic source of information of the health and safety aspects of electric generation stations and as a structure for methodologies for health and safety review. These two aspects of the work are summarized in the remaining sections of this introduction and summary. The four chapters of the Overview Report which follow this introduction and summary correspond roughly to the four tasks of the work statement for this project.

S4. Health and safety impacts of electric generating facilities: a summary

The primary effects which electric generating facilities may have on the public health and safety occur due to the emission and dispersion of harmful substances through environmental media with which the public has contact. Because of this, a basic function of the public agencies charged with protecting the public health has been to limit such emissions, considering both the benefit to the public and the feasibility (including cost) of controls. Because the facility design clearly affects emissions and can also have a direct effect on the safety of workers, such design is also regulated, but to a lesser extent. Only for nuclear power plants among the facility types of interest does plant safety have a sufficiently strong potential impact on the public safety to have warranted detailed regulation of the plant design.

The principal media through which harmful substances may reach the public are air and water. For each medium, limitations on ambient concentrations and on emissions of various substances have been developed, based on the current understanding of their effect on human health and welfare. We have operationally divided these substances into radioactive and "conventional" pollutants, both of which include substances in gaseous, liquid, and particulate form.

S4.1 Health effects associated with nuclear power plants

Radioactive materials are the emissions of principal concern from nuclear power plants. A separate report (LBL-5285) discusses these emissions, as well as the effects of radiation and the standards for protection of humans from exposures arising from radioactive releases, whether routine or accidental.

The principal radioacive emissions from routinely operating nuclear power plants are tritium, carbon, iodine, and the noble gases krypton and xenon. The major emissions of these radionuclides are into air, although

the tritium—an isotope of hydrogen which is typically incorporated into water molecules—may also escape in the liquid discharges. From the radiological point of view, the significant measure of emissions is the ultimate dose to which humans are subjected; the dose from an operating nuclear power plant is typically very small compared with the dose received from other sources, either natural background sources or medical exposures.

Our present understanding of the effects of radiation arises from several major sources, including the inhabitants of Hiroshima and Nagasaki exposed to radiation from nuclear weapons, patients treated with radiation as part of medical procedures, and those who have been occupationally exposed to radiation. The major concern associated with low levels of radiation exposure, such as those ordinarily caused by commercial nuclear power operations, is the possible induction of cancer or other latent effects. The above sources of information serve as a tentative basis for estimating the effects of these low doses. Although specific estimates of latent effects may be the subject of controversy, overall it is clear that the exposures caused by routine emissions from nuclear power plants are not of major importance relative to other risks.

A number of bodies, both international and national, take responsibility for assembling information on the health effects of radiation and for formulating guidelines for limiting either exposures of the general public or occupational exposures. The recommended limits on "dose equivalent" from man-made causes other than medical are 500 mrem/year for individual members of the general public and 170 mrem/year for populations. These numbers may be compared with the doses typically received from background sources (about 130 mrem/year) or from medical procedures (about 70 mrem/year). However, the agency with primary authority for the regulation of nuclear facilities, the Nuclear Regulatory Commission, adheres to the guideline that exposures should be "as low as is reasonable achievable." Currently the numerical guidelines specify a maximum exposure to members of the general public from nuclear power plants of about 5 mrem/year. The average individual exposure from operating plants is much lower than this.

A rough estimate of the significance of these routine releases can be obtained from relating doses to health effects (particularly cancer) with a linear function extrapolated from the observed effects at high doses (greater than about 100,000 mrem in a short period of time) to those at low doses.

Such an estimate leads to the conclusion that the total emissions from all presently operating nuclear power plants cause less than one death per year. This is very small compared with the risk from other sources, including other types of power plants. However, see section S4.3 for discussion of the significance of accidental releases.

S4.2 Health effects associated with fossil-fuel and geothermal power plants

The principal health impacts from fossil-fuel and geothermal power plants occur through the emission of "conventional" pollutants, primarily into the atmosphere and secondarily into water resources. A separate report (LBL-5287) discusses these emissions, their possible health effects, and related standards.

The two major categories of air emissions from fossil-fuel and geothermal plants are gases and particulates. In general, the important gases are compounds of sulfur, nitrogen or carbon, often with oxygen (i.e., oxides). The particulate matter may contain important amounts of all these elements, often in more complex molecules, and in addition may contain significant amounts of heavy metals. In addition, mercury and selenium may be emitted as vapors. Less important discharges into air are radioactive materials, water, and heat. A wide array of substances, in various forms, may be discharged into water from such plants, but for the most part their control is well enough understood that they do not pose as significant a hazard as emissions into air. The main exception could be materials leached from solid (or slurry) waste disposal sites into water supplies. Finally, these plants can produce significant levels of noise.

The relative and absolute importance of these emissions is highly dependent on the individual technology. The basic types of fossil-fuel systems to be considered are conventional coal, oil, and gas fired plants, although advanced systems may assume increasing importance. The only significant geothermal power generation in California is based on vapor-dominated fluids, but plants at liquid-dominated resources are under rapid development. In spite of the important differences in detailed emissions from these several technologies, the general classes of emissions and their effects are similar, and it has been useful to consider them together.

The emission of materials from fossil-fuel and geothermal power plants has been observed to alter significantly the ambient levels of atmospheric constituents in regions around the plants. Generally, though, there are

competing sources of comparable importance, so that the effects of a particular power plant cannot be treated independently. This is particularly true, since, more than in the case of radioactive emissions, the pollutants undergo extremely important alterations in the atmosphere. This occurs even if only the emissions from a single source are present because the various gaseous and particulate substances interact among themselves or with naturally occurring atmospheric constituents. To complicate analysis further, available information on the effects of pollutant emissions (and their products) on human health lacks precision regarding what health effects take place and the quantitative relationship between exposures and observed effects.

Two general categories of human experience provide such information: occupational exposures and exposures of the general public. Either source may provide data on either acute, high levels of exposure or chronic, low levels. The results of acute and large exposures are more easily identified. Lower levels require careful study, particularly since the effects must be distinguished statistically from other effects and causes. Study of effects under any exposure condition is complicated by synergistic effects among species.

It is useful to distinguish between toxic levels, resulting in acute effects, and lower levels, leading to disease or its aggravation. For the latter exposure type, the principal concern is that many of these pollutants appear capable of inducing important types of disease, including respiratory illness, heart and circulatory disease, and cancer. However, because these diseases appear independently of the pollutants, correlations are difficult and have not been established in any comprehensive way. They are derived from a combination of data from acute air pollution episodes, occupational exposures, more general epidemiological work, and laboratory studies with humans and animals. In spite of the large uncertainties, it is clear that these pollutants are emitted in sufficient quantity to cause distress among large portions of the population. It is suspected that these pollutants can cause serious illness and death among the general population, and this fact has been established for a number of air pollution episodes. Finally, the emission of these pollutants from fossil-fuel power plants in particular makes a significant contribution to any illness and death which occur from the total of such emissions. It is thought that such a power plant induces more such effects via routine emissions than does a nuclear power plant.

Research on such health effects is widely conducted, funded by a number of agencies, primarily national. The Federal agency responsible for establishing, on the basis of such information, standards for the protection of the health and welfare of the general public is the Environmental Protection Agency. Such standards are developed for both air and water. The EPA relies largely on state agencies such as the Air Resources Board for the implementation of these or more stringent, standards. Moreover, these agencies (such as the local Air Pollution Control Districts) review new stationary sources, including power plants. However, air and water quality standards are by no means complete, a reflection of the state of the present understanding of health effects.

S4.3 Risks from power plant accidents

In addition to causing effects by routine pollutant emissions, power plants have a potential for accidents that may significantly affect the public and workers. For conventional power plants, the primary concern is not such accidents, but rather the more usual pollutant emissions. However, the situation is quite different for nuclear power plants.

Routine radioactivity emissions from a nuclear power plant constitute only a very small portion of the radioactivity produced in the reactor, but a much larger portion could be released during a major plant accident. Such a release would pose a substantial threat to surrounding populations, even at some distance from the plant, in the form of early and latent illness and death. The primary study which attempted to calculate in a comprehensive manner the risk to the public from such accidents was the Reactor Safety Study, conducted by the Nuclear Regulatory Commission and resulting in the report designated WASH-1400. This study, as well as work performed by the Electric Power Research Institute on related techniques and the report to the American Physical Society from the study group on light water reactor safety (which examined the causes and consequences of accidents and the overall light-water reactor safety research program), are discussed in a separate report (LBL-5286).

WASH-1400 calculated, on a mechanistic basis, the probability of accidents of various types, then calculated the consequences of such accidents, using weather and population information from known sites in the United States. These results were combined to obtain the net risk of early and latent illness and death, as well as property damage, from typical plants in this country. The calculated early fatalities were compared with risks from other types of accidents to show that the nuclear accident risk is substantially smaller

than other risks incurred from man-made and natural accidents. (However, calculated latent fatalities are far more numerous than the early fatalities.)

Many groups and individuals have expressed skepticism over the WASH-1400 results. Both the probabilistic techniques and the consequence calculations have been criticized, the first on the grounds that they have a strong potential for leaving out possible accident sequences, particularly those which result from simultaneous system failures due to a single component or human failure. More important from our point of view are criticisms of the consequence calculations based on the fact that they cannot easily be adapted to analyzing the potential risks at a specific site of interest. It is clear that the risk depends highly on the local meteorological conditions and on the disposition of populations around the site.

Regardless of these details, the average risk from such plant accidents was found to be greater than that posed from routine emissions, largely due to the latent effects (which dominate the overall accident risk). (However, this is not to say how the risk from such accidents compares with the routine risk from other plants, such as those which are fossil-fuel fired.)

In spite of criticisms, the WASH-1400 results have been supported in large part by the results of other similar studies. A somewhat earlier study, the Swedish Urban Siting Study arrived at risks which were considerably less than those calculated in WASH-1400. However, the Swedish study committee based its probability for major accidents on the opinion that catastrophic vessel failure was the major initiator of such accidents, and that this would only occur less than once per million years of reactor operation. Although other important studies, such as an Advisory Committee on Reactor Safeguards study (WASH-1285), a recent British study (the "Marshall" report), and the APS study, agree with the failure probability, the meltdown probability in WASH-1400 (once per 20,000 reactor years) exceeds that in the Swedish study (once per 1 to 10 million reactor years) largely because of the risk from <u>other</u> accident initiators, primarily pipe breaks and transients of other sorts. Other work on probabilistic modeling <u>per se</u>, both in the United States and abroad tends to support the WASH-1400 results, more often accusing the authors of being overly conservative in areas of uncertainty than the converse. This contrasts with the critics of probabilistic techniques, who — as mentioned above — are skeptical of the dependability of such techniques.

However, presuming that the results of such techniques have some validity, the ability to perform site specific analysis would be helpful for assessing comparative risks at alternative plant sites. For a given site, it could be used as a partial basis for determining the adequacy of emergency planning (see LBL-5920) and of population density control measures (see LBL-5921), both being techniques to reduce population exposures in the event of accidental releases. Together, such an analytical technique and appropriate criteria would serve as the basis for land use planning around nuclear facilities.

However, it is useful to note in this context that WASH-1400, and typical environmental statements for nuclear power plants, give a misleading impression as to what size accidents contribute most of the risk from nuclear power plants. Both of these sources imply (but do not state directly) that small accidents are the main contributors. However, the data presented in WASH-1400 belies this impression, showing that the large accidents ("class 9", in the language of the environmental statements) actually contribute most of the risk.

The discussion above has been limited to the assessment of risks from nuclear power plants. A more fundamental point of view is pursued in most research and development on, as well as criticism of, reactor safety. For example the report to the APS examined the specific areas in which research was occurring or was needed, and many other groups have identified such areas. The Advisory Committee on Reactor Safeguards maintains a list of "generic items relating to reactor safety," actually specific areas in which uncertainty exists, and this list includes essentially all areas of reactor safety on which concerns have been raised. We have arranged these generic items into a number of categories, in order to indicate the range that they encompass. The categories are: 1) ECCS and LOCA related items, including containment response, 2) quality assurance, inspection, test, and monitoring, 3) general equipment and system adequacy and protection (including, for example, common mode failures and fire protection), 4) reactor pressure vessel, 5) seismic response, 6) emergency control, 7) general reactor operation: control and instrumentation, 8) protection against sabotage, and 9) effluents and decontamination. Even though both partisans and critics of nuclear power would agree that the items fitting into these categories deserve attention, they would not agree on the urgency of these matters or the extent to which these uncertainties contribute to risk from nuclear power plants now being licensed.

S4.4 Safety standards and plant reliability

Safety at ordinary plants is assured by reliance on a wide range of engineering standards and, to a lesser extent, by regulatory requirements, largely occupational safety (OSHA-type) regulations. The single exception is nuclear power plants, for which the Nuclear Regulatory Commission exercises broad authority to review plant systems which are deemed to have safety significance. The design for the remaining systems, and for all systems in non-nuclear facilities, is performed by the utility (and its contractors) without regulatory review, except for general industrial safety matters.

To suggest the detail and type of standards used in review of nuclear plants, we have prepared a compilation of the criteria used by the Nuclear Regulatory Commission in its Standard Review Plans for review of light-water reactors. Most of the standards included therein are suggested, but effectively required, solutions for regulatory requirements. We have also prepared a compilation of generally applicable standards (that is engineering standards for fossil-fuel and geothermal plants, as well), selected from a large number of sources, but not comprehensive. These are standards which may be utilized in the design (or review) of facilities. However, as discussed in the next section, choosing standards for use in a regulatory context requires substantial effort.

One basis for such choice might be to devote attention to systems which historically have contributed significantly to lack of plant reliability. The periodic report of the Edison Electric Institute on power plant availability for the 10 years 1965-1974 was examined (LBL-5922) to obtain such information, first broadly characterizing the availability of various plants type, then assigning observed outages times to major plant systems (such as the boiler or reactor, the turbine, etc.). Finally, on the basis of an accompanying outage cause report, outages were broken down into component classes for each of the major systems. Significant outages are caused by a broad range of components, the most easily identifiable group being fossil plant boiler tubes. Effectively, the data indicate that any regulatory program intended to improve reliability would have to include a broad range of plant systems and components.

S5. Methodologies for health and safety review: a summary

For the health and safety review, three matters need consideration: the areas of review, the standards for use in the review, and the structure of the review. The primary consideration is the health and safety of the public, so that the review is not intended to include an environmental review or an engineering review, except to the extent that these are relevant to health and safety. However, the structure indicated below can be extended to include these areas without difficulty. It is based on the prescribed division of the ERCDC review into a Notice of Intention (NOI) process and an Application for Certification (AFC) process.

S5.1 Areas of review

Considering the structure of the review process, divided into NOI and AFC stages, it in convenient to make what is, in any case, a natural division of review areas into a site-specific review and facility design review. The site-specific review would concentrate on two areas, the flow of materials into and — especially — out of the plant site, and the mechanical interaction between the proposed site and plant. Since the major material flow to be considered is emissions from the plant, this review takes on the character of a "health" aspects review, particularly since the effect of these emissions on air and water quality and on the surrounding populations would be included for review. Thus the demographic aspects of the proposed site would be of major interest. The physical aspects of the site would be examined to judge the adequacy of the site to support the proposed facilities; this examination would include both general stability and hydrological characteristics and also the potential for seismic or flood activity. All judgments in this review would be based on generic information for the plant type being considered.

The facility design review can, in principle, include many design areas, but from the point of view of a health and safety review, some selection can be made. The two areas which clearly have health and safety implications are the emission control equipment, which is of direct interest to the general public, and occupational and plant safety features, of interest to workers and to the safety of the plant. For a nuclear power plant, plant safety has much more direct implications for the safety of the public. There are many other design areas which do not have direct health and safety significance, but which provide the basis for safe operation and also for general reliability, and hence

economy, of the facility. Of course, the examination of facility design must also be considered in view of the physical characteristics of the site which will support the structure.

S5.2 Standards for review

Many of the standards required for review are the responsibility, sometimes exclusive, of other agencies, and we do not attempt to detail how the ERCDC coordinates its review with such agencies. Major examples are standards related to air and water quality. The ERCDC would check compliance with these standards, both for emissions and for ambient concentrations, but the local air pollution control districts and comparable water districts would logically be closely consulted. Most emission standards, the primary class of "health" standards, will require such coordination.

The main area of possible "health" review for which standards are not easily identified is any overall assessment of human impacts which would be performed. Such assessment and comparison of alternative sites (and even technologies) might be considered to be part of the ERCDC review responsibility. For nuclear plants, such assessment would examine the site-specific impact of potential accidental releases of radioactivity; associated with this examination would be review of the character and adequacy, in view of the potential impacts, of emergency planning and, possibly, of population density controls surrounding nuclear power plants. For fossil-fuel and geothermal plants, where the major concern from the public point of view is routine emissions, such impact assessment would have to be based on a set of exposure categories (for pollutants of concern) for which populations at risk could be calculated, based on plant emission characteristics and on local demography; although the available data are not sufficient to yield net health impacts, the populations at risk could serve as an indicator for comparison of alternative sites.

The identification of standards for "safety" or design review is more difficult than for health. Thousands of such standards exist, in the form of engineering standards formulated by professional societies, but they are not normally intended to be established as regulations. The Nuclear Regulatory Commission depends heavily on such standards, but only as suggested means of satisfying regulatory requirements. For any of the design areas mentioned above as possible areas for review, there are standards which may be used, but the process of selecting them for regulatory use would require substantial effort, particularly if many design areas are to be reviewed. For any system designated for review,

perhaps on the basis of the reliability data described in section 4.4, careful coordination of staff effort with the efforts of appropriate professional societies is to be encouraged, both to reduce the huge potential for ERCDC effort in this area and to assure development of standards acceptable to the engineering community. Alternatively, a review could be based on standards chosen by the applicant, although this has some difficulties. See the discussion below under the Application for Certification Review.

S5.3 The Notice of Intention Review

The basic purpose of the NOI review is to examine site-related aspects of proposed sites and facilities. The main focus of the "health and safety" review at this stage is on emissions from the plants and on the interaction of the facility proposed with the site itself. To establish a review process that puts all technologies on a common footing, it is possible to devise a common methodological structure, such as that used in the methodology report (LBL-5923). The review would depend largely on staff analysis, but in some areas previous experience and outside expert opinion would probably be utilized. The proposed NOI health and safety review structure is divided into three stages, roughly characterized by their depth of analysis: 1) emissions and site characteristics; 2) basic impact analysis; and 3) assessment of human impacts. For the first two stages, the general categories of review are air emissions, water emissions, noise emissions, waste disposal, site geophysical characteristics, and site developmental (including demographic) characteristics. Under each of these categories, specific characteristics of the three technologies — nuclear, geothermal, and fossil-fuel — are treated. For the third stage, which to a large extent goes beyond traditional reviews of this type in that it actually suggests a framework within which human impacts may be assessed, the major divisions are by technology (rather than by the categories of review listed above).

1. Emissions and site characteristics — deals with fundamental parameters of the generic facility type proposed and of the proposed sites. These "fundamental" parameters are those which may be compared directly with applicable standards and guidelines, without any detailed analysis. As such, this stage would amount to a preliminary assessment of the general character of the facility and of its straightforward compliance with regulatory requirements.

- air emissions — compares amounts of "conventional" and radioactive materials to be emitted with the applicable emissions standards
- water emissions — compares amounts of chemical, radioactive, and thermal

effluents with the applicable effluent standards

- noise emissions — compares expected off-site noise levels with applicable community standards
- waste disposal — determines the stability of any on-site disposal of solid wastes
- site geophysical characteristics — determines the suitability of proposed site mechanical and hydrological characteristics
- site developmental characteristics — examines population distribution around the site, and availability of land, transportation, and other utilities.

2. Basic impact analysis — deals with the impacts of the facility on the site and surroundings, as can be calculated on the basis of the emissions and site characteristics determined in the first stage. The results of this analysis would, for example, include ambient concentrations, calculated using models such as discussed in LBL-5998, of various pollutants in the region in which the plant would be built; these concentrations could then be compared with applicable air quality standards and could be used to calculate the effect of air emissions on other media (interactive effects); furthermore, they would serve as the basis of the human impacts assessment of the third stage. The basic distinction to be made between stages one and two is that the first is restricted to an examination, effectively, of specifications of the facility and site, whereas the second uses this information for detailed analysis.

- air emissions — analyzes the impact of the plant on regional air quality in view of applicable air quality standards
- water emissions — analyzes the impact of water effluents on water resources in view of applicable receiving water standards
- noise emissions — analysis essentially complete at stage 1
- waste disposal — analysis essentially complete at stage 1, except that impacts of waste transport (such as radioactive) must be treated
- site geophysical characteristics — analyzes (mostly mechanical) interactive effects between the site and facility (e.g., facility-induced seismicity)
- site developmental characteristics — determines adequacy of measures for protecting populations from adverse effects.

3. Assessment of human impacts — examines, to the extent possible, the effects on human health and safety of a plant with characteristics and impacts as determined in the first two stages. The third stage would include any judgments which are to be made, such as between alternative sites or facilities, or between costs and benefits. These judgments would have to be based on standards and guidelines yet to be developed. Moreover, the major considerations are extremely technology-specific.

- fossil-fuel plants — attempts to establish a framework for assessing health impacts of emissions; potential for accidents is a lesser, albeit important, focus
- geothermal plants — different in detail, but has similar assessment difficulties as for fossil-fuel, with the exception of potential geophysical interactions
- nuclear — the primary assessment question is the potential for harm to surrounding populations from accidents; requires site-specific accident analysis.

S5.4 The Application for Certification Review

The purpose of the AFC review is to examine a specific combination of a proposed facility and site in detail, based on a site-facility combination that was previously accepted as a result of the Notice of Intention review. The AFC review examines the detailed proposal with a view to final certification. Although this review must to some extent re-examine matters considered during the NOI review, a new emphasis may be placed on the engineering of the plant itself, i.e., what has by convention been referred to as "safety" during this work. As a result, the AFC review must consider not only the detailed manner in which the plant, as designed, complies with the specific health-related criteria which were examined on a generic basis during the NOI review, but also whether the plant design is consistent with engineering criteria selected to guarantee the operational safety of the plant itself. These considerations are more explicit in the five stages suggested for the AFC review:

1. Review of treatment in NOI review — checks whether new data and regulations can affect validity of NOI review. If changes can affect conclusions significantly, review of certain areas may have to be repeated at this stage; alternatively, the applicability of the NOI review may be invalidated, thereby requiring a return to the NOI. The general areas of concern are possible

alteration of standards, alteration of site characteristics, and alteration of the facilities proposed.

2. Emission control equipment — examines the specific control equipment incorporated in the plant design, a natural subject for review during the AFC, considering: 1) the importance this equipment plays in mitigating potential impacts of plant emissions on the public; and 2) the intention that the AFC review examine the manner in which criteria presumed at the NOI review are actually met in the detailed design. The equipment for controlling emissions into both air and water would be examined. As a minimum, the expected performance of this equipment could be specified and a monitoring program for determining compliance with these performance criteria could be established. The actual design (as distinguished from the performance) of the equipment could also be reviewed within the framework discussed below under stage 4.

3. Safety design — determines whether the plant design complies with applicable safety criteria. Two generic areas for review may be identified: 1) occupational safety in the plant; and 2) operational safety systems. For occupational safety, the applicable criteria are either Occupational Safety and Health Administration specifications (for any type of plant) and Code of Federal Regulations, Title 10, Parts 20 and 50 regulations (for nuclear power plants). To assure occupational safety, the ERCDC may simply require agreement from the plant operator to comply with the regulations, depending on inspection to verify compliance, or may actually review the detailed design for compliance. The operational safety systems are of great importance in nuclear power plants. The Nuclear Regulatory Commission examines such systems on the basis of legislative criteria, regulatory guidelines, and industry standards, during its construction permit and operating license review processes; the ERCDC may involve itself in areas with which it is concerned, perhaps in a joint review process with the NRC. For fossil-fuel and geothermal power plants, the safety systems are directed more toward protection of workers and the plant itself than towards the general public. For this reason, the California OSHA standards may serve as a basic set of criteria for ERCDC review of such systems. These standards include specifications for boiler and pressure vessel safety, fire and electrical safety, petroleum safety, and other areas. As above, the ERCDC may simply require agreement to comply or may actually review the plant design for compliance with these standards. If the ERCDC reviews areas other than those covered by OSHA standards, it may implement such review as described in the next stage.

4. General facility design — determines suitability of the plant on the basis of more general criteria than above, which emphasized emissions, occupational safety, and operational safety systems. More general bases for review include: 1) the broad safety implications of systems which are not specifically designed to the occupational and operational safety criteria of stage 3; 2) the extent to which the general facility design promotes reliability and/or efficiency; and 3) cost considerations. Although not all of these more general bases are specific concerns of the health and safety review, certain plant systems — not generally regarded to be safety systems — might be construed to have safety implications. For such systems and for the detailed design of certain systems above, such as the emissions control equipment, regulatory standards have not been specified. To implement a review process for such areas, the ERCDC would have to formulate a basis of review. Several possibilities exist:

- The review may be only cursory, i.e., its purpose may simply be to establish that the design includes features understood to be necessary for the protection of the public or for worker health and safety.
- The review may be more substantive, but may be based on the applicant's submitted design standards and associated inspection or quality assurance (QA) program. Such a review would still require the cursory review above to determine that the applicant had submitted standards and related verification programs for all the areas of concern.
- The review may directly examine the detailed design. In this case, the ERCDC must have chosen standards or guidelines to be utilized by the applicant during design and by the ERCDC during review. For any design area in which this possibility is selected, a substantial effort in the formulation and/or selection of standards or guidelines must be expected, as discussed at the end of section S5.2.

5. Overall assessment of site and facility acceptability reaches a final judgment of site suitability from the point of view of potential health and safety impacts. Since overall site acceptability cannot be judged solely from this point of view, this stage would amount to a summarization of the specific areas where the proposed site and facility failed to meet applicable criteria, of the health and safety impacts which the facility could be expected to have, and perhaps of benefits associated with the various technologies.

S6. Present standards and future needs in review standards and methodologies

A very substantial basis now exists for the ERCDC review of the health and safety aspects of proposed sites and facilities. The two broad areas in which the review methodologies described above are incomplete are related to possible assessment functions which the ERCDC might choose to perform in the area of health impacts and to any review of the detailed facility design which might take place.

For nuclear plants, the most substantial methodological gap lies in the area of techniques for site-specific accident analysis. Such tools could be used both for overall impact analysis and for use in determining the adequacy of emergency planning and of proposed techniques for population density controls. As for detailed plant design, extensive review standards exist in the form of NRC regulations and related standards, covering the systems related to emissions and plant safety.

For fossil-fuel and geothermal plants, the lack of precise information on the relationship between exposures to pollutants and resulting health effects precludes any calculation of health effects. Some substitute, such as exposure categories, would have to be devised for use in the assessment of impacts, either relative or absolute. In the area of design review, decisions must be made on what systems to review, how thoroughly to perform the review, and how to select standards for use in the review. Possible areas of direct relevance to health and safety are the emission control equipment, and occupational and operational safety systems.

A number of other areas need further examination or analysis. We summarize briefly a number of important areas where possible impacts are largely uncertain or where analytical capabilities require substantial work.

The following areas applicable to nuclear, geothermal, and fossil-fuel power plants recommend themselves to ERCDC attention:

- the implementation of substantial in-house or external capabilities for dispersion analysis suited to ERCDC needs
- the implementation of substantial in-house or external capabilities for analysis of site characteristics related to seismicity or subsidence
- further analysis of the potential impacts of fuel and waste transportation.

For nuclear power plants, the following additional areas should be considered:

- the details of implementing local emergency planning and population density controls
- the implementation of capabilities for performing site-specific accident analysis, both in connection with the above planning and for more general purposes of impact analysis.

In addition, the ERCDC should give its continuing attention to the general questions of reactor safety, as exemplified by the ACRS generic items relating to light-water reactors, and to methods for assessing risks from nuclear accidents. This attention should extend to radiological health standards, where, however, substantial changes in the standards are not generally foreseen. However, it is not to be expected that the ERCDC can make substantial independent advances in these areas, except for the application of existing techniques to site-specific analysis.

For fossil-fuel and geothermal power plants, the following additional areas should be considered:

- the possibility of developing exposure categories as a surrogate for actual health effects calculations in the assessment of health impacts from power plant emissions
- the development of performance standards, and associated monitoring provisions, for emission control equipment
- the satisfactory disposal of solid wastes

In addition, the ERCDC should give its attention to the development by other agencies of more specific and complete air and water quality standards.

These are specific areas which the ERCDC might consider for further work and possible inclusion in review methodologies. Certain broader questions must also be resolved before any review methodology can be implemented. One such question involves the relationship of the health and safety review to other areas of review, particularly the general environmental review and any review of plant design for efficiency and dependability. These areas could be covered by natural extensions of the review methodologies discussed earlier.

Another broad question is how the results and conclusions of the health and safety review are melded with the results of other aspects of the review process. Although certain matters of the health and safety review can be considered independently of other areas, any judgment based on comparison of costs and benefits of mitigating health impacts would have to be considered

in the context of similar comparisons for other matters of interest.

Finally, although the list of areas where uncertainties exist and where analytical tools are deficient is not negligible, this does not imply that any review function must await resolution of these uncertainties. A decision to proceed or not must be considered in light of the overall needs of the public. Although currently available standards and techniques are subject to improvement, they constitute a substantial interim basis for review of the health and safety impacts of proposed sites and facilities.

1. HEALTH EFFECTS OF ELECTRIC POWER GENERATION

The primary effects which electric generating plants may have on the public health and safety occur due to the emission and dispersion of harmful substances through environmental media with which the public has contact. Because of this, a basic function of the public agencies charged with protecting the public health has been to limit such emissions, considering both the benefit to the public and the feasibility (including cost) of controls.

The principal media through which harmful substances may reach the public are air and water. For each medium, standards have been established or are being developed both to limit ambient concentrations and to limit emissions from either stationary or mobile sources. Such limitations on ambient concentrations and on emissions have been developed for a number of substances in a manner consistent with the current understanding of their effects on human health or other values. The number of substances for which regulations exist is large; they may be divided operationally into radioactive and "conventional" pollutants. Either of these categories includes substances in gaseous, liquid, and solid (usually "particulate") form.

These pollutants may have a broad range of effects on human health. These effects vary both as to general nature and as to severity. Moreover, they depend not only on the type of pollutant, but on its concentration in the medium considered and on the subject's exposure to history, whether exposure is for a long or short period and whether the exposure is acute or chronic. As further complications, the pollutants may undergo health-significant transformations after their emission, and the effects of pollutants on human health depend on the combination of substances to which humans are exposed. Finally, the effects of any exposures(s) depend significantly on the individual exposed.

On the basis of our current understanding of the effects of emissions from power plants, public agencies have instituted regulatory programs designed to mitigate harmful effects to the public and to workers. Such agencies exist at the national, state, regional, and local levels.

The national agency with the broadest responsibilities for protecting the public from contamination of air and water is the U.S. Environmental Protection Agency. In accordance with its legal mandates, it has established a variety of standards, placing limitations on both ambient concentrations in and emissions into environmental media. However, for radioactive substances

much of the responsibility for regulation rests with the Nuclear Regulatory Commission, which has specific responsibility for the licensing of nuclear facilities, including nuclear power plants.

To a large extent, the Environmental Protection Agency delegates the responsibility for implementing Federal air and water quality related standards to agencies in the states and permits these agencies to establish stricter standards; the Nuclear Regulatory Commission delegates such authority to a much smaller extent. In California, although the state Health Department has broad responsibilities for the protection of the public health, implementation and/or development of standards on air and water quality are functions of the state air and water resources boards and of regional agencies. In addition, local agencies regulate many matters with some relevance to the public health and welfare, although it is important to note that for electric generating facilities these are more often concerned with the construction of plants than with their emissions. Construction of plants is considered in Section 2 of this report. Moreover, occupational safety and health standards — some of which are related to considerations in this section — are also considered in Section 2.

The California Energy Resources Conservation and Development Commission (ERCDC) is charged[1] with granting land use to electric generating facilities in a manner that provides for the protection of the public health and safety. It is responsible for determining compliance of proposed sites and facilities with applicable health standards, including those mandated by other agencies and any additional standards which it may deem necessary, except that it may not formulate air and water quality standards.

This section summarizes the health affects which may result from operation of nuclear, geothermal, and fossil-fuel electric generating facilities. Particular attention is given to the existing standards for the protection of the public health and to their relationship to our present understanding of potential health effects. As indicated below, this summary depends largely on several other reports developed during the course of this work. As will be evident in the following discussion, although the power plants alone were given our attention, many of the same considerations are applicable to related facilities, such as those for fuel extraction and preparation and for reprocessing and waste disposal.

1.1 Nuclear power plants

Radioactive releases are the principal health-related concern associated with the operation of nuclear electric generating plants. They are, of course, not the sole emissions. For the most part, the "conventional" emissions from nuclear power plants arise from rather ordinary water treatment systems, waste heat removal systems, and fossil-fired auxiliary boilers; conventional pollutants are discussed in section 1.2 on fossil-fuel and geothermal power plants. The discussion of the present section is confined to the possible health effects of and the standards applicable to radioactive emissions.

A separate report on "Radiological Health and Related Standards for Nuclear Power Plants" (LBL-5285)[2] discusses the effects of radiation and the standards applicable to the protection of humans from exposures arising from radioactive releases, whether routine or accidental, from nuclear power plants. That radiological health report serves as the primary basis of the present section. Several other reports, on emergency planning around nuclear power plants[3], on control of population densities around nuclear power plants[4], and on reactor safety studies[5], are closely related, and reference will be made as necessary. However, since these reports are largely concerned with the probability and consequences of nuclear accidents, rather than of routine emissions, they are also discussed in section 2, on the safety aspects of power plants.

1.1.1 Emissions from nuclear power plants

During the operation of a nuclear power plant a large array of radionuclides are produced principally as fission products (the fragments remaining after the fission of nuclei) or as activation products (the radioactive nuclides resulting from the interaction of a nucleus with some form of radiation, such as a gamma ray or a neutron). Only a small number of these radionuclides can escape from a normally operating power plant in significant quantities. These are isotopes of hydrogen, carbon, iodine, and the noble gases krypton and xenon. Radioactivity may be expressed in terms of the "Curie", which is a measure of activity, the number of disintegrations occurring per second. In these terms, the amounts of the most important isotopes routinely emitted from a 1000 MWe light-water reactor power plant are approximately:

^{3}H (tritium, an isotope of hydrogen)	500	Curies/year
^{14}C (carbon)	8	Curies/year
$^{129,131,133}I$ (isotopes of iodine)	0.02	Curies/year
^{85}K (krypton) and ^{133}Xe (xenon)	10,000	Curies/year

The amounts emitted in any specific case may vary by about a factor of 5 from those given. The carbon, iodine, and noble gases are emitted primarily into the air, while the tritium may be emitted into either air or water. The amounts of tritium and noble gases emitted from the power plant are substantially less than the amounts which might be released into the atmosphere from the spent fuel when it is reprocessed, unless controls are introduced to prevent their escape at the reprocessing plant.

In any case, a more significant quantity than activity, from the point of view of human health, is the amount of exposure to radiation. It is convenient to express this in terms of rem (or mrem, which is 0.001 rem), the unit of "dose equivalent". This is a measure of the amount of energy deposited per mass of body tissue, but normalized to account for the biological effectiveness of differing types of (or energy) radiation. If given as "whole body" rem, the dose implies exposure of the entire body.

Typical doses to members of the general public from sources other than nuclear power are roughly 200 mrem/year whole body, including about 130 mrem/year from natural background sources and about 70 mrem/year from medical diagnostic and therapeutic procedures. Nuclear power plants currently being licensed are prohibited from exposing an individual at the site boundary to more than about 5 mrem/year. Exposures of this size are carefully regulated, not because they may cause any effects soon after the exposure, but because they may cause lesser damage, resulting in "latent" effects — such as cancer or genetic damage — which show themselves much later.

As for any pollutant, the process of calculating the human exposures resulting from specified emissions is a complicated procedure, most suitably employing a computer-based meteorological model to simulate the dispersion of pollutants in the atmosphere. (Modeling of dispersion through water pathways to humans may be achieved in a similar manner.) Such meteorological models are discussed in a separate report[6]. A significant simplification for treatment of radioactive pollutants, as compared with others, is that the tendency for chemical transformation in the atmosphere to alter the character or effect of resulting pollutants is not as marked as for chemically active

Table 1-1. IMPORTANT RADIATION EXPOSURES (whole body dose equivalents)

Typical individual annual dose from natural background sources (both terrestrial and cosmic rays)	≈0.13 rem/year
Average annual individual dose from medical procedures	≈0.07 rem/year
Recommended limit (NCRP) for dose to individual members of the general public	0.5 rem/year
Recommended limit (NCRP) for occupational exposures of individual workers	5 rem/year
NRC limit on dose to individual members of the general public from a single nuclear facility (air emissions)	0.005 rem/year
EPA limit on dose to individual members of the general public from all nuclear fuel cycle facilities	0.025 rem/year
EPA projected individual dose for initiating protective actions during a nuclear incident (Protective Action Guide)	1 to 5 rem
Typical total annual general-public population dose from nuclear plants meeting the NRC limit above	≈5 man-rem/ reactor-year*
Typical total annual population dose to workers at a nuclear power plant	≈500 man-rem/ reactor-year
Predicted average annual general-public population dose from accidents at a typical nuclear power plant (estimated from WASH-1400 results)	200 man-rem/ reactor-year
Population dose that is roughly equivalent to one induced latent fatality	≈20,000 man-rem

*Typical value cited in environmental statements — only includes the exposures taking place during the operation of the plant, not utilizing concept of "dose commitment" to calculate continuing exposure from radionuclides and the environment.

pollutants. As a result, the exposure of humans to radiation from radioactive emissions is more easily calculated than are corresponding exposures to conventional pollutants. Moreover, the fact that assessments of radiation-induced health effects often employ a linear dose-response function (see below) clearly identifies and simplifies what exposure is to be calculated. As discussed in the next section, and in section 4, the situation for calculating exposures to conventional pollutants is not as favorable. See table 1-1 for typical doses.

The emissions from nuclear power plants, and the resulting exposures of the general public are sensitive to the control measures employed at the particular nuclear plant under consideration. It is relatively difficult to prevent the escape of a certain portion of the radioactive noble gases and iodines from the reactor (as distinguished from the power plant containing the reactor), and the same is true of tritium, which becomes incorporated into water, the liquid used as the reactor coolant. On the other hand, the amount of these radioisotopes which ultimately escapes into the environment may be altered by introducing liquid and gaseous cleanup systems, as well as "holdup" systems, which can retain certain short-lived radioactive substances until the greater part of them has decayed radioactively to stable isotopes or at least to ones with less potential for harm.

The extent to which such emission control systems are implemented should be determined considering the cost and effectiveness of the systems as compared with the benefit from preventing emissions. This is the philosophy used in implementing the "as low as is reasonably achievable" guideline, with explicit numerical guidelines given in the Code of Federal Regulations, Title 10, Part 50, Appendix I. (See the discussion of regulations below.) However, it is only possible to employ such cost-benefit analyses on the basis of some appreciation of the relationship of exposures to health effects and ultimately some evaluation of human health or life. As discussed below, our understanding of the effects of radiation exposures is extensive enough that a unable basis (although often regarded as conservative) does exist for quantitatively estimating health effects of radiation exposures.

The same statement may be made of the short-term, but substantial, radiation doses which could result from accidental releases of large amounts of radioactivity from nuclear power plants. Under such circumstances, a larger array of radionuclides could be released, and in much larger amounts, than

under routine conditions. The large doses which are possible can cause not only latent damage, but also acute effects, both sickness and death. Calculation of such effects may be performed using the same dispersion modeling procedures as suggested above, but the dose-response function clearly exhibits a threshold, so that the results may be very sensitive to the modeling assumptions. (See the discussion of nuclear accidents below and in section 2.)

1.1.2. Health effects of exposure to radiation

Although the maximum dose to members of the general public from nuclear power plants is typically less than 5 mrem/year, the fundamental data on the effects of radiation exposures arises from doses substantially larger than one rem (1000 mrem) that were sustained over relatively short time periods. The major instance of such exposures were the bombings at Hiroshima and Nagasaki, which induced substantial numbers of both latent (such as cancer) and early effects. Data of comparable significance for latent effects arise from medical procedures and from occupational exposures, such as uranium mining and radium worker exposures. Large amounts of important data have also been obtained from laboratory experiments on animals. A number of scientific bodies, both international and national have taken responsibility for assembling and interpreting information on the health effects of radiation.

It is clear from these data that a whole-body dose of 1000 rem from "external" radiation delivered over a short period of time causes death within a short time (roughly a month). Depending on the medical procedures available for mitigating the effects of radiation damage, the dose which will cause death in 50% of humans is roughly 500 rem. As the dose is reduced to the vicinity of 100 rem, death no longer occurs, but sickness is induced by less acute cellular damage. Such sickness is no longer observed as the dose received becomes lower than approximately 20 rem.

On the other hand, doses of the size just discussed (20 to 1000 rem) may be sustained without early sickness or death if the dose is spread over longer periods, so that the body can repair the acute damage. However, radiation may also cause latent damage, which — among other possibilities — may either show itself as cancer, a decade or more later, or cause defects in succeeding generations. Early effects could assume some importance during a large release at a nuclear power plant. However, even for these large releases and certainly for routine releases, the latent effects from low doses and dose

rates are the important question, because these effects appear to be the dominant risk. However, measurement of the dose-response for cancer induction is much more difficult than for early effects because of the large time period required for malignancies to show thermselves, and because the effects must be observed statistically out of a population which would experience cancer incidence even in the absence of increased exposure to radiation.

In spite of these difficulties, the data are sufficient to demonstrate a relationship between radiation exposure and cancer. (We do not emphasize the demonstrated potential for genetic damage, because awareness of such damage has long existed; however, even for genetic damage, the precise response is not certain.) For external exposures, such as the gamma ray and neutrons exposures resulting from bombings of Japan, the data may only be used to demonstrate this relationship down to an integrated dose of approximately 100 rem. Extrapolating these data to low dose and dose rate in order to estimate the effects of typical doses from nuclear power plants is a subject of much controversy. It has long been presumed that a "threshold" existed, so that — for doses below some minimum — an individual would not be in danger of cancer induced by the exposure. However, the view that effects may be caused at arbitrarily low doses is gaining adherents. Regardless of which view is correct, it has been recent practice — for purposes of risk assessment — to adopt some version of the latter view, i.e., to presume that a certain total dose, summed over a population, will produce the same number of effects, regardless of how the dose is distributed among that population. This is equivalent to a statement that the dose-response function is linear and that no threshold exists. The view of most experts and regulatory agencies is that this is a "conservative" assumption. Certainly, for some types of radiation — in particular, radiation from "internal" emitters, those which are actually accumulated at sites within the body (such as radium at the skeleton) — there does appear to be a threshold in the effects so far observed. However, arguments may be made to indicate that the linear hypothesis (without threshold), although somewhat conservative, is not a gross overestimate, particularly for external radiation. See the body of the accompanying radiological report[2] for more details. It may be said roughly that the linear hypothesis, as presently applied, would assign one cancer-induced death to each 20,000 rem (within a factor of 2) distributed over any population.*

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* This would be referred to as 20,000 "man-rem".

1.1.3 Radiological protection standards

The basic radiation protection criteria recommended by international and national bodies, such as the National Committee on Radiation Protection and Measurements (NCRP), for the protection of the general public from low levels of radiation, were originally based on an understanding of the genetic effects of radiation. The most fundamental standard was that individuals should receive no more than 15 rem during their genetically significant lifetime, of roughly 30 years. This leads to an average annual dose of 500 mrem. For large populations, where some level of genetic damage was deemed the maximum acceptable, the doses were 5 rem for the 30 years, or 170 mrem/year. Dose levels similar to these were obtained by reducing doses acceptable for occupational exposures (5 rem/year) by a factor of 10, a normal practice in obtaining levels acceptable to members of the general public as compared with workers. These occupational levels had been based on observations of the effects both of internal emitters (such as radium) and of external exposures (such as x-rays). The 5 rem/year, 500 mrem/year, and 170 mrem/year remain the numerical guidelines, respectively, for maximum exposures (for other than medical reasons) of workers, members of the general public, and populations.

However, an overriding guideline, in general, is that exposures should be kept "as low as is reasonably achievable". What is reasonable depends on the technology available and its cost, as compared with some evaluation of the effect of exposures. The Atomic Energy Commission (AEC), in its early actions on licensing nuclear power plants, required emission controls whose effectiveness was "adequate", but not judged on any quantitative basis. At that time, the guideline was "as low as is practicable". However, subsequent analyses, particularly by the Advisory Committee on the Biological Effects of Ionizing Radiation (the BEIR Committee) of the National Academy of Sciences — National Research Council, provided a quantitative basis, grounded on the linear extrapolation menioned above, for comparison of costs and benefits. On this basis, it was judged that a maximum dose outside the site boundary of 5 mrem/year was "reasonably achievable" and this has been written into 10 CFR 50, Appendix I. The inheritor of the AEC's regulatory responsibilities, the Nuclear Regulatory Commission (NRC), utilizes this guideline in current licensing proceedings on nuclear power plants. As a further specification in Appendix I, the applicant must implement additional controls to a level corresponding to an interim valuation of $1000 per man-rem dose equivalent,

although it is thought by the regulatory agencies that this valuation is conservative. (If 20,000 man-rem causes one death, this is the rough equivalent of a valuation of $20 million per death.) Some of the NRC regulatory guides indicating how routine and accidental emissions are to be analyzed and controlled are listed in table 1-2.

Other types of standards for low level radiation protection exist, but they are all derived from the basic exposure standards of 5, 0.5, and 0.17 rem/year discussed above. Based on these dose rates and on models for exposures due to concentrations in air and water, limits on ambient levels in these media may be calculated. However, these are ordinarily considered to be only operationally convenient standards; the basic standards are those limiting dose (or dose rate, as above). Basic limitations on dose rate, such as these, are incorporated into the California Administrative Code.

Other types of standards exist and are discussed in the radiological report[2]. A class of standards of potential importance in any nuclear emergency gives guidance on the dose levels at which actions should be taken to protect the population or emergency workers. According to guides developed by the Environmental Protection Agency, the projected whole-body dose at which emergency actions for population protection (evacuation, sheltering, or prophylactic measures) should be considered is 1 to 5 rem. As in many standards, a separate dose level for the thyroid alone is specified, since that organ concentrates iodine, one of the more significant emissions from nuclear power plants, under either routine or emergency conditions. Further discussion of emergencies is contained in section 1.1.5 on "protection during emergencies" and in section 2 of this report.

In general, the standards for radiological protection of either workers or the general public are more comprehensive than comparable standards for protection from "conventional" pollutants. As a result, judgments of the adequacy of control measures may be made in the quantitative manner suggested above; the resulting limit on doses to the general public is much lower than the 500 mrem/year guideline limit. However, in some respects, controversy over the standards and their implementation does exist; furthermore, confusion exists over implementation of measures to protect the public during emergencies. These matters require further discussion.

Table 1-2 Selected Nuclear Regulatory Commission Regulatory Guides

Guides pertaining to evaluation of routine emissions:

1.23 ONSITE METEOROLOGICAL PROGRAMS (2/72)

1.109 CALCUATION OF ANNUAL DOSES TO MAN FROM ROUTINE RELEASES OF REACTOR EFFLUENTS FOR THE PURPOSE OF EVALUATING COMPLIANCE WITH 10 CFR 50, APPENDIX I (3/76)

1.110 COST-BENEFIT ANALYSIS FOR RADWASTE SYSTEMS FOR LIGHT-WATER-COOLED NUCLEAR POWER STATIONS (3/76)

1.111 METHODS FOR ESTIMATING ATMOSPHERIC TRANSPORT AND DISPERSION OF GASEOUS EFFLUENTS IN ROUTINE RELEASES FROM LIGHT-WATER-COOLED REACTORS (3/76)

1.112 CALCULATION OF RELEASES OF RADIOACTIVE MATERIALS IN GASEOUS AND LIQUID EFFLUENTS FROM LIGHT-WATER-COOLED POWER REACTORS (4/76)

1.113 ESTIMATING AQUATIC DISPERSION OF EFFLUENTS FROM ACCIDENTAL AND ROUTINE RELEASES FOR THE PURPOSE OF IMPLEMENTING APPENDIX I (5/76)

Guides pertaining to accident analysis and site characteristics:

1.3 (1.4) ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A LOSS OF COOLANT ACCIDENT FOR BOILING WATER REACTORS (PRESSURIZED WATER REACTORS) (Revision 2, 6/74)

1.5 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A STEAM LINE BREAK ACCIDENT FOR BOILING WATER REACTORS (3/71)

1.25 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A FUEL HANDLING ACCIDENT IN THE FUEL HANDLING AND STORAGE FACILITY FOR BOILING WATER AND PRESSURIZED WATER REACTORS (3/72)

1.52 DESIGN, TESTING, AND MAINTENANCE CRITERIA FOR ENGINEERED-SAFETY-FEATURE ATMOSPHERE CLEANUP SYSTEM AIR FILTRATION AND ADSORPTION UNITS OF LIGHT-WATER-COOLED NUCLEAR POWER PLANTS (7/76)

1.101 EMERGENCY PLANNING FOR NUCLEAR POWER PLANTS (11/75)

4.7 GENERAL SITE SUITABILITY CRITERIA FOR NUCLEAR POWER STATIONS (9/74)

1.59 DESIGN BASIS FLOODS FOR NUCLEAR POWER PLANTS (Revision 1, 4/76)

1.60 DESIGN RESPONSE SPECTRA FOR SEISMIC DESIGN OF NUCLEAR POWER PLANTS (Revision 1, 12/73)

1.76 DESIGN BASIS TORNADO FOR NUCLEAR POWER PLANTS (4/74)

1.1.4. Standards: information gaps and controversies

Significant uncertainties exist with respect to the effects of radiation Hence the standards, or more particularly their implementation, are subject to some change. Some of the uncertainties arise from incomplete understanding of the "experimental" details, such as the conditions of exposure, the dose received, the relative biological effectiveness of various types of radiation, etc. However, the most significant uncertainty, broadly speaking, was referred to above, i.e., the reliability of the linear (non-threshold) hypothesis.

Uncertainty over this hypothesis resolves itself into several questions. The first is whether a threshold exists, if only for some types of exposure; there is evidence that it exists for some internal emitters, but not for external emitters. The second is the question of linearity itself; to the extent that a threshold exists, it is an intrinsically conservative representation. In the absence of a threshold, there is reason to believe that the actual response may be a combination of linear plus higher order terms. Some argue that this leads to the conclusion that the linearity assumption is only slightly conservative (by approximately a factor of two). This question is basically one of the correctness of the hypothesis for doses of different magnitude. A third question concerns alterations in dose rate. The consensus is that lower dose rates cause a reduction in the effects of a given dose-equivalent of radiation. Such reductions from the strict linearity assumption on the basis of low dose and dose rate were incorporated in the consequences analysis of the NRC Reactor Safety Study (discussed in section 2 of this report and in reference 5).

Another broad area of controversy deserving mention in this brief summary concerns internal alpha emitters, in particular plutonium. The portion of this controversy which has received the most attention is the "hot particle hypothesis", which purports that the biological effectiveness of the alpha particle radiating from plutonium and similar elements is substantially increased due to the concentration of the atoms into small particles. The fact that these radioactive materials may lodge in the lungs in this form would imply, on the basis of this hypothesis, that the cancer induction rate is greatly increased over that that would be estimated, neglecting the particulate nature of the radioactivity. This is a notion that had been examined in the past, but which has been raised again in connection with the production of plutonium in light-water reactors and its intended use for recycle fuel and

for a "breeder" reactor system. However, reexamination of the issue by bodies such as the National Academy of Sciences has led to the conclusion that such "hot particles" have little, if any, more effect than the same quantity of radioactive material more uniformly distributed. This implies that no substantial change in plutonium standards is warranted.

Other controversies surround such inhaled alpha emitters. These include the general question of the sensitivity of the tissues lining the lung passages to radiation and the manner in which calculation of the effects of deposited alpha emitters (such as plutonium) takes account of this sensitivity.

In general, it appears that the current radiological protection standards may be altered slightly, but certainly not to the extent suggested by some critics of nuclear power. Moreover, many of the alterations would be based on slight changes in the manner in which doses and responses are modeled, rather than on any gross change in the understanding of the effects of radiation on humans.

1.1.5. Protection during emergencies

Another class of regulations and guidelines, dissimilar from those emphasized above, is associated with potential accidents at nuclear facilities. The probability and consequences of such accidents are discussed in section 2.4, in connection with a review of reactor safety studies[2]. However, certain actions, both preventive and protective, may be taken to mitigate the effects of such accidents on surrounding populations. The measures usually considered are protective measures, such as evacuation, sheltering, and prophylactic measures (such as iodine blocking pills), and these are considered in detail in a report, "Radiological Emergency Response Planning for Nuclear Power Plants in California" (LBL-5920)[3]. A related preventive measure is the siting of nuclear plants in low population areas; moreover, in connection with such criteria, controls on population densities might be implemented. Such controls are mandated by the legislation constituting the ERCDC[1] and are considered in a report on "Control of Population Densities Surrounding Nuclear Power Plants" (LBL-5921)[4].

The Nuclear Regulatory Commission, in its review of proposed facilities, examines emergency planning for on-site emergencies, but leaves off-site planning largely to local authorities, with limited guidance from the NRC. In the view of many observers, including the NRC, planning at the local level has not been adequate. Moreover, a curious situation exists with regard to the question

of when emergency actions, such as evacuation, should begin. Although the Environmental Protection Agency Protective Action Guides give a projected whole-body dose of 1 to 5 rem as the level at which actions should be taken, the level used for much of the planning in California is 500 mrem, a level which is chosen because of the recommended limit of 500 mrem/year for dose rate. However, the 500 mrem/year limit is based on the lifetime dose limit of 15 rem, which — from this point of view — could as easily have been chosen as the emergency action dose level. However, it is not clear how significant the difference between 500 mrem and the EPA levels of 1 to 5 rem would turn out to be during an actual emergency.

The NRC also explicitly considers, during its review, a low population zone, defined so that no one outside the zone would receive a maximum specified dose during a formally postulated accident. It is intended that this zone could be effectively evacuated on the basis of local emergency planning. This zone typically has a radius of up to a few miles. (See Table 1-3 for California data.) The NRC also examines population densities at distances up to 30 or 40 miles from the plant site and applies density guidelines in considering whether alternative sites might be more appropriate.

Were the ERCDC to implement controls on population densities around nuclear power plants, it would seem practical for them to concern themselves with a region similar in size to the low population zone. Control measures such as private acquisition of development rights or more traditional zoning regulation could be used to prevent substantial increases in populations in such a zone. However, use of such controls over a region of radius 30 to 40 miles would be much more difficult. Furthermore, a consideration of the probability and consequences of accidental releases versus the costs of controlling such a large region do not suggest that such broad control is appropriate. However, a more detailed analysis of the potential benefits and possible controls should be performed than was possible in reference 4.

Table 1-3. Populations surrounding present California nuclear power plants.

Plant	Exclusion Zone Radius (miles)	Low Population Zone (LPZ) Radius (miles)	1972 Population within LPZ	1972 Population within 10 mile rad.	1972 Population within 30 mile rad.
Humboldt	0.13	2.0	2000	49,000	≈90,000
San Onofre	0.1	2.0	0	36,000	644,000
Rancho Seco	0.4	4.7	300	6,000	908,000
Diablo Canyon	0.5	6.0	14*	4,900	135,000

*5 miles

1.2 Fossil-fuel and geothermal power plants

The principal health impacts from fossil-fuel and geothermal power plants may occur through the emission of "conventional" pollutants, primarily those that are emitted into the atmosphere. Pollution of water resources is of somewhat less concern than air emissions, but can have important impacts if the available control technology is not incorporated into the plant. Radioactive materials are also emitted from these plants, but are not the major concern; possible impacts of and relevant standards for radioactive emissions were treated in section 1.1 on nuclear power plants. The discussion of the present section is confined to the possible health effects of and the standards applicable to conventional emissions. It is based on the much more detailed treatment contained in a separate report on "Health Effects and Related Standards for Fossil-fuel and Geothermal Power Plants" (LBL-5287)[7]. The major emphasis is on emissions into air, but noise and emissions into water are also treated more briefly. A related report[6] treats meteorological models for simulation or analysis of pollutant dispersion.

1.2.1 Emissions from fossil-fuel and geothermal power plants

The two major categories of air emissions from fossil-fuel and geothermal plants are gases and particulates. In general, the important gases are compounds of sulfur, nitrogen, and carbon. The particulate matter may contain important amounts of all of these elements, usually in compounds, and in addition may contain significant amounts of heavy metals; such metals as mercury and selenium may be emitted in vapor form. Less important discharges into air are radioactive materials, water, and heat. Cooling towers may also

emit a number of these substances into air and — in addition — salts from the makeup water. A wide array of substances, in various forms, may be discharged into water from such plants, but for the most part their control is well enough understood that they do not pose as significant a hazard as emissions into air. The one possible exception is materials which may be leached from waste disposal sites into water supplies. Finally, these plants can produce significant levels of noise.

The relative and absolute importance of these various emissions is highly dependent upon the specific technology. The basic types of fossil fuel systems to be considered are conventional coal, oil, and gas-fired plants, although advanced systems may assume increasing importance. The only significant geothermal power plants in California are based on vapor-dominated fluids, but liquid-based plants are under rapid development. Not only do the fossil-fuel and geothermal technologies differ from one another, but the variants of each differ significantly among themselves. However, the general classes of emissions and their effects are similar, so that it has been useful to consider them together.

Fossil-fuel plants can contribute significant amounts of atmospheric pollutants known to have significant impacts on the public health. The emissions from these plants arise primarily from the combustion process itself and, not surprisingly, depend on the fuel used and on detailed combustion conditions, as well as on control technologies. For several important types of emissions and for several types of plants, Table 1-4 gives typical uncontrolled emission rates, rates if available control technology is used, and applicable emission limitations.

The gases emitted from the plant, resulting from combustion, are a combination of sulfur, nitrogen, and carbon compounds. All of these can have significant health impacts, the only major exception being carbon dioxide. Although carbon dioxide may affect human welfare through long-term alterations of atmospheric makeup, it is not generally considered a pollutant. Particulates, as discussed below, are a major class of emissions; moreover, they interact with gaseous pollutants.

The most important sulfur emission is "SO_x", made up primarily of the dioxide, SO_2, but including some sulfur trioxide, SO_3, both produced from combustion of sulfur compounds in the fuel. These compounds appear to be converted to sulfates in the atmosphere. Lesser amounts of other sulfur compounds, including hydrogen sulfide (H_2S) may be emitted from fossil-fuel plants. SO_2 emissions depend on the sulfur content of the fuel. Control systems in the form of flue-gas scrubbers may be added on to the plant in order to reduce sulfur emissions. Their unfortunate features are cost and

Table 1.4. Typical Emissions from Various Types of 1000 MWe Fossil-Fuel Power Plants. (All emissions in tons/hour)

Type of Emission		Plant Type: Coal-fired	Residual fuel oil	Natural gas	Oil-fired combined cycle
Particulate:	Uncontrolled	29.0	1.2	0.022-0.066	0.16
	Controlled	0.15	0.19	0.023-0.068	0.16
	NSPS[a]	0.52	0.49	0.48	0.45
SO_x:	Uncontrolled	4.6	2.53	0.0026	0.87
	Controlled	0.49	1.32	0.0027	0.90
	NSPS[a]	6.2	3.9	--	3.6
NO_x:	Uncontrolled	4.3	3.3	3.08	2.1
	Controlled	3.6	1.5[b]	0.95[b]	1.3[b]
	NSPS[a]	3.6	1.5[b]	0.95[b]	1.3[b]
CO:	Uncontrolled	0.24	0.094	0.075	0.48
	Controlled	0.26	0.098	0.077	0.49
	NSPS[a]	--	--	--	--
Hydrocarbons:	Uncontrolled	0.072	0.063	0.0044	0.17
	Controlled	0.078	0.065	0.0045	0.18
	NSPS[a]	--	--	--	--

[a]NSPS = New Source Performance Standards

[b]NO_x control efficiency: sufficient to meet NSPS (no other pollution controls)

large amounts of product sludge, which must be disposed in a manner that does not itself cause difficulties, (either emissions into air or leaching into water). However scrubbers are expected to be incorporated into new plants, based on the judgment that they provide an important measure of protection to the public.

The gaseous nitrogen compounds are primarily oxides, labelled "NO_x", and result partly from combustion of nitrogenous compounds in the fuel, and partly from oxidation of atmospheric nitrogen during the combustion process. The principal oxide emitted is nitric oxide (NO), with lesser amounts of nitrogen dioxide (NO_2). However, much of the NO converts to NO_2 in the atmosphere. NO_2 is directly involved in the formation of photochemical smog, a primary concern in California. Since NO occurs as a product of combustion, the amounts produced can be altered by modification of combustion conditions; significant reductions of this type have been achieved through flue gas recirculation. Moreover, methods for flue gas treatment show promise.

Gaseous carbon compounds are not one of the major concerns among emissions from power plants. Contributions of power plants to either total carbon monoxide (CO) emissions or total hydrocarbon ("HC") emissions are small. The major gaseous emission, carbon dioxide (CO_2), has no direct health impact.

A final and extremely important, but ill-defined, emission from fossil-fuel power plants remains, i.e., particulates. The particles emitted from these plants may be characterized in a number of ways, which will only be indicated here. They are important not only as primary pollutants, but because they may be sites for important conversion processes occurring in the atmosphere. As a result, their size and composition are important, not only as factors in determining their direct effect on humans, but also for understanding the manner in which they may participate in atmospheric conversion.

Although the chemical composition of these particulates is clearly important, we first note their physical properties, such as mass, size, or surface area. These are important, not only because they have an obvious effect on the manner in which they are transported from their emission point, but because they determine the extent to which the particles are respirable and the effectiveness with which the particles may participate in chemical reactions. These are extremely important factors, which are not indicated by simple specification of the total mass of particulate emissions.

Properties which have more direct connection with the chemical makeup of the particulates are chemical composition, heterogeneity, and solubility. These are relevant to the effects which these particulates may have on humans and to the manner in which they become involved in atmospheric conversions. Again, these are not indicated by "total particulate emissions".

The character of particulates emitted from power plants depends strongly on the fuel. In general, they may contain various carbon, sulfur, and nitrogen compounds, as well as significant amounts of metals, such as iron, nickel, and lead. The specific amounts depend on fuel type. This is also true of size distribution. Furthermore, the total mass and size distributions are affected by the control measures which may be implemented at the various types of plant. In general, a coal plant, with its larger amount of particulates, having larger average size, will require more severe control techniques, including electrostatic precipitators or substantial "baghouse" filter systems, which effectively remove small particles as well as large. On the other hand, an oil-fired plant, with its smaller total mass of particulate emissions with smaller average size, may utilize inertial separation systems, which are not as effective for small particles. As a result, the implementation of control systems at these differing plants may cause oil-fired plants to emit more of the important fine particle fraction than coal-fired plants. Gas-fired plants emit very little particulate matter, by mass, but what is emitted is likely to be in the form of very small particles.

Of the gaseous emissions previously mentioned, some generalizations may be made for the differing types of plants. NO_x emissions can be relatively independent of fuel type, if combustion conditions are such as to oxidize much atmospheric nitrogen. However, if this process is strongly controlled, the NO_x emissions may arise primarily from fuel nitrogen, which does depend on the particular fuel. Sulfur emissions depend very strongly on the fuel, since they are connected directly with the amount of sulfur initially contained therein. Coals vary greatly in the amount of sulfur they contain, as do fuel oils; gas may contain H_2S, but this is usually removed during preprocessing. Sulfur scrubbers may be incorporated, as needed, in either coal or oil fired plants, with their attendant disadvantages of large amounts of sludge for disposal. As mentioned above, this sludge may also constitute the most serious impact of the power plant on water resources.

Geothermal power plants emit both gases and particulates as above, but the important emissions differ. The most significant gaseous emissions are hydrogen sulfide (H_2S), although ammonia (NH_3) and radon, a radioactive gas, may also be significant. The hydrogen sulfide may be rapidly converted to SO_2, leading to the same ultimate impact, but on a smaller scale, as for the fossil-fuel plants. Near the site, however, the primary H_2S could have direct impacts. In addition, a geothermal plant can emit particulates, although they do not have the same character as the particulates from fossil fuel plants. They may, however, also contain heavy metals. Furthermore, because of the rather direct interaction of the geothermal power plant with the surrounding site, the potential for water contamination is more severe than for a fossil-fuel plant. The danger of this depends on the efficiency with which reinjection of the geothermal fluid is performed, and the extent to which any sludges from cooling towers or other plant systems may leach into water resources. The potential impacts of any particular plant will depend on the details of the system and on the basic character of the geothermal resource being utilized.

For any of the emissions from fossil-fuel and geothermal power plants into air, a very significant factor — more than for the case of nuclear — is the potential for chemical processes in the atmosphere to transform various substances. Moreover, the manner in which different emissions interact with one another during these conversions is an important aspect of air pollution analysis and, ultimately, of control. Not only can the various gaseous species interact with one another, possibly influenced by other factors such as sunlight, but they may interact with or at the site of particulate matter, which may itself have been emitted from human sources. As a result, the possible processes involved in the atmosphere are very complex, making it difficult to isolate the effect of any particular emission. Whatever the difficulties of such analysis may be, it is clear that the ultimate impact of any particular emission may depend very heavily on a number of other factors, including the array of other emissions and various aspects of weather conditions. Some discussion of models for simulating atmospheric dispersion and conversion processes is given in reference 6.

1.2.2 Health effects of conventional emissions from power plants

Information on the effects of pollutants may be obtained from two categories of human experience: occupational exposures and exposures to the general public.

Both types of experience can provide information relating to both acute, high levels of exposure and to chronic, low levels of exposure. For obvious reasons, the results of acute and large exposures are more easily identified. The effects of chronic lower levels of exposure require much more careful study, particularly since the effects must be unraveled statistically from other effects and causes, including possible synergistic effects.

Many examples of acute illness, primarily respiratory or circulatory, associated with short-term exposure to high concentrations of various forms and combinations of air pollution have been reported. Such episodes have occurred in occupational as well as community settings. Occupational exposures generally arise from breakdowns in process equipment or work practices. In community settings, acute exposures typically occur when meteorological conditions act to prevent the dispersal of pollutants, resulting in excessive local concentrations.

During the last two decades, studies of the health effects of pollution have been reported from many different parts of the world. While most of these suffer from a number of methodological difficulties, the results consistently reveal a direct association between particulate and gaseous pollutants and various disease manifestations. These include: total death rates, respiratory disease mortality, and selected cancer morbidity and mortality. However, because of the complexity of atmospheric processes and the multiplicity of human activities, it has not been possible to establish precise quantitative relationships between emissions and disease.

While it is feasible to identify many of the components of ambient air, it is extremely difficult to isolate their individual effects in epidemiological studies. Laboratory and clinical experimental studies have provided considerable information regarding the potential health effects of many known pollutant constituents. Furthermore, such studies may elucidate specific mechanisms whereby pollutants produce such effects.

The most important pollutant constituents contributed from fossil-fuel power plants arise from: particles, particularly those containing carbon and trace metals; sulfur compounds, which may rapidly evolve into particulate species (such as sulfates); and nitrogenous compounds, which become involved in the photochemical cycle. All of the above have been shown in laboratory and/or clinical studies to have irritant effects on the respiratory system. Several of the trace metals, such as chromium and nickel, have been demonstrated in

such studies to be carcinogens in animals. However, cardiovascular effects have not been demonstrated in laboratory or clinical studies.

As suggested above, the information available from population studies is even less certain in specifying the effects of particular species. What can be said about the disease potential of certain species and classes is the following: there is a considerable consensus that suspended particulates, including sulfates, and the gaseous sulfur species are associated with respiratory symptomology and disease; the symptom-producing potential of photochemical smog is in little doubt; there is much less certainty regarding the cardiovascular and cancer-producing potential of airborne agents.

In considering the health effects of power plant emissions, it is important to treat explicitly the atmospheric processes which involve these emissions, often producing species which have their own health significance. We noted above two potentially important atmospheric processes: the photochemical cycle, which involves NO_x and produces oxidants, including ozone; and the various processes which may convert SO_x emissions to other species, including particulate sulfates. These processes are affected very strongly by the local meteorological conditions, which therefore need to be considered explicitly in siting decisions.

1.2.3 Air quality standards

Based on occupational experiences, on the classic air pollution episodes, and on continuing epidemiological and laboratory studies, standards related to the protection of air quality are formulated and implemented. Although the development of the data base is being supported by a number of agencies, the Environmental Protection Agency, acting at the national level has promulgated air quality standards. Agencies in the states, such as the California Air Resources Board, and local Air Pollution Control Districts implement the national standards or stricter standards which they have formulated. National standards have been promulgated for oxidant (ozone), carbon monoxide, nitrogen dioxide, sulfur dioxide, suspended particulate matter, and hydrocarbons. All of these have some relevance to power plants, although — as indicated above — the carbon monoxide and hydrocarbon standards are of less direct significance. However, the hydrocarbons can interact significantly with emissions from power plants. California recently promulgated a sulfate standard. A summary of State and Federal standards is given in Table 1-5. In general, the EPA leaves it to state agencies to implement standards; this delegation takes the form of State Implementation Plans required of each state. The responsible agency in California is the Air Resources Board, which was — in fact — active before the national standards were implemented.

In support of such ambient air quality standards, the EPA has also formulated New Source Performance Standards, which place limitations on emissions from stationary sources, including power plants. The agencies in California which have responsibility for review of new stationary sources are the regional Air Pollution Control Districts. These districts may also adopt their own stationary source emission standards, as provided for in their responsibilities. However, it is the EPA position that a simple review of compliance with these emission standards is not sufficient. In addition, the New Source Review, which is to be performed by these Air Pollution Control Districts, is to take explicit account of the effect which new sources will have on the ambient air quality goals as represented by air quality standards. Such a comparison can result in the denial of permission to construct such sources.

For each state, including California, the EPA has required provision for identification of areas which will have difficulty meeting or maintaining the national air quality standards. For these "air quality maintenance areas", the states are to analyze in detail the respects in which the standards are

TABLE 1.5: AMBIENT AIR QUALITY STANDARDS (from ref. (5))

Pollutant	Averaging Time	California Standards[1]		National Standards[2]			Objectives of the standard (ref. (6)).
		Concentration[3]	Method[4]	Primary[3, 5]	Secondary[3, 6]	Method[7]	
Oxidant (Ozone)	1 hour	0.10 ppm (200 ug/m^3)	Ultraviolet Photometry	160 ug/m^3 (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method	To prevent eye irritation and possible impairment of lung function in persons with chronic pulmonary disease. Also to prevent damage to vegetation
Carbon Monoxide	12 hour	10 ppm (11 mg/m^3)	Non-Dispersive Infrared Spectroscopy	–	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy	To prevent interference with oxygen transport by the blood based on carboxyhemoglobin levels greater than 2%.
	8 hour	–		10 mg/m^3 (9 ppm)			
	1 hour	40 ppm (46 mg/m^3)		40 mg/m^3 (35 ppm)			
Nitrogen Dioxide	Annual Average	–	Saltzman Method	100 ug/m^3 (0.05 ppm)	Same as Primary Standards	Proposed: Modified J-H Saltzman (O_3 corr.) Chemiluminescent	To prevent possible risk to public health, and atmospheric discoloration
	1 hour	0.25 ppm (470 ug/m^3)		–			
Sulfur Dioxide	Annual Average	–	Conductimetric Method	80 ug/m^3 (0.03 ppm)	–	Pararosaniline Method	To prevent possible increase in chronic respiratory disease and damage to vegetation
	24 hour	0.04 ppm (105 ug/m^3)		365 ug/m^3 (0.14 ppm)	–		
	3 hour	–		–	1300 ug/m^3 (0.5 ppm)		
	1 hour	0.5 ppm (1310 ug/m^3)		–	–		To prevent possible alteration in lung function, and irritating odor
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m^3	High Volume Sampling	75 ug/m^3	60 ug/m^3	High Volume Sampling	To improve visibility and prevent acute illness when present with about 0.05 ppm sulfur dioxide
	24 hour	100 ug/m^3		260 ug/m^3	150 ug/m^3		
Sulfates	24 hour	25 ug/m^3	AIHL Method No. 61	–	–	–	To prevent possible increase in chronic respiratory disease
Lead	30 Day Average	1.5 ug/m^3	AIHL Method No. 54	–	–	–	To protect health
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m^3)	Cadmium Hydroxide Stracian Method	–	–	–	To prevent offensive odor
Hydrocarbons (Corrected for Methane)	3 hour (6-9 a.m.)	–	–	160 ug/m^3 (0.24 ppm)	Same as Primary Standards	Flame Ionization Detection Using Gas Chromatography	To prevent the formation of photochemical smog
Ethylene	8 hour	0.1 ppm	–	–	–	–	To prevent damage to vegetation
	1 hour	0.5 ppm					
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 10 miles when the relative humidity is less than 70% (8)		–	–	–	To improve visibility

APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:

Carbon Monoxide	8 hour	6 ppm (7 mg/m^3)	NDIR	–	–	–	To prevent interference with oxygen transport by the blood based on carboxyhemoglobin levels greater than 2%.
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 30 miles when the relative humidity is less than 70% (8)		–	–	–	To improve visibility

NOTES:

1. California standards are values that are not to be equaled or exceeded.
2. National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.
3. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.
4. Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.
5. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).
6. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.
7. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.
8. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

not expected to be met. In California the EPA has designated eight state-proposed areas to be maintenance areas. The Air Resources Board is responsible for the development of long-range plans to meet air quality standards in these areas.

The EPA also provides for the protection of air quality ("prevention of significant deterioration") where the air is superior, with respect to SO_2 and particulate concentrations, to that required by standards. Since these have not been the substances of most concern in California, the Air Resources Board has been developing an Air Conservation Program which both meets the requirements of prevention of significant deterioration and performs a similar function for pollutants of more immediate concern in California and for which ambient standards exist.

Finally, the state has developed an Air Pollution Emergency Plan, designed to provide for actions to protect populations in instances of severe air pollution episodes. This plan provides for action at several levels of concentrations for a number of pollutants, and includes action both for decreasing the pollutant levels which would otherwise develop and for reducing the effect of actual levels on members of the population. For certain pollutants, particularly SO_2, the possible actions include several that would affect the operation of fossil-fuel power plants, including shutdown or fuel switching.

This completes a summary of the present types of standards for air quality. We have not included the emission standards, because of their great number. In particular, each of the roughly fifty air pollution control districts in California has developed its own emission standards, generally for the same array of primary emissions as discussed above: NO_x, SO_x, total suspended particulates. It is clear, though, that the present array of standards is not comprehensive; improvements are being made. But even in their present state they provide a substantial basis for protecting the public health.

1.2.4 Information gaps: health effects and standards

We have emphasized above the extent to which our understanding of the connection between emissions (or ambient concentrations) and health effects is deficient. Elucidation of this connection requires substantial further studies of the atmospheric processes, and the epidemiology and physiology of air pollution. Only very tentative correlations have been made between power-plant-related pollutants and health effects.

One of the more important aspects of the problem is the characterization of air pollutants. Until the pollutants themselves are sufficiently well characterized, it will not be possible either to establish their quantitative connection with incidence of disease and death or to establish fully appropriate standards for ambient levels or, ultimately, for primary emissions, including those from power plants.

Even with our presently cloudy view, it is clear that the standards are deficient in some important respects. The most obvious is the specifications of particulate standards. Total particulate mass is not a directly significantly parameter either for ambient or for emission standards. The importance of particulates is known to depend critically on their size and other physical parameters. And it is further obvious that their importance depends on their chemical composition. Particulate standards, with the exception of the California sulfate standard, reflect neither of these considerations, and so must be considered only operational standards. As soon as monitoring methods that are more precise than total mass measurement are accepted, it will be appropriate to change the standards to reflect the existing understanding of the importance of particulates of differing size and composition.

In spite of the deficiencies of the standards, and the presently unsatisfactory understanding of health effects which stands behind them, they do serve as measures (i.e., standards) on the basis of which human activities, including the construction of power plants, may be regulated. This regulation provides a significant measure of protection to the public health.

1.3 Transmission lines

Every electric generating plant considered above is accompanied by transmission systems for transporting electrical energy to local distribution systems. The primary components of these transmission systems are normally high-voltage overhead transmission lines. Such systems do not have any effluent streams in the usual sense, and it is normally via such streams that the public may be affected in a physical sense. However, two aspects of transmission lines may be construed to constitute such emissions. The first is also common to the power plants themselves, i.e., noise. The second is related to the intrinsic character of these systems, i.e., that they are high voltage AC

systems, which may therefore emit electrical energy in the form of electromagnetic radiation and, perhaps more simply, may cause magnetic and electric fields near the lines themselves.

The physical and psychological effects of noise are a matter of ordinary experience. Occupational standards exist for noise, and it is also regulated by many local ordinances.

The possible effects of fields from high-voltage transmission lines are not so much a matter of common experience, nor do applicable standards usually exist. The possible exceptions are: 1) requirements for grounding metal structures near transmission lines to prevent the development of voltages across such structures, and 2) possible maximum recommended magnetic fields. Studies of possible health implications of such fields are presently being pursued. It does not appear that such effects are a matter of major concern, especially when compared with the other effects associated with the construction of power plants.

In fact, the most substantial impact of transmission lines may occur through accidents, including line breakage, a potential which depends highly on land use questions, and on the resulting routing of transmission lines.

2. SAFETY AT ELECTRIC GENERATING FACILITIES

The basic perspective in this work has been to identify the manner in which potential impacts of electric generating facilities on human health and safety may be minimized. Although the concept of "health and safety" is not actually able to be divided, we have made an operational distinction between those aspects of power plants which may have direct impacts on the public — i.e., primarily the emissions — and the internal design of the power plant. This distinction is not unambiguous, but it has led to the treatment of the "health" aspects of power plants in the previous part, and in the reports mentioned therein, and to treatment of the "safety" aspects of power plants in the present part. These "safety" features may be construed to include various engineering aspects of the plants, but their relationship to human "health and safety" depends on the plant type under consideration and on the aspect being examined.

For most industrial facilities, "safety" refers primarily to the health and safety of the workers at the facilities, and this is the typical interpretation for fossil-fuel and geothermal power plants. However, for nuclear power plants, the word takes on added significance, since lapses in plant "safety" can have a more severe impact on the public, because of the potential for releasing large amounts of radioactivity. As a result, whether safety at a power plant is considered with the public or the workers primarily in mind depends on the plant type.

In either case, "safety" is assured by the detailed design of the facility. However, a further distinction may be made between specifically safety aspects of the design and the more general engineering design. The general engineering design provides the context in which safety features are implemented, but much of the effort directed to the engineering of the plant is simply intended to make it operable, reliable, and hence economic.

This work has given some attention to general questions of power plant safety, and even reliability, as will be clear below. However, because of the perception that the major potential for plant accidents to affect the public is associated with nuclear power plants, only this potential has been examined in detail.

2.1 Types of safety standards

Although reference was made above to the areas for which standards might be formulated, i.e., public safety, worker safety, and general plant design, we have not yet distinguished between regulatory standards, "voluntary" standards, and standard engineering practice. Such a distinction was not as important in part 1, emphasizing health, because the difference between a regulatory standard or requirement and a recommended guideline was clearer. For the safety engineering of a plant, the distinction must be emphasized, because — although safety-regulated aspects of power plants are regulated, whether fossil-fuel, geothermal, or nuclear — the bulk of "standards" are not regulatory standards, but rather are standards developed by professional engineering societies or may even be only "standard practice" in an industry or a given company. All of these fit the definition of a standard, "that which is established as a measure". A brief comment on each category is useful:

Regulatory standards are specified by responsible governmental agencies, at the national, state, regional, or local level, to protect the safety (and health) of the public or workers. The manner of their formulation and enforcement may vary widely, but it is required that they be met. Often these standards, whether for occupational safety, reactor safety, or other applications, will depend very heavily on what were referred to above as normally "voluntary" engineering standards. Such engineering standards, however, will often be used only as "guidelines" for compliance with more broadly specified regulatory standards. As discussed below, the regulation of nuclear power is a prime example of this practice.

Engineering standards are formulations of engineering practice available for the use of the engineering, industrial, and regulatory community at large. They are typically formulated by a committee of an engineering society for use is the area of the society's specialty. Thousands of such standards exist, formulated and published by scores of societies and associations. In the United States, the American National Standards Institute serves as a central organization concerning itself with such standards and attempting to impose an orderly process in their formulation, adoption, and use. The National Bureau of Standards serves as a governmental research organization which, among its functions, supplies basic data for use in such standards.

Often such a standard may have arisen naturally out of the apparent need felt by one of the engineering communities for standardization of some area of engineering. They may also be formulated at the specific request of or in conjunction with a regulatory agency which identifies a need for some engineering standard, which could then be utilized, often only as a guideline, in its regulatory procedures. The general statement may be made, though, that engineering standards are formulated on the basis of a more general pool of engineering knowledge and experience. Portions of this pool will, prior to the formulation of an actual standard, have been identifiable as standard engineering practice.

Standard practice is not formulated in publicly available standards, and hence might not be considered at all in this discussion. However, it must be recognized that - in many areas where standards, either regulatory or general engineering, do not exist - standard practice is necessarily the basis for engineering design. They are almost semantically identical. However, it is useful to point out the concept of standard practice, both because of its importance in the normal course of designing any facility and because any example of such practice may be considered to constitute a primordial standard. However, the process of creating the actual standard may be very lengthy, requiring substantial work on the part of experienced professionals.

2.2 Use of safety standards

In practice, the review of the design of a facility as complex as a power plant must rely on a set of reference standards, so that both the designer and the reviewer have a frame of reference in which to perform their tasks. Historically, engineering standards have been developed by a large number of organizations, primarily professional engineering societies, and these standards have been developed primarily for the convenience of the individual industries to which they apply, primarily as tools for the engineer to apply in the design of a device or facility. The nuclear power industry may be regarded as one exception to this basic philosophy since, unlike facilities in other industries, nuclear facilities have been subject to a substantive engineering review by federal agencies (the Atomic Energy Commission and, now, the Nuclear Regulatory Commission). However, even in the case of nuclear facilities, the many applicable engineering standards do not have any required regulatory application; they stand only as tools of convenience for

the designer and, incidentally, for the reviewer.

2.2.1 Assurance of safety and reliability

For any industrial facility, the engineering standards which are available stand as a codified body of understanding which eases the task of design and at the same time increases the probability of a successful design, leading to a reliable facility. Attention to reliability (particularly of components) forms the basis, in many instances, of safety at such facilities. For this reason, such standards may be regarded, in a general sense, as "safety" standards. However, as discussed below, there is in fact a more restricted class of standards which are specifically developed to assure safety. Most of the full set of engineering standards do not belong to this restricted class, but are more generally intended to assure the availability or economy of the facility. These are often the primary goals sought in design of power plants, and the primary reasons for reliance on the engineering standards developed by professional societies. Only in the case of nuclear, where the design is relatively closely regulated, is safety the basic reason for the development and application of many standards.

2.2.2 Present application of standards to electric generating facilities

As indicated above, nuclear power plants present the only instance where substantive review of the facility design is ordinarily undertaken by regulatory agencies. Even in this case, a practical distinction is made between aspects of the facility design which are safety related and those which are not. The primary intent of the review is to assure a design which is adequate to protect the health and safety of the public and of workers at the facility. In practical terms, the review of the engineering of the plant may be divided into two areas, review of normal operation of the plant and review of systems to prevent abnormal occurrences which might release unusual amounts of radioactivity. The first area would, for example, include systems which are designed to remove radioactivity from the gaseous and liquid effluent streams from the plant. The second category would include, among other things, equipment associated with emergency core cooling systems and containment. The general design of the facility is reviewed only to the extent that it has a bearing on these areas.

However, it must be emphasized that the review is not only confined to the design per se. Although the major part of the review is devoted to such

design and relies as much as possible on the engineering standards applicable to the various safety-related system, an equally important part of the review examines the measures taken by the utility and its contractors to assure that the facility is actually constructed in compliance with approved standards and that materials and components are of the quality specified in the design. Thus safety is assured by adequate design supported by a quality assurance (QA) program. Both the design itself and the QA program are subjects of review, although to some extent this idea is not unambiguous, since part of the responsibility of the regulatory agency may then be to become involved in the program of quality assurance and inspection.

In matters which have little bearing on safety, this review and inspection is not applied. However, the utility itself has an obvious interest in proper design in these other areas. To a large extent, various engineering standards are applicable to these areas, for the general reasons discussed above, and they will be used where desirable. In general, the utility must rely in a broad way on standard engineering practice. Moreover, where appropriate, the utility itself will establish programs of inspection or QA with varying degrees of rigor, in its own interest.

In general, these last comments apply to all design areas for non-nuclear facilities, including geothermal and fossil-fuel power plants. Typically, there is no regulatory review of the detailed design of such facilities, except possibly for areas which may directly affect the surroundings of the plant, such as emissions and related control systems. In attempting to establish such a review process, any regulatory agency would first have to establish the formal basis for review a set of standards to be applied. This requirement exists even though the standards themselves would probably not carry direct regulatory force. Instead, as discussed above, they are necessary as practical tools to be used at the design and review stages. It is impractical for a detailed review of complex designs to be established in the absence of working guidelines, which is what engineering standards provide in the regulatory context.

2.3 Identification of safety standards for power plants

As a part of the present work, we have completed two compilations of "safety" standards with, however, no evaluation of these standards. The first includes standards currently employed by the Nuclear Regulatory Commission in

its review of the safety of proposed nuclear power plants. The second is compiled from many sources and constitutes a list of standards which may be used in the design or review of power plants. These compilations have been communicated to the ERCDC, but have not been composed as formal reports. Their origin and use is discussed in the remainder of this section. The only substantive analysis which we have performed relating to the safety of power plants is discussed in the succeeding sections on nuclear safety and power plant reliability. Sections 3 and 4 discuss how the ERCDC might select or formulate review standards for its own use.

2.3.1 Nuclear safety standards

The basic Nuclear Regulatory Commission review mechanism is the examination of a Safety Analysis Report (SAR) submitted by the utility or its agents. A Preliminary Safety Analysis Report is submitted prior to the authorization of plant construction and a final version precedes the issuance of an operating license. The latter is essentially an update of the former, so that we do not distinguish them in what follows.

The SAR presents the information necessary for the NRC to determine compliance of the proposed facilities with regulatory requirements. These requirements are specified in title 10 of the Code of Federal Regulations, which deals with the responsibilities of the NRC. Safety criteria for nuclear power plants are given in 10 CFR 50, but important criteria are contained elsewhere, including radiological criteria in 10 CFR 20 and site criteria in 10 CFR 100. The information required to be included in the SAR is described in the NRC publication, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. LWR Edition, Revision 2."[8]

The NRC has also formulated and published Standard Review Plans[9] (SRP) for the safety review based on the SAR. These SRP give detailed information on the subject and manner of analysis, the NRC branches which perform the analysis, and the criteria used for analysis, for each subject treated in the SAR and by the safety review. It should be noted that the SAR, the Standard Format mentioned above, and the SRP all have the same structure. They are divided into 17 chapters. Table 2-1, largely abstracted from the Standard Format, indicates by chapter the information required, and hence the subjects of interest, for the safety review. Note that the review extends all the way from site characteristics to facility engineering and operation. More detailed information is

Table 2-1 (Reproduced from reference 2)

TABLE 2-6. Contents of Safety Analysis Report

1. INTRODUCTION AND GENERAL DESCRIPTION OF PLANT - presents an introduction to the report and a general description of the plant. This chapter should enable the reader to obtain a basic understanding of the overall facility without having to refer to the subsequent chapters. Review of the detailed chapters that follow can then be accomplished with better perspective and with recognition of the relative safety importance of each individual item to the overall plant design.

2. SITE CHARACTERISTICS - provides information on the geological, seismological, hydrological, and meteorological characteristics of the site and vicinity, in conjunction with present and projected population distribution and land use and site activities and controls. The purpose is to indicate how these site characteristics have influenced plant design and operating criteria and to show the adequacy of the site characteristics from a safety viewpoint.

3. DESIGN OF STRUCTURES, COMPONENTS, EQUIPMENT, AND SYSTEMS - should identify, describe, and discuss the principal architectural and engineering design of those structures, components, equipment, and systems important to safety; discusses the seismic and quality group classifications, then the criteria for qualifying various components and systems.

4. REACTOR - provides evaluation and supporting information to establish the capability of the reactor to perform its safety functions throughout its design lifetime under all normal operational modes, including both transient and steady-state, and accident conditions. Should include information to support the analyses presented in Chapter 15. The major topics to be considered in Chapter 4 are fuel system design, nuclear design, thermal and hydraulic design, reactor materials, and the design of the reactivity control systems.

5. REACTOR COOLANT SYSTEM AND CONNECTED SYSTEMS - provides information of the reactor coolant system and systems connected to it, making a point to include information on the entire "reactor coolant pressure boundary" as defined in 10 CFR 50.2(v). Topics included are a summary description, the integrity of the reactor coolant pressure boundary, the reactor vessel, and component and subsystem design.

6. ENGINEERED SAFETY FEATURES - provides enough information on features designed to mitigate the consequences of postulated accidents that an adequate evaluation of their performance ispermitted. The information includes experience and testing, consideration of component reliability and system design, provisions for inservice test and inspection, and evidence that materials will stand the accident environment. Systems to be considered may include containment systems, emergency core cooling systems, habitability systems, fission product removal and control systems, and others.

7. INSTRUMENTATION AND CONTROLS - provides information on the reactor instrumentation which senses the various reactor parameters and transmits appropriate signals to the regulating systems during normal operation, and to the reactor trip and engineered safety feature systems during abnormal and accident conditions; emphasizes those instruments and associated equipment which constitute the reactor protection system.

8. ELECTRIC POWER - provides information directed toward establishing the functional adequacy of safety-related electric power systems and ensuring that these systems have adequate redundancy, independence, and testability in conformance with current criteria.

Table 2-1 (continued)

TABLE 2-6 (continued)

9. AUXILIARY SYSTEMS - provides information on auxiliary systems including fuel storage and handling, water systems, process auxiliaries (such as air handling, water drainage, etc.), ventilation systems, and others (such as fire protection, lighting, etc.). Systems that are essential for safe plant shutdown or for the protection of the public health and safety should be identified and discussed in detail (design bases, safety evaluation, etc.).

10. STEAM AND POWER CONVERSION SYSTEM - provides information on the steam system and turbine generator units, as defined by the secondary coolant system in a PWR or by the system beyond the reactor steam isolation valves in a BWR. Information should be broadly descriptive, with emphasis on those aspects of design or operation which might affect the reactor and its safety features or contribute toward the control of radioactivity.

11. RADIOACTIVE WASTE MANAGEMENT - describes 1) the capabilities of the plant to control, collect, handle, process, store, and dispose of liquid, gaseous, and solid wastes that may contain radioactive materials, and 2) the instrumentation used to monitor the release of radioactive wastes; information covers normal operation, including anticipated operational occurrences. Radwaste systems should be capable of complying with 10 CFR 20 and 50, Appendix I.

12. RADIATION PROTECTION - provides information on methods for radiation protection and on estimated occupational exposures of operating and construction personnel during normal operation and anticipated operational occurrences; should describe facility and equipment design, the planning and procedures programs, and the techniques and practices employed to meet 10 CFR 20.

13. CONDUCT OF OPERATIONS - provides information relating to the preparations and plans for operation of the plant; the purpose is to provide assurance that the applicant will establish and maintain a staff of adequate size and technical competence and that operating plans to be followed by the licensee are adequate to protect the public health and safety.

14. INITIAL TEST PROGRAM - provides information on the initial test program for structures, systems, components, and design features for both the nuclear portion of the plant and the balance of the plant. The information provided should address major phases of the test program, including preoperational tests, initial fuel loading and initial criticality, low-power tests, and power-ascension tests.

15. ACCIDENT ANALYSES - includes analyses of the response of the plant to postulated disturbances in process variables and to postulated malfunctions or failures of equipment. Previous SAR chapters evaluated structures, systems, and components important to safety for their susceptibility to malfunction or failure. In this chapter, the effects of anticipated process disturbances and postulated component failures should be examined to determine their consequences and to evaluate the capability built into the plant to control or accommodate such failures and situations; analysis should include anticipated operational occurrences, off-design transients that induce fuel failures above those expected from normal operational occurrences, and postulated accidents of low probability.

16. TECHNICAL SPECIFICATIONS - the applicant proposes Technical Specifications that set forth the limits, operating conditions, and other requirements imposed on the facility operation for, among other purposes, the protection of the health and safety of the public.

17. QUALITY ASSURANCE - provides a description of the applicant's quality assurance program to be established during design, construction, preoperational testing and operation.

available in the Standard Format and the SRP themselves. A summary of the content of the Safety Analysis Report and of the Standard Review Plan is provided in reference 10.

As a guide to the public (and the applicant), the NRC issues Regulatory Guides (RG), which are best described by the NRC itself:

> Regulatory Guides are issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

Division 1 of the RG is devoted to power reactors. The Standard Format is actually published as RG 1.70. At the present time, some 130 RGs have been issued or made available for comment in this division. They serve as substantial sources of information on achieving compliance with regulatory requirements. However, they are far from complete. Some important examples were given in Table 1-2.

Just as the Regulatory Guides are useful devices for fulfilling regulatory requirements, they in turn depend to a large extent on engineering standards, especially those which have been developed for nuclear power applications. However, to the extent possible, these are simply extensions of standards developed for more general applications. Many of the regulatory guides specify standards which are useful in fulfilling regulatory requirements.

The Standard Review Plans specify, for the many subjects of review, the general criteria (from 10 CFR), the Regulatory Guides, and the most important engineering standards that may be used in the review, and hence which constitute acceptable guides to design. Furthermore, the American National Standards Institute has compiled a list of engineering standards for nuclear power applications. Finally other workers[11] have compiled a composite list of criteria, regulatory guides, and engineering standards for general types of reactors. Based on these sources of information, we have compiled such a list,[12] intended to set forth the criteria, guides, and standards for light-water reactors as of June, 1976. These various "standards" are organized by chapter in the Standard Review Plan, and the result has been communicated to the ERCDC staff. The result is very extensive, but is only useful when considered in connection with the Standard Review Plans themselves.

We should emphasize that the NRC review, and the documents referred to in this discussion only relate to specifically safety aspects of nuclear power

plants, and not to the more general engineering of such plants. For this broader area, more general standards apply.

2.3.2 Generally applicable standards

Two classes of standards are usefully considered in connection with the more general design of nuclear power plants and the entire design of fossil-fuel and geothermal power plants. The standards pertaining to the safety of nuclear plants were discussed above. The comparable body of standards for other power plants are contained in title 8 of the California Administrative Code (CAC), Chapter 4: Industrial Safety Orders. These are basically occupational safety and health (OSHA-type) standards, but — as suggested previously — questions of plant safety at non-nuclear facilities are not usually perceived to have great impact on the public health and safety. This is an oversimplication, but the codes in CAC 8.4 which protect worker safety necessarily protect the public, also, albeit as a secondary benefit. CAC chapter 8.4 has a number of subchapters which may be construed to pertain to power plant safety.*

A larger body of standards is applicable to the general engineering of industrial facilities, including power plants. A brief survey[13] was made of such standards, based on a number of sources, including the American National Standards Institute, the National Bureau of Standards, utilities, numerous engineering societies and associations, and the ERCDC staff (which previously compiled "construction" standards). Standards which might be applicable to power plant design or operation were selected from these sources, purely on their face value, not on the basis of known usage. They were organized in the fashion indicated in Table 2-2 and communicated to the ERCDC staff. Roughly a thousand standards were listed, but they are certainly not comprehensive, nor are they all applicable. They do, however, indicate the number and variety of standards, and numerous instances where several standards may be applied to the same area can be identified. On the other hand, there are many areas of direct interest in this work for which explicit standards are not to be found.

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*These include 8.4.1 (Unfired Pressure Vessel Safety Orders), 8.4.2 (Boiler and Fired Pressure Vessel Safety Orders), 8.4.7 (General Industry Safety Orders, largely directed to occupational safety), and 8.4.15 (Petroleum Safety Orders).

Table 2-2. Generally Applicable Engineering Standards

1. GENERAL

2. STRUCTURAL - CONSTRUCTION
   - 2.1 - General
   - 2.2 - Concrete
   - 2.3 - Steel
   - 2.4 - Welding
   - 2.5 - Painting
   - 2.6 - Screws, Bolts, Nuts
   - 2.7 - Testing
   - 2.8 - Safety
   - 2.9 - Others

3. BOILERS AND PRESSURE VESSELS

4. GENERATORS, MOTORS, TURBINES, ETC.

5. PIPING SYSTEMS AND RELATED ITEMS
   - 5.1 - General
   - 5.2 - Pipes and Fittings
   - 5.3 - Valves and Flanges
   - 5.4 - Welding and Supports

6. ELECTRICAL SYSTEMS
   - 6.1 - General
   - 6.2 - Storage Batteries and Auxiliary Power Systems
   - 6.3 - Cables, Wires, Insulators
   - 6.4 - Conduit, Ducts, and Trays
   - 6.5 - Circuit Breakers, Switch Gears, Fuses, and Relays
   - 6.6 - Transformers and Capacitors
   - 6.7 - Transmission Lines, Substations, and Busways
   - 6.8 - Control Apparatus
   - 6.9 - Motors and Other Equipment
   - 6.10 - Safety and Protective Devices
   - 6.11 - Test
   - 6.12 - Measurement

7. COOLING TOWERS, EQUIPMENT

8. MISCELLANEOUS EQUIPMENT
   - 8.1 - Pumps and Water Treatment Equipment
   - 8.2 - Air Handling Systems
   - 8.3 - Lighting
   - 8.4 - Hoists and Cranes
   - 8.5 - Industrial Trucks

9. FUELS - STORAGE, ETC

10. FIRE
    - 10.1 - General
    - 10.2 - Extinguishing Devices
    - 10.3 - Flammable Materials
    - 10.4 - Fire Prevention and Detection
    - 10.5 - Doors, Windows, Walls, and Roofs

11. WASTES

12. SAFETY (OCCUPATIONAL)

2.3.3 A brief look at specific safety-related standards

To indicate how comprehensive (or deficient) currently available standards are, we have identified nine broad areas of plant design and operation for which standards might be useful. Four are primary aspects of facility design:

1. operational safety systems,
2. seismic design,
3. pressure vessels and piping,
4. explosion and fire,

Two support these and, indeed, all aspects of design and operation:

5. quality assurance and monitoring,
6. safety equipment and training.

Three tend to be closely related to emissions and site characteristics, although they are also aspects of plant design and operation:

7. site geophysical characteristics (seismology, soil stability, hydrology, and meteorology),
8. fuel handling and waste disposal, including transportation,
9. emission control equipment.

For these areas, we briefly discuss applicable standards, beginning in each case with nuclear plants, since the standards are most comprehensive for this technology and they may be used as a guide for development of standards for fossil-fuel and geothermal plants. The NRC not only sets forth criteria in its Regulatory Guides, but often gives detailed "guidance" in its Standard Review Plans and its Branch Technical Positions.

1. Operational safety systems: these are of primary importance for nuclear power plants and may be considered to include the systems for normal operation, including basic control and instrumentation systems, as well as "engineered safety features", such as the emergency cooling systems and the containment, with its various subsystems. For all these, the NRC has recommended engineering standards and, in many cases, developed Regulatory Guides. Many of the standards applicable to the systems for normal operation may also be applied to fossil-fuel and geothermal plants. However, for such plants, the systems do not assume a safety significance comparable to the case of nuclear. The standards applicable to pressure vessels and piping and to explosion and fire are considered below.

2. Seismic design: for nuclear power plants, where seismic events have the potential for inducing large radioactive releases, the need for plant designs that prevent such occurrences has led to the formulation of Regulatory Guides for categorizing plant equipment, for specifying the seismic response spectra to be considered, and for selecting damping values for seismic design. Making a comparable effort for fossil-fuel and geothermal plants might be excessive, considering the lesser potential for harm to the public. The independent question of determining the potential for seismic events at a specific site is considered under site characteristics.

3. Pressure vessels and pipings: for all types of plants, standards have been formulated for these components. Of particular importance are the (ASME) Boiler and Pressure Vessel Code (BPVC) and related standards, which have especially stringent specifications for fabrication and inservice inspection of vessels for nuclear service, since these vessels operate under unusual pressure and radiation conditions. The BPVC is effectively a regulatory standard, due to its incorporation into both NRC and OSHA regulations. Similarly, such standards exist for use on piping components.

4. Explosion and fire: specific NRC Regulatory Guides apply to design areas with a potential for explosion and fire; attention to these matters is intense, primarily because of possible effects on reactor operation and ultimate integrity, rather than because of direct effects of explosion or fire. OSHA requirements, applicable to any industrial facility, are directed toward the latter effects.

5. Quality assurance and monitoring: nuclear plants have stringent quality assurance programs applied to them. The NRC Regulatory Guide on QA is based on an industry standard (ANSI N45.2-1971) for nuclear plants. In addition, Regulatory Guide 1.70 and supporting documentation provide more specific guidance. These same techniques may be applied to other types of facilities, but — as for any generally applicable engineering standard — would not specify what areas quality assurance would be applied to or who shall create the required management and inspection structure. As for monitoring, in most design areas for which standards exist, the standards specify monitoring and inspection needs.

6. Safety equipment and training: The NRC has primary responsibility for specifying requirements for radiological safety and related equipment. Regulatory Guides (Division 8) are a guide to implementing 10 CFR 20. OSHA performs the corresponding task for conventional hazards. The NRC Regulatory Guides (Division 1) also specify qualifications for reactor operators.

7. Site geophysical characteristics: for nuclear power plants, the information required for analyzing site suitability is specified in a number of Regulatory Guides (especially 1.70 and 4.7 for general seismic and stability requirements, 1.23 for meteorology, 1.59 for hydrology, and 1.76 for tornado). These site characteristics must be considered in connection with the actual design of the plant, such as the seismic response. Typically, such a detailed analytical program has not been formulated for fossil-fuel and geothermal plants and it can therefore be said that comparable standards do not exist. In principle, though, the NRC approach may be adapted to other types of plants to the extent considered necessary.

8. Fuel handling and waste disposal; transportation: for nuclear plants, fuel handling is carried out in manner consistent with the safety of workers, and fuel storage requirements are specified in Regulatory Guides. Radioactive waste disposal does not occur on the site, and off-site disposal is a matter of controversy. A specific set of Regulatory Guides (Division 7) is devoted to transportation. For fossil-fuel and geothermal plants, no standards are explicitly formulated for these areas, even though they would be useful, primarily because of the large bulk of material handled and stored or disposed, and the associated potential for leaching harmful chemicals into water resources.

9. Emission control equipment: in order to meet the specifications in 10 CFR 20 and 50, the NRC gives rather detailed guidance on the design, fabrication, testing, inspection, and operation of radioactive emission control systems. Such guidance is not typically available for the comparable control equipment at fossil-fuel and geothermal facilities, although it is to be expected that some guidance will develop as the control equipment sees expanded use. It should be noted that the NRC guidance extends both to operational parameters for the control equipment and to design bases, materials, and other standards for the equipment.

Part 3 of this report discusses how the ERCDC might evaluate or select standards for use in power plants in California. Before turning to that subject, we treat the specific question of reactor safety assessment and design (Section 2.4) and how power plant reliability might be affected by regulatory measures (Section 2.5).

2.4 Reactor safety studies

It appears that routine radioactive emissions from nuclear power plants have less potential for harm to the public than routine emissions from fossil-fuel and geothermal power plants. On the other hand, the implications to the public of accidential releases from nuclear facilities can be much more severe than their routine emissions or than potential accidents at non-nuclear facilities. For this reason, a major portion of our work on plant safety was devoted specifically to nuclear power plants. In addition to the compilation of nuclear-related standards discussed in Section 2.3, we have summarized the state-of-the-art for assessments of overall nuclear reactor safety in the report "A Review of Light-Water Reactor Safety Studies" (LBL-5286)[5] and, as indicated in Section 1.1, we have reviewed the state of emergency planning for nuclear power plants[3] and have considered controls for population densities surrounding these plants.[4] The discussion of this section is based primarily on the review of reactor safety studies.

2.4.1 Major studies considered

Three notable studies were examined in detail, of which two, the Reactor Safety Study of the Nuclear Regulatory Commission and the American Physical Society (APS) study of light-water reactor safety, are quite different, yet complementary; the third group of studies, by the Electric Power Research Institute (EPRI) is one example of extensions of techniques such as were used in the Reactor Safety Study.

The NRC Reactor Safety Study, whose work was published as WASH-1400, attempted to assess the accident risk from the operation of nuclear power reactors of the type now being used. The fundamental approach was: 1) to use a probabilistic technique to calculate the probability of various types of accidents, based on a detailed analysis of the safety systems at a typical pressurized-water reactor power plant and a typical boiling-water reactor power plant; then 2) to calculate the consequences of this accident spectrum, utilizing a simplified meteorological model, weather and population distribution characteristics from already identified reactor sites, models for calculating the dose to individuals exposed to the radioactivity released, and dose-response relationships as described in Section 1.1; and finally 3) to join these results to yield accident probabilities versus consequences.

The probabilistic technique employed "event trees" to identify possible accident sequences and "fault trees" to calculate the safety system failure

probabilities which, when incorporated into the accident sequences identified from the event trees, yielded the probability of failure. "Failure" was taken to be meltdown of the core, followed by escape of the molten core materials from containment. However, the time sequence and size of radioactive releases, particularly to the atmosphere, depended critically on which safety-related systems failed, leading to the meltdown and breach of containment.

The actual consequences of release were calculated for a limited number of "release categories" characterized by the time sequence and size of the release, and defined on the basis of the results of the event tree analysis.

The consequences calculated were: "early" effects (illness and death), latent effects (thyroid nodules, cancer deaths, and genetic effects), and property damage (including denial of property and evacuation costs). These consequences were displayed graphically versus probability of occurrence for a single power plant and for the first 100 plants. Early deaths and illness were also compared with the consequences from other types of accidents, arising from both man-made and natural causes. This led to the observation that the risk posed by nuclear plant accidents was considerably less than other risks normally suffered. (This comparison was not made for the latent effects from nuclear plant accidents, even though these effects dominate the total consequences to human health.) Furthermore, the results were summed to give the net risk of various types of consequences to individuals and society; these again were smaller than other risks.

The American Physical Society study group conducted a somewhat more wide-ranging investigation of reactor safety, although on a much smaller scale than the NRC study. The APS study was not intended to "assess the risk" from nuclear power plants, but to examine more generally the broad state of light-water reactor safety. In accordance with this broader mandate, the study examined both institutional and technical aspects of reactor safety and reactor safety research. The basic material of the resulting report is concentrated into three areas: 1) a discussion of events which may initiate accidents, 2) examination of the course of an accident, with special attention to loss-of-coolant phenomena and the associated emergency core cooling systems, to containment behavior, and to accident consequences, and 3) an analysis of the light-water reactor safety research program, including work being supported both by the NRC and EPRI.

Of the conclusions of the APS report, perhaps the most notable are: 1) that the reactor safety research program should be improved in a number of ways, including greater emphasis on developing more realistic accident simulation computer programs (with experimental verification after predictions are made by the programs) and a greater willingness to make changes in basic reactor design in order to ease the difficulty of designing and analyzing reactor safety systems; and 2) that the one aspect of the (draft) WASH-1400 report that was examined in detail, the consequences calculation, was seriously deficient in that it grossly underestimated latent effects. After the suggested corrections to WASH-1400 were made, the latent effects were much more numerous, although felt over a much longer period of time, than the early health effects.

The EPRI work of interest examined the draft WASH-1400 and extended the probabilistic analytical techniques in a useful manner. These extensions included development of a more general fault tree analysis, with the advantage that system interdependencies could be treated more naturally than in WASH-1400. It should be noted that such connections may give rise to "common mode" failures (the failure of two or more systems due to the failure of a single component or human failure), and that a basic criticism often raised against the use of probabilistic analysis is the possibility that such failures are not identified. A second extension of interest was the development of "sensitivity indicators", which show analytically the dependence of one quantity of interest, such as consequences, on other parameters, such as the failure rate for a particular component. These indicators can be useful in identifying where changes would provide the most benefit in the reduction of risks from accidents.

However, an important point about all of these studies is that they do not quantify the risk posed by saboteurs. Nor has the risk from earthquakes been treated in detail, although WASH-1400 treated it roughly.

2.4.2 Other assessments; criticisms of WASH-1400

Prior to the studies just discussed, no detailed assessment of the risk from nuclear plant accidents had taken place. The classic study, WASH-740, had been performed two decades before and had simply predicted the consequences of postulated accidents, without attempting to calculate probabilities. The consequences of the largest accident examined were quite severe, including thousands of early fatalities and billions of (1957) dollars in property damage.

An update of these consequences was begun during the next decade, to take account of the larger reactors being designed, but was never completed. In retrospect, it is clear that the calculated consequences would have been proportionately larger than the earlier results.

However, it is WASH-1400 which presently stands as the primary public example of anything resembling an actual assessment of the risk from nuclear power plants. Both the draft and final reports have been subject to much criticism, some in the form of useful independent work. The APS study was one such example, with respect to its modeling of accident consequences, although that report was not primarily a review of WASH-1400. Other criticisms dwell on the probabilistic (event tree-fault tree) methodology itself; often cited are the unreliability of these techniques when used to calculate small probabilities, the scantiness of the failure rate data base, and the difficulty of identifying all the important accident sequences, particularly those involving common-mode failures. The importance of this last difficulty is often supported by the example of the fire at the Brown's Ferry plant, which resulted in a multiple loss of control and safety systems. The final WASH-1400 report attempts to answer these points, though not to the satisfaction of many critics.

A second class of criticisms, including those of the APS study (which, however, examined only the draft report), concentrate on the consequences calculations. In addition to the meteorological and dosimetric modeling, the actual dose-response function for latent effects has been criticized because it departs from a simple linear extrapolation from available data in that it makes corrections for low dose and dose rate. This departure was criticized, in particular, by the Environmental Protection Agency. The EPA was also critical of the assumptions made with regard to evacuation following the accident. However, the consequences modeling in the final report is such that any corrections made in response to these criticisms are not likely to change the calculated <u>average</u> risk drastically.

We have said nothing of the risk presented by any individual nuclear power plant. It is, however, not possible to use the results presented in WASH-1400 for site specific evaluation. The fact that the Reactor Safety Study was not intended for such evaluation does not lessen the fact that the results of the study would have been more useful had they been presented in a more comprehensive way, including intermediate results. This is a common criticism of the report and one with which we concur. Judging from the calculations of

workers outside the Reactor Safety Study, including the foreign work discussed below, potential consequences vary drastically from one site to another, and it would be useful to employ the results of WASH-1400 for specific sites. Furthermore, presentation of intermediate results in the WASH-1400 calculations would make those calculations more amenable to outside examination and possible improvements.

This lack is primarily a deficiency in the presentation of the results in WASH-1400. Another such deficiency is the careful manner in which the report fails to emphasize the relative importance of latent effects, as compared with early effects. This omission was pointed out above, but leads to rather glib comparisons of the risk from nuclear plant accidents with that from other accidents (such as meteorite strikes), comparisons which typically completely neglect the dominant consequence of nuclear accidents, the latent health effects.

2.4.3. Foreign studies

Only a small effort was devoted to examination of foreign efforts related to light-water reactor safety. In many respects, such efforts in this area follow the lead of work in the United States, as is to be expected considering that this country led in the development of these reactors. However, some important considerations are highlighted in foreign work, and we briefly summarize the information which is publicly available on European work. However, it should be noted that the foreign work is not conducted in as open a manner as in this country, so that the public information can only be regarded as representative of foreign work.

Substantial efforts in probabilistic analysis have been taking place in recent years in Europe. The earliest such study often referred to is the Swedish Urban Siting Study (1974), which analyzed the potential impacts of siting dual purpose power plants in urban areas for power generation and district heating. However this study adopted a probabilistic approach only to the consequences modeling and not to the matter of accident probabilities. The authors were of the opinion that the most important initiator of core-meltdown accidents was catastrophic reactor vessel failure, with a probability of occurrence of 1 in 1 to 10 million reactor years. This core meltdown probability is 50 to 500 times smaller than that calculated in WASH-1400! Because the authors adopted, rather than calculated, a meltdown probability, the results of this study are actually more comparable to the WASH-740 study

(of consequences of postulated accidents) than to the WASH-1400 mechanistic risk assessment.

In some respects, European work has extended or supplanted the techniques of WASH-1400, though — even in the European community — WASH-1400 is regarded as the archetype and most complete example of such studies. Some of these extensions take the form of different, perhaps more sophisticated, probabilistic analysis techniques, much as work in this country (such as that pursued by EPRI) constitutes such improvements. Another major area where European work takes place is to apply these techniques to site-specific risk analysis. This is just the type of extension that was discussed above in connection with WASH-1400. In any event, it is worth noting that the practitioners of probabilistic analysis in Europe do not appear to obtain results which differ greatly from those of WASH-1400, except in specific respects which result from differences in reactor design or in population distributions.

In LWR reactor safety design, European work depends heavily on that performed in the United States. However, with respect to the safety of PWRs, an extremely interesting report was recently made to the United Kingdom Atomic Energy Authority by a study group on pressure vessel integrity chaired by W. Marshall. Concern over the probability of pressure vessel failure, voiced most prominently by Sir Alan Cottrell, had been one of the reasons for the British decision in 1974 to emphasize other types of reactors and had resulted in initiation of the Marshall study. (This study is now one of the main inputs to a generic review of PWR safety now being performed by the British Nuclear Installations Inspectorate.) The Marshall group was satisfied that PWR vessel integrity could be satisfactorily assured provided NRC regulations were fully implemented and supplemented by a number of other specifications; Cottrell himself appears satisfied with the Marshall Report, but points out the importance of three of these specifications, having to do with: 1) limiting operational transients, 2) injection of ECC water at high temperatures, and 3) rigorous inservice inspection. In this country, the NRC/ACRS appear satisfied with 1 and 3, but 2 is among the items in table 2-3. (See next section.)

In general, the European community appears more sanguine about the risks from nuclear power than does the United States community. Often regulatory requirements relating to routine emissions or to reactor safety are not as severe as in the United States. Although there are European critics of nuclear power, the public as a whole more readily accepts the potential hazards

Table 2-3. Rough Categorization of ARCS Generic Items Relating to Light Water Reactors[a]

ECCS AND LOCA RELATED ITEMS, INCLUDING CONTAINMENT RESPONSE

I-1 Net Positive Suction Head for ECCS Pumps
I-3 Hydrogen Control After a Loss-of-Coolant Accident (LOCA)
I-20 Capability of Biological Shield Withstanding Double-Ended Pipe Break at Safe Ends
IA-5 ECCS Capability of Current and Older Plants
IB-3 Performance of Critical Components (pumps, cables, etc.) in post-LOCA Environment
IB-4 Vacuum Relief Valves Controlling Bypass Paths on BWR Pressure Suppression Containment

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*II-2 Effective Operation of Containment Sprays in a LOCA
II-8 BWR Recirculation Pump Overspeed During LOCA
II-10 Emergency Core Cooling System Capability for Future Plants
*IIA-1 Pressure in Containment Following LOCA
IIA-3 Ice Condenser Containments
IIA-5 PWR Pump Overspeed During a LOCA
*IIB-3 Behavior BWR Mark III Containments
IIC-1 Locking Out of ECCS Power Operated Valves
IIC-5 Vessel Support Structures
IIC-8 Behavior of BWR Mark I Containments

QUALITY ASSURANCE, INSPECTION, TEST, AND MONITORING

I-9 Vibration Monitoring of Reactor Internals and Primary System
I-11 Quality Assurance During Design, Construction and Operation
I-12 Inspection of BWR Steam Lines Beyond Isolation Valves
I-15 Pressure Vessel Surveillance of Fluence and Shift
I-18 Criteria for Preoperational Testing
I-23 Quality Group Classifications for Pressure Retaining Components
I-25 Instrumentation to Detect Stresses in Containment Walls
IA-2 Primary System Detection and Location of Leaks
IB-2 Fixed Incore Detectors on High Power PWRs

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*II-4 Instruments to Detect Fuel Failures
II-5 Monitoring for Excessive Vibration or Loose Parts Inside the Pressure Vessel
II-11 Instrumentation to Follow the Course of an Accident
IIA-8 ACRS/NRC Periodic 10-Year Review of all Power Reactors
IIC-7 Maintenance and Inspection of Plants

EMERGENCY CONTROL

I-2 Emergency Power
IA-4 Anticipated Transients Without Scram
IB-5 Emergency Power for Two or More Reactors at the Same Site
IB-7 Control Rod Ejection Accident

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*IIA-2 Control Rod Drop Accident (BWRs)

PROTECTION AGAINST SABOTAGE

I-8 Protection Against Industrial Sabotage

IIC-3 Design Features to Control Sabotage

GENERAL EQUIPMENT AND SYSTEM ADEQUACY AND PROTECTION

I-6 Fuel Storage Pool Design Bases
I-7 Protection of Primary System and Engineered Safety Features Against Pump Flywheel Missiles
I-13 Independent Check of Primary System Stress Analysis
I-14 Operational Stability of Jet Pumps
I-19 Diesel Fuel Capacity
I-24 Ultimate Heat Sink
IA-1 Use of Furnace Sensitized Stainless Steel
IA-2 Primary System Detection and Location of Leaks
IC-1 Main Steam Isolation Valve Leakage of BWR's
IC-2 Fuel Densification

II-1 Turbine Missiles
*II-6 Common Mode Failures
II-7 Behavior of Reactor Fuel Under Abnormal Conditions
*IIA-4 Rupture of High Pressure Lines Outside Containment
*IIA-6 Isolation of Low Pressure From High Pressure Systems
IIA-7 Steam Generator Tube Leakage
IIB-2 Qualification of New Fuel Geometries
IIB-4 Stress Corrosion Cracking in BWR Piping
IIC-2 Fire Protection
IIC-6 Water Hammer

SEISMIC RESPONSE

I-5 Strong Motion Seismic Instrumentation
I-22 Seismic Design of Steam Lines
IC-4 Seismic Category I Requirements for Auxiliary Systems

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*II-9 The Advisability of Seismic Scam

REACTOR PRESSURE VESSEL

I-10 Inservice Inspection of Reactor Coolant Pressure Boundary
I-16 Nil Ductility Properties of Pressure Vessel Materials

II-3 Possible Failure of Pressure Vessel Post-LOCA By Thermal Shock

GENERAL REACTOR OPERATION: CONTROL AND INSTRUMENTATION

I-4 Instrument Lines Penetrating Containment
I-17 Operation of Reactor With Less Than All Loops in Service
I-21 Operating One Plant While Other(s) is/are Under Construction
IB-1 Positive Moderator Coefficient
IC-3 Rod Sequence Control Systems

IIB-1 Hybrid Reactor Protection System

EFFLUENTS AND DECONTAMINATION

IB-6 Effluents from Light-Water-Cooled-Nuclear Power Reactors

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IIC-4 Decomination and Decommissioning of Reactors

[a]Class I items are "resolved"; class II are not. A, B, and C indicates, respectively, items that were added in the second, third, and fourth ACRS reports.

*Items considered resolved by the NRC staff but pending by the ACRS

associated with its use and often regards these hazards as smaller than the risks from other technologies. A sentence from the recent British report on "Nuclear Power and the Environment" (the "Flowers" report) could easily have come from WASH-1400:

> "The risk of serious accident in any single reactor is extremely small; the hazards posed by reactor accidents are not unique in scale nor of such a kind as to suggest that nuclear power should be abandoned for this reason alone."

2.4.4 Areas of continuing research and development

The sections above have emphasized the form and adequacy of analytical techniques for predicting the probability and consequences of reactor accidents. Of the studies discussed above, the only ones which devoted a significant portion of their effort to the basic question of reactor design and related analysis were the American Physical Society study group on light-water reactor safety and the British study group on pressure vessel integrity. The latter study was rather narrow in its focus, but the APS report reviews a number of important areas for reactor safety, including pressure vessel integrity, emergency core cooling system design, containment response, quality assurance, and computer modeling of LOCA phenomena. It also provides a view of the reactor safety research program which has been pursued in recent years. Although this view was based on information available in late 1974, the situation has not changed drastically, except that the responsibility for licensing (and related research on) light-water reactor power plants now resides with the Nuclear Regulatory Commission, rather than the Atomic Energy Commission. The report of the APS is summarized in reference 5.

A more recent perspective on the present status of reactor safety can be had indirectly through the eyes of the Advisory Committee on Reactor Safeguards (ACRS), the committee which advises the Nuclear Regulatory Commission in regulatory matters. Although the ACRS regards the current safety design of light-water reactors adequate to warrant their licensing for operation, it has established the practice in recent years of maintaining a list of "generic items" relating to light-water reactors. These are items which indicate specific areas of uncertainty related to light-water reactors. They do not necessarily imply that LWR design is deficient in these areas, but rather that an area has been identified as being unsatisfactory in some respect. Often it is the data base or analytical technique that is unsatisfactory, so that there is not sufficient information on which to base a judgment.

Resolution of an item usually involves an improvement in the data base or the available analytical tools (or in the manner in which standards are formulated) and may or may not involve an alteration in reactor design or operation.

The ACRS began reporting such a list of generic items in 1972 and has updated the list on a roughly yearly basis. Of the approximately 70 items which had been placed on the list by the time of the fourth report (April 16, 1976), about half had been resolved by that time. Because these items indicate areas of uncertainty in LWR safety, we list them in table 2-3. They are roughly categorized by broad safety-related areas. As might be expected, these broad areas themselves constitute a list of the important areas of concern in reactor safety, from the point of view of both the partisans and critics of nuclear power.

For each of the areas displayed in table 2-3, the resolved items are listed first and followed by items which in April 1976 were outstanding. The fact that such items are brought up for consideration and gradually resolved is not surprising, considering how complex, important, and highly-regulated the safety aspects of nuclear power plants are. Consider, for example, the items listed under "ECCS and LOCA related items, including containment response". Both the resolved and outstanding items include specific areas of emergency core cooling design, containment design, and component behavior in a post-accident environment, all of which are fundamental areas of safety design. Considered as a whole, the items listed in the table may be regarded either as a guide to areas of concern in reactor safety or as a glimpse of the manner in which uncertainties in reactor design are identified and resolved. It is therefore not surprising that these categories include the primary concerns expressed by organizations such as the Sierra Club and the Union of Concerned Scientists and by various individuals in recent hearings before the Joint Committee on Atomic Energy and before the Subcommittee on Energy and the Environment of the House Committee on Interior and Insular Affairs.

Work in all of the areas listed by the ACRS and indicated in table 2-3 is continuing. Many of the more important areas are discussed, for example, in the report to the APS discussed above. However, it is instructive to consider the fact that many of the areas of work described in that report are summarized very succintly in the ACRS comment on one of its outstanding generic items, II-10: "ECCS Capability for Future Plants":

"The ACRS has placed considerable emphasis on ECCS safety R&D so that the extent of conservatism in the ECCS licensing requirements could be made more precise. With more experimental data a realistic and quantitative appraisal of ECCS systems would lead to valid judgments on the changes in licensing which could be put on a firm basis.

"Parallel approaches that seek to improve the reliability of ECCS systems, to improve the monitoring of low power peaking, and to improve those fuel assembly designs which lower peaking factors are encouraged. Further, changes in plant design which improve reflooding of the reactor core should be sought and evaluated.

"R&D efforts on analysis of core blowdown and reflood should be increased and combined with the results of standard problems and the associated experiments. Improved analytical methods would provide a basis for optimized ECCS."

2.4.5 Uses of reactor safety studies

Reactor safety studies, including the types discussed in the previous sections, may be directed to two broad ends. The first is to improve the safety design of reactors, thereby reducing risk, and the other is to assess risk. Often these functions cannot be separated.

Of particular interest to the present work is that site-specific studies of the risk from accidents may lead to quantitative information on the comparative risks of alternative sites and that such studies may be useful in making decisions on land use or population density controls surrounding nuclear power plants (see section 1.1.5). The latter possibility is discussed in reference 4. The results of WASH-1400 are not in a form to be applied directly to specific sites. It would not be a difficult task to present them more completely. Moreover, some workers, both domestic and foreign, have independently begun to cast the results in a form that may be used for site-specific analysis. Once that is done, the tools developed for the overall assessment which was the goal of the Reactor Safety Study become available for use in making decisions on individual sites.

With regard to use of such analysis in considering the needs for emergency planning and population density control, we note that the writers of WASH-1400 gave the impression that most of the risk from nuclear power plants arises from accidents which harm small numbers of the public rather than large. The report does not say this explicitly; rather it only emphasizes that the probability of small accidents is much greater than of large ones, which is no

doubt true. However, a brief analysis of the results which WASH-1400 gives indicates that indeed most of the risk (i.e., the sum of probability times consequences) arises from the large, albeit improbable, accidents. Although this detail was of little importance from an overall assessment viewpoint, the balance between the risk from large and small accidents may have an influence on the character of emergency planning or the perceptions of nuclear risk.

It is also interesting to note that environmental statements for nuclear power plants, in a manner similar to WASH-1400, give the clear impression that large-consequence accidents do not pose a net risk comparable to that from smaller accidents. These statements typically treat accidents of class 1 through 8 (these are the classes analyzed in the Safety Analysis Report) explicitly, usually characterizing the risk from these accidents as "very low". On the other hand, they do not analyze the risk from larger accidents ("class 9"), on the presumption that the risk from these is "extremely low" (emphasis added). That these reports should imply that the risk from these large accidents ("extremely low") is smaller than that from the lesser accidents ("very low") is ironic considering that — as we have noted — precisely the opposite is true. It is, however, a fact that the large consequence accidents are predicted to occur so rarely that it is difficult to consider their contribution to the total risk on the same basis as that of more routine occurrences.

2.5 Power plant reliability

The point was made in section 2.1 and 2.2 that attention to component reliability of plants provides a foundation for both safe and economic operation. It is the first quality that is of interest in the present work, rather than the second. Much attention has been given recently to comparisons of the relative "availability"* of fossil-fuel (often coal) plants and nuclear plants, since availability and the related quantity, "capacity factor",* are important to planning the total generating capacity that is necessary and the relative cost of electricity generated by alternative technologies. However, planning capacity and cost is not the subject of this work. Rather it is health and safety and, to the extent it is pertinent, reliability. For this

*"Availability" may be defined as the percentage of time during which a plant was either operating or held in reserve (the alternative being that it was undergoing repairs or maintenance). "Capacity factor" is the ratio of the actual energy delivered by a plant to the amount it would deliver if operated at its rated capacity 100% of the time.

reason, our examination of operating experience has been restricted to an effort to identify in a preliminary way those systems and components which are primarily responsible for outages on the presumption that these components have an influence on plant safety. The data examined have been those published periodically by the Edison Electric Institute (EEI) on operating experiences with fossil-fuel, nuclear, and other types of electric generating facilities. Their report for the 1965-1974 period received most of our attention. The results of our examination is reported separately in "Power Plant Reliability-Availability and State Regulation" (LBL-5922).[14]

As a preliminary, we examined the overall statistics on operating experience, including the parameters referred to above, availability and capacity factor. The data used do not distinguish between the differing types of fossil-fuel plants. However, they do break these plants down into several size categories, which is useful since the large sizes (greater than 100 MWe) are of interest to us. If plants of all sizes are considered, it may be said that fossil-fuel plants have a better operating experience than nuclear plants. However, if a comparison is made between only the larger fossil-fuel plants and all the nuclear plants, so that the groups being compared have similar average sizes, fossil-fuel and nuclear plants have very similar operating experiences (roughly 60% capacity factor and availability) and, interestingly enough, the average ages of the plants being compared is similar (3 or 4 years). Any more detailed analysis would have to make finer distinctions, on the basis of fossil-fuel plant type and individual experiences with aging or running in.

However, for the purposes of identifying the scope of regulatory attention required to reduce component failure, the information is useful. Much of the power plant as a whole is similar for fossil-fuel and nuclear plants, since both use steam turbo-generators, but have differing ways of producing the steam, a boiler for fossil-fuel and a reactor for nuclear. For this reason, the next level of examination was that of major system outage rates for fossil-fuel, nuclear, and gas turbine systems. The last type, used primarily for peak loads, is very different than the others, which constitute most of a system's generating capacity, so that we will not comment further on gas turbines.

Based on the similarities in operating experiences and on the fact that they are both steam generating systems used in similar contexts, it is not surprising that similar outage experiences should be found for fossil-fuel and

nuclear plants, except that one has a boiler and one a reactor. It is the boiler and reactor that cause the bulk of outage time (whether forced or scheduled); however the turbine and the generator also make important contributions. More detailed comparisons are to be found in reference 14.

A possibility of major interest is whether detailed information on outage causes might lead to identification of areas where regulatory attention could result in an improvement in reliability. For this reason, our examination of outage causes descended another level, to the separate EEI outage cause report, prepared to accompany the more general availability and outage report. The outage cause report assigns outages to component failure at a very detailed level. The detail is so great, in fact, that we attempted to group the many failure categories into a number small enough to be more useful for the present purpose. The results are given in a tabular form in reference 14. As an example, under "boiler", a number of component failure types were grouped into the single category, "tube failures", a category of some interest since it is the major cause of boiler-induced forced outage time.

The question remains whether such information may serve as the basis of regulation for reliability. It is clear from the brief examination in ref. 14 that such an effort would have to be directed to a wide array of component types if it is to attack all the substantial contributors to outage time. Were such an effort to be mounted, to improve <u>safety</u>, a more detailed examination of component failure <u>rates</u> than was possible in this work would be appropriate, were such an effort to be directed to increased <u>availability</u>, a more careful attention to component-reduced outage <u>times</u> versus plant type would be needed.

3. EVALUATION OF STANDARDS FOR USE BY THE ERCDC

The previous sections have treated the health and safety aspects of electric generating facilities without explicit attention to the role that the Energy Resources Conservation and Development Commission might play in the review of such facilities. The subject of this section is the status of health and safety standards and the manner in which the ERCDC might evaluate (or develop) such standards for use in its review of proposed sites and facilities. This question is closely tied to the subject of section 4 of this report, methodologies for ERCDC review, and will be developed further in that section.

The relationship of standards to a review methodology raises a critical question with respect to the employment of such standards, i.e., whether they are regulatory standards or merely guidelines. The distinction has been touched on in the discussion of previous sections, but it is one which has to be carefully examined to view of the responsibilities and authority of the ERCDC. Whether the standards have regulatory force or serve as guidelines determines the character of the review process and must be kept in mind in consideration of the following discussion.

3.1 Present Standards: Sources and Status

Sections 1 and 2 treated, respectively, the "health" and "safety" aspects of power plants and, in doing so gave attention to health and safety standards. The purpose of this section is to summarize the current situation, especially with respect to standards which might be applicable to subjects of review by the ERCDC. Possible "areas of review" are summarized briefly at the beginning of Section 4 and not here, although such areas will be mentioned below. As before, we distinguish between health standards and safety standards.

3.1.1 Health Standards

We may divide health standards into two broad areas, those which deal directly with the emissions from power plants and their effect on environmental media and, ultimately, humans, and those which are more specifically related to site characteristics which could affect these emissions or their impact. Because the distinction between health and safety is ambiguous we choose, as a convention, to place any engineering standards which relate directly to

emissions or to site features in the section on safety standards, which immediately follows.

As a general rule, standards relating to air and water pollution are formulated by the Environmental Protection Agency, at the national level, and the air and water resources boards, together with regional districts, at the state level. These standards, although they are still being developed, are intended to be relatively complete, except that they are limited in the extent to which they may be used for overall assessment functions (such as comparison of the relative merits of proposed sites). The ERCDC appears to be charged[1] with relying on air and water quality standards developed by other agencies in its review of electric generating facilities. Although semantically a limitation on "emissions" is not necessarily an "air quality standard" or a "water quality standard," it appears likely that the emissions standards adopted by other agencies would be used by the ERCDC.

A similar comment may be made with respect to standards applicable to radioactive materials. Although the enabling legislation[1] is not as explicit with regard to radioactive emissions and exposure standards, in the absence of glaring deficiencies the ERCDC would not attempt to develop standards different than those employed by the Nuclear Regulatory Commission.

However, there are substantial areas, often related to more general "assessment" functions, for which standards do not exist, but which the ERCDC might wish to review. In the case of nuclear power plants, for example, site characteristics and land use are clearly legitimate areas of review by the ERCDC, at least as judged by AB 1575[1]. The same is true for other types of plants, although the major concerns are somewhat different. In either case, the ERCDC might judge the overall impact which a particular plant and site would have on the general public. For nuclear, where the major concern is accidental releases, this might lead to standards for emergency planning of population density control in some region surrounding the plant, as discussed in ref. 3 and 4. Standards, or even guidelines, for these considerations are far from complete. For fossil-fuel plants, where the major health impacts occur even during routine operation of the plant, and are typically spread over an air basin, standards for air quality exist, but not for actually judging the net impact of alternative sites or plant types. These matters are discussed in greater detail in section 3.2 and part 4.

3.1.2 Safety Standards

For convenience, we divide safety standards into two broad areas, those which deal with the manner in which site characteristics affect the facility (as opposed to the general public as above) and those engineering standards used in the design of the facility itself. The first category might be construed to be included in the second, but separating site characteristics is useful nonetheless.

As noted above, certain site characteristics, primarily demography, directly affect the net potential impacts of any emissions on surrounding populations. A category of comparable importance includes those site characteristics, primarily geophysical, which affect the facility directly. The geophysical characteristics which would properly be considered under "health" are those which affect the dispersion of emissions from the facility: meteorological and, to some extent, hydrological characteristics have such implications. On the other hand, the mechanical characteristics of the land on which the plant would be built directly affect the facility safety (and reliability). Hydrology could also be involved in this area. However, it is fair to say that few actual standards exist for such characteristics. They typically fall under the purview of "engineering judgment," i.e., standard engineering practice, the necessarily ill-defined category mentioned in section 2.1. The one possible exception is encountered for nuclear facilities, where such considerations are certainly within the scope of the Nuclear Regulatory Commission review. The NRC reviews seismological and flood characteristics, and NRC review standards might serve as a model for other facilities. Regardless of the present situation, such characteristics clearly fall within the interest of the ERCDC and, should it choose to exercise its authority, standards or at least working guidelines would have to be adopted.

The state of engineering standards has been dealt with more fully in section 2. Few such standards are utilized in a direct regulatory manner, except for nuclear power plants. However, a large pool of standards does exist, which could be utilized in any ERCDC review. The one area where choice does not exist is that covered by title 8 of the California Administrative

Code, Chapter 4, on industrial safety standards. These would serve as one component in any safety review performed by the ERCDC. The manner in which the ERCDC might select or develop other engineering standards is discussed in the next section.

3.2 Evaluation and Development of Standards by the ERCDC

Section 3.1 summarized the present situation with regard to standards for review of areas of interest to the ERCDC. In many areas other agencies have responsibilities for setting standards which supersede those of the ERCDC. In such areas, the ERCDC would presumably employ the standards developed by other agencies. In areas where responsibility may lie with the ERCDC or where standards have not been formulated, the ERCDC must evaluate existing standards, or formulate its own standards or guidelines, should it choose to review those areas.

As noted above, air and water quality standards are the responsibility of other agencies, and presumably this includes standards generally regarded to be in this class, such as emission standards. On the other hand certain more general considerations, such as the populations at risk for specific proposed sites, might be matters of review for the ERCDC. Since these have such a direct relationship to the question of granting land use, they could be of major interest to the ERCDC and are the major topic considered below in the brief discussion of the development of health impact standards.

Except for nuclear plants, the safety aspects of power plants are presently regulated primarily with respect to occupational safety (and health). Of the detailed engineering of the plant, two areas of review suggest themselves for ERCDC attention because of their direct relationship to the public health and to the site, respectively; these are emission control equipment and the site geophysical characteristics. They will be considered below in the general context of safety-engineering standards.

3.2.1 Development of Health Impact Standards

The overall health impact of any emission source is basically determined by the damage which may be caused by the substances emitted and by the populations exposed to these emissions. Most air and water quality standards are directed to the ambient levels of substances and the emissions which various sources contribute. However, any overall assessment of the impact of any source,

such as a power generating facility, would also consider how many people are exposed to the emissions. This notion may be more carefully specified, but it underlies the idea of "populations at risk." Presuming that a given concentration of a pollutant or a given radiation dose may cause some harm, it is better to expose a small number of people to that concentration or dose than to expose a large number. The number exposed is the population at risk for the given level or dose, and is a number that is useful in assessing the impact or relative merits of proposed site-facility combinations.

Such a notion is avoided, in a way, in the case of calculating population exposures from routine emissions from nuclear power plants, because the individual radiation doses are all small and, because a linear dose-response relationship is often used, all that is calculated is the total population exposure in "man-rem." However, for potential accidental releases from nuclear plants and for routine releases from other types (see below), explicit attention to reducing the population at risk is worthwhile. For nuclear accidents, this is possible through exercising control over local population densities or through provision for effective evacuation should an accident occur. The extent to which such measures should be implemented may be judged by comparing the benefits, in terms of reduced illness or death, with the cost of control; approaches to such analysis are based on site-specific risk assessment. On the other hand, the legislation constituting the ERCDC[1] may be understood to require population density controls based on Nuclear Regulatory Commission criteria. However, as discussed in section 1.1.5 and in reference 4, there are a number of ways to interpret this mandate to, effectively, control the population at risk.

For fossil-fuel plants, the major impacts on the public are associated with routine emissions from these plants, not with those resulting from accidents. However, as indicated in the discussion in section 1.2, not enough is presently known to assess quantitatively the impacts in terms of actual incidence of disease and death. To some extent, existing air and water quality standards serve in lieu of such an assessment, but only if an effective threshold for health effects exists. Because the validity of such an hypothesis is questionable and because, in any case, air quality standards are occasionally (or often) exceeded, some more direct indicator of actual impacts might be useful, particularly for comparing alternative sites. Populations at risk are

precisely such an indicator. That is, even though ultimate health impacts are not known, human exposures to potentially harmful pollutants can still be calculated. If such a scheme is adopted, the analyst first would have to establish exposure categories, then—on the basis of emission rates, meteorological modeling (which would be necessary in any case to determine effects on ambient air quality) and population distributions—would have to caluclate the population at risk (the number of people) for each exposure category. These numbers could serve as indicators in lieu of actual health impacts. (At such time as the data on the relationship between health effects and exposure category become more reliable, the populations at risk can be converted directly into predicted health effects.) Guidelines for comparing sites could be developed in terms of such exposure categories.

3.2.2 ERCDC selection of safety-engineering standards

To the extent that the ERCDC intends to review the actual design of proposed facilities, it must select an adequate set of safety and engineering standards. That is, for any area of design in which the ERCDC will involve itself in a regulatory capacity, it must first establish the basis on which review will be undertaken. However, the ERCDC may choose to review only certain areas, those which have the most critical bearing on the safety (or reliability) of the plants. For those areas which the ERCDC does not review, the utility (or perhaps other agencies) would have responsibility. By limiting the breadth of its review, the ERCDC could focus its attention on what it regards to be the most important areas of plant design, thereby reducing the time and staff necessary for the review. A similar consideration is the depth of the review to be performed by the ERCDC. For example, the review could—in principle—cover design of the entire plant, with full reviews reserved only for critical areas and less thorough analysis devoted to other aspects of the facility. In practice, limiting the breadth of review or varying its depth will not avoid emphasizing certain areas of design, those that are intrinsically safety related. However, a conscious choice of approach is useful, in order to determine the type of standards required and the staff necessary for the review.

It is the choice of critical areas for review that most strongly affects the standards required. Review of the engineering can be conceptually divided

in a number of different ways, but one that is most useful reflects the extent to which various aspects of the facility have the most direct bearing on the health and safety of the public or employees, i.e., review of: 1) emission controls (including any equipment or operations which have a direct effect on the emissions from the plant, primarily under conditions of normal operation), 2) plant safety (aspects of the facility which could affect the health and safety of employees or which serve to prevent emergencies at the plant), and 3) general facility design (the entire engineering of the plant). The first two are relatively narrow areas of plant design, and the third includes all aspects of design, many of which serve as the basis for emission control and safety systems. Limitation of the review to the first two areas would substantially restrict the set of standards to be selected or formulated and/or the extent of facility review, while still offering substantial review of design aspects directly pertinent to health and safety. On the other hand, certain of the areas relegated to "general facility design" might usefully be reviewed if the intent is more general, i.e., to assure plant reliability. However, many of these areas might also be construed to lie within the "plant safety" area, in which case they ought to be very narrowly defined, so that they do not greatly increase the breadth of review or, correspondingly, the standards required.

Turning now to the three categories of design just set forth, we note that the "generally applicable standards" discussed in section 2.3 include, to a large extent, the standards associated with "plant safety" and "general design". Certainly the California Administrative Code (CAC) 8.4 provides an initial basis for review of plant safety. However, it is by no means complete, if only because 8.4 is intended to cover all industrial facilities and not only power plants. For this reason, there will be areas of plant safety, peculiar to particular types of power plants, for which regulatory standards do not exist, at least in 8.4. This is clearly true in the case of nuclear power plants, where a large body of criteria, guides and standards exist, as described in section 2.3, all related to safety. However, it is unlikely that the ERCDC would soon become involved in the technical aspects of nuclear plant engineering; the questions of land use discussed above, under development of health standards, are likely to be addressed first. For other types of facilities, no regulatory agencies exist to formulate programs for design review, even of

plant safety, except as set forth in CAC 8.4. For this reason, the ERCDC could exercise independent action in selecting or formulating safety standards to cover plant safety systems not adequately addressed in 8.4. Standards could be selected from the pool of general engineering standards, of which the compilation described in section 2.3 is representative.

The same large pool of standards could serve as the basis for establishment of a general design review. As suggested above, this would be a large endeavor, considering the breadth and depth of engineering knowledge involved in the design of a power plant. It is possible that information on reliability could be used to identify areas where regulation might be useful, i.e., where reliability might be improved. The brief analysis of reference 14 on power plant reliability provides preliminary data of this kind. However, relating such data to applicable engineering standards is not an easy task. Moreover, for many important types of component or system failures, no specific standards have been formulated. Rather, design of these components or systems falls into the vague category of "standard engineering practice". Adopting a set of standards or guidelines to address even the most important causes of plant outages is truly a formidable task, since directly applicable standards do not usually exist. It should be judged in terms of the many committees set up by professional societies for precisely this purpose, committees which in toto have thousands of members and have devoted many thousands of man-years to the task of standards development. We will return to this question in the discussion below of staff requirements.

We have not yet considered standards for performance or design of emission control equipment. This is an area that the ERCDC could review considering its importance to public health and its relatively narrow scope, a combination recommending it to regulatory attention more than many other areas of design. In a sense, it is already effectively regulated, since emission standards are applicable. These, from the engineering point of view are nothing more than standards of performance. Going one step further, the design itself might be reviewed. However, design standards for such equipment do not exist and would have to be developed. Because of the well-defined nature of the problem, this might be feasible, particularly if outside professional committees were relied upon in a substantial way.

This discussion of safety-engineering standards has been directed primarily at standards for the plant itself and not as much for the site, even though this

is the foundation on which the plant must rest. However, standards for mechanical stability of the site are not generally available, although the NRC provides guidelines. This type of question rests very squarely in the area of engineering judgment. It is pertinent to some extent to the question of plant safety and more broadly to general design and reliability. Since nuclear power represents one model for a rather comprehensive treatment of engineering safety, its physical site criteria may serve as a model for examination of sites for other facilities as well, if such a comprehensive review is regarded to be necessary.

3.2.3 ERCDC staff requirements for development and use of standards

Staff requirements for development of standards depend largely on the breadth and depth of review intended. To some extent, it also depends on the precision required of the standards, i.e., whether they are to be requirements or only guidelines, and on the degreee to which the staff actually reviews the facility design or only monitors a program of quality assurance. (Presumably any individuals on the staff who develop standards or guidelines would be involved in their actual application during the review process.) Finally, staff requirements for standards development will depend on the extent to which the development occurs "in house", i.e., is performed by the staff itself, or occurs outside, utilizing contractors or committees of professional societies. It must be emphasized that the potential effort involved in either the evaluation and selection or the development of standards is very large, but that it depends very greatly on the factors just mentioned, particularly on the anticipated breadth and depth of review and on the extent to which outside societies, contractors, or agencies are involved.

This potentially huge effort is associated not so much with "health" standards as with "safety" standards. The remainder of the present discussion is directed primarily to the latter class, although similar considerations apply to health standards. As was indicated above, most areas of health standards are the responsibility of other agencies, so that most of the ERCDC's attention in this area could be directed to consideration of possible "impacts" guidelines discussed in section 3.2.1.

A useful approach to the question of staff requirements or general level of effort is to consider the three areas or levels described in section 3.2.2: 1) emission controls, 2) plant safety, and 3) general facility design. We can subsequently consider the operational questions: are the standards to be

regulatory or only recommended? During the review, does the staff actually review the design itself or only check agreement to comply, then monitor a quality assurance program designed to assure compliance?

Emission control equipment represents a very specific part of the plant, provided one takes care to exclude the underlying systems which fundamentally produce the emissions. For example, in a fossil-fuel plant, the burner system and boiler produce the various substances subject to control, but "control equipment" is normally a relatively well-defined system which serves as a primary barrier between the source of the emissions and the media, air and water, to which the public is exposed. Such control equipment is under active development, for which reason it is unlikely that directly applicable engineering standards now exist. On the other hand, performance standards do exist, if only in the form of emission standards (such as new source performance standards) formulated by agencies with responsibilities for air quality. However, standards for the performance of the equipment itself would serve as an operational basis for review of the control equipment. Going one step further, more complete standards for equipment design could be formulated, which could serve as the basis for a more fundamental review of the design of the control equipment.

Equipment performance standards would be likely to be developed on the basis of operating experience with similar equipment, so that the development of such standards would involve little effort. The individual who would ultimately be concerned with the review of this equipment could effectively suggest such standards, which could be adopted after consultation with engineers involved in the design of such equipment and with agencies having responsibilities for air quality. (Such agencies already will have guidelines for use in their review.) On the other hand, standards for the design (rather than the operation) of such equipment may only be developed on the basis of a more detailed familiarity with the engineering principles involved. Such engineering standards are appropriately developed as necessary by professional societies. The ERCDC would avoid any large commitment of effort by encouraging such societal development, if these standards are deemed necessary, and by giving a staff member responsibility for maintaining contact with (or even being a member of) the committee responsible for developing such standards. Should the ERCDC attempt to develop design standards internally or through contractors, a much larger effort (a minimum of several staff members) would be involved, and further, their acceptability to the engineering community would be left in doubt.

A question worth considering is whether the adoption of standards only as guidelines (rather than as regulations) would alter the effort required, should the ERCDC choose to act independently. The very fact that existing engineering standards serve only as guidelines under present conditions suggests that the effort devoted to standards development would be little affected by their use only as guidelines and not as regulations. However, the political effort involved in formally adopting a standard or in gaining acceptability of mandatory standards among the engineering community could be prodigious.

Plant safety standards include both regulatory industrial safety orders and other standards which are applicable to specifically safety systems in power plants. The first category requires no developmental effort. The second may involve a combination of selection (evaluation) and development, depending on which areas have seen previous developmental work. Most areas which are genuinely safety-related will already have been examined and should be represented, in fact, in the industrial safety orders. For any major system not represented there or in the pool of generally applicable engineering standards, a developmental effort similar to that discussed above for design of control equipment would be required. Moreover, similar considerations for regulatory versus guidance standards would apply.

General facility design standards represent the most difficult area to deal with, because of their breadth of coverage and because of the lack of previous detailed regulatory involvement. An effort to define a complete set of standards for facility design cannot be seriously considered without facing a developmental effort approaching that performed for nuclear power by the Nuclear Regulatory Commission. For this reason, any efforts in this area should be devoted to carefully chosen plant systems, most likely those which are most fundamental to plant safety or most important to overall reliability. More detailed information than is presented in reference 14 would be necessary in making these choices. They would have to be based on detailed examination of plant design and the relationship between the various sytems. Several difficulties with a major effort of this type suggest themselves: 1) each area treated would require an effort comparable to that indicated above for the control equipment; it is not clear that the ERCDC has sufficient personnel of the experience necessary to make judgments of this type or even to provide the necessary liaison with a standards committee of some professional society; 2) gaining acceptance

of such a program by the utilities and their contractors (including the engineering community) would be necessary and possibly difficult; 3) such regulation might have an inhibiting effect on improvements in design, with little compensating benefit to the general public.

This last consideration is ultimately the most important: would regulation of general facility design, including those aspects without direct safety significance, provide substantial benefit to the public? The question does not, however, apply to nuclear power plants, where many areas of general design are deemed to have safety significance and hence are subject to review by the NRC. For other plants, the safety benefit of detailed design review is somewhat remote. Furthermore, if the intention is to improve reliability, with its attendant economic benefit, it still remains to be seen whether regulatory involvement will succeed. The economic benefit from increased reliability would have to exceed the added cost of regulation and the increased cost of design, if not construction. If the utilities are now giving due consideration to this balance, it is unlikely that added costs would provide comparable economic benefits. The effect could actually be negative, especially considering the general inhibition it would present to design improvements and initiative on the part of the utilities. It would appear that direct health and safety benefits must remain the primary basis for regulatory involvement in design of facilities.

Regardless of the areas to be regulated, those given above being possible examples, staff requirements must be considered not only for the development of the standards which represent the regulatory framework, but also for the review process itself, the subject of section 4. However, one specific point to be considered here is the possibility that the review process might be designed so that the staff familiarity with or development of engineering standards might be minimized. For example, the ERCDC might simply require that, for designated design areas, the applicant itself supply a listing of the standards by which the facility is to be designed, accompanied by a program for assuring compliance with these standards. The staff would only then serve as a monitor for an inspection program based on a design which the staff had not reviewed. except possibly to ascertain that certain areas had been covered by standards. This would minimize both the effort devoted to standards development and the review effort itself.

It is not clear how effective such an approach would be. For certain

areas where standards are already adopted, such as the industrial safety orders, a clear basis for judging the adequacy of the applicant's proposed standards and quality assurance programs exists. However, it is precisely in these areas that little ERCDC effort would be necessary for standards development in any case. For areas where no clearly specified standards exist, there is little basis for judging the adequacy of the applicant's design and quality assurance programs; by submitting a rather complete program, the applicant would only be creating difficulties for himself. This may not be a tenable regulatory approach, unless the ERCDC has previously established an adequate basis for regulation. Such a basis would be a staff with sufficient size and competence to identify areas which need regulatory attention and to judge the adequacy of the applicant's program. Whether such a staff could be supported within ERCDC budgetary constraints is not obvious. In any case, as discussed above, such a program should not be implemented unless its cost, to the ERCDC and applicant, would be outweighed by its benefit to the public.

4. METHODOLOGIES FOR REVIEW OF PROPOSED SITES AND FACILITIES

The fundamental object of this project has been to develop possible methodologies for the review of the health and safety aspects of proposed electric generating facilities. The primary consideration has been the health and safety of the public, but the well-being of workers at these facilities has also been considered. To the extent possible, in view of the many areas of uncertainty, the methodologies set forth in this work have been based on the considerations summarized in the preceding portions of this report. The methodologies themselves are presented in outline form, with limited discussions, in a separate report.[10]

4.1 Considerations in formulating review methodologies

4.1.1 Areas of review

In examining the potential impacts of a proposed facility on human health and safety, there are a variety of ways in which such an examination may be structured conceptually. One basic distinction which may be drawn is to separate the internal engineering details of a plant from the interaction of that plant with its surroundings. This turns out to be a very practical distinction from the point of view of the utility proposing the facility and of any agencies reviewing it. The utility and the agency may make preliminary, but very important, judgements, such as facility type or site selection on the basis of generic plant types. Once these selections are made, both parties may then devote their attention, as appropriate, to the detailed engineering of the facility. There will be many matters for which this distinction is difficult to make, but — as discussed below — it serves as a practical basis for differentiating between the two stages of review performed by the ERCDC.

Even presuming this division, there are many possible ways to structure the various matters to be considered within either the site-specific review or the engineering review. There are a number of ways in which the facility interacts with its surroundings, and review of the engineering of a plant may employ many approaches.

The site-specific review may concentrate on two general areas, 1) the flow of materials (in a general sense) into and out of the plant and 2) the basically mechanical interaction of the plant itself, i.e., its buildings and various facilities, with the site. We have taken it as a fundamental view that one particular aspect of the material flow, i.e., emissions into the air, has the greatest potential for impacts on the public health and safety. However, other major impacts may occur through liquid or solid wastes, through production of noise, or through other means, including — for example — transportation of fuels or wastes and of workers to and from the plant. However, as noted, the primary concern in the class of material flows is emissions into environmental media through which the plant may affect human health.

The manner in which the plant interacts with the site per se, i.e., the mechanical interaction, may have possible implications as far as these emissions are concerned or it may simply affect the stability, and hence operability, of the plant. Possible considerations include the physical characteristics of the site, including ground stability or availability of cooling water, as well as human characteristics, such as demography and the presence of roads or other utilities. There are a number of ways in which site characteristics may directly affect emissions. In the case of geothermal plants, where the basic heat source is situated underground and where fluids may be injected back into the ground, possible interactions between site characteristics and emissions are obvious. However, for all plant types, interactions are possible; for example, earthquakes or tsunami may stress the facility so as to cause extraordinary emissions. More generally, though, these physical site characteristics are engineering considerations.

Review of the engineering of a facility may be structured in a number of ways, but it is useful to choose a structure that emphasizes the primary consideration: human health and safety. One such structure roughly divides the areas of review into: 1) emission control features, 2) occupational and plant safety features, and 3) general facility design. These three categories are certainly not distinct (after all, the last

includes the other two), but rather indicate the emphasis to be made and the depth of the engineering review. Emission control design relates directly to the most immediate consideration as far as human health and safety is concerned, the possible release of harmful materials from the plant. The second category, safety, may be considered more general in that it could include all systems which are specifically designed to assure the operation of the plant in a safe manner. However, the basis of any such operation in the general design of the facility, which would be covered by the third category.

4.1.2 Other agencies with responsibilities for health and safety review

It is clear that if the ERCDC reviews all aspects of health and safety for power plant sites and facilities, it will be reviewing areas in which other agencies have overlapping, and even exclusive, authority. The legislation constituting the ERCDC[1] makes explicit allowance for a number of other agencies with responsibilities that are exclusive; these include the national, state, and local agencies with authority to set air and water quality standards, the coastal commission, and the Nuclear Regulatory Commission. Moreover, many local agencies exercise permit authority in many areas, particularly in the raising of any structure and in land use.

It is difficult to predict *a priori* how the staff of the ERCDC, in its review process, will interact with these other agencies. Distinct ambiguities exist in the division of actual review responsibilities even in cases where the standard-setting authority is clear. For example, whereas local air pollution control districts are intended to set emission standards for new sources, including power plants, it appears that the ERCDC — in addition to the local districts — has review responsibilities. A joint review might be conducted, but the details of such collaboration, and the division of specific responsibilities, are best developed on the basis of an actual review. This approach seems preferable for all such cases of overlapping responsibilities. For this reason, we have not attempted to suggest how the ERCDC might make arrangements with other

agencies for resolving these questions. It is important to note that, after the initial steps are taken by a utility to obtain certification from the ERCDC, the ERCDC schedules informational hearings. These serve as an appropriate forum for identifying, where there is any doubt, agencies with interests which overlap those of the ERCDC. These would include Federal, as well as State, regional, and local agencies.

4.1.3 Distinction between the NOI and AFC stages of review

The ERCDC's review of proposed sites and facilities will be divided into two major processes, although technically the first is only preparatory to the second. The basic responsibility of the ERCDC is to grant "certification" for land use for proposed electric generating facilities. From this point of view, the basic application made to the ERCDC by a utility is the Application for Certification (AFC) of a proposed site and/or facility. However, it is required[1] that the AFC be based on a site which has already been judged acceptable at a preliminary review stage. This preliminary stage is initiated by submission by the applicant of a "Notice of Intention (NOI) to file an application for certification", which proposes at least three alternative sites. A positive judgement at the end of the NOI review effectively gives approval to the proposed combination of site and facility.

This division into two stages permits a practical division to be made between aspects of the proposal that are site specific and aspects that involve the actual engineering of the facility. On the basis of the site specific features, the ERCDC, at the NOI stage, makes a judgement of site acceptability for the type of facility proposed. On the basis of more detailed information, both for the site and facility, the ERCDC makes a final judgement, at the AFC stage, of whether to certify the proposed facility.

In most of this work, the distinction has been made between "health" and "safety" review, a distinction that is quite ambiguous. However, the division of review areas between the NOI and AFC stages is easier to make. Most of the "health" considerations, such as compliance with emissions standards fit into the NOI review. Moreover, the "safety" (i.e., engineering)

aspects of the facility itself - but not the questions of site suitability - would be deferred to the AFC stage. At the NOI stage, the acceptability of the site would be judged on the basis of generic information on the type of facility proposed, rather than on the detailed design. Of course, even at the AFC stage, the detail in which the design is examined is a question of great practical importance, and one whose resolution is not apparent, as has been made clear in this report.

4.1.4 Possible breadth and detail of review by the ERCDC

Section 3, in its brief treatment of how the ERCDC might select standards for review, necessarily indicated questions as to the breadth and depth of review. These questions extend to both the health and the safety areas or, by implication, to both the NOI and AFC stages of review. It might be thought that the "health" related areas, which make up much of the NOI stage, were relatively well-defined. This is not true, for two reasons. The first, noted above, is that the manner in which the ERCDC shares responsibilities with other agencies is not clear; for example, would the air pollution control district or the ERCDC use meteorological modeling to check the impact of the proposed facility on ambient air quality? The second, briefly mentioned in previous sections, is that the ERCDC may wish to exercise a more general assessment role than is required by regulatory standards. The possibility of interests of this type is made clear by hearings which the ERCDC has already been conducting, particularly for nuclear power plants. A similar interest might be appropriate for fossil-fuel plants, as suggested by the allusion in section 3.2.1 to possible health "impact" guidelines for comparing possible impacts of alternative sites. Once such guidelines are developed, it should be noted, the major effort is complete, since the review process associated with them is only a slight extension of otherwise required calculations of ambient air concentrations.[10]

The effort required for the AFC review is dependent on both the areas chosen for review and on the manner in which the review is conducted. It was suggested in section 3 that a review function may only be practical for areas where standards, either required or only suggested, have been

chosen by the ERCDC. Once such standards exist, a review may be conducted, in principle, in one of two ways. Either the staff may actually review the proposal for actual compliance, or the staff may check that the applicant has agreed to use the chosen standards and may check compliance by monitoring the applicant's inspection or quality assurance program. If the latter review mode is chosen, and the standards of interest for a particular area are only for guidance (that is, suggested), difficulties may arise when the applicant proposes a deviation, because — in such a case — the staff would have to review the proposed design in detail. This situation may not often arise, but the staff must have such a capability if the standards are not mandatory. As pointed out at the end of section 3.2.3, a similar capability may be needed if, alternatively, applicant-supplied standards are used as the basis for a QA program.

The principal areas where the ERCDC might wish to avoid detailed staff review are in the design of the facility. Acquiring the capability for review of the entire design does not seem practical. On the other hand, if narrow areas are chosen, such review would seem possible without a huge staff for engineering review. However, if the ERCDC wishes to regulate areas for which standards are not now required, it must be prepared to become involved — in one of the ways outlined in section 3.2 and discussed more systematically in 4.3.2 — in the selection of standards.

A final note should be made with regard to those areas which are not amenable to standardization. One such area is the broad range of physical site characteristics. For such areas, engineering judgment is often the only practical standard. Yet many such areas — particularly with regard to site selection — are of major interest to the ERCDC. In such cases, either the staff must have the professional capability to judge these areas or the review must rely on expert advice. For considerations such as ground stability that are directly related to facility design, the judgment of the applicant itself may be deemed acceptable, on the premise that they have a direct interest in adequacy of the design. Such concessions may not be acceptable in areas with the potential for severe impacts on the public such as in the case of nuclear power plants. However, in that case, the

engineering review performed by the Nuclear Regulatory Commission might serve as the basis for review, with modifications as might be suggested by the staff, or even by interested members of the public.

Various aspects of this question of the breadth and detail of the ERCDC review will be apparent in the rest of this section and in reference 10.

4.2 Methodologies for site-specific review: the NOI stage

At the Notice of Intention (NOI) stage, the applicant proposes alternative sites on which facilities described on a generic basis would be operated. The purpose of the NOI review is to judge the acceptability of the proposed sites for the generic facility type. Possible review methodologies are presented in some detail in a separate report on "Methodologies for Review of the Health and Safety Aspects of Proposed Nuclear, Geothermal, and Fossil-Fuel Sites and Facilities"[10].

During the NOI review, the basic focus of the proposed "health and safety" review methodologies is on emissions from the plant, which may have impacts on the surroundings of the plant, and on the interaction of the facility proposed with the site itself. As indicated below, a common methodological structure may be devised for the differing types of facilities, because the routes by which emissions may affect the public are conceptually similar for the various technologies and the connection between the facility and site involves similar considerations. For this reason, the initial stages of the review methodologies are divided according to several categories of review, applicable to each of the generating technologies, nuclear, geothermal, and fossil-fuel. These categories are:

- air emissions
- water emissions
- noise emissions
- waste disposal
- site geophysical characteristics
- site developmental characteristics.

The first three categories indicated are emissions, all of which may have human impacts. The last three categories include aspects of the site and facility which may affect these emissions or their human impacts.

The NOI methodology may be divided into three stages (see table 4-1).

Stage 1 — emissions and site characteristics, which deals with the basic parameters of the generic facility type proposed and of the proposed sites;

Stage 2 — basic impact analysis, which treats the impacts of the facility on the site surroundings, as can be calculated on the basis of the parameter emissions and site characteristics determined in the first stage;

Stage 3 — assessment of human impacts, which examines, to the extent possible, the effects on human health and safety of a plant with characteristics and impacts as determined in the first two stages.

The emission-dispersion-exposure causal chain serves as the archetype, and indeed the reason for, the three stage structure outlined above. However, this structure is also more generally useful since it amounts to 1) a preliminary review of the proposed sites and facilities based solely on

Table 4-1 NOI Review Methodologies

Stage 1 — Emissions and site characteristics	
1.1	Air emissions
1.2	Water emissions
1.3	Noise emissions
1.4	Waste disposal
1.5	Site geophysical characteristics
1.6	Site developmental characteristics
Stage 2 — Basic impact analysis	
2.1	Air emissions
2.2	Water emissions
2.3	Noise emissions
2.4	Waste disposal
2.5	Site geophysical characteristics
2.6	Site developmental characteristics
Stage 3 — Assessment of human impacts	
3.1	Introduction and general considerations
3.2	Fossil-Fuel plants
3.3	Geothermal plants
3.4	Nuclear plants

their principal characteristics, 2) an analysis of the effects of the proposed facilities on environmental media which may affect the public, and 3) a judgment of suitability based on conformance with specific criteria and on the overall impact of the facilities on the public health and safety.

At each of the stages, for any of the categories of review mentioned above, it may be necessary to consider several operational modes:

- normal operation, including startup and shutdown of the facility
- abnormal operation, such as use of the facility with a fuel for which it was not designed
- emergencies, including either plant emergencies, such as explosion or meltdown, and external emergencies, such as air pollution episodes.

For any facility type, several portions of the facility may have to be considered, including:

- basic generation facility, including, for example, the boiler and turbogenerator
- fuel storage facilities
- waste disposal facilities
- transmission lines
- transportation facilities, for both supply and disposal.

Finally, the basic plant types considered are:

- nuclear, utilizing both pressurized-water and boiling-water reactors
- geothermal, using both vapor and liquid dominated resources
- fossil-fuel, using coal, oil, or gas.

The three stages of review are elaborated slightly below. Although it will not be apparent here, wherever possible an attempt was made to divide sections into: methodological approach, generally applicable considerations, and technology-specific considerations. With regard to methodological approach, in most cases it will be appropriate for the ERCDC staff to perform the necessary analysis, sometimes in conjunction with other agencies; but in other cases the staff may have to rely directly on expert advice, perhaps even from the applicant, and on experience with similar facilities. Reference 10 treats the matters discussed here in much greater

detail, although — as will be clear from an examination of the methodologies contained therein — a full development will only occur as the ERCDC staff proceeds through the various stages during an actual review. Finally, the structure given below would serve equally well for a more general environmental impact review, although that is not its primary purpose.

4.2.1 Emissions and site characteristics

The first stage of review effectively performs preliminary analysis of the proposed sites and facilities, including emissions from the generic facility and basic characteristics of the site. The air emissions characteristics would be reviewed in a manner consistent with the new source review required in any case by the local Air Pollution Control Districts for each of the alternative sites. An up-to-date tabulation of air quality standards was prepared in the course of this work; however, the rapidity with which the standards are changing, particularly at the local level, makes it clear that all such standards would have to be checked for accuracy at the time of the health and safety review. This should present little difficulty, considering the fact that the review would have to be coordinated with the local districts in any case. This is equally true of water quality standards and noise standards, although they have been given less explicit attention in this work because of the lesser impact which these emissions from power plants have on the public health, as compared with air emissions.

Characteristics of the site are also examined at this stage of the review. The intention is to assure compliance with any directly applicable standards and, in addition, to collect information that may be needed at later stages of the health and safety review. Aside from general site suitability requirements, such as mechanical stability (for which expert opinion might be required), other requirements such as directly applicable population density criteria (for nuclear plants) could be applied.

In general, this stage identifies the fundamental parameters of the proposed site-facility and compares them with applicable standards and guidelines, without any detailed analysis. As such, this stage would amount to a preliminary assessment of the general character of the facility and of its straightforward compliance with regulatory requirements:

- air emission — compares amounts of gases, particulates, and radioactive material to be emitted with the applicable emissions standards.
- water emissions — compares amounts of chemical, radioactive, and thermal effluents with the applicable effluent standards
- noise emissions — compares expected off-site noise levels with applicable community standards
- waste disposal — determines stability of any on-site disposal of solid wastes
- site geophysical characteristics — determines the suitability of the mechanical and hydrological characteristics of the proposed site
- site developmental characterisitcs — examines population distribution around the site, and availability of land, transportation, and other utilities.

4.2.2 Basic impact analysis

The information developed at stage 1 not only serves as the input to any preliminary screening criteria, but also provides the information needed for analysis of the actual impact of the proposed plant on environmental media and, in addition, on the site itself. A model for the analysis to be performed at this stage is calculation of the alteration of ambient concentrations of pollutants with applicable standards; indeed, such a calculation may be performed for any pollutant thought to have health significance, since this would serve as the input data for the "health impact" assessment of stage 3, an analysis which does not depend directly on the existing air quality standards.

The range of meteorological models which might be employed in this analysis is discussed in reference 6. The choice depends both on the site type, i.e., the regional characteristics, and on the detail and depth of analysis desired, as well as the resources and data available. It is clear that, for the comparison with applicable air quality standards that would take place at this stage, the ultimate choice must lie largely with

other agencies (the local APCD and, perhaps, the ARB) who have responsibility for the new source review. On the other hand, if the ERCDC chooses to perform an assessment function at stage 3, the analysis would have to be compatible with those requirements.

Such detailed analysis is unlikely for water emissions, if only because the ERCDC review process is not likely to require a detailed dispersion analysis; a power plant is unlikely to have as severe impacts on water as on air. This may not, however, be true of fossil-fuel or geothermal plants with on-site waste disposal, which may have a serious potential for contaminating ground water. For considerations of this type, which ordinarily do not pose the major impact from such plants, the ERCDC would not be inclined to perform detailed independent analyses; reliance on other entities, whether agencies with primary responsibilities for water quality or simply experts in the field, is a likely result.

A final example of the impact analysis performed at this stage would be comparison, for nuclear plants, of surrounding population distributions with any criteria which depend on an analysis that is site specific; such criteria may, for example, depend on local dispersion characteristics.

In general, the basic distinction to be made between stages 1 and 2 is that the first is restricted, effectively, to an examination of the specifications of the sites and facility, whereas the second uses this information for detailed analysis of impacts on air, water, and land.

- air emissions — analyzes the impact of the plant on regional air quality in view of applicable air quality standards.
- water emissions — analyzes the impact of water effluents on water resources in view of applicable receiving water standards.
- noise emissions — analysis essentially complete at stage 1, although that analysis could equally well have been performed here
- waste disposal — analysis essentially complete at stage 1, except that impacts of waste transport (such as radioactive) must be treated

- site geophysical characteristics — analyzes the interactive effects, primarily mechanical, between the site and facility (for example, geothermal-induced seismicity)
- site developmental characteristics — determines adequacy of measures for protecting populations from adverse effects.

4.2.3 Assessment of human impacts

The impact analysis of stage 2 is basically directed to environmental media with which humans have contact. The analysis at stage 3 would take the final step, employing demographic information on the alternative sites, to assess or at least indicate the absolute or relative human impacts. For nuclear power plants, such a comparison is trivial, once the dispersion calculation of stage 2 has been carried out, because doses may be calculated using conversion tables and health effects may be conservatively estimated by a linear dose-response function. However, since it is not the routine nuclear effluents that are of the greatest concern, the analysis for nuclear power plants would have to emphasize the potential for accidents. This would presume the availability of models for site-specific accident analysis, models that could be developed relatively easily based on the techniques employed by the NRC in its Reactor Safety Study, but which do not now exist. Such analytical techniques could also provide a more realistic method than presently exists for determining the adequacy of proposed population density controls.

For fossil-fuel and geothermal facilities, the assessment of health effects would have to depend on establishment of exposure categories which, considering the ill-defined character of dose-response relationships for conventional pollutants, would have to serve in the stead of such relationships. In such an approach, the populations at risk could be calculated, again using the data developed in stage 2, to serve as an indicator for comparison of alternative sites.

There is a substantial question whether the ERCDC would choose to perform overall assessment functions of this type, but it now appears inclined to do so. The third stage would include any judgments which have

to be made, such as between alternative sites, or between costs and benefits, including specific benefits which may be associated with use of a particular technology. These judgments would have to be based on standards and guidelines yet to be developed. Moreover, the major considerations — as noted above — are extremely technology specific:

- nuclear plants — the primary assessment question is the potential for harm from accidents to surrounding populations; requires site-specific analysis
- geothermal plants — different in detail, but has similar assessment difficulties as for fossil-fuel, although the air emissions may not have as severe an overall impact; however, potential geophysical interactions have to be considered more seriously
- fossil-fuel plants — attempts to establish a framework, using exposure categories, for assessing health impacts; potential for accidents is a lesser, albeit important, consideration.

4.3 Methodologies for review of facility engineering: the AFC stage

The purpose of the AFC stage is to review in detail a proposed facility to be constructed on a site that was previously accepted at the NOI stage. A successful application results in certification by the ERCDC. Whereas the NOI stage is a site-specific process, emphasizing what is called "health" areas in this work, the AFC stage makes a final determination on these matters and, in addition, treats the facility design, largely for areas that have been referred to as "safety" in this work. Possible AFC review methodologies are presented in reference 10, although not in as much detail as for the NOI review. A brief outline of AFC methodologies is given in table 4-2.

Because of the possible scope of the AFC review, even including the entire plant design, the ERCDC must define carefully the subjects for review. The first stage would presumably be a review of the NOI treatment to determine any changes. However, the remainder of the AFC review could be devoted to the actual facility design. In the previous discussion (sections 3.2.2 and 3.2.3), a tentative division of this area into three stages has been suggested, largely because such a division appears to rank the importance

Table 4-2 AFC Review Methodologies

Stage 1 — Review of NOI treatment: site-specific impacts

- 1.1 Emissions and site characteristics
- 1.2 Basic impact analysis
- 1.3 Assessment of public impacts

Stage 2 — Emission control equipment

- 2.1 Performance characteristics
- 2.2 Monitoring performance
- 2.3 Design and quality assurance

Stage 3 — Safety design

- 3.1 Occupational safety and health
- 3.2 Operational safety systems

Stage 4 — General facility design

- 4.1 Purposes of reviewing the general facility design
- 4.2 General approaches to an engineering design review
- 4.3 Safety-related design areas

Stage 5 — Overall assessment of site and facility acceptability

of these areas according to their potential impacts on the public. Stage 2, on emission control equipment, would develop naturally out of the considerations of stage 1 (and of the NOI); stage 3 would focus on occupational safety and on those aspects of plant operation which could have significant impacts on the public; stage 4 could examine broader areas of plant design. Effectively, then, stages 1 through 4 represent an orderly development, and the ERCDC could draw the line where it wishes, simply by stopping at some point in the sequence. Finally, stage 5 could make an overall assessment of the health and safety impacts of the site and facility.

The possible content of these five stages is developed somewhat further here and in reference 10. However, the development is far from complete, as will be made clear below and in section 4.3.2 (on implementation of engineering design review), because the ERCDC must make fundamental choices on what design areas to review, on how the review should be carried out, and ultimately on the size of staff which can be devoted to this review.

4.3.1 The AFC review process

Stage 1 - Review of the NOI treatment: site-specific impacts

The purpose of this stage is to determine whether the validity of the NOI review may have been affected by any changes in the data or regulations. Basically, three possible areas of change need to be considered: applicable standards or criteria, the characteristics of the site itself, and the generic characteristics of the proposed facility. In principle, any changes in applicable review methodologies may be regarded to be included in the first of these areas.

Any substantial alterations in these areas could call into question the validity of the entire NOI review. Lesser, but still significant, changes could be handled at this stage of the AFC review process. With regard to any of the areas mentioned, it is probable that new information has developed since the NOI stage; it will obviously be true in regard to the facility itself. It is clear that some judgment will have to be used to determine the significance of these changes and how they should be handled in the review process.

The details given in reference 10 follow carefully the structure which had previously been given for the NOI stage. As a result, the AFC stage 1 is divided into three areas:

- emissions and site characteristics
- basic impact analysis
- assessment of human impacts.

The discussion of section 4.2 indicates the matters that will have to be reviewed during this stage.

Stage 2 - Emission control equipment

The NOI review, and also the AFC stage 1, were predicated on the ability of the proposed facilities to meet applicable emission standards. In examining the actual design of the facility, perhaps the first area to be considered, then, is the emission control equipment, which is appropriate since this equipment plays a large role in mitigating potential impacts of power plant emissions on the public. This examination would extend to equipment for controlling emissions into both air and water, including even noise.

Review of this equipment may be divided into two possible levels.

- performance characteristics and monitoring
- design characeristics.

Of most immediate importance, from the point of view of public impacts, is the performance characteristics of the control equipment and the associated monitoring program for verifying performance. The actual design, as distinguished from the overall performance, of the equipment may be reviewed within the frame work discussed in section 4.3.2, on implementation of engineering design review.

For conventional power plants, detailed attention is not ordinarily given to review of the performance and design of the control equipment. However, a perception of the equipment performance is implicit in any new source review. Therefore, there is little difficulty in establishing performance review as a part of the facility design review. The details of the emission monitoring program would also be reviewed.

For nuclear power plants, these systems are presently subjected to detailed review, both at the level of performance and monitoring and at the level of design (even to the materials used in construction). As a result, a fairly complete set of criteria exist for review of equipment for control of routine emissions. (This is also true for control of releases in accident situations, but this is more properly a subject of review in connection with safety systems at stage 3.)

Stage 3 — Safety design

Stage 3 would determine the compliance of the plant design with applicable safety criteria. This includes two generic areas:

- occupational safety and health
- operational safety systems.

For occupational safety and health, the applicable criteria are either the Occupational Safety and Health Administration (OSHA) specifications, for any type of plant, or the NRC regulations, 10 CFR 20 and 10 CFR 50, for nuclear power plants. In principle, the ERCDC may simply require agreement from the plant operator to comply with the regulations, depending on inspection (even of other agencies) to verify compliance, or may actually review the detailed design for compliance; the latter would entail a substantial staff commitment.

The operational safety systems are of great importance in nuclear power plants. Accordingly, the Nuclear Regulatory Commission examines such systems on the basis of legislative criteria, regulatory guidelines, and industry standards during its construction permit and operating license review processes. The criteria just mentioned provide a substantive basis for review of these systems by the ERCDC, should it choose to become involved; one mode of involvement could be a coordinated review process with the NRC. A summary of the NRC safety review is given in reference 10, pointing out areas of specific interest to the ERCDC.

For fossil-fuel and geothermal plants, system safety specifications are directed more toward protection of workers and the plant itself than toward the general public. For this reason, the California OSHA standards serve as a basic set of criteria for such systems, perhaps useful to any ERCDC review. These standards include specifications for boiler and

pressure vessel safety, fire and electrical safety, petroleum safety, and other areas. As above, the ERCDC may simply require agreement to comply or may actually review the plant design in accordance with these criteria. In addition, the ERCDC may identify other important - or perhaps simply more specific — areas for review. Such review may be implemented as discussed in section 4.3.2.

Stage 4 — General facility design

Review of the facility design may proceed one step further. Stage 1, 2, and 3 above treated the areas of direct relevance to health and safety, i.e., emission control, occupational safety, and operational safety systems. Stage 4 could, if desired, examine the suitability of the plant design on the basis of more general criteria, including

- the broad safety implications of systems which are not specifically designed to the occupational and operational safety criteria of Stage 3
- the extent to which the general facility design promotes reliability and/or efficiency
- cost considerations.

Although not all of these criteria are concerns of a health and safety review, certain plant systems — not specifically regarded to be "safety" systems — might be construed to have safety implications. Strictly speaking, any such systems could be treated at stage 3. In any case, for any systems for which there are no applicable regulatory standards, the ERCDC would have to formulate a basis for review. The several possibilities including 1) that a cursory review by performed to verify that the overall design includes important features, 2) that a substantive review take place based on applicant-supplied standards and quality assurance programs, or 3) that the ERCDC staff undertake a detailed design review based on its own criteria, are discussed in section 4.3.2.

Stage 5 — Overall assessment of site and facility acceptability

Having completed the detailed reviews of stages 1 through 4, the AFC review may be completed by assembling the important results of those reviews for a final overall judgment of site suitability from the point of

view of potential health and safety impacts. This requires attention to the extent to which specific health and safety related criteria are met, as well as assessment of the overall health and safety impacts from both routine operation and plant accidents, and attention to specific benefits related to particular technologies. Since overall site and facility acceptability cannot be judged solely from the health and safety point of view, assembling and summarizing this information can only serve as input to the overall judgmental process, in which alternatives may be considered and costs must be weighed as compared with benefits. The manner in which compliance with health and safety criteria and overall health and safety impacts are to be considered in this process can only be determined by decision of the ERCDC.

4.3.2 Implementation of engineering design review

The effort needed to establish an engineering design review depends on the design area of interest. Possible areas of interest have been discussed in the earlier portions of this report, including section 4.3.1. However, two generic situations may be identified: those where regulatory standards or criteria have been specified by other agencies and those where previous specification has not taken place or where it is judged inadequate. In the latter cases, a basis for review must be established, after which the review process may be similar for cases where applicable standards have already been determined.

For areas where determination of standards has already been made, either by the ERCDC or by other agencies, the ERCDC may use these standards in several possible ways, which are listed in the order of their commitment of ERCDC staff effort:

1. The staff may simply determine that the applicant has agreed to comply with the required standards on the basis of a simple checklist. The ERCDC may also, sometimes in conjunction with other agencies, institute a program of inspection and monitoring to verify that the facility, as actually built and operated, complies with these standards. As an example, for applicable OSHA standards, the applicant would normally specify compliance, in any case, and the ERCDC may participate or initiate corresponding inspection of facilities for compliance.

2. For certain areas, in addition to agreeing to comply with applicable standards, the applicant may be required to submit a corresponding quality assurance program, specifying a management structure and inspection procedure. In this case, the ERCDC would presumably monitor the results of the QA program. It should be noted that to some extent the applicant will have, for its own purposes, instituted inspection programs in important areas. Whether formal QA programs should be implemented for these or other areas must be determined from a comparison of the additional costs and the increased benefits.

3. On the basis of the standards for specific areas, the ERCDC staff may actually review these areas of design. This would require a corresponding and large staff commitment and, again, the costs and benefits have to be compared. This approach would, of course, include the first approach noted above, but it may or may not include a quality assurance program (i.e., the second approach just cited).

For areas where standards have not been specified, but for which the ERCDC considers them necessary, the ERCDC may either encourage other agencies to formulate such standards, which may then be used in the context discussed above, or it may undertake one of the following approaches:

1. For certain areas, the review may only be cursory. It is to be expected that the ERCDC would, in any case, broadly examine the features of the proposed facility, if only to familiarize itself with the overall design. However, such oversight may also be applied to verify that the design includes features which have been determined to be necessary for protection of the public or for occupational health and safety. Such oversight would also serve to prevent obvious, but unaccountably unnoticed, flaws in the design. Depending on the particular area, the ERCDC may limit its review to such oversight (perhaps including attention of the applicant's inspection program), or this may only be a prelude to the determination of standards considered in the following approaches.

2. For areas where the ERCDC considers greater regulatory involvement appropriate, the applicant may be required to submit the standards

which were used in preparation of the submitted design. Depending on the area, the ERCDC may then adopt one of the three approaches discussed above for areas where standards have been specified; i.e., a simple monitoring or inspection program may be established, a formal quality assurance program may be required and monitored, or the ERCDC may undertake a design review based on these standards.

3. Alternatively, the ERCDC may institute programs in certain areas to actually develop the necessary standards. How this could be done was discussed, for a number of areas, in section 3.2.3. As was noted there, standards for the design (rather than only the performance) of equipment are appropriately developed by specialized professional societies. The ERCDC would minimize its effort, in areas where standards needed development, by encouraging such societal development. Should the ERCDC independently attempt to develop design standards internally or through contractors, a much larger effort would be involved and their acceptability to the engineering community would not be automatic.

An associated question which was considered in section 3.2.3 was whether formulating recommended guidelines rather than required standards would minimize the effort required. However, engineering standards are in any case developed on the presumption that they are voluntary, and the effort required for their formulation is still very substantial.

Once standards are developed, they may be employed in any of the three review procedures considered earlier in this section. The choice of review procedure and of a method for determining standards will depend on the particular area being considered. The approach chosen may clearly vary from one area to another. In each case, the decision will be based on the needs of the particular area and on consideration of the comparative costs and benefits of alternative approaches.

It is beyond the scope of this work to determine the adequacy of existing standards. In section 2, we have considered whether engineering standards exist for a number of important areas. In section 3.2.2, we have given general criteria for determining the important areas, based on the extent to which design deficiencies may affect the health and safety of

the public or workers. These considerations led to the structure of the AFC methodologies outlined in section 4.2.2. In section 3.2.3, various approaches which the ERCDC might take to developing standards in these areas were discussed. A final determination in these matters must depend on their consideration by the ERCDC in conjunction with a broader community, including both the public and the utilities. Ultimately, the choices will have to balance the cost of implementation to the utilities and to the ERCDC, the increased protection afforded members of the society, and the benefits accruing to the public from the individual technologies.

It is useful to point out, too, that this final determination need not occur at once. The alternatives listed above for selection of standards or for review procedures represent, in each case, a logical progression which may occur in various areas as the review process is more fully developed. At any given moment, the best available course should be taken, with due consideration to the needs of the public. The fact that a complete review methodology is not available (and never will be) should not, of itself, bring a halt to the review and construction of power plants.

4.4 What needs to be done

In the course of this work, and to some extent in section 4 and in earlier portions of this report, a number of areas where further work is needed have been identified. ERCDC efforts in some of these areas would be appropriate and fruitful. On the whole, though, a very substantial basis exists for the present health and safety related review functions of the ERCDC. However, it is useful to summarize areas for further work, emphasizing those which require most immediate attention.

We have identified two broad areas in which the review methodologies described above are incomplete. One has to do with possible assessment functions which the ERCDC might choose to perform with respect to health impacts. The second concerns the extent of review of facility design. In addition, a number of specific matters associated with individual technologies have large uncertainties.

Health impacts assessment would extend beyond the specification of standards for environmental media to the ultimate impacts which emissions have on humans. The uncertainties attendant upon such assessment pertain both to the manner in which the ERCDC would coordinate its efforts with other agencies and to possible standards or guidelines which could be used for impact assessment. For fossil-fuel and geothermal plants, the basic requirement is a method for assessing health impacts, or at least their relative size, with appropriate indicators. This resolves itself into the need to establish exposure categories for which the populations at risk could be estimated for proposed sites and facilities. For nuclear plants, such assessment tools are generally available. What is needed instead, in view of the fact that the potential impact on the public arises largely from the possibility of accidents, is a method for reviewing the adequacy of local emergency planning and density controls. This would require adoption of basic planning and control techniques, possibly supported by analytical tools for site-specific accident analysis.

Facility design review cannot proceed without an identification of areas to be reviewed, a determination of the depth of review, and a selection (or development) of standards for review. These choices will have a major impact on the effort required for completion of the design review methodology and for performance of the review function. From the point of view of public and occupational health and safety impacts, the design areas of primary importance are the systems for emission control and for occupational and operational safety.

Somewhat more clearly defined areas than the above, but ones which require substantial attention in support of the site-specific review, are the required capabilities for dispersion analysis and for analysis of the geophysical site characteristics. It is important that staff members of sufficient expertise in these areas devote their efforts both to elucidation of the review methodology and to performance of the review itself. Otherwise, the ERCDC will have to depend on outside entities for these functions. Dispersion analysis is highly important for both routine conventional releases and for accidental nuclear releases and needs to be developed to fulfill the specific needs of the ERCDC. Geophysical

site characteristics are important to the general design of any structure, but have particular importance for geothermal power plants, where the potential for seismic and subsidence effects is ill defined, and for nuclear plants, where the seismic potential for proposed sites needs to be carefully determined because of the potential impacts on reactor safety.

Furthermore, this work has devoted little attention to certain rather broad auxiliary aspects of power plants, including transmission lines and transportation. Both of these areas can have important impacts, although they differ considerably in nature. Transmission lines represent substantial land use problems as their primary impact. Aside from a vaguely determined possibility of health effects, their major health and safety impact may arise from associated accidents, such as line breakage; however, this depends directly on routing, which is directly controlled by land use commitments.

Transportation of fuel and wastes (including spent nuclear fuel) can have impacts from both routine operations and accidents. The former can be handled within the context of the review methodologies discussed in this report, but the potential impacts of accidents may be larger, and must be determined on the basis of further analysis. Accordingly, transportation impacts may be regarded as an area for further study, in addition to others emphasized in this work. As to actual waste disposal, potential impacts of sludge from sulfur control (and also ash, if a coal-fired plant) from fossil-fuel plants need to be considered and controlled carefully; wastes from geothermal plants need similarly careful disposal, and nuclear wastes are beyond the scope of our consideration (if only because it would never occur at the site).

Additional important considerations, especially the adequacy of air quality standards for conventional pollutants and the continuing work on specifically reactor safety, are the responsibility of other agencies. However, they are listed in the following summary because the ERCDC may still exercise some influence in these matters.

We summarize briefly a number of important areas where possible impacts are largely uncertain or where analytical capabilities require substantial work. This list should not be construed to be a ranking of

potential impacts or a recommendation that the ERCDC weigh various impacts in any particular manner. Rather it specifies areas where improvements in information or analytical capabilities would be appropriate.

The following areas recommend themselves to ERCDC attention for all of the technologies considered here, nuclear, geothermal, and fossil-fuel:

- the implementation of substantial in-house or external capabilities for dispersion analysis suited to ERCDC needs
- the implementation of substantial in-house or external capabilities for analysis of site characteristics related to seismicity or subsidence
- further analysis for the potential impacts of transportation of fuels and wastes.

For nuclear plants, the following specific areas should be considered:

- the details of implementing local emergency planning and population density controls
- the implementation of capabilities for performing site-specific accident analysis, both in connection with the above planning and for more general purposes of impact analysis.

In addition, the ERCDC should give its continuing attention to the general questions of reactor safety, as exemplified by the ACRS generic items relating to light-water reactors, and to the methods for assessing risks from nuclear accidents. The same is true of radiological health standards, where, however, substantial changes in the standards are not generally foreseen. However, it is not to be expected that the ERCDC can make substantial independent advances in these areas, except for the application of existing analytical techniques to site-specific analysis.

The following specific areas should be considered for fossil-fuel and geothermal plants:

- the possibility of developing exposure categories as a surrogate for actual health effects calculations in the assessment of health impacts from plant emissions
- the development of performance standards, and associated monitoring provisions, for emission control equipment
- the satisfactory disposal of solid wastes.

In addition, the ERCDC should give its attention to the development of more specific and complete air quality standards; of particular importance is more detailed specification of particulate standards.

Although we are able to list these areas for ERCDC attention, there are considerable uncertainties as to how or to what extent that ERCDC should proceed in these areas. The most basic questions are those suggested above; i.e., to what extent the ERCDC will become involved in overall assessment of health impacts and in the review of detailed facility design. The ultimate form of any health and safety review methodology will depend on decisions in these areas.

This form will also depend on its relationship to other areas of review than health and safety. Of particular importance is the relationship of the health and safety review to the general environmental review and to the review of the proposed plant for efficiency and availability. These areas have not been included in our work. However, the NOI structure may be extended naturally to include more general assessment of environmental impacts; and the AFC structure may be extended to consider design matters related to efficiency and availability. A decision on these questions is needed.

The health and safety review is related to other areas in a more general way that is also more difficult to analyze. This review may explicitly consider the costs and benefits associated with specific measures to protect the public and worker health and safety. However, a final decision on any proposal must treat the health and safety implications as only one, albeit important, consideration in the cost-benefit balance. As a result, any health and safety assessment must be considered in this more general context.

Finally, it is important to emphasize that the ultimate details of health and safety review methodologies will be developed over a substantial period of time. Thus, even if the ERCDC chooses to act in certain of the areas listed above, it is not to be expected that these areas could be fully treated in reviews performed in the near future. Not only will many

details be worked out during the course of actual review performance, but most of the above areas would require specific and important decisions on the part of the ERCDC and would require a good deal of work for their implementation. On the other hand, a substantial and largely satisfactory basis exists, for near-term reviews, in the form of existing standards and regulations and existing analytical methods. Although they may be further developed, these standards and techniques can serve as an interim basis for current review of the health and safety impacts of proposed sites and facilities.

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