SOME GEOGRAPHICAL CONSIDERATIONS OF SITING NUCLEAR POWER REACTORS ALONG THE CALIFORNIA COAST

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Rapid change has traditionally been one of the dominant characteristics of the geography of California. Population increase and technological innovation have prompted constant reassessment of man's relationship to his environment in an almost fluid geographical context. Unprecedented population growth has engendered major societal shifts and migrations, and caused profound environmental change. One of the acknowledged necessities of the urban-industrial society that has become the landscape dominant in California is electricity, and the insatiable demand for it doubles every nine years.[1] By 1990, power demands will be four times the present level.[2]

The demand for electricity is high not only because of rapid population increase, but because of the wider use of electricity on a per-capita basis.[3] In short, electricity is one of several technological innovations affected by man as a culture builder, and with it may be assigned many benefits. However, most, if not all, technology carries with it some costs which are absorbed by the environment. Given conventional means of electrical generation, the environmental costs take two forms: (1) the consumption of non-renewable fossil fuels (coal, fuel oil, or natural gas), and (2) the release of oxides of sulfur and nitrogen and partially burned fuel as waste products into the atmosphere. In a real sense, exhibited here is a self-defeating, resource-consuming, environmental-polluting system that with the probability of certainty will increase environmental costs as population continues to increase.[4]

To meet the present and future demand for electricity in California, the major private and public power companies, in conjunction with the State of California, are now committed to a program of increased use of nuclear energy as a basis for electrical power generation.[5] Nuclearization of the power industry will provide a source of electricity independent of fossil fuel consumption, and one that can reduce visible amounts of atmospheric pollution.[6] As uranium supplies diminish, emphasis will likely be placed on sodium-cooled, fast-breeder reactors that, under normal operation, have the capacity to generate as much uranium fuel as is consumed, and thus assure abundant future supplies of electricity.[7]

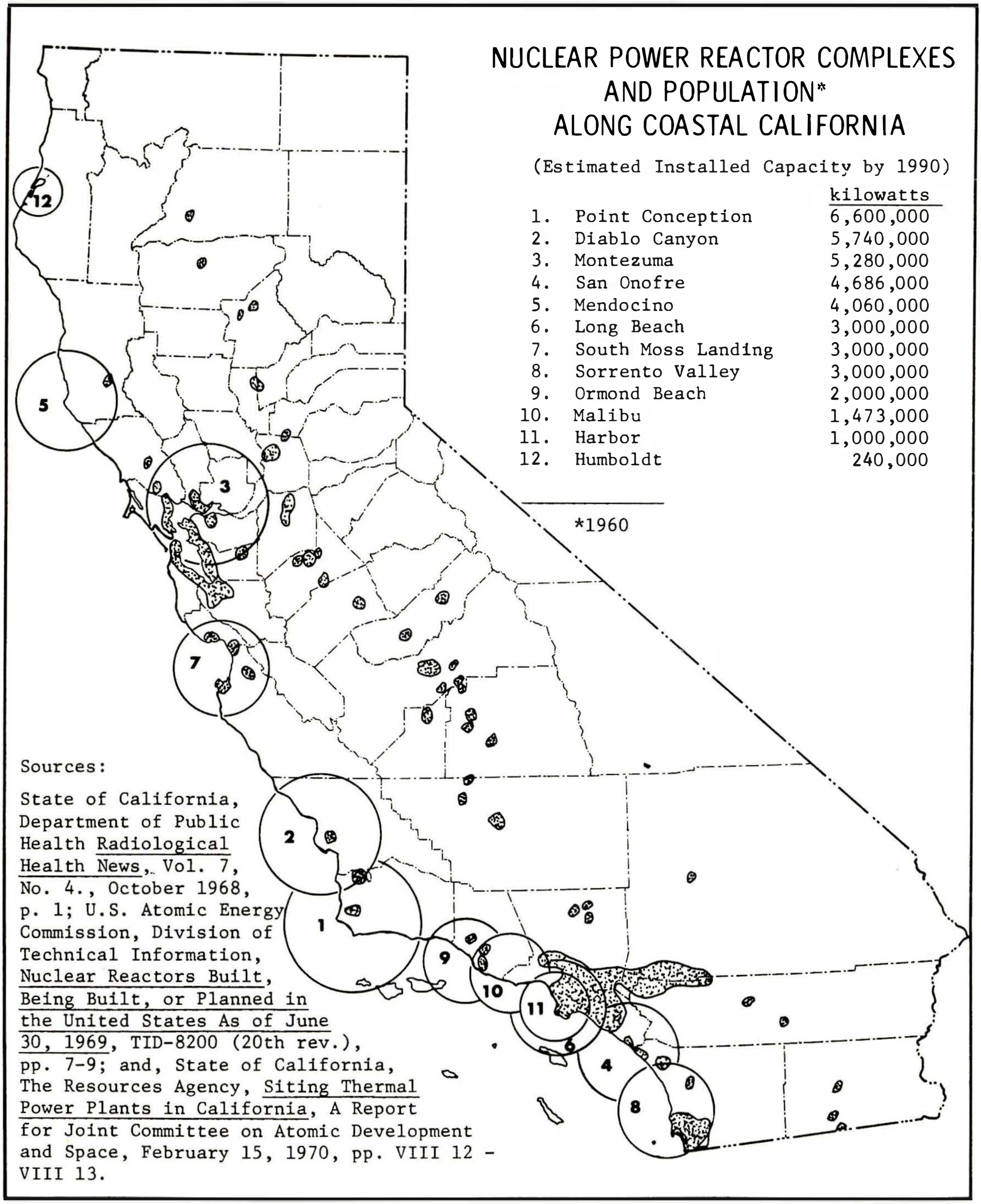
BENEFITS AND COSTS OF NUCLEAR POWER REACTORS

Benefits

The benefits of nuclearization are believed to be numerous, although pronounced differences of opinion and facts are revealed by proponents and opponents of the technology. The cost of electricity derived from use of nuclear energy is believed to be quite low. Some disagree, however, and indicate that nuclearization does not and is not expected to compete with conventional means of power generation. In fact, several utility companies have been forced to raise power rates because of their nuclearization programs.[8] Moreover, the costs of nuclearization would be greater if the disposal of spent reactor waste fuel was not assumed by the federal government.[9]

A second benefit of nuclearization, affecting society indirectly, is its non-consumption of mineral fuels. Coal, petroleum, and especially natural gas are in decidedly short supply when viewed in the context of rapid population increase and proportionate increase in electricity consumption.

Nuclear power plants are believed to be producers of relatively "clean" electricity when viewed in contrast with coal- or petroleum-fueled power plants which emit various combinations of oxides of nitrogen and sulfur and hydrocarbons into the atmosphere. This advantage over non-nuclear power plants may be one of the more persuasive points in defense of nuclearization.


NUCLEAR POWER REACTOR COMPLEXES
AND POPULATION*
ALONG COASTAL CALIFORNIA
(Estimated Installed Capacity by 1990)
kilowatts
1. Point Conception 6,600,000
2. Diablo Canyon 5,740,000
3. Montezuma 5,280,000
4. San Onofre 4,686,000
5. Mendocino 4,060,000
6. Long Beach 3,000,000
7. South Moss Landing 3,000,000
8. Sorrento Valley 3,000,000
9. Ormond Beach 2,000,000
10. Malibu 1,473,000
11. Harbor 1,000,000
12. Humboldt 240,000
*1960
Sources:
State of California, Department of Public Health Radiological Health News, Vol. 7, No. 4., October 1968, p. 1; U.S. Atomic Energy Commission, Division of Technical Information, Nuclear Reactors Built, Being Built, or Planned in the United States As of June 30, 1969, TID-8200 (20th rev.), pp. 7-9; and, State of California, The Resources Agency, Siting Thermal Power Plants in California, A Report for Joint Committee on Atomic Development and Space, February 15, 1970, pp. VIII 12 - VIII 13.
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Map 1

Costs

Cost factors are both obvious and obscure. Production costs are common to both nuclear and non-nuclear plant alike. The nuclear reactor program is developmental[10] and not operational, meaning that the practical economical value of nuclearization cannot be demonstrated. In such a context, the assessment of cost factors in comparison with conventional power plants is difficult. Personnel costs may be a second important factor. The relatively high level of technological sophistication associated with the reactor program may require a higher-salaried technical work force than would be required of non-nuclear plants. In any case, obvious personnel cost factors, plus waste fuel disposal and aggregate liability costs assumed by the federal government, are directly or indirectly passed on to the consumer and taxpayer.[11]

Less obvious costs are passed on to the environment. Unfortunately, these are not only poorly documented but, where documented, are poorly understood as they affect the ecosystem.[12] In the single-minded attempt to meet societal demands for electricity, the benefits of nuclearization qualitatively and quantitatively tend to overshadow the costs of the technology. Moreover, population pressures force the system to compress time in accord with present and prospective electricity demand, which does not allow sufficient means to objectively assess or carefully test the effects of this developmental technology on the environment.[13]

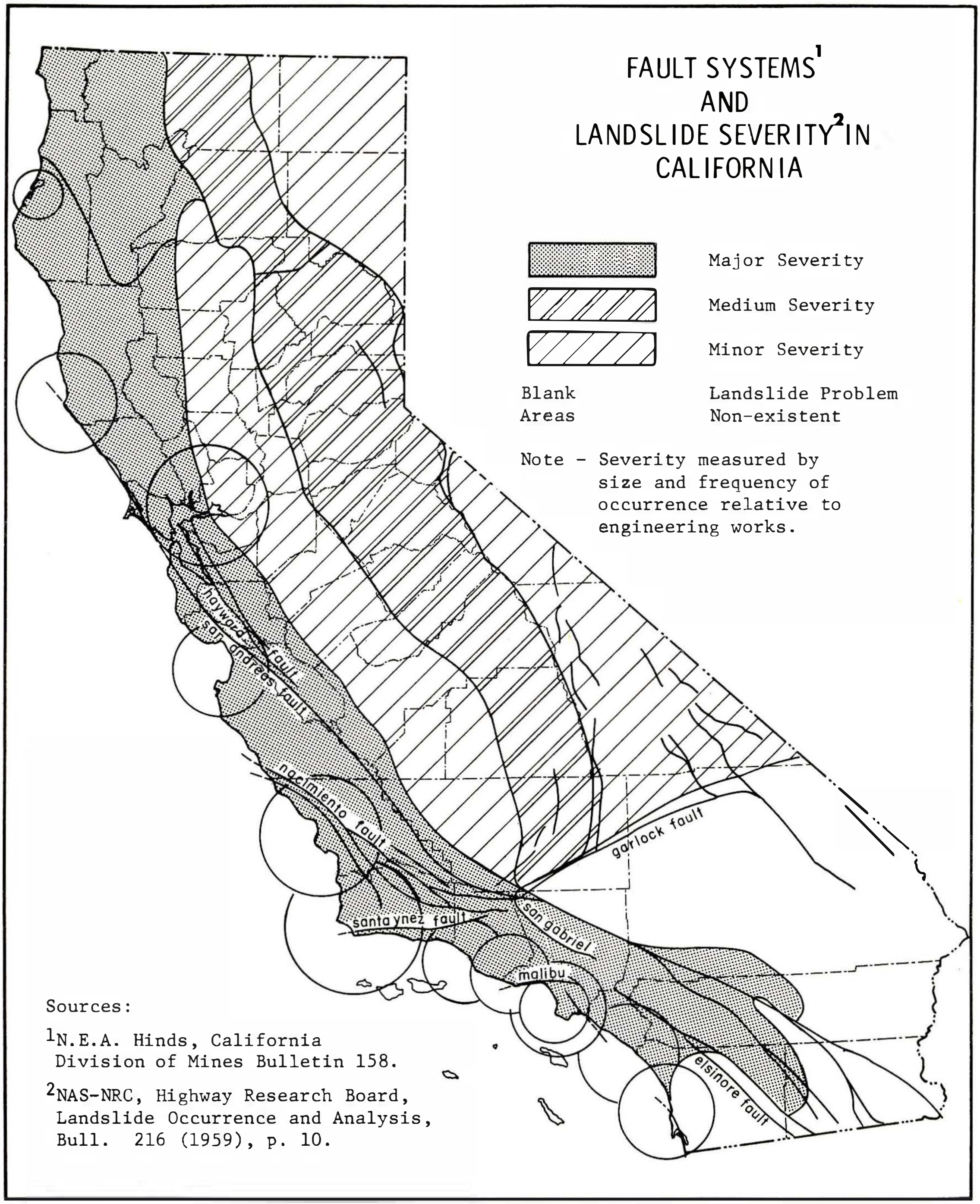
Some of the specific costs passed on to the environment include: (1) release of heated water, causing thermal pollution of marine and riverine environments; (2) release of radionuclides into the atmosphere, raising the level of atmospheric radioactivity; (3) release of radionuclides into marine and riverine environments to be incorporated into the ecosystem for circulation and biological concentration at various levels of the food chain; (4) net release of radionuclides into the total environment to bring about both short-term (somatic) and long-term (genetic) effects within densely settled populations; and (5) production of waste reactor fuel which, when removed from the reactor, exhibits high radioactivity and temperature levels and must be carefully transported, processed, and disposed of in storage areas for several decades.[14] Explicit in the transfer of highly radioactive spent reactor fuel from reactor source to waste disposal location is the potential for accidental release of this lethal material which presents an additional cost. Environmental recovery from failures in the technology of handling highly radioactive wastes is seldom complete, which may in fact be much too high a price to pay for electricity.[15]

Nuclear power reactors in general are relatively simple in design and operation and, given the apparent demand for increased electricity, such plants offer many benefits. The obvious economic and less-obvious environmental costs will vary in importance according to the geographical site and situation of the reactor. For this reason, attention is directed to the present and future development and siting of nuclear reactors in the California coastal environment.

DISTRIBUTION OF NUCLEAR POWER REACTORS AND POPULATION IN CALIFORNIA

Most Californians live in cities clustered along the coastal and/or southern part of the state. Moreover, the state's center of population—now near the UCLA campus in the Santa Monica Mountains—is shifting steadily southward. Adding to the increasing concentration and congestion of population along the coast is the continued preference of newcomers to choose either the San Francisco Bay area or southern California as living sites. Future population growth is expected to bring the coalescence of these two centers into a West Coast megalopolis, including the urbanization of the Central Valley.

The distribution of nuclear power plants[16]—operative, under construction, or planned for the next two decades—indicates (1) a large concentration of uniformly sized plants in Southern California in close proximity to major urban centers, and (2) a series of variable-sized and irregularly spaced large plants from Point Conception northward to Point Arena (Figure 1). Most plants are in close proximity to either dense populations or areas likely to experience considerable population increase and urban development over the next



FAULT SYSTEMS[1]
AND
LANDSLIDE SEVERITY[2] IN
CALIFORNIA
Major Severity
Medium Severity
Minor Severity
Blank Areas
Landslide Problem Non-existent
Note - Severity measured by size and frequency of occurrence relative to engineering works.
hayward fault
san andreas fault
nacimiento fault
garlock fault
santa ynez fault
san gabriel
malibu
elsinore fault
Sources:
1N.E.A. Hinds, California Division of Mines Bulletin 158.
2NAS-NRC, Highway Research Board, Landslide Occurrence and Analysis, Bull. 216 (1959), p. 10.

Map 2

decade. The size of the reactor determines both the amounts of nuclear fuel necessary to generate power to reactor capacity and, accordingly, the amounts of spent nuclear fuel produced and radionuclides released to the environment under normal operation. Moreover, the potential energy for nuclear excursion (or failure) is related to reactor size, which is an important factor to consider in siting nuclear reactors near centers of existing or future population.[17]

NUCLEAR POWER REACTORS IN THE CALIFORNIA COASTAL ENVIRONMENT

Inspection of the distribution of present and future nuclear reactors reveals a pattern of siting that interrelates reactors with several important environmental factors, including existing patterns of faults and fault zones, landslide severity, and atmospheric pollution, all of which are directly related to problems of reactor safety and environmental pollution.

Faults and Fault Zones

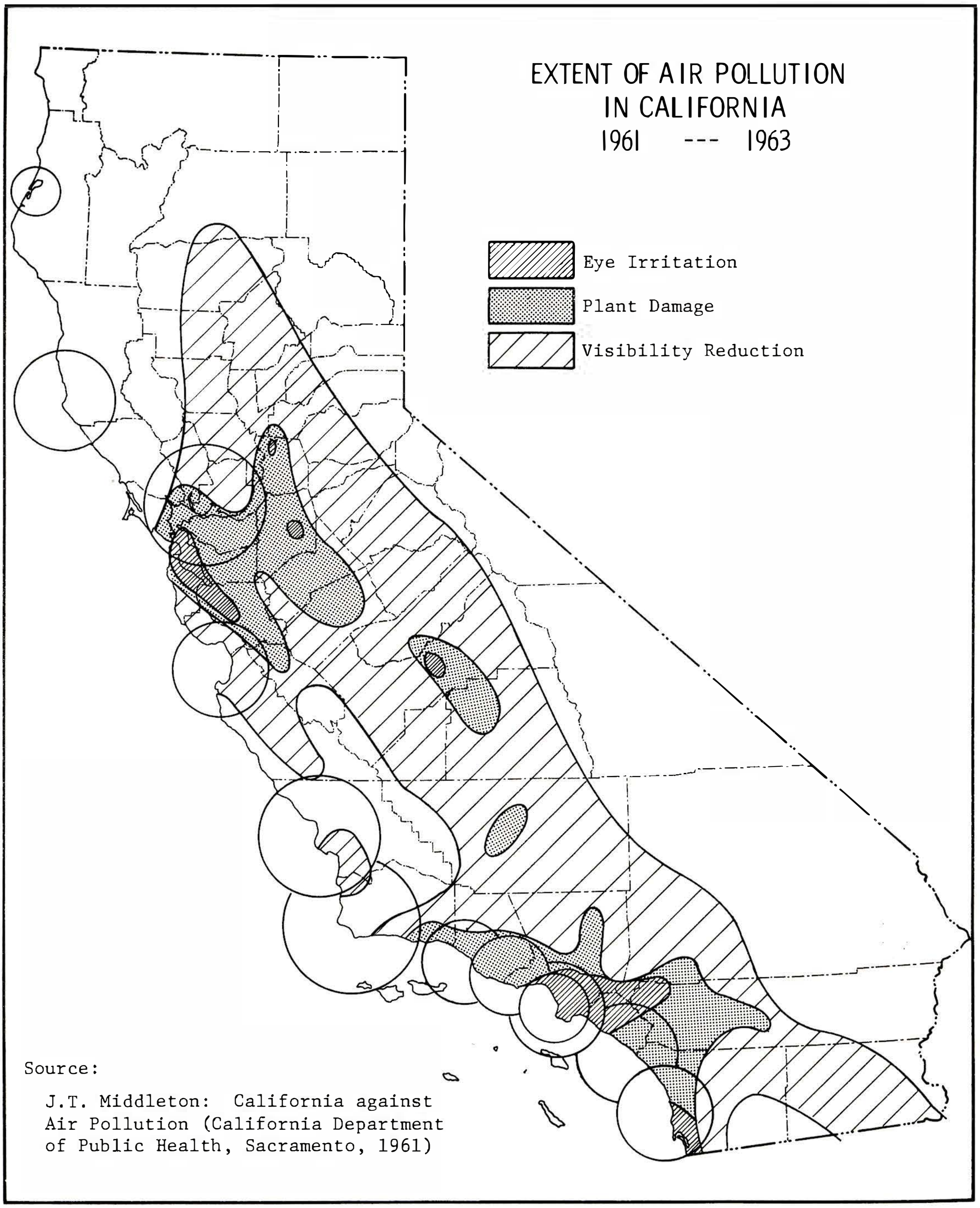
The almost daily tremors felt by residents of many coastal California cities is sufficient reminder that this is an area of tectonic-seismic instability. The crust of coastal California is shaped by an intricate network of faults that lace the Coast, Transverse, and Peninsular Ranges. Most of these faults have been active during the Quaternary Era. Mapped traces of faults indicate relatively broad fracture zones along which faulting and earthquake activity has occurred, and it seems realistic to assume that areas between mapped fault zones are also tectonically unstable. In any case, man in settling these areas assumes the risk of possible earthquake damage and destruction.

Structures that house nuclear reactors are engineered and constructed according to specifications established by the U.S. Atomic Energy Commission (AEC) which has ultimate responsibility and authority in nuclear reactor licensing. Crowe indicates that often the criteria used for regulation of an industry are determined by the industry that is being regulated.[18] The case of the AEC, in part, supports this view because experts on atomic energy most often heard at AEC reactor licensing hearings are selected from the ranks of both the AEC and the power industry seeking the permit to operate reactors. Assumed in the licensing criteria is the factor of safety of the reactor core in the event of intense seismic activity and subsequent earthquake damage.

A comparison of the distribution of nuclear power plants with existing patterns of faults and fault zones indicates that (1) one-half are situated on active fault zones; (2) 16 percent are within ten miles of an active fault; (3) 16 percent within twenty miles of an active fault; and (4) 16 percent beyond the twenty-mile limit (Figure 2). Given the likelihood that some of the faults mapped are believed to be inactive, it is prudent to note that well over two-thirds of the reactors planned are situated in or near seismically unstable regions through which pass active fault systems.

Landslide Severity

The factors that tend to promote slope failure, mass-wasting, and related landslide forms in coastal California can possibly endanger structures housing nuclear reactors. The relationship between climate and landscape development has become almost assumed in most geomorphological research, as factors and elements of climate ultimately govern the rate and magnitude of geomorphic process development. Specific forms of landslide activity are commonly related to the factors of over-steepening, over-loading, and over-saturation of slope to promote slope failure. Seasonally high precipitation concentrated in one or two winter months tends to both overload and lubricate slope material. The combined processes of active stream erosion and valley development and active wave erosion and cliff development oversteepen slopes to promote slope failure. A map of regional landslide severity (Figure 2)[19] indicates that all present or planned nuclear power plants are situated in areas with major landslide severity. Given the past slope development history of the region, reactor structures sited in this region are subject to damage, potential reactor failure, and nuclear excursion.


EXTENT OF AIR POLLUTION
IN CALIFORNIA
1961 --- 1963
Eye Irritation
Plant Damage
Visibility Reduction
Source:
J.T. Middleton: California against
Air Pollution (California Department
of Public Health, Sacramento, 1961)

Map 3

Atmospheric Pollution

The California climate is diverse, due in large part to the strong definition of climatic controls upon the landscape. Several of these promote atmospheric stagnation and seasonally raise the air pollution potential for much of the coastal segments of the state. Among these are included (1) a subtropical high pressure (Pacific High) that imparts stable, subsiding air to produce an upper-air subsidence inversion over much of the state during the summer; (2) a cold off-shore ocean current that chills and cools the lower atmosphere and promotes low-level inversion conditions; and (3) pronounced topographic barriers of the Coast, Transverse, and Peninsular Ranges that rise above the coastal inversion layer, allowing the air trapped below to stagnate and become polluted along the relatively narrow confines of the limited coastal fringe.

Nuclear power plants add to atmospheric pollution (atmospheric radioactivity) under normal operation through regular releases of radionuclides in amounts considered to be below measurable harm to man. Under abnormal operation, wherein technical failures result in a malfunction of the reactor or environmental factors damage the reactor core, potentially massive amounts of radioactive material are released to all realms of the environment, including the atmosphere. The effect of the net release of radionuclides into the relatively stable atmosphere of the air basins along the California coast is difficult to assess. The probability is real that, in time, such substances enter the food chain and pass indirectly at concentrated levels to man and, ultimately, his progeny. Reactor sites may be well-ventilated according to AEC reactor licensing specifications, but the air basin within which the automobile, conventional power plant, and nuclear power plant alike are situated may ultimately suffer under excessive burdens of waste.[20]

Comparing the distribution of existing patterns of air pollution[21] as a fairly accurate measure of regional air pollution potential with the distribution of nuclear reactors, it is found that (1) one-quarter are situated in areas now suffering from acute air pollution (eye irritation); (2) one-third in areas of noticeable air pollution (plant damage); and (3) 16 percent in areas with moderate air pollution (reduced visibility) (Figure 3). Since air pollution is related to population increase it is presumed that, since 1963 when data were assembled for the air pollution map, the quality of the atmosphere has degraded.

The combination of seismic, geomorphologic, and atmospheric environmental factors all relate very directly to the security and safety of nuclear reactors. The first two—earthquakes and landslides—endanger the reactor structures and increase the chance of risking the release of massive amounts of radioactive material (fuel and spent fuel) into the environment. The last—the atmosphere—is one environmental realm that receives considerable amounts of fissionable material. Over the short run, the environmental consequences of reactor failure are evident, but perhaps most important are the long-term consequences of normal radioactive waste release into the relatively limited air basis of the agricultural-urban regions of the California coast, and the eventual incorporation and biological concentration of radionuclides into the food chain.

CONCLUSION

The California environment is being rapidly changed through complexly interrelated processes that accompany urbanization. As our technological civilization continues to advance through successive stages, it becomes apparent that the benefits of science and technology on the quality of life must be weighed against costs inflicted upon the environment. Nuclear reactors represent an important technological solution to the man-environmental problems of fossil fuel consumption and atmospheric pollution caused by conventional means of power generation. Through geographical analysis, this paper has sought to present the broad environmental context of siting nuclear power reactors in California, and to raise the question of long-term environmental costs weighted against the short term benefits of nuclearization.

Within California over the past century the many problems that have arisen have been equalled by the determination and resolve of many to develop effective solutions. The impact of technology and urbanization on the California environment may be ultimately the most important problem. At stake now may not be the quality of life, but survival of life as we know it.

REFERENCES

[1] State of California, The Resources Agency, *Siting Thermal Power Plants in California*, A Report Prepared for Joint Committee on Atomic Development and Space, California Legislature (House Resolution 459), February 15, 1970, pp. 1-2.

[2] *Ibid.*

[3] See R. Holcomb, "Power Generation: The Next 30 Years" *(Science, 1970)* Vol. 167, pp. 159-160.

[4] Thermal pollution is an additional agent of environmental degradation that is associated with large scale power generation. By 1980 20 percent of all the fresh water runoff in the United States will be used for power plant cooling purposes. During periods of drought and/or during low rainfall seasons 30-50 percent of total runoff will likely be used in this way. See *Environmental Science and Technology* (1968), Vol. 2, p. 399.

[5] See footnote number 1 for reference to a report recently published in conjunction with the power industry which details the plans for future development of nuclear power in California. Particular attention is given to ways and means by which public intervention and opposition to nuclearization may be eliminated or minimized so as to not unnecessarily delay the program.

[6] Artificial production and release of radioactivity to the atmosphere is one consequence of large-scale nuclearization. Artificial radioactivity penetrates and biologically concentrates in all realms of the environment. See M. Eisenbud, *Environmental Radioactivity* (New York: McGraw-Hill Book Company, Inc. 1963).

[7] This is an advanced reactor being developed to eventually replace conventional reactors. Because both are developmental many technological problems must be solved, particularly for the breeder reactor. According to Government estimates, the state of the art for breeder reactors will not be perfected until at least 1974. Some shortcomings of the breeder program are outlined by G. F. Tape, "The Increasing Importance of the Breeder Program (A Symposium)," Chicago, Illinois, April 23, 1968. USAEC release No. S-17-68, April 23, 1968.

[8] Subsidies paid by the U.S. Government to support nuclearization of the private power industry include (1) contribution to reactor construction costs, (2) research and development support, (3) five-year waiver of lease charges on fuel, (4) low guaranteed charge for reprocessing irradiated fuel, (5) high guaranteed buy-back prices on by-product plutonium for weapons use, (6) undefined costs in radioactive waste disposal, and (7) Government indemnity to cover third-party liability claims in the event of major reactor accidents. Unfortunately for power consumers, rising power rates often attend nuclearization despite generous Government subsidy. See A. J. Ackerman, "Atomic Power Plants--What's Wrong With Them?" Hydroelectric Power Session, American Power Conference, April 28, 1965, Chicago, Illinois.

[9] The AEC currently assumes the burden of radioactive waste storage. Some uncertainties surrounding the environmental effects of radioactive waste storage are indicated by R. Curtis and E. Hogan *Perils of the Peaceful Atom* (New York: Ballantine, 1969), and S. Novick, *The Careless Atom* (Boston: Houghton-Mifflin, 1968). Also see International Atomic Energy Agency *Proceedings on Disposal of Radioactive Wastes*, (Vienna, 1960); and M. Eisenbud, *op. cit.*, pp. 258-269.

[10] According to the Atomic Energy Act, atomically produced electricity is in the research and development stage. All nuclear power reactors are experimental, not commercial, because their practical (economic) value has not been demonstrated.

[11] Section 170c. of Public Law 88-703 (Price-Anderson Act of 1957) states "...the aggregate liability for a single nuclear accident (reactor accident)...shall not exceed the sum of $500,000,000 together with the amount of financial protection required..." Thus the total liability assumed by Government is not more than $500,000,000 plus private insurance obtained by the reactor operator which to date has not exceeded $50,000,000. Thus 1/14th of the total $7 billion cost of a "maximum credible accident" is assumed by Government and the power industry. For a discussion of possible reactor accidents see USAEC, *Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Reactor Plants*, WASH-740, U.S. Government Printing Office, March, 1957, Washington, D.C., and L. Mattison and R. Daly, "Bodega: The Reactor, The Site, The Hazard," *Nuclear Information*, April, 1964, pp. 1-2.

[12] For a discussion of the movement and effects of radioactivity in the ecosystem see M. Eisenbud, *op. cit.*, pp. 99-131.

[13] B. Commoner (1963), *Science and Survival*, (New York: Viking Press).

[14] M. Eisenbud, *op. cit.*, p. 262.

[15] The fire at the Dow Chemical-AEC Rocky Flats plutonium fuel facility near Denver, Colorado, did an estimated $20,000,000 worth of damage, but decontamination costs exceeded $40,000,000.

[16]Total reactor capacity in kilowatts was the criterion for determining reactor size. Sources included: State of California, Department of Public Health, *Radiological Health News*, Vol. 7, No. 4, October 1968, p. 1; U.S. Atomic Energy Commission, Division of Technical Information, *Nuclear Reactors Built, Being Built, or Planned in the United States as of June 30, 1969*, TID-8200 (20th rev.)., pp. 7-9; and, State of California, The Resources Agency, *Siting Thermal Power Plants in California*, A Report for Joint Committee on Atomic Development and Space, February 15, 1970, pp. VIII 12 - VIII 13.

[17] Reactor accidents from various known and unknown causes can result in varied levels of damage. An "excursion," an uncontrolled nuclear reaction, may result in (1) the containment of reaction products within the reactor structure, (2) the release of volatile fission products, or (3) the 50 percent release of all fission products from the containment building. These spatial and temporal hazard levels associated with reactor failure are detailed in references cited in footnote 11.

[18]B. L. Crowe, "The Tragedy of the Commons, Revisited" (*Science, 1969*) Vol. 166, p. 1103.

[19]R. F. Baker and R. Chieruzzi, "Regional Concept of Landslide Occurrence," pp. 1016 in National Academy of Sciences-National Research Council, Highway Research Board Bulletin 216, *Landslide Occurrence and Analysis* (Washington: G.P.O. 1959).

[20]P. Mason, *Atmosphere Pollution Potential from the Pacific Gas and Electric Diablo Canyon Power Plant Complex*. Submitted at request of Atomic Energy Commission on January 13, 1970. February 2, 1970.

[21]P. A. Leighton, "Geographical Aspects of Air Pollution," *The Geographical Review, (1966)*, Vol. LVI, pp. 166.