PERSPECTIVES ON RADIATION RISKS

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Gertrude Stein, looking over your program for this conference, might well sum it up, "A man-rem is a man-rem is a man-rem." This might be an assault on Women's Lib -- a double assault if the feminine perception unmasks the wiles of the roentgen-equivalent-man.

It seems to me that full understanding of the man-rem concept will make society aware of the need to balance radiation risks. We must be concerned with the man-rem as a unit of national exposure and conclude that the consequences of radiation risk-taking should be evaluated independently of the radiation source. We should not discriminate between man-rems from radioactive fallout, from nuclear power plant effluents, or from diagnostic x rays.

The BEIR[1] report which your organization has so wisely taken as the main topic for discussion today needs to be translated from the technical jargon of the radiation specialist and injected into the public discourse. This is not an easy undertaking, for the nature and dimension of things familiar to scientists is strange territory for the average person.

The BEIR Translation

The great value of the BEIR report is that it systematically reviews the data on somatic and genetic effects of ionizing radiation and provides us with an understandable linkage between radiation dose (man-rem) and injury to humans. Your organization will be discussing the genetic effects in detail, so I shall confine myself to somatic effects. Here the BEIR translation reads:

> "Continuous exposure of a population of 1 million persons to the level of 1 rem per year may result in the incidence of 150 to 200 cancer deaths per year."

I shall make the assumption the 200 figure is valid.

You have titled this session "Radiation Perspective in the United States of America," and I shall proceed to address this issue on the following basis:

(1) That the BEIR man-rem dose to cancer-death response applies to very low levels of radiation.

(2) That perspective may be achieved by extrapolating human exposure data to the year 2000.

I shall not attempt to leap into the 21st century, even though it may happen that certain sources of ionizing radiation relased in this century will persist into the next. I plan to rely on the U.S. Environmental Protection Agency report ORP/CSD 72-1, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," as a data base with some modification. I shall use 1 million man-rem as a basic unit and disregard all sources of dose very much less than this unit.

Natural Background Radiation Risk

The average whole-body annual dose due to the natural background radiation in the United States is taken to be 0.13 rem. Cosmic radiation dose increases with altitude and is taken as 0.045 rem per year for the United States. Radiation emanating from terrestrial sources external to man averages about 0.06 rem per year, while the internal radiation dose, primarily ^{40}K and ^{210}Po plus ^{222}Rn averages 0.025 rem.

Within the 50 States the external dose to man varies from a high of 0.225 rem per year in Colorado to a low of 0.075 in Louisiana. Adding in the internal dose contribution, we see that the natural background radiation varies from about 0.1 to almost 0.3 rem per year within the borders of the United States. Man, of course, alters his environment and lives in structures of varying radioactive content, thus increasing his external dose.

The present U.S. man-rem dose from natural sources of radiation is taken as 27 million man-rem, and by extrapolation to a year 2000 population[2] of 280 million I arrive at an end-of-century dose total of 36 million man-rem. The cumulative 30-year dose approaches 1 billion man-rem, and this equates to almost 200,000 cancer deaths. This figure represents about 1 percent of the spontaneous cancer deaths due to all causes.

One might be tempted to look for some correlation in the cancer deaths in a city like Denver and a sea-level city with half the natural background, but this is a signal-to-noise problem that taxes the ingenuity of the biostatistician. Moreover, it turns out that lower level cities may exhibit higher rates of cancer mortality.

Radioactive Fallout Risks

Global drizzle or protracted fallout from debris introduced into the stratosphere by atmospheric tests of nuclear weapons is, like the natural background, an unavoidable source of radiation exposure. Beginning with the high-yield megaton-class weapons detonated in 1952, there have been additions to this stratosphere burden of radioactive material. France and China continue to add to this source of global contamination, but the other nuclear powers agreed to a Limited Nuclear Test Ban in 1963. It will be recalled that grassroots support for this ban came from widespread public fear of fallout, symbolized by strontium-90.

Strontium-90 is a bone-seeker having a radioactive half-life of 29 years (138 curies per gram). A person born in 1954, the year when the U.S. initiated high fission-yield megaton tests in the Pacific, would accumulate a dose to the bone of about 1.2 rem by the end of the century.

Cesium-137, half-life = 137 years, deposited on the ground is the major source of external radiation from fallout. Other shorter-lived emitters contributed to the human dosage in the 1950s and 1960s. For example, in the U.S. in 1963 the total gamma radiation (external) plus dosage due to internal uptake of fallout nuclides produced a 0.013-rem dose per U.S. individual. This decreased to 0.004 rem in 1970, and it is assumed to increase slowly to 0.005 rem in the year 2000. The present 1-million man-rem dose per year is expected to reach 1.4 million man-rem at the end of the century. The 30-year dose is estimated to be 34 million man-rem, corresponding to a total of 6,800 cancer deaths of fallout origin.

Radiation Risks in Jet Travel

The demands of modern living make it almost an involuntary act to travel by jet aircraft. Scheduled airlines in the U.S. customarily seek altitude in the 25,000- to 35,000-foot altitude range or higher for purposes of passenger comfort and fuel conservation. At such altitudes passengers are exposed to an average of roughly 0.004 rem per hour[3]. In 1971 domestic air travel in the U.S. amounted to 106 billion passenger revenue miles on scheduled carriers[4]. Air travel of this type increased over tenfold in the past 20 years[5], and on the basis of a recent Department of Transportation report[6] I estimate that the annual radiation dose to U.S. air travelers will reach a 2-million man-rem total by the year 2000.

A 2-million man-rem dose per year would mean an annual cancer fatality rate of 400. To put this in perspective, CHART I illustrates the historic pattern of airline accident mortality. The lower curve plots the annual deaths due to accidents on scheduled airlines and indicates that the public is willing to accept airline fatalities at a rate of about 200 per year. The upper curve records the annual fatalities experienced in U.S. civil aviation; it would indicate that private parties are willing to accept an almost tenfold higher annual level of air fatality.

Extrapolation of the scheduled carrier mortality rate to the future is problematic, but with the increasing dependence on high-density flights, partly as a result of diminished availability of jet fuels in the future, the United States might well experience annual fatality rates approaching 1,000. At such a level the radiation risk would be less than half that for fatal accidents, and presumably the Surgen General would not require imprinting "AIR TRAVEL INVOLVES RADIATION RISKS HARMFUL TO YOUR HEALTH" on your air ticket.

Medical Diagnostic Radiation Risks

The present annual dose from medical diagnostic pratice in the U.S. exceeds 15 million man-rem. Assuming that there is no significant change in the use of x rays as a diagnostic tool, then it is expected that the national dose will reach 20 million man-rem by the year 2000. A 30-year total of somewhat more than 500 million man-rem corresponds to 100,000 cancer deaths, although it is true that not all can be considered "extra" since the radiology might not be specific to the patient's cancer.

Assuming that all 100,000 cancer deaths are actually iatrogenic, it is pertinent to place some sort of dollar value on a human life. This is an uncertain calculation, but there is legal precedent for estimating such a dollar value in court cases. Often an estimate of 20 years life-income denied is used, and awards in the range of $300,000 are made. (Assessment of the lifelong cost of maintaining a genetic defective would involve much larger sums, but only somatic radiation effects will be considered here.) On this reckoning the societal cost of excessive x radiation may be computed. One, of course, has to make some estimate of "excessive," and I shall assume that 50 percent of the diagnostic dose is unnecessary and that proper technique and well-regulated x-ray equipment could produce the desired diagnostic results. With no attempt at precision, but only to scope the problem, I estimate that 250 million man-rem multiplied by $60 per man-rem represents a $15 billion cost in the United States for the 1970-2000 period.

Nuclear Power Effluent Risks

Here in the United States there has been rather heated controversy about the radiation risks posed by nuclear radioeffluents. It should be understood that routine release of radioactivity from a nuclear power plant is basically a matter of fuel clad failure with subsequent entry into the primary coolant of certain fission products. Release of short-lived noble gases is subject to temporary holdup to reduce the effluent activity. All U.S. nuclear power sites are subject to independent radiation monitoring, and the environmental surveys of the environs are available to the public. Critics[7] of nuclear power have charged that nuclear power effluents would permit irradiation of the U.S. population to the extent that 32,000 extra cancer deaths would be incurred annually.

The Atomic Energy Commission published earlier this year a projective evaluation of the radiological consequences of a large regional nuclear power plant operation in the year 2000 after having circulated a draft report of the study to critics. This WASH 1209 report[8] concludes that, "The average radiation potentially received by the total body of an individual in the study area in the year 2000, resulting from the operation of the assumed facilities, was calculated to be 0.17 millirem."

This AEC projected dose rate would yield 0.05-million man-rem dose to the U.S. population in the year 2000, corresponding to 10 cancer deaths per year. The 1970-2000 total would be about 90 cancer deaths associated with nuclear power, according to the dose-risk relation of the BEIR report.

The question of dose commitment of long-lived radionuclides introduced into the environment by the year 2000 is beyond the scope of my discussion. However, I call your attention to two very useful treatments of the nuclear fuel cycle:

ENVIRONMENTAL SURVEY OF THE NUCLEAR FUEL CYCLE, U.S. Atomic Energy Commission, Directorate of Licensing, November 1972.

SITING OF FUEL REPROCESSING PLANTS AND WASTE MANAGEMENT FACILITIES, Oak Ridge National Laboratories Document ORNL-4451, July 1970.

Nuclear Power Plant Accident Risks -- Siting Policy

Public opposition to nuclear power has recently concentrated on risks associated with a catstrophic accident; i.e., a Class 9 accident according to the AEC's 1 to 9 classification of reactor accidents. I cannot do more than survey some of the highlights of this problem of a low-probability high-consequence accident. I call to your attention the fact that the Atomic Energy Commission will publish sometime next year a detailed analysis of Class 9 accidents, including both the probability of accidents and estimates of the extent of their consequences. In 1957 the AEC did bring out WASH-740, "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants," but to use a Washington word, this report is considered "inoperative" today.

The lack of an authoritative and realistic evaluation of radiation risks attending major reactor accidents has allowed antinuclear spokesmen to sieze upon the "worst case" postulated by the WASH-740 report and to focus on it as a probable occurence. It is true that power reactors today are seven times more powerful than the 500-megawatt plant assumed in the AEC's 1957 study. Moreover, populations at risk in the vicinity of nuclear plants have grown since WASH-740 was published. CHART II, for example, illustrates the cumulative populations at risk near selected nuclear power sites. The Calvert Cliffs site on the

Chesapeake 45 miles from Washington, D.C., has a population at risk beyond 5 miles, very much less than that assumed in the WASH-740 analysis. On the other hand, Indian Point north of New York City represents a considerably greater risk in population distribution for the Burlington site near Philadelphia; this was not approved by the AEC. Currently pending is a construction permit application for Newbold Island reactors sited 6 miles from the defunct Burlington site. I have publicly opposed approval of this siting on the basis that the Atomic Energy Commission has not placed in the public domain evidence of nuclear safeguards reliable enough to compensate for the greater population at risk in the Newbold Island area. If the AEC approves Newbold Island, then the way is open for other utilities to press for closer metropolitan siting.

It is true that the AEC has issued its WASH-1250 report, "The Safety of Nuclear Power Reactors and Related Facilities" (July 1953), in response to the October 1971 request of the Joint Committee on Atomic Energy. This will serve as the basis for public hearings to be chaired by Congressman Melvin Price, beginning September 25th. But the WASH 1250 report does not deal with a Class 9 accident and its consequences.

On March 23, 1962, the AEC issued document TID-14844, "Calculation of Distance Factors for Power and Test Reactor Sites," as a guide for utilities to determine:

(1) An exclusion area such that an individual exposed at the boundary fence would not receive more than 25 rem whole-body dose in 2 hours or more than 300 rem dose to the thyroid.

(2) A low population zone such that cloud passage would not deliver more than 25 rem (whole-body) or 300 rem (thyroid) dose at its outer boundary.

(3) Population center distances specifying distance to centers of large population concentrations.

This AEC siting criteria document did not take a conservative view of thyroid dosage since members of this organization recognize that 300 rem is a significant dose to the thyroid as evidenced by the experience with Rongelap natives exposed to fallout from the March 1, 1954, Bikini bomb test. I maintain that the AEC needs to put forth an updated version of its siting criteria.

Class 9 Probabilities

The Wash-740 report had very little to say about the probability of a major reactor accident. In the past few years there has been increased emphasis on probabilistic assessment of reactor risks. Reactor designers are trying to define how safe their nuclear machines are, and this they do in terms of postulating a spectrum of initiating events and following their consequences sequentially as they affect the pathway leading from the nuclear fuel pellet to the environment.

The only way for the fuel pellet's stored radioactivity to escape from the core is to overheat to the point where the clad deteriorates and fission products are released within the core. Pellet heatup can occur as a result of Loss of Coolant Accident (LOCA) uncless coolant is resupplied to the core channels. The AEC requires that U.S. nuclear power reactors be equipped with Emergency Core Cooling Systems (ECCS) as safeguards to prevent fuel melting. If P_1 is the probability of a LOCA and P_2 is the probability that ECC systems will not prevent fuel melting, then the probability P_{12} of a LOCA + ECCS failure is $P_1 \times P_2$. Nuclear vendors estimate that the probability of a pipe break is about

10^{-4} per reactor year and the chance that ECCS will fail to perform its function is 10^{-3} per reactor year. Thus, P_{12} becomes 10^{-7} per reactor year.

This vendor-estimated low probability for LOCA + ECCS failure has to be compounded by an additional probability; i.e., failure of containment safeguards, before the meltdown-released radioactivity is released to the atmosphere. Here one has to deal with a complex problem of containment failure in various modes affecting the time-release of specific fission products. For example, water sprays could effectively reduce the release of iodine-131.

I might interpolate at this point that for ocean-sited nuclear power plants the Advisory Committee on Reactor Safeguards (ACRS), which makes an independent review of each reactor application for licensing, has under discussion a requirement for a core-catcher to prevent loss of meltdown fission debris through containment.

Let us assume that vendor estimates are wrong by a factor of 10 in each P_1 and P_2 estimate; i.e., $P_{12} = 10^{-5}$ per reactor year. In other words, with 100 reactors operating, as will soon be the case in the U.S., the overall probability for a major reactor accident of a Class 9 type would be one chance in a thousand per year.

Class 9 Radiation Consequences

Would the public accept a risk of one in a thousand per year when 100 reactors are operating? It's premature to extrapolate this to one in a hundred per year when 1000 reactors are operating because that's several decades from now, and presumably new and more reliable safeguards will be available then. When the AEC grants an operating license to a utility to run a nuclear power reactor, it presumably makes a judgment that the public risk of accident comes within acceptable limits. But these limits have not been defined for the American people.

If one were to take a public opinion poll of Americans inquiring into attitudes about the probability of an accident to a nuclear reactor, I suspect that people would immediately ask, "How serious an accident?" In attempting to answer this question, we have to go back to our chain of probabilities; i.e., to P_{123} where P_3 is the probability for release of X curies of various radionuclides through containment.

We must now introduce three additional probabilities:

P_4 = that allowing for the meteorology prevailing at the time of the accident release.

P_5 = that governing the population distribution in the downwind area of the nuclear site

P_6 = shielding factors reducing exposure to people in the downwind sector

Certain pessimistic values for P_3 and P_4 led to high-consequence estimates in the Wash-740 report, leading to an extreme projection of a lethal dose as far out as 15 miles from the accident site. I think that when one is dealing with a probability that is itself a compounding of six separate probabilities; i.e.,

$$P_{123456} = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6$$

it is easy to postulate extreme consequences by taking very high values for each individual probability. In fact, some antinuclear spokesmen put $P_1 \times P_2 = 1$, then assume almost complete venting of the fission products and couple this with the highest possible values of P_4, P_5, and P_6. Thus, they arrive at most improbable and in some cases impossible fallout patterns blanketing a state as large as Pennsylvania.

Allow me to cite a single example of such nuclear extremism. I have here a letter signed by Dr. John W. Gofman for the Committee for Nuclear Responsibility, Inc. (July 1972) on a letterhead listing the names of four Nobel Prize winners. It begins:

> "Dear Friend,
>
> Do you live within 100 miles of the locations indicated on the attached map? If so, you also live, or will live, within deadly range of a nuclear power plant . . . "

CHART III is adapted from the most recent AEC report on accident (Class 9) consequences, "An Evaluation of the Applicability of Existing Data to the Analytical Description of a Nuclear Reactor Accident--Core Meltdown Evaluation," BMI-1910 (July 1971). The upper curve represents a pessimistic core meltdown accident, $P_1P_2 = 1$, but assigned no probability in the report; and P_3, involving pressure vessel meltthrough and 50-percent fission product escape from the core with a 2-hour delay for relase of the noble gases and inversion conditions for $P_4 \times P_5$, is not defined because the graph is for individual dosage and $P_6 = 1$. To illustrate the impact of a single variable (P_4), I have plotted as the lower curve an estimate of how the dose distribution would look under average conditions of meteorology[9]. Note that the lethal distance (radius for LD^{50} dose of 500 rem) is less than 1 mile.

Indian Point and Calvert Cliffs Estimates

Although it is not at all clear, based on AEC publications to date, as to which radionuclide dose is of greatest lethality in a Class 9 accident (i.e., noble gas external dose, ingested dose to the gut, radioiodine dose to the thyroid), for the purpose of illustrating the significance of multiplying P_4 by P_5 I shall apply the two curves in CHART III to a population distribution for the Indian Point and Calvert Cliffs site. I shall assume a uniform distribution of population in all directions from the reactor site. I deduce the following population doses:

Meteorology assumed	Inversion	Average (millions of man-rems)
Indian Point	10	1
Calvert Cliffs	1	0.1

Naturally, the real values for the population dose would depend on the wind direction. In the case of Calvert Cliffs a westerly wind would mean a tenfold or more reduction in dose. The man-rem dose for an accident situation cannot be directly related to dose as estimated for other sources of radiation since it is a single-shot affair. In making any such comparison, the doses given for the accident situation need to be reduced by a factor of 10.

So far I have said nothing about P_6. If we regard the rem dose as an open-field measurement, then we have to introduce shielding factors due to housing and the body itself. These are generally assumed to be 0.4 and 0.8 so that the effective dose is about one-third that of open-field dose. In an emergency situation (remembering that a reactor accident could involve several hours of warning for much of the community nearby) there is the option of evacuation or of shelter-seeking.

To the best of my knowledge, the various States and cities in the U.S. have no plans for a Class 9 accident. The emergency plans I've seen are patterned to Class 8 situations which do not pose very serious radiation risks.

Comparison of Radiation Risks (1970-2000)

I shall now summarize the dose estimates for various sources of radiation thus far annualized.

Source	30-year dose (millions of man-rems)
U.S. natural background.........	1,000
Weapons test fallout...........	34
Domestic jet travel............	36
Medical diagnosis..............	500
Routine nuclear effluents.......	0.45

It will be noted that test fallout and nuclear effluents plus waste products have dose commitments persisting beyond the year 2000.

There's nothing much we can do about the first two items in this tabulation, and since the third item is not a dose to the total population, I shall concentrate on a discussion of the radiation risks of medical diagnosis and nuclear power facilities, bearing in mind the admonition of the BEIR report (page 7):

> "An additional important point, often overlooked, is that even if the benefit outweighs the biological cost, it is in the public interest that the latter still be reduced to the extent possible providing the health gains achieved per unit of expenditure are compatible with the cost-effectiveness of other societal efforts."

Nuclear Safety Costs

AEC technical specifications for power reactors force U.S. utilities to spend about $40 million in capital costs and operations for added safeguards per 1,000-megawatt installation to provide a wide margin of safety against accidents. These costs are in addition to those that a utility would pay for normal insurance against damage to the reactor. One thousand reactors expected by the year 2000 would therefore entail expenditures of $40 billion. In addition, I would estimate that the AEC, EPA, and HEW will probably spend up to $10 billion on safety and radiation control.

A Double Radiation Standard?

In 1972 the 50 States spent a total of $7.2 million implementing radiation controls, not all of which apply to the diagnostic use of x rays. Considering the very much greater population dose associated with medical diagnosis as compared to nuclear power dosage, it seems to me that our society has a split vision on radiation risks and is setting up a double standard for radiation risks. I am not advocating relaxation of the As Low As Practicable radiation limits set forth by the AEC, nor am I suggesting cutbacks in nuclear safety expenditures, but it does seem to me that some standards have to be applied to the dominant controllable radiation risk in America; namely, the diagnostic use of x rays.

According to my reckoning, the excessive use of x rays will mean 50,000 cancer deaths in the rest of this century. All of these can be avoided if we as a nation put radiation risks in perspective and establish rational restraints on that most lethal weapon -- the x-ray machine. I agree with Dr. C. L. Comar who proposes[10] that such standards "should be established in terms of minimal exposures required to fill society's needs."

Costs for Alternative Sources of Energy

Although opponents of nuclear power argue that there are environmentally and economically acceptable alternative sources of power to substitute for nuclear power, their proposals are not viable options for utilities before the year 2000. Competent energy experts are in agreement that the single candidate option is coal. It is therefore valid to reckon the costs of the coal fuel cycle, assuming that coal-fired plants replace nuclear units. I estimate that in the year 2000 such plants would require an annual boiler feed of 2 billion tons of high-rank coal.

Burning 2 billion tons of coal subjects a society to a risk-chain stretching from the mine to the smokestack. Let's consider, first, the occupational hazards in a coal-vs-nuclear comparison. I shall use data just made available by the Council on Environmental Quality[11].

Assuming that almost all year 2000 coal is strip-mined, I estimate that the occupational costs of mining, processing, transporting, and using coal for 1,000 plants would total 2,640 deaths per year. The CEQ estimate for Light Water Reactor occupational risks is 153 deaths per year. In other words, the coal substitution would be 17 times more costly than nuclear risks in the year 2000 -- meaning the conventional risks of the uranium fuel cycle,

Two environmental hazards predominate in the coal cycle, the acres disturbed in strip-mining and the stack emissions, primarily SO_x effluents. Uranium ore has a specific energy content up to 40 times higher than coal so the acres disturbed are very much less for present generation nuclear plants, and with the advent of the power-breeder, nuclear power will enjoy a thousandfold or more advantage in reduced environmental impact as compared to coal.

The 1975 primary and secondary standards on stack emission will crack down on SO_x effluents from coal-burning plants, and it is to be assumed that use of compliance fuels and new developments in sulfur control will serve to make year 2000 effluents much lower in level than even the 1975 standard. But some SO_x will come out of the stack, and the biological damage of chemical pollutants will have to be assessed. The 0.45-million man-rem 1970-2000 dose from routine release of nuclear power effluents sets a very high standard for fossil fuel plants to achieve.

Conclusion

I have attempted to put radiation risks in perspective and, in particular, to suggest that it should be a national objective to reduce the man-rem dose to the U.S. population and to bring radiation risks into better balance. I have also attempted to scope the problem of a nuclear reactor accident, and I would suggest that at your next Congress you devote major attention to the Atomic

Energy Commission 1974 study of this problem. In the meantime I would suggest that members of the International Radiation Protection Association have an individual responsibility to (a) persuade the medical profession to reduce the diagnostic dose and (b) act as brokers for the communication of reliable information to the public in matters of nuclear safety.

References

[1] The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences.

[2] The ORP/CDS 72-1 estimate is based on a year 200 population of 321 million.

[3] H. J. Schaefer. Radiation in air travel, Science 173:780 (1971).

[4] U.S. Statistical Abstract, Table 932 (1972).

[5] R. E. Lapp. The Logarithmic Century, Figures 2-5, Prentice-Hall (1973).

[6] Research and Development Opportunities for Improved Transportation Energy Usage, Figure III-1. Department of Transportation Report No. DOR-TSC-OST-73-14 (April 1973).

[7] John W. Gofman and Arthur R. Tamplin, as cited in references listed on pages 204-5 of the BEIR Report, footnote 1.

[8] The Potential Radiological Implications of Nuclear Facilities in the Upper Mississippi River Basin in the Year 2000. U.S. Atomic Energy Commission (January 1973).

[9] Meteorology and Atomic Energy. U.S. Atomic Energy Commission Report TLD-24190 (1968).

[10] Science 181:611 (August 1973).

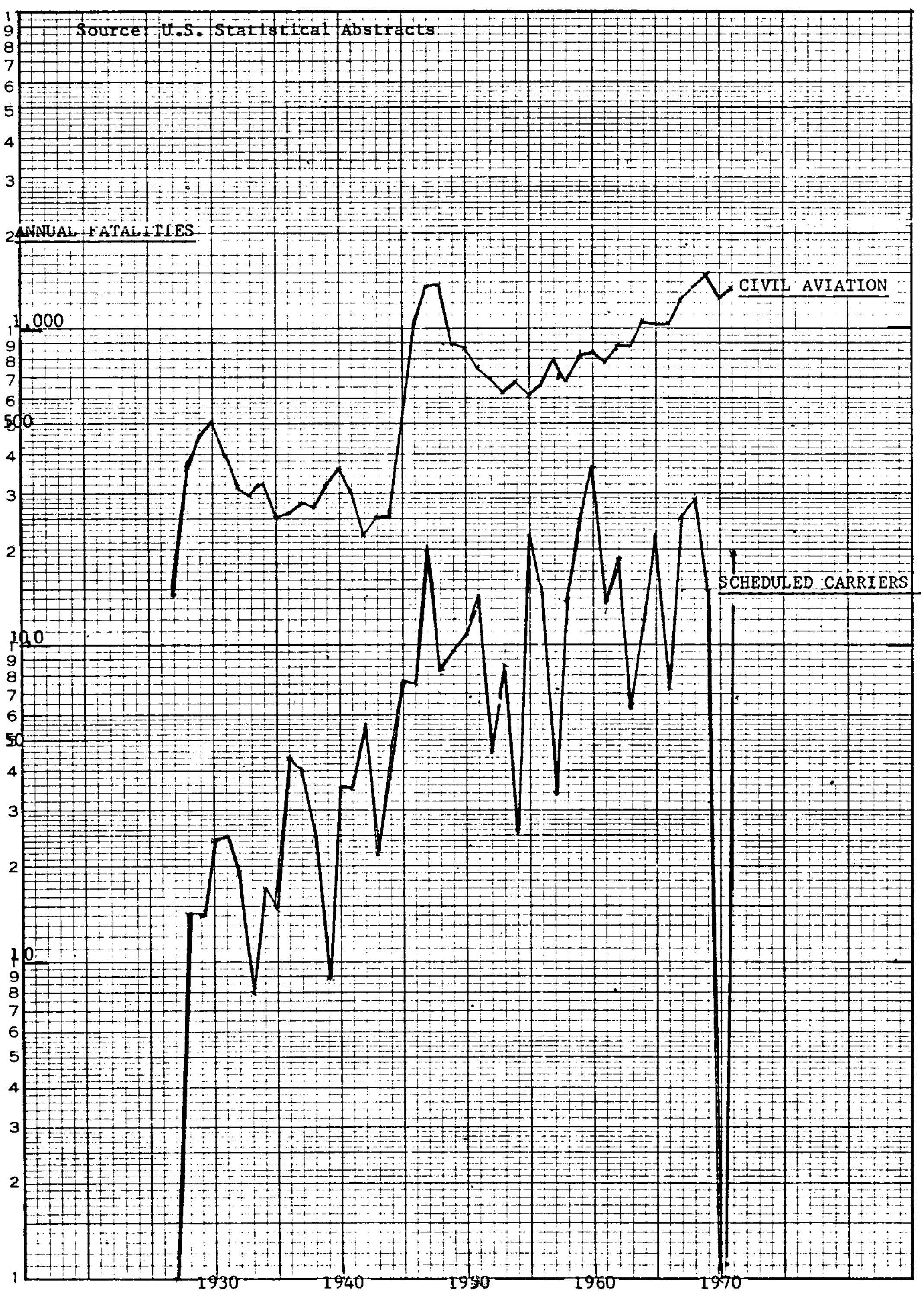
[11] Energy and the Environment. Electric Power (August 1973). (Data cited are taken from Tables A-2 and A-11).

CHART I Historical Record of U.S. Air Fatalities (1927-1972). Data taken from U.S. Statistical Abstracts for recent years and Historical Statistics of the United States, Colonial Times to 1957 (Government Printing Office, Washington, D.C.).

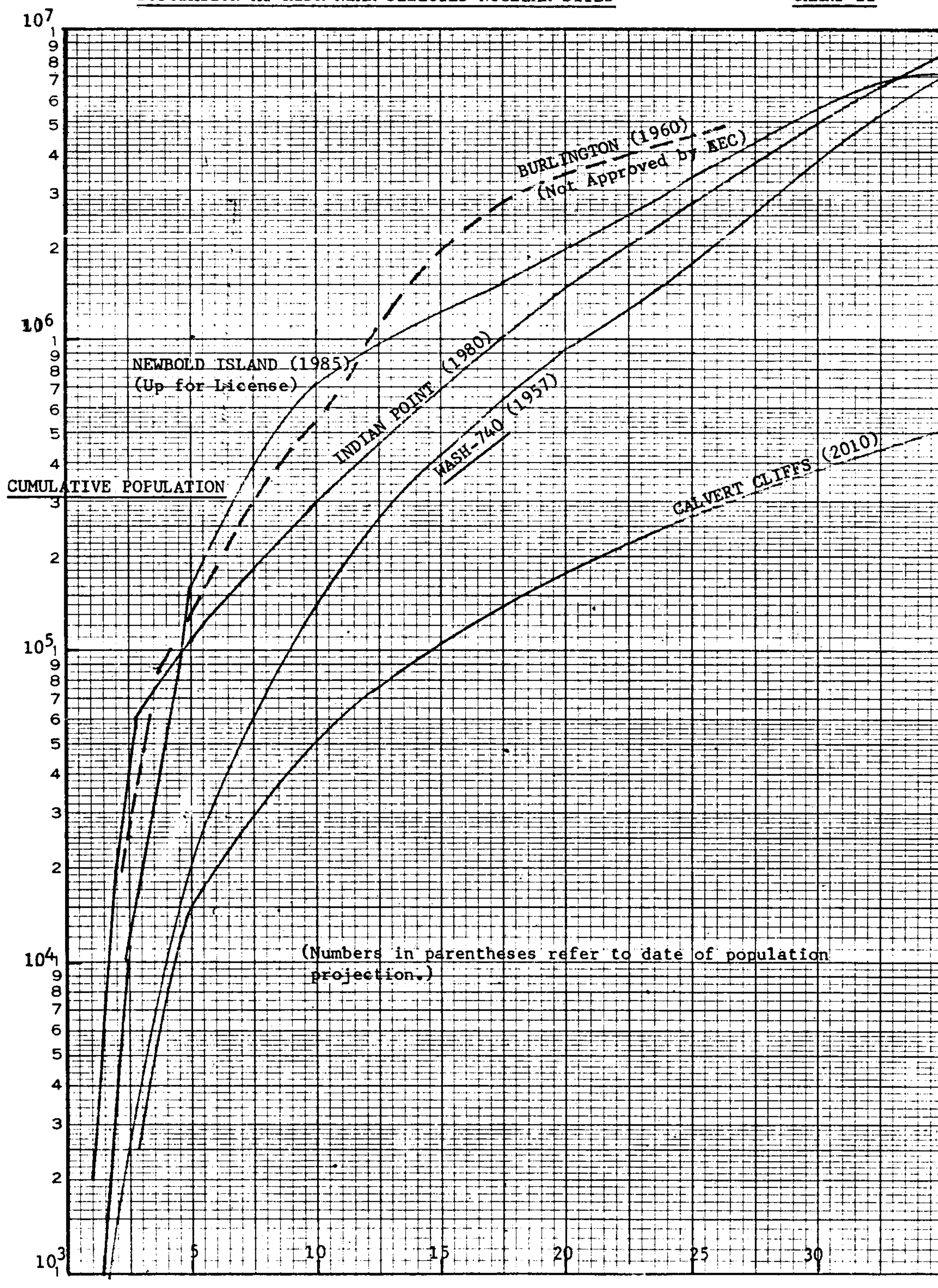
CHART II Population (Cumulative) at Risk Near Selected Nuclear Sites. Data are taken from U.S. AEC Public Dockets for Calvert Cliffs, from TID-14844, and from Figure 2 in article, "Siting Practice and Its Relation to Population," by H. B. Piper and F. A. Heddleson, to be published in Nuclear Safety, Vol. 14, No. 6 (1973).

CHART III Whole Body Radiation Dosage -- Class 9 Accident. Upper curve is taken from Figure 14, page 31, BMI-1910 (July 1971). Lower curve is author's estimate based on data in fn. 9.

U.S. AIR FATALITIES (1927-1972) CHART I



POPULATION AT RISK NEAR SELECTED NUCLEAR SITES   CHART II



WHOLE BODY RADIATION DOSAGE//CLASS 9 ACCIDENT CHART III