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REACTOR EFFLUENTS: AS LOW AS PRACTICABLE OR AS LOW AS REASONABLE?

MASTER

Andrew P. Hull
Health Physics & Safety Division
Brookhaven National Laboratory
Upton, New York 11973

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Brookhaven National Laboratory
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ABSTRACT

Recent amendments proposed by the U.S. Atomic Energy Commission to 10CFR50, set forth numerical guides to keep radioactivity in light-water-cooled nuclear power reactors as low as practicable. These are intended to restrict the exposures of nearby persons to 1% or less of the current limits to individuals in the general public.

For the most part the amendments contain "across the board" concentration limits, primarily based on their technical practicability. These are radiologically questionable, insofar as they are not related to a projected dose to an individual with reference to specific nuclides, and they are not detectable by straightforward environmental sampling and analysis techniques.

The proposed 1% limits in radiation exposures from power reactor effluents are lacking in scientific warrant insofar as the calculated risk related to current reactor effluents is insignificant, relative to other sources of exposure and other kinds of environmental hazards. If adopted, they would occasion a projected expenditure of from $\$3 \times 10^4$ to $\$1 \times 10^6$ per man-rem saved, which is shown to be excessive on several cost-benefit comparisons.

Design guides for reactor effluent releases based on 10% of current standards would appear adequate to achieve the AEC's intent. To remove public misunderstanding of the possible total population exposure from the operation of nuclear reactors, a population dose limit of 0.017 rem/year to be specifically apportioned to such operation and related activities is also proposed.

*Research carried out at Brookhaven National Laboratory under contract with the U. S. Atomic Energy Commission.

INTRODUCTION

The assumption that all exposures to radiation, no matter how small, have some element of risk has been applied by health physicists in radiation protection practices since the inception of our profession. The principle of keeping radiation exposures and releases of radioactivity to the environment as low as practicable follows directly from it. The zero threshold assumption and the derived as low as practicable principle result from the application, in the absence of definitive information about the radiation effects at low doses and dose-rates, of the so-called "linear hypothesis", which is that the dose-effect relationship observable at intermediate and high radiation doses and dose-rates is applicable down to the lowest levels of dose, and that all doses are additive.

The principle of the lowest practicable level was recognized in 1954 by the National Committee on Radiological Protection in NBS Handbook 59, and in 1958 by the International Commission on Radiological Protection in ICRP Publication 1. It also formed part of the guidance given in 1960 by the Federal Radiation Council in its Report No. 1. It has been well understood by health physicists that this principle was applicable to the maximum permissible concentrations and/or radiation protection standards, as recommended by the NCRP, ICRP and FRC, and as adopted by the Atomic Energy Commission in 10CFR20, "Standards for Protection Against Radiation". Health physicists have also been well aware of the limitations of the MPC's and standards, namely that they are applicable only to the direct pathway of the inhalation or ingestion of radionuclides, that reconcentration was possible through the food chain via some indirect pathways, and that the ultimate objective was that doses be kept within the prescribed maximum in the standards on which the MPC's were based.

Until recently, only a few large nuclear reactor facilities existed. Their effluents were at the most matters of local concern. The implementation of keeping effluents as low as practicable was pretty much left to the judgment of health physicists and other responsible persons at each facility. During the 1960's several light-water-cooled nuclear power reactors became operational. Reports⁽¹⁾ of their effluent releases indicated that although not then officially embodied in 10CFR20, the principle of keeping them "as low as practicable" was generally prevalent. That is, these effluents were for the most part less than a few percent of the MPC's specified in 10CFR20, and the resultant exposures to the public even in the immediate vicinity of operating power reactors were an even smaller fraction of the standards.

Despite this experience, late in the 1960's Gofman and Tamplin, Sternglass, and other scientist-critics mounted a vociferous criticism of the adequacy of the radiation protection standards and of the MPC's. In the context of the public hearings on power reactor license applications, of public debates about power reactor hazards, and even of Congressional hearings on electricity and the environment, large numbers of additional cancers or of infant deaths were adduced if the entire population of the United States or some large fraction thereof were exposed to the upper limit specified by the standards (variously interpreted as 170 or 500 mrem per year), or if power reactor effluent nuclide levels were continuously at the MPC's.

In what seemed at least a partial response to these conjectural misrepresentations of the facts, early in 1970 the AEC formally proposed "as low as practicable" amendments into 10CFR20 and 10CFR50, "Licensing of Production and Utilization Facilities". The announced intent was to place

additional control on radiation exposures of the public and on the releases of radioactivity to the environment. These were formally adopted in December of 1970. At that time, the Commission indicated that it was considering more definitive guidance. In June of 1971, the Commission proposed additional amendments to 10CFR50, setting forth "numerical guidance to keep radioactivity in light-water-cooled nuclear power reactor effluents as low as practicable". The essential details of this guidance appear in Table I.

The proposed amendments have broad radiation protection implications in that these numerical guides are applicable not only as design goals, but also as upper operational limits. In the latter context the amendments stipulate that if, averaged any quarter, it appears that estimated annual quantities or concentrations are likely to exceed twice the design objectives, the licensee should investigate the cause and initiate a program to reduce the release rates. If, over a quarter, the annual quantities or concentrations are likely to exceed four to eight times the design objectives, the amendments specify that the Commission will "take appropriate action to assure that such release rates are reduced". Applied thus as upper operational limits, these numerical guides become de facto radiation protection standards, and they were thusly perceived⁽²⁻⁴⁾ by reporters, critics and members of the general public.

In its announcement, the Commission indicated that among the expected consequences of these guides for design objectives were that they would provide reasonable assurance that the annual exposures to individuals living near a light-water-cooled nuclear power reactor (LWCNPR) will generally be below 5% of average exposures from natural background (100 - 125 millirems per year), and that the annual exposures to sizeable population groups from LWCNPR effluents will generally be less than 1% of natural background radiation.

It also indicated that conformance with the proposed guides would provide reasonable assurance that the resultant whole body dose to the total exposed population would be less than 400 man-rem per year per 1,000 megawatts electrical installed generating capacity.

At the time these amendments were announced, the Commission specified a 60-day period for comments, which was subsequently extended for 60 more days. Late in 1970, the AEC announced that a public rule making hearing would be convened on January 20, 1972 "for the purpose of aiding the Commission in its determination as to whether or not the amendments should be adopted as proposed, or adopted in some other form". The actual hearing took place on eighteen days over the period between then and May 6, 1972, when it adjourned pending the completion of the environmental report required under the National Environmental Protection Act.

A total of fifty-five individuals submitted comments. There were twelve full and sixteen limited participants in the rule making hearings. However, included in the former were the consolidated participation as a unit of some fifty-three environmentalist-conservation groups, and another consolidated unit of some thirty utilities. During the stipulated period some comments on the amendments were drawn up, circulated within and accepted by a majority of the Standards Committee of the Health Physics Society. However, since the approval of the Board for the Committee to submit them was not forthcoming, the Health Physics Society did not make any official comment, nor was it a participant as such in the hearings. Twelve health physicists submitted comments in their own name; three health physicists submitted testimony on behalf of full participants, and two entered individual testimony as limited participants. It may also be assumed that additional health physicists were involved in the preparation of comments and testimony submitted by executives, lawyers and others.

The preponderant comment and the testimony presented at the hearings, including that by health physicists, questioned to varying degrees the necessity for, the practicability and reasonableness of, and the cost-benefit implications of the amendments, as proposed by the Commission. Since much of the supporting argument for them has already been made available⁽⁵⁾ to the members of the Health Physics Society, in what follows an attempt will be made to present the problems that the author (who was a limited participant) and others found with the proposed amendments.

NEED

Pointing out that no new biomedical data had been introduced to suggest a need for the amendments, that after a recent reevaluation of basic radiation criteria the NCRP had not seen fit to alter those applicable to the general public, and that the National Academy of Sciences was mid-way in an extended review of radiation risks, some participants⁽⁶⁻⁹⁾ questioned the necessity for the amendments at this time. In its introduction to them, the Commission referred to the low levels that have prevailed in LWCNPR effluents. Its published data⁽¹⁰⁾ for power reactor effluents during 1970, as shown in Tables II and III, makes this apparent. These and earlier⁽¹⁾ data suggest that in most cases reactor designers and operators had been limiting the amounts and concentrations of releases to levels comparable to or less than those proposed. The necessity for mandating what already prevailed is therefore unclear.

PRACTICABILITY

Almost all of those offering comment and testimony supported the philosophy of maintaining effluent releases "as low as practicable". However, the practicability of establishing essentially equal numerical guides for design objectives and for operating limits was questioned by Hunter⁽¹¹⁾,

who pointed out that although sophisticated systems can operate at peak performance under ideal conditions, they will not operate continuously at such levels. In his supplementary testimony, Minnick⁽¹²⁾ suggested that early shut-down at the first sign of a fuel defect might greatly increase the difficulty of determining the particular cause, meanwhile increasing the cost and decreasing the reliability of electric power.

More specifically, there seemed general agreement among those testifying on the matter that with the current state of the art for effluent control and radwaste systems, both currently designed boiling water reactors and pressurized water reactors could meet the gaseous and air particulate limits. Considering possible "small sneak" circuit releases into large volumes of air in turbine buildings, doubt was expressed by several participants⁽¹³⁻¹⁶⁾ that the effective ¹³¹I release limit imposed by the restriction of environmental concentrations to 1/100,000 of those specified in 10CFR20 ($1 \times 10^{-10} \mu\text{Ci}/\text{cm}^3$) could be satisfied by any practicable technology. It was also suggested by Barkley⁽¹⁷⁾ that the releases which would cause these proposed environmental concentration limits to be considerably exceeded, could not be immediately detected with available "state of the art" on-line stack monitors. It was also suggested^(6,13,16) that the ability of "once-thru" cooling system PWR's to meet the proposed ³H limits is marginal, and it appears that these water cooling towers would be unable to do so.

In its introduction to the amendments, the Commission indicated an awareness that the levels of exposure anticipated under them would not be measurable with existing techniques. In the testimony presented at the hearings, several participants indicated^(6-8,13,15,17-19) that these levels are within local area variations in background, as well as being beyond "state of the art" field instrumental capability. It was suggested by

Malley⁽⁶⁾ that this might make it extremely difficult for a licensee to demonstrate compliance and might occasion costly measurements of biologically insignificant levels.

REASONABLENESS

Almost all of those presenting comment and testimony on the proposed amendments questioned the reasonableness of the specifics proposed by the Commission, particularly in their application as operating limits or de facto standards. Much of this centered on what was felt to be the over-conservatism of the specific release amount and concentrations. There were several suggestions^(6,14,15,18,20,21) that the Commission's intent could have more reasonably been furthered by the specification of an individual and a population dose limit, allowing each applicant the opportunity of demonstrating in a safety analysis report how these would be met in terms of the design features, the meteorology, the hydrology and the potential exposure pathways of each specific facility. Although the amendments contain an escape clause from their quantity and concentration limits, doubt was expressed⁽²⁰⁾ that the reasons for seeking such relief would be readily accepted by the AEC Regulatory Staff or understood by the public.

Part of the Commission's testimony made explicit the assumptions connecting the proposed activity and concentration limits to a gaseous and particulate effluent and a liquid effluent dose limit of 5 mrem/yr. Several participants^(6,11,20) questioned the relevance of these assumptions to real life situations. In a detailed analysis, Goldman⁽⁸⁾ suggested that the gaseous and particulate effluent limits were about ten times more conservative than a typical exposure situation, and the liquid effluent limits between 90 and 150 times more conservative than needed to meet the proposed dose limits in a typical situation.

Several participants^(7,14,19) questioned the departure from 10CFR20 as either a basis for design guidance or for operating limits. With regard to design guidance, it was variously suggested that 10% or 1% of these limits be utilized, while the recommendations for operating limits ranged from an acceptance of 10CFR20 as is, to 1% of it, with appropriate recognition of concentration factors if applicable.

The reasonableness of the "across the board" application of a reduction factor of 100,000 to the 10CFR20 air concentration limits for radioactive iodines and particulates with half-lives greater than eight days was quite generally questioned^(6-8,11,13,15,18), it being pointed out that this stipulation was irrelevant unless grazing milk-producing animals were nearby, and that in most U.S. locations such animals would not be in pasture all year, nor would their milk likely be 100% of a central dairy's pooled output.

The reasonableness of a 5 mrem/yr "fence-post" dose limit was also seriously questioned^(6,7,11,14,18,22). Several participants^(6,7,14,23) felt that the Commission should have stated more explicitly that the proposed amendments were based on practicability, and that they should not be interpreted as a reduction in radiation protection standards, lest the public's confidence in the adequacy of the standards be unwarrantedly diminished.

Objections were also made^(11,14,17,18,20) to the proposed quarterly accounting of releases as small as two times the proposed release limits, which was felt to be unnecessarily cumbersome and inflexible. The wisdom of shutting down a power producing facility in the event that a hypothetical "fence-post" dweller might be exposed in one quarter to 5-8 mrem was also questioned.

COST-BENEFIT

Many doubts were expressed^(6-9,11,21,22) that the prospective costs of 1% design specifications or operating limits for LWCNPR's could be justified in terms of any quantifiable health or environmental benefits. From

the Commission's testimony⁽²⁴⁾, it was apparent that the total current LWCNPR exposures from airborne effluents are only a few hundred man-rem per year, and that the current exposures from their liquid effluents are too small to be quantifiable in this fashion. Current release experience from pre-amendment LWCNPR's suggests that the total exposure per site should be less than 100 man-rem. Some of the estimates presented by Rogers⁽¹⁶⁾ of annual costs of various arguments to the design of currently on-line LWCNPR's, necessary to provide assurance of meeting the proposed amendment limits, are shown in Table IV. Depending on the specifics, it appears that costs of from $\$10^3$ to $\$10^6$ per calculated man-rem saved will be occasioned by these arguments.

According to a summary by Cohen⁽²⁵⁾, estimates of the biological cost of radiation damage lie between \$10. and \$250. per man-rem. On this basis, prospective expenditures of $\$10^3$ per man-rem saved appear questionable, and those approaching $\$10^6$ appear preposterous. In this connection it was also indicated^(7,8,15) that the total exposure rate of the public from the medical use of x-rays is in the order of 2×10^7 man-rem/yr, and their exposure from natural background comparable. It has been suggested elsewhere by Terrill⁽²⁶⁾ that if the extra design cost per reactor to meet the more restrictive limits were applied to x-ray exposure reduction, the annual population dose could be reduced by 35 millirem per capita (a total of 7×10^6 man-rem).

Perhaps more pertinent to power reactor effluents, a Committee on Pollution of the National Research Council⁽²⁷⁾ has calculated that the total annual cost attributable to air pollutants from fossil plants is $\$1.3 \times 10^9$. Starr⁽²⁸⁾ has indicated that these effluents cause about 20,000 deaths annually. Considering the benzo(a)pyrene (BAP) in fossil fuel

power plant effluents, Watson⁽²⁹⁾ has estimated the mortality of 480 in the population of 10^8 at risk.

Table V summarizes some quantitative estimates of radiation and other more common risks in terms of the probability of fatal injury or effect per year to an exposed individual. That for radiation is inferred from data published by the ICRP. The other estimates are based on Starr's calculations⁽³³⁾. From the indicated radiation risk, it can be estimated that the fossil fuel-related BAP mortality indicated by Watson would correspond to a population dose of 4.8×10^6 man-rem.

This and the other indicated levels of generally accepted risk, make that from a few millirems per year exposure to an individual living adjacent to a LWCNPR seem trivial. The expenditures by the utilities (and ultimately by the general public) which the proposed amendments are anticipated to occasion seem regrettably misdirected toward making what is already quite safe even safer, to the neglect of other significant aspects of radiation protection and environmental pollution.

RECOMMENDATIONS

The International Commission on Radiological Protection (ICRP) has observed⁽³⁴⁾ that when whole populations or large numbers of persons are exposed, it becomes necessary to consider not only the risk to the individual but also the aggregate risk to the numbers of persons exposed. The current AEC radiation protection guides explicitly consider only the dose to the individual in the general population, which for whole body irradiation is 0.5 rem/yr. The recommendation⁽³⁵⁾ of the Federal Radiation Council for a radiation protection guide of 5 rem in 30 years average genetic exposure of the population is presumably also applicable in principle. The lack to date of an officially specified aggregate population dose limit has facilitated a popular misunderstanding that in granting licenses for the operation

of nuclear power reactors, the AEC has not considered the radiation dose to the population as a whole, even though in fact the average dose to the public has been effectively limited to much less than 1 mrem/yr.

As previously indicated, the Commission noted that conformance with the proposed guides would provide reasonable assurance that the resultant whole body dose to the total population would be less than 400 man-rems per year per 1,000 megawatts electrical installed nuclear generating capacity at a site, and that average exposures to large population groups would be less than 1 mrem/yr.

It appears that public understanding and acceptance of nuclear power generation would be assisted by the explicit allocation, within the overall FRC Guide, of a population dose limit specifically related to this purpose. While this choice must be somewhat arbitrary, 1 rem/30 years appears reasonable. It would be half of the ICRP's illustrative apportionment⁽³⁶⁾ for all nuclear energy programs and is consistent with the population dose limits already adopted by some nations with significant nuclear power programs, as shown in Table VI. It appears desirable to reserve some portion, such as half of this, for the possibility of exposure from uncontrolled releases related to these programs. Thus, the operational upper limit for the average exposure of the general public from routine nuclear power activities would be 0.5 rem/30 years, or 0.017 rem/year. The actual allocation which appears within the province of the Environmental Protection Agency, could be anticipated by the Commission by incorporating into the AEC rules a consistent upper limit in total man-rems per year per megawatt of electrical power capacity.

Within the above indicated overall population average exposure limit of 0.017 rem/year, it appears reasonable that not more than half be designated for routine nuclear power plant effluents, with the other portion

reserved for such ancillary activities as fuel transportation, reprocessing and waste disposal. It has been projected that in the year 2000, the installed nuclear capacity in the United States will be about 0.003 MW per person. With this in mind, a population dose design guide of 2 man-rem per year per megawatt of installed electrical capacity (at the time a reactor is constructed) is recommended. For an installed capacity of 0.003 MW per person, this upper limit would correspond to an average general population exposure of 0.006 rem/year. This would leave a leeway of 0.0025 mrem/year for population growth in the immediate area of a reactor, for possible underestimation of the projected 0.003 MW per person, and for possible increased electrical production per capita after the year 2000.

With regard to the exposure of persons living in the immediate vicinity of nuclear power plants, the radiation protection standard of 0.5 rem/year, as currently embodied in the Rules of the Atomic Energy Commission (10CFR20), and of 0.17 rem/year average to a suitable sample of the nearby population, appears to provide for a greater degree of protection from adverse effects than do the counterpart standards for any other potentially deleterious agents in the environment. It appears that a maximum design objective for LWCNPR effluent releases of 10% of the current radiation protection standards, with suitable allowance for realistic reconcentration potentials, would be sufficient to produce compliance with these standards.

From current experience, it can be anticipated that with such a formal design guide specification, most reactors would in fact achieve a degree of effluent control so that the average "fence-post" dose at their boundaries would be within the 5 mrem/year goal of the proposed amendments. As has been indicated^(40,41), this limitation of the exposure of individuals adjacent

to nuclear power reactors should be more than sufficient to restrict the average population exposure to far below the previously suggested limit of 6 mrem/year.

The Commission in its final version of the proposed amendments should give greater recognition that the end objective of radiation protection is to minimize dose, and that effluent control is a means to this end. Such effluent limits as are set forth should be considered only an alternate means of satisfying the dose criteria, in lieu of a detailed specific facility-site analysis.

The Commission's more strident critics have made most of their case against an imaginary target, that large numbers of persons are or would be exposed to the upper limit of the radiation protection standards from nuclear power reactor effluents. The Commission risks accrediting the undue concern about the radiation risks attendant with power reactors which has been thus generated, by promulgating release limits predicated on extremely conservative assumptions about doses and pathways that have not been demonstrated in practice. Recognition should be given to the potential coercive power of such limits to occasion large expenditures for additional effluent control features to assure compliance, but which may actually accomplish little or nothing in the way of dose reduction.

As indicated at the offset, for several decades health physicists have attempted to keep all possible exposures to radiation "as low as practicable" on the conservative assumption that all radiation, no matter how low the dose or dose-rate, had some potential risk. Over the years, we have acquired enough information to make some conclusions about the extent of this risk and to compare it quantitatively with other generally accepted risks. Such comparisons in the present instance make it apparent that it

is "practicable" to carry the limitation of radioactive effluents to unreasonable lengths. It is my conviction that the profession of health physics has a responsibility to indicate both what is reasonable, as well as what is practicable in radiation protection.

REFERENCES

1. J.E. Logsdon and R.I. Chissler, "Radioactive Waste Discharges to the Environment from Nuclear Power Facilities", BRH/DER 70-2.
2. H.M. Schmeck, "A.E.C. Urges Curbs for Power Plant Reduction", New York Times, 6/8/71.
3. R. Gillette, "Reactor Emissions: AEC Guidelines Move Toward Critics Position", Science, 172:1215-16, 6/18/71.
4. -----, "Four Leading Critics of Radiation Standards Comment on New AEC Rules", Nuclear Industry, 18:6, pp. 18-19, 6/71.
5. H.M. Parker, "The Rationale of 10CFR50 Appendix I", HPS Newsletter, 2/72.
6. J.F. Malley, Statement on behalf of Babcock & Wilcox, AEC Docket RM 50-2, 4/3/72.
7. A.P. Hull, "Comment on Proposed Numerical Guidance to Keep Radioactivity in Light-Water-Cooled Nuclear Power Reactors as Low as Possible", AEC Docket RM 50-2, 1/20/72.
8. M.I. Goldman, Statement on Behalf of the Consolidated Utility Group, AEC Docket RM 50-2, 3/17/72.
9. G.H. Whipple, Testimony on the Proposed Appendix I to 10CFR50, AEC Docket RM 50-2, 3/3/72.
10. -----, "Report on Releases of Radioactivity from Power Reactors in Effluents During 1970", Div. of Compliance, USAEC, 10/71.
11. R.S. Hunter, Statement on Behalf of American Electric Service Corp., AEC Docket RM 50-2, 2/22/72.
12. L.E. Minnick, Supplemental Statement on Behalf of the Consolidated Utility Group, AEC Docket RM 50-2, 4/26/72.
13. R.D. Allen, Statement on Behalf of Bechtel Corporation, AEC Docket RM 50-2, 2/15/72.
14. C.L. Storrs and D.A. Miller, Limited Participation Statement of Combustion Engineering Corp., AEC Docket RM 50-2, 3/3/72.
15. J.R. Smith, Testimony on Behalf of General Electric Corp., AEC Docket RM 50-2, 4/26/72.
16. W.A. Rogers, Statement on Behalf of Consolidated Utility Group, AEC Docket 50-2, 3/17/72.
17. H.B. Barkley, Comments on Behalf of National Aeronautics and Space Administration, Lewis Research Center, AEC Docket RM 50-2, 2/11/72.

18. M.E. Eisenbud, Statement on Behalf of Committee on Environmental Law and Technology, Atomic Industrial Forum, AEC Docket RM 50-2, 2/16/72.
19. J.H. Wright, Statement on Behalf of Westinghouse Electric Corp., AEC Docket RM 50-2, 2/14/72.
20. R.M. Hartman, Statement on Behalf of EBASCO, AEC Docket RM 50-2, 1/20/72.
21. S.G. Goodman, Statement on Behalf of Gilbert Associates, Inc., AEC Docket RM 50-2, 1/19/72.
22. R.D. Wilson, Statement on Behalf of Nebraska Public Power District, AEC Docket RM 50-2, 2/10/72.
23. J.E. Ward, Statement on Behalf of Sargent & Lundy, AEC Docket RM 50-2, 3/1/72.
24. L. Rogers, H. Denton and C.C. Gamertsfelder, AEC Staff Statements, AEC Docket RM 50-2, 1/20/72.
25. J.J. Cohen, "A Suggested Guideline for Low-Dose Radiation Exposure to Populations Based on Risk-Benefit Analysis", UCRL-72848 (1971).
26. J.G. Terrill, "Cost-Benefit Estimates for Major Sources of Radiation Exposure", APHA Journal, 62:7 (July 1972).
27. -----, "Waste Management and Control", NAS-NRC, Publication 1400 (1966).
28. C. Starr, "Social Benefit versus Technological Risk", Science, 165, pp. 1232-38 (1969).
29. D.E. Watson, "Goals of Cost-Benefit Analysis in Electrical Power Generation", UCRL-73567 (1971).
30. A.P. Hull, "Some Comparisons of the Environmental Risks from Nuclear and Fossil Fueled Power Plants", Nuclear Safety, 12:3, (May-June 1971).
31. -----, "The Evaluation of Risks from Radiation", A Report prepared for Committee I of the ICRP, Health Physics, 12:2, pp. 239-302 (1966).
32. -----, "Radiosensitivity and Spatial Distribution Dose", ICRP Publication 14, Pergamon Press (1969).
33. C. Starr, "Radiation in Perspective", Nuclear Safety, 5:4, pp. 326-333 (1964).
34. -----, "Recommendations of the International Commission on Radiological Protection", ICRP Publication 9, p. 9 (1966).

35. -----, "Background Material for the Development of Radiation Protection Standards", FRC Report No. 1 (1960).
36. -----, "Recommendations of the International Commission on Radiological Protection", ICRP Publication 6, p. 31 (1962).
37. S.W.O. Bergstrom, "Environmental Consequences from the Normal Operation of an Urban Nuclear Power Plant", Proceedings of Fifth Annual Health Physics Society Mid-Year Topical Symposium, R. Voilleque, ed., Eastern Idaho Chapter HPS (1971).
38. A.W. Renny and N.T. Mitchell, "United Kingdom Waste Management Policy", Management of Low and Intermediate Level Wastes, IAEA (1970).
39. I.K. Dibobes, et al., "Radiation Safety Standards (NRB-69)", Translated from Atomnaya Energize, 28:6, pp. 463-467, Plenum Publishing Co. (1970).
40. J.B. Knox, "Airborne Radiation from the Nuclear Power Industry", Nuclear News, pp. 27-32, Feb. 1971.
41. J.H. Wright, et al., "The Impact of Environmental Radiation and Discharge Heat from Nuclear Power Plants", IAEA Symposium on Environmental Aspects of Nuclear Power Stations, SM 146/20 (1970).

TABLE I

NUMERICAL GUIDES FOR DESIGN OBJECTIVES AND LIMITING CONDITIONS
FOR OPERATION TO MEET THE CRITERION "AS LOW AS PRACTICABLE" FOR RADIOACTIVE
MATERIAL IN LIGHT-WATER-COOLED NUCLEAR POWER REACTOR EFFLUENTS†

LIQUID EFFLUENTS

	<u>Annual Quantity</u>	<u>Annual Average Concentration</u>
Except ^3H	$\leq 5 \text{ Ci}$	$\leq 20 \text{ pCi/l}$
$^3\text{H}^*$	-	$\leq 5,000 \text{ pCi/l}$

*Prior to dilution in a natural body of water.

GASEOUS EFFLUENTS

	<u>Annual Avg. Boundary Exposure Rate</u>	<u>Annual Avg. Boundary or Off-Site Concentration</u>
Noble Gases	$\leq 10 \text{ mrem}$	-
Iodines or Particulates with $T_{1/2} > 8 \text{ days}$	**	$\leq \frac{10\text{CFR}20}{100,000}$

**Calculated so that exposure of individuals off-site $\leq 5 \text{ mrem/year}$.

† From Appendix I, Section 50.36a, 10CFR50.

TABLE II

RELEASES OF RADIOACTIVITY FROM POWER REACTORS IN LIQUID EFFLUENTS, ^{1/} 1970*

MIXED FISSION & CORROSION PRODUCTS

TRITIUM

<u>Facility</u>	<u>Released (Ci)</u>	<u>Concentration Limit (10⁻⁷ μCi/ml)</u>	<u>Percent of Limit</u>	<u>Released (Ci)</u>	<u>Percent of MPC</u>
OYSTER CREEK	18.5	1	71 ^{2/}	22	0.0028
DRESDEN 1	8.2	1	25	5	0.0005
NINE MILE POINT	28	1	21 ^{3/}	20	0.0015
DRESDEN 2	13	1	15	31	0.0012
HUMBOLDT BAY	2.4	1	15	< 7	< 0.0014
SAN ONOFRE	7.6	1	12	4800	0.26
GINNA	10	3	5	110	0.005
BIG ROCK POINT	4.7	15	3.1	54	0.018
CONN. YANKEE	6.7	3.6	2.8	7400	0.38
SAXTON	0.012	1	0.33	10	0.01
INDIAN POINT 1	7.8	70	0.28	410	0.03
PEACH BOTTOM	0.006	1	0.15	< 50	< 0.05
YANKEE ROWE	0.034	1	0.14	1500	0.21
LA CROSSE	6.4	300	0.067	20	0.002

1/ In addition to the activity listed on this page, quantities of dissolved noble gases have been detected in liquid effluents at some facilities. Estimated curie quantities of these gases are as follows: San Onofre 56; Conn. Yankee 16; Oyster Creek 2, and the others less than 1 curie.

2/ Percent of limit has been increased by a factor of 3.76 to account for possible recirculation in Barnegat Bay.

3/ In accordance with the Nine Mile Point License the percent of limit is based only on the curies of activity identified by gross beta analysis (9.44 Ci).

TABLE III
RELEASES OF RADIOACTIVITY FROM POWER REACTORS IN GASEOUS EFFLUENTS 1970 *

<u>Facility</u>	<u>NOBLE AND ACTIVATION GASES</u>			<u>HALOGENS AND PARTICULATES</u>		
	<u>Released</u>	<u>Curies</u> <u>Permissible</u>	<u>Percentage of</u> <u>Permissible</u>	<u>Released</u>	<u>Curies</u> <u>Permissible</u>	<u>Percentage of</u> <u>Permissible</u>
OYSTER CREEK	110,000	9.4×10^6	1.2	0.32	130	0.25
DRESDEN 1 ^{4/}	910,000	1.8×10^7	5.2	3.3	75	4.3
NINE MILE POINT	9,500	2.7×10^7	0.037	< .06	63	< 0.1
DRESDEN 2 ^{4/}	250,000	2.2×10^7	1.1	1.6	110	1.4
HUMBOLDT BAY	540,000	1.6×10^6	34	0.35	5.6	6.2
SAN ONOFRE	4,200	5.7×10^5	0.75	< 0.0001	0.8	< 0.001
GINNA	10,000	3.6×10^5	2.8	0.05	1.7	3
BIG ROCK POINT	280,000	3×10^7	0.88	0.13	37	0.35
CONN. YANKEE	700	2.8×10^5	0.24	0.0015	0.2	0.7
SAXTON	2,200	3.7×10^3	59	0.15	10	1.5
INDIAN POINT 1	1,800	5.3×10^6	0.03	0.075	7.6	1
PEACH BOTTOM	5.7	1.9×10^5	0.003	< 0.0006	0.1	< 0.6
YANKEE ROWE	17	6.6×10^3	0.26	Not Measured		
LA CROSSE	950	3.2×10^5	0.3	< 0.063	1.6	< 4

^{4/} The Dresden 1 and 2 percentages are based on their individual limits. The percentage of the site limit is the sum of the individual percentages.

* From Report on Releases of Radioactivity from Power Reactors and Effluents During 1970, Division of Compliance, U. S. Atomic Energy Commission, October 1971.

TABLE IV
ANNUALIZED OPERATING COST SUMMARY FOR BWR AND PWR ARGUMENTS
TO MEET AS LOW AS PRACTICABLE NUMERICAL GUIDELINES†

	<u>Gaseous</u>		<u>Iodine</u>		<u>Liquid</u>	
	<u>"Fence-Post" Dose mrem/yr</u>	<u>Annualized Cost</u>	<u>"Fence-Post" ¹³¹I Conc. $\mu\text{Ci}/\text{cm}^3$</u>	<u>Annualized Cost</u>	<u>Discharge Ci/yr</u>	<u>Annualized Cost</u>
BWR (1)	10.5	\$442,000.	2.2×10^{-14}	\$ 727,000.	3.5	\$ 58,000.
	4.2	718,000.	6.8×10^{-16}	1,186,000.	0.4	585,000.
PWR (2)	--	--	4.5×10^{-14}	666,000.*	4.8	75,000.
					0.2	530,000.

*Largest amount indicated for smallest practicable PWR ¹³¹I release.

- (1) Calculated for a 975 Mw(e) BWR, 100,000 $\mu\text{Ci}/\text{sec}$ noble gas release rate after 30-minute holdup, and 700 $\mu\text{Ci}/\text{sec}$ Iodine release rate into reactor coolant.

$$\frac{X}{Q} : \text{Stack} - 2 \times 10^{-13} \text{ sec}/\text{cm}^3; \text{Building Vent} - 2 \times 10^{-12} \text{ sec}/\text{cm}^3.$$

- (2) Calculated for a 975 Mw(e) PWR, 0.5% failed fuel.

$$\frac{X}{Q} : \text{Building Vent} - 2 \times 10^{-12} \text{ sec}/\text{cm}^3; 3 \text{ cm}^3/\text{sec} \text{ Steam Generator Leakage Rate; 90 day gas decay tank holdup.}$$

† From Supplemental Statement of Dr. Walton A. Roger on behalf of Consolidated Utility Group, AEC Docket RM 50-2, 4/26/72.

TABLE V

ANNUAL PROBABILITY OF FATAL INJURY FROM RADIATION AND OTHER CAUSES

<u>Cause</u>	<u>Individual Probability of Fatal Injury or Effect per Year at Exposure</u>	<u>Reference</u>
Radiation (1 mrem/yr)	1×10^{-7}	Note 1 31,32
Natural Disasters	2×10^{-6}	33
Fossil Power Plants	4×10^{-6}	33
Electricity	2×10^{-5}	33
Firearms	2×10^{-5}	33
Air Pollution	1×10^{-4}	Note 2 27
Smoking	5×10^{-4}	Note 3 33
Automobiles	1×10^{-2}	33
All Diseases	1×10^{-2}	33

Notes:

1. Estimated from ICRP data, 31,32, which conservatively assumes effects observed at higher levels (100 rem) are linear with decreasing dose and dose-rate.
2. Assumes entire population exposed 100% of the time.
3. Assumes smoker at continuous risk.

TABLE VI

GENERAL POPULATION THIRTY YEAR DOSE LIMIT
(From All Non-Medical Sources)*

		<u>Reference</u>
ICRP	2.0 rem	36
Sweden	1.0 rem	37
United Kingdom	1.0 rad	38
U.S.S.R.	2.0 rem	39

*Does not include radiation workers.