SM-1461 10
CONF-700810--28

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

CRITERIA FOR THE CONTROL OF RADIOACTIVE EFFLUENTS*

By

K. Z. Morgan and E. G. Struxness
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Abstract

Some uniformity in regulating radioactive effluents from reactor power plants is highly desirable. Several approaches have evolved which fall short of providing information needed for realistic assessments of effluent hazard and the application of radiation protection guidelines oftentimes is superficial or mistaken. Failure to move toward uniformity in this area endangers both optimum development of nuclear energy and protection of the public health.

Frequently, three mistakes are made in this connection: (1) the rules and regulations fail to relate a given plant discharge rate to some potential population dose; (2) the dose criteria used for measuring "safety" do not make proper allowance for potential population doses from other sources; and (3) the planners or regulators, in the one extreme, overlook conservative approaches to keeping all doses as low as practicable or, in the other extreme, set an unreasonable price for radiation safety by demanding that all doses be kept as low as possible.

*Research sponsored by U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

It is suggested that a suitable basis for uniformity can be found in criteria based on recent recommendations of ICRP. The ICRP emphasizes that the annual dose to individuals and the genetically significant dose to whole populations are the important criteria for determining whether given operations are safe from the standpoint of radiation exposure. It de-emphasizes the desirability of placing reliance on secondary standards, such as the concentration of radionuclides in air and water at the boundary of a plant. Additionally, the ICRP's concept of "critical" radionuclides, pathways and population groups provides a practical mechanism for simplifying complicated assessments, taking account of the known or expected behavior of released radionuclides in the plant environs and their interactions with populations likely to be affected. Considering potential exposures and estimating doses in this context, it is then appropriate to compare the estimated dose(s) to critical group(s) with ICRP's population dose limits in deciding whether the release is "safe".

Factors are discussed that have a significant bearing on efficacy of the assessment, including: (1) description of released radioactive material; (2) environmental pathways; (3) bioenvironmental behavior of released radionuclides; (4) population distribution, habits and characteristics; (5) radiation dosimetry applications; (6) primary standards; (7) dose apportionment; and (8) dose criteria for reactor effluents.

Introduction

At the outset of these discussions, we would like to make it clear that although we are employees of Oak Ridge National Laboratory, members of the Health Physics Society and the International Radiation Protection Association, and closely associated with the work of the International Commission on Radiological Protection and the National Council on Radiation Protection, the opinions we express here are our own and do not necessarily represent the views of these organizations.

In discussing criteria for the control of radioactive effluents from reactors and associated facilities, it must be kept in mind that everything, including effluents from all power plants whether they operate with fossil fuels or nuclear energy, contains some radioactive material. Therefore, we will not consider how

these levels of radioactive contamination in effluents from reactors and their facilities can be reduced to zero or even to the lowest possible level but how the total contribution to the environment can be kept at a practical and reasonably safe level. Most of our discussions will deal with the matter of routine discharges of radioactive waste to the environment, but we will not overlook the possibility of rare events which might permit the accidental release of large quantities of radioactive material. In this latter case, we would like to make it clear at the outset that we will not consider a nuclear explosion of the type that occurs with the detonation of a nuclear weapon because such explosions with nuclear power plants and their facilities are impossible. In the case of routine discharges of radioactive wastes, we will be concerned at most with the release of a few curies per day resulting in a few microcuries/cc of air or water in the immediate environment of these facilities, and in the rare event of a major accidental release, we might be concerned with the rather sudden and short-period release of a percent or so of the fission inventory amounting to many gigacuries to the environment. Protection from occurrence of the latter type of release is provided by many safety features built into the reactor system and incorporated in operating procedures, in the several containment systems and in the isolation provided by the low population zone surrounding the facility and usually a considerable distance to the nearest population center. These features of the reactor system should be such that the probability of a major accidental release is exceedingly small (not greater than 10^{-4} and preferably as small as 10^{-5} accidents per year per reactor). If the probability of such an accident approaches a negligible value, we believe the principal thrust of this paper should be directed toward routine discharges of radioactive contamination. A study by Martin et al⁽¹⁾ has shown that the radioactive gases discharged from a boiling water reactor can produce more radiation exposure to man than the natural radioactivity from an older, less efficient-type of coal-burning power plant but that this cool plant can produce more air-borne radiation exposure than the gases from a pressurized water reactor. The air contamination by nuclear plants is predominantly from

radioactive noble gases (^{85}Kr most significant) which do not concentrate in the body and are responsible primarily for external exposure. In sharp contrast, radionuclides in fly ash, if soluble, are long-lived bone seekers (^{226}Ra , ^{228}Ra , ^{232}Th , ^{228}Th and ^{230}Th) and a kidney seeker (^{238}U) that may reside in body organs for a very long time. It follows, therefore, that for some types of power plants the radiation risk to persons living downwind may be greater from fossil fuel plants than from those operating on nuclear fuel. In addition, as indicated by Table 1,⁽²⁾ fossil fuel plants contribute about 25% of the nitrogen oxides and particulate matter and about half of the oxides of sulphur as major pollutants of our atmosphere. Therefore, in considering the acceptability of certain risks introduced by nuclear power plants, we must not overlook the desirability of choosing the lesser of the evils to man and his environment when meeting the future needs for electrical power. In addition to gaseous discharges of radioactive material from a nuclear power plant, there will be low levels of radionuclides in the cooling water, a small fraction of which reaches water in the human environment. This consists of a fraction of a microcurie/cc of water of mixed fission products such as ^3H , ^{90}Sr , ^{137}Cs , etc., and induced radionuclides such as ^3H , ^{24}Na , ^{32}P , ^{60}Co , etc. As will be emphasized in the following discussions, often the principal radiation risk to population in the neighborhood of these nuclear power plants is not from direct external exposure to the radioactive cloud or the internal exposure from drinking the radioactive water from the rivers below the plants but rather from the buildup or reconcentration of these radionuclides in certain parts of man's food chain.

In providing adequate radiation protection for members of the public, the concentration of radioactive materials in the air, water and food as a consequence of reactor operations must be kept at such a low level that the risks of somatic and genetic injury are exceedingly low and less than or comparable with those introduced by other common industries and they must be acceptable by the individual and the society of which he is a part. During the past few decades, there have been progressive (or perhaps regressive) changes in terminology used for setting acceptable levels of exposure, i.e., from tolerable

Table 1

SOURCE OF AIR POLLUTION⁽²⁾
(in millions of tons annually (1966))

	Carbon Monoxide	Sulfur Oxides	Nitrogen Oxides	Hydro- Carbons	Particulate Matter	Total
Motor vehicles	66	1	6	12	1	86
Industry	2	9	2	4	6	23
Power plants	1	12	3	1	3	20
Space heating	2	3	1	1	1	8
Refuse disposal	1	1	1	1	1	5
Total	72	26	13	19	12	142

to allowable to permissible to working level, etc. Some of these changes were introduced to get away from the concept that there is a level of exposure or a threshold dose which is tolerable and which would not produce any body damage. Some persons have not liked the use of the word "permissible" because it seems to suggest that this amount of exposure is quite acceptable and would not warrant measures to reduce exposures below this level. The expression of "maximum permissible exposure" has led to some difficulties because on occasion it has suggested that below this level one is safe, but at slightly above this level the person may suffer serious consequences. Although prior to about 1930 many persons thought there was a threshold dose of ionizing radiation below which there was little or no radiation damage, more and more information has accumulated since then to show that although there seems to be some repair of radiation damage in time, a certain fraction of the radiation damage is permanent and cumulative. Until man has developed a completely coherent theory of radiation damage, it may not be possible to state precisely the risk involved to a human population exposed to very low doses at very low dose rates. In animal studies as the doses under investigation become smaller, the number of animals required to prove the existence of an effect soon becomes prohibitively large. In human studies, there are many obvious difficulties in obtaining direct information on the effect of doses at levels considered acceptable as maximum permissible values. However, there has been a number of epidemiological studies by Brian MacMahon and others ⁽³⁾ of the effects of low diagnostic exposures, e.g., 1 to 3 rads to woman during pregnancy. Some of these studies have involved hundreds of thousands of children and indicate an increased incidence of leukemia of 30-40% among the children of these mothers compared to children not so exposed in utero. Genetic studies of Russell ⁽⁴⁾ indicate that for mice at decreasing dose rates, the number of point mutations per roentgen following exposure to oocytes of the female begins to drop off at about 5,000 R/hr, and the drop continues on presumably to the background level at dose rates below about 0.5 R/hr. However, for exposure of the spermatogonia of males, the drop-off in point mutations per roentgen begins at the same dose rate of

about 5,000 R/hr but having dropped by a factor of 3 reaches another plateau at about 50 R/hr and continues on this plateau with no further reduction in mutations per roentgen on down to doses as low as 60 mR/hr. Thus, the number of genetic mutations per roentgen for mice exposed at very low dose rates such as are commonly encountered at permissible levels appears to be reduced no more than by a factor of six below what is observed at high dose rates. With such data in mind, the only prudent assumption that can be made by agencies which set radiation standards (the National Council on Radiation Protection and Measurements, NCRP, and the Federal Radiation Council, FRC, in the United States and the International Commission on Radiological Protection, ICRP, on the international level) is and has been that there is no threshold dose or dose rate so low that the probability of radiation damage is zero, and there is always some risk of radiation damage even at very low doses and dose rates such as those recommended as acceptable for population exposure. Table 2 summarizes the basic assumptions made by ICRP⁽⁵⁾ in setting radiation protection standards and values of permissible dose. It has been the practice of ICRP, NCRP and FRC to set the permissible exposure values for members of the public at 10% of those allowed for the occupational workers. The reasons exposure levels for members of the public are set lower than those for the occupational workers are summarized in Table 3.⁽⁶⁾

From the above discussion, it is realized that permissible exposure levels to ionizing radiation for the occupational workers or members of the public are not set on the thesis that below these levels there will be no risk even of the more serious forms of radiation damage such as leukemia, thyroid cancer, bone tumors or mental defects and deformities to the offspring. However, they are set such that the risk is exceedingly low and, hopefully, sufficiently low to be worthy of acceptance by society in view of the benefits that are expected, in this case from the nuclear energy industry. The hypothesis used in setting these levels is that the risk is independent of dose rate and increases linearly with accumulated dose and the number of individuals exposed. Thus, the population risk can be doubled either by doubling the average accumulated dose or doubling the size of the exposed population; it would be increased by a factor of 4 by doubling both.

Table 2

BASIC ASSUMPTIONS MADE BY ICRP IN SETTING RADIATION PROTECTION STANDARDS AND VALUES OF PERMISSIBLE DOSE

1. They carry a negligible probability of severe somatic or genetic injuries.
2. Effects that ensue more frequently, e.g., life shortening, are of a minor nature and are acceptable to exposed individuals and by competent medical authorities. These effects are hidden by normal biological variations.
3. Severe somatic injuries, e.g., leukemia, are limited to an exceedingly small fraction of exposed group.

Table 3

**REASONS WHY RADIATION EXPOSURES OF THE POPULATION AT LARGE
MUST BE LESS THAN THOSE PERMITTED TO THE OCCUPATIONAL (6) (28)
WORKER**

1. These other groups are larger, hence contain a correspondingly larger number of individuals with injurious effects per rem of dose equivalent.
2. Employment involving occupational hazard from radiation exposure is voluntary and, in principle, the hazard can be foreseen by the individual accepting the risk that may be involved.
3. Industrial workers are screened so those least able to meet any particular hazard may be channeled into other activities.
4. In industry there can be evaluation and control of the hazards by radiation monitoring.
5. Population groups other than occupational are more likely to contain children and embryos that are more sensitive to radiation damage and also they may contain older adults who may be more susceptible to radiation damage.
6. The number of years of occupational exposure will be less than the number of years of environmental exposure.
7. Each industry cannot be permitted to impose a full measure of its peculiar occupational hazards on the environment.

Although at first it seems to surprise some people when they realize there is apparently no so-called safe level or threshold of exposure to ionizing radiation, this is by no means an unusual situation. For example, statistically, we can set the risk on a mile basis for travel by commercial airlines. Making some simplifying assumptions, again the risk of death in commercial airline accidents is doubled if on the average each traveler doubles the number of miles he rides on commercial airlines or if twice the number of people ride on commercial airlines.

The ICRP, NCRP and FRC have indicated that in setting levels of permissible exposure to radiation it is a matter of balancing the benefits against the risks as indicated in Figure 1. This can be set more easily as a principle than it can be carried out in practice. In the first place, one can justifiably ask who or what group is competent and sufficiently authoritative and representative to balance the risks against the benefits in setting these standards. The NCRP, ICRP and FRC are made up of scientists and medical men who set the levels of permissible exposure to ionizing radiation in terms of what are considered to be acceptable risks in comparison with other common risks in industry and society in general. They are aware of the great benefits from the use of ionizing radiation but have not carried out a quantitative analysis listing all the benefits with their weighting factors or balanced them against all the properly weighted risks from such exposure. In any case, such an all wise group would have to obtain for all forms of man-made sources of radiation a summation of the ratio of the benefits to the risks to all members of the population who may be at risk and/or who may receive benefits. It would be extremely difficult to attach a quantitative unit of measurement to each type of benefit and to each form of damage. Certainly in such a balancing act there would be many members of society who would receive great benefits with very few risks, while for others the reverse would be true. I doubt if it will ever be possible to carry out this balancing of benefits against the risks on a completely quantitative basis, but I believe those responsible for setting acceptable radiation exposure standards should strive constantly to do a better job in making these evaluations.

The aim of this paper is to show how dose limitations for members of the public should be applied in the control of radioactive effluents from nuclear power plants. It is important to emphasize that in the final analysis the primary and most essential limitation must be on the absorbed dose allowed to the critical body organs of individual members of the population and for the population as a whole. These absorbed dose limitations may be brought about by controlling a number of secondary and tertiary parameters, but the measures taken are not adequate unless they take into proper account factors of dilution and reconcentration, meteorological conditions, population size and age distribution, ecological factors, food chains and in summary all important parameters which determine what happens between the point of release of the radioactive contamination at the reactor (and fuel reprocessing facilities) and the dose received by the individual in the population.

Official U.S. Guides

As indicated by the previous speaker, L. Rogers, the U.S. Atomic Energy Commission has published a Code of Federal Regulations referred to as Title 10, Parts 20 and 100 which refer specifically to permissible dose equivalents and measures which are required of reactor operations to assure the protection of occupational workers and members of the public from excessive exposure to ionizing radiation. Because of the detailed discussion of these regulations by Rogers, I will refer simply to a few tables and a graph which summarize these rules and regulations. Table 4 indicates the permissible dose equivalents in unrestricted areas. Table 5 indicates the surveillance requirements to assure the permissible dose equivalents in unrestricted areas are not exceeded. Table 6 summarizes precautionary measures which are specified by the AEC to minimize the risk of exceeding the AEC dose limits. Figure 2 indicates the meaning of the terms, exclusion area, low population zone and nearest population center. It is to be noted that the facilities are to be so designed and operated, and the exclusion area and low population zones are to be so defined that in the case of major accidental releases of radionuclides, persons living in the exclusion area will not receive more than 25 rem total body dose or 300 rem to the thyroid from any two hour exposure.

Table 4**PERMISSIBLE DOSE EQUIVALENTS IN UNRESTRICTED AREAS
(AEC Title 10, Part 20.105)**

1. A person is permitted to receive no more than 500 mrem/year.
2. Areas which could be continuously occupied must not deliver to a person more than 2 mrem/hr.
3. Areas which could be continuously occupied must not deliver to a person more than 100 mrem/week.

Table 5**SURVEILLANCE REQUIREMENTS TO ASSURE PERMISSIBLE DOSE
EQUIVALENTS IN UNRESTRICTED AREAS ARE NOT EXCEEDED
(Title 10, Part 20.106)**

Concentrations of Effluents averaged over a year at boundary of restricted area must not exceed values in AEC Table II of Title 10, Ch. I. These values in most cases are 1/10 of the values given by ICRP Publ. 2 (1959)(7) and ICRP Publ. 6 (1964)(19) for continuous occupational exposure, 168 hrs/wk.

Table 6

**PRECAUTIONARY MEASURES SPECIFIED BY THE AEC TO MINIMIZE RISK
OF EXCEEDING AEC DOSE LIMITS
(Title 10, Parts 20 & 100)**

1. Licensee shall "minimize the radioactivity discharged in effluents to unrestricted areas."
2. Licensee shall make "such surveys as may be necessary for him to comply with the regulations."
3. "Reactors will reflect through their design, construction and operation an extremely low probability of accidents that could result in release of significant quantities of radioactive fission products."

- (1) Distance $C \geq 4/3$ distance Z
- (2) In Low Population Zone:
 - (a) persons subject to protective measures;
 - (b) person must not receive > 25 rem total body dose or > 300 rem to thyroid from exposure during time of passage of cloud.
- (3) In Exclusion Area:
 - (a) highways, railways and waterways subject to closure and persons subject to evacuation;
 - (b) person must not receive > 25 rem total body dose or > 300 rem to thyroid from two hours' exposure.

FIGURE 2

Persons living in the low population zone must not receive more than these same doses from exposure during the entire time of passage of the radioactive cloud. Populations in both areas are subject to protective measures such as evacuation and the use of shelters in case of the passage of a radioactive cloud. There is perhaps not much which can be done effectively to assure protection of populations once the radioactive cloud passes beyond the boundary of the low population zone. However, the nearest boundary of a population center with greater than 25,000 inhabitants must not be closer to the reactor than $4/3$ of the distance of the boundary of the low population zone from the reactor. This means that under the worst meteorological conditions some persons living in the nearest population center also might receive doses approximately equal to the limiting design values for persons living in the low population zone. Table 7 indicates, for example, the possible consequences of 10% of such average exposure to a population of 10^6 persons during the time of a major reactor accident if one makes use of data provided by the ICRP.⁽⁸⁾

Before discussing the guidelines set by FRC and the recommendations of ICRP, it should be noted that in Title 10, Part 20, the AEC specifies that for routine discharge of radioactive materials from a nuclear power plant, it may be necessary to limit the quantities of released radioactive materials under certain circumstances into the air or water if it appears the daily intake of radioactive material from air, water or food by suitable samples of the exposed population averaged over a period of a year would otherwise exceed the daily intake from continuous exposure to air or water containing $1/3$ the concentration of radioactive materials specified in AEC Table 2 of Title 10, Chapter 1. As indicated above, MPC values in this AEC table in most cases correspond to 10% of the MPC values given in ICRP Publications 2⁽⁷⁾ and 6⁽¹⁹⁾ for continuous exposure of the occupational worker 168 hours per week. These occupational MPC values in turn correspond to dose rates to the standard man after 50 years of occupational exposure as given in column 2 of Table 8. Thus, the dose rates given in column 3 of Table 8 correspond approximately to the MPC values given in AEC Table 2 of Title 10, Chapter 1. One-third of these AEC MPC values would correspond approximately to the dose rates listed in column 4

Table 7

**CONSEQUENCES OF AN EXTREMELY RARE HYPOTHETICAL REACTOR DESIGN
ACCIDENT**

<u>Type of Radiation Damage</u>	<u>Consequences of Exposure of 10⁶ Persons to 10% AEC Design Exposures^Δ</u>	
1. Genetic	40*	(1700)**
2. Fatal Neoplasms		
Leukemia	40	
Other Cancers	40	
3. Thyroid Carcinoma	40 ‡	(400)
4. Life Shortening	120 ^{¶¶}	
Total		300 to 2300

^Δ This assumes 10⁶ persons are exposed to an average of 10% of the AEC Design Exposures (i.e., 10% of 25 rem to total body and 10% of 300 rem to thyroid). This assumes the linear hypothesis of ICRP⁽⁸⁾ applies.

*This includes only the 1st generation genetic deaths and assumes the factor of 1/6 applies.

**This includes genetic deaths in 40 subsequent generations and assumes the factor of 1/6 applies.

‡ This includes only 10% of the thyroid carcinomas on assumption 90% respond successfully to medical treatment.

¶¶ This assumes 70 years of life shortening corresponds to one death.

Table 8
RECOMMENDED PERMISSIBLE DOSE RATE

Critical Body Organ	Values Recommended by ICRP for Occ. Worker (rem/y)	AEC Values Corresponding* to AEC, Table II, Title 10, Ch. 1 (rem/y)	Limiting AEC Values Under Special Circumstances (mrem/y)	Radiation Protection Guides Given by FRC9,10,14 for Exposure of Population Groups During Normal Peacetime (mrem/y)
Gonads, total body & red bone marrow	5	0.5	170	170
Skin, bone**	30	3	1000	500 [‡]
Other internal organs	15	1.5	500	

* These are estimated dose rates reached in the indicated body organ following intake of water or air concentrations of radionuclides given in AEC Title 10, Ch. 1, Table II by the typical adult individual continuously for 50 years.

** Thyroid was originally included with this group but is included now with "other internal organs".

[‡] This FRC-RPG was given only for bones.

of Table 8. It is to be noted that the first value in this column 4 of Table 8 is the same as the average genetically significant dose limit set for the total population by the ICRP and the FRC. Values of FRC radiation protection guides for exposures of population groups are given in column 5 of Table 8.

The average population dose in the U.S. at the present time from the nuclear energy industry is not known. We obtain this average population dose by dividing the total dose received by everyone in the U.S. (from all operations of the AEC contractors and from nuclear power plant operations) by the total population of the U.S. Our rough estimates indicate this dose is about 0.5% of the limiting AEC dose of 170 mrem/y or less than 1 mrem/y. This includes both the dose received by the occupational workers and the environmental dose from these operations. It does not include the fallout dose from atmospheric testing of nuclear weapons.

For illustration we have assumed in obtaining values in Table 9 that everyone in the U.S. received 0.5% of this 170 mrem/y (or 0.85 mrem/y) and that the linear hypothesis of ICRP(8) applies. On such assumptions this low level continuous exposure would result in about 18 deaths/y or about 140 deaths introduced into the population per year as indicated in column 2 of Table 9. The genetic deaths would be limited to those among the live births but in the case of the 140 deaths/year most of these deaths would occur over the next 40 generations (1200 years). Also for comparison we have indicated the number of deaths per year in case the nuclear energy industry were to permit everyone in the U.S. to receive 0.5% of the present AEC dose limitations listed in column 4 of Table 8. In this case, as indicated in column 3 of Table 9, there would be about 30 deaths/y and 150 deaths introduced into the population per year. The values in Tables 7 and 9 are rounded off in order not to imply unwarranted accuracy.

We believe the deaths per year listed in column 2 of Table 9 represent an upper limit to the radiation deaths per year from present operations of the nuclear energy industry in the U.S.

The realism of these estimates of risk and their acceptability depend on many factors beyond the realm of this discussion. We expect the assumptions made in Tables 7 and 9 lead to maximum estimates of radiation deaths and that at least

Table 9

**CONSEQUENCES OF HYPOTHETICAL EXPOSURE OF
POPULATION-AT-LARGE TO ROUTINE RADIOACTIVE
EFFLUENTS FROM REACTORS**

<u>Type of Radiation Damage</u>	Consequences of Exposure of Entire U.S. Population to:	
	<u>0.5% of Limiting Dose Rate (0.85 mrem/y)</u>	<u>0.5% of AEC Limiting Dose Rates (of Col. 4, Table 8)</u>
1. Genetic	3* (120)**	3* (120)**
2. Fatal Neoplasms		
Leukemia	3	3
Other Cancers	3	14***
3. Thyroid Carcinoma	0.2 [‡] (2)	0.7 [‡] (7)
4. Life Shortening	9 ^{‡‡}	9 ^{‡‡}
Total		
	18 to 140	30 to 150

* This includes only the 1st generation genetic deaths and assumes the factor of 1/6 applies.

** This includes genetic deaths in 40 subsequent generations and assumes the factor of 1/6 applies.

*** This assumes 1/2 of cancers originate in bone and 1/2 in other tissue.

[‡] This includes only 10% of thyroid carcinomas on assumption 90% respond successfully to medical treatment.

^{‡‡} This assumes 70 years of life shortening corresponds to one death.

for the next 30 years it is reasonable to expect the probability of a design accident such as that assumed in Table 7 or others of greater magnitude is less than 10^{-4} per year per reactor, i.e., less than one on the average per 50 years for an average of 200 operating power reactors. This would be equivalent in terms of 1st generation deaths to the crash of one of the larger aircraft every 50 years; hopefully the risk is less than 10^{-5} . If, however, the risk of a design accident is as large as 10^{-4} , the average risk over the next 50 years for an average of 200 nuclear power plants, in terms of average deaths per year, is less than one-half the risk from the routine operation of the nuclear energy industry, (i.e., 6 compared to 18 deaths/y or 46 compared to 140 deaths/y introduced into the population). Since any worthwhile enterprise of man is possible only by accepting certain inherent risks, the nuclear energy industry probably is not exception. The choice, therefore, seems to be between these relatively small hypothetical risks of the nuclear energy industry and the very real risks of power shortages or a smog polluted environment and the associated respiratory diseases we might expect from fossil fueled power plants. If the population of the U.S. doubles by the year 2000 and the average dose to this population increases to 5% of the limiting AEC dose of 170 mrem/y (i.e., increases to an average of 8.5 mrem/y from the nuclear energy industry) the risk on the ICRP⁽⁸⁾ linear hypothesis for routine operation of reactors will have increased to 360 deaths/y and will be introducing 2800 deaths per year into future generations. If the risks of a design accident remained about the same in the year 2000, the total risks in terms of death/y would be less than the present risks of death in the U.S. from automobile accidents during a typical 3-day holiday weekend or the total deaths/y introduced into future generations would be less than those at present from automobile accidents in a single month. This contrast with automobile accidents justifies neither the automobile accident rate nor any relaxation in our vigilance in maintaining radiation risks of the nuclear energy industry as low as practicable. It emphasizes that health physicists must continue their efforts in maintaining the nuclear energy industry as one of the safest of all industries and must set a good example which will be emulated by the others.

In 1958 the Federal Radiation Council (FRC) was authorized by Congress to "advise the President with respect to radiation matters directly or indirectly affecting health." As instructed by Congress, it "consults qualified scientists and experts in radiation matters, including the President of the National Academy of Sciences, the Chairman of the NCRP, and qualified experts in the field of biology and medicine and health physics." The Secretary of Health, Education and Welfare is Chairman of this Council which consists of the Secretary of Health, Education and Welfare, Secretary of Labor, Secretary of Agriculture, Secretary of Commerce, Secretary of Defense, Chairman of the U.S. Atomic Energy Commission and the Special Assistant to the President for Science and Technology. The FRC publications have provided information on the amount of fallout from weapons tests and estimates on the possible consequences. They provide data, also, on some of the more important radionuclides that are of concern in the routine operation of nuclear power plants and of those of primary concern in case of reactor accidents. FRC Report No. 2⁽⁹⁾ provided three ranges to serve as guidance for surveillance and control of radioactive contamination. These ranges are related to the probability of exposed individuals reaching or exceeding the radiation protection guides, RPG's (column 5 of Table 8). The RPG's are defined as absorbed doses to individuals of the general population which warrant protective action and that should not be exceeded without careful consideration of the reasons for doing so. It was indicated that every effort should be made to encourage the maintenance of radiation doses as far below these guides as practicable, and these guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so. Intakes in Range I would not under normal conditions be expected to result in any appreciable number of individuals in the population reaching a large fraction of the RPG. The only action required in this range is surveillance adequate to provide reasonable confirmation of calculations. Exposures in Range II are still not expected to exceed the RPG's but are high enough to require control

measures, to observe trends and to be on the lookout for sudden rises in the activity which could lead to levels above the RPG unless certain countermeasures were taken. Exposures in Range III would be presumed to result in exposure exceeding the RPG if continued for a sufficient period of time. Transient rates of intake within this range could occur without the population exceeding the RPG if the annual average intake fell within Range II or lower. "Control actions would be designed to reduce the levels (from Range III) to Range II or lower and to provide stability at lower levels. These actions can be directed toward further restriction of the entry of radioactive materials into the environment or the control of radioactive materials after entry into the environment in order to limit intake by humans. Sharply rising trends in Range III would suggest strong and prompt action." Table 10 summarizes some of the values suggested for these ranges by the FRC for some of the more important fallout that might occur during the operation of nuclear reactors. In general, Range I is where operations would be expected, and Range II should not ordinarily be exceeded.

The FRC^(11,12) has provided three categories of exposure to the radio-nuclides which are considered to be of greatest concern in reference to fallout from nuclear operations, i.e., strontium-89, strontium-90, cesium-137 and iodine-131. Table 11 summarizes the values of protective action guides, PAG, for these three categories of exposure.

When the FRC was first established, some of us were very optimistic in the hope that this organization would make a serious attempt to balance the benefits against the risks in the use of ionizing radiation as illustrated in Figure 1. Unfortunately, this has not been the case. Some effort has been made by the FRC to review the risks discussed in reports of ICRP, NCRP, United Nations Scientific Committee on the Effects of Atomic Radiation, the National Academy of Sciences, etc., but no effort has been applied toward matching these risks against the benefits as illustrated in Figure 1. Also, it was hoped that the FRC

Table 10

VALUES SUGGESTED BY FRC FOR RANGES OF RADIONUCLIDES

<u>Range</u>	<u>^{131}I (pCi/d)</u>	<u>^{90}Sr (pCi/d)</u>	<u>^{89}Sr (pCi/d)</u>
I	0 - 10	0 - 20	0 - 200
II	10 - 100	20 - 200	200 - 2000
III	100 - 1000	200 - 2000	2000 - 20,000

Table 11

FRC PROTECTIVE ACTION GUIDE ^{11, 12}

Category

- I** Applies to early transmission (mostly 1st 100 days) by pasture-cow-milk-man pathway. The PAG for individuals is 10 rad from ^{89}Sr , ^{90}Sr and ^{137}Cs in 1st yr to bone marrow or whole body and the total integrated dose must not exceed 15 rad (assumed that total dose of ^{89}Sr and ^{137}Cs = 1st yr dose or 10 rad and total dose of ^{90}Sr = 5 x 1st yr dose $\leq$ 15 rad*). In the case of ^{131}I the PAG is met if the average dose to the thyroid is $\leq$ 30 rad/yr to the individual or $\leq$ 10 rad/yr to a suitable sample of children of approximately 1 yr of age using milk from a reasonably homogeneous supply. It is assumed the PAG is met if the average projected dose to a suitable population sample $\leq$ 1/3 above values for individuals (i.e. 10 rad/yr for ^{131}I , 3 rad/yr for ^{89}Sr and ^{137}Cs , and 1 rad/yr for ^{90}Sr).
- II** Applies to dietary transmission during the 1st yr by pathways other than Category I. The PAG for individuals is 5 rad from ^{89}Sr , ^{90}Sr and ^{137}Cs in 1st yr to bone marrow or whole body. Assumed the PAG is met if average projected dose to a suitable population sample $\leq$ 2 rad in 1st yr.
- III** Applies to long-term transmission of ^{90}Sr through soil into plants. (May apply to ^{137}Cs for 1 to 2 years). Doses to bone marrow after 1st yr may exceed 0.5 rad to individuals or 0.2 rad to a suitable population sample thus requiring appropriate evaluation and action.

* Although not stated specifically this implies the 1st yr dose of ^{90}Sr should not exceed 3 rad.

would take the initiative in ferreting out potentially dangerous radiation risks and take appropriate action before the development of serious consequences. In particular, we have in mind 1) the fallout of ^{131}I during the Nevada weapons tests leading to considerable population exposure in some cities of the U.S. in 1962 and 2) the exposure of uranium miners in the Colorado plateau area of the United States during the past decade. In spite of the 1961 statement of the FRC⁽⁹⁾ quoted above regarding actions that would be appropriate for Range III, when the "chips were down" and milk producers in the Salt Lake area were putting their cows on dry feed and replenishing their supplies with imported milk because the milk levels were in Range III, the FRC recanted its position in a letter dated August 29, 1962, to the Joint Committee on Atomic Energy stating, "We want to point out that the guides are not intended to set a line at which protective action should be taken or indicate what kind of action should be taken." The situation regarding exposure of uranium miners illustrates the lack of action by the FRC until its hand was forced. As early as the year 1500, it was known that miners of certain ores (later discovered to contain uranium) died after a few years of mining of a so-called miners' disease. It was many years later before it was recognized that these deaths were attributable to lung carcinoma resulting from exposure to the daughter products of radon given off from the uranium in these mines. Centuries later it was observed that bronchogenic, epithelial carcinomas appeared five to 20 years following exposure in the Schneeberg mines of Saxony and the Joachimsthal mines of Bohemia. In spite of these centuries of unhappy human experience from exposure of miners to uranium ores, the Federal Radiation Council did not take the initiative in calling attention to the many miners in the Colorado plateau who were engaged in mining operations where the levels of exposure probably were equal to or greater than those that led to early tragic experiences, and in any case they often were 10 to 100 times the levels set by ICRP^(7,19). Even after the seriousness of this problem was brought into focus by the excellent work of Holaday⁽¹³⁾ and others with the Public Health Service, the FRC

was slow in recognizing the problem and taking appropriate action. Finally, after long delays, the FRC recommended what amounted to 1 working level, WL, which was three times the 0.3 WL recommended by the Department of Labor. This 0.3 WL was approximately equal to the value which ICRP⁽⁷⁾ had recommended ($3 \times 10^{-8} \mu\text{c/cc} \approx 0.3 \text{ WL}$) in 1959. An even greater disappointment to some of us is the fact that the Federal Radiation Council has failed to take any action regarding what is by far the principal source of man-made exposure, namely, excessive and unnecessary medical exposure. Many studies have indicated that diagnostic exposure can be reduced at least by a factor of 10 with very little effort. It is much higher in the United States than other advanced countries of the world and comprises on the average over 90% of all man-made exposure in the United States. It is encouraging that the FRC provided so much information in evaluating the problem associated with fallout from testing nuclear weapons which in the U.S. at the peak of fallout amounted to about 5 mrem/y but discouraging that it has done nothing to reduce the genetic medical diagnostic dose of 55 mrem/yr. Of greater concern is the fact that although in 1960⁽¹⁴⁾ and 1962⁽⁹⁾ it first published the 170 mrem/yr as the average genetically significant dose and dose to the whole body and bone marrow of the population, it made no attempt to indicate how this dose might be apportioned among various sources of ionizing radiation. In its early publications,^(5,7) the ICRP suggested how this genetically significant dose might be apportioned, but in more recent publications⁽¹⁵⁾ it has delegated this responsibility to the various countries by stating, "The Commission wishes to point out that it is important to insure that no single type of population exposure take up a disproportionate share of the total. The way in which this is done will depend upon circumstances which may vary from country to country and will be determined by national, economic and social considerations." If the FRC had taken this matter seriously some years ago and assigned some reasonable percent of the 170 mrem/yr to the nuclear power industry, it is very likely that some of the heated discussions, misunderstanding and controversy in the United States regarding the appropriateness of this exposure level for reactor siting might have been avoided. We have no

doubt that the AEC never intends to permit the nuclear power industry to use up all the total recommended population dose (averaged over the entire U.S. population) but it is clear that some persons are interpreting AEC Regulations, Title 10, Part 20 to this effect and the FRC could have assisted if it had apportioned the 170 mrem/y to various man-made sources of exposure as recommended by ICRP.

The National Council on Radiation Protection and Measurements has had considerable influence in setting the official U.S. guides for radiation protection. Most of those who have prepared reports for the Federal Radiation Council have been members of NCRP. The basis of the AEC values in Table 2 of Title 10, Chapter 1, are essentially 10% of the occupational values given in the NCRP⁽¹⁶⁾ Handbook 69. These NCRP values, in turn, are almost identical to those given in ICRP Publication 2 because many members of the NCRP committee which prepared the NCRP internal dose handbooks Nos. 52⁽¹⁷⁾ and 69⁽¹⁶⁾ were also members of a corresponding ICRP committee which prepared the ICRP internal dose handbook. Thus, the NCRP recommendations need not be discussed further at this time.

ICRP Recommendations

In view of the fact that the recent past chairman of ICRP has discussed the scientific basis for ICRP recommendations, there seems little need here to do more than summarize some of these recommendations. Table 8, column 3, lists the ICRP recommended dose limits for members of the public with the exception that the 0.5 is not specified as a limit for total body dose. In addition, the limit of 7.5 rem/yr is given for exposures to hands, forearms, feet and ankles.⁽¹⁵⁾ As indicated above, ICRP in its earlier publications recommended 5 rem/30 yr (corresponding to an average of 170 mrem/yr) as the genetically significant dose for a population. This continues to be a firm recommendation of ICRP, but, unlike its earlier publications, ICRP no longer attempts to subdivide this 170 mrem/yr among various sources of radiation exposure in a given population but rather encourages the various national bodies to perform this function taking into account the various sources of radiation and their importance to the population. The size of the population over which this genetically significant dose might be

averaged appropriately has never been defined clearly but is understood to be a population of similar social and ethnic backgrounds such that there is relatively unrestricted intermarriage among members of the population. For simplicity, it is often taken as the entire population of a country, but in some countries or communities it might be considered appropriate to take a particular ethnic group or social or religious segment of society over which to average this dose. ICRP considers that dose equivalent to a critical organ of the body is the basic or primary recommendation. In the case of internal dose, organ burdens would be a secondary recommendation, microcuries taken into the body per day a tertiary recommendation, and microcuries/cc a quaternary recommendation. The values in column 3 of Table 8 are planned exposures for individuals of the public and are referred to as dose limits. In the case of unplanned exposures from uncontrolled sources such as accidents, ICRP suggests various action levels be set by appropriate national authorities and that careful plans be made in order to offer guidance and appropriate action should certain emergencies arise. In most routine reactor operations, extensive monitoring of all elements in the environment including the population is not necessary. The ICRP⁽¹⁸⁾ emphasizes that pre-operational surveys should be made, and from these and as a result of surveys continued after operations begin, it should be possible to select with considerable reliability the critical radionuclides, their critical pathways and the critical groups in the population. The critical radionuclides are those most likely to present problems in terms of ultimate exposure to man and/or detrimental effects on the environment. The critical pathways represent the various food chains including, for example, irrigation as one step by which these radionuclides may be transported and concentrated as they pass through the various stages of the ecosystem where they may produce damage directly or indirectly to man. The critical group in the population is that group of individuals relatively small in number and reasonably homogeneous that is considered to receive the largest dose to critical body organs and/or to receive the greatest damage from the radioactive contamination. Some of the facts which must be considered in selecting this critical group are location and age distribution, dietary habits, special occupational habits,

type of dwelling and heating equipment, domestic habits, hobbies, etc. The critical group may for example be limited to males, females, pregnant women or children of a given age. It may be individuals who eat certain types of food, religious groups that follow certain customs or persons with certain illnesses which affect their habits or metabolism. In any case, it is recognized that due to individual variability there will always be some spread in the dose received within such a critical group in spite of the fact that it is relatively homogeneous from practical considerations. The Commission⁽¹⁸⁾ allows half of the members of this critical group to exceed its dose limits in that the average dose of the critical group may be equal to but not greater than the dose limits given in column 3 of Table 8. It recognizes further that there will always be some members in a large population which have peculiar habits which markedly enhance radionuclide uptake, for example, an individual who may obtain a large fraction of his food from fish soup in which the bones as well as the flesh of the fish are consumed. In such cases the doses he receives may be considerably greater than the recommended dose limits even though the ICRP's recommendations are complied with in that the average dose received by the critical group does not exceed these limits. This recommendation of ICRP is perhaps less restrictive than the AEC Regulations summarized in Table 4 in that the AEC states its dose limits are applicable to the individual and not the average dose received by a critical group.

The ICRP wisely points out that it is important that the design of the monitoring program should be reconsidered from time to time, and the initial design may have to be revised in terms of oversights, underestimates and new information. In our operations over more than a quarter of a century at Oak Ridge National Laboratory, we have found it extremely important to carry on certain forms of environmental monitoring in order to assure ourselves that our early estimates and those revised from time to time regarding the dose limits are sufficiently conservative. One can point to page after page of calculations which seem to show an operation is very safe, but this can never be as convincing as occasional grass samples, samples of fish and milk, studies of iodine uptake by the thyroids of cattle, sampling of various crustaceans

in the rivers, occasional total body counts of a few inhabitants from the population and results of continuously monitoring air samples and river sampling devices downwind and downstream, respectively, from the reactor operations. The magnitude and extent of such confirming evidence which is desirable depends upon the circumstances, the magnitude of the operation, the size of the exposed population, the types of radionuclides that may be discharged, etc.

Interpretation and Application of Radiation Protection Guides

As indicated above, the basis for limiting exposures of members of the public is the dose to critical body organs and not derived criteria. In early ICRP publications^(5,7), it was suggested that for planning purposes, one might as a first consideration use 1/10 of the MPC values for continuous occupational exposure as acceptable levels for the public, and because of environmental and human factors, an additional factor of 1/3 might be applied in the case of somatic exposure and an additional factor of 1/10 applied for genetic exposure. In other words, the suggestion was that in planning the discharge from a reactor or radioisotope facility into the public domain one might as a first consideration set acceptable concentrations of radionuclides in air and water such that in the case of radionuclides for which gonads are the critical tissue, the values were 1/100 of the MPC values for continuous occupational exposure. For all other radionuclides, the values might be set at 1/30 the MPC values for continuous occupational exposure. In retrospect perhaps this statement of ICRP had best not have been made because it has been misunderstood on so many occasions. We believe what ICRP really intended to say and what it has clearly emphasized in all subsequent publications^(15,19) is that the dose to individual members of the population or the average dose to critical segments of the population should not exceed 10% of the values for the critical organs recommended by ICRP for the occupational worker (ICRP population dose limits listed under column 3 of Table 8). Ten percent of the MPC values for continuous exposure of occupational workers is not the same as 10% of the dose values listed in column 2 of Table 8 for many reasons, some of which are as follows: (1) the MPC values for continuous exposure of the occupational worker are derived for the standard or typical man and may not apply for the child, infant, or uterine individual, or members in the

population who have certain diseases. For example, if the child drinks the same quantity of milk per day as the standard man and has a thyroid 1/10 the size of an adult, the dose to the child's thyroid would be roughly 10 times that to the standard man. The metabolic characteristics of many members of the population may differ substantially from those of the standard man, and there may be groups in the population for which the eating and breathing habits, e.g., the water and air consumed per day, differ markedly from those of the standard man; (2) the MPC values for continuous exposure to the occupational worker are based on the dose rates reached in the critical body organs after 50 years of occupational exposure at a constant concentration of the radionuclides in air or water. For exposure of the public to long-lived radionuclides such as strontium-90 and plutonium-239, the calculation should be based on the dose rate reached in the critical organs after at least 70 years of exposure; (3) the MPC values for continuous exposure of the occupational worker apply specifically to air and water. They can be applied to most foods since (with the exception of certain foods such as butter) most foods are comprised principally of water. However, if, for example, a reactor operation were to rely solely on maintaining the levels of radionuclides in the air and water at its boundaries at 10% or less of the ICRP MPC values for continuous occupational exposure (or the AEC values in Table 2 of Title 10, Chapter 1), no consideration would be given to the possibility of reconcentration factors in the environment. It is well known that when radioiodine contained in air at the permissible concentration is washed out by rains and settles in the grass of a dairy farm, it is theoretically possible that the concentration of iodine in the milk could be 1,000 or more times the permissible concentration. Likewise, in river systems the bones of fish and certain crustaceans may concentrate some of the radionuclides by factors of 10^5 or more. Therefore, although the levels of radioactivity in the air and water as they pass over the boundary of the reactor operation or exclusion area may be equal to or less than the values given in AEC Table 2, Title 10, Chapter 1, or 10% of ICRP's MPC values for continuous exposure to the occupational workers, such numbers alone do not provide assurance that members of the population

are adequately protected. In many instances, there may be dilution factors due to meteorological conditions in the air or the mixing in river systems such that 10% of the ICRP MPC values for continuous exposure of the occupational worker is unnecessarily conservative. Furthermore, the exposure limits for members of the population (Table 8, column 3) are given on an annual basis and high dose rates are quite acceptable provided the integrated annual doses do not exceed the values given in Table 8, column 3. On the other hand, barring these dilution factors and in circumstances where reconcentration factors may lead to excessive annual doses of large populations or to critical groups of the populations such operations would be unacceptable. As explained previously, the ICRP has indicated that it usually is not necessary to carry out very extensive environmental monitoring at reactor and isotope facilities, but in preplanning and in subsequent studies to confirm the accuracy of calculations and the safety of an operation, it is essential that a number of various types of measurements be made to assure that the critical segment of the population has been properly identified and that no factors of reconcentration have been overlooked. Usually, the values given in column 3 of Table 8, should be regarded as upper limits of dose to individual members of the population, but ICRP would allow some slight deviation from this rule by applying these values to the average dose received by the critical segment of the population and not the maximum dose to any single individual. From a few limited studies by Snyder and Cook⁽²⁰⁾, it is not anticipated that the maximum would exceed the average in this homogeneous critical segment of the population by a factor greater than 3 approximately 5% of the time although it is recognized in exceptional cases the deviation would be much greater.

As explained above, one reason for departing from terminology such as maximum permissible, allowable, or tolerable dose was that it left the impression that such doses were quite acceptable and that no effort need be made to stay below these levels but that serious trouble would result if these doses were exceeded. It was for this reason that the Federal Radiation Council used such terms as radiation protection guides. Throughout the publications of ICRP, it is emphasized repeatedly that maximum permissible doses, dose limits, action levels,

radiation protection guides, etc., are not to imply a serious risk to the individual should they be exceeded. On the other hand, every effort should be made to operate as far below these levels as practicable (not as far below as possible). How far below these levels "is practicable" is a matter that must be given due consideration by the national authorities when authorizing radioisotope and nuclear facilities with reference to each particular site. Due account must be given as discussed later to the use factor, reconcentration, population size and other sources of radiation exposure to the population. With sufficient expenditure, the concentration of radioactive effluents from a power plant could always be maintained very low and even lower than ambient levels in the environment. Although the levels of radioactivity added to the effluents by a power plant could be kept at such a level that the dose to the critical segment of the population would not exceed, for example, 1/1,000 of the dose levels summarized under column 5 of Table 8, this might not be necessary or worth the effort unless it could be done at little or no cost to the operation. If measures to keep the population dose far below dose limits set in Table 8 were very expensive, the goals probably should be set with less stringent standards. In any case, the purpose of health physics protection would be defeated if the required operating levels for a nuclear power plant were set so low that a fossil fuel plant was constructed at a site and especially if in exchange the population doses from radioactive effluents from the plant were higher than those from a nuclear plant which, in addition, would not discharge chemical contaminants into the environment.

Criteria for the Control of Routine Discharges of Radioactive Effluents from Nuclear Energy Establishments

In the remainder of this paper, we shall consider routine discharges from nuclear energy establishments of low activity effluents to the atmosphere or to some nearby river. Problems associated with release of high activity debris following a serious reactor accident are special situations outside the scope of this paper, requiring considerations primarily related to reactor design, engineered

safeguards and reactor siting. We shall concern ourselves here only with the development of criteria for the control of routine discharges from normally operating nuclear energy installations (e.g., research reactors, power reactors, fuel reprocessing plants, etc.). While our discussion deals with this matter as we would face it in the U.S., we hope that the principles involved apply in any nuclear country.

Criterion as used here means the dose allocations and corresponding secondary and tertiary standards that are selected and applied in this context to keep the actual or potential doses to man from this single type of population exposure, i.e., the exposures of members of the public to routine radioactive discharges from nuclear establishments, as low as practicable.

In presenting this, we recognize a number of obstacles which must be overcome before these suggestions are likely to be accepted by today's public. There is a credibility gap concerning basic radiation protection standards in the U.S. created by the claims of some that current permissible dose limits of the Federal Radiation Council are too high and that population exposures up to these levels will produce deaths numbering in the tens of thousands. There is another credibility gap concerning nuclear reactors themselves. Nuclear power reactors are being criticized in the U.S. today on grounds that their effluents are hazardous to the public or that they release dangerous amounts of radioactivity. Another obstacle is today's concern for environmental quality. This concern for environmental values co-exists with an unprecedented public demand for participation in nearly all facets of the decision-making process. Thus, any criteria for the control of all waste effluents, not just reactor effluents, must be prudent and presented in language the public can understand so that the public can make the choice in its own self interest.

Factors for Consideration in Selecting Criteria for the Control of Radioactive Discharges to the Environment

Our study of the radiological problems with routine discharges of low activity effluents from nuclear establishments leads us to enumerate several factors which we believe should be considered by national authorities in selecting dose

allocations and corresponding secondary and tertiary standards to be applied in this context. Let us be reminded again that we are concerned here only with the radiological effects of radioactive materials in effluents discharged to the environment and not with other considerations as, for example, thermal effects in the environment.

(1) The main objective of these criteria should be to protect man. This is not to say that ecological effects are unimportant, but rather that routine discharges from normally operating nuclear plants have not been shown to be of ecological significance. The possibility of ecological effects must not be ignored, however, now or in the future.

(2) For the reason given in (1) above, the basis for control should be the actual or potential dose to man, he being the radiation receptor of primary concern. The ICRP suggests that the basis for limiting radiation exposures of members of the public should be "the dose to the various body organs (of man) and not the derived criteria by which the dose is controlled."⁽²¹⁾

(3) The actual or potential radiation dose to man from exposure to routine discharges of low activity effluents from nuclear plants should not take up a disproportionate share of the actual or potential radiation doses from all sources, excluding natural background and medical sources. This follows from other guidance offered by the ICRP: "-----it is important to ensure that no single type of population exposure takes up a disproportionate share of the total."⁽²²⁾

(4) The ICRP recommends that the genetic dose of 5 rems in 30 years from all sources, excluding natural background and medical sources, be apportioned for planning purposes to allow for development of nuclear energy programs.⁽²³⁾ Underscoring the importance attached to this problem, the ICRP, in one of its early reports⁽²⁴⁾, suggested an illustrative apportionment. This came to be regarded as having more significance than the ICRP intended, so its latest report merely summarizes the contributions to genetic dose from various sources and suggests that the actual apportionment should be done by national authorities.⁽²⁵⁾ As stated before, we believe the Federal Radiation Council should get on with this task now so that an appropriate dose allocation and the corresponding criteria can be applied in this context. Incidentally, because of the comparatively high

mean genetic dose to the U.S. population of 55 mrem/year from medical exposures, we believe, contrary to the ICRP's point of view, that this should be considered in the FRC's apportionment of genetic dose for the U.S.

(5) With the possible exception of the criterion related to genetic dose in (4) above, there is reason to believe that dose allocations to organs other than gonads applied in the control of radioactive discharges to the environment could vary from place to place, just as other environmental qualities vary from one area to another. Such situations, however, are not likely unless there is evidence that a given population group's exposure history is, and will continue to be significantly higher than the norm from whatever radiation source, natural or man-made.

(6) The dose allocations applied in controlling radioactive effluents should be revised from time to time as knowledge is obtained on the population doses from low activity effluents. The present U.S. criteria⁽²⁶⁾, for example, are essentially ten years old; we believe it's time they were recast. The 10 CFR 20 Rules and Regulations are subject to misinterpretation and, in some measure, are responsible for the current controversy concerning the hazard of reactor effluents.

(7) The present plans to reduce and control country-wide air pollution in the U.S., where the Federal government and the States cooperate in establishing ambient air quality standards and air quality control regions, could be extended to include the control of radioactive pollutants as well, permitting use of the capabilities of existing pollution control agencies at the federal, state and local levels to implement an effective radiation monitoring program in the geographical areas where it is needed now and in other areas of the country as the need arises. We believe the radiation monitoring program should be established in officially designated natural air basins and watersheds in which the nuclear establishments are located. Unlike the air quality control regions being designated presently, where political subdivisions within given areas appear to be an important consideration in setting the boundaries of control areas, we believe the control areas should be small, natural air basins and watersheds (whose boundaries need not necessarily coincide) where climate, meteorology,

hydrology and topography form a more or less homogeneous environmental unit. These control areas should not be so large in areal extent that the radionuclide identities and concentrations in environmental media attributable to the nuclear plant(s) in question are "lost" long before the air or water has reached the boundaries of the basin. Other considerations in setting the boundaries of control areas would be: land use, the presence of other polluters, the jurisdiction of existing pollution control agencies, population density and distribution, and perhaps others.

(8) The control area in (7) above should be monitored in accordance with the principles of environmental monitoring defined by the ICRP.⁽¹⁸⁾ The monitoring program would then "trace" the critical radionuclides through critical exposure pathways to the critical population group. The aim is to obtain only that information on the above "critical" factors needed to obtain a valid estimate of annual population doses or assurance that annual population doses do not exceed an upper limit of dose. Control area monitoring should supplement that required of the plant operator in (9) below.

(9) Each nuclear plant operator should be required to monitor his operations such that the emissions of radionuclides discharged in significant amounts from the plant site are known and reported to the pollution control agency in the air basin or watershed involved. Here, too, the environmental monitoring principles described in ICRP Publication 7⁽¹⁸⁾ should be applied.

(10) The restrictions placed on radioactive discharges from a given nuclear plant by the pollution control agency in the air basin or watershed involved, aimed at keeping the population doses within a selected radiation dose allocation, should be based on actual plant performance, and not on design specifications or predictions.

(11) A technical basis should be established in each air basin or watershed (control area) which will serve to limit radioactive discharges from nuclear plants currently in operation and which will afford a logical basis for limiting additional discharges to the air basin or watershed from nuclear plants of the future.

Establishment of Criteria for Radioactive Discharges to the Environment. It is not within our purview to suggest what quotas or dose allocations of the currently permissible dose limits should be assigned to this type of population exposure, i.e., the exposures to members of the public to radioactive contamination in the environment due to discharges of radioactive effluents from normally operating nuclear plants. This should be done by an appropriate national authority as, for example, the Federal Radiation Council in the U.S. In establishing a country's dose allocations for this type of population exposure, the national agency should take account of the following: (1) the country's current inventory of radiation and radioactive contamination sources that cause significant population exposures (in numbers of people exposed and/or in actual or potential doses received) and estimated population doses resulting therefrom; (2) the country's plans for expanding nuclear energy programs and increasing the number and/or size of nuclear plants (e.g., power reactor plants and reactor fuel reprocessing plants); (3) the country's population exposures from other significant radiation or radioactive contamination sources (e.g., population groups living downwind or downstream from existing nuclear plants, population groups living in areas where world-wide fallout levels are above average or where unusual concentrations of fallout radionuclides occur, population groups experiencing above average radiation doses from medical and dental X-ray exposures, etc.) and (4) other social and economic considerations, attempting some sort of balancing of benefits and risks. When this is done, it might be expected that some appropriate fraction of each permissible dose limit for each critical organ will be allocated to this particular type of population exposure. For purposes of simplifying the application of these dose allocations in practice, some practical limits (e.g., permissible concentrations of radionuclides in air and water, permissible daily intakes, or permissible body or organ burdens of radionuclides) can be derived from these dose allocations and applied as in usual health physics practice. We would prefer that it become standard health physics practice to carry the assessment through to an estimate of organ dose or at least, short of that, to an estimate of radionuclide intake. These values, then, are the "criteria" referred to in the context of limiting population exposures from radioactive discharges to the environment.

Implementing and Applying Radiation Dose Allocations to Radioactive Effluents

We look upon the potential benefits and risks of nuclear energy programs as being worthy an entire nation's concern. We, therefore, believe that an important degree of planning and regulating of the nuclear industry should rest with agencies of the national government, such as, for example in the U.S., the Federal Radiation Council, the Atomic Energy Commission, the Public Health Service. Perhaps other agencies in the U.S. government also should be involved, e.g., the President's Council on Environmental Quality, the Federal Power Commission, and the proposed Environmental Protection Agency. We believe the leadership and coordination needed should be provided by the Environmental Quality Council. The main objective of such planning and regulating at the federal level should seek to place the nuclear plants in the safest and most effective locations. Once this is accomplished, most, if not all, of the radiological safety problems are minimized and rather easily managed. Another important objective of activities both at the federal and state levels should be a forthright program of public education about nuclear energy, including its benefits and its risks.

To apply the dose allocations, and the corresponding secondary and tertiary standards, in this context will require a carefully designed area monitoring program. The aim is to establish a reasonable program that provides the information needed to evaluate the impact of low activity discharges from nuclear plants to an air basin or watershed in terms of population radiation doses. The low activity levels and the consequent low population doses to be expected will require an accurate monitoring system that focuses sharply on (1) the physical and biogeochemical behavior of radionuclides released to the basin in significant amounts and (2) the population factors which affect the actual or potential radiation dose to the critical organs of concern.

Designation of Control Areas. Federal agencies, such as the Environmental Sciences Service Agency (ESSA) and the U.S. Geological Survey (USGS) in the U.S., should be given responsibilities to define the air basins and watersheds which will serve as control areas for radioactive discharges to the atmosphere and to rivers, respectively. These environmental units will suggest themselves,

to begin with, because of the common climate, meteorology and topography in air basins, and the common climate, topography and hydrology in the watersheds. The boundaries of the air basins and watersheds need not coincide. Further definition of the boundaries of a given air basin or watershed may be suggested by other factors held to be in common such as land use, water use, industry, agriculture, recreation, etc. The boundaries of these control areas, in our opinion, should not be set by state or local political subdivision, although that may be the only practical solution in some circumstances. Once the boundaries of the control areas have been tentatively established the pollution control agencies at the federal, state and local levels should conduct public hearings in the geographic areas involved to allow citizens or their representatives a chance to be heard and to understand all of the implications involved in the designation. This is a very important first step, and the success of succeeding steps in the procedure hinges largely on the effectiveness and public understanding and acceptance of these designated control areas.

Establishing Minimal Area Monitoring Requirements. The federal agencies responsible for establishing the boundaries of the control area, presumably on the basis of good information concerning the meteorological and hydrological characteristics of the air basin or watershed involved, together with the federal, state and local pollution control agencies concerned, should reach an agreement on the restrictions to be applied and the minimal monitoring program that will be required. If the state or local authorities involved wish to apply tighter restrictions on nuclear plant discharges, and therefore to implement a more elaborate monitoring program, than those required to meet federal requirements, and if such restrictions are compatible with those of the neighboring control areas, they should be permitted to do so.

Monitoring the Control Area. Some pollution control agency having responsibilities in the control area (e.g., state or local public health departments, state or regional air and water pollution control boards, and environmental protection agencies) should assume responsibility for implementing the area monitoring program. The meteorological and hydrological characteristics of the control area and monitoring information

should be built into a dispersion model and computer program that will permit estimates of intakes or dose estimates to be made relative to exposure of individuals and/or critical groups. The results of monitoring, which will be in terms of annual average doses, should be made public as frequently as desired, or at least four times each year. These dose estimates should be reported in terms understandable to the public.

Applying the Criteria. Given an effective area monitoring system based on (1) knowledge of the radioactivity being released from the nuclear site(s); (2) models simulating meteorological and hydrological characteristics of the basin which tend to disperse the activity released from the nuclear site(s); (3) understanding of the exposure pathways leading to man; and (4) dosimetry techniques for estimating and/or measuring radiation doses received by man, it is then possible to assess the population exposure situation in the control area at any time, comparing the actual or potential dose(s) to the critical group(s) with the dose allocations established for that area.

As the first nuclear plant in a control area "comes on stream", and its performance is demonstrated, the pollution control agency in the control area may choose to allow routine discharges which result in a population dose or dose estimate up to the full level of the dose allocation; however, as succeeding nuclear plants are built and their discharges are added to the basin "load", then proportionate decreases in the respective discharges of each plant will be required.

It should be understood that the steps outlined above are taken only where and as the need arises. For example, the designation of control areas should begin only with the geographical areas in which power reactors or nuclear installations are currently operating or soon to be built. From there on, the designations and implementations can proceed into other areas, as new plants are built and the nuclear industry expands.

It is possible also that the discharges of radioactive effluents from some plants, after their operations have been demonstrated and their effluents monitored, are so insignificant that area monitoring programs will not be required, i.e., the plant operator's monitoring reports will be sufficient to assure the public that the plant's discharges are not hazardous.

REFERENCES

- (1) **MARTIN, JAMES E., HARWARD, EARNEST D. , OAKLEY, DONALD T.,** Comparison of radioactivity from fossil fuel and nuclear power plants, Public Health Service, Department of Health, Education and Welfare (November 1969).
- (2) "Considerations affecting steam power plant site selection," a report sponsored by the Energy Policy Staff, Office of Science and Technology, and submitted as part of Hearings before the Subcommittee on Air and Water Pollution on S.7 and S.544, Serial 91-2, Part 4, p. 1109.
- (3) **MACMAHON, BRIAN,** X-ray exposure and malignancy, JAMA, Vol. 183, p. 721 (1963).
- (4) **RUSSELL, W. L.,** Studies in mammalian radiation genetics, Nucleonics, Vol. 23, No. 1 (January 1965).
- (5) **International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, ICRP Publ. 1, paras.30-31, Pergamon Press, London (1959).**
- (6) **Somatic radiation dose for the general population: Ad Hoc Committee Report of the National Committee on Radiation Protection and Measurements, May 6, 1959, Science 131, 482 (1960).**
- (7) **International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, ICRP Publ. 2, Pergamon Press, London (1959).**
- (8) **International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, ICRP Publ. 8, Pergamon Press, London (1966).**
- (9) **Federal Radiation Council, Background Material for the Development of Radiation Protection Standards, FRC Publ. 2 (Sept. 1961).**
- (10) **Federal Radiation Council, Health Implications of Fallout from Nuclear Weapons Testing Through 1961, FRC Publ. 3 (May 1962).**
- (11) **Federal Radiation Council, Background Material for the Development of Radiation Protection Standards, FRC Publ. 5 (July 1964).**
- (12) **Federal Radiation Council, Background Material for the Development of Radiation Protection Standards, Protective Action Guides for Strontium-89, Strontium-90, and Cesium-137, FRC Publ. 7 (May 1965).**

- (13) **HOLADAY, D. A.,** Radiation hazards in uranium mines, *Radiological Health Data* 3, 135 (1967).
- (14) **Federal Radiation Council,** Background Material for the Development of Radiation Protection Standards, FRC Publ. 1 (May 13, 1960).
- (15) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 9, Pergamon Press, London (1966).
- (16) **Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure,** Recommendations of the National Committee on Radiation Protection, National Bureau of Standards Handbook 69 (1959).
- (17) **Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water,** Recommendations of the National Committee on Radiation Protection, National Bureau of Standards Handbook 52 (1953).
- (18) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 7, Pergamon Press, London (1965).
- (19) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 6, Pergamon Press, London (1964).
- (20) **SNYDER, W. S., COOK, M. J.,** Variability of relative organ concentration of trace elements in human tissue, *Health Physics*, Vol. 9, pp. 57-62 (1963).
- (21) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 9, p. 13, para. 74, Pergamon Press, London (1966).
- (22) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 9, p. 15, para. 87, Pergamon Press, London (1966).
- (23) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 6, p. 32, para. 65, Pergamon Press, London (1964).
- (24) **International Commission on Radiological Protection,** Recommendations of the International Commission on Radiological Protection, ICRP Publ. 6, p. 31-32, para. 65, Pergamon Press, London (1964).

- (25) International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, ICRP Publ. 9, p. 16, paras. 88 through 94, Pergamon Press, London (1966).
- (26) U. S. Atomic Energy Commission Rules and Regulations, Title 10, Parts 20 and 100, Code of Federal Register.
- (27) MORGAN, K. Z., Adequacy of present standards of radiation exposure, Testimony before the Subcommittee on Air & Water Pollution of the Senate Committee on Public Works, Washington, D. C., 1970.
- (28) MORGAN, K. Z., TURNER, J. E., Principles of Radiation Protection, John Wiley & Sons, Inc., New York, London, Sydney (1967).