방사선방어학회지
제12권 제2호 1987

Exposure of the Population in the United States to Ionizing Radiation

Dr. Melvin W. Carter
President, International Radiation Protection Association
and
Neely Professor, Georgia Institute of Technology Atlanta, Georgia, United States
and
Mr. Robert W. Oliver
Georgia Institute of Technology

• Abstract •

The exposure of the population in the United States to ionizing radiation has recently been evaluated by the National Council on Radiation Protection and Measurements (NCRP). This was done by constituting six organizational groups to address various phases of the work and the results of this work are summarized in this article. The article is based on the report, by the same title, which is scheduled for publication by the NCRP in September, 1987.

The six organizational groups are titled Radiation Exposure from Consumer Products, Natural Background Radiation, Radiation Associated with Medical Examinations, Radiation Received by Radiation Employees, Public Exposure from Nuclear Power, and Exposure from Miscellaneous Environmental Sources. These titles are descriptive of the subject areas covered by each of these separate groups.

The data evaluated are for the years 1977-1984 with the majority of the data being for the period 1980-1982. Summary information is presented and discussed for the number of people exposed to given sources, the effective dose equivalent, the average effective dose equivalent to the U.S. population, and the genetically significant dose equivalent.

The average annual effective dose equivalent from all sources to the U.S. population is approximately 3.6 mSv (360 mrem). Exposures to natural sources make the largest contribution to this total. Radon and radon decay products contribute 2.0 mSv (200 mrem) whereas the other naturally occurring radionuclides contribute 1.0 mSv (100 mrem).

Among man-made or enhanced sources, medical exposures make the largest additional contributions, namely 0.39 mSv (39 mrem) for diagnosis and 0.14 mSv (14 mrem) for nuclear medicine. It was not possible to evaluate exposures for therapy.

Most of the other sources of population exposure, including nuclear power and consumer products, are minor. A possible exception would be the use of tobacco products. These exposures are discussed in relation to a negligible individual risk level of 10 μSv/y (1 mrem/y). The NCRP considers exposures below the negligible individual risk level as trivial and as such should be dismissed.

INTRODUCTION

1. Sources of Population Exposure

Members of the United States population are inevitably exposed to sources of ionizing radiation, some to a few sources and others to a wide variety of such sources. These sources are of three general types, man-made sources, those of natural origin and unperturbed by human activities, and those of natural origin but affected by human activities(termed enhanced natural sources).

The natural sources include cosmic radiation, terrestrial radiation from natural radioactive sources, radiations from radionuclides naturally present in the body and radionuclides of natural origin which are inhaled and ingested. The varying human exposures depend upon location and other special circumstances. If these exposures are substantially above the average they are refered to as "elevated".

Enhanced natural sources are those for which man's actions, deliberate or otherwise, have increased human exposures. Examples would be air travel at high altitudes and people living in house built on phosphate or other waste landfills containing elevated levels of radionuclides. Another example world be indoor radon exposures which result from elevated natural levels of radon in structures. On the other hand, exposures to the nuclear fuel cycle are usually covered as a separated case of man-made exposures rather than enhanced exposure from natural sources.

A wide variety of exposures results from man-made materials, devices and activities. These include radiopharmaceuticals and x-rays in medicine, smoke detectors and static eliminators containing radioactive materials, accidents in nuclear power plants, atmospheric nuclear weapons tests, etc.

This report is the first time that a comprehensive effort has been made to determine the overall exposure from all sources of ionizing radiation to the U.S. population. In the presentation of data and related discussion, it is convenient to categorize the sources of exposure according to their origins, namely: natural radiation, occupational, nuclear fuel cycle, consumer products, miscellaneous environmental sources due to human activities, and medical diagnosis and therapy. The information and data available in these various areas are variable in terms of their accuracy and quality and these limitations will be noted in the discussion.

2. Earlier Surveys and Assessments

International assessment activities have been reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UNSCEAR, 1958) and by joint groups of the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) (ICRPICRU, 1957, 1961) on medical exposures. Such efforts emphasized global considerations rather than national assessments of population exposure. The UNSCEAR reports, however, continue to provide global assessments of population exposures from a variety of sources and rely on well-documented critical assessments of exposures at the national level to a substantial degree (UNSCEAR, 1982).

An early assessment of the exposure of the population in the U.S. by Moeller, Terrill, and Ingram (1953) drew attention particularly to medical diagnostic radiation and natural background radiation exposures. For the former, the average annual dose to a limited region of the body was estimated at about two roentgens to a "large portion" of the U.S. population whereas the latter source was estimated to result in an exposure of about nine roentgens in a 70-year lifetime. Less important sources considered were medical therapy, dental x-rays, x-rays in industry and research, radioisotopes in medicine, radium in luminous paints, static eliminators, transportation of radioactive materials, nuclear reactors. and particle accelerators. Due to the fragmentary nature of much of the data for these sources, definitive conclusions on the magnitude of the relevant radiological problems could not be reached.

A report of the Federal Radiation Council (FRC) in 1960 contained a section on sources of radiation exposure (FRC, 1960). Conclusions were that natural sources produced average annual dose equivalents to bone marrow, gonads and soft tissue of between 0.8 mSv (80 mrem) and 1.7 mSv (170 mrem) whereas from medical sources the annual genetically significant dose (GSD) was 0.8 mSv (80 mrem) to 2.8 mSv (280 mrem) and the mean bone marrow dose was of the same order. Fallout from weapons tests resulted in an average GSD of 0.53 mSv (53 mrem) for the following 30 years if there were no more atmospheric nuclear tests subsequent to the test moratorium beginning in 1958, but some eight times the dose if atmospheric testing were resumed and continued at the same rate as for the previous five years. For these two circumstances, the 70-year mean bone marrow dose would be 3.3 mSv (330 mrem) and 26.5 mSv (2, 650 mrem), respectively. At that time, the population dose from radionuclide releases from the nuclear fuel cycle was considered to be insignificant.

Another effort of the FRC in 1970 led to a report by the U.S. Environmental Protection Agency (EPA) in 1972 (EPA, 1972) on U.S. population exposure to environmental sources for the years 1960-1970 with projections to the year 2000. In 1960, the average annual natural background exposure was 1.3 mSv (130 mrem) while exposure from previous atmospheric weapons test fallout was expected to drop to three percent of the natural background by 1970 and remain relatively constant through 2000. All other environmental sources were considered to be minor.

A later EPA report (EPA, 1977) concluded that the major categories of collective exposure of the U.S. population to ionizing radiation were environmental radiation, medical and dental radiation, application of pharmaceuticals in medicine, and technologically enhanced natural radiation. On an individual basis the largest doses were attributed to technologically enhanced natural radiation, medical radiation, environmental radiation, consumer products, occupational and industrial operations, and federal nuclear facilities. In the first category, radon was idenified as responsible for high individual doses when it was released from uranium mill tailings that had been used in the construction of residences. This report also stressed to make major improvements in the data base for dose assessment in the U.S.

3. Quantities and Units

The biological effects of concern are the small probabilities of stochastic effects such as cancer induction and/or sever genetic effects. This is due to the low doses likely to be received by members of the public and the presumption that the expected doses will be well below the thresholds for any nonstochastic effects. The only exception would be possible nonstochastic side effects in therapy patients and these are beyond the scope of this report.

The dosimetric quantities used in this report include the absorbed dose, the dose equivalent, the effective dose equivalent, the collective effective dose equivalent, and the genetically significant dose equivalent.

The *absorbed dose, D,* is the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.

The *dose equivalent, H,* is a quantity used for radiation protection purposes that expresses on a common scale for all radiations, the irradiation incurred by exposed persons. It is defined as the product of the absorbed dose, D, and the quality factor, Q, which accounts for the variation in biological effectiveness of different types of radiation.

For the purpose of relating exposure to risk, a convenient quantity is the *effective dose equivalent,* H_E, which is either H_{wb}, the dose equivalent when the whole body is irradiated uniformly, or the weighted sum of the dose equivalents, H_T, to each of the tissues(T) of the body, *i.e.,* $H_E = \sum H_T w_T = H_{wb}$. By such weighting, one obtatins a value of H_E which is estimated to be proportional to the radiation-induced risk (somatic and genetic) even though the body is *not* uniformly irradiated. In this report, the effective dose equivalent and the weighting factors (w_T) defined by the International Commission on Radiological Protection (ICRP, 1977, 1978) are used.

Among the exposures to be described in this report are some that result in the irradiation of specific organs or tissues only (such as the lung in the case of radon), others that result in partial irradiation of the body (as in many medical procedures), and some that irradiate the entire body more or less uniformly (such as cosmic radiation). To account for these differing circumstances the effective dose equivalent is appropriate.

For the irradiation of selected organs, the dose equivalent to the organ will specified in this text and the appropriate weighting factors will be used to obtain H_E. For "whole-body irradiation", the dose equivalent, H_{wb}, will be the same as the effective dose equivalent for that circumstance. Measurements of the dose equivalent to the whole body are usually only approximations to H_{wb} which are, however, considered acceptable. These approximations vary with the circumstances and, in the case of photons, are more accurate for high energies than for low energies(ICRU, 1985).

For each source and source category, the number of people involved and the average effective dose equivalent to those exposed will be presented. The *collective effective dose equivalent* is obtained by multiplying the average effective dose equivalent to the exposed population by the number of people exposed. This collective effective dose equivalent is then divided by the entire U.S. population (230, 000, 000 in 1980) to obtain the average effective dose equivalent for a member of the U.S. population. This quantity is, in some circumstances, such as occupational exposure, a highly artificial number but it is nevertheless useful for comparison purposes.

For purposes of expressing the genetic risk, a convenient quantity is the *genetically significant dose equivalent* (GSD). This is the dose equivalent to the gonads weighted for the age and sex distribution of the irradiated population, *i.e.,* to take into account the expected number of future children for each sex and age category. The GSD is expressed in sieverts (hundreds of rem). The gonadal dose equivalent is an upper limit to the GSD and when the dose equivalent is small, the gonadal dose equivalent itself may be used for the GSD. Additionally, when the exposure is to the entire U.S. population, the average gonadal dose equivalent and the GSD are equal.

In some instances, the dose equivalent to some specific organ will be the quantity of interest for deriving the H_E or the GSD. These organ dose equivalents are listed in the tables where appropriate.

Most of the exposures to be discussed below arise from radiation having low linear energy transfer (LET); where high-LET alpha-ray sources are involved, a quality factor, Q, of 20 will be applied to absorbed doses to estimate the dose equivalents. For neutrons, the quality factor will be specified where appropriate.

Throughout this report, SI units will be shown first followed by the value in present conventional units in parentheses. Conventional prefixes in the SI system (micro, milli, etc.) will also be used.

The terms "dose" and "exposure" will also be used throughout the text in their general sense.

4. This Paper

The information and data presented in this paper are summarized from the Report (NCRP, 1987h) prepared by Scientific Committee 48 (SC 48) of the National Council on Radiation Protection and Measurements (NCRP). Six assessment groups, Radiation Exposure from Consumer Products, Natural Background Radiation, Radiation Associated with Medical Examinations, Radiation Received by Radiation Employees, Public Exposure from Nuclear Power, and Exposure from Miscellaneous Environmental Sources, provided input materials for use by SC 48 in preparing its Report, "Exposure of the Population in the United States to Ionizing Radiation".

Each of the assessment groups, except that on Miscellaneous Environmental Sources, will produce and publish its separate detailed report. These reports are titled and referenced as follows:

Public Radiation Exposure from Nuclear Power Generation in the United States, NCRP Report 92(NCRP, 1987a)

Exposure of the U.S. population from Natural Background Radiation(NCRP, 1987c)

Radiation Exposure of the U.S. Population from Occupational Radiation(NCRP, 1987d)

Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources(NCRP, 1987e)

Radiation Exposure of the U.S. Population from Medical Examinations(NCRP, 1987f)

The reader is referred to these individual reports for additional detail regarding their respective subject areas.

In the material to follow we shall summarize the contributions of each source category to the average effective dose equivalent and genetically significant dose to the U.S. population. Also covered will be the range of uncertainty in the estimates and some suggestions for improvement in future information and data.

Certain sources are minor in significance and if they produce an annual dose equivalent of less than 10 μSv (I mrem) to an individual they can be dismissed from further consideration. This level is defined by the NCRP as the negligible individual risk level (NCRP, 1987b). The NCRP assumes that it is highly unlikely that many persons would be exposed to more than ten such very small sources of exposure.

The various categories of radiation exposure will also be discussed in relationship to whether or not efforts at dose reduction are considered.

Higher exposures would appear to justify more effort at reduction and, when appropriate, dose reduction methods will be addressed.

RESULTS AND DISCUSSION

1. Exposure of the U.S. Population from All Sources of Ionizing Radiation

The numbers of people exposed to these sources, the effective dose equivalent to those exposed, the effective collective dose equivalent, and the average effective dose equivalent to the U.S. population are presented in Table 1. Table 2 contains the contributions of the exposures to the GSD.The data covers various years within 1977-1984, with most being during 1980-1982.

The average annual effective dose equivalent from all sources to the total U.S. population is obtained by summing the annual collective effective dose equivalents and dividing by the U.S. population in 1980, namely 230,000,000. The resulting value is about 3.6 mSv (360 mrem) on an annual basis for all people in the U.S. from all sources, exclusive of tobacco products. The average daily effective dose equivalent from all sources to the entire U.S. population is approximately 0.01 mSv (1 mrem).

Additional exposures occur to the 50,000,000 people who smoke from the naturally occurring radionuclides in tobacco products. The effective dose equivalent is difficult to estimate, may not be meaningful, and appears to average about 0.16 Sv per year (16 rem per year) to a small segment of the bronchial epithelium (the exposure probably depends upon the number of cigarettes smoked).

The Genetically Significant Dose from Table 2 is a total of approximately 1.3 mSv/year (130 mrem/year) from all known sources. This includes a small contribution from consumer products which irradiate the whole body.

Figure 1 summarizes the data contained in Table 1 in graphic from. The relative contributions of the various sources of exposure to the annual effective dose equivalent to the U.S. population are depicted as percentages of the total.

2. The Most Significant Exposures

The data presented (Table 1 and Figure 1) show that the greatest contribution to the average annual effective dose equivalent for members of the U.S. population is from natural sources. Among these natural sources, radon and its decay products indoors account for about two thirds of the total of the average annual effective dose equivalent, although they make a small contribution to the annual GSD.

These estimates for exposure from radon and its decay products are higher than those reported earlier by the NCRP (NCRP, 1975). The increase in the bronchial epithelium dose equivalent is due to the use of a higher quality factor for alpha particle radiation and higher estimates of radon levels indoors. Exposures of other sources of naturally occurring radioactivity and radiation have changed very little from 1975.

Among man-made or enhanced sources, medical exposures contribute the largest additional exposure. These exposures are different in character however, from inadvertent exposures, in that they contribute to the benefit of the specific individual receiving them. Other people are affected only through the GSD to the population. Furthermore, medical exposures as a source appear to be smaller than formerly estimated. This is mainly due to the method of dose calculation utili-

Table 1. Annual Effective Dose Equivalent to the U.S. Population Circa 1980-82

Source	Number of People Exposed (thousands)	Average Annual Effective D.E. to the Exposed Population (mSv)[b]	Annual Collective Effective D.E.[a] (person-Sv)[c]	Average Annual Effective D.E.[a] to the U.S. Population (mSv)[a]
Natural sources				
Radon	230, 000	2.0	460, 000	2.0
Other	230, 000	1.0	230, 000	1.0
Occupational	930[d]	2.2	2, 000	0.009
Nuclear fuel cycle	—[e]	—	136	0.0005
Consumer products				
Tobacco[f]	50, 000	—	—	—
Other	120, 000	0.05-0.3	12, 000-29, 000	0.05-0.13
Miscellaneous environmental sources	~25, 000	0.006	160	0.0006
Medical				
Diagnostic	—[g]	—	91, 000	0.39
Nuclear Medicine	—[h]	—	32, 000	0.14
Rounded Total	230, 000	—	835, 000	3.6

a. Dose Equivalent
b. 1 mSv = 100 mrem.
c. 1 person-Sv = 100 person-rem.
d. The nominally exposed total 1.68×10^6
e. Collective doses were calculated to the regional population within 80㎞ (50 miles) of each facility.
f. Effective dose equivalent difficult to determine; dose to a segment of bronchial epithelium estimated to be 0.16 Sv/y (16 rem/y).
g. Number of persons exposed is not known. Number of examinations was 180 million and H_E per examination 500 μSv.
h. Number of persons exposed is not known. Number of examinations was 7.4 million and H_E per examination 4, 300 μSv.

zing the effective dose equivalent which accounts for the fact that many medical exposures are only to part of the body.

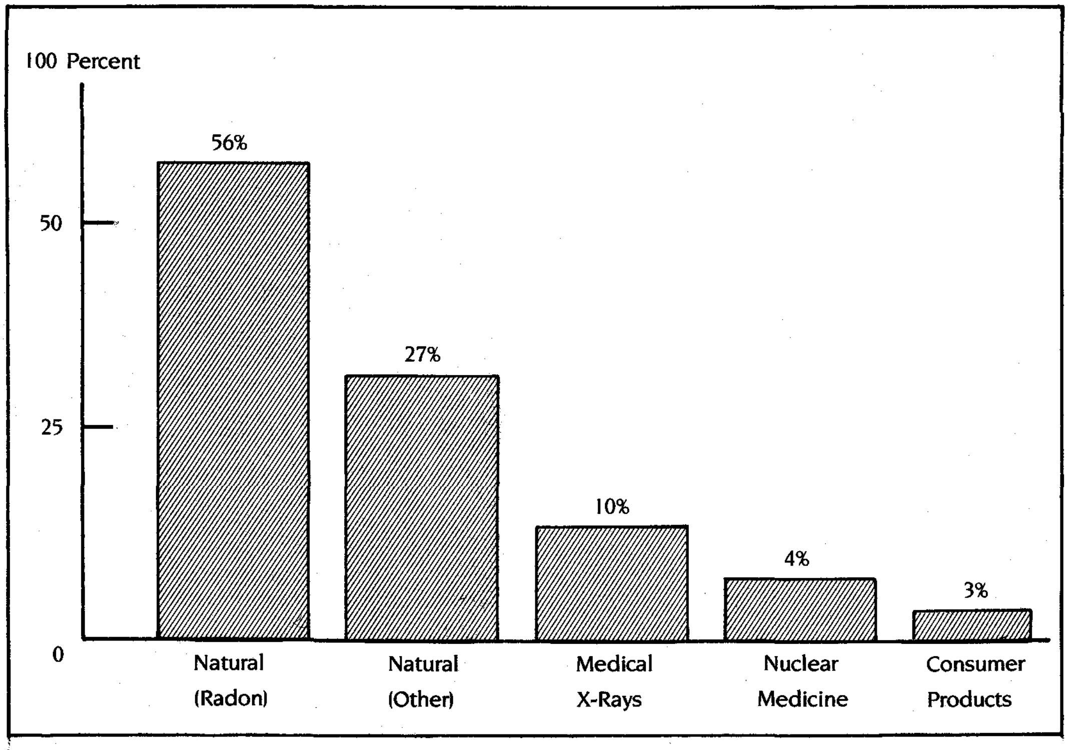
The contributions from all the other sources, including occupational, nuclear fuel cycle, miscellaneous environmental sources, and consumer products(with the possible exception of tobacco products), are minor.

Table 2. Annual GSD to the Population Circa 1980-82

Source	Contributions To Gsd (mSv)[a]
Natural Sources	
Radon	0.1
Other	0.9
Occupational	~0.006
Nuclear fuel cycle	<0.05
Consumer products	
Tobacco	—
Other	~0.05
Miscellaneous	
Environmental sources	<0.001
Medical	
Diagnostic	0.2-0.3
Nuclear Medicine	0.02
Rounded Total	~1.3

a.1 mSv = 100 mrem.

Figure 1. Most Significant Contributors of Exposure of the U.S. Population



3. Special Considerations

The various uncertainties in the data are usually on the order of two or three. However, they are much less for exposures from cosmic and terrestrial radiation but much greater for exposures to some consumer products.

For the most important exposure, namely that of the lungs to radon and its decay products, many uncertainties exist. These include our limited knowledge of both the average and the distribution of radon concentrations indoors in the United States, problems concerned with the dosimetry of alpha particles in the lungs, and the assessment of an actual effective dose equivalent from this source.

In the case of smokers, additional uncertainties arise because of the small region of bronchial epithelium exposed to a relatively high dose and the difficulty of assigning a meaningful weighting factor to obtain an effective dose equivalent. The exposure circumstances resulting from smoking tobacco should continue to be the subject of further examination.

The use of the effective dose equivalent has made it possible to combine the exposures from the several different source categories and thus to determine an average annual effective dose equivalent to the U.S population, which, presumably, has some meaning with respect to the overall somatic risk. Similarly, the GSD enables estimates from different sources to be combined into an average GSD that presumably has some meaning for overall genetic risk. However, additional uncertainties are probably introduced with these combinations.

Another difficulty arises in combining data from different sources. The data are not for the same years. The occupational exposures are mainly, but not entirely, for the year 1980. The medical exposures from diagnostic x-rays are for the year 1980 whereas those for nuclear medicine are for 1982. Transportation data included in miscellaneous environmental sources are for the year 1983. Exposures from sources such as consumer products and natural radiation have been assessed over a period of years whereas the muclear fuel cycle estimates are for the early 1980's. Theses factors, primarily, render very difficult the definition of an accurate average exposure for members of the U.S. population in any given year and thus the observation of precise trends from year to year. Nevertheless, it seems that a firmer base for such exposures is beginning to be established.

RECOMMENDATIONS

1. Recommendations for Dose Redution

Natural background is the largest contributor to the average effective dose equivalent to individuals in the U.S. population. Its components include external cosmic and terrestrial radiation, radionuclides in the body, and inhaled radon and its decay products. External cosmic radiation varies some degree with altitude but is otherwise essentially constant over the United States. External terrestrial radiation varies little over the surface of the United States in normal (undisturbed) circumstances. Radionuclides in the body (other than radon), mainly ^{40}K, are essentially constant. None of these three is amenable to dose reduction in any obvious and simple way.

Radon as a source is not only the largest component of natural background, it is also the most variable. It may be responsible for a substantial number of lung cancer deaths annually (NCRP, 1984b), but its actual concentration indoors is still not well known in all parts of the country. Consequently, NCRP Reports No. 77 and No. 78 (NCRP, 1984a, 1984b) recommended actions relative to the control of indoor radon levels, the recommendation of remedial action levels (NCRP, 1984a), and the introduction of mitigation techniques to reduce radon levels indoors (NCRP, 1987g). The radon problem is now receiving considerable attention nationally in the United States. This should result in a reduction in overall population exposure from this source in the course of time.

Among the man-made sources, the most important is the use of x-rays and radionuclides for medical diagnosis. In recent years, this has become well known and techniques for dose reduction have been widely recommended. The NCRP supports these efforts strongly. However, it is also appreciated that the benefits of these procedures accrue mainly to the person being exposed and dose reduction at the expense of important diagnostic information is not warranted. Thus, while every effort should be made to minimize the dose, the overall welfare of the patient must be the over-riding consideration.

Consumer products also contribute a small fraction of the total average effective dose equivalent to individuals in the U.S. population. Dose reduction would seem not to be feasible or cost effective in the case of building materials or mining and agricultural products. It may have some value in connection with the removal of radon from domestic water supplies, along with other means of reducing indoor radon and proper venting procedures which can be helpful with natural gas heaters.

The NCRP considers that exposures below 10 μSv/y (1 mrem/y) correspond to a negligible individual risk level (NCRP, 1987b) and should not be considered further. Therefore, additional dose reduction procedures world not appear to be warranted in the case of other consumer products, for the nuclear fuel cycle, or for miscellaneous sources including transportation. In occupational circumstances, the application of ALARA principles, the dose limits, and a recent NCRP guideline (NCRP, 1987b) are aimed at minimizing exposures to radiation workers.

2. Recommendations for Future Improvements in the Data Base

1) Natural Background

External cosmic and terrestrial radiation and internal radionucludes in the body appear to be quite well documented for the purpose of assessing population exposure. If, at some time in the future, other sources become better documented and assessments are made on a regional basis, more detail of a regional nature might then be warranted and useful.

Radon information is clearly still much too limited and the following recommendations are made for improvement:

a. A national survey of radon levels in homes is needed; first, to obtain a general overall scope of the problem, followed probably by more detailed regional surveys.
b. Better identification is required of the factors controlling indoor levels.
c. Development of mitigation techniques to reduce radon in higher-level homes is necessary.
d. Building codes need to be modified to limit ra-

don concentrations in future home construction.

e. Improved understanding should be sought of the deposition of radon and decay products in the lungs and the alpha-radiation dosimetry associated with it.

f. Better known estimates of the risk of lung cancer from a given exposure to radon and its decay products are needed.

2) Occupational

The information on this source of exposure appears to suffer from important uncertainties.

a. The number of people actually involved in radiation work is not easily determined. Improved methods for defining and ascertaining the number of workers need to be developed.

b. As far as possible, individual radiation measurements should be made on all radiation workers.

c. If the exposure is above a minimum value, about 1 mSv/y (100 mrem/y), consideration should be given to interpreting the exposure in terms of the effective dose equivalent.

3) Nuclear Fuel Cycle

A more consistent procedure for translating effluent and environmental monitoring data into collective effective dose equivalents for different portions of the fuel cycle is needed.

4) Consumer Products

The most important problem here is to establish the number of people actually exposed to the more important sources, such as domestic water supplies (whether from ground water or surface water supplies) and building materials. Knowledge of the actual doses to which people are exposed from these sources also needs improvement. Further study of the circumstances of exposure to ^{210}Po in tobacco smoke is necessary to properly evaluate the magnitude of this exposure.

5) Miscellaneous Environmental Sources

Although this is currently a very small contributor, the problem of determining all the sources to be assessed and the number of people exposed to them needs further study.

6) Medical Sources

Presumably the assessment of the number of examinations is reasonably accurate, but not known precisely is the number of people exposed to each medical procedure. Possibly, the average number of examinations could be determined in a limited sample. More information on the dose range for each procedure, and the effective dose equivalent resulting from it would be very useful.

CONCLUSIONS

The average annual effective dose equivalent to individuals in the U.S. population is estimated as 3.6 mSv (360 mrem), about 10 μSv/day (1 mrem/day). The major part of this, 3 mSv (300 mrem), is from natural background radiation and includes 2 mSv (200 mrem) from radon and its decay products. The largest man-made source is medical diagnosis and amounts to about 0.5 mSv/y (50 mrem/y). Consumer products contribute the remaining 0.1 mSv/y (10 mrem/y). The nuclear fuel cycle, occupational practices, and miscellaneous other sources, including transportation, are essentially negligible. Smoking results in additional exposure from ^{210}Po in the lungs but the exposure from this source is difficult to estimate and thus to compare with other exposures.

The most important source of exposure, radon and its decay products, is variable and can range to high values. Recommendations are made for better characterization of this source and dose reduction. Additional recommendations are made to improve data acquisition in the future.

It would seem highly desirable to undertake another assessment of the exposure of the U.S. population in about ten years.

ACKNOWLEDGEMENTS

Appreciation is given to Mrs. Betty Crumbley for her skillful handling of the typing of this manuscript.

REFERENCES

EPA (1972) Enviromental Protection Agency, *Estimates of Ionizing Radiation Doses in the United States 1960-2000,* A. W. Klement, C. R. Miller, R. P. Minx and B. Shleien, Eds. ORP-CSD 72-1 (Environmental Protection Agency, Washington, D. C.).

EPA (1977) Environmental Protection Agency, *The Radiological Quality of the Environment in the United States 1977,* EPA 520/1-77-009 (Environmental Protection Agency, Washington, D.C.).

ERC (1960) Federal Radiation Council, *Background Material for the Development of Radiation Protection Standards,* Staff report of the Federal Radiation Council (Federal Radiation Council, Washington, D.C.).

ICRP-ICRU (1957) International Commission on Radiological Protection International Commission on Radiation Units and Measurements, "Exposure of man to ionizing radiation arising from medical procedures", Physics Med. Biol. 2, 107.

ICRP-ICRU (1961) International Commission on Radiological Protection International Commission on Radiation Units and Measurements, "Exposure of man to Ionizing Radiation arising from medical procedures with special reference to radiation induced diseases", *Physics Med. Bio.* 6, 199.

ICRP (1977) International Commission on Radiological Protection, *Recommendations of the ICRP,* Publication 26, Annals of the ICRP, *1,* No.3 (Pergamon Press, New York).

ICRP (1978) International Commission on Radiological Protection, *Statement from the 1978 Stockholm Meeting of the ICRP,* Publication 28, Annals of the ICRP, 2, No.1 (Pergamon Press, New York).

ICRU (1985) International Commission on Radiation Units and Measurements, *Determination of Dose Equivalents Resulting from External Radiation Sources,* ICRU Report 39 (International Commission on Radiation Units and Measurements, Bethesda, Maryland).

NCRP (1975) National Council on Radiation Protection and Measurements, *Natural Background Radiation in the United States,* NCRP Report No.45 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1984a) National Council on Radiation Protection and Measurements, *Exposures from the Uranium Series with Emphasis on Radon and Its Daughters,* NCRP Report 77 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1984b) National Council on Radiation Protection and Measurements, *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States,* NCRP Report No.78 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1985) National Council on Radiation Protection and Measurements, SI *Units in Radiation Protection and Measurements,* NCRP Report No.82 (National Council on Radiation Protection and Measurements, Betheseda, Maryland).

NCRP (1987a) National Council on Radiation Protection and Measurements, *Public Radiation Exposure from Nuclear Power Generation in the United States,* NCRP Report No. 92 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987b) National Council on Radiation Protection and Measurements, *Recommendations on Limits for Ionizing Radiation Exposure,* NCRP Report No.91 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987c) National Council on Radiation Protection and Measurements, *Exposure of the U.S. Population from Natural Background Radiation,* Report of Scientific Committee 43, to be published (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987d) National Council on Radiation Protection and Measurements, *Radiation Exposure of the U.S. Population from Occupational Radiation,* Report of Scientific Committee 45, to be published (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987e) National Council on Radiation Protection and Measurements, *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources,* Report of Scientific Committee 28, to be published (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987f) National Council on Radiation Protection and Measurements, *Radiation Exposure of the U.S. Population from Medical Examinations,* Report of Scientific Committee 44, to be published (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987g) National Council on Radiation Protection and Measurements, *Mitigation of Radon Levels Indoors,* Report of Scientific Committee 82, to be published (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1987h) National Council on Radiation Protection and Measurements, *Exposure of the Population in the United States to Ionizing Radiation,* Report of Scientific Committee 48, to be published, (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

UNSCEAR (1958) United Nations Scientific Committee on the Effects of Atomic Radiation, *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation.* Document A 3838 (United Nations, New York).

UNSCEAR (1982) United Nations Scientific Committee on the Effects of Atomic Radiation, *Ionizing Radiation: Sources and Biological Effects,* No. E.82. IX.8., 06300P (United Nations, New York).