LA-UR-82-744

Conf-820427--1

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TITLE: BASIS FOR RADIATION PROTECTION OF THE NUCLEAR WORKER

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LA-UR--82-744

DE82 012130

SUBMITTED TO Mexican-American Engineering Society 6th National Symposium on Engineering, University of Houston, Houston, TX, April 11-14, 1982

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BASIS FOR RADIATION PROTECTION OF THE NUCLEAR WORKER

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ABSTRACT

A description is given of the standards for protection of persons who work in areas that have a potential for radiation exposure. A review is given of the units of radiation exposure and dose equivalent and of the value of the maximum permissible dose limits for occupational exposure. Federal Regulations and Regulatory Guides for radiation protection are discussed. Average occupational equivalent doses experienced in several operations typical of the United States Nuclear Industry are presented and shown to be significantly lower than the maximum permissible. The concept of maintaining radiation doses to As-Low-As-Reasonably-Achievable is discussed and the practice of imposing engineering and administrative controls to provide effective radiation protection for the nuclear worker is described.

INTRODUCTION

The difficulties that have been encountered here in Texas and elsewhere throughout the nation in building and licensing nuclear power plants should not mislead us into thinking the industry is not viable. As a matter of fact today there are 72 commercial nuclear power reactors[1] licensed to operate in this country with a capacity to produce a net 55,000 megawatts of electricity to pour into our national grid. This represents approximately 5%[2] of our national requirement. Throughout the rest of the world there are currently 177[3] nuclear power plants in commercial operation with a net capacity of approximately 100,000 MW. Also both here and abroad there are many nuclear units under construction or planned for the future. So far only commercial nuclear power plants have been mentioned. The fact is that those plants are an important part of, but not the total nuclear industry. In the United States and the rest of the world there are many other occupations where nuclear materials or radiation are encountered. The objective of this presentation is to describe the radiation protection standards that protect the workers.

THE OVERALL INDUSTRY

As part of the continuing effort to insure that radiation protection standards are adequate the Environmental Protection Agency (EPA) performed a comprehensive study of the occupations where there is a potential for exposure to ionizing radiation[4] for the year 1975. It was estimated that in that year there were 1.1 million employees performing ionizing radiation related work in the United States and that they had received a total collective dose of 130,000 person-rem. The categories of workers and radiation received are shown in Table 1 below:

TABLE 1. THE MAJOR OCCUPATIONAL CATEGORIES FOR IONIZING RADIATION AND RADIATION EXPOSURE DOSE EQUIVALENTS FOR 1975

Worker Category	No. of Workers	Collective Dose Person-Rem	% of Total Collective Dose
Medical	539,000	52,000	40
Industrial	198,000	26,000	20
Federal Government and Contractors	187,000	23,400	18
Miscellaneous (mostly transportation and universities)	99,000	3,900	3
Nuclear Regulatory Commission licenses	77,000	24,700	19
TOTAL	1,100,000	130,000	100

Since 1975 it is estimated that the number of workers in the above occupations has increased by 3 to 6% per year. In the case of commercial power plants licensed by the NRC the work force has almost doubled. Incidentally college students should note the excellent career opportunities that are available in this area and that will continue to be for the foreseeable future.

STANDARDS SETTING RELATED ORGANIZATIONS

Three major functions interact in the setting of standards for protection against ionizing radiation. The first is a scientific estimation of the risks and recommendation for numerical standards. The second is the enabling legislation or executive directives that derive from the Congress and the President of the United States. The third function is the promulgation and enforcement of the rules and regulations.

Advisory Scientific Organizations.[5]

1. The National Council on Radiation Protection and Measurement (NCRP). The predecessor agency, the Advisory Committee on X-ray and Radium Protection in 1934 was the first to set a numerical standard for radiation workers, 0.1 R/day. (The R designates the Roentgen, the first unit used for expressing the amount of exposure to radiation. This unit and other relevant units are defined and discussed in the following section.) The objectives of the NCRP are to collect, develop, and disseminate information relative to radiation protection and the related measurements. The NCRP is charted through the United States Congress, is an independent agency, and has no legal authority.

2. The International Commission on Radiologicaly Protection (ICRP). The ICPR is similar to our NCRP. It operates on a worldwide basis. Fourteen countries including the United States participate in its activities.

3. The National Academy of Sciences -- National Research Council (NAS-NRC) prepares comprehensive, critical reviews of the effects of ionizing radiation on living organisms. In 1955 in response to the concern over nuclear weapons testing in the atmosphere it appointed the Committee on the Biological Effects of Atomic Radiation (the BEAR committee). Later the NAS-NRC appointed the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR). The BEIR committee has made two reports, one in 1972 and the other in 1980. These reports undertook a complete review and re-evaluation of the scientific knowledge concerning the effects on humans of exposure to ionizing radiations. The members of these committees have been unable to come to a unanimous opinion concerning the risks of low level ionizing radiation.

4. Environmental Protection Agency (EPA).

   The Office of Radiation Programs of the EPA advises the President with respect to radiation matters and includes guidance for all federal agencies in the formulation of radiation standards. The EPA commissioned the studies by the BEIR committee and also reports on its own studies relating to radiation and the environment. Its predecessor agency is the Federal Radiation Council which was abolished in December 1970. Currently EPA is proposing new recommendations to the President for guidance to federal agencies for the protection of workers exposed to ionizing radiation. The recommendations have been published in the Federal Register[6] for discussion and comment. One of the new proposals would reduce the maximum annual and lifetime radiation dose that any worker can get by about 60%. The current EPA Radiation Protection Guide (RPG) value is 3 rem per three months with a lifetime limit to age N of 5(N-18) rems and would be replaced by an EPA RPG of 5 rem per year. Individual federal agencies use this guidance as the basis upon which to develop detailed standards and regulations to meet their specific statutory responsibilities.

Promulgation and Enforcement of the Rules and Regulations.

The United States Congress provides enabling legislation that establishes the regulatory agencies. With one exception the Nuclear Regulatory Commission (NRC) regulates the overall commercial nuclear fuel cycle activities necessary for the production of nuclear energy. The exception is the regulation of the health and safety of uranium miners; this is undertaken by the states and the federal Mine Safety and Health Administration (MSHA). The MSHA regulates exposure of all underground miners on the basis of the Federal guide that limits the exposure of their lungs to radioactive decay products of raden gas. The Occupational Safety and Health Administration (OSHA) regulates the remainder of the private industry of the nation. The Department of Energy regulates its own nuclear programs and those of its contractors. The Department of Defense (DOD) regulates the radiation exposures of the military and its nuclear defense contractors. Several states have entered into agreements with NRC and OSHA to regulate some activities that operate within the state.

RADIATION DEFINITIONS AND UNITS

It is assumed that the reader is familiar with the basic principles of radioactive decay (or disintegration) of the atomic nucleus and the products of that decay, alpha (α) particles, Beta (β) particles, or gamma (γ) rays. Recall that gamma rays are the same as the familiar x-ray except more energetic and that both those rays are forms of electromagnetic radiation. The term ionizing radiation used throughout this report refers to the interaction of α, β, γ, neutron, or proton radiations with matter to cause ionization of the atoms or molecules of the irradiated material. Examples of non-ionizing radiation are sunlight, radio and TV signals, and microwaves.

Radiation Dose Units.[5]

The first unit that was internationally accepted for expressing the amount of exposure to radiation is the roentgen and is based on the ionization produced in air. The roentgen (R) is defined as the quantity of x-rays or γ rays that will produce in 1 kilogram of dry air a total charge of 2.58×10^{-4} coulomb. The roentgen is a defined unit for exposures to γ and x-rays which are electromagnetic forms of radiation and does not apply to particle-type radioactivity such as α and β particles. Because the amount of energy absorbed from radiation of a given R value is not the same for all matter another unit was required to express energy deposited. The rad, an acronym for radiation absorbed dose was defined.

The rad is defined as the radiation dose that deposits 100 erg (10^{-5} joules) of energy per gram of absorbing material. In the international system (SI), a new definition of absorbed dose is the gray (Gy), representing the deposition of 1 joule of energy per Kg of material. The Gy is equal to 100 rads.

In the evaluation of the defined units it became necessary to deal with the fact that a given value of absorbed dose in rad (or Gy) does not necessarily result in the same biological effect because the response or damage is dependent on the characteristics of the radiation, namely its form and energy level, and on the characteristics of the irradiated material. An α particle causes more ionization than a β particle, and a β particle more than a γ ray. Of course the higher the energy level of the radiation the more severe will be its effect on the irradiated material. And finally, the more radiosensitive the material is to the radiation the more severe will be the resulting effect. Therefore, another unit, the rem, was defined to account for the differing characteristics of radiations and responses of irradiated materials.

The rem is defined as the absorbed dose in rads multiplied by the modifying factors required to adjust the differing responses to different radiations to an equivalent basis. The modifying factors are a subject of continuing study and subject to change. However, the following generalities can safely be assumed. For X and γ rays and β particles the dose equivalent in rems for a given radiation exposure is approximately the same as the absorbed dose in rads. For radiation caused by α particles within the body, the modifying factor varies from 10 to 20. The dose equivalent in rems from internal α irradiation could be as much as 20 times higher than the absorbed dose in rads. In the case of radiation workers and also for members of the public, the dose equivalent for any radiation exposure that occurs is satisfactorily evaluated in terms of the rem. The dose equivalent rem is useful because it reduces doses to a common basis and thus several dose equivalents may be added to orovide an integrated estimate of the total exposure for comparison with the maximum permissible dose (MPD) established by the standards. The new SI unit for the dose equivalent is the Sievert (Sv) and is equal to 100 rems.

Related Units or Terms[7]

The MPD is a term used by the NCRP and the ICRP to quantify the amount of ionizing radiation which in the light of present knowledge is not expected to cause any identifiable bodily injury to a person at anytime during that person's lifetime. The EPA uses a different term for an equivalent quantity and calls it the radiation protection guide (RPG).

For human intake of radioactivity through air or water maximum permissible concentrations (MPC) have been defined. The MPCs in air and water are estimated radiation protection limiting quantities that take into account the many variations in uptake of the various radioactive materials, the quantities of air or water used by humans, and the retention of a specific material in a particular organ. The MPCs are regarded as radionuclide concentrations for human intake that should not be exceeded as an annual average over a working lifetime in order to prevent buildup in the body to a maximum permissibe body burden (MPBB).

The MPBB is defined as that quantity of radioactive material retained in the body which will deliver the maximum permissible dose, the MPD, to the whole body or any critical organ. The principal critical organs are the lung, the bone, the gastrointestinal tract, the thyroid, and the skin.

The MPBB is typically expressed in millionths of a curie (uCi). The Ci is the basic unit of radioactive disintegration.
The Ci is defined as the activity of a quantity of a radionuclide that decays at a rate of 3.7×10^{10} nuclear disintegrations per second (d/s). The Ci is the fundamental unit and is widely used in radiation protection to indicate source strengths and the MPCs that were described above. The SI unit is the Becquerel which is defined as the rate of one per second. Thus, one Ci is equivalent to 3.7×10^{10} Becquerels.

QUANTIFICATION OF THE STANDARDS

The setting of numerical limits for radiation protection standards has from the beginning of the industry presented a very difficult challenge to the scientists of the advisory organizations. The quantification of the standards recognizes that within practical limits as little radiation exposure as possible should be received. The approach is to err on the safe side because the response to low levels of ionizing radiation has not been accurately determined. The scientists making the recommendations take into account the experiences from the past, the natural background of radiation, and results of continuing studies on the effects of low levels of radiation.

For acute exposures to high levels of radiation the biological effects are well known from historical incidents such as, the internal uptake exposures that occurred in the early 1900s to the radium dial painters who licked their dial brushes with their lips, a few accidents involving nuclear workers, and the bombing of the Japanese in World War II. Based on these and other experiences, the expected effects from acute exposures to γ or x-ray radiation of high intensity are summarized in Table 2[7]. The occupational exposures that occur during normal operations are much less than the 15 R value. Limited studies have been made of the effects of radiation on National Laboratory plutonium workers showing discernable effects. In an attempt to obtain more definitive results the scope of these limited studies has been expanded. An extensive epidemiologic investigation of mortality and the incidence of cancer and other diseases among plutonium workers at six major DOE facilities is underway by the Epidemiology Group at Los Alamos[8] to analyze for any correlation to levels of exposure experienced.

TABLE 2. PROBABLE RESPONSE TO ACUTE WHOLE BODY γ RADIATION[7]

Radiation Intensity	Probable Effect
15 to 25 R	Threshold of any response that may be detected from a statistical interpretation of group blood counts.
50 R	Minimum exposure that may be detected for a given individual from his blood count.
75 R	Nausea in 10% of persons exposed.
100 R	Loss of hair in 10% of persons exposed.
200 R	Disabling illness to 90% of persons exposed.
400 to 500 R	Lethal dose to 50% of persons exposed.

For γ ray and β particle radiation it is approximately true that the numeric value of the R exposure is equivalent to the other two units of dose (the rad and the rem). Thus the values of Table 2 are approximately the same dose value in rems. The effects described above apply only when the whole or a major portion of the body is exposed. The absorption of the same doses but by a smaller portion of the body will cause very much less injury. A good example of that fact is that radiation doses of several thousand rems have been applied locally for the destruction of a malignant growth and the patient may only become nauseated, with very minor response to any other ill effects.

Background Radiation

All of us live in a sea of natural background radiation that is part of our planet Earth. This radiation to which we are all subjected is caused by interactions of our atmosphere with electrically charged particles from outer space called cosmic rays. Also, we all receive terrestrial radiation from the thorium and uranium radionuclides and their radioactive decay daughters present in our ground and air, and even from the trace of potassium-40 that is naturally present in our bodies. The values of the natural background dose equivalent in rems per year varies throughout the globe depending principally on elevation and soil. The highest known value, 5 rem (5000 mrem) per year, occurs in Kerala, India a town of about 70,000 people. The unusually high background radiation in Kerala is attributed to the large deposits of thorium sands that exist there. In the United States it is estimated our dose equivalent for natural background radiation averages approximately one twelfth of one rem (80 millirem) per year.[9] When man-made contributions to background are added, (that is, medical x-rays, atmospheric weapons testing, radioactivity from the nuclear industry, radiation from buildings that are constructed from naturally radioactive materials and flights in high altitude airliners) the United States average background dose equivalent is approximately 120 mrem per individual. For perspective it should be noted that the NRC regulates the dose equivalents from the normal operation of a nuclear power plant to a maximum of 5 mrem per year to any member of the public who may be in a location to receive any radiation from operation of the plant.

In setting numerical values for the occupational dose equivalent standards, the objectives of the advisory committees, the NCRP, and the ICRP, and the BEIR Committee are to recommend MPD values that will protect the radiation worker from any risk while recognizing that a zero exposure limit is unattainable. As more knowledge is attained revisions are periodically issued. Currently the new recommendations by the EPA are being reviewed for acceptance. The United States and most foreign countries are currently operating under the values listed in Table 3[10] for maximum occupational doses. These values were adopted from recommendations of the ICRP and NCRP in 1971.

TABLE 3. NCRP 1971 RECOMMENDED VALUES FOR MAXIMUM PERMISSIBLE DOSE EQUIVALENTS FROM OCCUPATIONAL EXPOSURES[10]

Whole Body (Ideal)	5 rems in any one year
Whole Body (Accumulation to age N year)	(N-18) x 5 rems
Skin	15 rems in any one year
Hands	75 rems in any one year (25/qtr)
Forearms	30 rems in any one tear (10/qtr)
Other Organs or Tissues	15 rems in any one year
Fertile Women (with respect to fetus)	0.5 rem in gestation period
Dose limits for occasionally exposed individuals of the public	0.5 rem in any one year
Students	0.1 rem in any one year
Public Population at large	0.17 rem average per year
Emergency Life Saving	100 rems one time whole body
Emergency - less urgent	25 rems

An important change that the new standards proposed by the EPA would cause is the removal of the flexibility that permits more than 5 rem per year occasionally. In the past, 5 rem per year could be exceeded as long as the (N-18) x 5 rems limit on total career accumulation to age N is not exceeded. The standards would be tightened so that a maximum of 5 rems in any one given year should not be exceeded. This revised limit is also in the process of being implemented in DOE and NRC regulations.

REGULATIONS AND GUIDES

Commercial production and utilization of nuclear energy.

The NRC in its regulation of the Commercial nuclear fuel cycle acts through Title 10 (Energy) of the Code of Federal Regulations. Part 20 of Title 10 is titled "Standards for Protection Against Radiation." In part 20 Section 20.101 the permissible doses, levels and concentrations that a commercial licensee must not exceed are defined. The occupational dose limits are specified on a per quarter year basis and are within the 1971 values recommended by the NCRP. Part 20 Section 20.401 requires that each licensee shall maintain records showing the radiation exposures of all individuals who are monitored for radiation dose and Section 20.407 requires annual reports of personnel monitoring statistical summaries be made to the NRC. Part 20 in Appendix B lists for all radionuclides the maximum concentrations in air and water above natural background that are permitted for both the restricted areas controlled by the licensee and the unrestricted areas that members of the public could be in. The regulations in Part 20 apply to all persons licensed by the NRC to receive, possess, use, or transfer nuclear materials and in general includes medical therapy and research and development facilities as well as commercial and industrial facilities for the production and utilization of nuclear energy. In addition to regulations, the NRC also publishes a series of regulatory guides that outline good practices that a licensee may adhere to in order to ensure a particular operation or design will be acceptable to the NRC licensing staff. Division 8 of the NRC regulatory guide series consists of the guides that have been published for occupational health. Of particular interest to the subject of this report are Regulatory Guide (R.G.) 8.8, "Information Relevant To Ensuring That Occupational Radiation Exposures At Nuclear Power Stations Will Be As Low As Is Reasonably Achievable", and R.G. 8.10, "Operating Philosophy For Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable." The R.G.'s do not have the force of law but do specify the standards an applicant must meet or exceed in order to be licensed. The NRC issues an annual report of the occupational exposures that have occurred in its licensed facilities. Data from that report will be presented later.

DOE Facilities

The Department of Energy through its operating contractors manages a large complex of nuclear facilities throughout the continental United States. The radiation protection standards for the employees are promulgated through DOE orders initiated by the Operational and Environmental Safety Division. In the Order DOE 5480.1 "Environmental Protection, Safety, and Health Protection Program for DOE Operations" Chapter XI "Requirements for Radiation Protection," radiation protection standards for DOE and DOE contractor employees are established based upon the recommendations of the EPA and the NCRP. In Chapter XI maximum concentrations above background in air and water are listed for all radionuclides for the controlled and uncontrolled areas. The DOE issues an annual report of occupational exposures at its facilities. Data from that report will be presented later.

Other Programs and Facilities

For the other major categories that are listed in Table 1, that is, medical, industrial, and miscelleneous, the regulations and guidance are provided mostly by OSHA and to a lesser degree by the states. All these other activities also abide by the NCRP recommended values for occupational dose standards.

OPERATING EXPERIENCE

A summary of the data that is available for radiation occupational doses in the United States is presented in Tables 4, 5, and 6. The data are taken from the 1975 EPA study,[4] the 1979 DOE report,[11] and the 1980 NRC report.[12]

TABLE 4. OCCUPATIONAL DOSES FOR RADIATION WORK IN THE UNITED STATES IN 1975[4]

Occupational Category	Total Workers	Total Exposed	Annual Average Whole Body Dose Equivalent in rem
Medical	539,000	161,700	.320
Industrial	198,000	49,200	.520
Nuclear Regulatory Commission Licensees	77,000	39,400	.630
Federal Government Contractor	187,000	99,700	.230
Miscellaneous:			
University Researchers and Transportation	99,000	19,000	.200
Total	1,100,000	369,000	(Av .335)

In the United States for all radiation workers actually exposed, the average annual dose equivalent in 1975 was approximately 340 mrem, well below the 5000 mrem per year value of the standards for occupational dose. It is estimated that a growth of from 3 to 6% per year has occurred in the number of workers since 1975 but the average annual dose equivalent should not change significantly. In fact, because of the emphasis on the concept of maintaining doses as-low-as-reasonably-achievable (ALARA) it is expected any change in the average occupational dose should show a decrease. The ALARA concept will be discussed later.

The only update data available were the DOE and the NRC annual reports. The Federal Government and its contractors, principally in the DOE nuclear related programs had approximately 130,000 employees in 1979 of which approximately 55,000 received measureable doses. The total collective dose equivalent was approximately 9000 man-rem. Therefore, in 1979 the average annual dose equivalent for those employees actually exposed in the DOE programs is approximately 160 mrem. Table 5 shows the major activities of the DOE in which the major occupational doses occurred.

TABLE 5. 1979 SUMMARY OF MAJOR DOE PROGRAMS AND OCCUPATIONAL DOSES EXPERIENCED

Program	Workers With Measurable Exposure	Collective Dose man-rem	Av. Annual Dose Equivalent m rem
Reactors	4,368	1,389	320
Fuel Fabrication	948	278	290
Fuel Processing	2,611	1,209	460
U Enrichment	8,680	466	50
Nuclear Weapon Fabrication	10,827	1,247	120
General Research	13,554	1,845	140
Accelerators	1,615	492	310
Miscellaneous (Waste Mgmt, etc.)	11,720	2,074	180
DOE Administrators	660	9,043	70
Total	54,983	9,043	(Av 164)

These activities are carried out principally in the DOE facilities located in Savannah, GA.; Oak Ridge, TN; Idaho Falls, ID; Rocky Flats, CO; Livermore, CA; Hanford, WA; and Albuquerque and Los Alamos, NM. It is of interest to note that during 1979 at the Los Alamos National Laboratory, 2862 employees wore thermoluminescence dosimeters to measure their radiation exposure. Of these, 1060 had measureable doses. The annual average dose equivalent per individual with a measureable dose was 340 mrems. The major part of the occupational doses experienced at this major government research and development Laboratory is attributed to workers handling special nuclear material.

The principal occupational doses at NRC licensed facilities occur for commercial nuclear power reactors. The 1980 annual report issued by the NRC was compiled for the 69 nuclear power plants that had completed at least one full year of operation as of December 31, 1980. The data indicated that the number of employees monitored during 1980 was 133,898 and that the collective dose incurred by these individuals was 53,796 man-rem. Only approximately 80,000 of the monitored employees received measureable doses. The average annual dose equivalents for these workers receiving measurable exposures in 1980 was approximately 700 mrem. Table 6 summarizes the occupational dose percentages by operating function. It should be noted that in 1975, 44 commercial reactors were operating and in 1980 there were 68. The work force in this industry almost doubled in that interval but growth now is almost at a standstill. The growth has resulted in more workers potentially exposed to radiation but the annual average dose equivalent for those with measurable doses is decreasing slightly each year.

TABLE 6. PERCENTAGES[12] OF 1980 ANNUAL COLLECTIVE OCCUPATIONAL DOSE AT UNITED STATES COMMERCIAL NUCLEAR POWER PLANTS BY WORK ASSIGNMENT

Work Assignment	Percentage of Total 1980 Collective Dose
Reactor Operation and Surveillance	9.5
Routine Maintenance	35.4
Inservice Inspection	5.5
Special Maintenance	40.5
Waste Processing	3.0
Refueling	6.1

It is of interest to note that the major exposures occur to craftsmen performing routine and special maintenance. It is in this area that the strongest effort has to be made by designers and managers to keep occupational doses ALARA.

REDUCING OCCUPATIONAL EXPOSURES TO ALARA

Recorded data for United States radiation workers indicate that occupational dose equivalents incurred by the workers are well below the numerical standard of 5 rem per year per individual. This is in keeping with the basic goal of all radiation protection programs, namely to maintain exposures as low below the standard as practical. The current efforts to achieve this goal incorporate the concept formerly identified "as low as practical" and now changed to "as-low-as-reasonably-achievable." ALARA implies that there is some practical value to which doses can be reduced when risk and benefit are both considered. The bottom line is that there should be no exposure to any individual without a commensurate benefit.

The elementary principles of radiation protection involve the concept of time, distance, and/or shielding. A given source of radioactivity can result in an exposure only as long as an individual spends time in its field. Distance from a source is important because the strength of its field can be diminished by increasing the distance from the source. The strength of the radiation decreases as $1/r^2$ where r is the distance from a point source to the exposed individual. Engineering design can provide adequate protection by the interposition of an adequate shielding material between the source and the worker. Good ALARA practice calls for a continued effort to ensure that the three protection factors are incorporated to the maximum benefit of the worker by imposing rigid administrative controls and sound engineering design. The concept of ALARA provides a focal point for individuals and managers dealing with radioactivity to evaluate whether any person is being exposed without justification.

A recent report[13] from the Memorial Sloan-Kettering Cancer Center presents the description of their radiation protection policy that has evolved over 27 years of operation. The Center uses radioisotopes extensively for a variety of metabolic, diagnostic, and treatment procedures. A vital part of the program has been the research and development activities carried out on measurement of exposures in medical procedures and on the reduction of staff and patient exposure. An operating record of exposures below 0.5 rem per year has been achieved for 95% of their exposed population and maximum exposures are held substantially less than 2.0 rem. The most dramatic improvement occurred in their inhouse plant for the production of radon interstitial sources. The doses for some of the workers at that plant had been exceeding 20 rem per year. By modifying the design to include sliding lead shields with viewing windows and the administrative modification of collection schedules it was possible to reduce those doses to below 2 rem per year. There is no doubt that the individual and management must both be committed to the principle of ALARA for occupational exposures to be justifiable on a risk-benefit basis.

CONCLUSIONS

Commercial nuclear power plant employment represents only a small part of the overall job market that exists for workers where there is a potential for radiation exposure. The radiation protection measures that are in place have been successful in maintaining the average annual dose commitment to the more than one million Americans engaged in radiation work to much less than the maximum permissible dose of 5 rem per year. The advisory scientific organizations that recommend the numerical values for the standards controlling occupational radiation exposures maintain a continued effort to revise the standards as more knowledge of the risks of low level ionizing radiation on humans becomes available. Management and individual commitment to the concept of ALARA will ensure that doses to workers will be maintained at levels where there is no unjustified risk to the workers. Actual occupational doses experienced in radiation related work throughout the country show that these occupations are as free from health risks[14] as the safest categories of industry that an individual can work in.

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