UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION I
475 ALLENDALE ROAD
KING OF PRUSSIA, PENNSYLVANIA 19406-1415

September 13, 2001

Docket No. 030-20931
License No. 37-23934-01

Robert Umstead
Manager
Borough of Royersford
300 Main Street
P. O. Box 188
Royersford, PA 19468

SUBJECT: RESULTS OF PERSONNEL MONITORING AT THE ROYERSFORD WASTEWATER TREATMENT FACILITY

Dear Mr. Umstead:

In a telephone conversation on July 25, 2001, Betsy Ullrich of this office informed an individual employed at the Royersford Wastewater Treatment Facility (RWTF) that the personnel dosimeter assigned to the individual for the period of April-May-June 2001 (second quarter 2001) was reported as receiving a radiation dose of 153 millirem. Since personnel dosimeters were first issued to employees at your facility in 1998, reported doses have ranged from 5 millirem to 60 millirem; in most quarters, less than 15 millirem was received by the dosimeter. For this individual during the three monitoring periods in 1998, the dosimeters received a total dose of 69 millirem; in 1999 and 2000, the dosimeters received a total of 39 millirem and 66 millirem, respectively; and during the first quarter of 2001, the dosimeter received 116 millirem, and in the second quarter, 153 millirem.

Based on the telephone discussion, we understand that the individual was away from work at the RWTF for extended periods of time between June of 2000 and April of 2001. The individual stated that, on return to work full time in 2001, the individual worked in and around the reedbeds used for dewatering sludge, performing decanting and transfer of sludge. Typically, the individual spent about 15 minutes each day in or above the reed bed to review conditions, and approximately once each month, spent 1 hour in each of the two reed beds performing decanting and sludge transfer. The individual also stated more time was spent than usual during the past few months in an effort to improve the sludge drying process, including spending about 4 hours on each of two days working in the reed beds. The individual confirmed that during the second quarter 2001, the individual wore the dosimeter daily, at waist level; did not leave the dosimeter in or around the reed beds; did not have any medical scans in which radionuclides or radiation were used; and did not wear the dosimeter in the vicinity of any other known sources of radiation.

Calculations based on the time the individual spent in the reedbed, and the doses received by the environmental radiation monitoring dosimeters in the reedbeds, lead us to expect that the individual would have rece4ived a dose of 30 millirem during the second quarter 2001. These calculations are summarized in Enclosure 1. It is possible that the discrepancy between the measured doses and the expected dose results from radiation levels in areas over the reed bed which are higher than the radiation levels at the edge where the dosimeters are located, or that handling of the sludge during transfer results in the personnel dosimeter being in close proximity to radioactive materials. Because of this discrepancy, we plan the following activities, with your assistance and the assistance of the employees at the RWTF:

1) Perform observations and surveys at the RWTF of activities performed in or near the reedbeds, such as decanting and transfer of sludge, mechanical dewatering of sludge, and any activities related to closure of the reedbeds. The RWTF employees should contact Betsy Ullrich when they expect such activities to occur, so we can arrange to meet with them to observe their activities and perform surveys.

2) Contact the dosimetry provider regarding response of the environmental dosimeters compared to the personnel dosimeters, to determine if differences in the responses could lead to a discrepancy between the doses predicted by the environmental dosimeters and actual radiation dose measured by the personnel dosimeters.

3) Continue analysis of samples by the Oak Ridge Institute for Science and Education (ORISE).

4) Send copies of this letter to the Pennsylvania Department of Environmental Protection, Bureau of Radiological Protection, and to UniTech Services Group, Inc. as we do with other information related to the radiological conditions at your facility.

We hope the following information will be helpful in understanding the radiation doses discussed above. The NRC limit for dose to members of the public from activities performed with radioactive materials is 100 millirem in a year, and the NRC limit for dose to a worker performing activities with radioactive materials is 5000 millirem (5 rem) in a year. For comparison, in the United States, the natural background exposes most people to about 360 millirem each year, and a diagnostic x-ray typically exposes persons to radiation levels between 25 and 55 millirem. Enclosed are two documents regarding risks from radiation exposure. The first document, Regulatory Guide 8.29, “Instruction Concerning Risks from Occupational Radiation Exposure”, includes a discussion of the acronym “ALARA”, which stands for “As Low As Reasonably Achievable”. This means that every effort should be made to minimize the exposure to radiation when it is necessary to work with radioactivity. At the RWTF, this can be done by minimizing the time employees spend in or around the reedbeds for maintenance and sludge application, and by employees maintaining distance from the reedbeds when possible, such as choosing to walk along the west side of the secondary digester rather than the east side when going between the office and the laboratory buildings. The second document, NUREG/BR-0125, Volume 3, No. 1, “Review of Recent Epidemiological Studies of Radiation Risks” discusses studies which indicate that doses of greater than 50 rem appear to increase the rate at which cancers appear in a population, but that lower doses have not demonstrated any discernible biological effects. We hope these will be helpful in understanding the radiation doses to employees.

If you have any questions for us regarding the use of dosimeters at the RWTF, or you have additional information regarding the RWTF that would improve our understanding of the doses measured by the personnel dosimeters, please contact Betsy Ullrich of my staff at (610) 337-5040.

Thank you for your cooperation.

Sincerely,

Original signed by John D. Kinneman

John D. Kinneman, Chief
Nuclear Materials Safety Branch 2
Division of Nuclear Materials Safety

enclosures:
1. Calculation of Doses from the Reedbed
2. RWTF Standard Quarter TLD Results, Locations 1 through 8
3. RWTF Standard Quarter TLD Results, Locations 9 through 18
4. TLD Locations, RWTF
5. Regulatory Guide 8.29
6. NUREG/BR-0125, Volume 3, No. 1

cc w/enclosures:
D. Neeley, UniTech Services Group, Inc
M. Fuller, UniTech Services Group, Inc.
D. Allard, PADEP
I. Shanbaky. PADEP

bcc w/o enclosures:
M. Claflin, Borough of Royersford

distribution:
G. Pangburn, RI
F. Costello, RI
R. Ragland, RI
D. White, RI

DOCUMENT NAME: C:\Program Files\Adobe\Acrobat 4.0\PDF Output\591 Rob Umstead.wpd
To receive a copy of this document, indicate in the box: "**C**" = Copy w/o attach/encl "**E**" = Copy w/ attach/encl "**N**" = No copy

OFFICE	DNMS/RI	N	DNMS/RI		DNMS/RI			
NAME	EUllrich /BU/		JKinneman /JK/					
DATE	9/13/01		9/13/2001					

OFFICIAL RECORD COPY

Enclosure 1: Calculation of Personnel Doses from the Reedbed, Based on Results of Environmental Radiation Dosimeters

Environmental radiation monitoring dosimeters are placed at 16 locations at the Royersford Wastewater Treatment Facility. They are exchanged quarterly. The results of quarterly monitoring for the period January 1998 through June 2001 are graphed in Enclosures 2 and 3. A diagram of the locations is included as Enclosure 4. Dosimeters placed at Locations 1 and 2, in the reed beds, measure radiation doses significantly higher than at the other dosimeter locations. Radiation levels are reduced during the winter months when no new radioactive material [sludge] is applied and the radionuclides remaining decay in accordance with their various half-lives, and there may be some shielding due to snow cover.

Time Working at Designated Locations to Reach 150 Millirem

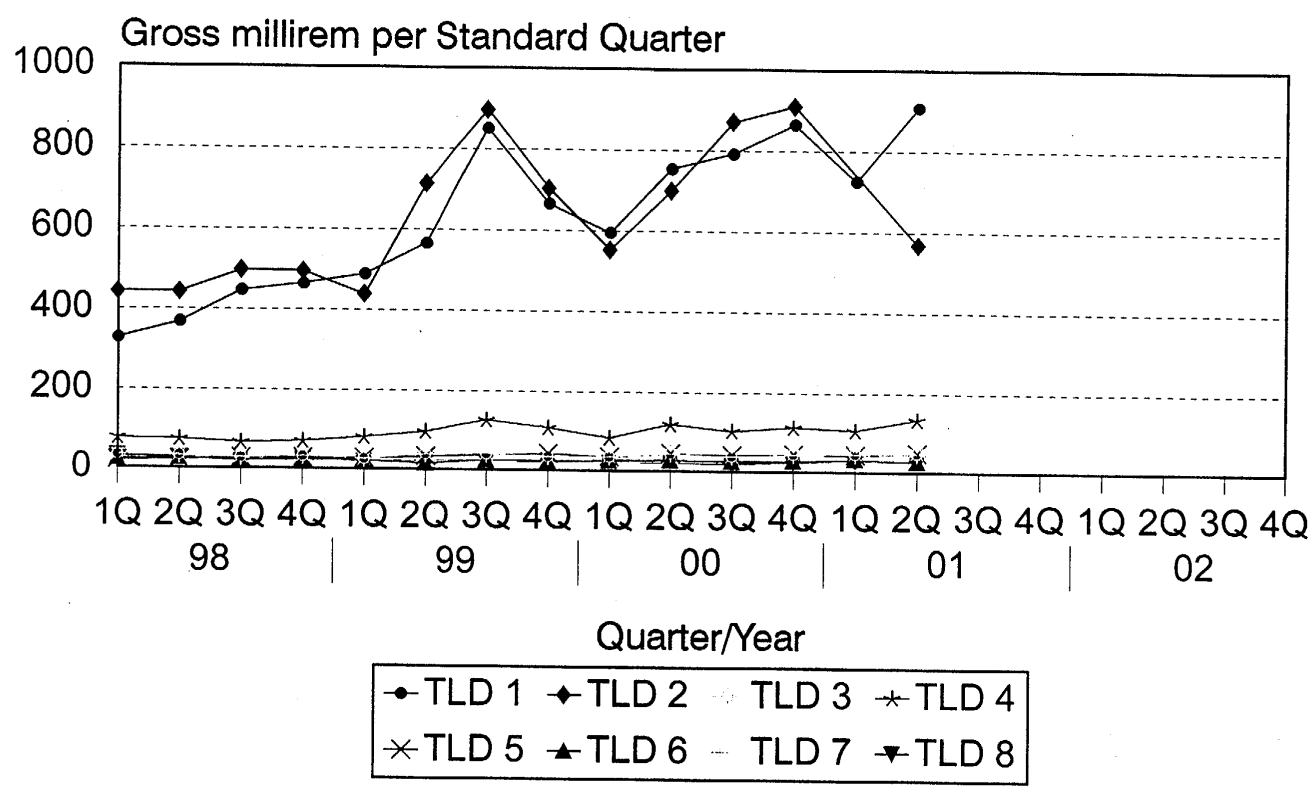
Location	Dose, Second Quarter 2001	Dose Rate (2160 hours/Q)	Time to reach 150 millirem
1 (Reedbed 1)	908 mrem	0.42 mrem/h	357 hours
2 (Reedbed 2)	569 mrem	0.26 mrem/h	577 hours
4 (railing by lab building door)	134 mrem	0.06 mrem/h	2500 hours
13 (ladder of primary digester)	144 mrem	0.07 mrem/h	2143 hours
14 (east side of secondary digester)	90 mrem	0.04 mrem/h	3750 hours
3 - 16 (average)	51 mrem	0.02 mrem/h	6353 hours

Personnel Doses Resulting from Time Working in Designated Areas

Location	Time Estimated in Designated Location, Second Quarter 2001	Dose Rate, Second Quarter 2001	Dose
Location 1 (reedbed)	15 minutes/day x 90 days x 1 h/60 min = 22.5 hours	0.42 mrem /h	9.5 mrem
Location 1 (reedbed)	1 hour/month x 3 months x 2 reedbeds = 6 hours	0.42 mrem/h	2.5 mrem
Location 1 (reedbed)	4 hours/d x 2 days x 2 reedbeds = 16 hours	0.42 mrem/h	6.7 mrem
Locations 3 -16 (average)	520 hours/Q - 44.5 hours (worked in reedbeds) = 475.5 hours	0.02 mrem/h	11.3 mrem
			TOTAL: **30 mrem**

RWTF Standard Quarter TLD Results

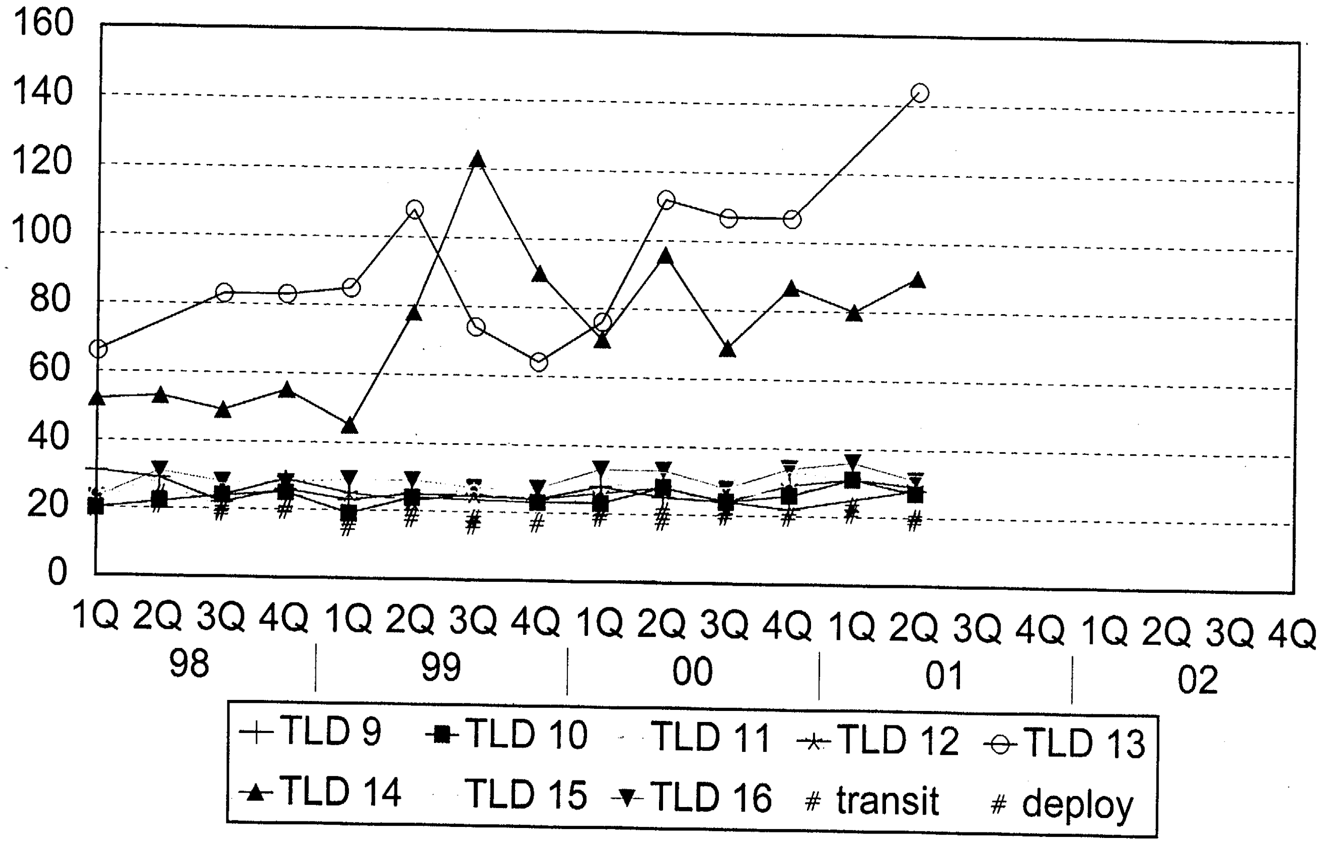
Locations 1 through 8



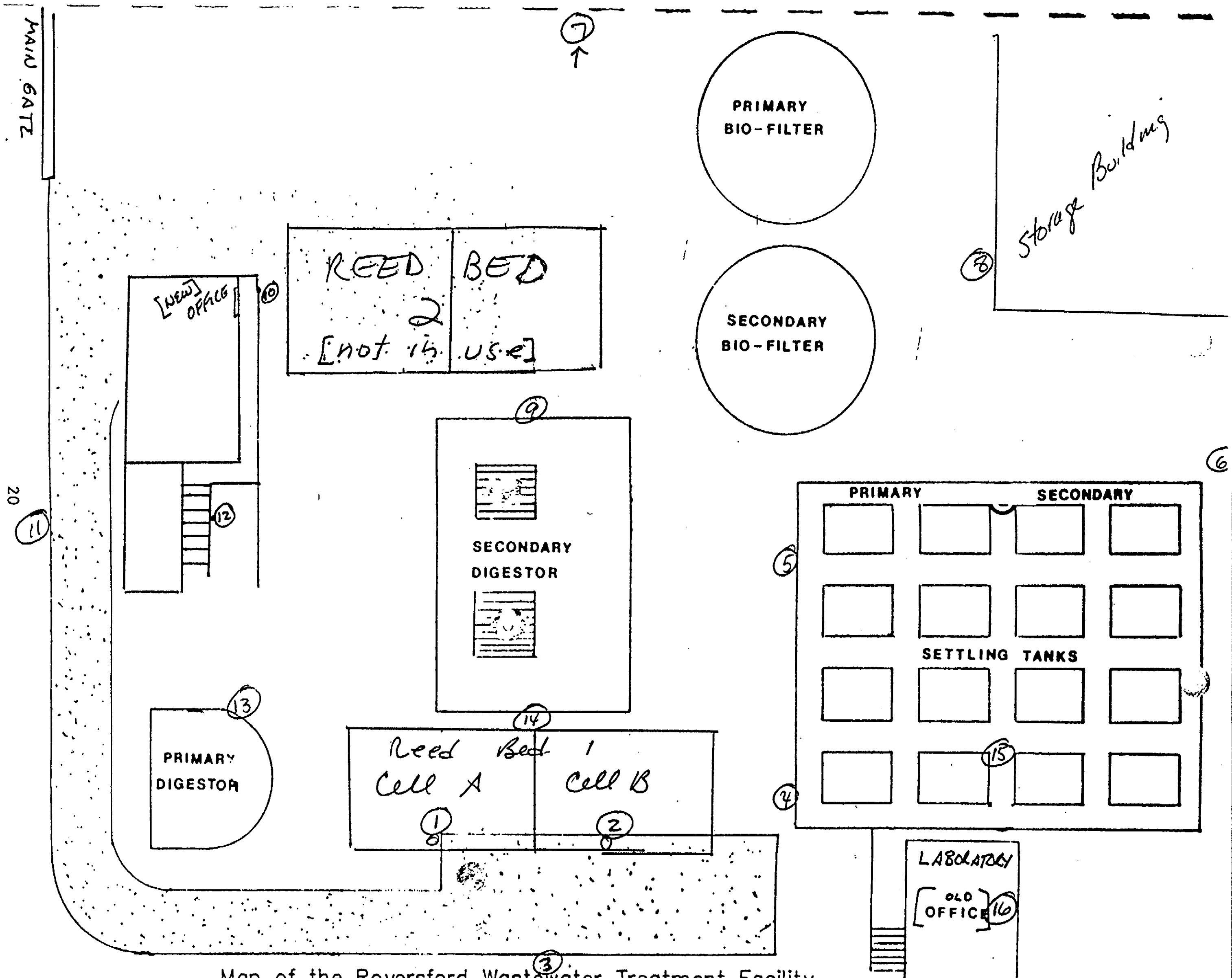
Landauer TLD Monitoring

RWTF Standard Quarter TLD Results

Locations 9 through 16



Landauer TLD Monitoring



Map of the Royersford Wastewater Treatment Facility
Indicating Locations of TLD MONITORS

REVISED 7-1-98

OFFICE OF NUCLEAR REACTOR REGULATION
U.S. NUCLEAR REGULATORY COMMISSION

NRR

TECHNICAL NEWSLETTER

NUREG/BR-0125
Vol. 3, No. 1
March 1992

Reviews of Recent Epidemiological Studies of Radiation Risks

Frank J. Congel and Charles A. Willis

Introduction

The NRC is responsible for protection of the public and workers from the ill effects of exposure to ionizing radiation. To meet this responsibility effectively, the NRC needs to understand the magnitude of the risks associated with radiation exposure. Thus, when new studies are reported that purport to cast new light in this issue, the staff examines them carefully. The staff recently reviewed five new epidemiological studies of radiation risks and the results of those reviews are summarized here.

Background

Everyone is exposed to radiation at all times. This has always been true, although no one knew about it until 1895 when x-rays were discovered. Radiation injuries were reported only a few months after radiation was discovered. Since that time, radiation and its biological effects have been the subject of intense world-wide scientific investigation. The important effects were soon identified. Even the possibility of genetic damage was reported in 1911. The fundamentals of radiation protection also were identified within a few years of the discovery of radiation. The first person known to be killed by man-made radiation was Thomas Edison's assistant, Clarence Dally. By the time of Mr. Dally's death in 1904, Edison reported that proper precautionary measures had been developed and that "I would continue the work myself but my wife won't let me."

Radiation protection measures were not always applied and, as a result, hundreds of people died of radiation-induced cancer and others suffered radiation injuries. Early injuries initiated public controversy before 1900. Radiation injuries caused by the use of x-rays to investigate wounds during World War I contributed to the controversy. Despite the controversy, radiation was misused. Misuse is exemplified by Radium tonics being sold through the mail and fluoroscopes being available in most shoe stores. The public controversy, legal actions, and voluntary control measures combined to eliminate most of the gross misuses of radiation by the end of World War II.

The development of the atomic bomb provided new impetus and funding for radiobiological research. In 1956, the National Academy of Sciences declared that radiation was the best understood environmental hazard. Research has continued and, today, radiation risks are very well understood. However, we have not yet determined the magnitude, if any, of risks from exposure to low levels of radiation (such as less than about 10 rem per year).

If the mechanisms of radiation injury were known, the question of risk from low-level exposure could be answered with laboratory investigations. Since the mechanisms are not known, epidemiological studies are conducted to try to reduce the degree of uncertainty.

Current risk estimates for low-level exposure are based primarily on the results of epidemiological studies of the survivors of the nuclear weapon detonations at Hiroshima and Nagasaki. These results are supported by studies of other highly irradiated groups such as the radium dial painters, patients irradiated as a treatment for ankylosing spondylitis, and women irradiated as a treatment for cervical cancer. Where doses are high (above about 50 rem) cancer rates are increased. For example, the cancer rates for the survivors of Hiroshima and Nagasaki apparently were increased about 5 percent.

Researchers have conducted numerous studies of groups receiving lower doses, but the results are inconclusive. Generally, they have found no increase in cancer rates, even in Guarapari, Brazil, where 12,000 people receive doses of about 0.64 rem per year, which is about 6 times the average background dose; in Kerala, India (0.38 rem per year); or in Yanjiang County, China (0.3 to 0.4 rem per year).

No radiation-induced genetic effects have been observed in any human population.

Epidemiological Studies Reviewed

The five studies reviewed were conducted by the National Cancer Institute (NCI) [1], the Three Mile Island Public Health Fund (TMIPH) [2], the Massachusetts Department of Public Health (MDPH) [3], Steve Wing, et al. [4, 5]; and Sternglass and Gould [6]. The populations investigated differed in most respects between each of the studies and the investigators reached markedly differing conclusions. The extremes were the NCI and the Sternglass-Gould studies. The NCI study reported no detectable ill effect in the populations around any nuclear power plant or Department of Energy (DOE) facility in the U.S. However, Sternglass and Gould contend that effluents from the Trojan nuclear plant are killing thousands of people annually in Oregon.

We reviewed these studies and concluded that none of them convincingly showed any discernible effect of low-level radiation or provided any reason to believe that the NRC should revise its effluent control practices.

The Sternglass-Gould Report

E. Sternglass has long had the reputation of being one of the most uninhibited of the antinuclear activists, and J. M. Gould is rapidly developing a similar reputation. In conducting their work, which was funded by a political group trying to shut down the Trojan plant, they concluded that radioactive effluents are killing over 8,000 people each year in Oregon. Their basis for this conclusion is that the death rate in Oregon declined in the 2 years preceding the startup of Trojan. If this "trend" had continued, the death rate in Oregon would be far below its current value. Sternglass and Gould contend that the effluents from Trojan caused the difference between the actual and the projected death rates. However, if this "trend" had continued, the present death rate in Oregon would be far below the national average and, in another 75 years, the life expectancy in Oregon would reach 1,000 years. Clearly, the logic and the conclusion lack substance.

The contention by Sternglass and Gould is made even more dubious by the Trojan's outstanding effluent control record. Radioactive effluents have been so limited that the total calculated population dose from all releases through 1986 was only 1.0 person-rem (NUREG/CR-2850, Vol. 8). By comparison, the dose from natural background radiation to the population in the vicinity of Trojan exceeds 1 person-rem every 4 minutes.

The Massachusetts Department of Public Health Study

The MDPH study also is seriously flawed. This was a case-control study of leukemia (other than chronic lymphatic leukemia (CLL), which other investigations show to be non-radiogenic) in people over 12 years of age in the 22 communities within 25 miles of the Pilgrim Nuclear Power Station. The MDPH identified "cases," people for whom leukemia had been diagnosed, from medical records and selected matching "controls". The researchers estimated relative doses and assumed the extent to which the cases had doses higher than the control group to be a measure of the impact of radiation. The MDPH researchers found one time period in which the estimated doses were higher for the cases than for the controls. The MDPH concluded that radiation had quadrupled the leukemia rate in that period for the more highly exposed group.

In our review, we found the MDPH conclusion untenable for several reasons. First, the short duration of the increased incidence of leukemia is inconsistent with the increase being radiogenic; that is, the elevated incidence disappeared just when it would have been approaching a maximum if it had been caused by radiation. Second, the distribution of doses from effluents assumed by the MDPH is totally inconsistent with the actual calculated doses from effluents; the doses from natural background and other radiation are ignored. Third, the method used for determining the location of the people is highly inaccurate: questioning a surviving friend or relative by telephone to determine where the person lived and worked many years ago. Fourth, the leukemia incidence of the low dose group was well below the average for the state. Fifth, the presumed consequences are totally inconsistent with the doses, based on generally accepted methods.

The total calculated population dose from Pilgrim effluents was only 260 person-rem. The National Academy of Sciences (BEIR-V) estimates that this dose could cause a total of from 0 to 0.05 cancer deaths. Furthermore, the doses from effluents were only a small fraction of doses from natural background radiation. Thus, even if very high values are assumed for the radiation risk factors, the effluent doses could not have caused a discernible increase in leukemia.

Oak Ridge Workers Study

Steve Wing proclaimed on national television that he had shown that radiation risks are 10 times greater than the National Academy of Sciences' estimates. Before the proclamation, there was little interest in this work because the sponsor, DOE, said no ill effects were being found. DOE epidemiologists expressed surprise at both the conclusion and the public announcement.

Our review was complicated by the omissions from the publications: they did not contain either the data or a full description of the methodology. We were told that neither is available.

The population studied consisted of the white males hired to work at Oak Ridge between 1943 and 1972. This population excluded people who worked there for less than a month, those who worked at other nuclear facilities, and those for whom the dose or demographic data were incomplete. The researchers drew their conclusions from the following reported observations: (1) the lifetime doses were quite low, with the average being only 1.7 rem and with only 321 people (3.8 percent) getting more than 1 rem; (2) the average death rate of these people was significantly less than expected (based on the data for white male Americans); (3) the cancer death rate also was less than expected; (4) the leukemia death rate was 63 percent higher than expected; and (5) with the arbitrary selection of a "lag time" (latent period), the death rate could be correlated with dose.

In our review, we noted the following. The observed effects could not be related to radiation dose because the measured doses were only a small fraction of the total doses and because exposure to other carcinogens was not taken into account. Second, the higher-than-expected leukemia rate is a common variation in situations where radiation exposure cannot be the cause. Third, resorting to an anomalous "lag time" tends to invalidate any correlation found between dose and effect. Fourth, the short time between completion of the study and publication precluded meaningful peer review; one reviewer was not given time for even a cursory review. Fifth, the report contains obvious errors in the few instances in which numbers can be checked. Finally, the publication contains an antinuclear discourse that indicates a nonscientific agenda. Therefore, we concluded that the Oak Ridge study did not constitute a basis for changing regulatory practice.

The TMI Public Health Fund Study

In this study researchers investigated the population living within 10 miles of the Three Mile Island Nuclear Station (TMI) for childhood cancers, leukemia, lymphoma, lung cancer, and all cancers. The researchers estimated the radiation doses from the TMI accident, from the normal effluents and from natural background radiation. The researchers found exposure rates to vary from 50 to 90 millirem per year from external sources of natural background radiation. The maximum exposure from the TMI accident was less than 100 millirem and the exposure from normal effluents was much less than that value. The authors acknowledged being unable to find any effect, while admitting their disappointment. However, they should have been expected to find no effects of exposure to plant effluents because effluent exposures were less than variations in natural background.

The National Cancer Institute Study

This study was a heroic effort, covering 51 nuclear power plant sites and 10 DOE facilities for a 35-year period. The researchers divided cancers into 15 categories and analyzed the populations in 5-year age groups. The researchers based the study primarily on mortality data but also included incidence data where they were available. They calculated both standard mortality and relative risk ratios and produced over 23,000 statistical tests for evaluation.

One especially important feature of the NCI study was the inclusion of calculations for the years before the plants went into operation. This clearly showed the variation in the data that could not be the result of plant effluents. For example, of the six standard mortality ratios for childhood leukemia that were significantly greater than one, four occurred before startup. Similarly, in those instances in which relative risks were significantly different from one, only four were greater than 1 while 14 were less than 1. Thus, even though the study included old DOE facilities in which releases were relatively high during World War II, the NCI found "no suggestion that nuclear facilities may be linked causally with deaths from leukemia or other cancers."

In reviewing this document, we note that the results are what would be expected from current knowledge of releases and radiation risks.

References

1. Jablon, Seymour, Zdenek Hrubec, John D. Boice, and B. S. Stone, "Cancer in Populations Living Near Nuclear Facilities," National Institutes of Health Publication 90-874, July 1990.

2. Hatch, Maureen C., Jan Beyea, Jeri W. Nieves, and Mervyn Susser, "Cancer Near the Three Mile Island Nuclear Plant: Radiation Emissions," Am. J. Epidemiology, Vol. 132, No. 3, pp 397-412, September 1990.

3. Morris, Martha and Robert S. Knorr, "Southeastern Massachusetts Health Study, 1978-1986," Massachusetts Department of Public Health Report, October 1990.

4. Wing, Steve, Carl M. Shy, Joy L. Wood, Susanne Wolf, Donna L. Cragle, and E. L. Frome, "Mortality Among Workers at Oak Ridge National Laboratory: Evidence of Radiation Effects in Follow-Up through 1984," JAMA, Vol. 265, No. 11, pp 1397-1402, March 20, 1991.

5. Wing, Steve, et al., "Mortality Among Workers at Oak Ridge National Laboratory: Evidence of Radiation Effects in Follow-Up Through 1984—Supplementary Document," National Auxiliary Publication Service document 04849 (P. O. Box 3513, Grand Central Station, New York, NY 10163-3513) no date.

6. Sternglass, E. J. and J. M. Gould, "A Study of Recent Rises in Leukemia and Other Mortality Rates in Oregon Following Radioactive Releases from the Trojan Nuclear Plant," Unpublished Manuscript, October 25, 1990.

U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
February 1996

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 8.29

(Draft was issued as DG-8012)

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

A. INTRODUCTION

Section 19.12 of 10 CFR Part 19, "Notices, Instructions and Reports to Workers: Inspection and Investigations," requires that all individuals who in the course of their employment are likely to receive in a year an occupational dose in excess of 100 mrem (1 mSv) be instructed in the health protection issues associated with exposure to radioactive materials or radiation. Section 20.1206 of 10 CFR Part 20, "Standards for Protection Against Radiation," requires that before a planned special exposure occurs the individuals involved are, among other things, to be informed of the estimated doses and associated risks.

This regulatory guide describes the information that should be provided to workers by licensees about health risks from occupational exposure. This revision conforms to the revision of 10 CFR Part 20 that became effective on June 20, 1991, to be implemented by licensees no later than January 1, 1994. The revision of 10 CFR Part 20 establishes new dose limits based on the effective dose equivalent (EDE), requires the summing of internal and external dose, establishes a requirement that licensees use procedures and engineering controls to the extent practicable to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA), provides for planned special exposures, establishes a dose limit for the embryo/fetus of an occupationally exposed declared pregnant woman, and explicitly states that Part 20 is not to be construed as limiting action that may be necessary to protect health and safety during emergencies.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 19 or 10 CFR Part 20. These regulations provide the regulatory bases for this guide. The information collection requirements in 10 CFR Parts 19 and 20 have been cleared under OMB Clearance Nos. 3150-0044 and 3150-0014, respectively.

B. DISCUSSION

It is important to qualify the material presented in this guide with the following considerations.

The coefficient used in this guide for occupational radiation risk estimates, 4×10^{-4} health effects per rem, is based on data obtained at much higher doses and dose rates than those encountered by workers. The risk coefficient obtained at high doses and dose rates was reduced to account for the reduced effectiveness of lower doses and dose rates in producing the stochastic effects observed in studies of exposed humans.

The assumption of a linear extrapolation from the lowest doses at which effects are observable down to the occupational range has considerable uncertainty. The report of the Committee on the Biological Effects of Ionizing Radiation (Ref. 1) states that

> "... departure from linearity cannot be excluded at low doses below the range of observation. Such departures could be in the direction of either an increased or decreased risk. Moreover, epidemiologic data cannot rigorously exclude the existence of a threshold in the 100 mrem dose range. Thus, the possibility that there may be no risk from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero."

The issue of beneficial effects from low doses, or hormesis, in cellular systems is addressed by the United Nations Scientific Committee on the Effects of Atomic Radiation (Ref. 2). UNSCEAR states that "... it would be premature to conclude that cellular adaptive responses could convey possible beneficial effects to the organism that would outweigh the detrimental effects of exposures to low doses of low-LET radiation."

In the absence of scientific certainty regarding the relationship between low doses and health effects, and as a conservative assumption for radiation protection purposes, the scientific community generally assumes that any exposure to ionizing radiation can cause biological effects that may be harmful to the exposed person and that the magnitude or probability of these effects is directly proportional to the dose. These effects may be classified into three categories:

Somatic Effects: Physical effects occurring in the exposed person. These effects may be observable after a large or acute dose (e.g., 100 rems[1] (1 Sv) or more to the whole body in a few hours); or they may be effects such as cancer that may occur years after exposure to radiation.

Genetic Effects: Abnormalities that may occur in the future children of exposed individuals and in subsequent generations (genetic effects exceeding normal incidence have not been observed in any of the studies of human populations).

Teratogenic Effects: Effects such as cancer or congenital malformation that may be observed in children who were exposed during the fetal and embryonic stages of development (these effects have been observed from high, i.e., above 20 rems (0.2 Sv), acute exposures).

The normal incidence of effects from natural and manmade causes is significant. For example, approximately 20% of people die from various forms of cancer whether or not they ever receive occupational exposure to radiation. To avoid increasing the incidence of such biological effects, regulatory controls are imposed on occupational doses to adults and minors and on doses to the embryo/fetus from occupational exposures of declared pregnant women.

Radiation protection training for workers who are occupationally exposed to ionizing radiation is an essential component of any program designed to ensure compliance with NRC regulations. A clear understanding of what is presently known about the biological risks associated with exposure to radiation will result in more effective radiation protection training and should generate more interest on the part of the workers in complying with radiation protection standards. In addition, pregnant women and other occupationally exposed workers should have available to them relevant information on radiation risks to enable them to make informed decisions regarding the acceptance of these risks. It is intended that workers who receive this instruction will develop respect for the risks involved, rather than excessive fear or indifference.

C. REGULATORY POSITION

Instruction to workers performed in compliance with 10 CFR 19.12 should be given prior to occupational exposure and periodically thereafter. The frequency of retraining might range from annually for licensees with complex operations such as nuclear power plants, to every three years for licensees who possess, for example, only low-activity sealed sources. If a worker is to participate in a planned special exposure, the worker should be informed of the associated risks in compliance with 10 CFR 20.1206.

In providing instruction concerning health protection problems associated with exposure to radiation, all occupationally exposed workers and their supervisors should be given specific instruction on the risk of biological effects resulting from exposure to radiation. The extent of these instructions should be commensurate with the radiological risks present in the workplace.

The instruction should be presented orally, in printed form, or in any other effective communication media to workers and supervisors. The appendix to this guide provides useful information for demonstrating compliance with the training requirements in 10 CFR Parts 19 and 20. Individuals should be given an opportunity to discuss the information and to ask questions. Testing is recommended, and each trainee should be asked to acknowledge in writing that the instruction has been received and understood.

[1] In the International System of Units (SI), the rem is replaced by the sievert; 100 rems is equal to 1 sievert (Sv).

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes acceptable alternative methods for complying with specified portions of the Commission's regulations, the guidance and instructional materials in this guide will be used in the evaluation of applications for new licenses, license renewals, and license amendments and for evaluating compliance with 10 CFR 19.12 and 10 CFR Part 20.

REFERENCES

1. National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR V), National Academy Press, Washington, DC, 1990.

2. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation*, United Nations, New York, 1993.

APPENDIX

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

This instructional material is intended to provide the user with the best available information about the health risks from occupational exposure to ionizing radiation. Ionizing radiation consists of energy or small particles, such as gamma rays and beta and alpha particles, emitted from radioactive materials, which can cause chemical or physical damage when they deposit energy in living tissue. A question and answer format is used. Many of the questions or subjects were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training.

This Revision 1 to Regulatory Guide 8.29 updates the material in the original guide on biological effects and risks and on typical occupational exposure. Additionally, it conforms to the revised 10 CFR Part 20, "Standards for Protection Against Radiation," which was required to be implemented by licensees no later than January 1, 1994. The information in this appendix is intended to help develop respect by workers for the risks associated with radiation, rather than unjustified fear or lack of concern. Additional guidance concerning other topics in radiation protection training is provided in other NRC regulatory guides.

1. What is meant by health risk?

A health risk is generally thought of as something that may endanger health. Scientists consider health risk to be the statistical probability or mathematical chance that personal injury, illness, or death may result from some action. Most people do not think about health risks in terms of mathematics. Instead, most of us consider the health risk of a particular action in terms of whether we believe that particular action will, or will not, cause us some harm. The intent of this appendix is to provide estimates of, and explain the bases for, the risk of injury, illness, or death from occupational radiation exposure. Risk can be quantified in terms of the probability of a health effect per unit of dose received.

When x-rays, gamma rays, and ionizing particles interact with living materials such as our bodies, they may deposit enough energy to cause biological damage. Radiation can cause several different types of events such as the very small physical displacement of molecules, changing a molecule to a different form, or ionization, which is the removal of electrons from atoms and molecules. When the quantity of radiation energy deposited in living tissue is high enough, biological damage can occur as a result of chemical bonds being broken and cells being damaged or killed. These effects can result in observable clinical symptoms.

The basic unit for measuring absorbed radiation is the rad. One rad (0.01 gray in the International System of units) equals the absorption of 100 ergs (a small but measurable amount of energy) in a gram of material such as tissue exposed to radiation. To reflect biological risk, rads must be converted to rems. The new international unit is the sievert (100 rems = 1 Sv). This conversion accounts for the differences in the effectiveness of different types of radiation in causing damage. The rem is used to estimate biological risk. For beta and gamma radiation, a rem is considered equal to a rad.

2. What are the possible health effects of exposure to radiation?

Health effects from exposure to radiation range from no effect at all to death, including diseases such as leukemia or bone, breast, and lung cancer. Very high (100s of rads), short-term doses of radiation have been known to cause prompt (or early) effects, such as vomiting and diarrhea,[1] skin burns, cataracts, and even death. It is suspected that radiation exposure may be linked to the potential for genetic effects in the children of exposed parents. Also, children who were exposed to high doses (20 or more rads) of radiation prior to birth (as an embryo/fetus) have shown an increased risk of mental retardation and other congenital malformations. These effects (with the exception of genetic effects) have been observed in various studies of medical radiologists, uranium miners, radium workers, radiotherapy patients, and the people exposed to radiation from atomic bombs dropped on Japan. In addition, radiation effects studies with laboratory animals, in which the animals were given relatively high doses, have provided extensive data on radiation-induced health effects, including genetic effects.

It is important to note that these kinds of health effects result from high doses, compared to occupational levels, delivered over a relatively short period of time.

Although studies have not shown a consistent cause-and-effect relationship between current levels of occupational radiation exposure and biological effects, it is prudent from a worker protection perspective to assume that some effects may occur.

[1]These symptoms are early indicators of what is referred to as the acute radiation syndrome, caused by high doses delivered over a short time period, which includes damage to the blood-forming organs such as bone marrow, damage to the gastrointestinal system, and, at very high doses, can include damage to the central nervous system.

3. **What is meant by early effects and delayed or late effects?**

EARLY EFFECTS

Early effects, which are also called immediate or prompt effects, are those that occur shortly after a large exposure that is delivered within hours to a few days. They are observable after receiving a very large dose in a short period of time, for example, 300 rads (3 Gy) received within a few minutes to a few days. Early effects are not caused at the levels of radiation exposure allowed under the NRC's occupational limits.

Early effects occur when the radiation dose is large enough to cause extensive biological damage to cells so that large numbers of cells are killed. For early effects to occur, this radiation dose must be received within a short time period. This type of dose is called an acute dose or acute exposure. The same dose received over a long time period would not cause the same effect. Our body's natural biological processes are constantly repairing damaged cells and replacing dead cells; if the cell damage is spread over time, our body is capable of repairing or replacing some of the damaged cells, reducing the observable adverse conditions.

For example, a dose to the whole body of about 300–500 rads (3–5 Gy), more than 60 times the annual occupational dose limit, if received within a short time period (e.g., a few hours) will cause vomiting and diarrhea within a few hours; loss of hair, fever, and weight loss within a few weeks; and about a 50 percent chance of death if medical treatment is not provided. These effects would not occur if the same dose were accumulated gradually over many weeks or months (Refs. 1 and 2). Thus, one of the justifications for establishing annual dose limits is to ensure that occupational dose is spread out in time.

It is important to distinguish between whole body and partial body exposure. A localized dose to a small volume of the body would not produce the same effect as a whole body dose of the same magnitude. For example, if only the hand were exposed, the effect would mainly be limited to the skin and underlying tissue of the hand. An acute dose of 400 to 600 rads (4–6 Gy) to the hand would cause skin reddening; recovery would occur over the following months and no long-term damage would be expected. An acute dose of this magnitude to the whole body could cause death within a short time without medical treatment. Medical treatment would lessen the magnitude of the effects and the chance of death; however, it would not totally eliminate the effects or the chance of death.

DELAYED EFFECTS

Delayed effects may occur years after exposure. These effects are caused indirectly when the radiation changes parts of the cells in the body, which causes the normal function of the cell to change, for example, normal healthy cells turn into cancer cells. The potential for these delayed health effects is one of the main concerns addressed when setting limits on occupational doses.

A delayed effect of special interest is genetic effects. Genetic effects may occur if there is radiation damage to the cells of the gonads (sperm or eggs). These effects may show up as genetic defects in the children of the exposed individual and succeeding generations. However, if any genetic effects (i.e., effects in addition to the normal expected number) have been caused by radiation, the numbers are too small to have been observed in human populations exposed to radiation. For example, the atomic bomb survivors (from Hiroshima and Nagasaki) have not shown any significant radiation-related increases in genetic defects (Ref. 3). Effects have been observed in animal studies conducted at very high levels of exposure and it is known that radiation can cause changes in the genes in cells of the human body. However, it is believed that by maintaining worker exposures below the NRC limits and consistent with ALARA, a margin of safety is provided such that the risk of genetic effects is almost eliminated.

4. **What is the difference between acute and chronic radiation dose?**

Acute radiation dose usually refers to a large dose of radiation received in a short period of time. Chronic dose refers to the sum of small doses received repeatedly over long time periods, for example, 20 mrem (or millirem, which is 1-thousandth of a rem) (0.2 mSv) per week every week for several years. It is assumed for radiation protection purposes that any radiation dose, either acute or chronic, may cause delayed effects. However, only large acute doses cause early effects; chronic doses within the occupational dose limits do not cause early effects. Since the NRC limits do not permit large acute doses, concern with occupational radiation risk is primarily focused on controlling chronic exposure for which possible delayed effects, such as cancer, are of concern.

The difference between acute and chronic radiation exposure can be shown by using exposure to the sun's rays as an example. An intense exposure to the sun can result in painful burning, peeling, and growing of new skin. However, repeated short exposures provide time for the skin to be repaired between exposures. Whether exposure to the sun's rays is long term or spread over short periods, some of the injury may not be repaired and may eventually result in skin cancer.

Cataracts are an interesting case because they can be caused by both acute and chronic radiation. A certain threshold level of dose to the lens of the eye is required before there is any observable visual impairment, and the impairment remains after the exposure is stopped. The threshold for cataract development from acute exposure is an acute dose on the order of 100 rads (1 Gy). Further, a cumulative dose of 800 rads (8 Gy) from protracted exposures over many years to the lens of the eye has been linked to some level of visual impairment (Refs. 1 and 4). These doses exceed the amount that may be accumulated by the lens from normal occupational exposure under the current regulations.

5. What is meant by external and internal exposure?

A worker's occupational dose may be caused by exposure to radiation that originates outside the body, called "external exposure," or by exposure to radiation from radioactive material that has been taken into the body, called "internal exposure." Most NRC-licensed activities involve little, if any, internal exposure. It is the current scientific consensus that a rem of radiation dose has the same biological risk regardless of whether it is from an external or an internal source. The NRC requires that dose from external exposure and dose from internal exposure be added together, if each exceeds 10% of the annual limit, and that the total be within occupational limits. The sum of external and internal dose is called the total effective dose equivalent (TEDE) and is expressed in units of rems (Sv).

Although unlikely, radioactive materials may enter the body through breathing, eating, drinking, or open wounds, or they may be absorbed through the skin. The intake of radioactive materials by workers is generally due to breathing contaminated air. Radioactive materials may be present as fine dust or gases in the workplace atmosphere. The surfaces of equipment and workbenches may be contaminated, and these materials can be resuspended in air during work activities.

If any radioactive material enters the body, the material goes to various organs or is excreted, depending on the biochemistry of the material. Most radioisotopes are excreted from the body in a few days. For example, a fraction of any uranium taken into the body will deposit in the bones, where it remains for a longer time. Uranium is slowly eliminated from the body, mostly by way of the kidneys. Most workers are not exposed to uranium. Radioactive iodine is preferentially deposited in the thyroid gland, which is located in the neck.

To limit risk to specific organs and the total body, an annual limit on intake (ALI) has been established for each radionuclide. When more than one radionuclide is involved, the intake amount of each radionuclide is reduced proportionally. NRC regulations specify the concentrations of radioactive material in the air to which a worker may be exposed for 2,000 working hours in a year. These concentrations are termed the derived air concentrations (DACs). These limits are the total amounts allowed if no external radiation is received. The resulting dose from the internal radiation sources (from breathing air at 1 DAC) is the maximum allowed to an organ or to the worker's whole body.

6. How does radiation cause cancer?

The mechanisms of radiation-induced cancer are not completely understood. When radiation interacts with the cells of our bodies, a number of events can occur. The damaged cells can repair themselves and permanent damage is not caused. The cells can die, much like the large numbers of cells that die every day in our bodies, and be replaced through the normal biological processes. Or a change can occur in the cell's reproductive structure, the cells can mutate and subsequently be repaired without effect, or they can form precancerous cells, which may become cancerous. Radiation is only one of many agents with the potential for causing cancer, and cancer caused by radiation cannot be distinguished from cancer attributable to any other cause.

Radiobiologists have studied the relationship between large doses of radiation and cancer (Refs. 5 and 6). These studies indicate that damage or change to genes in the cell nucleus is the main cause of radiation-induced cancer. This damage may occur directly through the interaction of the ionizing radiation in the cell or indirectly through the actions of chemical products produced by radiation interactions within cells. Cells are able to repair most damage within hours; however, some cells may not be repaired properly. Such misrepaired damage is thought to be the origin of cancer, but misrepair does not always cause cancer. Some cell changes are benign or the cell may die; these changes do not lead to cancer.

Many factors such as age, general health, inherited traits, sex, as well as exposure to other cancer-causing agents such as cigarette smoke can affect susceptibility to the cancer-causing effects of radiation. Many diseases are caused by the interaction of several factors, and these interactions appear to increase the susceptibility to cancer.

7. Who developed radiation risk estimates?

Radiation risk estimates were developed by several national and international scientific organizations over the last 40 years. These organizations include the National Academy of Sciences (which has issued several reports from the Committee on the Biological Effects of Ionizing Radiations, BEIR), the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Each of these organizations continues to review new research findings on radiation health risks.

Several reports from these organizations present new findings on radiation risks based upon revised estimates of radiation dose to survivors of the atomic bombing at Hiroshima and Nagasaki. For example, UNSCEAR published risk estimates in 1988 and 1993 (Refs. 5 and 6). The NCRP also published a report in 1988, "New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates" (Ref. 7). In January 1990, the National Academy of Sciences released the fifth report of the BEIR Committee, "Health Effects of Exposure to Low Levels of Ionizing Radiation" (Ref. 4). Each of these publications also provides extensive bibliographies on other published studies concerning radiation health effects for those who may wish to read further on this subject.

8. What are the estimates of the risk of fatal cancer from radiation exposure?

We don't know exactly what the chances are of getting cancer from a low-level radiation dose, primarily because the few effects that may occur cannot be distinguished from normally occurring cancers. However, we can make estimates based on extrapolation from extensive knowledge from scientific research on high dose effects. The estimates of radiation effects at high doses are better known than are those of most chemical carcinogens (Ref. 8).

From currently available data, the NRC has adopted a risk value for an occupational dose of 1 rem (0.01 Sv) Total Effective Dose Equivalent (TEDE) of 4 in 10,000 of developing a fatal cancer, or approximately 1 chance in 2,500 of fatal cancer per rem of TEDE received. The uncertainty associated with this risk estimate does not rule out the possibility of higher risk, or the possibility that the risk may even be zero at low occupational doses and dose rates.

The radiation risk incurred by a worker depends on the amount of dose received. Under the linear model explained above, a worker who receives 5 rems (0.05 Sv) in a year incurs 10 times as much risk as another worker who receives only 0.5 rem (0.005 Sv). Only a very few workers receive doses near 5 rems (0.05 Sv) per year (Ref. 9).

According to the BEIR V report (Ref. 4), approximately one in five adults normally will die from cancer from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits. Thus, in any group of 10,000 workers, we can estimate that about 2,000 (20%) will die from cancer without any occupational radiation exposure.

To explain the significance of these estimates, we will use as an example a group of 10,000 people, each exposed to 1 rem (0.01 Sv) of ionizing radiation. Using the risk factor of 4 effects per 10,000 rem of dose, we estimate that 4 of the 10,000 people might die from delayed cancer because of that 1-rem dose (although the actual number could be more or less than 4) in addition to the 2,000 normal cancer fatalities expected to occur in that group from all other causes. This means that a 1-rem (0.01 Sv) dose may increase an individual worker's chances of dying from cancer from 20 percent to 20.04 percent. If one's lifetime occupational dose is 10 rems, we could raise the estimate to 20.4 percent. A lifetime dose of 100 rems may increase chances of dying from cancer from 20 to 24 percent. The average measurable dose for radiation workers reported to the NRC was 0.31 rem (0.0031 Sv) for 1993 (Ref. 9). Today, very few workers ever accumulate 100 rems (1 Sv) in a working lifetime, and the average career dose of workers at NRC-licensed facilities is 1.5 rems (0.015 Sv), which represents an estimated increase from 20 to about 20.06 percent in the risk of dying from cancer.

It is important to understand the probability factors here. A similar question would be, "If you select one card from a full deck of cards, will you get the ace of spades?" This question cannot be answered with a simple yes or no. The best answer is that your chance is 1 in 52. However, if 1000 people each select one card from full decks, we can predict that about 20 of them will get an ace of spades. Each person will have 1 chance in 52 of drawing the ace of spades, but there is no way we can predict which persons will get that card. The issue is further complicated by the fact that in a drawing by 1000 people, we might get only 15 successes, and in another, perhaps 25 correct cards in 1000 draws. We can say that if you receive a radiation dose, you will have increased your chances of eventually developing cancer. It is assumed that the more radiation exposure you get, the more you increase your chances of cancer.

The normal chance of dying from cancer is about one in five for persons who have not received any occupational radiation dose. The additional chance of developing fatal cancer from an occupational exposure of 1 rem (0.01 Sv) is about the same as the chance of drawing any ace from a full deck of cards three times in a row. The additional chance of dying from cancer from an occupational exposure of 10 rem (0.1 Sv) is about equal to your chance of drawing two aces successively on the first two draws from a full deck of cards.

It is important to realize that these risk numbers are only estimates based on data for people and research animals exposed to high levels of radiation in short periods of time. There is still uncertainty with regard to estimates of radiation risk from low levels of exposure. Many difficulties are involved in designing research studies that can accurately measure the projected small increases in cancer cases that might be caused by low exposures to radiation as compared to the normal rate of cancer.

These estimates are considered by the NRC staff to be the best available for the worker to use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should try to keep exposure to radiation as low as is reasonably achievable (ALARA) to avoid unnecessary risk.

9. If I receive a radiation dose that is within occupational limits, will it cause me to get cancer?

Probably not. Based on the risk estimates previously discussed, the risk of cancer from doses below the occupational limits is believed to be small. Assessment of the cancer risks that may be associated with low doses of radiation are projected from data available at doses larger than 10 rems (0.1 Sv) (Ref. 3). For radiation protection purposes, these estimates are made using the straight line portion of the linear quadratic model (Curve 2 in Figure 1). We have data on cancer probabilities only for high doses, as shown by the solid line in Figure 1. Only in studies involving radiation doses above occupational limits are there dependable determinations of the risk of cancer, primarily because below the limits the effect is small compared to differences in the normal cancer incidence from year to year and place to place. The ICRP, NCRP, and other standards-setting organizations assume for radiation protection purposes that there is some risk, no matter how small the dose (Curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (Curve 3), the threshold effect. The ICRP and NCRP endorse the linear quadratic model as a conservative means of assuring safety (Curve 2).

For regulatory purposes, the NRC uses the straight line portion of Curve 2, which shows the number of effects decreasing linearly as the dose decreases. Because the scientific evidence does not conclusively demonstrate whether there is or is not an effect at low doses, the NRC assumes for radiation protection purposes, that even small doses have some chance of causing cancer. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory limits; doses should be kept as low as is reasonably achievable (ALARA). This is as true for natural carcinogens such as sunlight and natural radiation as it is for those that are manmade, such as cigarette smoke, smog, and x-rays.

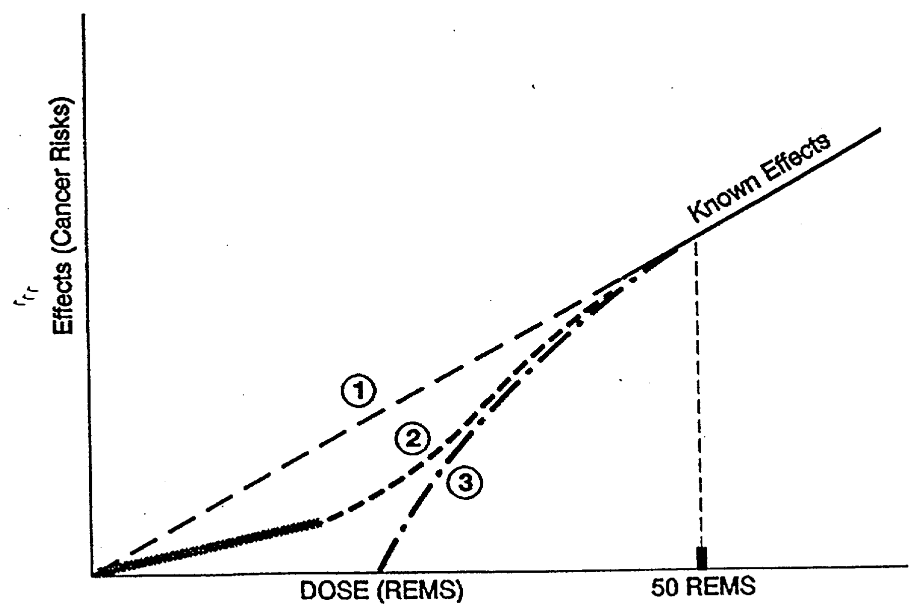


Figure 1. Some Proposed Models for How the Effects of Radiation Vary With Doses at Low Levels

10. How can we compare the risk of cancer from radiation to other kinds of health risks?

One way to make these comparisons is to compare the average number of days of life expectancy lost because of the effects associated with each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from specific causes, and estimating the average number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total observed group.

Several studies have compared the average days of life lost from exposure to radiation with the number of days lost as a result of being exposed to other health risks. The word "average" is important because an individual who gets cancer loses about 15 years of life expectancy, while his or her coworkers do not suffer any loss.

Some representative numbers are presented in Table 1. For categories of NRC-regulated industries with larger doses, the average measurable occupational dose in 1993 was 0.31 rem (0.0031 Sv). A simple calculation based on the article by Cohen and Lee (Ref. 10) shows that 0.3 rem (0.003 Sv) per year from age 18 to 65 results in an average loss of 15 days. These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.

It is also useful to compare the estimated average number of days of life lost from occupational exposure to radiation with the number of days lost as a result of working in several types of industries. Table 2 shows average days of life expectancy lost as a result of fatal work-related accidents. Table 2 does not include non-accident types of occupational risks such as occupational disease and stress because the data are not available.

These comparisons are not ideal because we are comparing the possible effects of chronic exposure to radiation to different kinds of risk such as accidental death, in which death is inevitable if the event occurs. This is the best we can do because good data are not available on chronic exposure to other workplace carcinogens. Also, the estimates of loss of life expectancy for workers from radiation-induced cancer do not take into consideration the competing effect on the life expectancy of the workers from industrial accidents.

11. What are the health risks from radiation exposure to the embryo/fetus?

During certain stages of development, the embryo/fetus is believed to be more sensitive to radiation damage than adults. Studies of atomic bomb survivors exposed to acute radiation doses exceeding 20 rads (0.2 Gy) during pregnancy show that children born after receiving these doses have a higher risk of mental retardation. Other studies suggest that an association exists between exposure to diagnostic x-rays before birth and carcinogenic effects in childhood and in adult life. Scientists are uncertain about the magnitude of the risk. Some studies show the embryo/fetus to be more sensitive to radiation-induced cancer than adults, but other studies do not. In recognition of the possibility of increased radiation sensitivity, and because dose to the

Table 1 Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk		*Estimate of Life Expectancy Lost (average)*
Smoking 20 cigarettes a day		6 years
Overweight (by 15%)		2 years
Alcohol consumption (U.S. average)		1 year
All accidents combined		1 year
Motor vehicle accidents	207 days	
Home accidents	74 days	
Drowning	24 days	
All natural hazards (earthquake, lightning, flood, etc.)		7 days
Medical radiation		6 days
Occupational Exposure		
0.3 rem/y from age 18 to 65	15 days	
1 rem/y from age 18 to 65	51 days	

[a]Adapted from Reference 10.

Table 2 Estimated Loss of Life Expectancy from Industrial Accidents[a]

Industry Type	*Estimated Days of Life Expectancy Lost (Average)*
All industries	60
Agriculture	320
Construction	227
Mining and Quarrying	167
Transportation and Public Utilities	160
Government	60
Manufacturing	40
Trade	27
Services	27

[a]Adapted from Reference 10.

embryo/fetus is involuntary on the part of the embryo/fetus, a more restrictive dose limit has been established for the embryo/fetus of a declared pregnant radiation worker. See Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure."

If an occupationally exposed woman declares her pregnancy in writing, she is subject to the more restrictive dose limits for the embryo/fetus during the remainder of the pregnancy. The dose limit of 500 mrems (5 mSv) for the total gestation period applies to the embryo/fetus and is controlled by restricting the exposure to the declared pregnant woman. Restricting the woman's occupational exposure, if she declares her pregnancy, raises questions about individual privacy rights, equal employment opportunities, and the possible loss of income. Because of these concerns, the declaration of pregnancy by a female radiation worker is voluntary. Also, the declaration of pregnancy can be withdrawn for any reason, for example, if the woman believes that her benefits from receiving the occupational exposure would outweigh the risk to her embryo/fetus from the radiation exposure.

12. Can a worker become sterile or impotent from normal occupational radiation exposure?

No. Temporary or permanent sterility cannot be caused by radiation at the levels allowed under NRC's occupational limits. There is a threshold below which these effects do not occur. Acute doses on the order of 10 rems (0.1 Sv) to the testes can result in a measurable but temporary reduction in sperm count. Temporary sterility (suppression of ovulation) has been observed in women who have received acute doses of 150 rads (1.5 Gy). The estimated threshold (acute) radiation dose for induction of permanent sterility is about 200 rads (2 Gy) for men and about 350 rads (3.5 Gy) for women (Refs. 1 and 4). These doses are far greater than the NRC s occupational dose limits for workers.

Although acute doses can affect fertility by reducing sperm count or suppressing ovulation, they do not have any direct effect on one's ability to function sexually. No evidence exists to suggest that exposures within the NRC's occupational limits have any effect on the ability to function sexually.

13. What are the NRC occupational dose limits?

For adults, an annual limit that does not exceed:

- 5 rems (0.05 Sv) for the total effective dose equivalent (TEDE), which is the sum of the deep dose equivalent (DDE) from external exposure to the whole body and the committed effective dose equivalent (CEDE) from intakes of radioactive material.
- 50 rems (0.5 Sv) for the total organ dose equivalent (TODE), which is the sum of the DDE from external exposure to the whole body and the committed dose equivalent (CDE) from intakes of radioactive material to any individual organ or tissue, other than the lens of the eye.
- 15 rems (0.15 Sv) for the lens dose equivalent (LDE), which is the external dose to the lens of the eye.
- 50 rems (0.5 Sv) for the shallow dose equivalent (SDE), which is the external dose to the skin or to any extremity.

For minor workers, the annual occupational dose limits are 10 percent of the dose limits for adult workers.

For protection of the embryo/fetus of a declared pregnant woman, the dose limit is 0.5 rem (5 mSv) during the entire pregnancy.

The occupational dose limit for adult workers of 5 rems (0.05 Sv) TEDE is based on consideration of the potential for delayed biological effects. The 5-rem (0.05 Sv) limit, together with application of the concept of keeping occupational doses ALARA, provides a level of risk of delayed effects considered acceptable by the NRC. The limits for individual organs are below the dose levels at which early biological effects are observed in the individual organs.

The dose limit for the embryo/fetus of a declared pregnant woman is based on a consideration of the possibility of greater sensitivity to radiation of the embryo/fetus and the involuntary nature of the exposure.

14. What is meant by ALARA?

ALARA means "as low as is reasonably achievable." In addition to providing an upper limit on an individual's permissible radiation dose, the NRC requires that its licensees establish radiation protection programs and use procedures and engineering controls to achieve occupational doses, and doses to the public, as far below the limits as is reasonably achievable. "Reasonably achievable" also means "to the extent practicable." What is practicable depends on the purpose of the job, the state of technology, the costs for averting doses, and the benefits. Although implementation of the ALARA principle is a required integral part of each licensee's radiation protection program, it does not mean that each radiation exposure must be kept to an absolute minimum, but rather that "reasonable" efforts must be made to avert dose. In practice, ALARA includes planning tasks involving radiation exposure so as to reduce dose to individual workers and the work group.

There are several ways to control radiation doses, e.g., limiting the time in radiation areas, maintaining distance from sources of radiation, and providing shielding of radiation sources to reduce dose. The use of engineering controls, from the design of facilities and equipment to the actual set-up and conduct of work activities, is also an important element of the ALARA concept.

An ALARA analysis should be used in determining whether the use of respiratory protection is advisable. In evaluating whether or not to use respirators, the goal should be to achieve the optimal sum of external and internal doses. For example, the use of respirators can lead to increased work time within radiation areas, which increases external dose. The advantage of using respirators to reduce internal exposure must be evaluated against the increased external exposure and related stresses caused by the use of respirators. Heat stress, reduced visibility, and reduced communication associated with the use of respirators could expose a worker to far greater risks than are associated with the internal dose avoided by use of the respirator. To the extent practical, engineering controls, such as containments and ventilation systems, should be used to reduce workplace airborne radioactive materials.

15. What are background radiation exposures?

The average person is constantly exposed to ionizing radiation from several sources. Our environment and even the human body contain naturally occurring radioactive materials (e.g., potassium-40) that contribute to the radiation dose that we receive. The largest source of natural background radiation exposure is terrestrial radon, a colorless, odorless, chemically inert gas, which causes about 55 percent of our average, nonoccupational exposure. Cosmic radiation originating in space contributes additional exposure. The use of x-rays and radioactive materials in medicine and dentistry adds to our population exposure. As shown below in Table 3, the average person receives an annual radiation dose of about 0.36 rem (3.6 mSv). By age 20, the average person will accumulate over 7 rems (70 mSv) of dose. By age 50, the total dose is up to 18 rems (180 mSv). After 70 years of exposure this dose is up to 25 rems (250 mSv).

Table 3 Average Annual Effective Dose Equivalent to Individuals in the U.S.[a]

Source	*Effective Dose Equivalent (mrems)*	
Natural		
Radon	200	
Other than Radon	100	
Total		300
Nuclear Fuel Cycle		0.05
Consumer Products[b]		9
Medical		
Diagnostic X-rays	39	
Nuclear Medicine	14	
Total		53
Total		about 360 mrems/year

[a]Adapted from Table 8.1, NCRP 93 (Ref. 11).

[b]Includes building material, television receivers, luminous watches, smoke detectors, etc. (from Table 5.1, NCRP 93, Ref. 11).

16. What are the typical radiation doses received by workers?

For 1993, the NRC received reports on about a quarter of a million people who were monitored for occupational exposure to radiation. Almost half of those monitored had no measurable doses. The other half had an average dose of about 310 mrem (3.1 mSv) for the year. Of these, 93 percent received an annual dose of less than 1 rem (10 mSv); 98.7 percent received less than 2 rems (20 mSv); and the highest reported dose was for two individuals who each received between 5 and 6 rems (50 and 60 mSv).

Table 4 lists average occupational doses for workers (persons who had measurable doses) in various occupations based on 1993 data. It is important to note that beginning in 1994, licensees have been required to sum external and internal doses and certain licensees are required to submit annual reports. Certain types of licensees such as nuclear fuel fabricators may report a significant increase in worker doses because of the exposure to long-lived airborne radionuclides and the requirement to add the resultant internal dose to the calculation of occupational doses.

Table 4 Reported Occupational Doses for 1993[a]

Occupational Subgroup	Average Measurable Dose per Worker (millirems)
Industrial Radiography	540
Commercial Nuclear Power Reactors	310
Manufacturing and Distribution of Radioactive Materials	300
Low-Level Radioactive Waste Disposal	270
Independent Spent Nuclear Fuel Storage	260
Nuclear Fuel Fabrication	130

[a]From Table 3.1 in NUREG–0713 (Ref. 9).

17. How do I know how much my occupational dose (exposure) is?

If you are likely to receive more than 10 percent of the annual dose limits, the NRC requires your employer, the NRC licensee, to monitor your dose, to maintain records of your dose, and, at least on an annual basis for the types of licensees listed in 10 CFR 20.2206, "Reports of Individual Monitoring," to inform both you and the NRC of your dose. The purpose of this monitoring and reporting is so that the NRC can be sure that licensees are complying with the occupational dose limits and the ALARA principle.

External exposures are monitored by using individual monitoring devices. These devices are required to be used if it appears likely that external exposure will exceed 10 percent of the allowed annual dose, i.e., 0.5 rem (5 mSv). The most commonly used monitoring devices are film badges, thermoluminescence dosimeters (TLDs), electronic dosimeters, and direct reading pocket dosimeters.

With respect to internal exposure, your employer is required to monitor your occupational intake of radioactive material and assess the resulting dose if it appears likely that you will receive greater than 10 percent of the annual limit on intake (ALI) from intakes in 1 year. Internal exposure can be estimated by measuring the radiation emitted from the body (for example, with a "whole body counter") or by measuring the radioactive materials contained in biological samples such as urine or feces. Dose estimates can also be made if one knows how much radioactive material was in the air and the length of time during which the air was breathed.

18. What happens if a worker exceeds the annual dose limit?

If a worker receives a dose in excess of any of the annual dose limits, the regulations prohibit any occupational exposure during the remainder of the year in which the limit is exceeded. The licensee is also required to file an overexposure report with the NRC and provide a copy to the individual who received the dose. The licensee may be subject to NRC enforcement action such as a fine (civil penalty), just as individuals are subject to a traffic fine for exceeding a speed limit. The fines and, in some serious or repetitive cases, suspension of a license are intended to encourage licensees to comply with the regulations.

Radiation protection limits do not define safe or unsafe levels of radiation exposure. Exceeding a limit does not mean that you will get cancer. For radiation protection purposes, it is assumed that risks are related to the size of the radiation dose. Therefore, when your dose is higher your risk is also considered to be higher. These limits are similar to highway speed limits. If you drive at 70 mph, your risk is higher than at 55 mph, even though you may not actually have an accident. Those who set speed limits have determined that the risks of driving in excess of the speed limit are not acceptable. In the same way, the revised 10 CFR Part 20 establishes a limit for normal occupational exposure of 5 rems (0.05 Sv) a year. Although you will not necessarily get cancer or some other radiation effect at doses above the limit, it does mean that the licensee's safety program has failed in some way. Investigation is warranted to determine the cause and correct the conditions leading to the dose in excess of the limit.

19. What is meant by a "planned special exposure"?

A "planned special exposure" (PSE) is an infrequent exposure to radiation, separate from and in addition to the radiation received under the annual occupational limits. The licensee can authorize additional dose in any one year that is equal to the annual occupational dose limit as long as the individual's total dose from PSEs does not exceed five times the annual dose limit during the individual's lifetime. For example, licensees may authorize PSEs for an adult radiation worker to receive doses up to an additional 5 rems (0.05 Sv) in a year above the 5-rem (0.05–Sv) annual TEDE occupational dose limit. Each worker is limited to no more than 25 rems (0.25 Sv) from planned special exposures in his or her lifetime. Such exposures are only allowed in exceptional situations when alternatives for avoiding the additional exposure are not available or are impractical.

Before the licensee authorizes a PSE, the licensee must ensure that the worker is informed of the purpose and circumstances of the planned operation, the estimated doses expected, and the procedures to keep the doses ALARA while considering other risks that may be present. (See Regulatory Guide 8.35, "Planned Special Exposures.")

20. Why do some facilities establish administrative control levels that are below the NRC limits?

There are two reasons. First, the NRC regulations state that licensees must take steps to keep exposures to radiation ALARA. Specific approval from the licensee for workers to receive doses in excess of administrative limits usually results in more critical risk-benefit analyses as each additional increment of dose is approved for a worker. Secondly, an administrative control level that is set lower than the NRC limit provides a safety margin designed to help the licensee avoid doses to workers in excess of the limit.

21. Why aren't medical exposures considered as part of a worker's allowed dose?

NRC rules exempt medical exposure, but equal doses of medical and occupational radiation have equal risks. Medical exposure to radiation is justified for reasons that are quite different from the reasons for occupational exposure. A physician prescribing an x-ray, for example, makes a medical judgment that the benefit to the patient from the resulting medical information justifies the risk associated with the radiation. This judgment may or may not be accepted by the patient. Similarly, each worker must decide on the benefits and acceptability of occupational radiation risk, just as each worker must decide on the acceptability of any other occupational hazard.

Consider a worker who receives a dose of 3 rems (0.03 Sv) from a series of x-rays in connection with an injury or illness. This dose and any associated risk must be justified on medical grounds. If the worker had also received 2 rems (0.02 Sv) on the job, the combined dose of 5 rems (0.05 Sv) would in no way incapacitate the worker. Restricting the worker from additional job exposure during the remainder of the year would not have any effect on the risk from the 3 rems (0.03 Sv) already received from the medical exposure. If the individual worker accepts the risks associated with the x-rays on the basis of the medical benefits and accepts the risks associated with job-related exposure on the basis of employment benefits, it would be unreasonable to restrict the worker from employment involving exposure to radiation for the remainder of the year.

22. How should radiation risks be considered in an emergency?

Emergencies are "unplanned" events in which actions to save lives or property may warrant additional doses for which no particular limit applies. The revised 10 CFR Part 20 does not set any dose limits for emergency or lifesaving activities and states that nothing in Part 20 "shall be construed as limiting actions that may be necessary to protect health and safety."

Rare situations may occur in which a dose in excess of occupational limits would be unavoidable in order to carry out a lifesaving operation or to avoid a large dose to large populations. However, persons called upon to undertake any emergency operation should do so only on a voluntary basis and with full awareness of the risks involved.

For perspective, the Environmental Protection Agency (EPA) has published emergency dose guidelines (Ref. 2). These guidelines state that doses to all workers during emergencies should, to the extent practicable, be limited to 5 rems (0.05 Sv). The EPA further states that there are some emergency situations for which higher limits may be justified. The dose resulting from such emergency exposures should be limited to 10 rems (0.1 Sv) for protecting valuable property, and to 25 rems (0.25 Sv) for lifesaving activities and the protection of large populations. In the context of this guidance, the dose to workers that is incurred for the protection of large populations might be considered justified for situations in which the collective dose to others that is avoided as a result of the emergency operation is significantly larger than that incurred by the workers involved.

Table 5 presents the estimates of the fatal cancer risk for a group of 1,000 workers of various ages, assuming that each worker received an acute dose of 25 rems (0.25 Sv) in the course of assisting in an emergency. The estimates show that a 25-rem emergency dose might increase an individual's chances of developing fatal cancer from about 20% to about 21%.

Table 5
Risk of Premature Death from Exposure to 25-Rems (0.25-Sv) Acute Dose

Age at Exposure (years)	*Estimated Risk of Premature Death (Deaths per 1,000 Persons Exposed)*
20–30	9.1
30–40	7.2
40–50	5.3
50–60	3.5

Source: EPA–400–R–92–001 (Ref. 2).

23. How were radiation dose limits established?

The NRC radiation dose limits in 10 CFR Part 20 were established by the NRC based on the recommendations of the ICRP and NCRP as endorsed in Federal radiation protection guidance developed by the EPA

(Ref. 12). The limits were recommended by the ICRP and NCRP with the objective of ensuring that working in a radiation-related industry was as safe as working in other comparable industries. The dose limits and the principle of ALARA should ensure that risks to workers are maintained indistinguishable from risks from background radiation.

24. Several scientific reports have recommended that the NRC establish lower dose limits. Does the NRC plan to reduce the regulatory limits?

Since publication of the NRC's proposed rule in 1986, the ICRP in 1990 revised its recommendations for radiation protection based on newer studies of radiation risks (Ref. 13), and the NCRP followed with a revision to its recommendations in 1993. The ICRP recommended a limit of 10 rems (0.1 Sv) effective dose equivalent (from internal and external sources), over a 5-year period with no more than 5 rems (0.05 Sv) in 1 year (Ref. 13). The NCRP recommended a cumulative limit in rems, not to exceed the individual's age in years, with no more than 5 rems (0.05 Sv) in any year (Ref. 14).

The NRC does not believe that additional reductions in the dose limits are required at this time. Because of the practice of maintaining radiation exposures ALARA (as low as is reasonably achievable), the average radiation dose to occupationally exposed persons is well below the limits in the current Part 20 that became mandatory January 1, 1994, and the average doses to radiation workers are below the new limits recommended by the ICRP and the NCRP.

25. What are the options if a worker decides that the risks associated with occupational radiation exposure are too high?

If the risks from exposure to occupational radiation are unacceptable to a worker, he or she can request a transfer to a job that does not involve exposure to radiation. However, the risks associated with the exposure to radiation that workers, on the average, actually receive are comparable to risks in other industries and are considered acceptable by the scientific groups that have studied them. An employer is not obligated to guarantee a transfer if a worker decides not to accept an assignment that requires exposure to radiation.

Any worker has the option of seeking other employment in a nonradiation occupation. However, the studies that have compared occupational risks in the nuclear industry to those in other job areas indicate that nuclear work is relatively safe. Thus, a worker may find different kinds of risk but will not necessarily find significantly lower risks in another job.

26. Where can one get additional information on radiation risk?

The following list suggests sources of useful information on radiation risk:

- The employer—the radiation protection or health physics office where a worker is employed.
- Nuclear Regulatory Commission Regional Offices:

King of Prussia, Pennsylvania	(610) 337-5000
Atlanta, Georgia	(404) 331-4503
Lisle, Illinois	(708) 829-9500
Arlington, Texas	(817) 860-8100

- U.S. Nuclear Regulatory Commission
  Headquarters
  Radiation Protection & Health Effects Branch
  Office of Nuclear Regulatory Research
  Washington, DC 20555
  Telephone: (301) 415-6187
- Department of Health and Human Services
  Center for Devices and Radiological Health
  1390 Piccard Drive, MS HFZ-1
  Rockville, MD 20850
  Telephone: (301) 443-4690
- U.S. Environmental Protection Agency
  Office of Radiation and Indoor Air
  Criteria and Standards Division
  401 M Street NW.
  Washington, DC 20460
  Telephone: (202) 233-9290

REFERENCES

1. B.R. Scott et al., "Health Effects Model for Nuclear Power Plant Accident Consequence Analysis," Part I: *Introduction, Integration, and Summary*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Revision 2, Part I, October 1993.*

2. U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA-400-R-92-001, May 1992.

3. International Commission on Radiological Protection, *Annals of the ICRP, Risks Associated with Ionising Radiation*, Volume 22, No.1, Pergamon Press, Oxford, UK, 1991.

4. National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR V), National Academy Press, Washington, DC, 1990.

5. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR); *Sources, Effects and Risks of Ionizing Radiation*, Report E.88.IX.7, United Nations, New York, 1988.

6. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation*, United Nations, New York, 1993.

7. National Council on Radiation Protection and Measurements, *New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates*, Proceedings of the Twenty-third Annual Meeting of the National Council on Radiation Protection and Measurements Held on April 8–9, 1987 (1988).

8. National Council on Radiation Protection and Measurements, *Comparative Carcinogenicity of Ionizing Radiation and Chemicals*, NCRP Report No. 96, March 1989.

9. C.T. Raddatz and D. Hagemeyer, "Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 1993," U.S. Nuclear Regulatory Commission, NUREG-0713, Volume 15, January 1995.*

10. B.L. Cohen and I.S. Lee, "Catalog of Risks Extended and Updated," *Health Physics*, Vol. 61, September 1991.

11. National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 93, September 1987.

12. U.S. Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register*, Vol. 52, No. 17, January 27, 1987.

13. International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, UK, 1991.

14. National Council on Radiation Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, NCRP Report No. 116, March 1993.

*Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202) 634-3273; fax (202) 634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202) 512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

BIBLIOGRAPHY

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev. 1, Part II, May 1989.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Recent Reports on Health Effects of Ionizing Radiation, Low LET Radiation," Part II: *Scientific Basis for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 1, August 1991.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Addition of Effects of Exposure to Alpha-Emitting Radionuclides," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 2, May 1993.[1]

International Commission on Radiological Protection, *Radiation Protection*, Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Pergamon Press, Oxford, UK, January 1977.

National Council on Radiation Protection and Measurements, *Public Radiation Exposure From Nuclear Power Generation in the United States*, NCRP Report No. 92, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the U.S. Population From Occupational Radiation*, NCRP Report No. 101, June 1989.

National Council on Radiation Protection and Measurements, *Risk Estimates for Radiation Protection*, NCRP Report No. 115, December 1993.

National Council on Radiation Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, NCRP Report No. 116, March 1993.

National Safety Council, *Accident Facts, 1993 Edition*, Itasca, Illinois, 1993.

U.S. Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register*, Vol. 52, No. 17, January 27, 1987.

U.S. Nuclear Regulatory Commission, "Instruction Concerning Prenatal Radiation Exposure," Regulatory Guide 8.13, Revision 2, December 1987.[2]

U.S. Nuclear Regulatory Commission, "Monitoring Criteria and Methods To Calculate Occupational Radiation Doses," Regulatory Guide 8.34, July 1992.[2]

U.S. Nuclear Regulatory Commission, "Planned Special Exposures," Regulatory Guide 8.35, June 1992.[2]

U.S. Nuclear Regulatory Commission, "Radiation Dose to the Embryo/Fetus," Regulatory Guide 8.36, July 1992.[2]

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202) 512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

[2]Single copies of regulatory guides may be obtained free of charge by writing the Office of Administration, Attn: Distribution and Services Section, USNRC, Washington, DC 20555, or by fax at (301) 415-2260. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343.

BIBLIOGRAPHY

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev. 1, Part II, May 1989.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Recent Reports on Health Effects of Ionizing Radiation, Low LET Radiation," Part II: *Scientific Basis for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 1, August 1991.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Addition of Effects of Exposure to Alpha-Emitting Radionuclides," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 2, May 1993.[1]

International Commission on Radiological Protection, *Radiation Protection*, Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Pergamon Press, Oxford, UK, January 1977.

National Council on Radiation Protection and Measurements, *Public Radiation Exposure From Nuclear Power Generation in the United States*, NCRP Report No. 92, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the U.S. Population From Occupational Radiation*, NCRP Report No. 101, June 1989.

National Council on Radiation Protection and Measurements, *Risk Estimates for Radiation Protection*, NCRP Report No. 115, December 1993.

National Council on Radiation Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, NCRP Report No. 116, March 1993.

National Safety Council, *Accident Facts, 1993 Edition*, Itasca, Illinois, 1993.

U.S. Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register*, Vol. 52, No. 17, January 27, 1987.

U.S. Nuclear Regulatory Commission, "Instruction Concerning Prenatal Radiation Exposure," Regulatory Guide 8.13, Revision 2, December 1987.[2]

U.S. Nuclear Regulatory Commission, "Monitoring Criteria and Methods To Calculate Occupational Radiation Doses," Regulatory Guide 8.34, July 1992.[2]

U.S. Nuclear Regulatory Commission, "Planned Special Exposures," Regulatory Guide 8.35, June 1992.[2]

U.S. Nuclear Regulatory Commission, "Radiation Dose to the Embryo/Fetus," Regulatory Guide 8.36, July 1992.[2]

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202) 512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

[2]Single copies of regulatory guides may be obtained free of charge by writing the Office of Administration, Attn: Distribution and Services Section, USNRC, Washington, DC 20555, or by fax at (301) 415-2260. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this Revision 1 to Regulatory Guide 8.29. A value/impact statement, which evaluated essentially the same subjects as are discussed in a regulatory analysis, accompanied Regulatory Guide 8.29 when it was issued in July 1981.

This Revision 1 to Regulatory Guide 8.29 is needed to conform with the Revised 10 CFR Part 20, "Standards for Protection Against Radiation," as published May 21, 1991 (56 FR 23360). The regulatory analysis prepared for 10 CFR Part 20 provides the regulatory basis for this Revision 1 of Regulatory Guide 8.29, and it examines the costs and benefits of the rule as implemented by the guide. A copy of the "Regulatory Analysis for the Revision of 10 CFR Part 20" (PNL-6712, November 1988), is available for inspection and copying for a fee in the NRC's Public Document Room at 2120 L Street NW., Washington, DC 20555-0001.