PUBLIC HEALTH PERSPECTIVE

V. PUBLIC HEALTH PERSPECTIVE

In developing this document, NIOSH has been challenged to carefully consider all of the Institute's legislative, scientific, and moral responsibilities. Two legislative mandates are important in understanding NIOSH's responsibilities in developing this document and the recommendations it contains. First, the Occupational Safety and Health Act of 1970 [Public Law (PL) 91-596], which established NIOSH, requires safe and healthful working conditions for every working person. The Act further requires NIOSH to preserve our human resources by providing medical and other criteria that will ensure, insofar as practicable, that no worker will suffer diminished health, functional capacity, or life expectancy as a result of work experience [PL 91-956, Section 6(b)(5)]. The Act also authorizes NIOSH to develop new recommended criteria to further improve working conditions [PL 91-596, Sections 22(c) and (d)]. In addition, the Federal Coal Mine Health and Safety Act of 1969 [PL 91-173] and the Federal Mine Safety and Health Amendments Act of 1977 [PL 95-164] require NIOSH to develop and revise recommended occupational safety and health standards for mine workers. The Secretary of Health, Education, and Welfare (now the Secretary of Health and Human Services) shall consider, "in addition to the attainment of the highest degree of health protection for the miner . . . the latest available scientific data in the field, the technical feasibility of the standards, and experience gained under this and other health statutes" [PL 91-173, Title 1, Section 101(d)].

NIOSH has been required to review diverse scientific data that are subject to uncertainty and then, in keeping with its mandates, to recommend criteria that will attain the highest level of health protection and will at the same time account for other factors such as technical feasibility and insights gained through research and development.

To develop a public health perspective on the risk posed by occupational exposure to radon progeny, NIOSH must weigh a number of factors, as follows.

1. Human and animal data both clearly establish that exposure to radon progeny increases the risk of lung cancer. The human data consist of a number of positive epidemiologic studies, several of which demonstrate an exposure-related health risk that is not accounted for by smoking behavior. The animal studies demonstrate that lung cancer risk increases with exposure in the absence of smoking. It is important to note that smoking by miners appears to greatly exacerbate the risk of lung cancer posed by exposure to radon progeny alone.

2. The NIOSH risk assessment, based on a USPHS study of uranium miners [Lundin et al. 1971], demonstrated a significant exposure-response relationship. This analysis indicates that exposure to radon progeny at the current MSHA occupational exposure limit of 4 WLM over a working lifetime will result in 42 excess lung cancers per thousand miners. A miner's working lifetime has been defined as 30 years (MSHA uses 30 years as a miner's working lifetime). Risk declines substantially if a lower annual cumulative exposure is received over the working lifetime. Any risk assessment is subject to uncertainty because risk assessment

models may not reflect risk in a completely reliable way and because the data on which they are based are subject to uncertainties and limitations.

The Cox proportional hazards model, which was chosen for the NIOSH risk assessment, is considered one of the strongest analytical approaches for longitudinal epidemiologic data. But it is not clear how accurately the data can be extrapolated to predict risk below the levels of observed exposure. Current biological theory hypothesizes that carcinogenic processes involve an initiation stage that is followed by other stages before an actual malignancy is established. The essential characteristics of all of these stages remain to be delineated. The Cox proportional hazards model is very powerful in describing human risks based on epidemiologic data. Its strength is partly due to the model's ability to accommodate long follow-up periods during which changes occur in some of the risk factors, e.g., cumulative exposure. Nevertheless, it is not clear how accurately the Cox model or any other risk assessment model predicts the risk from a multistage cancer process when exposures are below levels that have been studied.

The USPHS study [Lundin et al. 1971] on which the NIOSH risk assessment was based is an extensive study, but the risk assessment is subject to uncertainties and limitations because of the nature of the data. For example, more uncertainty would be inherent in the risk estimates at the lower range of exposure because a relatively small proportion of this study population received the lowest cumulative exposures. Approximately 7% of the USPHS uranium miners (which included 7 lung cancers) had received cumulative occupational exposure levels of 30 WLM or less. At lower cumulative exposure levels, even smaller proportions of the cohort and fewer lung cancers were represented. Thus point estimates at these lower cumulative exposure levels would be more subject to the influence of chance occurrences. In addition, exposure levels are subject to measurement error. The uncertainty of exposures have been estimated to range from a relative standard deviation of 38% [Schaiger et al. 1981] to as high as 97% (see Appendix II).

3. Radon progeny and its associated risk are present in our ambient environment as well as in the mining environment and cannot be totally eliminated. Radon progeny are ubiquitous in that they emanate from all ore-bearing deposits containing elements that decay to produce radon gas. The national average exposure to radon progeny has been estimated to be 0.2 WLM [NCRP 1975]. Areas containing large amounts of ore-bearing deposits (e.g., the Colorado Plateau) are likely to have higher-than-average background levels of radon progeny [NCRP 1975]. The NIOSH risk assessment uses a fitted estimate of 0.4 WLM as the background exposure (the average annual cumulative exposure incurred in nonoccupational environments) in the Colorado Plateau. Although no adequate measurement data are available to characterize the level and variability of exposure in the homes of the general population and of miners, it is clear that everyone is exposed and that the degree of exposure depends on each individual's home and work environment. The limits of concentration detection and the accuracy of the measurement techniques become a potential problem when quantifying the very low

radon progeny exposure and concentration levels that may be found in the ambient environment (these levels are generally much lower than those found in underground mining environments). Extrapolation of risk to such low levels would become even more problematic than at higher levels because of the reduced accuracy of measuring such concentration levels. The elimination of radon progeny from the ambient and mining environments is not possible.

The primary engineering method for controlling radon progeny exposure is dilution ventilation. However, if radon progeny are ubiquitous in our ambient environment, no source of air is free of contamination. The only protective equipment that would eliminate exposure to radon progeny is the self-contained breathing apparatus (SCBA). SCBAs are unaccept able for wear in the ambient environment and represent a significant safety hazard if worn extensively in the mining environment.

4. It is valuable to compare the lung cancer risks associated with the miner's occupational and background exposures. No assessment has yet been made of the lung cancer risk associated with background exposures, either for the general U.S. population or for the population living in the Colorado Plateau. Until studies in homes are completed, it will be impossible to directly contrast the risks of occupational and background exposures.

Nonetheless, it is important to consider occupational risk in the context of the lung cancer risk experienced by the general population. On the basis of State vital statistics records, NIOSH estimates that the lifetime risk of lung cancer in the Colorado Plateau, uncorrected for smoking, is approximately 45 lung cancers per 1,000 white males. Unfortunately, accurate lung cancer rates are not available for nonsmokers in the Colorado Plateau.

Given this value for the lung cancer risk of background exposure, another question that must be considered is to what level it would be reasonable to control occupational risk. In its benzene decision, the U.S. Supreme Court gave the following example for the basis of evaluating occupational risk of chemically induced leukemia. The example indicated that an exposure associated with 1 excess death per 1 million exposed persons might pose an acceptable risk, whereas an exposure associated with 1 excess death per 1,000 exposed persons would pose a significant risk that should be reduced. This example is useful but it cannot be strictly applied in all cases, since it was offered as an illustration and not a fixed rule. In the specific case of lung cancer risk associated with radon progeny exposure, the example cannot be strictly applied because the risk of lung cancer is much greater than the risk of leukemia at background exposure levels and because cigarette smoking is known to create a confounding effect that greatly increases risk. An excess of 1 lung cancer death per 1,000 would probably not be detectable in a general population if the data were subject to considerable uncertainty, since it would necessitate differentiating between 46 and 45 deaths per 1,000.

5. The technical feasibility of achieving lower exposure levels is subject to the limitations of available technology. A report commissioned by the Bureau of Mines [Bloomster et al. 1984a, 1984b] has been the primary source for NIOSH's assessment of the technical feasibility of lower exposure levels. On the basis of an extensive engineering analysis of two uranium mines, these investigators indicated that it might be feasible to meet an operating standard of 1 WLM using the best available engineering controls. They expressed doubt about the technical feasibility of operating these uranium mines at a standard of 0.5 WLM. This analysis has been used by NIOSH to define exposure limits that are technically achievable with the best available technology.

These are some of the issues that have been considered by NIOSH in developing a recommended standard to prevent lung cancer associated with exposure to radon progeny. This process of weighing risk from a public health perspective parallels the philosophy of risk presented in the 1985 document entitled Risk Assessment and Risk Management of Toxic Substances: A Report to the Secretary [CCERP 1985]. In the process of developing this public health perspective, NIOSH has performed the following actions:

- NIOSH has identified a public health hazard posed by an occupational exposure. Exposure to radon progeny that occurs in underground mines and the ambient environment has been shown to cause a significant increase in lung cancer among uranium and other underground miners.

- NIOSH has developed recommendations in a manner that is prudent and in concert with the public need. This process was accomplished by complying with the Institute's legislative mandates to attain the highest level of health protection and at the same time consider other factors such as technical feasibility.

- NIOSH has sought appropriate public participation by eliciting external reviews. Reviews were requested from more than 60 individuals or groups, including industry, labor, academia, and government representatives. NIOSH has received and considered the comments from more than 30 of these reviewers.

- NIOSH has communicated risk understandably to both experts and lay persons. NIOSH has expressed risk as relative risk, which most epidemiologists and biostatisticians believe to be the most appropriate mode of expressing human cancer risk. NIOSH has also expressed risk as lifetime excess risk per 1,000 miners, an expression that can easily be interpreted by both experts and lay persons.

- NIOSH has used all currently available information and the most extensive pertinent set of human data to estimate risk. The USPHS study of uranium miners [Lundin et al. 1971] is the most extensive set of data available in the United States on the radon progeny exposure of underground miners. Unlike other analyses, this study used the entire qualifying cohort in the risk assessment, regardless of exposure level. These investigators felt this was the most valid way to analyze epidemiologic data using the selected model.

- NIOSH has considered alternative recommendations for risk control that are based on viable exposure limits and engineering controls. The considered options ranged from proposing no REL to prohibiting all occupational exposure to radon progeny. The REL presented in this document was chosen after a thorough weighing of the available data and Institute mandates.

- NIOSH has advanced the process of risk assessment and policy development by conducting the most thorough risk assessment possible on underground miners exposed to radon progeny. The NIOSH risk assessment permitted estimation of lung cancer risk at the lower range of the observed exposure levels. The assessment also suggested meaningful research areas such as lung cancer risks at low radon exposure levels, synergistic effects of other exposures such as cigarette smoke, effects of radon progeny on late versus early stage cancer, and the need for improved engineering control of exposure.

An extensive and complicated process has been used to develop the recommendations in this criteria document. After weighing the conclusions drawn from available data, the mandates of the Institute, and the public health issues, NIOSH recommends an annual cumulative exposure limit of no more than 1 WLM per year. However, as stated earlier, even this exposure poses a significant risk of lung cancer over a working lifetime. Thus NIOSH further recommends that mine operators regard this REL as an upper limit and that they make every effort to limit radon progeny to the lowest possible concentrations. In addition, NIOSH wishes to emphasize the fact that this standard contains many important provisions in addition to the annual exposure limit. These include recommendations for limited work shift concentrations of radon progeny, sampling and analytical methods, recordkeeping, medical surveillance, posting of hazardous information, respiratory protection, worker education and notification, and sanitation. All of these recommendations help minimize risk.

NIOSH recognizes its commitment to protect the health of the Nation's miners and will continue to reexamine this complex occupational health issue. Research on new and more effective methods for reducing occupational exposures will improve the available control technologies. Additional data on exposure levels and associated health risks will permit firmer estimates of risk and hence better recommendations. NIOSH will revise its recommended standard as important new data become available.

REFERENCES

AIF [1984]. Exposure of U.S. underground uranium miners to radon daughters in 1982 as reported by 29 underground uranium mine operations, from a survey made April 24, 1984. Unpublished report submitted to Mine Safety and Health Administration by Atomic Industrial Forum.

AIF [1986]. Exposure of U.S. underground uranium miners to radon daughters in 1984 as reported by 20 underground uranium mine operations, from a survey made December 11, 1986. Unpublished report submitted to Mine Safety and Health Administration by Atomic Industrial Forum.

Auxier JA, Becker K, Robinson EM, Johnson DR, Boyett RH, Abner CH [1971]. A new radon progeny personal dosimeter. Health Phys 21:126.

Axelson O, Sundell L [1978]. Mining, lung cancer and smoking. Scand J Work Environ Health 4:46-52.

BLS [1987]. Occupational injuries and illnesses in the United States by industry, 1985. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, Bulletin No. 2270.

Bernhard S, Pineau JF, Rannou A, Zettwoog P [1984]. 1983: One year of individual dosimetry in French mines. In: Stocker H, ed. Proceedings of the International Conference on Occupational Radiation Safety in Mining. Volume 1. Toronto, Ontario, Canada: Canadian Nuclear Association, pp. 526-540.

Bigu J, Kaldenbach R [1984]. Theory, operation and performance of a time-integrating, continuous, radon (thoron) daughter working level monitor. Radiat Prot Dosimetry 9:19-26.

Bigu J, Kaldenbach R [1985]. A microprocessor based continuous monitor with alpha spectroscopy capabilities for the determination of radon, thoron and their progeny. Radiat Prot Dosimetry 12:251-260.

Bloomster CH, Enderlin WI, Young JK, Dirks JA [1984a]. Cost survey for radon daughter control by ventilation and other control techniques. Volume I. Richland, WA: Battelle Memorial Institute, Pacific Northwest Laboratories, NTIS PB85-152932.

Bloomster CH, Jackson PO, Dirks JA, Reis JW [1984b]. Cost survey for radon daughter control by ventilation and other control techniques: radon emissions from underground uranium mines. Volume II. Richland, WA: Battelle Memorial Institute, Pacific Northwest Laboratories, NTIS PB85-152940.

Borak TB, Franco E, Schiager KJ, Johnson JA, Holub HF [1981]. Evaluation of recent developments in radon progeny measurements. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 419-425.

Boyd JT, Doll R, Faulds JS, Leiper J [1970]. Cancer of the lung in iron ore (haematite) miners. Br J Ind Med 27:97-105.

Breslin AJ, George AC, Weinstein MS [1969]. Investigation of the radiological characteristics of uranium mine atmospheres. New York, NY: Atomic Energy Commission, New York Operations Office, Health and Safety Laboratory. HASL-220, December 1969.

Brookins DG [1986]. Indoor and soil Rn measurements in the Albuquerque, New Mexico, area. Health Phys 51:529-533.

Casarett AP [1968]. Radiation biology. Englewood Cliffs, NJ: Prentice-Hall, Inc.

CCERP [1985]. Risk assessment and risk management of toxic substances. A report to the Secretary, Department of Health and Human Services (DHHS). DHHS Committee to Coordinate Environmental and Related Programs.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Chameaud J, Perraud R, Lafuma J, Masse R, Pradel J [1974]. Lesions and lung cancers induced in rats by inhaled radon 222 at various equilibriums with radon daughters. In: Karbe E, Park JF, eds. Experimental lung cancer: carcinogenesis and bioassays. New York, NY: Springer Verlag, pp. 411-421.

Chameaud J, Perraud R, Chretien J, Masse R, Lafuma J [1980]. Combined effects of inhalation of radon daughter products and tobacco smoke. In: Sanders CL, Cross FT, Dagle GE, Mahaffey JA, eds. Proceedings of the Nineteenth Annual Hanford Life Sciences Symposium on Pulmonary Toxicology of Respirable Particles. U.S. Department of Energy, Technical Information Center. NTIS CONF-791002, pp. 551-557.

Chameaud J, Perraud R, Masse R, Lafuma J [1981]. Contribution of animal experimentation to the interpretation of human epidemiological data. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 222-227.

Chameaud J, Perraud R, Chretien J, Masse R, Lafuma J [1982]. Lung carcinogenesis during in vivo cigarette smoking and radon daughter exposure in rats. Recent Results Cancer Res 82:11-20.

Chameaud J, Masse R, Lafuma J [1984a]. Influence of radon daughter exposure at low doses on occurrence of lung cancer in rats. Radiat Prot Dosimetry 7:385-388.

Chameaud J, Masse R, Morin M, Lafuma J [1984b]. Lung cancer induction by radon daughters in rats. In: Stocker H, ed. Proceedings of the International Conference on Occupational Radiation Safety in Mining. Volume 1. Toronto, Ontario, Canada: Canadian Nuclear Association, pp. 350-353.

Cooper WE [1981]. A comparison of radon-daughter exposures calculated for U.S. underground uranium miners based on MSHA and company records. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineering, Inc., pp. 292-295.

Corkill DA, Dory AB [1984]. A retrospective study of radon daughter concentrations in the workplace in the fluorspar mines of St. Lawrence, NFLD. Ottawa, Canada: Atomic Energy Control Board, July 1984, INFO-0127.

Cross FT [1984]. A review of radon inhalation studies in animals with reference to epidemiological data. In: Assessment of the scientific basis for existing federal limitations on radiation exposure to underground uranium miners. Unpublished report prepared for the American Mining Congress by Senes Consultant Ltd. Appendix C, pp. 1-66.

Cross FT, Palmer RF, Busch RH, Filipy RE, Stuart BO [1981]. Development of lesions in Syrian Golden Hamsters following exposure to radon daughters and uranium ore dust. Health Phys 41:135-153.

Cross FT, Palmer RF, Filipy RE, Dagle GE, Stuart BO [1982a]. Carcinogenic effects of radon daughters, uranium ore dust and cigarette smoke in beagle dogs. Health Phys 42(1):33-52.

Cross FT, Palmer RF, Dagle GE, Busch RH, Buschbom RL [1982b]. Influence of radon daughter exposure rate, unattachment fraction, and disequilibrium on occurrence of lung tumours. Radiat Prot Dosimetry 7(1-4):381-384.

Cross FT, Buschbom RL, Dagle GE, et al. [1983]. Inhalation hazards to uranium miners. In: Drucker H, et al., eds. Pacific Northwest Laboratory annual report for 1982 to the DOE Office of Energy Research - Part 1, biomedical sciences. Richland, WA: Pacific Northwest Laboratory, pp. 77-80, DE83 007585.

Cross FT, Buschbom RL, Dagle GE, et al. [1984]. Inhalation hazards to uranium miners. In: Park JF, et al., ed. Pacific Northwest Laboratory Annual Report for 1983 to the DOE Office of Energy Research - Part 1, Biomedical Sciences. Richland, WA: Pacific Northwest Laboratory, pp. 41-44, DE84 007437.

Damber L, Larsson L-G [1982]. Combined effects of mining and smoking in the causation of lung carcinoma: A case-control study in northern Sweden. Acta Radiol (Oncol) 21:305-313.

Domanski T, Chruscielevski W, Swiatnicki G [1982]. The performance of passive differentiating track detectors containing a diffusion barrier. Radiat Prot Dosimetry 2:27-32.

Doull J, Klaassen CD, Amdur MO [1980]. Casarett and Doull's toxicology: the basic science of poisons. Second edition. New York, NY: Macmillan Publishing Co., Inc.

Droullard RF, Holub RF [1977]. Continuous working-level measurements using alpha or beta detectors. Denver, CO: U.S. Department of the Interior, Bureau of Mines. Report of Investigation RI-8237.

Droullard RF, Holub RF [1985]. Continuous radiation working-level detectors. Denver, CO: U.S. Department of the Interior, Bureau of Mines. Information Circular IC-9029.

Durkin J [1977]. An electronic instrument for radon daughter dosimetry. Denver, CO: U.S. Department of the Interior, Bureau of Mines. Investigation Report 8255.

Edling C, Axelson O [1983]. Quantitative aspects of radon daughter exposure and lung cancer in underground miners. Br J Ind Med 40:182-187.

EPA, CDC [1986]. A citizen's guide to radon. U.S. Environmental Protection Agency and U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, August 1986. OPA-86-004.

Evans RD [1969]. Engineers' guide to the elementary behavior of radon daughters. Health Phys 17:229-252.

Federal Register [1986]. 30 CFR 45678-45688, Part 57, December 19, Mine Safety and Health Administration. Ionizing radiation standards for underground metal and nonmetal mines. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Filipy RE, Dagle GE, Palmer RF, et al. [1977a]. Carcinogenesis of inhaled radon daughters with uranium ore dust in beagle dogs. In: Thompson RC et al., eds. Pacific Northwest Laboratory annual report for 1976 to the ERDA Assistant Administrator for Environment and Safety. Richland, WA: Battelle Laboratories, pp. 49-52.

Filipy RE, Palmer RF, Stuart BO [1977b]. Non-neoplastic pulmonary disease from inhaled radon daughters with uranium ore dust in beagle dogs. In: Thompson RC, et al., ed. Pacific Northwest Laboratory Annual Report for 1976 to the ERDA Assistant Administrator for Environment and Safety. Richland, WA: Battelle Laboratories, BNWL-2100 PT1, pp. 52-55.

Fox AJ, Goldblatt P, Kinlen LJ [1981]. A study of the mortality of Cornish tin miners. Br J Ind Med 38:378-380.

Gaven JC, Palmer RF, McDonald KE, Lund JE, Stuart BO [1977]. Comparative toxicity in rats vs. hamsters of inhaled radon daughters with and without uranium ore dust. In: Thompson RC, et al., eds. Pacific Northwest Laboratory Annual Report for 1976 to the ERDA Assistant Administrator for Environment and Safety. Richland, WA: Battelle Laboratories, BNWL-2100 PT1, pp. 56-60.

Grealy G, Peggie J, Leads V, Solomon S [1982]. A radon and thoron integrating personal dosimeter. Radiat Prot Dosimetry 1:207.

Haider B, Jacobi W [1973]. Long-term measurements of radon daughter activity in mines. In: Proceedings of the 3rd International Conference of the International Radiation Protection Association. Washington, DC: U.S. Atomic Energy Commission, p. 920.

Holaday DA, Rushing DE, Coleman RD, Woolrich PF, Kusnetz HL, Bale WF [1957]. Control of radon and daughters in uranium mines and calculations on biologic effects. Washington, DC: U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of State Services, Division of Special Health Services, Occupational Health Program. Public Health Service Publication No. 494.

Holmgren RM [1974]. Working levels of radon daughters in air determined from measurements of RaB + RaC. Health Phys 27:141.

Holub RF [1980]. Evaluation and modification of working level measurement methods. Health Phys 39:425.

Howe GR, Nair RC, Newcombe HB, Miller AB, Abbatt JD [1986]. Lung cancer mortality (1950-80) in relation to radon daughter exposure in a cohort of workers at the Eldorado Beaverlodge Uranium Mine. JNCI 77:357-362.

ICRP [1977]. Annals of the International Commission on Radiological Protection: Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. New York, NY: Pergamon Press.

ICRP [1981]. Annals of the International Commission on Radiological Protection: Limits for inhalation of radon daughters by workers. ICRP Publication 32. New York, NY: Pergamon Press.

James AC, Strong JD [1973]. A radon daughter monitor for use in mines. In: Proceedings of the 3rd International Conference of the International Radiation Protection Association. Washington, DC: U.S. Atomic Energy Commission, p. 932.

Jingyuan Z, Xiehua W, Xinhui H, et al. [1981]. Investigation of the radioactive etiological factors of lung cancer among miners. Zhongguo Yixue Kexueyuan Xuebao 3:127-131 (in Chinese).

Jorgensen HS [1973]. A study of mortality from lung cancer among [iron ore] miners in Kituna 1950-1970. Work Environ Health 10:126-133.

Jorgensen HS [1984]. Lung cancer among underground workers in the iron ore mine of Kiruna based on thirty years of observation. Ann Acad Med, Singapore 13:371-377.

Kalos F [1986]. Study factors that influence the use of respirators in uranium mines. Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, INFO-0193. A report prepared for the Atomic Energy Control Board, Ottawa, Canada.

Kawaji M, Pai HL, Phillips CR [1981]. Use of gross filter activities in a continuous working level monitor. Health Phys 40:543-548.

Kunz E, Sevc J, Placek V [1978]. Lung cancer mortality in uranium miners (methodological aspects). Health Phys 35:579-580.

Kusnetz HL [1956]. Radon daughters in mine atmospheres, a field method for determining concentrations. Am Ind Hyg Assoc Q 17:87.

Linauskas SH, Kalos F [1984]. Study of efficiency and current use of respiratory protective devices. Atomic Energy of Canada Limited, INFO-0144. A report prepared for the Atomic Energy Control Board, Ottawa, Canada.

Lundin FE, Wagoner JK, Archer VE [1971]. Radon daughter exposure and respiratory cancer: quantitative and temporal aspects. U.S. Department of Health, Education, and Welfare, Public Health Service, National Institute for Occupational Safety and Health, National Institute of Environmental Health Sciences, Joint Monograph No. 1.

MMWR [1987]. National traumatic occupational fatalities. Morbidity and Mortality Weekly Report 36(28):461-464.

McCurdy DE, Schiager KJ, Flack ED [1969]. Thermoluminescent dosimetry for personal monitoring of uranium miners. Health Phys 17:415.

Monson RR [1980]. Occupational epidemiology. Boca Raton, FL: CRC Press, Inc., 219 pp.

Morrison HI, Semenciw RM, Mao Y, et al. [1985]. Lung cancer mortality and radiation exposure among the Newfoundland fluorspar miners. In: Stocker H, ed. Proceedings of the International Conference on Occupational Radiation Safety in Mining. Volume 1. Toronto, Ontario, Canada: Canadian Nuclear Association, pp. 365-368.

MSHA [1986]. Preliminary regulatory cost analysis and regulatory flexibililty statement - ionizing radiation standards for underground metal and nonmetal mines, 30 CFR part 57. Unpublished report released to the National Institute for Occupational Safety and Health by the Mine Safety and Health Administration, Arlington, VA, December 1, 1986.

Muller J, Wheeler WC, Gentleman JF, Suranyi G, Kusiak R [1985]. Study of mortality of Ontario miners. In: Stocker H, ed. Proceedings of the International Conference on Occupational Radiation Safety in Mining. Volume 1. Toronto, Ontario, Canada: Canadian Nuclear Association, pp. 335-343.

NAS [1987]. The effects on populations of exposure to low levels of ionizing radiation. Washington, DC: National Academy of Sciences (NAS) Committee on the Biological Effects of Ionizing Radiations (BIER), National Academy Press.

National Safety Council [1981]. Falls on floors. Chicago, IL: National Safety Council, Data Sheet I-495-81.

NCRP [1975]. Natural background radiation in the United States. Bethesda, MD: National Council on Radiation Protection and Measurements Report No. 45.

NCRP [1984a]. Exposures from the uranium series with emphasis on radon and its daughters. Bethesda, MD: National Council on Radiation Protection and Measurements Report No. 77.

NCRP [1984b]. Evaluation of occupational and environmental exposures to radon and radon daughters in the United States. Bethesda, MD: National Council on Radiation Protection and Measurements Report No. 78.

NIOSH [1975a]. Criteria for a recommended standard: occupational exposure to inorganic arsenic. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication No. 75-149.

NIOSH [1975b]. Criteria for a recommended standard: occupational exposure to chromium(VI). Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication No. 76-129.

NIOSH [1977]. Criteria for a recommended standard: occupational exposure to inorganic nickel. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication No. 77-164.

NIOSH [1985]. Evaluation of epidemiologic studies examining the lung cancer mortality of underground miners. Unpublished report submitted to the Mine Safety and Health Administration, May 9, 1985. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Standards Development and Technology Transfer.

NIOSH [1987]. NIOSH respirator decision logic. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Standards Development and Technology Transfer. DHHS (NIOSH) Publication No. 87-108.

NTP [1984]. National Toxicology Program--Technical Report Series No. 248. Toxicology and carcinogenesis studies of 1,3-butadiene (CAS No. 106-99-0) in B6C3F_1 mice (Inhalation Studies). U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, NIH Publication No. 84-2544:2.

Pham QT, Gaertner M, Mur JM, et al. [1983]. Incidence of lung cancer among iron miners. Eur J Respir Dis 64:534-540.

Phillips CR, Pai HL, Jokura K [1979]. Comparative evaluation of CEA track etch and LiF TLD personal alpha dosimeters of radon and thorium in a uranium mine. Ottawa, Ontario, Canada: Atomic Energy Control Board, AECB-1170.

Placek V, Smid A, Sevc J, Tomasek L, Vernerova P [1983]. Late effects at high and very low exposure levels of the radon daughters. In: Broerse JJ, Barendsen GW, Kal HB, Vanderkogel AJ, eds. Radiation research - somatic and genetic effects. Proceedings of the Seventh International Congress of Radiation Research, Amsterdam, the Netherlands, July 3-8, 1983.

PNL [1978]. Study of the combined effects of smoking and inhalation of uranium ore dust, radon daughters and diesel oil exhaust fumes in hamsters and dogs. Richland, WA: Pacific Northwest Laboratory, PNL-2744.

Radford EP, Renard KGSC [1984]. Lung cancer in Swedish iron miners exposed to low doses of radon daughters. N Eng J Med 310:1485-1494.

Radiation Policy Council [1980]. Report of the task force on radon in structures. Washington, D.C.: The Council, RPC-80-002.

Rolle R [1972]. Rapid working level monitoring. Health Phys 22:233.

Samet JM, Kutvirt DM, Waxweiler RJ, Key CR [1984]. Uranium mining and lung cancer in Navajo men. N Engl J Med 310:1481-1484.

Schiager KJ [1977]. The 3R-WL working level survey meter. Health Phys 33:595-604.

Schiager KJ, Borak TB, Johnson JA [1981]. Radiation monitoring for uranium miners: evaluation and optimization. Fort Collins, CO: U.S. Department of Interior, Bureau of Mines.

Sevc J, Kunz E, Placek V [1976]. Lung cancer in uranium mines and long-term exposure to radon daughter products. Health Phys 30:433-437.

Sevc J, Kunz E, Placek V, Smid A [1984]. Comments on lung cancer risk estimates. Health Phys 46:961-964.

Shapiro J [1981]. Radiation protection--A guide for scientists and physicians. 2nd edition. Cambridge, MA: Harvard University Press.

Sheeran CT, Franklin JC [1984]. Microcomputer-based monitoring and control system with uranium mining application. Spokane, WA: U.S. Department of the Interior, Bureau of Mines. Information Circular IC-8981.

Shreve JD [1976]. Presentation at Specialist Meeting on Personal Dosimetry and Area Monitoring Suitable for Radon and Radon Daughter Products. Elliott Lake, Ontario, Canada.

Shreve JD, Miller RW, Cleveland JE [1977]. A new instrument for quick determination of radon and radon daughter concentrations in air - concept, analytical basis, calibration caveats: The embodiment and field results. In: Proceedings of the 4th International Conference of the International Radiation Protection Association. Washington, DC: U.S. Atomic Energy Commission, p. 111.

Snihs JO [1981]. Radiation protection in Swedish mines: special problems. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 283-285.

Solli HM, Andersen A, Stranden E, Langard S [1985]. Cancer incidence among workers exposed to radon and thoron daughters at a niobium mine. Scand J Work Environ Health 11:7-13.

Southwest Research Institute [1980]. Radon daughter dosimeter tests in active uranium mines. San Antonio, TX: Southwest Research Institute.

Stevens GA, Moyer ES [1987]. Efficiency dependence of commercial respirator filters on humidity pretreatment. Morgantown, WV: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Safety Research.

Szymusiak SM, Ryan JP [1982a]. Prevention of slip and fall injuries, Part I. Professional Safety, June, pp. 11-15.

Szymusiak SM, Ryan JP [1982b]. Prevention of slip and fall injuries, Part II. Professional Safety, July, pp. 30-35.

Tirmarche M, Brenot J, Piechowski J, Chameaud J, Pradel J [1985]. The present state of an epidemiological study of uranium miners in France. In: Stocker H, ed. Proceedings of the International Conference on Occupational Radiation Safety in Mining. Volume 1. Toronto, Ontario, Canada: Canadian Nuclear Association, pp. 344-349.

Tsivoglou EC, Ayer HE, Holaday DA [1953]. Occurrence of nonequilibrium atmosphere mixtures of radon and its daughters. Nucleonics 11:40.

Urban M, Binns DAC, Estrada JJ [1985]. Radon measurements in mines and dwellings. Kernforschungszentrum Karlsruhe GmbH, Report No. KfK 3866, CNEN 1101. Available from NTIS.

Wagoner JK, Miller RW, Lundin FE, Fraumeni JF Jr., Haij ME [1963]. Unusual cancer mortality among a group of underground metal miners. N Eng J Med 269:284-289.

Wang CH, Willis DL, Loveland WD [1975]. Radiotracer methodology in the biological, environmental, and physical sciences. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Wang X, Huang X, Huang S, et al. (1984). Radon and miners lung cancer. Zhonghua Fangshe Yixue Fanghu Zazhi 4:10-14 (in Chinese).

Waxweiler RJ, Roscoe RJ, Archer VE, Thun MJ, Wagoner JK, Lundin FE [1981]. Mortality follow-up through 1977 of the white underground uranium miners cohort examined by the United States Public Health Service. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 823-830.

White O [1971]. Evaluation of MOD and ORNL radon daughter dosimeters. Washington, DC: U.S. Atomic Energy Commission, Health and Safety Laboratory Technical Memorandum 71-17.

White MK, Ronk R [1984a]. Do you have a hot and/or strenuous job? Professional Safety, May, pp. 27-29.

White MK, Ronk R [1984b]. Chemical protective clothing and heat stress. Professional Safety, December, pp. 34-38.

White MK, Hodous TK [1987]. Reduced work tolerance associated with wearing protective clothing and respirators. Am Ind Hyg Assoc J 48(4):304-310.

White MK, Hodous TK, Hudnall JB [1987]. Physiological and subjective responses to working in disposable protective coveralls and respirators commonly used by the asbestos abatement industry (draft report). Morgantown, WV: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

Whittemore AS, McMillan A [1983]. Lung cancer mortality among U.S. uranium miners: A reappraisal. JNCI 71(3):489-499.

WHO [1979]. World Health Organization. IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. Polynuclear aromatic compounds, part 3, industrial exposures in aluminum production, coal gasification, coke production, and iron and steel founding. IARC Monographs, Vol 34; supplement 1.

Zettwoog PR [1981]. State-of-the-art of individual dosimetry in France. In: Gomez M, ed. International Conference: Radiation Hazards in Mining. New York, NY: Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 321-331.