

dose information on medical workers only after 1958. Early cohort studies of radiologists and radiological technologists generally demonstrated an excess risk of leukemia and excess risks for some solid cancers (1, 2), but the evidence is based on comparison of the standardized mortality ratios among subgroups working in different periods or between radiologists and other medical professionals working in the same period. In some studies, for example in Canada (3), measured doses were available but only for the period after the introduction of monitoring in 1951. Risk values based on such incomplete dose data are likely to be overestimated. In the absence of individual dose information, investigators have used a number of proxy measures. The proxy measures are typically based on work history, e.g., how long the subject worked as a radiological technologist, especially during the early years, and whether the subject administered fluoroscopic examinations and other diagnostic and therapeutic procedures. Data using these proxy measures that must take into account different periods, without dose estimates, clearly have limitations. However, several findings, such as the excess risk of breast cancer, leukemia, skin cancer, and more recently non-cancer diseases,<sup>4</sup> have provided new information on the risks associated with chronic radiation exposure, and they merit further study.

For further study, however, dosimetry is critically important. Currently, efforts are under way in at least three major studies to construct individual dose estimates. Dose reconstruction work carried out for the U.S. radiological technologist cohort will be discussed by subsequent speakers. Briefly, this involves construction of models using film-badge measurement data, extrapolation and modification of the models to earlier periods, and construction of doses for the earliest period using published, largely disconnected, information. These models, along with detailed radiological work history data obtained by questionnaires, are used to estimate individual organ doses. Retrospective dose reconstruction has also been attempted for the Chinese X-ray worker cohort, involving simulation of past working conditions with a phantom, interviewing of subjects for detailed work histories, mathematical models, and verification by chromosomal aberration data (4). Reconstruction of early doses is also being undertaken for the Canadian radiation worker cohort.

Medical radiation worker cohorts hold a unique position in radiation studies and offer one of the few chances for obtaining information regarding chronic radiation exposure. The chronic doses received range from a negligibly small to a considerably high level. The subjects represent a healthy working population of both sexes and a wide range of ages. Long-term follow-up is continuing in many studies. The subjects are cooperative and responsive to epidemiological studies and are agreeable to biologically motivated studies of gene-radiation interactions. Together, these open the possibility of gaining critically important insights into health risk of chronic exposure and their underlying mechanisms, about which so little is known at present.

#### References

1. A. Berrington, S. C. Darby, H. A. Weiss and R. Doll, 100 years of observation on British radiologists: mortality from cancer and other causes. *Br. J. Radiol.* **74**, 507–519 (2001).
2. G. M. Matanoski, R. Seltzer, P. E. Sartwell and E. L. Diamond, The current mortality rates of radiologists and other physician specialists: Deaths from all causes and from cancer. *Am. J. Epidemiol.* **101**, 188–198 (1975).
3. J. P. Ashmore, D. Krewski, J. M. Zielinski, H. Jiang, R. Semenciw and P. R. Band, First analysis of mortality and occupational radiation exposure based on the National Dose Registry of Canada. *Am. J. Epidemiol.* **148**, 564–574 (1998).
4. J. X. Wang, L. A. Zhang, B. X. Li, Y. C. Zhao, Z. Q. Wang, J. Y. Zhang and T. Aoyama, Cancer incidence and risk estimation among

medical X-ray workers in China, 1950–1995. *Health Phys.* **82**, 455–466 (2002).

### Retrospective Exposure Assessment for Radiological Technologists

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In 1982, the National Cancer Institute (NCI) initiated a study of cancer incidence and mortality among radiological technologists in the United States. A cohort of approximately 146,000 technologists who were certified by the American Registry of Radiologic Technologists (ARRT) for at least 2 years during the period 1926–1982 was identified for study. The cohort is predominantly female with a current average age of 53 years. The NCI staff have collected extensive work history and health outcome data for the cohort members through the administration of two separate surveys, both of which had more than 90,000 respondents. In addition, the NCI has obtained approximately 1.3 million annual dosimetry badge readings for cohort members from 1977 through 1998. Several reports on the health effects observed in the cohort have been published previously without a substantial assessment of exposure (1, 2). One of these studies reported an excess of breast cancer associated with duration of employment which may be a surrogate for cumulative exposure.

In a collaborative agreement with the National Cancer Institute, researchers at the National Institute for Occupational Safety and Health have participated in an effort to retrospectively assess the occupational radiation exposure for this unique cohort. Because the quality, quantity and type of available exposure information varied considerably over time, it was recognized at the outset that several different exposure assessment strategies would be necessary. This is consistent with other studies that attempted to reconstruct exposures over long periods (3). Depending on availability of data, the assessment approach must incorporate the appropriate elements of either quantitative statistical or deterministic models. A summary of our findings for each of three exposure periods is presented below.

#### Assessment of Exposures between 1977–1998

The arithmetic mean badge dose for the cohort during this period was found to decrease in an approximately exponential manner from 2.9 mSv in 1977 to 0.3 mSv in 1998. This trend was in general agreement with that observed for medical workers (4). The geometric mean annual doses for this population were 0.5 and 0.04 mSv for 1977 and 1998, respectively. The percentage of workers with no detectable exposure increased from 20% in 1977 to almost 60% in 1998. Fewer than 1.6% of the measured annual doses were greater than 10 mSv. Within each year, the geometric standard deviations were very large (ranging from about 8 to 10).

An evaluation of the databases that contained the annual dosimetry results and the questionnaire responses revealed that at least partial information on exposure was available for about 51,000 of the 71,000 technologists who responded to both questionnaires. Using these exposure records and the information contained in the questionnaires, multivariate regression models were evaluated for their usefulness in assigning missing exposure information. Using a stepwise regression approach, the predictive value of candidate variables from the questionnaires was evaluated. The various predictors evaluated included the calendar year, the type of facility, the type of radiation procedure used, the frequency and duration of the use of the different procedures, the use of shielding, and the location of the dosimeter on the body. The statistical model that included responses from both questionnaires was found to explain at best about 30% of the variance in the data. Other models that relied on less complete

<sup>4</sup> M. Hauptmann, A. K. Mohan, M. M. Doody, M. S. Linet and K. Mabuchi, Mortality from diseases of the circulatory system in U.S. radiologic technologists. Unpublished results.

data were less predictive. The most strongly correlated predictors were type of facility (physician's office or hospital), year of exposure, and frequency of fluoroscopy use.

#### *Assessment of Exposures between 1960 and 1976*

There were considerably fewer electronic exposure records available for this period. A number of approaches were employed to collect data that might be useful in assessing exposures. These included (1) the collection of samples of microfilm records from a commercial supplier of dosimetry services, (2) the evaluation of exposure data collected previously from employers by the University of Minnesota, (3) a review of published exposure reports for similarly exposed populations, (4) the collection and evaluation of work practices and engineering controls descriptions, (5) collection and review of documents on the introduction of new technology and improvements in design, and (6) the evaluation of dosimetry records from government agencies and hospitals where retention of historical records was likely to be more conservative.

The above efforts resulted in the collection of approximately 3,800 annual exposure values from a combination of the data collected previously, new efforts on ascertainment of data, and published exposure summaries. A plot of the data collected by the University of Minnesota indicated that there was an almost level trend in the annual doses between 1960 and 1976, with an average dose of about 2.6 mSv. Published exposure summaries during this period tended to be considerably higher than those of the radiological technologists included in the University of Minnesota data. It is believed that this is due to the fact that the published data were collected at large teaching hospitals. This is consistent with our finding from the post-1977 period that radiological technologists who worked in physicians' offices had about one-half the exposure of those who worked in hospitals.

#### *Assessment of Exposures prior to 1960*

For exposures prior to 1960, very few individual monitoring results were found to exist. Because of this, statistical modeling of the exposures was not possible. It was decided that the base of this assessment would consist of a detailed literature review to document changes in regulations and technology. It was noted, for example, that the decrease in allowable exposure in the mid-1950s by a factor of three led to a significant reduction in worker exposure. Improvements in technology are also known to have resulted in decreased exposure per unit workload.

For this period, the available literature was sparse and tended to show great differences between workplace types. For example, annual means in large hospitals were reported to range from 30.0 to 50.0 mSv per year, while reported exposures at small medical clinics were less than 0.1 mSv per year. Data contained in seven of the early publications indicated an increasing trend in annual exposure going back in time from 1960. This trend appeared to roughly follow the changes in occupational exposure limits. Over the last year, the NCI has developed new exposure assessment models and approaches for risk estimation in the radiological technologist cohort.

#### *Summary*

Occupational radiation exposures for radiological technologists have been evaluated between 1940 and 1998. In this period, there has been a decreasing trend in annual exposure which prior to 1960 appears to follow changes in occupational exposure limits. In the most recent period (1977 through 1998), sufficient electronic information was available to conduct multivariate regression modeling. The most significant predictors of exposure during this time period were type of facility, year of exposure, and frequency of fluoroscopy use. Data were much more sparse in the earlier periods, prohibiting the use of regression modeling.

#### *References*

1. J. Boice, J. Mandel and M. Doody, Breast cancer among radiologic technologists. *J. Am. Med. Assoc.* **274**, 394–401 (1995).

2. M. Doody, J. Mandel, J. Lubin and J. Boice, Mortality among United States radiologic technologists, 1926–1990. *Cancer Causes Control* **9**, 676–675 (1998).
3. S. Yoshinaga, Y. Yamamoto, T. Aoyama and Y. Yoshimoto, Results and problems of occupational dose reconstruction for Japanese radiological technologists. *Radiat. Prot. Dosim.* **77**, 73–78 (1998).
4. *Occupational Exposure to Ionizing Radiation in the United States—A Comprehensive Review for the Year 1980 and a Summary of Trends for the Years 1960–1985*. Report 520/1-84-005, U.S. Environmental Protection Agency, Washington, DC, 1984.

### **Cancer Risks Associated with Employment as a Radiological Technologist**

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Radiological technologists represent a unique occupational group with low-dose and low-dose-rate radiation exposure. Small and large cohorts of radiological technologists and other radiation workers have been assembled in Denmark, Japan, China, Canada and the U.S. that have been followed for cancer mortality and incidence. Women comprise variable proportions (range 20 to 82%) of the cohorts in Denmark, China, Canada and the U.S. We summarize here reported findings from the cancer mortality and incidence studies. Many cohorts have been updated recently and we have chosen to focus on the most recently published findings. In the case of the U.S. radiological technologists, we present selected published and unpublished data on cancer mortality and incidence.

#### *Cancer Mortality Studies in Radiological Technologists*

One of the earliest studies assessed cancer and other mortality risks among male radiological technologists ( $n = 6,560$ ) serving in the U.S. Army during World War II. For comparison, men working as technologists in medicine or pharmacology or in a laboratory ( $n = 6,826$ ) were also followed. Over the period 1946–1974, Jablon and Miller (1) found no differences in deaths from cancer or other causes in this cohort. Even though the mid-1940s was a period when work-related medical radiation exposures were relatively high, the exposure duration was short (averaging less than 3 years), suggesting that the average cumulative exposure was probably low.

A cohort of Japanese male radiological technologists assembled from licensing records ( $n = 12,195$ ) was followed for 25 years, from 1969 to 1993 (2). Their cancer mortality experience was compared to corresponding cancer mortality rates in the general population of Japanese men and to a subgroup of Japanese men employed in professional/technical jobs. The calendar periods when the Japanese technologists worked are not known with complete certainty because licensing regulations were not instituted until 1968; many had presumably worked in previous years. Therefore, the cohort was divided, with the more highly exposed cohort comprised of radiological technologists born in 1933 or before and the second cohort born after 1933. Among those born prior to 1934 ( $n = 4,595$ ), nonsignificant excess risks of death were observed for colon cancer, lymphoma, multiple myeloma and leukemia. Significant deficits were observed for all solid cancers combined and for cancers of the stomach and lung. The Japanese technologists who were born before 1934 likely worked variable amounts of time in the earlier calendar periods when occupational exposure to radiation was high and personal exposure was not monitored.

Using certification records of the American Registry of Radiologic Technologists, 143,517 U.S. technologists (73% female) certified for 2 or

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## EXTENDED ABSTRACTS

### American Statistical Association Conference on Radiation and Health

Howard Johnson Plaza Resort, Deerfield Beach, Florida, June 23–26, 2002

The 15th ASA Conference on Radiation and Health, held June 23–26, 2002 in Deerfield Beach, FL, offered a unique forum for radiation researchers from a variety of disciplines to present and discuss recent findings and current issues related to the effects of radiation exposures on human health. The Conference also furnished investigators the opportunity to learn about new approaches to problems within their disciplines.

The focus of the 2002 conference was current issues in radiation and health with sessions on:

1. lung cancer related to residential radon exposures and cancer risk from plutonium exposure;
2. novel efforts at low doses such as the bystander effect, i.e. the response of neighboring cells not directly irradiated;
3. diagnostic medical radiation, which is the primary source of U.S. population exposure from man-made radiation;
4. sensitive subpopulations and novel approaches to characterize genetic predisposition to radiogenic cancers; and
5. exposure and cancer risks in medical radiation workers, plus a recent finding that work-required X-ray examinations account for the bulk of radiation exposure in a cohort of nuclear workers.

The Conference also included a timely and provocative banquet presentation on “Nuclear and Radiological Terrorism.” The 15th biannual conference on Radiation and Health proved to be as stimulating and informative as in previous years. The participants enthusiastically look forward to the 16th conference to be held in 2004!

Susan Preston-Martin, Co-Chair  
James M. Smith, Co-Chair