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A Health Survey of Radiologic Technologists

John D. Boice Jr, ScD, Jack S. Mandel, PhD,† Michele Morin Doody, MS,* R. Craig Yoder, PhD,‡ and Roland McGowan, BSRT§*

A health survey of more than 143,000 radiologic technologists is described. The population was identified from the 1982 computerized files of the American Registry of Radiologic Technologists, which was established in 1926. Inactive members were traced to obtain current addresses or death notifications. More than 6000 technologists were reported to have died. For all registrants who were alive when located, a detailed 16-page questionnaire was sent, covering occupational histories, medical conditions, and other personal and lifestyle characteristics. Nonrespondents were contacted by telephone to complete an abbreviated questionnaire. More than 104,000 responses were obtained. The overall response rate was 79%. Most technologists were female (76%), white (93%.), and employed for an average of 12 years; 37% attended college, and approximately 50% never smoked cigarettes. Radiation exposure information was sought from employer records and commercial dosimetry companies. Technologists employed for the longest times had the highest estimated cumulative exposures, with approximately 9% with exposures greater than 5 cGy. There was a high correlation between cumulative occupational exposure and personal exposure to medical radiographs, related, in part, to the association of both factors with attained age. It is interesting that 10%. of all technologists allowed others to practice taking radiographs on them during their training. Nearly 4% of the respondents reported having some type of cancer, mainly of the skin (1517), breast (665), and cervix (726). Prospective surveys will monitor cancer mortality rates through use of the National Death Index and cancer incidence through periodic mailings of questionnaires. This is the only occupational study of radiation employees who are primarily women and should provide new information on the possible risks associated with relatively low levels of exposure. *Cancer* 1992:69:586-598.

Quantitative information useful for estimating the potential cancer risk associated with occupational exposure to low-level radiation has been derived in large measure from populations exposed briefly to high doses.[1-3] Because radiation damage may be repaired when exposures are spread over many years, it is not clear whether such risk estimates are valid for occupational situations.[4,5]

Studies of the pioneering radiologists in the United States and England have linked leukemia and skin cancer with excessive occupational exposures.[6-12] However, dosimetric information was not available, and doses may have been as high as 300 to 800 cGy. Increased incidence of other cancers has not been found consistently in radiologists, perhaps because only mortality was evaluated and because the overall numbers studied were small (only 6524 radiologists in the United States and 1338 in the United Kingdom). A recent study in China identified a high risk of leukemia among 25,000 radiologists and technologists and also suggested increased incidence of cancers of the breast, thy-

From the *Radiation Epidemiology Branch, National Cancer Institute, Bethesda, Maryland; the †Division of Environmental and Occupational Health, School of Public Health, University of Minnesota, Minneapolis, Minnesota; ‡Tech/Ops Landauer, Inc., Glenwood, Illinois; and the §American Registry of Radiologic Technologists, Mendota Heights, Minnesota.

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Address for reprints: John D. Boice, Jr., ScD. Radiation Epidemiology Branch, National Cancer Institute, 6130 Executive Boulevard Suite 408, Bethesda, MD 20892.

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roid, and skin.[13] The absence of reliable dosimetry measures, however, once again limits the usefulness of these data for risk quantification. A small mortality survey of Army radiologic technologists also did not provide quantitative information on possible radiation risks.[14] Occupational studies of workers at nuclear reactor facilities have yet to yield risk estimates of useful precision, in all likelihood because of the low cumulative doses and small numbers studied to date.[15-17]

There are few populations available for studies of the carcinogenic effect of low-dose fractionated exposures.[18] The existence of a professional registry of more than 229,000 medical radiologic technologists in the United States since 1926, however, offered the possibility of studying a large cohort of radiation workers, primarily women, for whom reasonably accurate estimates of exposure might be possible. Exposure information was available from employee records and dosimetry companies for many of the technologists. Because most registrants started working while in their late teens or early twenties, it would be possible to study the two most sensitive organ sites for radiation carcinogenesis, the breast and thyroid, at the level of incidence in a population with at least some exposures at particularly vulnerable ages.[19,20] For other cancers, especially leukemia and cancer of the lung, mortality evaluations should provide information on possible radiation risks. Recently, a National Academy of Sciences committee concluded that cancer risk estimates from low-dose radiation might be four times higher than previously believed.[1] The current study thus was performed to test the validity of these extrapolations from studies of brief high-dose exposures to occupational settings of protracted low doses.

Methods

A collaborative survey was initiated between the American Registry of Radiologic Technologists (ARRT), the University of Minnesota School of Public Health, and the National Cancer Institute to evaluate the health status, primarily with regard to cancer, of all current and former ARRT registrants, Addresses were sought for all technologists, questionnaires mailed to those found to be alive, and death certificates requested for those reported to have died. Records of radiation exposure were requested from places of employment and commercial dosimetry companies. In this first report, we describe the overall study design, methods, and descriptive results from the responses to more than 100,000 questionnaires.

Population

From 1926 through 1982, 174,678 people requested certification by the ARRT. Applicants were excluded from the health survey who were never certified (8.3%), whose certification was for less than 2 years (0.7%), or who resided outside the United States (0.3%). The final study population consisted of 143,517 technologists, of whom 92% were certified in radiography, 3% in nuclear medicine, 0.5% in radiation therapy, and 4% in some combination of these three professions (Table 1). As of April 1987, 17,201 eligible registrants were no longer active members of the ARRT. Termination of ARRT membership could have resulted from illness or death, change of occupation, retirement, or other reasons.

Tracing

A current address was sought for all registrants who were alive and a death certificate for those who had died. For active members, the most recent address from the ARRT files was available. Tracing efforts for inactive members included the use of motor vehicle departments, Health Care Financing Administration records, the post office address correction service, Social Security Administration records, credit bureaus, telephone or city directories, the Internal Revenue Service (through a collaborative agreement with the National Institute for Occupational Safety and Health [NIOSH]), the National Death Index, and state mortality tapes. More than 13,600 of the 17,201 inactive registrants (79%) were located, and approximately 6000 were reported to have died (Table 2).

Table 1. Radiologic Technologists Registered With the American Registry of Radiologic Technologists, by Certification Status as of 1982

	No.	Percent
Certified		
>2 yr	143,517	82.2
Radiology	131,731	(91.8)
Nuclear medicine	3804	(2.7)
Radiation therapy	773	(0.5)
Combination	7209	(5.0)
<2 yr	1256	0.7
After 1980	14,723	8.4
Living outside United States	645	0.3
Refused participation in study	2	0.0
Not certified	14,535	8.3
Total	174,678	100.0

Table 2. Demographic Characteristics of the Study Population of Radiologic Technologists

Characteristic*	No.	Percent (n = 143,517)	Mean exposure score†	% with exposure score
Sex				
Male	38,206	26.6	2.4	18.2
Female	105,311	73.4	1.5	19.5
Birth year				
< 1930	17,805	12.4	3.9	4.3
1930–39	19,716	13.7	2.9	13.1
1940–49	45,829	31.9	1.9	19.2
1950–59	59,090	41.2	1.4	25.5
1960+	1003	0.7	1.0	32.6
Year certified				
1926–39	2283	1.6	—	—
1940–49	5583	3.9	3.1	1.8
1950–59	18,769	13.1	3.2	9.3
1960–69	40,399	28.1	2.1	17.3
1970–79	69,108	48.2	1.5	24.0
1980	7375	5.1	1.1	28.0
Vital status (as of 12/89)				
Confirmed deceased	4796	3.3	7.0	0.1
Presumed deceased	1211	0.8	0.3	0.7
Alive	129,708	90.4	1.8	21.2

* Missing and unknown categories are not listed, thus percentages do not sum to 100%.

† Based on single-year record of cumulative occupational exposure to radiation through December 1985 for approximately 20% of the population. Nominal unit is cGy, but should not be taken literally.

Questionnaire

For every active and inactive member of the ARRT with a current address, a detailed 16-page questionnaire was mailed that could be optically scanned directly into a computer. The questionnaire was designed to efficiently record and transfer information, eliminating transcription and computer entry errors and resulting in a substantial reduction in clerical time, Information on work experience, personal radiographic exposures, cancer risk factors, cancer diagnoses, and current health status was obtained. Several sections of the questionnaire were similar to those used in the Nurses' Health Survey (NHS), a large study of women older than age 30, which was designed to provide information on known and suspected risk factors for cancer and heart disease.[21-23]

Questionnaires were mailed by bulk rate to more than 130,000 registrants, and more than 104,000 responses were received (Table 3). Permission to access medical and dosimetry records also was requested with the questionnaire. To increase the response rate, technologists were called on the telephone if they did not receive or return a previously mailed questionnaire. Through the regular monthly mailing of ARRT certification notices, registrants were encouraged to complete the questionnaires. Brief letters were sent to study subjects with unlisted telephone numbers, and an abbreviated mail or telephone questionnaire was used as a last resort to obtain health information on cancer, thyroid conditions, and myocardial infarction. The total response rate of the 132,454 technologists eligible to respond to the questionnaire was 79%. This current report is based on 90,305 responses to the long questionnaire and, when appropriate, the 14,324 additional responses to the abbreviated questionnaire.

Dosimetry

A key feature of this survey is the potential ability to document occupational and medical exposure to radiation. Technologists frequently wore personal dosimeters during employment, and records of these exposures are kept by hospitals or other places of employment and also by commercial dosimetry companies. Permission to access this information was obtained from the technologists or their next of kin.

For people who had one of four key malignancies thought to be especially sensitive to the carcinogenic effect of radiation (i. e., cancers of the thyroid, breast, or lung or leukemia), intense efforts were made to obtain as much information as possible on actual radiation exposures received during employment. Comparable efforts were made for a stratified random sample (n

Table 3. Tabulation of Questionnaire Responses and Reasons for Nonresponse

	No.	Percent
Sent questionnaire		
Responded to long questionnaire	90,305	62.9
Responded to short questionnaire	14,324	10.0
Nonrespondents	27,890	19.4
Refused directly	3506	2.4
Too ill or incapacitated to respond	24	0.0
Promised to return questionnaire but did not	6913	4.8
Unpublished/unlisted phone number	4388	3.1
Found, no phone	5502	3.8
Found, never responded	7557	5.3
Not sent questionnaire		
Deceased	4580*	3.2
Reported deceased	1082*	0.8
Moved out of country	84	0.1
Not found	5252	3.7
Total	143,517	100.0

* These numbers are lower than in Table 2 because some technologists completed questionnaires and were later determined to have died.

= 4000) of the population selected on the basis of age, sex, and other characteristics. In this manner, it may be possible to directly contrast cancer risk with the amount of recorded exposure to occupational radiation. To date, record-linkage with the computerized database of a large commercial dosimetry company. has provided estimates of cumulative lifetime exposure for 27,529 technologists (19%), and it is expected that approximately 70% to 80% of the study population will likely have some exposure data available for analysis. For descriptive purposes, the average "cumulative exposures" obtained from the record-linkage procedures are included in many of the tables in this report. They are meant only to indicate "exposure scores," so that patterns might be evaluated (e.g., those who worked the longest had the highest scores). They are subject to great uncertainty and should not be taken literally. The nominal units are centigrams, as recorded from film badges or thermoluminescent dosimeters.

Results

Overall, 143,517 technologists were studied. The population was predominantly female (73%), and 58% were born before 1950 (mean, 1944) (Table 2). Certification spanned between 1923 and 1980 (mean, 1968), mainly in radiography (92%). Four percent had died, 4% were not located, 73% completed a questionnaire, and 19% did not respond to the questionnaire (Table 3). Nonre-

Table 4. Demographic Characteristics of Respondents

Characteristic*	No.	Percent	Mean exposure score†	% with exposure score
All respondents (n = 104,629)				
Sex				
Male	25,534	24.4	2.4	25.6
Female	79.095	75.6	1.6	25.0
Birth year				
< 1930	9027	8.6	3.9	8.1
1930–39	13,982	13.4	2.9	17.8
1940–49	34,534	33.0	1.9	24.4
1950–59	46,285	44.2	1.4	31.0
1960+	798	0.8	1.0	38.1
Long questionnaire respondents (n = 90,305)				
Race				
White	84,181	93.2	1.8	24.4
Black	2283	2.5	1.5	20.5
Hispanic	3716	4.1	1.9	22.7
Marital status				
Married	67,785	75.1	1.7	26.7
Widowed	1644	1.8	3.3	13.1
Divorced/separated	9067	10.0	1.9	28.3
Never married	10,796	12.0	1.9	33.1
Education				
Rad tech program	47,812	52.9	1.8	29.0
Some college	33,285	36.9	1.6	26.8
Graduate school	3136	3.5	1.8	15.6

*† See footnotes to Table 2.

Table 5. Smoking and Alcohol History Among Respondents to Long Questionnaire

Question*	No.	Percent (n = 90,305)	Mean exposure score†
Ever smoked 100+ cigarettes?			
No	42,653	47.2	1.6
Yes	47,452	52.5	1.9
No. of cigarettes/day‡			
<½ pack/day	14,118	30.1	1.6
½–<1 pack/day	19,550	41.7	1.9
1–<2 packs/day	12,036	25.6	2.1
2+ packs/day	1225	2.6	2.5
Do you smoke now?‡			
Yes	21,808	46.7	1.9
No	24,900	53.3	1.9
Alcoholic drinks/wk			
None	16,210	17.9	2.1
<1 drink	36,342	40.2	1.6
1–2 drinks	13,927	15.4	1.6
3–6 drinks	13,332	14.8	1.7
7–10 drinks	5622	6.2	1.7
> 10 drinks	4210	4.7	2.5

* Missing and unknown categories are not listed, thus percentages do not sum to 100%.

† Based on single-year record of cumulative occupational exposure to radiation through December 1985 for approximately 20% of the population. Nominal unit is cGy, but should not be taken literally.

‡ Persons who did not respond to the question were excluded from the percent calculation.

spondents were typically female (68%), born before 1950 (60%), certified after 1969 (55%), and living in California (14%). Characteristics of nonrespondents, however, were generally similar to those of the respondents, as presented below.

Demographic Characteristics

As shown in Table 4, 93% of the respondents to the long questionnaire were white, 75% were currently married, and 40% had attended college. States with the largest percentages of radiologic technologists included California (10%), New York (6.2%), Pennsylvania (6.2%), Texas (5.5%), Illinois (5.4%), and Ohio (5.3%).

Smoking and Drinking

To assess any association between radiation and cancer accurately, other factors were evaluated that might increase the risk of cancer. Cigarette smoking is the most important cause of cancer in our society, and 53% of the respondents reported smoking more than 100 cigarettes (Table 5). Most smokers (66%) began as teen-agers, and 28% usually smoked more than one pack per day. Compared with women who participated in the NHS, female radiologic technologists had similar percentages of never smokers (44% *versus* 46%, respectively) or former smokers (26% *versus* 28%, respectively) or current smokers (31% *versus* 24%, respectively).[24,25] Nearly 18% of the technologists reported that they never drink alcoholic beverages, whereas approximately 5% reported having ten or more drinks per week. In the NHS, 32% of more than 89,000 women reported no daily alcohol intake.[26]

Reproductive Factors

Pregnancy is one of the most important risk factors for breast cancer, with nulliparous women being at higher risk than women who had given birth to their first child

Table 6. Childbearing History of Respondents to Long Questionnaire, by Sex of Respondent

	Female technologists			Spouses of male technologists		
Technologist question*	*No.*	*Percent*	*Mean exposure score†*	*No.*	*Percent*	*Mean exposure score†*
Ever been pregnant? (yes)	51,156	73.7	1.4	15,521	74.5	2.6
Ever had children? (yes)	47,705	68.7	1.4	14,427	69.2	2.6
Age at birth of first child (yr)‡§						
< 20	1722	3.6	2.3	333	2.3	2.2
20–24	20,806	43.7	1.4	4771	33.4	2.6
25–29	19,414	40.8	1.4	6010	42.1	2.7
30–34	4715	9.9	1.2	2443	17.1	2.7
35+	951	2.0	1.1	719	5.0	2.3
Any children with birth defects? (yes)	4247	8.9	1.4	1130	7.9	2.3
Ever had miscarriage? (yes)	14,016	20.2	1.5	3774	18.1	2.4
Ever had still birth? (yes)	982	1.4	1.1	400	1.9	2.3

*†‡ See footnotes to Table 5.

§ Age of female and male technologists, not spouses of male technologists.

when younger than 30 years of age.[27] Among female technologists, 69% had given birth to children, of whom 12% had their first child after age 30 (Table 6). It is interesting that the spouses of male technologists had a parity experience similar to that of the female technologists (i. e., 69% of the male technologists had children, although 22% had fathered their first child after age 30). Women participating in the NHS had higher rates of fertility (93%), in all likelihood resulting from their older age distribution, and 12% of first births occurred after age 30.[26,28] Twenty percent of the female technologists reported having had a miscarriage and 1.4% a stillbirth. Among those having children, similar proportions of the female and male technologists reported having a child born with an observable defect (i.e., 9% and 8%, respectively).

Details of gynecologic and reproductive histories for the female radiologic technologists are found in Table 7. Two percent had their first menstrual period before age 10 and 21% after age 14 (mean, 12.5). Twenty-one percent have stopped having menstrual periods; and, in 27% of these women, menopause occurred before age 35. Somewhat higher percentages were observed in the NHS of older women (i. e., 29% were postmenopausal).[26] The most common reason for the cessation of menstrual periods among technologists was hysterectomy (59%); 34% reported undergoing a natural menopause. Among women having a hysterectomy, 40% had both ovaries removed during the procedure.

Table 7. Gynecologic Characteristics of Female Technologists Who Responded to Long Questionnaire

Characteristic*	No.	Percent (n = 69,458)	Mean exposure score†
Age at menarche (yr)			
< 10	1580	2.3	1.6
10	3110	4.5	1.5
11	9447	13.6	1.8
12	18,647	26.8	1.5
13	20,789	29.9	1.5
14+	14,718	21.2	1.5
Have menstrual periods stopped? (yes)	14,771	21.3	2.5
Age at menopause (yr)‡			
< 35	3840	27.4	2.4
35–39	2485	17.7	1.9
40–44	2266	16.2	2.3
45–49	2675	19.1	2.7
50–54	2260	16.1	4.0
55+	476	3.4	2.4
Reason periods stopped†			
Surgery (hysterectomy)	8681	58.8	2.3
Natural	5075	34.4	3.4
Radiation	73	0.5	1.3
Ever taken hormone pills for menopause? (yes)	5909	8.5	2.9
Ever taken birth control pills?	51,937	74.8	1.5
Currently taking birth control pills?‡	7320	13.3	1.4
Ever had a breast biopsy?	6689	9.6	2.0
Family history of breast cancer?	14,988	21.6	1.6
Personal history of breast cancer?	607	0.9	1.6

*†‡ See footnotes to Table 5.

Table 8. Employment History of Respondents to Long Questionnaire

Question*	No.	Percent (n = 90,305)	Mean exposure score‡
Ever worked as a radiologic technologist? (yes)	89,402	99.0	1.7
Working now as a radiologic technologist?	53,716	59.5	1.8
Ever worn a dosimeter?‡	86,232	97.5	1.8
Did you wear a dosimeter in your last job?‡	72,926	90.1	1.7
Years worked as a radiologic technologist?‡			
0–4	12,878	14.4	0.9
5–9	29,343	32.8	1.2
10–14	21,497	24.0	1.7
15–19	10,786	12.1	2.2
20–29	8456	9.5	3.0
30–39	2761	3.1	3.8
40–49	536	0.6	3.9
50+	539	0.6	6.5

*†‡ See footnotes to Table 5.

Nine percent of the female technologists reported taking hormone pills, primarily estrogens, for menopausal symptoms. Birth control pills had been taken by 75% of technologists, of whom 13% were current users. Comparable percentages in the NHS were 48% and 6%, respectively.[22] Ten percent of the female technologists reported a prior breast biopsy; 22% had a family history of breast cancer; and 0.9% had a personal history of breast cancer. Comparable percentages in the NHS were 24%, 5% (maternal), and 1.5%, respectively.[22,26] The risk of breast cancer associated with known and suspected risk factors has been studied extensively within the NHS.[22,23,25,26,29] Oral contraceptive use and cigarette smoking also have been linked with fatal and nonfatal myocardial infarctions within the NHS.[30,31]

Employment History

Practically all respondents (98%) had worked at one time as radiologic technologists, and 60% were employed in the field at the time they completed the questionnaire (Table 8). Almost 98% had worn a dosimeter on at least one job during their employment, and 90%

Table 9. Work Experience With Diagnostic and Therapeutic Procedures Among Respondents to Long Questionnaire

Ever worked with the following procedures?‡	No. (yes)	Percent (n = 90,305)	Mean exposure score†
Fluoroscopy	85,140	94.3	1.8
Portable radiograph	84,417	93.5	1.8
Routine radiograph	84,093	93.1	1.8
Multifilm procedures	82,958	91.9	1.8
Diagnostic radioisotopes	29,818	33.0	2.0
Dental radiograph	27,036	29.9	2.0
Cobalt-60	22,499	24.9	1.7
Radium therapy	21,446	23.7	1.8
Diagnostic ultrasonography	18,110	20.1	1.7
Orthovoltage	18,008	19.9	1.8
CAT scan	16,885	18.7	1.7
Other radioisotope therapy	11,886	13.2	2.2
Other radiograph teletherapy	5501	6.1	1.3
Microwave/ultrasound diathermy	4208	4.7	1.5
Betatron	2638	2.9	1.2

CAT: computed axial tomography.
†‡ See footnotes to Table 5.

had worn one on their most recent job. These data indicate that quantitative information should be available on the radiation exposure of the technologists, Half of the respondents had worked as radiologic technologists for 10 or more years (mean, 12 years), indicating the potential to accumulate meaningful exposures. More than 1000 people reported having worked for more than 40 years. Only 14% had worked for less than 5 years. There was a clear tendency for those who had worked the longest to have the highest radiation exposure scores.

Table 9 lists the radiologic procedures used during employment. Practically all technologists had used a portable radiograph machine (94%), 94% had used a fluoroscope, 93% had worked with routine radiographs, and 92% had worked with multifilm procedures. The use of other types of machines and procedures was much less frequent and included dental radiographs (30%), computer axial tomography (19%), diagnostic radioisotopes (33%), diagnostic ultrasonography (20%), orthovoltage therapy units (20%), cobalt-60 (25%), and radium therapy (24%). It is interesting that, during their training as technologists, 10% allowed others to practice performing radiographs and fluoroscope examinations on them. A small percentage of these students (4%) allowed others to take radiographs of them more than 50 times.

Table 10 indicates that 98% of the technologists wore a dosimeter at some time during their career and that most wore them on their beltloop, waist, or side pocket (52%). In addition, 95% reported wearing a lead apron when first employed. It is interesting that 40% of those currently wearing an apron place the badge inside the apron.

Personal Exposures to Radiographs

People working in radiology departments might be more likely to have personal radiographs because of the

Table 10. Personal Dosimetry Habits of Respondents to Long Questionnaire

Question*	No.	Percent (n = 90,305)	Mean exposure score†
Ever wear a dosimeter? (yes)‡	86,232	97.5	1.8
Most common location where worn‡			
Beltloop, waist, side pocket	46,159	52.2	1.3
Breast pocket	12,191	13.8	2.2
Lapel	28,222	31.9	2.2
Elsewhere	3643	4.1	2.5
Never worn	2208	2.5	1.7
Wear hand/wrist dosimeter also?‡	7081	8.1	2.7
Apron or lead shield used when first employed?‡	84,002	95.4	1.7
Do you wear apron or stand behind shield now?‡§	50,298	95.0	1.8
If wear apron now, where is badge worn?			
Apron only, no badge	1374	2.7	1.0
Badge inside apron	20,245	39.9	1.4
Badge outside apron	21,031	41.5	2.3
Location of badge varies	8037	15.9	1.7
Badge not worn, in room	1372	2.7	1.7

*†‡ See footnotes to Table 5.
§ Those currently employed as radiologic technologists.

Table 11. Personal Exposure to Diagnostic Radiation Among Respondents to Long Questionnaire

Procedure	Percent‡ (n = 90,305)	Mean no. of procedures	Mean exposure score (cGy)†
Chest radiograph	96.4	9.29	1.8
Dental radiograph	91.5	12.38	1.7
Upper GI series	42.3	2.04	2.0
Lumbar spine	39.0	2.59	2.0
Kidney/ureter/bladder radiograph	34.5	2.96	1.8
Abdominal radiograph	32.1	3.15	1.9
Cervical spine radiograph	31.6	2.10	1.9
Skull radiograph	30.2	1.93	1.9
Intravenous pyelogram	27.7	1.92	2.1
Lumbosacral spine	26.0	2.68	1.9
Barium enema	25.9	1.81	2.1
Cholecyst/cholangiogram	21.0	1.66	2.1
Breast mammogram	20.9	1.89	1.9
Pelvis radiograph	19.4	2.39	1.8
Shoulder radiograph	18.9	2.21	2.3
Other head/neck radiograph	17.1	2.62	2.0
Thoracic spine radiograph	15.9	2.23	2.0
Barium swallow	13.7	1.90	2.0
Rib radiograph	12.3	1.82	2.2
Collar bone radiograph	6.0	2.38	1.9
Cystography	5.1	1.84	2.1
Angiography	2.4	1.56	2.3
Urethrogram	2.3	1.92	2.1
Renal anteriogram	0.6	1.44	2.3

GI: gastrointestinal.

†‡ See footnotes to Table 5

availability of this service.[32] Thus, an accurate estimation of risks possibly associated with low-dose occupational exposures should also consider the magnitude of personal radiographic exposures.[33] Table 11 tabulates the distributions of medical examinations received by the radiologic technologists. As anticipated, the most common type of examination was of the chest, with 96% of the respondents reporting at least one procedure. The average number of chest radiographs was 9.3 per person. Dental radiographs also were frequent; 92% of the population received an average of 12.4 dental radiographs during their lifetime. No other examination was as frequent as these two. Examinations performed on 25% or more of the respondents included barium enemas (mean, 1.8 per person exposed), intravenous pyelograms (1.9), upper gastrointestinal series (2.0), skull radiographs (1.9), cervical spine radiographs (2.1), kidney/ureter/bladder (KUB) radiographs (3.0), abdominal radiographs (3.2), lumbar spine radiographs (2.6), and lumbosacral radiographs (2.7). Special procedures such as angiograms and urethrograms were infrequent.

More than 5000 technologists (6%) had received therapeutic radiographs (Table 12). Radioisotopes had been used for diagnostic or therapeutic reasons on 12% of the respondents, with most of these (60%) receiving radioisotopes for evaluation of the thyroid gland.

Thyroid Disease and Cancer

Because the thyroid is one of the most radiosensitive sites to ionizing radiation,[20] detailed information was requested on any thyroid condition diagnosed by a physician. Nine percent, or more than 9500 of the technologists responding to either questionnaire, reported having a thyroid condition. Of these, 220 (2.3%) had thyroid cancer (Table 13). Preliminary computations based on Connecticut incidence rates suggest that only about 100 thyroid cancers would be expected in a population of this size. However, these self-reported cancers have not all been confirmed, and it appears that some were not cancers, but adenomas or other conditions.

Overall, few technologists, only 3755 (3.6%), reported a total of 4755 cancers diagnosed by a physician (Table 14). The most prevalent cancer was of the skin (32%), followed by cancers of the cervix (15%), breast (14%), uterus (5%), and thyroid (5%). There were 76 reports of lung cancer, 42 leukemias, and 665 breast cancers. It is important to remember that these are prev-

Table 12. Personal Exposure to Therapeutic Radiation and Radioisotopes Among Respondents to Long Questionnaire

Question‡	No.	Percent (n = 90,305)	Mean exposure score†
Any therapeutic radiographs	5121	5.7	2.1
Head/neck radiographs§	1797	2.0	2.2
Pelvis radiographs	410	0.5	2.6
Extremity radiographs	2297	2.5	2.3
Chest radiographs	893	1.0	2.0
Other radiographs	1693	1.9	2.1
Radioisotopes (any)	10,372	11.5	2.2
Radioisotopes for thyroid‡	6243	6.9	2.0
Radioisotopes—other site	4932	5.5	2.6

†‡ See footnotes to Table 5.

§ Numbers for subgroups are greater than the overall category because some technologists reported exposures to more than one body area.

alent cases of cancer in the members of the population who are alive and do not include cancers that occurred in technologists who have died. Further, our initial validation procedures indicate that at least some percentages of these self-reported cancers were incorrect.

Death certificates still are being requested for approximately 200 technologists reported to have died. Among 6282 deaths coded to date, there were 1850 deaths due to cancer. The most frequent cancer death resulted from breast cancer (358), followed by cancer of the lung (350). Thus far, 85 leukemia deaths have been identified. Although the mortality data are incomplete, crude proportionate mortality ratios suggest slight, but not significant, increased risks for breast cancer (proportionate mortality ratio = 1.38) and leukemia (proportionate mortality ratio = 1.2), but not lung cancer (proportionate mortality ratio = 1.0).

Other Medical Conditions

Approximately 1.4% (or 1414) of the respondents reported having a myocardial infarction, with more than 50% of these having their first myocardial infarction before the age of 50. The NHS has evaluated the association between estrogen use, oral contraceptive use, and smoking with fatal and nonfatal heart attacks[29-31,34-38] and stroke,[24] and our survey should be able to provide additional information.

Other Factors

At one time it was thought that hair dye might be associated with breast cancer risk, and ARRT registrants were queried as to whether they regularly dyed their hair. More than 15,000 (22%) of the 69,298 female re-

Table 13. Thyroid Conditions Reported by Respondents to Long and Short Questionnaires

Question‡	No.	Percent (n = 104,629)	Mean exposure score†
Have you ever had a thyroid condition diagnosed by a physician?			
No	93,258	89.1	1.7
Yes	9508	9.1	1.8
Specific conditions reported§			
Hyperthyroidism	1530	1.5	1.6
Hypothyroidism	4527	4.3	1.6
Thyroiditis	601	0.6	2.2
Thyroid cancer	220	0.2	1.8
Goiter	1478	1.4	1.7
Thyroid nodules	621	0.6	1.7
Other thyroid condition	2534	2.4	1.5
Unknown thyroid condition	695	0.7	1.7

†‡ See footnotes to Table 5.

§ Numbers of thyroid conditions are greater than the overall because some technologists reported more than one condition.

Table 14. Cancer Incidence Reported by Respondents to Long and Short Questionnaire

Question*	No.	Percent (n = 104,629)	Mean exposure score†
Have you ever had cancer diagnosed by a physician?‡			
No	98,572	94.2	1.8
Yes	3755	3.6	2.1
Specific cancers reported‡			
Skin	1517	31.9	1.9
Cervix	726	15.3	2.2
Breast	665	14.0	1.7
Uterus	242	5.1	3.7
Thyroid	220	4.6	1.8
Colon	138	2.9	2.6
Ovary	108	2.3	4.3
Hodgkin's disease	91	1.9	1.3
Lung	76	1.6	1.7
Prostate	51	1.1	0.3
Leukemia	42	0.9	3.2
Multiple myeloma	34	0.7	0.4
Rectum	18	0.4	0.6
Stomach	13	0.3	3.3
Other	814	17.1	1.9
Total	4755	100.1	2.1

*†‡ See footnotes to Table 5.

§ Numbers of cancer cases are greater than the overall because some technologists reported more than one cancer.

spondents reported using hair dye regularly, and 16% had used hair dye for more than 20 years. The NHS reported that nearly 38% of the nurses had used permanent hair dyes, but no association with breast cancer was apparent.[39,40]

Dosimetry Linkage

For descriptive purposes only, we linked the file of ARRT registrants with the computer files of a large commercial dosimetry company for 1 calendar year (1985). Although these cumulative exposures are incomplete and are available at this time for only 20% of the population studied, the exposure patterns over certain characteristics are informative. These estimates are, of course, underestimates of actual cumulative doses received in the course of employment and should not be interpreted literally. Not all the occupational experience of these workers was covered by this one company, and the accuracy of a dosimeter in reflecting actual organ doses is likely to be poor. Additionally, in large part, dosimetry records are nonexistent before approximately 1950. These nominal cumulative exposures thus are labeled "exposure scores" to minimize the chance of misinterpreting their significance or accuracy.

The clearest trend linking radiation exposure to any characteristic was for years worked as a radiologic technologist. People who had worked for more than 40 years had three to seven times greater cumulative exposure scores than technologists employed for only a short time. Men had higher scores than women, reflecting, in part, their longer lengths of employment. Birth year and year of certification were inversely related to exposure score. The suggestion that people who were widowed or who had only a grade school education (not shown) had higher scores than others probably reflects, once again, the older age of these people. It is interesting that there is no evidence that employment or experience with certain types of procedures, whether with fluoroscope or high-energy therapy units, was associated with a significantly different cumulative exposure. With regard to personal practices during the educational experience, people who reported allowing other students to practice taking radiographs of them had much higher mean scores than those who did not, probably because of associations with attained age for both factors.

There were no unusual patterns of high exposure scores linked with any particular thyroid condition. There was a suggestion that patients in whom cancer developed might have had slightly higher scores than those who did not have cancer, but this may reflect the longer length of employment for people who were old enough for cancer to develop,

With regard to cancer risk factors in general, it did not appear that radiation dose varied appreciably with any of the factors evaluated, although a trend of increasing exposure score with increasing levels of cigarette smoking was suggested (Table 5). With regard to personal exposure to diagnostic radiation, there was a suggestion that higher exposure scores occurred among people who had more frequent procedures (not shown), possibly once again reflecting age and length of time working as a technologist. These data indicate, however, the importance of personal exposure to medical radiographs in evaluating occupational exposures (*i.e.,* those who have the highest mean occupational exposure also appeared to have the highest numbers of diagnostic radiographic procedures). A recent interview study, for example, reported an association between diagnostic radiography, especially gastrointestinal series and back radiographs, and chronic myelogenous leukemia.[41]

For most (58%) of the people for whom a cumulative exposure could be obtained with linkage with a commercial dosimetry company, exposures were less than 1 cGy (Table 15). This average is low because most active technologists began working in the 1970s, under improved radiation protection habits, and they had less

Table 15. Recent Cumulative Exposure Scores for 59% of the Study Population

Exposure score (cGy)*,†‡	No.	Percent
0	5722	6.8
< 1	43,375	51.3
1–1.9	13,208	15.6
2–2.9	7099	8.4
3–3.9	4455	5.3
4–4.9	2895	3.4
5–9.9	5418	6.4
10+	2320	2.7

*,† See footnotes to Table 5.

‡ Cumulative exposure as recorded in the computerized records of a large dosimetry company. Record-linkage with files through 1989 resulted in these tabulations.

time to accumulate a meaningful dose. Further, the linkage was based only on active workers and would be unlikely to include exposures occurring before approximately 1953, when the company began. Exposures at places of employment not contracting for services by this dosimetry company also may have been missed. Almost 10% of the population have received doses greater than 5 cGy. Over 100 radiologic technologists had cumulative dose readings in excess of 50 cGy. Current estimates of occupational exposure in the healing arts for a 12-year period would be 3.6 cGy,[1] which is higher than our crude overall estimate of about 2 cGy. Future linkages and inclusion of data obtained from places of employment will allow a more detailed characterization of the overall radiation exposure history of this population. Preliminary tabulations from our in-depth evaluation of employer records for a sample of some 4000 technologists suggest that cumulative exposures for most technologists employed for more than 10 years will range between 5 and 20 cGy.

Discussion

This large and well-defined population of more than 143,000 radiologic technologists should be able to provide new information on the possible risks associated with occupational exposure to ionizing radiation, accounting for important risk factors that might distort the relationship between radiation dose and cancer occurrence. Although studies of relatively low doses have inherent limitations with regard to adequate sample sizes and ability to control confounding factors, our survey should be able to judge the validity of current estimates of radiation risk (e.g., a relative risk of 1.5 at 10 cGy for leukemia), based on studies of brief, high-dose exposures.[1] The information obtained from the responses to more than 104,000 questionnaires will be helpful. not only in assessing the findings from the current health survey of cancer incidence and mortality, but also in future prospective evaluations.

The population of radiologic technologists in the United States can be characterized as follows: Most are female, white, and employed for 12 years on average; 40%. attended college; and approximately 50% never smoked cigarettes. Nearly 69% have had children; the average number of children is 1.5; and 9% of those having children reported a child born with an observable defect. Cancer was diagnosed in 3.6% of the radiologic technologists; 9.1% have had a thyroid condition develop; and 9.6% have had a breast biopsy. More than 94% have worked with fluoroscope, 94% with portable radiograph machines, 33% with isotopes, and 25% with therapy machines. During their education, 10% allowed other students to practice taking radiographs of them, a practice that was not uncommon in the 1940s.[42] Practically all technologists have worn dosimeters. Personal exposure to x-rays included barium enema (26%); intravenous pyelogram/retrograde pyelogram (28%); mammogram (21%); dental (92%; mean, 12), chest (96%; mean, 9), and lumbar spine (39%) radiographs; and head and neck radiation therapy (2%).

Although questionnaires were not completed by nearly 20% of the technologists, the nonrespondents did not differ appreciably from the respondents with regard to age, sex, state of residence, specialty, and year of certification. In a comparable health survey of 165,000 nurses, nonrespondents were also similar to respondents with regard to age, education, state of residence, employment status, field of employment, and major specialty, and a major bias due to nonresponse seemed unlikely.[43]

Although the linkage with dosimetry records is not yet complete, several interesting patterns were evident, As expected, technologists employed for the longest times had the highest cumulative exposure scores. Exposure scores for men were greater than for women, and approximately 9% were higher than 5 cGy. People reporting the greatest number of certain types of personal radiographs also had the highest cumulative exposure scores, indicating the importance of considering these exposures in any evaluation of occupational doses.[32] Increased age clearly was correlated with cumulative occupational dose, increased exposure to medical radiographs, and increased prevalence of medical conditions such as cancer. If future evaluations uncover a risk associated with occupation, it will likely be detected first among the early registrants, for whom dosimeters were rarely available in the 1920s to 1940s. In fact, before 1950, safe levels of radiation often were determined by whether decreases in blood counts could be detected after prolonged exposure. In the United States[44] and China,[13] depressed blood counts were not uncommon and would result in unplanned vacations for the radiation workers.

This is the first in a series of articles on a comprehensive health survey of radiologic technologists in the United States. Future evaluations will include mortality, cancer incidence, exposure assessment, dose response, and risk analyses. Additional questionnaire surveys are planned, so that incidence data can be obtained on important cancers, such as thyroid and breast cancer, for which mortality evaluations are often incomplete. Associations of health events with exposures to other factors, such as cigarette smoking, use of oral contraceptives, and use of menopausal estrogens, also will be possible. Continued mortality updates, with the use of the National Death Index and Social Security mortality records, are expected. It is anticipated that this survey of radiologic technologists will provide useful information on radiation risks as they relate to populations for whom radiation standards are set to protect.

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