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EXPECTATION OF LIFE AND MORTALITY FROM CANCER AMONG BRITISH RADIOLOGISTS

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It has been stated, in a report on "The Biological Effects of Atomic Radiation" by the United States National Academy of Sciences (1956), that the average age at death of American radiologists was about 5 years less than the average age at death of American physicians having no known professional contact with radiation. It was inferred from this finding that exposure to the levels of radiation dose which are received under occupational conditions would result in a reduction in the expectation of life, in the same way as the longevity of animals is reduced by large doses of whole-body radiation given at a high dose rate. Others have claimed that, in this respect, the action of radiation is non-specific and that exposure to even very low doses confers some degree of general unfitness to survive. In explanation, it has been suggested that radiation leads to an accelerated rate of senescence due to the accumulation of genetic damage in the somatic tissues (Failla, 1957; Henshaw, 1957).

The present report stems, in its inception, from the various studies that have been made on American radiologists, and gives the causes of death among a similar group of British radiologists during a 60-year period from 1897 to 1956. The investigation had two objects: firstly, to see whether there was evidence for a decrease in the expectation of life as the result of a non-specific ageing effect, and, secondly, to examine the mortality of British radiologists from cancer.

The Study Population

Through the co-operation of the Council of the British Institute of Radiology and the Council of the Faculty of Radiologists, lists were compiled of the members of each society who had a medical or a dental qualification. In subsequent descriptions members with dental qualifications have been classed with the medical members, whether or not they also had a medical qualification.

For the British Institute of Radiology, the lists were made retrospective to 1897, which was the foundation year of its precursor the X-ray Society, the first radiological society in the world. Soon after its foundation the name of the X-ray Society was changed to the

Röntgen Society, and in 1927 this society amalgamated with the British Institute of Radiology, which had been founded separately in 1922, to form the present institute. For the Faculty of Radiologists, lists of members were obtained from the date of its foundation in 1939 and also from the records of its antecedent societies, the British Association of Radiologists and the Society of Radiotherapists of Great Britain and Ireland, which were founded respectively in 1934 and 1935.

The period over which the data were collected includes the period of the early development of medical radiology, and consequently the persons studied include a large proportion, and probably the great majority, of the pioneer British radiologists, many of whom unwittingly exposed themselves to excessive amounts of radiation.

The lists contained the names of all who joined the societies up to December 31, 1954, and altogether records were obtained of 2,035 medical and dental members; 1,461 of these, on the basis of initial addresses in Britain or Eire or of belonging to the Colonial or Armed Services, were regarded as constituting the "Home" population. For simplicity of analysis, the few women in the population (80) were excluded and the study was limited to an analysis of the mortality among the 1,381 men in the "Home" population.

For each member of the population the following data were recorded:

Name and qualifications; address on entry and last known address; sex; date of birth; date of joining one of the societies; status on January 1, 1957; and (if dead) the date and cause of death.

The information required had to be obtained from a number of sources. It was sought primarily from the records of the societies, but when these were inadequate it was sought in the records of the General Register Office, the General Medical Council, the British Medical Association, other professional organizations, or the hospitals in which the members worked. In a few instances information was obtained direct from the member himself, or from other members or relatives. Whenever a member was known to have died, a copy was obtained of the cause of death entered on the death

certificate. This last information was omitted in a few cases in which the member was reported to have died abroad and there was little doubt about the cause of death—e.g., accidental death or death through enemy action. It proved possible to trace all but four members of the male population, and the subsequent analyses are therefore based on the 1,377 males whose status was known on January 1, 1957. The fact that those whose deaths had not been recorded were alive after this date was confirmed by (1) personal contact or (2) discovering that they had subsequently paid a subscription to one or other medical society.* The majority (probably the great majority) of these men were or are engaged in the practice of diagnostic radiology, and the group as a whole may be regarded as a group of radiologists.

It seems likely that most full-time radiologists in Britain and Eire are, or have been, members of one or other society. The survey is, however, deficient in that it does not include a number of radiologists—mostly perhaps part-time—who have not been members of either society. It is also possible that in the past such people may have been those least protected from radiation. Some indication that such workers have been overlooked arose when, during the course of the survey, the records were brought to our notice of a part-time diagnostic radiologist who recently died from aplastic anaemia and who had never been a member of either of the two societies.

The Extent of Radiation Exposure

It is only recently that active steps have been taken to record the amounts of exposure received by the staffs of radiological departments. Available evidence suggests that exposure, under modern conditions, is almost always well below the weekly maximum permissible dose of 0.3 r (Godfrey, Osborn, and Templeton, 1957). This, however, has not always been the case, and during its formative years medical radiology was often practised without any protective measures being taken. In the earliest days it was common practice for a radiologist to test the condition of his x-ray tube by the deliberate exposure of his hands, and he assessed the state of the tube by the density of the shadows of his hand bones cast on a fluorescent screen.

Hunter (1955) states that protective clothing was introduced in 1903, and Cuthbert Andrews (personal communication) says that by 1909 the wearing of such clothing was a fairly general practice. The clothing was clumsy and bulky to wear, and to obviate this steps were taken, during the first world war, to incorporate protective shielding into the x-ray equipment. In spite of this, radiation damage continued to occur, and in 1921 the British X-ray and Radium Protection Committee was formed as the result of co-operative action between the Royal Society of Medicine, the Röntgen Society, and a number of other interested bodies. This committee issued its first recommendations in July, 1921. There is reason to believe that the action of the committee was fairly quickly effective in arresting the sequence of casualties to x-ray and radium workers. In this survey, therefore, the study population has been divided into those members entering before 1921 and those joining one or other society in 1921 or afterwards. It is assumed that those joining after 1920 would on the whole commence the practice of radiology under recognized conditions of protection, and the comparison of these two sections of the population should be of value in ascertaining whether any significant radiation effects had occurred.

There is little point in attempting to assess the total exposure to radiation of individual members. No data exist

which permit such estimates to be made with any confidence. It seems reasonable, however, to proceed on the assumption that the average exposure of the pre-1921 members was excessively high, and that the average exposure of the post-1920 members has been within the various permissible limits that have been recommended.

Calculation of the Expected Mortality

To calculate the mortality expected among the members of the societies it is necessary to know the population at risk at each age and in each year from the date when the first members joined the first society (1897) until the end of the period of observation (December 31, 1956). Members were regarded as being at risk from the year in which they first entered a society until either their year of death or the end of 1956, whichever was the earlier, irrespective of the actual length of time membership may have continued. Each member was considered as being at risk for half a year in the year in which he first entered, and, in the event of death, for a similar period in the year in which he died. Members entered the population and deaths occurred more or less equally in each month, so that both events may be regarded as having occurred, on average, at mid-year. The population at risk was then obtained by counting the members at risk at each year of age and for each year from 1897 to 1956, and then adding in each five-year age group the numbers of "man-years" at risk for the period 1897 to 1915, for the quinquennia from 1916 to 1950, and lastly for the period 1951 to 1956.† Separate counts were made for the members who first entered the population before January 1, 1921, and for those joining on or after that date. The numbers of man-years at risk in each five-year age period and for each period studied are shown separately in Table I.

The expected numbers of deaths were estimated, as a first approximation, by assuming that the mortality should be the same as that recorded for all men in England and Wales in the same age groups and over the same periods of time. The numbers of man-years at risk were therefore multiplied by the corresponding age-specific male death rates (McKenzie, Case, and Pearson, 1957), and the total numbers of deaths expected were obtained by adding together the results for all the age groups.

These figures are, however, not the best estimates which can be made, as over the years there has been an appreciable difference between the mortality experience of different socio-economic classes and of different occupational classes. These differences can be allowed for by utilizing the data published in the Registrar-General's Occupational Mortality Supplements. Data have been published for the periods 1910-12, 1921-3, 1930-2, and 1949-53 (Registrar-General, 1923, 1927, 1938, 1958), and they are given separately for different social and occupational classes (including the medical profession). The data are also published in each instance for various age groups up to and including those 75 years of age and over. Some slight variations were made in the definition of the first socio-economic class in the different reports, but in general the class has corresponded to the members of the major professions, senior business executives, etc.

It is reasonable to suppose that the mortality of radiologists would most closely correspond to that of the first social class, which includes all members of the medical profession. The mortality of doctors as a whole has, however, differed appreciably from that of this class. To some extent this may be the result of specific risks associated with general practice, and it is possible that the conditions of life of men in social class I provide a better indication of the conditions of life of radiologists (apart from the latter's specific radiation exposure) than the conditions for the medical profession as a whole. Separate estimates have therefore been made of the total numbers of deaths which

*Except in one instance, when the only evidence that the member was alive later than 1954 was that his address was given in the British and Canadian Medical Directories. He joined the institute in 1949, when aged 30 years.

†These periods were chosen for convenience, since age-specific death rates have been published by McKenzie, Case, and Pearson (1957) for cancer of various sites for quinquennia from the period 1911-15.

would have been expected if the mortality of the members of the radiological societies had corresponded on the one hand to that of doctors and on the other to that of men in social class I.

To make the necessary corrections the mortality rates at each Census period were calculated for male doctors and for men in social class I for each age group for which data were given. These were expressed as percentages of the corresponding rates for all men during the same period, and the estimates of the correcting factors required for each of the periods studied were obtained by interpolation. Thus in 1921-3 the mortality of men in social class I aged 55 to 64 years was 88% of the general male population; in the period of 1930-2 it was 95%. Therefore in the quinquennium 1926-30 the correcting factor for social class at ages 55 to 64 years was taken to be $\{88 + 6/9 (95 - 88)\}/100$ or 93%. The numbers of deaths expected in each age group calculated on the mortality rates for England and Wales were multiplied by the corresponding correcting factors, and the results summed for all ages and periods to give the corrected estimates of the total mortality (estimates B in Tables II, III, and IV).

These corrections are, however, less satisfactory than might be thought. The reason lies in the fact that above the age of 65 years the Registrar-General's occupational mortality rates are increasingly biased, because a proportion of retired

men fail to give their last occupation on the Census schedule, whereas this is nearly always obtained by the Registrar on the registration of a death. As a result the mortality of all occupations (and of all social classes) is artificially increased in the older age groups, while a very low mortality is recorded for men classified as being unoccupied. This factor cannot be ignored, though it is perhaps less likely to affect the recorded mortality for doctors and for men in social class I generally than for men in most other occupations. It has therefore been thought wise to make a second estimate of the corrected mortality (for both social class and occupation) on the assumption that the mortality at ages over 65 years bears the same relationship to that for all men as does the mortality at ages 55 to 64 years—the oldest age group for which the data can be relied on with confidence (estimates A in Tables II, III, and IV).

The total numbers of deaths expected to be attributed to all types of cancer, and the appropriate corrections for occupation and social class, were calculated by the same method. Data are not available in the same detail to enable similar estimates to be made for expected cancer mortality at specific sites, and a more approximate method was used for this purpose. The numbers of expected deaths were calculated from the national mortality rates in the same way, but in deriving correction factors for social class age was ignored, and the appropriate factors for each

TABLE I.—Number of Years Lived in Five-year Age Groups by Radiologists who Came Under Observation Before or After the Beginning of 1921

Group of Radiologists	Age (Years)	No. of Man-years at Risk During								
		1897-1915	1916-20	1921-5	1926-30	1931-5	1936-40	1941-5	1946-50	1951-6
Joined Society before January 1, 1921	20-	7	2	0	0	0	0	0	0	0
	25-	82	16	5	0	0	0	0	0	0
	30-	225	58	65	5	0	0	0	0	0
	35-	410	110	105	65	5	0	0	0	0
	40-	527	188	170	102	65	5	0	0	0
	45-	532	230	244	164	101	65	5	0	0
	50-	433	232	248	231	161	99	65	5	0
	55-	299	187	236	224	209	147	97	65	5
	60-	148	142	178	201	197	187	118	89	61
	65-	60	74	121	148	152	164	144	87	102
	70-	18	21	48	88	108	117	129	116	81
	75-	6	4	5	31	56	65	80	93	72
	80-	5	1	4	1	12	33	31	35	47
	85 or above	4	1	1	2	1	6	23	28	32
	All ages	2,756	1,266	1,430	1,262	1,067	888	692	518	400
Joined Society on or after January 1, 1921	20-	—	—	18	2	4	0	2	2	1
	25-	—	—	77	77	62	48	47	106	52
	30-	—	—	53	177	225	201	232	366	568
	35-	—	—	41	198	315	346	314	522	944
	40-	—	—	55	165	315	394	431	381	839
	45-	—	—	31	150	215	362	423	503	545
	50-	—	—	16	100	178	239	377	459	645
	55-	—	—	12	47	106	186	239	359	561
	60-	—	—	12	36	67	108	164	226	407
	65-	—	—	1	16	43	68	101	141	238
	70-	—	—	0	6	12	39	52	88	140
	75-	—	—	0	0	5	7	26	38	98
	80-	—	—	0	0	0	1	2	11	35
	85 or above	—	—	0	0	0	0	1	0	7
	All ages	—	—	240	974	1,547	1,999	2,411	3,202	5,080

TABLE II.—Numbers of Deaths from All Causes; Observed and Expected, by Date of Death

Period	Pre-1921 Population				Post-1920 Population			
	No. of Deaths Observed	No. of Deaths Expected from Mortality of			No. of Deaths Observed	No. of Deaths Expected from Mortality of		
		General Population	Men in Social Class I A*	Doctors B*		General Population	Men in Social Class I A*	Doctors B*
1897-1915	26	44	39 - 39	40 - 40	—	—	—	—
1916-20	21	25	22 - 22	24 - 24	—	—	—	—
1921-5	27	29	26 - 27	31 - 30	0	2	2 - 2	2 - 2
1926-30	46	35	32 - 33	38 - 36	6	9	8 - 8	9 - 9
1931-5	31	37	35 - 36	40 - 38	13	16	14 - 15	17 - 16
1936-40	41	42	40 - 42	44 - 43	23	25	23 - 23	25 - 25
1941-5	38	39	38 - 41	38 - 39	30	32	30 - 31	31 - 31
1946-50	35	37	37 - 41	35 - 37	37	42	41 - 42	39 - 39
1951-6	37	36	37 - 41	33 - 37	52	75	75 - 79	68 - 71
All periods	302	324	306 - 322	322 - 323	161	201	193 - 200	192 - 193

* Estimates made on different assumptions about the relative mortality of men in these social groups aged 65 years and over: see section on "Calculation of the expected mortality."

period were obtained by interpolation from the standardized mortality ratios for ages 20 to 64 years published by the Registrar-General.* For example, the standardized mortality ratio for cancer of the stomach was 60% for social class I in 1921-3 and 55% in 1930-2; the correcting factor for the quinquennium 1926-30 was therefore calculated to be $\{60 + 6/9 (55-60)\}/100$ or 57%. No figures are available for the years prior to 1921, and the standardized ratios for 1921-3 have been taken as the correcting factors for all the preceding years. In the case of leukaemia the earliest available figure was 163% in 1930-2.

The Expectation of Life

Results

The numbers of deaths reported among those members who entered the population before January 1, 1921 (the "pre-1921 population"), and among those who entered in 1921 or later (the "post-1920 population") are shown in Table II separately for nine periods between 1897-1915 and 1951-56. The numbers of deaths in each group are compared with the numbers which it is estimated would have occurred among comparable groups representative of (1) all men in England and Wales, (2) men in social class I, and (3) male doctors. For reasons which have been stated previously two sets of figures are given for the expected numbers of deaths for men in the last two categories, and it is likely that the best estimate lies somewhere between them. The total numbers of deaths for each of the two populations are shown in Table III, subdivided according

TABLE III.—*Number of Deaths from Cancer and Other Causes: Observed and Expected, All Periods*

Group of Radiologists	Cause of Death	No. of Deaths Observed	No. of Deaths Expected from Mortality of		
			General Population	Men in Social Class I A* B*	Doctors A* B*
Pre-1921	Cancer	55	48	42 - 47	35 - 42
	Other cause	247†	276	264 - 275	287 - 281
	All causes	302	324	306 - 322	322 - 323
Post-1920	Cancer	24	38	36 - 37	26 - 29
	Other cause	137	163	157 - 163	166 - 164
	All causes	161	201	193 - 200	192 - 193
All members	Cancer	79	86	78 - 84	61 - 71
	Other cause	384†	439	421 - 438	453 - 445
	All causes	463	525	499 - 522	514 - 516

* See footnote to Table II.

† Including two deaths attributed to aplastic anaemia and one death for which information about the cause was not obtained.

to whether the deaths were attributed to cancer or to other causes. It is clear that the total of observed deaths (463) is less than would have been expected if the members had suffered a mortality similar to that experienced by all men in England and Wales over the same period (525). It is also less than expected for men either of the same social class (499 to 522) or of the same profession (514 to 516). If the deaths attributed to cancer are excluded the relative differences between the observed and expected numbers of deaths are more marked, and the difference from the smallest number which could reasonably be expected approaches statistical significance (observed 384, expected 421; $P=0.07$).

When the radiologists who joined before and after January 1, 1921, are examined separately it is found that the actual number of deaths was less than the expected number in both groups and that the deficiency was more marked among those who joined later. In the pre-1921 group, however, there was a small excess of deaths due to cancer, and if these are excluded the deficiency of deaths due to other causes is of the same order in both the groups.

*The standardized mortality ratios published for 1930-2 are for the age group 35 to 64 years and these ratios have been used for this period.

These findings should not be interpreted to mean that radiologists have an increased life expectancy as a result of their occupation. A large part of the deficiency is contributed by the experience of the first few years, and much of this is likely to be an artifact due to the exclusion of men who were particularly unhealthy. It is common actuarial experience that men who voluntarily join some organization have a healthier record than average for a few years, because those who know they are seriously ill tend not to undertake new responsibilities. In the course of time the effect of this type of selection must be expected to disappear, and it is unlikely to be appreciable after five years (Jordan, 1952). Whether it has contributed to the present results can be tested by calculating separately the number of deaths expected to occur within the first five years of joining one or other society. When this is done it appears that the deaths observed during this period were markedly fewer than those expected (24 against 42 expected on the basis of the national rates); it would therefore seem reasonable to exclude this part of each individual's membership from the study. The results obtained by so doing are shown in Table IV. The total mortality is still lower

TABLE IV.—*Numbers of Deaths from Cancer and Other Causes: Observed and Expected, First Five Years at Risk Excluded*

Group of Radiologists	Cause of Death	No. of Deaths Observed	No. of Deaths Expected from Mortality of		
			General Population	Men in Social Class I A* B*	Doctors A* B*
Pre-1921	Cancer	54	46	41 - 46	34 - 41
	Other cause	239†	261	251 - 262	273 - 267
	All causes	293	307	292 - 308	307 - 308
Post-1920	Cancer	22	35	32 - 34	23 - 26
	Other cause	124	141	139 - 144	145 - 143
	All causes	146	176	171 - 178	168 - 169
All members	Cancer	76	81	73 - 80	57 - 67
	Other cause	363†	402	390 - 406	418 - 410
	All causes	439	483	463 - 486	475 - 477

* See footnote to Table II. † See footnote to Table III.

than that expected from the experience of comparable social and professional groups (439 deaths against the lowest estimate of the expected number of 463), and the mortality from causes other than cancer is also lower than that expected—though now clearly not significantly lower (observed deaths 363, least number of expected deaths 390; $P=0.17$).

The slight deficiency of deaths due to causes other than cancer could have arisen because of an inadequate correction for social class and occupation. The correction for class and occupation could not be very accurate, as so many of the deaths occurred at ages 65 years and over and the occupational mortality data available for these ages are known to be unreliable. There has, however, been little change in life expectancy at these older ages over the last half-century, and it seems unlikely that social factors can have had a greater effect on mortality in this age group than at ages 55 to 64 years. It is believed, therefore, that the alternative method which has been used for correcting for social factors will have over-corrected rather than under-corrected the expected mortality. That the deficiency is not due to an error of this type is, moreover, suggested by examination of the mortality among men aged 45 to 64 years. Men in this age group will have had the maximum exposure to occupational radiation, and the corresponding correcting factors for social class and occupation are believed to be reliable. The results for this age group, after exclusion of the deaths which occurred during the first five years of membership, are shown in Table V. It is clear that in this group also there is no evidence of any excess mortality from causes other than cancer among either the pre-1921 or the post-1920 radiologists.

TABLE V.—*Number of Deaths from Cancer and Other Causes, Men Aged 45-64 Years: Observed and Expected, First Five Years at Risk Excluded*

Group of Radiologists	Cause of Death	No. of Deaths Observed	No. of Deaths Expected from Mortality of		
			General Population	Men in Social Class I	Doctors
Pre-1921	Cancer	22	18	16	14
	Other cause	69	82	76	88
	All causes	91	100	92	102
Post-1920	Cancer	13	19	17	12
	Other cause	63	67	65	70
	All causes	76	86	82	82
All members	Cancer	35	37	33	26
	Other cause	132	149	141	158
	All causes	167	186	174	184

Another explanation for the difference could be that the standard chosen for comparison was unsuitable. It is conceivable that, apart from the radiation to which they are exposed, radiologists may constitute a particularly sheltered group with a favourable expectation of life. It is, however, difficult to believe that any such added advantage over other doctors and other men of the same social class could be so great as to outweigh a substantial occupational hazard due to radiation.

Discussion

Experimentally it has been shown by several workers that a single sublethal dose of whole-body radiation shortens the average expectation of life of exposed animals. Experiments on rats and mice have shown that for such doses the reduction in life-expectancy is of the order of 25 to 50% per 1,000 r. Furthermore, it has been considered that the amount of shortening is proportional to the dose received. Mole (1957) has reviewed the existing experimental data on the effect of chronic irradiation on animals—that is, daily exposure, five, six, or seven days a week at dose levels permitting survival for at least six months. With doses of γ -rays, or their equivalent in fast neutrons, of 10 r per week or more there is a demonstrable and significantly reduced expectation of life. For doses of less than 10 r per week the position is equivocal, and in none of the nine reported studies at such low dose rates do the life-expectancies of the experimental groups differ significantly from the controls.

There has, however, been a tendency to draw conclusions about the possible effects of really low radiation doses from the effects observed to follow either single sublethal doses or chronic exposure at comparatively high dose rates. To effect such extrapolations Blair (1956), in particular, has developed a general mathematical theory of the effect of radiation on life expectancy, and, using this theory, Hursh (1956) has calculated that a man exposed to 0.3 r per week—the maximal permissible dose—for 20 years would suffer, in an expected life-span of 65 years, a reduction of life expectancy of two years. Jones (1957) has stated that he considers that in man a whole-body dose of 1 r will reduce the expectation of life by about five days. Failla and McClement (1957) have re-examined the theoretical background of the deductions from animal studies about the possible effects of low-dose exposure in man, and they have suggested that, so long as the exposure rate does not exceed 0.5 r per day, the reduction in life-expectancy per r of whole-body dose is likely to be one day.

There can, however, be no substitute for observations made directly on man. Warren (1956) studied the average age at death of American radiologists and claimed that the finding of a reduction of about five years in comparison with physicians not practising radiology was evidence of an ageing effect of radiation. He thought also that, as the average age at death was reduced for each of the several

causes of death studied, the effect was non-specific. The use of the average age at death as a biological indicator can, however, be justified only if the contrasted populations (1) have a similar distribution of ages at entry, (2) have a similar rate of loss from all causes other than death, and (3) are studied over the same period. In the comparison which has been made between radiologists and non-radiological physicians these conditions have not been met. Since radiology requires postgraduate study the age at entry is raised and the proportion of radiologists in the youngest medical age group is small. Since radiology is a young and growing specialty, the proportion of radiologists in the oldest age group is also small. Hence the test used by Warren—a comparison of their average ages—suggested that the groups were comparable when in fact, as Seltser and Sartwell (1958) have shown, there is a difference in the age distribution of the groups which is sufficient to account for the whole of the reported difference in the average age at death. It must be concluded, therefore, that Warren's data are not evidence of a reduction in longevity consequent upon occupational exposure to radiation.

Dublin and Spiegelman (1948) reported that the mortality of American specialists in radiology was less than that for all physicians—that is, 90%—but slightly more than that for all specialists (which was 78% of the rate for all physicians). Only 95 deaths were, however, recorded among the radiologists, and the differences are not large enough to be significant.

The mortality data for British radiologists, published by the Registrar-General for England and Wales (1958), relate to even smaller numbers. It may be noted, however, that only eight deaths were recorded among radiologists aged 20-64 years between 1949 and 1953, when the number expected from the rate for all occupied and retired men was 12. The standardized mortality ratio of approximately 70% compares with ratios of 89% for all doctors and 98% for all men in social class I.

The most reasonable interpretation of the results of the present study is that the expectation of life of British radiologists is similar to that of other men of comparable status and has not been substantially altered by their occupational exposure to radiation. This negative finding is all the more striking when the analysis is confined to those radiologists entering the population before 1921. This group of men contains the pioneer radiologists, and an analysis of the deaths from skin cancer (see below) provides good evidence that these men suffered excessive exposure, at least to their limbs.

It may be argued on theoretical grounds that an analysis of the deaths from all causes does not necessarily provide a true indication of whether a group of men is ageing at an accelerated rate. Certainly the process of ageing and the fact of death may be dissociated, and it is possible to visualize circumstances—for example, the outbreak of a severe epidemic causing a high proportion of deaths—in which the total number of deaths would provide a very inadequate measure of the ageing process. Under modern conditions, however, and in the absence of a direct measure, it is reasonable to accept the mortality rate from all causes as a first approximation to the rate of ageing. It can be held, therefore, that the present study provides no evidence of an ageing effect in man under the circumstances of radiation exposure examined. If such an effect does exist, it is apparent that in the case of radiologists it must be very small.

The Mortality from Cancer

Results

The numbers of deaths attributed to cancers of all types and the corresponding expected numbers are shown in Table III. The total cancer mortality is close to that which would have occurred among men of similar social class (79 deaths against an estimate of between 78 and 84), but it is slightly more than would have been expected from

comparison with the cancer mortality of doctors—that is, between 61 and 71. When, however, the population is divided according to the date of joining one or other society, it is seen that there is no reason to suppose that there has been any excess among those joining after 1920; there may, however, have been an appreciable excess among those joining in the earlier years. Among this group 55 deaths were attributed to cancer, and the lowest estimate of the mortality expected among a comparable group of doctors is 35 ($P<0.01$). Exclusion of the first five years at risk makes no appreciable difference to the results (Table IV).

TABLE VI.—Numbers of Deaths from Cancer of Different Types: Observed and Expected, All Periods

Type of Primary Cancer	Pre-1921 Radiologists			Post-1920 Radiologists			All Members		
	Obs. No. of Dths.	No. Expected from		Obs. No. of Dths.	No. Expected from		Obs. No. of Dths.	No. Expected from	
		Gen. Popn.	Soc. Cl. I		Gen. Popn.	Soc. Cl. I		Gen. Popn.	Soc. Cl. I
Stomach	8	9.9	5.6	2	7.3	4.2	10	17.2	9.8
Intestines and rectum	9	10.9	11.2	5	6.7	6.9	14	17.6	18.1
Pancreas	6	1.4	1.6	1	1.3	1.6	7	2.7	3.2
Lung	5	3.2	3.0	7	9.0	7.6	12	12.2	10.6
Skin	6	1.0	0.6	1	0.4	0.2	7	1.4	0.8
Leukaemia	2	0.3	0.5	1	0.7	0.9	3	1.0	1.4
Other	19	21.0	18.4	7	12.9	13.5	26	33.9	31.9
All types	55	47.7	40.9	24	38.3	34.9	79	86.0	75.8

The numbers of deaths attributed to cancer of different primary sites are shown in Table VI, in comparison with the numbers expected from (1) the mortality of all men in England and Wales, and (2) the mortality of men in social class I. As has been stated previously, it was not possible to make separate estimates of the mortalities to be expected specifically among doctors, and the estimates of the deaths which would have occurred among men in social class I have been made with a less detailed method than that used to derive the figures in the previous Tables. The estimates for the total numbers of cancers of all sites shown in Table VI had also to be made by the same methods and the figures for total cancers are therefore slightly different from those in Table III. The numbers of cases of each type of cancer are so small that it would be possible to recognize only gross differences in mortality, and small inaccuracies in the estimates of the expected numbers are unimportant.

No appreciable difference is made to the results by omitting the experience of the first five years' membership. One cancer death (due to cancer of the stomach) occurred in this period among the pre-1921 members, and the expected number of deaths for each site is reduced by about 4%. Two deaths (due to cancer of the pancreas and to a cerebral tumour) occurred among the post-1920 group, and the expected numbers of deaths are each reduced by about 10%.

From the data in Table VI there is no reason to believe that there has been any excess of cancer of any particular type among the post-1920 population; it should, however, be noted that the one death attributed to skin cancer was due to a typical radiation cancer of the fingers. Among the pre-1921 members the number of deaths from cancer of the skin was significantly greater than the expected social class mortality ($P<0.001$), and there is also evidence of an excess of deaths from cancer of the pancreas ($P<0.01$). Only two deaths were attributed to leukaemia; the disease, however, was seldom recognized in the early part of this century, and less than one case would have been expected (expected number 0.5, $P=0.09$). For other types of cancer, considered either as a group or individually, the numbers are close to those which it is estimated would have occurred among comparable non-radiological populations.

Other data for cancer in radiologists are few. Cases of skin cancer among the early radiologists have been reported by many authors, and there can be no doubt that the incidence was increased in several countries. There are good

grounds for believing that there was also an excessive incidence of leukaemia among radiologists in the U.S.A. (Dublin and Spiegelman, 1948; March, 1950). The mortality from types of cancer other than leukaemia was also slightly raised in Dublin and Spiegelman's study (133% for radiologists and 98% for all specialists against a standard of 100% for all doctors). The number of deaths from cancer other than leukaemia was, however, very small (13), and data were not given separately for the different types of the disease. Of the eight deaths among British radiologists reported by the Registrar-General (1958), one was attributed to cancer of the lung and one to leukaemia.

That ionizing radiations are an aetiological factor in certain forms of human cancer is well established. There is no doubt that radiations can induce tumours of the skin, bone, bone marrow, thyroid, and pharynx. There is reason to believe that tumours of other sites can also be induced, although the human evidence for this is not so strong. Animal studies, however, provide evidence that radiations can induce tumours in many deeply seated organs. It is of some importance, therefore, to find no evidence of an excess of cancer at any site in the post-1920 population. This presumably reflects the adequacy of the protective measures that have been recommended, but it is too early to be certain that they are wholly adequate, since half the members of this group have been observed for less than 15 years, and induction periods of 15 to 20 years and longer have been recorded for many radiation-induced tumours.

The study of the pre-1921 population reveals that the excess of cancers can be ascribed to an increased mortality from tumours of three particular sites: the skin, the bone marrow, and the pancreas.

The excess mortality from skin cancer is in keeping with the numerous reports of the development of tumours in skin showing evidence of radiation damage. In addition to the six cases in which death was ascribed to skin cancer, there are two in which this tumour is recorded as an associated cause. Records were also obtained, during the course of the survey, of a further 15 cases of severe damage to the skin of the hands, face, and legs. Many of these will have had associated tumours, and it is reasonable to assume that even this number is not comprehensive.

The increase in the mortality from leukaemia is appreciably less than might have been expected on the basis of the data for American radiologists. This is perhaps not so surprising as might appear at first sight. There seems little doubt that in Britain protective measures were introduced at a very early stage in the development of radiology: firstly, the use of heavy protective clothing, and, secondly, the combination of lighter apparel with shielding incorporated into the x-ray apparatus. These measures, coupled with the fact that x-ray beams of low penetrability were used and that only a small number of persons were at risk in the very early days, may explain the failure to find any large excess of deaths attributed to leukaemia. It has, however, already been pointed out that leukaemia was comparatively seldom diagnosed during the early part of the century, and it is worth noting that in two cases death was ascribed to aplastic anaemia. Both individuals concerned entered the population before 1921, and the deaths occurred in 1921 and in 1941. In the first case the illness is described as being of only a few weeks' duration; in neither case has it proved possible to check the validity of the death-certificate diagnosis. From previous experience (Court Brown and Doll, 1957) it appears that many cases in people suffering considerable radiation exposure may be examples of acute aleukaemic leukaemia, and it is possible that one or both cases may fall into this category.

There remains the unexpected finding of a significantly increased mortality from cancer of the pancreas. The fact that this occurs in the heavily exposed section of the population suggests that it may be related to radiation exposure. The pancreas is, however, a deeply seated organ and would of necessity have received proportionately smaller doses than the bone marrow. It would therefore have to be

postulated that the pancreas possessed a most unusual degree of sensitivity to radiation carcinogenesis. In the absence of supporting data it would be unwise to conclude that this increased mortality is a specific radiation effect. If confirmatory data are not forthcoming it may be presumed that the present findings are due to the operation of chance.

Applicability of the Findings

It is clear that under modern working conditions—that is, the provision of and adherence to adequate protective measures—the personnel of medical radiological departments have not run any substantial risk of (1) a reduction in the expectation of life from a non-specific ageing effect, or (2) an increased mortality from the common forms of cancer. These conclusions, however, are based on the study of fewer than 1,400 men, and in a group this size a very small risk would not have been easy to detect. Much larger numbers of persons are employed in industrial plants associated with the use of radiation sources of various kinds, and there can be no doubt that these numbers will increase considerably in the ensuing decades. These men are, on the whole, exposed to more energetic sources of radiation, and in some cases to types of radiations—for example, fast neutrons—for which the relative biological efficiency for the induction of delayed radiation effects may have a value greater than that of γ rays or medium voltage x rays. It is therefore necessary to be cautious in generalizing from the present experience.

The findings do, however, suggest that, so long as care is taken to introduce and observe the recommended measures of protection, the long-term somatic risks of radiation will be very small.

Summary and Conclusions

A study has been made of the causes of death of 1,377 male British radiologists during a 60-year period from 1897 to 1957.

A comparison of the observed and expected numbers of deaths from all causes provides no evidence that occupational exposure to ionizing radiations has caused a detectable non-specific shortening of the expectation of life. This is particularly striking, since the population includes most of the pioneer British radiologists, many of whom are known to have suffered from specific effects of over-exposure—that is, radiation dermatitis and skin cancer.

A significant excess of cancer deaths was found among those men entering the practice of radiology before 1921, the year in which the first committee to advise on protection was formed. The excess was confined to tumours of the skin and pancreas and (possibly) leukaemia.

No excess mortality from cancer was found in those men entering radiology subsequent to 1920; but it is as yet too early to be sure that the cancer hazard has been eliminated.

The suggestion that this survey should be undertaken was made by the External Radiation Subcommittee of the Medical Research Council's Committee on Protection against Ionizing Radiations, and we should like to record our indebtedness to the chairman, Dr. J. F. Loutit, and the other members of the subcommittee. We would like to thank the Council of the British Institute of Radiology and the Faculty of Radiologists for permission to make use of their records, and the members of their staffs for their ready assistance. We would like also to thank the General Medical Council, the British Medical Association, and the many persons who helped us to obtain information about the individual radiologists, and particularly Mrs. Tana Lloyd, Miss Flora Callaby, and Mrs. Marie Kidd, of the staff of the Medical Research Council, who collected the greatest part of the data.

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PRELIMINARY REPORT ON MASS VACCINATION OF MAN WITH LIVE ATTENUATED POLIOMYELITIS VIRUS IN THE BELGIAN CONGO AND RUANDA-URUNDI*

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Vaccination of man by oral administration of live attenuated poliomyelitis virus has been employed in clinical trials in the United States of America (Koprowski, 1955; Koprowski *et al.*, 1952, 1956a, 1956b). Several attenuated strains representing the three types of poliovirus were investigated, and the number of persons vaccinated in each trial was kept purposely small until a strain could be found which would satisfy laboratory and clinical criteria of safety. Such strains finally became available (Koprowski, 1957), and therefore it was decided to organize a clinical trial on a larger scale than had been previously attempted.

While participating in a rabies course organized by the World Health Organization in 1955 in Muguga, Kenya, one of the authors (H. K.) had the opportunity, through

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