PAPERS AND SHORT REPORTS

Collection and validation of data in the United Kingdom Atomic Energy Authority mortality study

PATRICIA FRASER, MARGARET BOOTH, VALERIE BERAL, HAZEL INSKIP, SARAH FIRSHT, SANDRA SPEAK

Abstract

The United Kingdom Atomic Energy Authority mortality study investigated the relation between mortality and recorded exposure to ionising radiation among employees working at the authority's seven establishments between 1946 and 1979. This report examines the design of the study and methods of data collection and validation.

The completeness of the study population was deemed to be unsatisfactory at two establishments, where records of employment before 1965 had been destroyed. Assessment of the magnitude of the deficit led to the conclusion that the data from these establishments were too incomplete for inclusion in the mortality analysis. At the other establishments validation showed that the data collected were accurate and unbiased. Certain characteristics of the 39 546 employees included in the mortality analysis were identified which were relevant in interpreting the findings.

Introduction

Controversy over the long term effects of repeated exposure to low levels of ionising radiation has prompted several organisations in Britain to examine the effects of radiation exposure on their workforce.[1-3] In 1978 the United Kingdom Atomic Energy Authority approached the Medical Research Council asking for an independent epidemiological group to be appointed to investigate the mortality of its employees. A contract was arranged between the authority and the MRC, and the Epidemiological Monitoring Unit at the London School of Hygiene and Tropical Medicine was appointed to conduct the study. The progress of the investigation was reviewed each year by a subcommittee of the MRC's Protection Against Ionising Radiation Committee (latterly the Committee on the Effects of Ionising Radiation).

The objectives of the study were to determine whether there was any relation between mortality and recorded exposure to ionising radiation and to use this information to assess whether relevant current risk estimates of the International Commission on Radiological Protection[4] were of the correct order of magnitude. To meet these objectives a historical prospective study was designed in which personnel and radiation data compiled by the United Kingdom Atomic Energy Authority were linked by the Epidemiological Monitoring Unit to mortality data obtained independently from sources outside the authority. The main findings are presented in our accompanying report (p 440).

The credibility of the results of any occupational cohort mortality study depends to a large extent on confidence that the data collected are accurate and the study population complete.[5] This paper describes the methods of data collection in the United Kingdom Atomic Energy Authority mortality study and the procedures used to verify the accuracy and completeness of the information obtained. It also examines some characteristics of the study population included in the mortality analysis that are relevant in interpreting the findings.

Epidemiological Monitoring Unit, Department of Epidemiology, London School of Hygiene and Tropical Medicine, London WC1E 7HT

PATRICIA FRASER, MD, senior lecturer
MARGARET BOOTH, MSC, research fellow
VALERIE BERAL, MRCP, senior lecturer
HAZEL INSKIP, MSC, research fellow
SARAH FIRSHT, BSC, computer programmer
SANDRA SPEAK, BSC, research assistant

Correspondence to: Dr Patricia Fraser.

Study population

Work began at the United Kingdom Atomic Energy Authority establishments at Harwell, London, Risley, and Culcheth in 1946. Work at Dounreay began in 1954, at Winfrith in 1957, and at Culham in 1960. The study population included all employees of these establishments in service at any time from 1 January 1946 to 31 December 1979, with the following exceptions. Employees of the authority who had been statutorily transferred with their records to the Radiochemical Centre and British Nuclear Fuels at their formation in 1971,

or to the Ministry of Defence when the Atomic Weapons Research Establishment came under its control in 1973, were excluded. Attached workers, contractors' staff, and vacation students were also excluded because of uncertainties in obtaining complete records. United Kingdom Atomic Energy Authority staff at British Nuclear Fuels establishments were included in the BNFL radiation mortality study,[1 2] whereas employees of British Nuclear Fuels at Risley formed part of the Risley component of the United Kingdom Atomic Energy Authority study. All employees thus defined were included irrespective of the duration of employment.

Data collection

PERSONNEL DATA

Personnel departments' records at the current or last establishment were used as the primary source to define the study population, using, wherever possible, the personnel files to obtain the items of information essential for the study—that is, name, address, sex, date of birth, establishment, works number, dates of entering and terminating employment, and employment grade on leaving. Complete work histories were not available for all employees, and only the last of any transfers between establishments was recorded. The relevant items were transcribed to purpose designed, uniquely numbered study cards by United Kingdom Atomic Energy Authority clerks using detailed notes for guidance. Where essential information was missing from the personnel files attempts were made to obtain it from other sources, such as radiation, medical, or security records. Provision was made to include National Health Service and national insurance numbers, place of birth, and general practitioner's name where these items were required for tracing.

At Harwell, Risley, and Culcheth the personnel files of employees who left or died before 1965 had been destroyed. At Harwell, but not at Risley or Culcheth, alternative data sources for these employees were held by the personnel department. When the mortality study began in 1980 data collection at Dounreay was already in hand in preparation for a possible commercial demonstration fast reactor public inquiry. The personnel data collected on Dounreay's study card were used as the basis for the main study, although, as described below, some modifications of procedure were necessary to achieve comparability.

Copies of all completed cards were sent to the authority chief medical officer's unit at Harwell for coding of employment grade and allocation to social class based on the Registrar General's classification of occupations, 1970.[6] Copies with names and addresses suppressed were then sent to the Epidemiological Monitoring Unit. A personal database was created both at Harwell and at the London School of Hygiene and Tropical Medicine.

RADIATION DATA

Since 1946 the United Kingdom Atomic Energy Authority has maintained records of external radiation exposure of all employees designated as radiation workers and of many other employees potentially exposed to radiation. These records were the main source of radiation data for the study. Employees without radiation records were deemed by default not to have been exposed. Personal dosimeters, such as films or thermoluminescence dosimeters, are used for measurement of external radiation exposure. In addition, employees at risk of internal contamination from handling radioactive substances are subjected to periodic urine analysis for appropriate radionuclides.

At each establishment study cards recording identifying details and information about annual radiation exposure were completed for every person with a radiation record. The data relating to external radiation consisted of the annual whole body exposure, expressed in millisieverts (mSv), along with the contributions from neutron irradiation and any "notional dose" allocated when a dosimeter or its measurement had been lost. The corresponding dose to the skin was also recorded. Other relevant details included the calendar year of exposure, the establishment recording the information, the number of dosimeters issued in the year, and the number recording a "threshold dose"—that is, an exposure below the level of detection of the measuring technique employed. For internal radiation exposure each calendar year was noted in which an employee was specially monitored for possible contamination with plutonium, tritium, or other unspecified radionuclides.

The radiation data were computer matched to the personnel data using, where possible, works number and establishment, name, age, and a check on the consistency between dates of employment and radiation monitoring. When a unique match could not be made recourse to personnel files was often necessary to establish the correct link. Where a radiation worker was found not to be on the personnel computer file all available sources of personnel data were searched for information which would enable the subject to be included in the study.

MORTALITY DATA

The vital state of current employees at 31 December 1979 was known ipso facto. For ex-employees the usual procedures for tracing subjects in medical research projects through the National Health Service central registers at Southport and Edinburgh were used[7]; death, emigration, and cancer registration are events noted routinely in these registers. The personnel cards for all ex-employees were submitted in batches by each establishment to the central registers for tracing and the results returned to the Epidemiological Monitoring Unit. A tally was kept by the monitoring unit of dispatches and returns. For subjects recorded as having died both the underlying and associated causes of death as stated on the death certificate were coded to the eighth revision of the International Classification of Diseases (ICD)[8] by the Office of Population Censuses and Surveys or the General Register Office for Scotland. Identifying information for Dounreay ex-employees had been sent to the central register in Edinburgh in preparation for the possible inquiry. Deaths and emigrations already notified to Dounreay were reidentified by the central register and sent to the monitoring unit. Deaths and emigrations among ex-employees at Dounreay occurring subsequently were notified in duplicate to both Dounreay and the monitoring unit.

Cards for ex-employees who could not be traced by the NHS central registers were returned to the Epidemiological Monitoring Unit. Where additional identifying information could be found by the United Kingdom Atomic Energy Authority, these cards were resubmitted to the central registers. Where the original details could not be supplemented, or tracing of an ex-employee failed on resubmission, identifying particulars were sent to the Department of Health and Social Security records branch at Newcastle. Where the DHSS notified a death or provided additional information the cards were amended and resubmitted to the central registers. A special search was made in the national death indexes by the central register staff at Southport for untraced persons who might have died between 1959 and 1963, during which records were removed from the alphabetical index after a death had been recorded in the register.

The follow up data collected by the Epidemiological Monitoring Unit were checked and linked by computer to the personnel and radiation data received from the United Kingdom Atomic Energy Authority. Information on mortality was passed to the authority only after all the radiation data had been received. This was to avoid any criticism that, knowing the outcome, the radiation data might have been corrupted. Deaths occurring in service and among pensioned ex-employees of the authority, and all deaths in Dounreay ex-employees, were of course already known to the authority.

SUMMARY OF DATA COLLECTED

The final gross study population numbered 49 456. Of these, 34 958 (71%) were ex-employees and 14 498 (29%) serving staff at 31 December 1979. There were 23 309 (47%) employees with a radiation record, of whom 92% were men. Table Im (miniprint) shows the distribution of the study population by current or last establishment, sex, and radiation state, and table IIm shows the percentage distribution of workers with a radiation record by cumulative whole body exposure at exit from the study. Overall, 64% of subjects received a cumulative whole body exposure of less than 10 mSv (1 rem). Exposure at individual establishments differed, however, with almost one in four of the workers at Dounreay and Winfrith having received a cumulative whole body exposure of more than 50 mSv (5 rem). The collective exposure recorded in the study population was 684 167 mSv. Table IIm also shows the percentages of radiation workers specially monitored at each establishment for possible internal contamination with radionuclides. Overall 7038 (30%) were specially monitored, of whom 97% were men.

No match could be found for about 100 radiation records from Risley, as their corresponding personnel records were among those which had been destroyed. Personnel cards for these employees were created on the basis of information derived solely from the radiation

record. A further 289 records from Harwell, with a collective exposure of only 345 mSv, remained unmatched after all possible sources of personnel data had been searched. Cumulative exposure for seven of these exceeded 10 mSv. The United Kingdom Atomic Energy Authority maintains radiation records for several other organisations, and these unmatched radiation records at Harwell may well have related to people who had never been authority employees. There were no unmatched records from Dounreay, Culham, or London and only four from Winfrith with no exposure recorded.

The first attempt at tracing through the NHS central registers identified 97% of the 34 958 ex-employees in the study. Further searches through the central registers and DHSS increased the tracing rate to 99·3%, only 252 ex-employees not being located in either record system. The tracing was most complete for men with a radiation record and least complete for women non-radiation workers. A total of 1553 ex-employees, 3% of the study population, were reported to have emigrated. When those currently employed on 31 December 1979 were included, the state of 49 204 (99·5%) members of the study population was known. Table IIIm summarises the results of tracing.

A total of 3825 deaths, 8% of the study population, had occurred by 31 December 1979. Table IVm shows their distribution by current or last establishment, sex, and radiation state. The NHS central registers could not locate death details for 11 subjects but a death certificate or the administratively equivalent death quote or death entry was received by the Epidemiological Monitoring Unit for 3814. For 13 of these the cause of death was not given. The ICD coding of the underlying and associated causes of death was checked manually by the monitoring unit, 29 death certificates or quotes being returned to the central registers for confirmation. Seven ICD codes were corrected by the Office of Population Censuses and Surveys or General Register Office for Scotland where the coding on the death quote differed from that on the original document. The remaining 22 were returned unchanged.

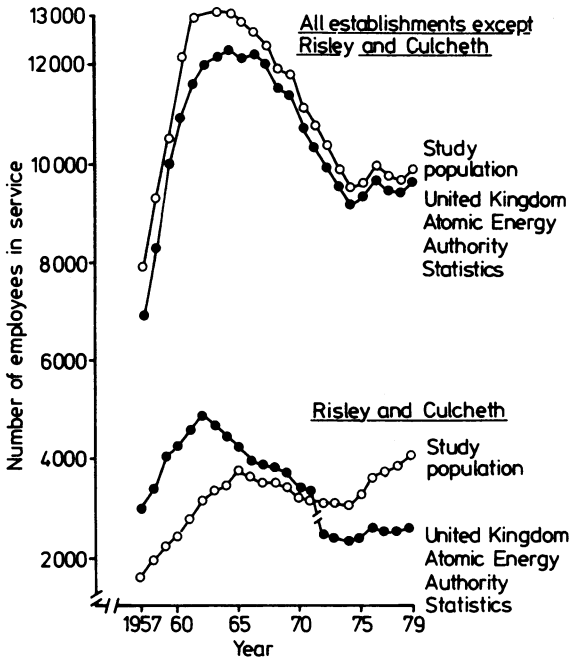
The cause of death was therefore ascertained in 3801 cases (99·4%) and known from the death certificate to have been confirmed by necropsy in 512 subjects with radiation records (26·4%) and 518 without (27·5%). The 24 deaths where the cause could not be ascertained were included in analyses of deaths from all causes but not in cause specific analyses.

Validation

COMPLETENESS OF STUDY POPULATION

In historical prospective studies, especially those based mainly on old records, confidence in the results depends in part on the degree of completeness of the study population. In such studies there is no absolute way of detecting whether or not people are missing, since the archives themselves may be incomplete. In this study, however, some estimate of possible bias from missing records could be made with data compiled independently of those used to define the study population.

The number of people employed by the United Kingdom Atomic Energy Authority each year from 1957 is available in annual reports and from other administrative sources. These numbers exclude student employees and count each part time worker as a half. For Risley and Culcheth the study population included only those who were in service or employed from 1965. Employees of British Nuclear Fuels were included in the study population from 1972, although they do not feature in United Kingdom Atomic Energy Authority statistics. Comparison of the yearly authority statistics for Risley and Culcheth with the numbers calculated from the study population disclosed these differences (figure). When British Nuclear Fuels was formed in 1971 a large number of employees at Risley transferred from the United Kingdom Atomic Energy Authority to employment there. This was



Number of employees of United Kingdom Atomic Energy Authority in service each year during 1957-79 at Risley and Culcheth and at all establishments except Risley and Culcheth: comparison of figures calculated from study population with those derived from authority's statistics.

MINIPRINT TABLES I to X

TABLE I—*United Kingdom Atomic Energy Authority study population distributed by current or last establishment, sex, and radiation state*

Last establishment	Men		Women		
	Without a radiation record	With a radiation record	Without a radiation record	With a radiation record	Total
Harwell	5 663	9 998	5 336	1 134	22 141*
Culham	1 439	673	498	23	2 633
London	766	64	627	5	1 642
Dounreay	894	4 979	1 260	287	7 420
Winfrith	1 629	3 088	1 379	182	6 278
Risley, Culcheth	6 104	2 758	2 543	157	9 542
All	14 495	21 520	11 643	1 788	49 456*

*Includes one with and nine without a radiation record where sex not known

TABLE II—*Percentage distribution within establishments of workers with a radiation record by final cumulative whole body exposure, and percentages of workers specially monitored for internal contamination*

Last establishment	Final cumulative whole body exposure (mSv*)					Average exposure per person (mSv)	Specially monitored
	< 10	10 -	20 -	50 -	>100		
Harwell	68	11	11	5	5	23·1	28
Culham	89	5	4	1	1	6·4	12
London	84	6	8	2	0	7·4	6
Dounreay	47	13	16	10	13	47·0	42
Winfrith	53	9	14	10	14	45·8	48
Risley, Culcheth	84	9	6	2	2	8·4	2
All	64	10	12	6	8	29·4	30

*10 mSv = 1 rem

TABLE III—*Summary of tracing of United Kingdom Atomic Energy Authority study population on 31 December 1979 by vital state, sex, and radiation state*

Vital state	Men		Women		
	Without a radiation record	With a radiation record	Without a radiation record	With a radiation record	Total
Alive: Current employees	3 955	7 500	2 681	362	14 498
Alive: Ex-employees	8 587	11 364	8 096	1 281	29 328
Deceased	1 448	1 871	434	72	3 825
Emigrated	437	770	280	66	1 553
Untraced	68	15	152	7	252*
All	14 495	21 520	11 643	1 788	49 456*

*Includes 10 where sex not known

TABLE IV—*Deaths in United Kingdom Atomic Energy Authority study population by current or last establishment, sex, and radiation state, 1946-79*

Last establishment	Men		Women		
	Without a radiation record	With a radiation record	Without a radiation record	With a radiation record	Total
Harwell	768	1 159	258	57	2 242
Culham	59	23	6	1	89
London	175	4	38	0	217
Dounreay	88	353	30	7	478
Winfrith	114	184	45	4	347
Risley, Culcheth	244	148	57	3	452
All	1 448	1 871	434	72	3 825

TABLE V—*Check on completeness of United Kingdom Atomic Energy Authority study population using Oxford Cancer Registry data*

Employer or occupation stated in registry records	Traced				Not traced
	Included in study	Excluded from study			
		Atomic Weapons Research Establishment	Radiochemical Centre	Contractor	
Atomic Energy Research Establishment	46			1	
United Kingdom Atomic Energy Authority	7	3	1		
Atomic Energy Authority	8	4			
Atomic Energy Establishment	3		2		
Atomic Research Establishment	5				
Atomic research	6				2
Total	75	7	3	1	2

TABLE VI—*Distribution of 83 additional deaths in United Kingdom Atomic Energy Authority study population by sex and radiation state*

Notification of death	Men		Women		
	Without a radiation record	With a radiation record	Without a radiation record	With a radiation record	Total
Deaths notified routinely	1 448	1 871	434	72	3 825
Deaths missed: Cancer	4	14	2	0	20
Deaths missed: Non-cancer	12	32	9	1	54
Deaths missed: Cause unknown	3	5	1	0	9
Total	1 467	1 922	446	73	3 908

TABLE VII—*Distribution of person years at risk from 1946 to 1979 in population analysed by age and cumulative whole body exposure*

Age group (years)	Without a radiation record	With a radiation record: cumulative whole body exposure (mSv*)					
		< 10	10 -	20 -	50 -	>100	Total
15-24	50 144	29 676	2 907	2 081	691	231	85 730
25-34	83 160	63 178	9 419	9 155	4 178	2 830	171 920
35-44	70 225	54 225	9 510	11 210	5 808	3 573	156 551
45-54	54 637	38 584	7 198	8 256	4 987	5 898	119 560
55-64	34 515	22 359	4 110	4 130	2 660	3 321	70 895
65-74	14 565	8 097	1 580	1 468	820	882	28 412
75-84	2 936	1 842	297	164	72	63	5 372
≥85	219	141	15	16	3	0	394
Total	310 399	219 102	35 036	36 480	19 019	18 798	638 834

*10 mSv = 1 rem

TABLE VIII—*Percentage distribution of population analysed by social class, sex, and radiation state by comparison with social class distribution of population of England and Wales in 1971*

Social class	Men			Women		
	Without a radiation record	With a radiation record	England and Wales, 1971	Without a radiation record	With a radiation record	England and Wales, 1971
I	12	17	5	1	6	5
II	35	25	18	13	38	20
III Non-manual	14	7	12	51	22	18
III Manual	19	24	39	2	<1	34
IV	17	27	17	20	28	17
V	4	<1	8	12	6	6
Total No	10 266	18 759		8 898	1 623	

TABLE IX—*Percentage distribution of population analysed by duration of employment, sex, and radiation state*

Duration of employment (years)	Men		Women	
	Without a radiation record	With a radiation record	Without a radiation record	With a radiation record
< 2	50	22	68	27
2 -	18	20	24	29
5 -	13	19	16	22
10 -	7	12	6	10
15 -	5	9	3	6
≥20	6	18	3	6
Total No	10 266	18 759	8 898	1 623

TABLE X—*Percentage distribution of population analysed by employment and radiation state*

Employment state	All employees	
	Without a radiation record	With a radiation record
Continuous employment (one establishment)	89	84
Re-employed (same establishment)	4	5
Re-employed (different establishment)	<1	<1
Ever transferred*	6	11
Total No	19 164	20 382

*Includes employees who transferred during one continuous employment and during one or more re-employments.

reflected in the authority's statistics by a sharp drop in the strength of the workforce between 1971 and 1972.

The figure compares the yearly United Kingdom Atomic Energy Authority figures, excluding Risley and Culcheth, with the study population, excluding Risley and Culcheth and student employees. As part time workers could not be identified from the personnel database no adjustment could be made for them. Although the overall pattern was similar, there was an excess of employees in the study population in each year. To some extent this may be explained by the way the part time workers were counted. We are uncertain why there was a relatively larger excess in the years before 1965. Plainly, however, only at Risley and Culcheth was there any evidence to suggest that large numbers of the study population were missing.

Although official United Kingdom Atomic Energy Authority statistics are unavailable before 1957, nominal rolls for non-industrial employees exist from 1946. At Harwell the names on these lists for 1948 and 1957 were compared with the names in the study population; only two out of the 3750 listed were not included. Checks were also made to ensure that radiation data had been recorded for 62 people who were the subject of legal and other inquiries, employees whose radiation records might have been removed from the archives for examination elsewhere; all were included, but special monitoring data for one subject were located by the authority too late for inclusion in the analysis. Radiation records were found among the medical records of two employees who had died from leukaemia. Staff of the authority searched the medical records of all employees known to have died from cancer and a sample of those who had died from other causes; no further records were found.

In the region covered by the Oxford Cancer Registry lie the United Kingdom Atomic Energy Authority establishments at Harwell and Culham, the Atomic Weapons Research Establishment at Aldermaston, the Radiochemical Centre at Amersham, and several other organisations engaged in radiation research. Staff in the cancer registry were asked to identify all people dying since 1957 where the death certificate or registry record explicitly named the United Kingdom Atomic Energy Authority as employer. They were also asked to include records mentioning Atomic Research Establishment (equally applicable to the authority or the Atomic Weapons Research Establishment) and any record mentioning simply "atomic research." Of the 88 people thus identified in the registry, 86 were satisfactorily accounted for, including all cases where the authority was explicitly mentioned (table Vm). Seventy five were included in the study, and the authority was also able to identify one contractor (non-employee) and 10 transferees to the Atomic Weapons Research Establishment or the Radiochemical Centre, groups specifically excluded from the study population. The two remaining people could not be traced, but in neither case was the authority named specifically in the cancer registry records and both might well have worked in atomic research elsewhere in the area. Thus this external check on the completeness of the subset of the study population whose cancer and subsequent death were recorded in the Oxford Cancer Registry was reassuring.

COMPLETENESS OF ASCERTAINMENT OF DEATH

While the ascertainment of death from sources outside the authority was an important principle of the study, the authority's own records of deaths in serving staff and pensioners provided a valuable cross check on the completeness of notification of death by the NHS central registers. Of the 1483 deaths in pensioners and serving staff between 1961 and 1979 known to the authority, 48 (3%) had not been notified to the Epidemiological Monitoring Unit and were flagged as alive at the central registers. Four were deaths in people known to have emigrated and eight others were known to have died abroad. The cross check with the Oxford Cancer Registry identified two more deaths in people who were flagged as alive. The NHS central registers are not informed routinely of deaths occurring abroad but the United Kingdom Atomic Energy Authority had been sent death certificates for nine of the deaths overseas.

There were 150 people in the study population who were aged 80 or over on 31 December 1979 and apparently still alive in 1983. Their low mortality in the preceding five years and the presence of some very old people raised the suspicion that some of these elderly people were, in fact, dead. A search through the DHSS records disclosed that 27 (18%) had died before the end of 1979, including two deaths overseas.

Death certificates were subsequently obtained from the central registers for 53 of the 77 missed deaths. The deaths were missed for the following reasons: emigrated (4); died while abroad (10); central register not notified of death (5); death recorded against duplicate NHS number (3); death not recorded in register, details from death index (36); no trace of details of death (10); clerical error (9). Table VIm shows the distribution of these 77 additional deaths (and six others notified too late for inclusion in the mortality analysis) by sex and radiation state. They represent 2·1% of the deaths in the study population. While the additional deaths in men were slightly biased towards those with radiation records, the proportions of cancer and non-cancer deaths were similar in both categories. All but one of the additional deaths in women occurred in those without radiation records, and non-cancer deaths predominated.

ACCURACY OF DATA COLLECTION

Computer checks—The personnel database at the London School of Hygiene and Tropical Medicine was validated using criteria developed as a result of stringent checking of the first batch of 1000 cards from each establishment. All errors, omissions, and inconsistencies in these 1000 records were checked on site against the primary data source by staff of the Epidemiological Monitoring Unit and United Kingdom Atomic Energy Authority. Very few genuine errors were found and almost all were easily rectified. For all subsequent batches of cards records rejected by the data checking program were listed and sent to the United Kingdom Atomic Energy Authority for verification. A similar procedure for extensive checking of the radiation records was adopted. As a result of checking the follow up data, 77 personnel cards were returned to the NHS central registers for confirmation of dates or linkage. Seven proved to have been mismatched and 70 dates were amended. The personnel databases compiled independently at Harwell and the London School of Hygiene and Tropical Medicine were compared to find errors which the validation program could not identify. A total of 95% of the records matched completely. Most of the discrepancies were due to data processing errors and easily rectified. The remainder stemmed from differences in the interpretation of ancillary information written on the personnel cards, and these were resolved after discussion with staff of the United Kingdom Atomic Energy Authority. Completion of the personnel database at Harwell enabled the authority to produce an alphabetical listing of the study population so that duplicated entries could be detected and deleted.

Random sample validation—During on site visits staff of the Epidemiological Monitoring Unit replicated the abstraction of personnel and radiation data for a 1% random sample of employees at each establishment. Comparison with the personnel cards previously completed by the United Kingdom Atomic Energy Authority staff showed that in general the initial transcription of the data had been very accurate. At one establishment, however, an unacceptably high error rate made it necessary to repeat the collection of personnel data. The relatively few errors in the radiation data led, on average, to overestimation of an annual recorded whole body exposure of 4 mSv by 0·011 mSv, and under estimation of an annual recorded surface exposure of 6 mSv by 0·033 mSv. Thus these errors were of minimal importance.

Remeasurement of films—Methods for reading radiation film dosimeters changed over the period covered by the study. Various densitometers were used which could potentially give differing readings. As part of an exercise to estimate the magnitude of exposures below the level of detection by the densitometer used at the time of the original reading, a sample of film badges from the 1950s was remeasured. Using modern techniques it was reassuring to find that the above threshold measurements varied little from those obtained originally.[9 10] This was important in establishing that in earlier years the recorded exposures were not distorted by the less refined techniques employed at the time.

Characteristics of population analysed

After exclusion of 9542 employees from Risley and Culcheth, a further 244 from other establishments who could not be traced, and 124 subjects for whom essential information such as sex, date of birth, and dates of employment were missing, 39 546 people remained for inclusion in the mortality analysis (see our accompanying report). Table VIIm shows the distribution of their person years at risk by age and cumulative whole body exposure. Their collective radiation exposure was 659 543 mSv, a reduction of 3·6% on the exposure of the original gross study population. The average duration of follow up was 16 years in those both with and without a radiation record.

There were certain characteristics of the United Kingdom Atomic Energy Authority study population which are relevant to the interpretation of the results of the mortality analysis. Being a selected working population, authority employees were likely to have a more favourable level of mortality than the general population of England and Wales. The general population is frequently used as a standard in occupational mortality studies because of the availability of reliable age, sex, calendar period, and cause specific mortality rates. These national rates, however, include the chronic sick and unemployed, groups who tend to have a higher mortality than a working population. Their use in calculating expected deaths in any occupational group is likely to result in artificially low standardised mortality ratios—the "healthy worker" effect.[11]

Table VIIIm shows that by comparison with the social class distribution of the population of England and Wales at the 1971 Census[12] the authority's workforce included in the mortality analysis had a greater proportion in the higher social classes—groups who experience a more favourable level of mortality than the population in general. The distributions in table VIIIm are not entirely comparable because social class within the study was defined by employment grade at the last date of service, an event occurring at any time between 1946 and 1979. Comparison of mortality between employees with and without radiation records, without reference to an external population, overcame to some extent the problem of selection for work. Table VIIIm shows, however, that some social class differences were still apparent. Men without radiation records were concentrated in administrative posts (social class II), whereas male radiation workers were predominantly scientists, technicians, and skilled workers and spread over several social classes. Half the women without radiation records were in clerical jobs (social class III, non-manual), whereas the greatest proportion of female radiation workers was in social class II. Table IXm shows that duration of employment also differed between employees with and without radiation records, being much greater in radiation workers. Half of both men and women employees without radiation records worked for less than two years, and relatively few were employed for 10 years or more. By contrast, 39% of men and 22% of women with radiation records worked for at least 10 years.

Some employees spent time off site during, for example, secondment overseas, national service, or while on university courses. These periods were considered as breaks in service, and re-entry to one of the authority's establishments was treated as re-employment. Some people resigned and re-entered the authority's service at a later date—either at the same establishment or, occasionally, at a different establishment. While most employees had one continuous period of employment with the United Kingdom Atomic Energy Authority, others transferred once or even several times between sites. As records of all the moves were not available such mobility could not be taken into account in the analysis, and all employees were considered to have been situated at the establishment where they were last or currently employed.

Table Xm shows the percentage of employees included in the mortality analysis who were in continuous employment, ever re-employed, or ever transferred. Overall, 91% of all employees worked at only one establishment, while 9% either transferred among or were re-employed at different establishments. Closer examination by radiation state showed that a slightly higher percentage of the workers with radiation records moved between sites. Radiation workers have their radiation records transferred with them and do not, therefore, necessarily receive their total cumulative radiation exposure at the establishment where they were last employed. This should be considered when making comparisons between establishments, although the resulting bias is likely to be small.

Conclusion

As a result of the various internal and external checks on the completeness of the United Kingdom Atomic Energy Authority study population, coverage was deemed to be as complete as could reasonably be expected at all establishments except Risley and Culcheth, where it was known before the study began that personnel files relating to employment before 1965 had been destroyed. Assessment of the magnitude of the deficit led to the conclusion that the data from these establishments were too incomplete for inclusion in the mortality analysis without seriously biasing the results.

At all other establishments stringent validation checks showed that the personnel and radiation data had been compiled accurately by the authority. Tracing of ex-employees through the NHS central registers and DHSS was almost complete and particularly good among radiation workers, where the existence of a radiation record had sometimes provided an additional source of identifying details. There was, however, no evidence to suggest that the cause of death had been better ascertained in subjects exposed to radiation, necropsies having been carried out in a similar proportion of those with and without radiation records. Checks on the completeness of notification of death disclosed a relatively small number of deaths in people reported to be alive, but it was judged that their omission was unlikely to introduce bias. With the exclusion of Risley and Culcheth it was concluded, therefore, that the remainder of the data collected in the United Kingdom Atomic Energy Authority mortality study were sufficiently reliable to justify detailed analysis.

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OF A VITIOUS DISORDERLY BIRTH, OR DIFFICULTY PRETERNATURAL

If the head come not forth first, and the hands and feet are upwards, there is an ill birth. Hippocrates reckons two causes, the largeness of the womb, and disorderly motion of the mother from pain, also the thickness of the membrane, which when it cannot break with the head it attempts to do with the feet and hands.

The Midwife may perceive in what figure the child comes forth. All disorderly coming forth is dangerous to mother and child, but there is least danger when both feet come forth, this is called by the Latins *Partus Agrippinus*.

Let the Midwife reduce it into the cavity of the womb when it comes not forth right, and place it right. When the feet cannot be thrust upwards, let the Midwife supple the parts with oyl, and take hold of the arm, and help it, and give neesings. Let her alwaies labor to put the child in a right posture by moving it with her hand, or taking the mother from the bed, and compose her in such a posture as may bring the child into a right posture, and that soon.

Nicholas Culpeper (1616-54)
Directory for Midwives, 1671