Health related selection and death rates in the United Kingdom Atomic Energy Authority workforce

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Abstract
Follow up data on 37 355 employees of the United Kingdom Atomic Energy Authority (UKAEA) for the period 1946–79 were analysed to investigate the extent to which selection for work on the basis of health affected subsequent death rates. Causes of death were grouped into two broad categories for analysis: all cancers and all other causes of death. Evidence for an effect of selection of healthy individuals into the workforce was sought primarily by examining standardised mortality ratios (SMRs) by period since recruitment. SMRs for both categories were particularly low during the first two years after recruitment (SMR = 69, 95% confidence interval (CI) 48–97 for all cancers; SMR = 55, 95% CI 44–69 for all other causes of death). SMRs for all cancers did not increase significantly with period since recruitment (χ^2 for trend = 0·4, p = 0·53) but did increase for causes of death other than cancer (χ^2 for trend = 11.1, p = 0·001). Although adjustment for social class strengthened the association between death from causes other than cancer and period since recruitment (χ^2 for trend = 18.8, p < 0·001), simultaneous adjustment for all confounding factors considered (age at death, sex, calendar period of death, geographical location of the workforce, and social class) produced results broadly similar to those obtained from the unadjusted analyses for both cause of death categories. SMRs remained low even after 25 years of follow up (SMR = 84, 95% CI 69–101 for all cancers; SMR = 81, 95% CI 72–91 for all other causes of death).The persistently low SMRs observed in this workforce are unlikely to be due to the selection of healthy individuals at the time of recruitment but may be due to differences in sociodemographic and lifestyle characteristics. The effect on mortality of selection of individuals out of the workforce due to ill health was also examined. SMRs were particularly high for both categories in the first two years after termination of employment in individuals who left before normal retirement age (SMR = 167, 95% CI 131–211 for all cancers; SMR = 149, 95% CI 128–173 for all other causes of death). In comparison, death rates for the subsequent three years after termination of employment were lower (SMR = 89, 95% CI 67–115 for all cancers, SMR = 99, 95% CI 85–115 for all other causes of death). Apart from this initial fall, there was little evidence of a systematic increase or decrease in mortality with increasing period since termination of employment. Mortality was not significantly associated with duration of employment for either cause of death category either before or after adjustment for confounding factors. Whereas selection of individuals into or out of the workforce on the basis of health affects the way in which death rates change with time, other factors such as sociodemographic characteristics or health related behaviour determine the general level of mortality in the longer term. The persistently low SMRs observed in this workforce throughout the follow up period suggest that selection on the latter factors are likely to have had a considerable effect on death rates in the UKAEA workforce.

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When interpreting the results of an occupational mortality study the effect of selection of the workforce is often an important consideration. Individuals are selected for employment on the basis of many factors, not the least of which is their ability to perform certain types of work. One aspect of the process relates to the selection of individuals on the basis of their health. In this respect individuals are partly self selected insofar as they must be sufficiently healthy to seek work but may also be selected by the employer where, for example, pre-employment medical checks are performed. The selection process

may also take health into account indirectly by selecting individuals on the basis of other factors that are health related, such as marital status, history of psychiatric illness, or alcoholism. The general population includes employed people as well as people who are too sick to seek work or who have been refused employment on health grounds. Consequently, calculation of standardised mortality ratios (SMRs) where expected deaths are obtained using national rates often results in values below 100. The term "healthy worker effect" is widely used to describe this phenomenon,[1-6] although some refer to it as selection or comparison bias[7 8] or simply to confounding.[3 9] It is of concern because adverse effects of exposures at work may be wholly or partly masked by an apparent deficit in mortality in the workforce.

Several factors have been identified as contributing to low SMRs often observed in occupational cohort studies. SMRs are usually lowest of all in the period shortly following recruitment,[1-4] in young employees,[1 2] in those who remain in employment for a relatively long period,[1 10 11] and in employees of higher social class.[11 12] The extent of deficits in mortality compared with the national average also varies according to cause of death, with SMRs for diseases with a chronic course, such as chronic respiratory disease, tending to be lower than for diseases such as cancer which often take a more acute and relatively rapid course. Published data by specific causes of death, however, are few.[1-3 12] The characteristic most often attributed to the healthy worker effect is that the deficit in mortality becomes less apparent, or "wears off," as period since recruitment increases.[1-6 12] This observation might suggest that the healthy worker effect could be minimised in an analysis by ignoring an initial period following recruitment. This is not an ideal solution, however, since any immediate effects of employment on mortality might then be missed. Furthermore, because the time course of the wearing off is not well understood, it is often not clear how long a period should be ignored.

Factors contributing to deficits in mortality of workforces have been divided into two general categories[3 13]—those associated with the initial selection of healthy individuals and those associated with sociodemographic differences between the workforce and the general population. The effects of initial selection on the basis of health are thought to change with time.[14] In contrast, the effects of sociodemographic characteristics of a workforce are less likely to vary over time and are often important predictors of the underlying death rates of a workforce.[13] Moreover, whereas sociodemographic factors vary greatly between workforces, the effect that the initial selection of healthy individuals has on death rates may be similar for different workforces. Study-

ing the way in which death rates change with time since recruitment is therefore most appropriate for understanding the way in which the initial health related selection process operates.

When discussing the selection of individuals on the basis of health in the employment process, a distinction is sometimes made between a "population selection effect" and a "survivor effect."[1 10 16] The population selection effect refers to the initial selection of healthy individuals into a workforce. As described above, this is usually investigated by examining the way in which death rates change with period since recruitment. The survivor effect refers to the retention in the workforce of healthy individuals or, conversely, the selective removal from the workforce of the sick.[16] The survivor effect is often manifest by the relatively low mortality of employees who remain in employment compared with those that leave[1 10 11] and might therefore be assessed by an examination of SMRs according to duration of employment. An alternative approach is to examine the way in which death rates change after termination of employment. A difficulty in analyses of mortality according to factors such as period since recruitment is that they may be subject to confounding by other time dependent variables.[3 4 6 11 15] For example, both age and period since recuitment may be associated with the level of mortality of a workforce when compared with general population rates, but age and period since recruitment are correlated because there are more recent recruits among younger workers than among older employees.

We examine here the effect of health related selection on death rates in a cohort of employees in the nuclear industry while taking into account the problem of confounding described above. Because of the potential for radiation to induce cancer, two broad categories of cause of death are examined—all cancers and all other causes of death.

Material and methods

The cohort discussed here consists of all employees of the United Kingdom Atomic Energy Authority (UKAEA) who were first recruited between 1946, when the Authority started operations, and 1979. The characteristics of the workforce and its mortality in relation to radiation exposure have been described in detail elsewhere.[17-19] In general, workers who had been monitored for exposure to radiation experienced similar death rates to those of other workers.[18-20] Moreover, increasing exposure to radiation had little or no effect on overall death rates; the only statistically significant finding was an increase in mortality from prostatic cancer with increasing levels of radiation exposure.[18] The data presented here relate to 37 355 employees who had a single period of continuous employment with the UKAEA. These con-

stitute 94% of the original workforce analysed.

Person-years at risk were calculated using standard methods.[21] Observed deaths and person-years at risk were stratified by different levels of the following variables: age at death in five year age groups (15–19, 20–24, ..., ≥85), sex, calendar period of death (1946–9, 1950–4, ... 1975–9), UKAEA establishment (Dounreay, Harwell, and associated establishments at Culham and London, and Winfrith), social class in six categories using the Registrar General's classification,[22] age at recruitment in ten year age groups (<24, 25–34, ... ≥65), period of recruitment (1946–9, 1950–4, ... 1970–9), period since recruitment (<2 years, 2–4, 5–9, ... ≥25), duration of employment (<2 years, 2–4, 5–9, ... ≥25), and period since termination of employment (<2 years, 2–4, 5–9, ... ≥25). Age at death, calendar period of death, period since recruitment, duration of employment, and period since termination of employment were treated as time dependent variables in the person-years at risk calculations.[21] Expected deaths were calculated for all cancers (ICD 140–209) and all other causes of death (ICD 000–139, 210–999), using the 8th revision of the International

Classification of Diseases,[23] by applying five year age, calendar period, and sex specific death rates for England and Wales to the stratified person-years at risk. SMRs were obtained by taking the ratio of the observed to expected deaths and multiplying by 100. Ninety five per cent confidence intervals for SMRs were based on the Poisson distribution[24] unless deaths exceeded 200, where confidence limits were obtained using the Normal approximation. For each factor, approximate k degree of freedom chi-squared statistics were obtained to test for differences between stratum specific SMRs by comparing the fit of linear models with and without terms representing the factor. The models assumed that the observed deaths in each stratum followed the Poisson distribution with mean equal to the expected deaths and were fitted by maximum likelihood using the computer package GLIM[25] as described by McCullagh and Nelder[26] and Breslow *et al.*[27] Where appropriate, a one degree of freedom approximate χ^2 test for trend across the strata of a particular factor was obtained. These resulted from fitting further linear models after assigning appropriate scores to each stratum of the factor and treating them as continuous variables

Table 1   *Standardised mortality ratios (SMR) and observed deaths (O) from all cancers and all other causes of death in the UKAEA workforce, 1946–79, by age, sex, calendar period of death, UKAEA establishment, and social class*

	Cancer mortality		All other causes of death	
	SMR	(O)	SMR	(O)
Age at death (y)				
<35	75·9	(26)	65·4	(120)
35–	79·4	(61)	67·6	(157)
45–	66·8	(141)	67·3	(342)
55–	79·5	(288)	77·6	(654)
65–	95·2	(295)	81·9	(748)
75–	104·9	(106)	82·2	(403)
χ^2 for trend (df = 1)	13·2	(p < 0·001)	14·5	(p < 0·001)
χ^2 for departures from trend (df = 4)	5·5	(p = 0·24)	2·5	(p = 0·64)
Sex				
Men	82·5	(754)	77·5	(2164)
Women	89·7	(163)	68·8	(260)
χ^2 for heterogeneity (df = 1)	0·9	(p = 0·34)	3·4	(p = 0·07)
Calendar period of death				
<1954	61·5	(18)	49·1	(54)
1955–	98·0	(64)	63·8	(132)
1960–	76·7	(99)	73·6	(290)
1965–	83·1	(170)	80·8	(464)
1970–	77·5	(224)	77·1	(651)
1975–	90·4	(342)	80·1	(833)
χ^2 for trend (df = 1)	1·1	(p = 0·29)	11·8	(p = 0·001)
χ^2 for departures from trend (df = 4)	6·4	(p = 0·17)	8·8	(p = 0·07)
UKAEA establishment				
Dounreay	67·5	(95)	96·0	(380)
Harwell, Culham, and London	85·3	(709)	74·1	(1808)
Winfrith	91·8	(113)	70·6	(236)
χ^2 for heterogeneity (df = 2)	5·9	(p = 0·05)	21·7	(p < 0·001)
Social class				
I + II	62·6	(165)	55·6	(431)
III	86·6	(278)	76·5	(677)
IV + V	92·8	(474)	87·2	(1316)
χ^2 for heterogeniety (df = 2)	20·3	(p < 0·001)	70·4	(p < 0·001)

df = Degrees of freedom.

in the analysis. In these cases the global k degree of freedom χ^2 statistic was divided into a one degree of freedom statistic for trend and a k-1 degree of freedom statistic for departures from trend.

Multivariate analyses were performed to assess the association between mortality and a specific factor of interest after adjusting for the effect of one or more potential confounding factors. Observed and expected deaths were obtained for strata defined by the joint levels of the factor of interest and each of the confounding factors. Linear models were then fitted with terms representing all the factors. From these last models, stratum specific relative standardised mortality ratios (RSMR) (relative to the rate in the lowest stratum) were estimated for the factor of interest adjusted by the effects of the confounding factors included in the model. Approximate 95% confidence intervals for RSMRs were obtained using the standard errors of coefficients in the fitted model.

Results

Table 1 gives the SMRs for all cancers and all other causes of death by age at death, sex, calendar period of death, UKAEA establishment, and social class. For age at death and social class, there was a statistically significant trend in SMR for both categories of causes of death. SMRs were lower in the younger age groups and for those in social classes I and II. SMRs increased significantly with calendar period of death for causes of death other than cancer but not for deaths from cancer. There were no significant differences between SMRs for men and women in either cause of death category. There were statistically significant differences between SMRs across establishments for causes other than cancer, with Dounreay having the highest SMR. For all cancers, however, Dounreay had the lowest SMR, the differences between cancer SMRs being of marginal significance.

Table 2 gives SMRs by period since recruitment, duration of employment, age at recruitment, and period of recruitment. For mortality from all cancers and all other causes of death, the trends in SMRs were highly significant for age at recruitment. The

Table 2   SMRs and observed deaths (O) from all cancers and all other causes of death in the UKAEA workforce, 1946–79, by period since recruitment, duration of employment, age at recruitment, and period of recruitment

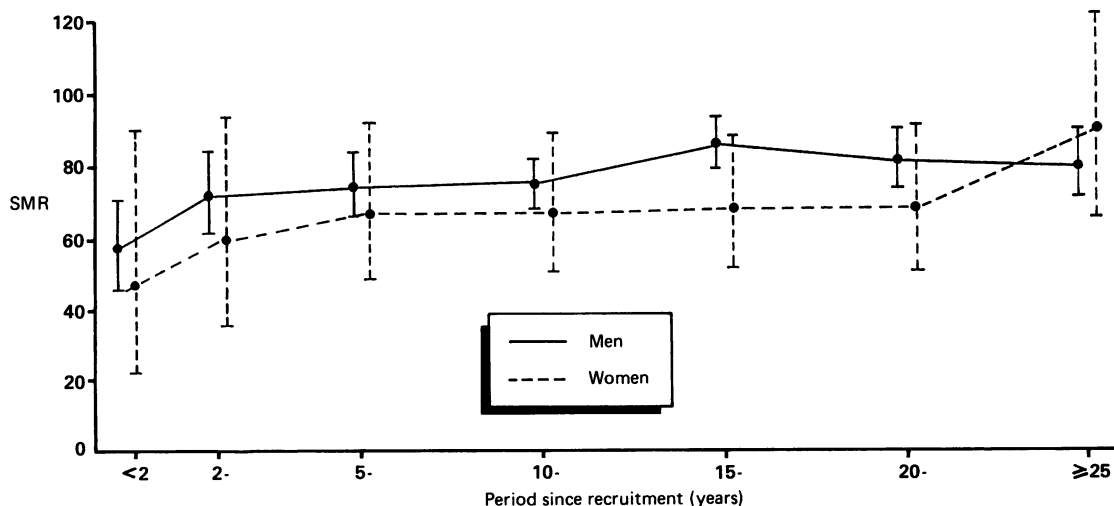|	Cancer mortality		All other causes of death	
	SMR	(O)	SMR	(O)
Period since recruitment (y)				
<2	69·1	(33)	55·5	(86)
2–	82·2	(70)	70·5	(180)
5–	79·7	(145)	73·1	(377)
10–	92·5	(213)	73·8	(477)
15–	78·4	(192)	83·5	(583)
20–	88·2	(157)	79·4	(419)
25–	84·0	(107)	81·3	(302)
χ^2 for trend (df = 1)	0·4	(p = 0·53)	11·1	(p = 0·001)
χ^2 for departures from trend (df = 5)	4·6	(p = 0·47)	7·5	(p = 0·19)
Duration of employment (y)				
<2	81·4	(214)	79·3	(597)
2–	80·7	(152)	74·5	(420)
5–	89·8	(215)	77·8	(569)
10–	85·1	(162)	74·8	(420)
15–	82·9	(100)	75·3	(244)
20–	88·5	(57)	75·2	(124)
25–	57·7	(17)	70·3	(50)
χ^2 for trend (df = 1)	0·0	(p = 0·84)	0·8	(p = 0·37)
χ^2 for departures from trend (df = 5)	4·3	(p = 0·51)	1·1	(p = 0·95)
Age at recruitment				
<25	60·6	(45)	65·9	(174)
25–	71·7	(114)	67·7	(295)
35–	78·2	(202)	77·9	(485)
45–	88·8	(313)	80·9	(757)
55–	93·7	(214)	78·3	(623)
65–	127·0	(29)	76·9	(90)
χ^2 for trend (df = 1)	15·9	(p < 0·001)	6·7	(p = 0·01)
χ^2 for departures from trend (df = 4)	1·2	(p = 0·88)	4·9	(p = 0·30)
Period of recruitment				
<1950	81·9	(202)	79·6	(601)
1950–	87·6	(206)	69·7	(505)
1955–	75·9	(274)	79·2	(808)
1960–	92·1	(153)	78·0	(342)
1965–	106·0	(71)	72·1	(128)
1970–	56·6	(11)	72·9	(40)
χ^2 for trend (df = 1)	0·5	(p = 0·48)	0·0	(p = 0·92)
χ^2 for departures from trend (df = 4)	9·7	(p = 0·05)	7·2	(p = 0·13)

Figure 1   Standardised mortality ratios (with 95% confidence intervals) for all causes of death except cancer by period since recruitment and sex.

significance of the trend for cancer mortality was only slightly reduced when recruits aged 65 and over were excluded (χ^2 for trend = 12·2, p < 0·001). SMRs for causes of death other than cancer also increased significantly with period since recruitment. By contrast, there was little evidence of a trend in cancer mortality with increasing period since recruitment, although the lowest SMR was observed in the first two years after recruitment. During this period, mortality in the workforce was 31% lower than national rates for all cancers (SMR = 69, 95% CI 48–97) and 44% lower for all other causes of death (SMR = 55, 95% CI 44–69). SMRs were lowest in individuals employed for longest although, overall,

there was no statistically significant association between duration of employment and mortality for either cause of death category. SMRs for cancer mortality, but not for deaths from other causes, varied according to period of recruitment strata, the differences being of marginal statistical significance.

Figures 1 and 2 show SMRs for all causes of death other than cancer by period since recruitment separately by sex and social class. The general pattern of increasing SMR with period since recruitment was observed in male and female employees (fig 1), although SMRs for women were below those of men in each stratum except the last. The increase in SMR with period since recruitment was also gen-
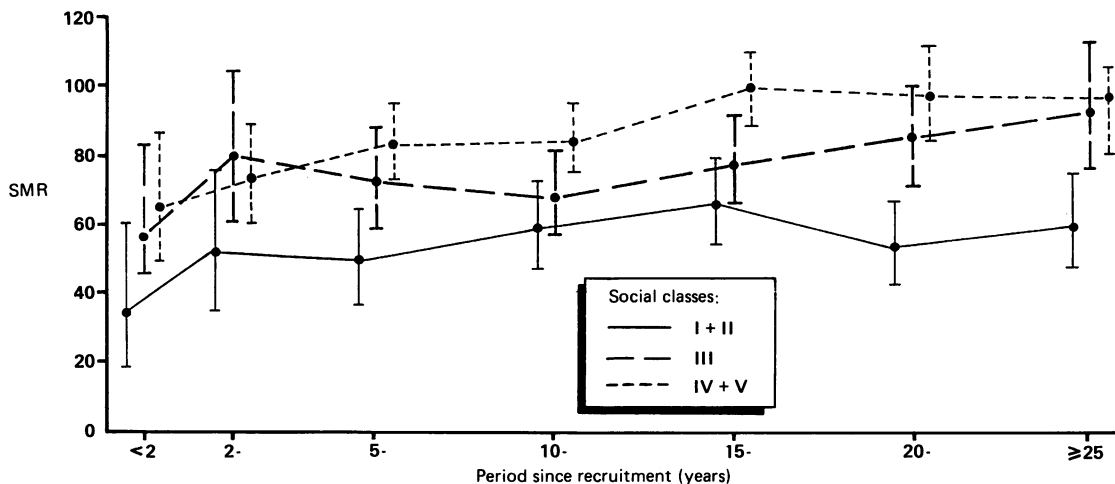

Figure 2   Standardised mortality ratios (with 95% confidence intervals) for all causes of death except cancer by period since recruitment and social class.

Table 3   SMRs and observed deaths (O) from all cancers in the UKAEA workforce, 1946–79, by period since recruitment amd duration of employment

Duration of employment (y)		Period since recruitment (y)							
		< 2	2–	5–	10–	15–	20–	⩾ 25	Total
< 2	SMR (O)	69 (33)	84 (16)	93 (37)	105 (50)	76 (35)	72 (25)	65 (18)	81 (214)
2–	SMR (O)	—	82 (54)	73 (20)	75 (23)	85 (25)	83 (16)	94 (14)	81 (152)
5–	SMR (O)	—	—	77 (88)	120 (56)	91 (38)	80 (19)	114 (14)	90 (215)
10–	SMR (O)	—	—	—	80 (84)	79 (36)	122 (28)	64 (8)	85 (162)
15–	SMR (O)	—	—	—	—	71 (58)	112 (34)	99 (14)	83 (100)
20–	SMR (O)	—	—	—	—	—	73 (35)	132 (22)	89 (57)
25–	SMR (O)	—	—	—	—	—	—	58 (17)	58 (17)
Total	SMR (O)	69 (33)	82 (70)	80 (145)	93 (213)	78 (192)	88 (157)	84 (107)	84 (917)

erally similar for social classes (fig 2). SMRs for social classes I and II were consistently lower than those of the remaining classes. In contrast with social class III, SMRs for other classes (social classes I and II combined and social classes IV and V combined) did not increase across the last two period since recruitment strata.

SMRs by period since recruitment and duration of employment are presented in table 3 for cancer mortality and in table 4 for all other causes of death. In both tables, although the variation is substantial, SMRs tend to increase with period since recruitment within each duration of employment stratum with the lowest SMRs tending to fall on the main diagonal. Data in these cells are contributed by individuals either while they were in employment or shortly after they had ended employment. When the data were analysed by period since termination of employment (table 5), SMRs were found to be particularly low in current employees but high in those who had recently left.

In analyses based on data on all employees SMRs were highest in the two years immediately after termination of employment for both cause of death categories (table 5). SMRs for cancer mortality decreased during the first five years after termination of employment and during the first two years for all other causes. Analyses were repeated excluding "normal retirees"—that is, by restricting data to individuals leaving before normal retirement age— when this was taken to be 65 for men and 60 for

women (table 5). SMRs for these individuals were generally below 100, apart from the first two years after termination of employment when SMRs were particularly high (SMR = 167, 95% CI 131–211 for all cancers; SMR = 150, 95% CI 129–174 for all other causes of death).

The analyses in table 1 identified social class and age at death as significant predictors of the SMR for both cause of death categories. SMRs for causes of death other than cancer also varied significantly according to UKAEA establishment and calendar period of death. While these are interesting findings, such associations potentially confound the analyses of SMRs according to other factors, such as period since recruitment.[28] Tables 6 and 7 show the results of analyses according to period since recruitment, duration of employment, and period since termination of employment (excluding normal retirees) adjusted for social class alone and adjusted for all the factors analysed in table 1—age at death, sex, calendar period of death, UKAEA establishment, and social class. Also shown are the earlier unadjusted results, expressed in a similar form—as relative SMRs (RSMRs) where the lowest stratum of each factor is taken as the baseline category for that factor.

Adjustment for social class alone produced a slight increase in the RSMR for all cancers with period since recruitment when compared with the unadjusted estimates (table 6), although the trend remained non-significant. Additional adjustment for all confounding factors reduced RSMRs such that, as

Table 4   SMRs and observed deaths (O) from all causes of death other than cancer in the UKAEA workforce, 1946–79, by period since recruitment and duration of employment

Duration of employment (y)		Period since recruitment (y)							
		< 2	2–	5–	10–	15–	20–	⩾ 25	Total
< 2	SMR (O)	55 (86)	90 (52)	84 (92)	90 (115)	79 (100)	80 (80)	93 (72)	79 (597)
2–	SMR (O)	—	65 (128)	77 (65)	74 (70)	90 (79)	71 (41)	88 (37)	75 (420)
5–	SMR (O)	—	—	68 (220)	78 (114)	82 (114)	100 (85)	92 (36)	78 (569)
10–	SMR (O)	—	—	—	64 (178)	93 (127)	86 (83)	64 (32)	75 (420)
15–	SMR (O)	—	—	—	—	78 (163)	66 (46)	76 (35)	75 (244)
20–	SMR (O)	—	—	—	—	—	70 (84)	88 (40)	75 (124)
25–	SMR (O)	—	—	—	—	—	—	70 (50)	70 (50)
Total	SMR (O)	56 (86)	71 (180)	73 (377)	74 (477)	84 (583)	79 (419)	81 (302)	76 (2424)

Table 5   SMRs and observed deaths (O) for all cancers and all other causes of death in the UKAEA workforce, 1946–79, by period since termination of employment

Period since termination of employment (y)	All employees		Excluding normal retirees†	
	Cancer mortality SMR (O)	*All other causes of death* SMR (O)	*Cancer mortality* SMR (O)	*All other causes of death* SMR (O)
0*	60 (234)	56 (595)	— (—)	— (—)
<2	140 (120)	112 (274)	167 (71)	149 (179)
2–	100 (122)	86 (303)	89 (58)	99 (177)
5–	95 (176)	82 (461)	93 (105)	82 (248)
10–	92 (127)	83 (358)	89 (94)	82 (227)
15–	78 (70)	85 (228)	73 (59)	79 (171)
20–	86 (45)	80 (121)	84 (43)	77 (109)
25–	72 (23)	93 (83)	73 (23)	94 (83)

*Mortality among employees who were employed at time of death.
†Analyses restricted to individuals leaving before normal retirement age, taken as 65 for men and 60 for women.

for the unadjusted analyses, there was little evidence of a trend in RSMR for all cancers with increasing period since recruitment. Adjustment for social class alone had a similar effect on the analyses of cancer mortality by duration of employment (table 6), with the adjusted RSMRs being generally increased relative to the unadjusted figures. Nevertheless, the trend in RSMR for all cancers with duration of employment remained clearly non-significant regardless of the adjusting factors used. The analyses

of cancer mortality according to period since termination of employment were rather less affected by the different adjustments considered. RSMRs from all analyses fell sharply across the first two strata of period since termination but remained relatively stable thereafter. This pattern was reflected in the statistically significant chi-squared statistics for departures from trend as well as those for trend in analyses according to period since termination.

The results for causes of death other than cancer

Table 6   Relative standardised mortality ratios (RSMR) (and 95% confidence intervals) for all cancers in the UKAEA workforce, 1946–79, by period since recruitment, duration of employment, and period since termination of employment (excluding normal retirees), with and without adjustment for age, sex, calendar period of death, UKAEA establishment, and social class*

	RSMR (95% confidence interval) adjusted for		
	Unadjusted	*Social class alone*	*Age, sex, calendar period, UKAEA establishment, and social class*
Period since recruitment (y)			
<2	1·0	1·0	1·0
2–	1·2 (0·8, 1·8)	1·2 (0·8, 1·6)	1·2 (0·8, 1·8)
5–	1·1 (0·8, 1·7)	1·2 (0·8, 1·7)	1·1 (0·8, 1·6)
10–	1·3 (0·9, 1·9)	1·4 (0·9, 1·9)	1·3 (0·9, 1·9)
15–	1·1 (0·8, 1·6)	1·2 (0·8, 1·7)	1·1 (0·7, 1·6)
20–	1·3 (0·9, 1·8)	1·4 (0·9, 2·0)	1·2 (0·8, 1·9)
25–	1·2 (0·8, 1·8)	1·3 (0·9. 1·9)	1·1 (0·7, 1·7)
χ²for trend (df = 1)	0·4 (p = 0·53)	2·0 (p = 0·16)	0·0 (—)
χ² for departures from trend (df = 5)	4·6 (p = 0·47)	4·2 (p = 0·52)	4·6 (p = 0·47)
Duration of employment (y)			
<2	1·0	1·0	1·0
2–	1·0 (0·8, 1·2)	1·0 (0·8, 1·2)	1·0 (0·8, 1·2)
5–	1·1 (0·9, 1·3)	1·1 (0·9, 1·4)	1·1 (0·9, 1·4)
10–	1·1 (0·9, 1·3)	1·1 (0·9, 1·4)	1·1 (0·9, 1·4)
15–	1·0 (0·8, 1·3)	1·1 (0·9, 1·4)	1·1 (0·9, 1·4)
20–	1·1 (0·8, 1·5)	1·3 (0·9, 1·7)	1·2 (0·9, 1·7)
25–	0·7 (0·4, 1·2)	0·9 (0·5, 1·4)	0·8 (0·5, 1·4)
χ² for trend (df = 5)	0·0 (—)	1·3 (p = 0·25)	0·9 (p = 0·34)
χ² for departure from trend (df = 5)	4·4 (p = 0·49)	3·5 (p = 0·62)	3·5 (p = 0·62)
Period since termination of employment (y)			
<2	1·0	1·0	1·0
2–	0·5 (0·4, 0·7)	0·5 (0·4, 0·7)	0·5 (0·4, 0·8)
5–	0·6 (0·4, 0·7)	0·6 (0·4, 0·7)	0·5 (0·4, 0·7)
10–	0·5 (0·4, 0·7)	0·5 (0·4, 0·7)	0·5 (0·3, 0·7)
15–	0·4 (0·3, 0·6)	0·4 (0·3, 0·6)	0·4 (0·3, 0·6)
20–	0·5 (0·3, 0·6)	0·5 (0·3, 0·7)	0·4 (0·3, 0·7)
25–	0·4 (0·3, 0·7)	0·4 (0·3, 0·7)	0·3 (0·2, 0·6)
χ² for trend (df = 1)	12·5 (p < 0·001)	14·0 (p < 0·001)	16·8 (p < 0·001)
χ² for departures from trend (df = 5)	14·6 (p = 0·01)	14·7 (p = 0·01)	13·5 (p = 0·02)

*Relative to the SMR in the lowest stratum which is arbitrarily set to 1·00.

Table 7 Relative standardised mortality ratios (RSMR)* (and 95% confidence intervals) for all causes of death other than cancer in the UKAEA workforce, 1946–79, by period since recruitment, duration of employment, and period since termination of employment (excluding normal retirees), with and without adjustment for age, sex, calendar period of death, UKAEA establishment, and social class

| | RSMR (95% confidence interval) adjusted for | | |
	Unadjusted	Social class alone	Age, sex, calendar period, UKAEA establishment, and social class
Period since recruitment (y)			
<2	1·0	1·0	1·0
2–	1·3 (1·0, 1·6)	1·3 (1·0, 1·6)	1·2 (1·0, 1·6)
5–	1·3 (1·1, 1·7)	1·3 (1·0, 1·7)	1·2 (1·0, 1·6)
10–	1·3 (1·1, 1·7)	1·3 (1·1, 1·7)	1·3 (1·0, 1·6)
15–	1·5 (1·2, 1·9)	1·5 (1·2, 1·9)	1·5 (1·1, 1·9)
20–	1·4 (1·1, 1·8)	1·5 (1·1, 1·9)	1·5 (1·1, 2·0)
25–	1·5 (1·2, 1·9)	1·6 (1·2, 2·0)	1·6 (1·2, 2·2)
χ^2 for trend (df = 1)	11·1 (p = 0·001)	18·8 (p < 0·001)	12·5 (p < 0·001)
χ^2 for departures from trend (df = 5)	7·3 (p = 0·20)	5·8 (p = 0·33)	3·8 (p = 0·58)
Duration of employment (y)			
<2	1·0	1·0	1·0
2–	0·9 (0·8, 1·1)	0·9 (0·9, 1·3)	0·9 (0·8, 1·1)
5–	1·0 (0·9, 1·1)	1·0 (0·9, 1·1)	0·9 (0·8, 1·1)
10–	0·9 (0·8, 1·1)	1·0 (0·9, 1·1)	0·9 (0·8, 1·0)
15–	0·9 (0·8, 1·1)	1·0 (0·9, 1·2)	0·9 (0·8, 1·1)
20–	1·0 (0·8, 1·2)	1·1 (0·9, 1·3)	1·0 (0·8, 1·2)
25–	0·9 (0·7, 1·2)	1·1 (0·8, 1·5)	1·0 (0·7, 1·3)
χ^2 for trend (df = 1)	0·8 (p = 0·37)	1·3 (p = 0·25)	0·3 (p = 0·58)
χ^2 for departures from trend (df = 5)	1·6 (p = 0·90)	1·8 (p = 0·88)	3·1 (p = 0·69)
Period since termination of employment (y)			
<2	1·0	1·0	1·0
2–	0·7 (0·5, 0·8)	0·7 (0·5, 0·8)	0·7 (0·5, 0·8)
5–	0·6 (0·5, 0·7)	0·5 (0·4, 0·7)	0·5 (0·4, 0·7)
10–	0·6 (0·5, 0·7)	0·5 (0·4, 0·6)	0·5 (0·4, 0·7)
15–	0·5 (0·4, 0·7)	0·5 (0·4, 0·6)	0·5 (0·4, 0·7)
20–	0·5 (0·4, 0·7)	0·5 (0·4, 0·6)	0·5 (0·4, 0·7)
25–	0·6 (0·5, 0·8)	0·6 (0·5, 0·8)	0·6 (0·5, 0·9)
χ^2 for trend (df = 1)	17·4 (p < 0·001)	23·7 (p < 0·001)	12·0 (p < 0·001)
χ^2 for departures from trend (df = 5)	33·2 (p < 0·001)	33·7 (p < 0·001)	36·0 (p < 0·001)

*Relative to the SMR in the lowest stratum which is arbitrarily set to 1·00.

according to period since recruitment were also strengthened by adjustment for social class (table 7). Although adjustment for all potential confounding factors considered resulted in a statistically significantly weaker association, in contrast with the unadjusted estimates, RSMRs from the adjusted analyses increased across all period since recruitment strata. The relatively low mortality from causes of death other than cancer in employees with longest durations of employment obtained from the unadjusted analyses disappeared after adjustment for social class (table 7). Mortality in this cause of death category continued to show no association with duration of employment in the adjusted analyses. As was the case for cancer mortality, regardless of the type of adjustment made, RSMRs for causes other than cancer showed a sharp decline after the first two years after termination of employment, with little evidence of a systematic change thereafter.

Similar adjustments were performed for analysis by age at recruitment (not shown). RSMRs for causes of death other than cancer showed no statistically significant association with age at recruitment after adjustment for social class alone (χ^2 for trend = 1·0,

p = 0·32) or all confounding factors (χ^2 for trend = 3·3, p = 0·07). RSMRs for all cancer remained significantly associated with age at recruitment after adjustment for social class alone (χ^2 for trend = 7·1, p = 0·01) but not after adjustment for all confounding factors (χ^2 for trend = 3·6, p = 0·06), although RSMRs for older recruits remained higher (RSMRs = 1·00, 1·45, 1·59, 1·74, 1·75, and 2·35 for the respective age at recruitment strata).

In the analyses described above duration of employment was treated as a time dependent variable—that is, an individual employed for ten years contributed person-years at risk to each of the duration of employment strata <2 years, 2–4, 5–9, and 10–14 years. This method is compatible with that used in other studies[11 15] but suffers from the criticism that an individual employed for ten years could not have died during the first ten years after entry to the industry.[29] To overcome this problem, SMRs were recalculated according to final duration of employment category using data only on individuals who had terminated employment. These analyses were confined to the period five or more years after

Table 8   SMRs and observed deaths (O) for all cancers and all other causes of death in the UKAEA workforce, 1946–79, by final duration of employment assessed at five or more years after termination of employment

Final duration of employment (y)	Cancer mortality SMR (O)	All other causes of death SMR (O)
<2	85 (163)	86 (451)
2–	82 (85)	81 (251)
5–	99 (100)	84 (285)
10–	86 (54)	83 (181)
15–	103 (38)	74 (83)
χ^2 for trend (df = 1)	1·1 (p = 0·29)	0·8 (p = 0·37)
χ^2 for departures from trend (df = 3)	1·7 (p = 0·64)	0·9 (p = 0·83)

termination so as to control for the initial period of high mortality in leavers. The results of these analyses (table 8) confirm the low mortality in short term employees and the general lack of association found earlier between mortality and duration of employment for both causes of death categories.

Discussion

The analyses described here show that several factors are associated with the level of mortality of the UKAEA workforce when compared with national rates. These may be divided into two groups. The first are sociodemographic factors and health related behaviours that characterise this particular workforce and determine the overall level of death rates observed. The second group relate to the selection of healthy individuals during the employment process which includes both self selection and selection on the part of the employers. One effect of the sociodemographic factors is evident in the statistically significant differences observed in SMRs by social class and UKAEA establishment. The different establishments are located in different parts of the country. The highest SMR for causes of death other than cancer was at Dounreay, located in Scotland, where death rates from these causes are higher than those of England and Wales.[30] SMRs were lowest for social classes I and II which have lower than average death rates.[30] Most of the workforce was located in the south of England at Harwell and Winfrith[17] where death rates are lower than average[30] and included a larger than average proportion of individuals from higher social classes.[17] Both these factors will have contributed to the generally low SMRs observed in the workforce. It is also possible that differences in health related behaviour, such as smoking or alcohol consumption, between the employees and the general population may have further contributed to its favourable mortality experience. Data on such factors were not available here and so their effects cannot be assessed.

The second group of factors associated with the

level of mortality in the workforce are those relevant to the initial selection of healthy individuals into the workforce. In contrast to sociodemographic and lifestyle factors, health related selection has a dynamic effect on death rates and must therefore be studied by analyses involving time dependent factors such as period since recruitment. Data on the UKAEA workforce are ideal for studying time dependent determinants of occupational mortality because all individuals in the study population were followed up from their data of first employment. Also, the size of the workforce, consisting of nearly 40 000 individuals, provides sufficient numbers of deaths and person-years at risk for the simultaneous investigation of the effects of more than one time dependent factor. Moreover, because the effect of exposure to radiation was not found to have an effect on overall death rates, analyses involving time dependent factors are unlikely to be confounded by the effects of work related exposures.[1 2 15]

SMRs for all cancers and all other causes of death were lowest during the first two years after recruitment, representing death rates that were, respectively, 31% (SMR = 69, 95% CI 48–97) and 45% (SMR = 55, 95% CI 44–69) lower than national rates. In univariate analyses period since recruitment was significantly associated with increasing mortality from causes other than cancer but not from cancer mortality. The results from the adjusted analysis were generally similar although, in contrast with the unadjusted results, mortality from causes other than cancer increased across all period since recruitment strata. A continued increase in mortality throughout the follow up period was observed only in social class 3 (fig 2). One explanation for this differential pattern might be that highest and lowest social classes are more prone to biases arising from loss to follow up. The higher social classes in this workforce included many scientists who are more likely to have emigrated than other workers (L Salmon, personal communication). Since emigrations from the United Kingdom are underreported (P Goldblatt, personal communication) many of these individuals may therefore contribute person-years at risk whereas any deaths that occurred among them are unlikely to have been notified and included in the study. The reason for poorer follow up in social classes IV and V is less likely to be due to emigration but possibly reflects the generally greater difficulties in linkage of records in these classes (P Goldblatt). Thus insofar as increases in mortality with period since recruitment reflect the initial selection of healthy individuals into the workforce, these data suggest that health related selection continues to exert an effect on death rates for causes other than cancer for more than 25 years. The contrasting limited increase in cancer mortality with period since recruitment lends support to the suggestion from data on other workforces that selection on

Duration of employment showed little association with mortality for either cause of death category, thus providing little evidence for a survivor effect whereby individuals who remain in employment experience lower mortality than those who leave. In particular, contrary to the findings in other work-forces,[11 31] there was no suggestion that short term workers had higher mortality than other workers.

Evidence for the selection out of employment of individuals due to ill health was provided by an examination of mortality by period since terminating employment. SMRs were found to be lowest of all in current employees but highest in those who had left recently. When data were confined to individuals leaving before normal retirement age, SMRs were high during the first two years after termination for mortality from cancer (SMR = 167, 95% CI 131–211) and for all causes except cancer (SMR = 149, 95% CI 128–173). By comparison, mortality for later periods was significantly lower for both cause of death categories and remained relatively constant with increasing period since termination regardless of the adjustment made for confounding factors. These analyses support the suggestion that the effect on death rates of selection of individuals out of employment due to ill health is confined to only the first few years after termination of employment.[29] This general pattern is similar to that found in another nuclear industry workforce[11] but our data do not exhibit the continued excess of cancer mortality in leavers found there.

The initial trend of increasing SMR with age at recruitment for causes other than cancer appeared to be explained largely by confounding by social class. This agrees with the lack of association between all cause mortality and age at recruitment in data on rubber workers.[3] The stronger association observed for cancer mortality did not disappear after adjust-ment for social class and remained marginally sig-nificant after adjustment for all confounding factors. The reason for this differential pattern is unclear and, since similar analyses have rarely been reported, is difficult to interpret. One reason considered was that older recruits might be more susceptible to the carcinogenic effects of radiation, although empirical evidence to support an association of increasing radiosensitivity with increasing age at first exposure is not strong.[32] Moreover, when analyses were carried out separately for workers who had radiation records and other workers (not shown), SMRs for all cancers increased in a similar way with age at recruitment, suggesting that radiation exposure is an unlikely explanation.

Whereas the level of mortality in an occupational cohort is likely to depend on its sociodemographic and other health related characteristics, the way in which death rates change with time may follow a common pattern determined by the processes of health related selection. Relevant analyses from other occupational cohorts are still relatively few so this is difficult to assess at present. Analyses such as those described here are useful as they increase our general understanding of the processes of health related selection during employment. They have the impor-tant additional benefit of identifying potential con-founders for consideration when investigating exposure effects in individual occupational mortality studies.

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