Nuclear industry family study: methods and description of a United Kingdom study linking occupational information held by employers to reproduction and child health*

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Abstract

Objectives—To describe the methods used in the nuclear industry family study for which a comprehensive database has been assembled that links employment in the nuclear industry and dosimetry records to information on employees' reproductive health and the health of their children. To discuss the response rates and characteristics of the study population.

Methods—Occupational cohort design leading to a retrospective cohort study of reproductive outcomes reported by 46 396 current and former employees of both sexes in the nuclear industry. Employees of nuclear establishments in the United Kingdom operated by the Atomic Energy Authority, the Atomic Weapons Establishment, and British Nuclear Fuels were surveyed with postal questionnaires to collect information on pregnancies, children, and periods of infertility. Information on employment and monitoring for ionising radiation was supplied by the employing nuclear authority and was linked to pregnancies and periods of infertility with unique personal identification numbers.

Results—The design and completion of this study resulted in high quality data on a representative population of the Atomic Energy Authority, Atomic Weapons Establishment, and British Nuclear Fuels workforces. The response to the survey was extremely good (82% for male workers and 88% for female workers, excluding undelivered questionnaires), and a unique relational database has been created which will enable infertility, pregnancy, and child health outcomes to be examined with respect to the employment and radiation monitoring characteristics of parents.

Conclusion—This is the first United Kingdom study to link detailed reproductive history data to occupational information held by employers. The methods developed for the study were found to be feasible and successful. The design can be adapted for other investigations of reproductive hazards to men and women in the workplace and is currently in use to survey over 100 000 armed forces personnel in an investigation of reproductive outcome among veterans of the Gulf war. (*Occup Environ Med* 1999;56:793-801)

Keywords: reproductive hazards; ionising radiation; occupational exposure

There has been considerable debate about the possible link between exposure to low level ionising radiation and the health of offspring. Concern about reports of high rates of leukaemia and non-Hodgkin's lymphoma in children and young adults living near certain nuclear establishments in the United Kingdom¹⁻⁹ has led to a series of population based case-control studies being conducted in their vicinity.¹⁰⁻¹³ These studies have all investigated the possibility that the excesses were related to parental employment in the nuclear industry by linking the names and dates of birth of the children's parents to employment in the nuclear industry files. However, the rarity of leukaemia and non-Hodgkin's lymphoma in young people, coupled with the rarity of employment at the nuclear establishments, has meant that the statistical power of these studies to detect anything other than extreme occupational associations was very low. Moreover, if harmful parental occupational exposures were to exist it is unlikely that their effect would be restricted to cancer among workers' children: such exposures might be expected to influence a broader range of reproductive problems, including infertility, miscarriage, and congenital malformations.¹⁴ These other aspects of reproduction remain largely unexplored.

The nuclear industry family study was set up to examine the occupational histories of a large population of nuclear industry workers in relation to all aspects of their reproduction and child health. The study was restricted to employees of nuclear establishments operated by the Atomic Energy Authority, Atomic Weapons Establishment, and British Nuclear Fuels because each of these industries had at least one plant that had been subject to a report alleging an increased incidence of leukaemia in young people residing in its vicinity.^{1-4 6 8 10 14} Generally, when an occupational hazard is suspected the health of the workers in the industries concerned is studied directly: for example, within the nuclear industry, several cohort studies have investigated the relation between cancer and mortality in relation to exposure to ionising radiation at work.¹⁵⁻²² The nuclear industry family study takes this one step further, linking the occupational exposure of workers to their pregnancies and the health of their children.

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Geographical location of principal establishments of the Atomic Energy Authority, Atomic Weapons Establishment, and British Nuclear Fuels.

Methods for doing such studies are not well developed. By contrast with the study of the health of workers themselves, where, for example, personal details held on occupational registers may be linked with cancer and mortality registration data, there is no way to link an occupational group to their reproductive histories other than to ask the workers themselves. The nuclear industry family study is the first study to approach employees in the nuclear industry directly to ask them about their pregnancies and the health of their children. The study design that was used developed from a survey of reproductive health in British radiographers,²³ which showed that a postal method could be used to obtain full reproductive histories from a large study population. The design of the nuclear industry family study, together with response rates and description of the study population, is described and discussed in this report.

Methods

STUDY POPULATION

The combined survey population consisted of all employees of the Atomic Energy Authority,

the Atomic Weapons Establishment, and British Nuclear Fuels who were in service at the time of the study, between 1993 and 1996 (8100, 6610, and 15 550 workers respectively). Also included were past employees of the Atomic Energy Authority and British Nuclear Fuels who were aged <75 years and who had an active or preserved pension administered by their joint pensions administration office (9678 and 6458 workers respectively). Past workers were thus only a sample of all past workers as although each industry kept a record of past employees, pilot investigations proved that the home address data was out of date. The pensions register was then found to be the most accurate source of home addresses. For technical reasons the Atomic Weapons Establishment was unable to assemble a past worker survey population. The study of past workers was restricted to those who were under 75 years old because data on reproductive history obtained from subjects older than this proved to be unreliable: as date of birth was not available to the researchers at the time of the survey, questionnaires were in fact sent to subjects of any age, but among those aged ≥ 75 recall of reproductive events (which may have occurred more than 50 years previously) was unacceptably poor and the proportions who had died or who were too sick to complete the questionnaire were high.

Of the total cohort of 46 396 workers aged <75, 78% were men. Employees worked, or had most recently worked, at a total of 15 different sites around Great Britain (figure). The composition of the cohort of workers aged <75 by authority, employment status, and most recent site of employment is shown in table 1.

COLLECTION OF DATA ON REPRODUCTIVE OUTCOME AND CHILD HEALTH

With a predominantly male population motivation was an important issue. Following advanced publicity at individual sites (all major sites were visited), in industry newsletters, and in extensive meetings with workers, management, and trade union representatives, each employee was sent a package containing a covering letter from management and trade union representatives, an information leaflet describing the study, a questionnaire (prenumbered with the subject's unique personal identifier) and a reply paid envelope addressed to the researchers. Packages to current workers were delivered in batches to individual sites, and those to past workers were sent to the home addresses supplied by the pensions administration office. Reminders were sent at intervals of 3–4 weeks, study subjects being requested at this stage to return the questionnaire blank if they did not wish to participate. The response rate was about 50% at each mailing. A freephone helpline giving direct access to the researchers was available to answer any queries about the study, and this was well used.

The questionnaire requested details of all liveborn children, including name, sex, date and place of birth, birth weight, and any serious medical conditions ever experienced. Also requested were details of any adverse pregnancy

Table 1 Composition of occupational cohort by site of employment and sex; employees of the Atomic Energy Authority (AEA), Atomic Weapons Establishment (AWE), and British Nuclear Fuels (BNFL) aged under 75 years at survey

Current worker cohort*			Past worker cohort†		
Site	n (%)	Men (%)	Most recent site of employment	n (%)	Men (%)
AEA:					
Culham/JET	711 (9)	75	Culham/JET	736 (13)	80
Dounreay	1507 (19)	75	Dounreay	1266 (32)	80
Harwell	2698 (33)	67	Harwell	3128 (4)	75
Risley (AEA)	1151 (14)	72	London Office	371 (19)	51
Windscale	506 (6)	80	Risley	1866 (5)	73
Winfrith	1026 (13)	80	Springfields	464 (5)	90
Police (BNFL sites)	273 (3)	87	Windscale/Sellafield	284 (3)	78
Police (AEA sites)	228 (3)	89	Winfrith	1385 (14)	82
			Aldermaston/Capenhurst/Chapelcross/Culcheth	116 (1)	82
			Maternity leave/career break/secondment	62 (1)	26
Total AEA current workers	8100 (100)	73	Total AEA past workers	9678 (100)	76
AWE:					
Aldermaston	5110 (77)	77			
Burghfield	694 (11)	75			
Cardiff	456 (7)	93	Not available to researchers		
Foulness	350 (5)	90			
Total AWE current workers	6610 (100)	79			
BNFL:					
Capenhurst (BNFL/URENCO)	1079 (7)	88	Capenhurst (BNFL/URENCO)	1137 (18)	88
Chapelcross	632 (4)	88	Chapelcross	209 (3)	82
Risley	2258 (15)	70	Risley	1113 (17)	69
Sellafield	8256 (53)	79	Sellafield	2257 (35)	77
Springfields	3325 (21)	88	Springfields	1742 (27)	90
Total BNFL current workers	15550 (100)	81	Total BNFL past workers	6458 (100)	81

*Current workers defined as all workers on employment lists at the time of survey.

†Past workers defined as all ex-workers under the age of 75 years who, at time of survey, were registered with an active or preserved pension at the AEA/BNFL joint pensions administration office in Thurso, Scotland.

outcomes (miscarriage, stillbirth, ectopic pregnancy, hydatidiform mole, missed abortion), or terminations of pregnancy for medical reasons, including date of pregnancy end, gestation, whether any abnormalities were detected in the fetus and sex of fetus if known. Questions relating to infertility were also included. In the advanced publicity campaign workers were encouraged to fill the questionnaires in with their partner, but this was not a requirement.

Parents who reported outcomes of interest were sent a second questionnaire to obtain further information about the condition and to request permission to consult relevant medical records. With appropriate maternal consent, general practitioners' or obstetric notes, or both, were consulted to verify the details of all reported fetal deaths of 16 weeks and over where abnormalities in the fetus were detected, and for all reported terminations for medical reasons. After written permission from parents (or the children themselves if aged ≥ 18), clinical notes were consulted to check the date and nature of the diagnosis where major congenital malformations, cancer, or death were reported in liveborn children. An additional check on the validity of reports of cancer and death was made by requesting a copy of the cancer registration or death certificate, or both, from the NHS central register, linking each child to the register with full name and date and place of birth. At the time of survey, however, cancer registration details were only available for the period 1971–93. All adverse health outcomes were double coded to the 10th revision of the international classification of diseases (ICD)²⁴ by a research nurse and an experienced epidemiologist, both of whom were blind to the exposure status of the worker. Using the coding rules of the revision in effect at the time of the event, reported cancers and deaths among

children were also coded to the 9th revision of the ICD (ICD-9)²⁵ for comparison with national mortality and cancer incidence (which had been coded in the same way).

Reporting of illness among children by the parents proved very accurate. For example, a total of 111 children were reported to have developed a malignancy before their 25th birthday (five of whom had both parents in the study), with years of diagnosis between 1951 and 1993. Confirmatory evidence in the form of a cancer registration, death certificate, or entry in medical notes was located for 108 (97%) of these 111 malignancies.²⁶ The remainder were not refuted, but simply could not be validated because of lack of parental permission or registration data.

Date of conception was estimated for each reported pregnancy as the date of the end of the pregnancy minus gestational age plus 14 days. Gestation was unknown for 99% of live-born children, and was estimated as 40 weeks (36 weeks or 28 weeks if prematurity was indicated on the questionnaire). Gestation was known for most incomplete pregnancies, and was otherwise estimated with the median reported gestation for all other reported pregnancies of the same type (stillbirth 34 weeks (5% estimated); miscarriage 12 weeks (6% estimated); termination 16 weeks (68% estimated); ectopic 8 weeks (43% estimated); blighted ovum 10 weeks (4% estimated); hydatidiform mole 14 weeks (23% estimated)).

EMPLOYMENT AND MONITORING DATA

Information about employment in the nuclear industry and potential exposure to ionising radiation at work was obtained from the personnel, health physics, and epidemiological databases maintained by the three authorities.

These databases are of a generally high quality, not only because radiation dose records have to be maintained for United Kingdom regulatory purposes, but also because the data have been used previously for several large epidemiological studies of the workers themselves.¹⁵⁻²² Data were supplied for all those responding who had ever had, or who had ever attempted to have, children, and were linked by computer to the cleaned, coded, and validated questionnaire based data with the subjects' unique personal identifiers. Thus the researchers were blind to the occupational exposure status of the workers when collecting data on reproduction and child health outcomes. All three authorities provided dates of first and last employment within the industry, site of current (or most recent) employment, and classification as an industrial or non-industrial worker. Also, the Atomic Energy Authority and British Nuclear Fuels provided an employment history for each worker, giving details of all employment periods (by site) at any of the three authorities. Care was taken to avoid duplication and to ensure the consistency of employment histories when employees had worked at more than one site or authority. Where people had worked for more than one authority, all records were collated and supplied by the authority of most recent employment. For non-responders, information on date of birth was supplied by the Atomic Energy Authority and the Atomic Weapons Establishment: for reasons of confidentiality British Nuclear Fuels declined to supply data on age for any person who had not returned a completed questionnaire.

All employees who are potentially at risk of exposure to external ionising radiation are required to wear personal dosimeters (film badges or thermoluminescent devices) to record the amount of exposure, and for regulatory and managerial purposes nuclear establishments maintain records of all such monitoring. The three authorities supplied radiation records for all workers who responded and either had children, or had attempted to have children. Workers who had at least one such radiation record are referred to in this study as "monitored workers". For each calendar year that they had worn a film badge, the industry supplied a record of the worker's total whole body (occupational) dose accumulated over the year at each establishment, expressed in millisieverts (mSv). (A worker could have more than one record in a year if they had worked at more than one establishment). Actual dates of first and last monitoring were provided in the personnel record. Natural background radiation was excluded and appropriate adjustments were made for factors such as the minimum detection dose value (threshold dose) of the dosimeter and for missing badges.^{21 27 28} Pre-conceptual doses were calculated by pro rata scaling of the annual doses.

As well as monitoring for external ionising radiation, employees may also have been investigated for possible internal contamination if they were considered to be potentially exposed through working with radioactive substances. These investigations consist of bioassays or

whole body monitoring (available since the 1960s). The type of information provided on this internal monitoring varied among authority, but all employers provided the calendar year in which an employee was monitored for the first time for potential internal contamination by any radionuclide. All workers for whom such a date existed are referred to in this study as internally monitored workers.

Although these data have been used for several epidemiological studies of the workers, previous checks were restricted to cumulative lifetime exposures of the worker. In the present study further extensive checking was required because of the unique need for accurate data—for example, employment and monitoring status, or accumulated dose—at the time of each reproductive event. Hence extensive validation and consistency checks of the computerised radiation and employment records supplied by the industry were carried out by the researchers, referring back to the primary (industry) data source where necessary. It was found, however, that certain inconsistencies could not be uniformly resolved, and such data were tagged as uncertain—for example, if the date of first employment in the personnel (summary) data predated the information from the employment history data, or if a radiation record of monitoring at one of the three authorities in the study predated the date of first employment in the personnel data—this intervening period was classified as a period of uncertain employment. For monitoring, uncertain status was assigned where data from the personnel records predated the year of first monitoring in the annual dosimetry records.

Further inconsistencies existed within the dosimetry data with transfer doses. These arise when a monitored worker moves between places of employment, either within or outside the authorities that make up this study cohort. When this happens either all annual radiation records for that worker are transferred to the new employer's radiation records, or a single summary transfer dose record is appended to the new records. Although in many cases single transfer doses could be associated with a known period of employment (hence a period of uncertain monitoring), for some subjects there was no way of knowing what period the transfer dose covered. In this situation they were designated as being of uncertain monitoring status from age 16. Among workers who had, or had ever attempted to have children, 164 (0.9%) men and nine (0.2%) women were allocated uncertain monitoring status back to age 16 in this way. On some occasions a transfer dose was found to be replicated by annual doses—that is, we had both the annual dosimetry data for the period and a transfer dose—in which case the transfer dose was removed.

Overall, among workers who had, or had ever attempted to have, children 942 (5%) men and 51 (1%) women had at least one period of uncertain monitoring before the date of survey, although only nine men and one woman had a period of uncertain employment. In terms of the pregnancies these workers conceived, 255 (1%) of pregnancies reported by men and 11

Table 2 Crude response rates and response rates adjusted for undelivered questionnaires among workers aged under 75 years* at time of survey: by employment and sex

	Current workers			Past* workers			Total*		
	n	Crude (%)	Adjusted† (%)	n	Crude (%)	Adjusted† (%)	n	Crude (%)	Adjusted† (%)
Male workers:									
Total questionnaires posted	23719	100	—	12623	100	—	36342	100	—
Returned undelivered‡	1005	4	—	1306	10	—	2311	6	—
Not returned	3521	15	16	1583	13	14	5104	14	15
Returned, refusal§	529	2	2	512	4	5	1041	3	3
Returned completed	18664	79	82	9222	73	81	27886	77	82
Among whom:									
Ever attempted to have children¶:	11623	62	—	7121	77	—	18744	67	—
Female workers:									
Total questionnaires posted	6541	100	—	3513	100	—	10054	100	—
Returned undelivered‡	291	4	—	466	13	—	757	8	—
Not returned	473	7	8	425	12	14	898	9	10
Returned, refusal§	95	1	2	140	4	5	235	2	3
Returned completed	5682	87	91	2482	71	81	8164	81	88
Among whom:									
Ever attempted to have children¶:	2948	52	—	1754	71	—	4702	58	—

*Date of birth not known for 22 AWE workers (15 with completed questionnaires), and 5468 BNFL workers (3533 current and 1935 past workers—none with completed questionnaires). These workers were assumed to have been aged under 75 at the time of survey.

†Adjusted for undelivered mail. Excluded from the denominator are all questionnaires returned undelivered (the remainder are assumed to have been delivered).

‡Questionnaires to current employees were returned by the workplace because they had left or retired, were on maternity leave, or were permanently sick. Questionnaires to past workers were returned by the post office or current occupants of the residence if the ex-worker had moved, or occasionally if the ex-worker was dead. A relative usually returned the questionnaire if the study participant had died or was too ill to complete it.

§Explicit refusal or return of blank questionnaire (this was requested if the recipient did not wish to participate).

¶With or without success.

(0.1%) reported by women were conceived during a period of uncertain monitoring, with just five pregnancies reported by men and none by women being conceived during a period of uncertain employment.

All data were held in an Oracle relational database system²⁹ and analysed with Stata.³⁰

Results

RESPONSE

Date of birth was not known for 22 Atomic Weapons Establishment workers (15 with completed questionnaires), and 5468 British Nuclear Fuels workers (3533 current and 1935 past workers: none with completed questionnaires). These workers were assumed to have been aged <75 at time of posting the questionnaire. This assumption is reasonable for current workers, but response rates for past

workers may be underestimated, as some of the 1935 non-responders with missing dates of birth will have been aged over 75 at survey and should have been excluded from the study.

Seven per cent (3068) of all questionnaires (excluding reminders) were returned undelivered. As expected, past workers were harder to trace, with 1596 (10%) questionnaires being returned because the addressee had moved and a further 176 (1%) because the addressee had died or was too sick to participate. Among workers assumed to have received a questionnaire, the response rate for completed questionnaires was 82% for men and 88% for women (representing 78% of the total survey population of 46 396 male and female workers originally identified for the study). This adjusted response rate was uniformly high across authorities, and by employment status.

Table 3 Age distribution at survey among responders* and non-responders by authority and sex: workers aged under 75 years†‡

Age at survey (y)	Authority							
	AEA				AWE†		BNFL‡	
	Current worker response*		Past worker response*		Current worker response*		Current worker response*	
	Yes	No	Yes	No	Yes	No	Yes	No
Male workers:								
n	4772	1180	5540	1844	4384†	805‡	9508	3070
%:								
<35	34	30	10	21	42	28	39	Data not supplied
35–54	55	55	15	37	41	43	53	11
≥55	11	15	75	42	17	29	9	75
Mean (SD) age	40.6 (10.5)	41.9 (11.1)	59.9 (13.5)	49.9 (15.6)	39.9 (12.7)	44.1 (13.2)	39.1 (10.8)	59.8 (14.6)
Female workers:								
n	1916	232	1664	630	1264†	157‡	2502	470
%:								
<35	49	40	16	27	35	30	60	Data not supplied
35–54	43	49	26	42	51	51	36	31
≥55	7	12	57	30	14	19	4	49
Mean (SD) age	37.3 (11.0)	39.8 (11.5)	54.3 (14.8)	46.0 (14.6)	41.1 (12.2)	42.7 (12.8)	34.5 (10.3)	51.2 (15.1)

*Responders returned a completed questionnaire. Non-response encompassed questionnaire returned undelivered, refusal to participate, and questionnaire not returned.

†Date of birth not known by AWE for 10 male and five female (current) workers who returned completed forms but left date of birth blank and five men and two women from whom no completed form was received (all such workers assumed to be under 75 years at survey, but are left out of calculations of age distributions).

‡No date of birth data made available by BNFL for subjects from whom a completed questionnaire was not received: among current workers this comprises 3064 men and 469 women; among past workers 1535 men and 400 women (all such workers assumed to be under 75 years at survey, but are left out of calculations of age distributions).

Table 4 Characteristics of all workers reporting ever having attempted to have children*

	Male workers n=18744 n (%)		Female workers n=4702 n (%)	
Age at survey (y):				
<35	2663	(14)	1111	(24)
35–54	8500	(45)	2363	(50)
≥55	7581	(40)	1228	(26)
Mean (SD)	50.9	(13.6)	46.1	(12.6)
Occupation:				
Most recent authority of employment:				
AEA	7331	(39)	2115	(45)
AWE	2442	(13)	815	(17)
BNFL	8971	(48)	1772	(38)
Year of first employment†:				
<1960	4282	(23)	258	(5)
1960–9	2765	(15)	414	(9)
1970–9	5765	(31)	1483	(32)
1980–9	4882	(26)	1970	(42)
1990–6	1050	(6)	577	(12)
Duration of employment (y)‡:				
<5	1569	(8)	995	(21)
5–14	6174	(33)	2379	(51)
15–29	6907	(37)	1078	(23)
≥30	4094	(22)	250	(5)
Median (range)	17.3	(0.01–46.6)	9.7	(0.2–47.2)
Ever monitored before survey§	15402	(82)	1333	(28)
Reproduction:				
At least one pregnancy¶	18416	(98)	4579	(97)
Number of pregnancies reported per worker** (mean (SD); range)	2.4	(1.1); 1–13	2.2	(1.1); 1–8
At least one livebirth	18131	(97)	4435	(94)
Number of livebirths reported per worker (Mean (SD); range)	2.2	(1.0); 1–15	2.0	(0.9); 1–7
Ever employed† before estimated date of conception†† of first pregnancy	9152	(49)	1953	(42)
Ever monitored before estimated date of conception†† of first pregnancy‡‡	6716	(36)	520	(11)
Lifetime cumulative whole body dose (mSv) before estimated date of conception of first pregnancy††:				
Never monitored	12028	(64)	4182	(89)
Monitored:				
0–9	3179	(17)	376	(8)
10–19	1019	(5)	69	(1)
20–49	1268	(7)	49	(1)
50–99	597	(3)	12	(0.3)
100–499	397	(2)	2	(0.04)
≥500	5	(0.03)	0	(0)
Uncertain	251	(1)	12	(0.3)
Median (range)	10.4	(0–1145.9)	3.8	(0–122.4)

*With or without success. Includes workers with primary infertility.

†By AEA, AWE or BNFL.

‡Total duration of employment for past workers, duration of employment to date of survey for current workers.

§Includes 154 male and 25 female workers with “uncertain” monitoring status, who had either evidence of internal monitoring or a date of first monitoring in personnel records, but no annual external dose records (see text).

¶Includes 96 male and 57 female workers who reported a first pregnancy current at time of survey.

**Includes 362 twin pregnancies and two triplet pregnancies reported by male workers, and 82 twin pregnancies reported by female workers (multiple pregnancies counted once only).

††Or date of first consultation with a doctor concerning problems with fertility for those with primary infertility.

‡‡Includes 251 male and 12 female workers with “uncertain” monitoring status, who had either evidence of internal monitoring or a date of first monitoring in personnel records which preceded the estimated date of conception of first child, but no annual external dose records (see text).

Only 3% (1276) of workers whose questionnaires were assumed to have been delivered chose the option of returning a blank questionnaire, or stated that they did not wish to participate (table 2).

CHARACTERISTICS OF NON-RESPONDENTS

Among current Atomic Energy Authority and Atomic Weapons Establishment workers, responders tended to be younger than non-responders, but the difference in mean age was not large, ranging from 1.3 years to 4.2 years (table 3). By contrast, Atomic Energy Authority past worker responders tended to be older than those not completing a questionnaire, with a difference in mean age of 10 years for men and 8.3 years for women. Although no data on age were available for non-responders at British Nuclear Fuels, the distribution of age among those returning completed questionnaires was very similar to that of Atomic Energy Authority workers, for both current and past employees.

Together with the high response rate, these data show that, in terms of age, current workers

who responded are representative of the total current cohort surveyed. Among past workers there is some evidence of a bias in favour of older responders. The most likely explanation is that younger ex-workers, who are not yet actively receiving their pension, may be less likely to have an up to date home address registered with the pensions office of their previous employer. Thus a higher proportion of the questionnaires may have failed to reach them than for older ex-workers who are receiving their pension. The age bias may have inflated the proportion of past workers reporting pregnancies and children, but it is unlikely that it would have resulted in biased reporting of adverse pregnancy outcome or childhood illness.

CHARACTERISTICS OF RESPONDENTS REPORTING PREGNANCIES (OR AN ATTEMPT FOR PREGNANCY)

At the time of survey 18 744 (67%) men and 4702 (58%) women who returned a completed questionnaire had attempted to have children, reporting either at least one pregnancy or primary infertility (table 2). These proportions

Table 5 Characteristics of pregnancies*

	Sex of reporting parent	
	Male n (%)	Female n (%)
Total reported pregnancies* (any gestation and outcome)	43710 (100)	9962 (100)
Pregnancy type†:		
One or more livebirth	39197 (90)	8802 (88)
One or more fetal death	4304 (10)	1092 (11)
Livebirth-fetal death (twin)	14 (0.03)	3 (0.03)
Termination for medical reasons	70 (0.2)	21 (0.2)
Blighted ovum	14 (0.03)	9 (0.1)
Ectopic pregnancy	93 (0.2)	27 (0.3)
Hydatidiform mole	18 (0.04)	8 (0.1)
Most recent authority of parental employment at time of survey:		
AEA	17731 (41)	4531 (45)
AWE	5581 (13)	1882 (19)
BNFL	20398 (47)	3549 (36)
Year of end of pregnancy:		
<1965	15172 (35)	3080 (31)
1965-74	10138 (23)	2648 (27)
1975-84	9596 (22)	1698 (17)
1985-96	8804 (20)	2536 (25)
Parent‡ ever employed‡ before estimated date of conception	23962 (55)	3634 (36)
Parent‡ ever monitored§ before estimated date of conception	17873 (41)	959 (10)
Lifetime cumulative whole body dose (mSv) before estimated date of conception:		
Never monitored	25837 (59)	9003 (90)
Monitored:		
0-9	7936 (18)	684 (7)
10-19	2721 (6)	144 (1)
20-49	3520 (8)	100 (1)
50-99	1836 (4)	19 (0.2)
100-499	1591 (4)	1 (0.01)
≥500 mSv	14 (0.03)	0
Uncertain	255 (0.6)	11 (0.1)
Median (range)	12.6 (0-1167.2)	4.2(0-122.4)

*Excludes 96 and 57 first pregnancies reported to be current at the time of survey by male and female workers respectively. Counted once only are 362 twin pregnancies and two triplet pregnancies reported by male workers, and 82 twin pregnancies reported by female workers.

†Relates only to parent reporting the pregnancy; pregnancies with both parents in the survey are reported twice, once for each parent.

‡By AEA, AWE or BNFL. Includes five pregnancies reported by male workers where parental employment before the estimated date of conception was "uncertain" (see text).

§Includes 255 and 11 pregnancies reported by male and female workers respectively where parental monitoring before estimated date of conception was "uncertain", there being either evidence of internal monitoring or a date of first monitoring in personnel records, but no annual external dose records (see text).

were higher in past workers (table 2), reflecting the older age distribution, but were similar among employees of the three different authorities.

Characteristics of the workers reporting pregnancies or an attempt for pregnancy are presented in table 4. At the time of the survey male workers were older than female workers and had served longer. Further, 82% of the men had been monitored at some time compared with only 28% of women. Among employees of the Atomic Energy Authority and British Nuclear Fuels 74% of ever monitored and 71% of never monitored men had been in continuous service at one site until either leaving the industry or date of survey. Similar proportions were found among women: 71% of ever monitored and 72% of never monitored workers had been in continuous service at one site (data not shown).

Only 328 (2%) male workers and 123 (3%) female workers reported that they had attempted to have a child but had never had a pregnancy. The remaining men and women reported an average of 2.4 and 2.2 pregnancies respectively per worker, 96 men and 57 women reporting a first pregnancy current at the time of survey. Overall, 18 131 men and 4435 women reported at least one liveborn child, with an average of 2.2 and 2.0 liveborn children respectively per worker (table 4). The ques-

tionnaire included a question asking whether the worker's partner had ever worked in the industry. With this information, plus various methods including matching on children's names, dates, and place of birth, it was possible to determine that 1232 male workers and 1233 female workers shared one or more liveborn child with a partner who was in the survey population. These included two male workers and one female worker who shared liveborn children with two different partners in the survey.

CHARACTERISTICS OF PREGNANCIES AND OFFSPRING

The characteristics of the 43 710 pregnancies reported by male workers, and the 9962 reported by female workers, are presented in table 5. More than half of all pregnancies reported by men were conceived after first employment by the Atomic Energy Authority, Atomic Weapons Establishment, or British Nuclear Fuels. Around 40% were conceived after the father had been first monitored, the median lifetime cumulative preconceptional dose being 12.6 mSv. In only 9% of these pregnancies conceived by ever monitored fathers (4% of all pregnancies reported by men) did the father have a cumulative preconceptional dose of ≥ 100 mSv (table 5). At the other end of the scale, only 716 pregnancies conceived by ever monitored fathers (2% of all pregnancies reported by men) had a cumulative preconceptional dose of <0.1 mSv.

Among pregnancies reported by female workers, just over a third were conceived after first employment by one of the three authorities, and 10% were conceived by ever monitored women (table 5). The median lifetime cumulative preconceptional dose for these pregnancies was 4.2 mSv, with only one pregnancy being conceived by a mother who had a lifetime cumulative whole body dose of ≥ 100 mSv. Nevertheless, most of these pregnancies had a cumulative preconceptional dose of >0.1 mSv, only 62 pregnancies conceived by ever monitored mothers (1% of all pregnancies reported by women) having a cumulative preconceptional dose of <0.1 mSv.

In total 39 557 liveborn children were reported by men and 8883 by women; their characteristics being summarised in table 6. Of the 46 107 individual children in the study, 2333 children had both a father and a mother in the survey population. The average age of living children at time of survey was 22.8 years for children of male workers and 21.6 years for children of female workers. The median preconceptional dose among liveborn children whose parents were monitored before their conception was 12.4 mSv for fathers and 4.3 mSv for mothers. Four per cent of children of male workers and 0.01% of children of female workers had parental preconceptional doses of ≥ 100 mSv, and 2% and 1% had parents with doses of <0.1 mSv before conception. Two per cent of children reported by male workers and 6% reported by female workers had a parent who was never employed or monitored at any time either before the child's conception or

Table 6 Characteristics of liveborn children

	Sex of reporting parent	
	Male n (%)	Female n (%)
Total reported liveborn children*	39557 (100)	8883 (100)
Most recent authority of parental employment at time of survey:		
AEA	16021 (41)	4024 (45)
AWE	5050 (13)	1698 (19)
BNFL	18486 (47)	3161 (36)
Year of birth:		
<1965	13994 (35)	2829 (32)
1965–74	9264 (23)	2422 (27)
1975–84	8609 (22)	1480 (17)
1985–96	7690 (19)	2152 (24)
Age of living children at survey (y):		
<5	4157 (11)	1209 (14)
5–14	8652 (22)	1812 (20)
15–24	8236 (21)	1859 (21)
≥25	18006 (46)	3883 (44)
Mean (SD); range	22.8 (13.0); 0.005–58.4	21.6 (12.9); 0.023–56.7
Parent† ever employed‡ before estimated date of conception	21300 (54)	3104 (35)
Parent† ever monitored§ before estimated date of conception	15898 (40)	801 (9)
Lifetime cumulative whole body dose (mSv) before estimated date of conception:		
Never monitored	23659 (60)	8082 (91)
Monitored (mSv):		
0–9	7131 (18)	567 (6)
10–19	2400 (6)	122 (1)
20–49	3108 (8)	82 (1)
50–99	1623 (4)	19 (0.2)
100–499	1396 (4)	1 (0.01)
≥500	10 (0.03)	0
Uncertain	230 (0.6)	10 (0.1)
Median (range)	12.4 (0–1167.2)	4.3 (0–122.4)
Parental monitoring before age 25, death or survey (including before conception):		
Never employed or monitored at any time	854 (2)	553 (6)
Never monitored	7180 (18)	6130 (69)
Monitored preconceptually, never monitored after birth	1409 (4)	387 (4)
Monitored both preconceptually and after birth	14489 (37)	414 (5)
Never monitored preconceptually, monitored after birth	15625 (40)	1399 (16)

*Includes 698 liveborn twins and six liveborn triplets reported by male workers, and 159 liveborn twins reported by female workers.

†Relates only to parent reporting the child; 2333 children with both parents in the survey are reported twice, once for each parent.

‡By AEA, AWE, or BNFL.

§Includes 230 and 10 livebirths reported by male and female workers respectively where parental monitoring before estimated date of conception was “uncertain”, there being either evidence of internal monitoring or a date of first monitoring in personnel records, but no annual external dose records.

during their childhood and early adulthood (before death, 25th birthday, or date of survey, whichever was earliest). Parental monitoring exclusive to the preconceptual period was rare (table 6).

Discussion

The nuclear industry family study is the first United Kingdom study to link detailed reproductive history information to occupational exposure data held by employers. With the methods already described we were able to assemble a database of over 53 000 pregnancies linked to parental occupational exposure to ionising radiation. This database has already been used to examine cancer incidence in offspring relative to parental exposure²⁶ and other adverse outcomes, notably infertility, fetal loss, and congenital malformations, are currently being investigated.

The feasibility of a postal questionnaire method to obtain detailed reproductive history has been confirmed. Despite initial reservations expressed by representatives of the industries involved, both male and female workers found the questionnaire acceptable. Questions relating to infertility, fetal loss, and childhood illness were relatively easy to answer and were not regarded as offensive. Indeed, the resulting response rate was higher than would normally be expected from a postal survey. This partly reflects the efforts made to inform participants

about the study and partly the importance of the issue as perceived by the workers themselves. As expected, the response rate was higher for female workers but that for men was very good, approaching 80% overall. Importantly, the quality of the data obtained from both men and women was high.

Despite the high response rate and excellent data quality, the possibility of responder bias must be considered. From the data we have available there is little evidence of unusual patterns of reproductive outcome in the group overall. We cannot be sure that all adverse health outcomes were reported, but to check this it would be necessary to locate and examine the obstetric records of all participating women (and of the partners of all participating men), as well as the medical records of all children in the survey. Clearly this would not be feasible in a study of this size. With regard to exposure, we obtained complete data (in this case employment and monitoring information) from employers, rather than workers. This was provided for all those who had ever attempted to have children. Linkage of occupational exposure data to reproductive events, and its completeness, was thus not biased by recall of exposure by respondents. In particular, it was possible to link both employment and monitoring information to the estimated time of conception of each reported pregnancy in an unbiased way. We are thus fairly confident that

responders are not a biased group with respect to reproductive outcome or exposure status at the time of conception.

There is increasing scientific and public interest in possible adverse reproductive effects of workplace exposures. The method described here has been shown to be feasible, and could be adapted for other occupational settings. Indeed, the method is currently in use to survey over 100 000 armed forces personnel in an investigation of reproductive outcome among veterans of the Gulf war.

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