Malignant Diseases near Nuclear Facilities – Epidemiological Studies Conducted in North America

Richard Wakeford, Warrington

Abstract
In the light of reports of raised levels of childhood leukaemia around certain nuclear facilities in Britain, it is of importance to determine what epidemiological support there is for a raised risk of childhood leukaemia around nuclear facilities in other countries. Studies have been carried out around nuclear facilities in Ontario, Canada, but no significantly raised levels of childhood leukaemia were found. In addition, no support was found for the hypothesis that paternal irradiation before conception materially increases the risk of leukaemia in offspring. A number of studies have been conducted in the US around individual nuclear facilities, with little convincing evidence of raised levels of childhood leukaemia. The one exception is the evidence of an excess risk of childhood leukaemia in south western Utah which might be attributable to exposure to radioactive fallout from the Nevada test site. The excess risk found in this study is consistent with that predicted from high dose studies. The most comprehensive and extensive study in the US was carried out by the National Cancer Institute, and included all major nuclear facilities. This study found no evidence for a raised risk of childhood leukaemia at the county level. Little evidence for a raised risk of other cancers has been found by studies of nuclear facilities in the US, the possible exception being thyroid cancer associated with exposure to radioiodine in fallout from the Nevada test site. Most of the studies carried out in North America were geographical correlation studies, and as a consequence, the results must be treated with caution. Individual based studies using assessed radiation doses are underway around a number of facilities. However, there is no convincing evidence in the epidemiological studies carried out in North America to date that radiation risks arising from the radioactive discharges of nuclear facilities have been underestimated.

INTRODUCTION

The findings of geographical correlation studies, for example, epidemiological studies that seek statistical associations between nearness to nuclear facilities and rates of malignant diseases, are difficult to interpret scientifically. One reason for this is that such studies are often exploratory and therefore many cancer types, age groups, time periods and areas are examined. Under these circumstances, a number of statistically significant associations might be expected to be found by chance alone because of multiple statistical testing. Therefore, statistically significant results need to be viewed in the context of the findings of other relevant studies in order that they may be properly interpreted.

On the basis of the predicted risks arising from radiation doses received from routine discharges of radioactive material from nuclear facilities, the excess risks are so small as to be incapable of being detected statistically against background fluctuations in cancer rates [27]. However, studies carried out in Britain during the 1980s have found that raised rates of childhood leukaemia exist near certain nuclear facilities [14, 43]. It must be appreciated that the principal study carried out in Britain showed „conclusively" that there had been

no general increase in cancer mortality in the vicinity of nuclear facilities [13], so that it is childhood leukaemia (in particular, childhood lymphoid leukaemia) which must be of primary interest in other studies.
A further difficulty in the interpretation of the results of geographical correlation studies is that areas surrounding nuclear facilities are unlikely to be typical of the country as a whole. In Britain, attempts have been made to deal with the potential effects arising from this through the selection of control areas, or through the adjustment of national rates, to account for factors such as the socioeconomic class of the area near a facility. Even so, a study of areas around potential sites of nuclear facilities in Britain (those sites where a nuclear power plant had been planned but was not built or was not operational) showed a pattern of cancer mortality which was „strikingly similar“ to that for existing sites, even after such adjustments [8]. It must be kept in mind that geographical proximity to a nuclear facility may be confounded by some other factor associated with the type of area in which the facility is constructed.
Individual-based (cohort and case-control) studies are less likely to suffer from the deficiencies of geographical correlation studies. A number of case-control studies have been carried out in Britain, and cohort studies have been conducted in the vicinity of the Sellafield nuclear installation in England and the Dounreay facility in Scotland.
Not only must the effects of multiple statistical testing in geographical correlation studies be considered, but also the effects of chance and bias arising from the selection of the data used in a particular analysis on the basis of prior knowledge of such data. In an interesting review of this subject, Davis and Inskip [10] have noted

„It cannot be emphasised too strongly that when testing a hypothesis there can be no exploration: the precise comparison to be made must be defined in advance without prior knowledge of the results. To look first at the results, and then to choose the district, age-group and date definitions which most strongly support the hypothesis (or most strongly refute it) constitutes manipulation of the data with hindsight, and is a form of scientific dishonesty“.

Glass et al. [16] illustrated the difficulties of interpretation of *post hoc* leukaemia clusters by identifying extreme clusters of cases by „gerrymandering boundaries around cases of leukaemia“ in a dataset of childhood leukaemia deaths in Los Angeles County between 1960 and 1964 which displayed no evidence of clustering using a framework of boundaries selected before the distribution of cases was known. The *post hoc* clusters were as extreme as those that had been described previously in the scientific literature. The authors stated

„In the study of a relatively rare disease such as leukemia, it is important to keep in mind the possibility that seemingly high concentrations of cases may be generated by over-zealous statistical manipulation“.

Such considerations must be borne in mind when interpreting particular findings. In general, unless there are good *a priori* reasons for considering individual sites (such as at Three Mile Island), more reliable results will be obtained by examining groups of installations. This has the added benefit of increasing the statistical power of detecting a genuinely raised risk near nuclear facilities. Similarly, more secure results will be obtained from the examination of the longest available time period, unless there are sound reasons to the contrary.
A prime example of the way in which a geographical correlation study should be conducted is given by the study of Bithell et al. [4]. They analysed childhood leukaemia and non-Hodgkin's lymphoma (because this group of malignancies had been previously identified as being of

principal importance) around all existing nuclear facilities (grouped into major and minor according to the level of discharges) and potential sites in England and Wales, using the longest period for which reliable registration data were available (1966-87), and used appropriate statistical methods (selected *a priori*) based on small areal units (electoral wards). Apart from Seascale near Sellafield (which generated the hypothesis being tested) they found „virtually no convincing evidence for a geographical association of childhood leukaemia and non-Hodgkin's lymphoma with nuclear installations in general".
From this introductory discussion, it will be seen that the North American studies should be viewed in the context of the findings elsewhere, particularly in Britain. Consequently, in this review, the principal results will be taken as those derived from groups of facilities with the longest periods since start-up of the facilities for which reliable data are available, and with childhood leukaemia as the principal malignant disease of interest (unless there are good *a priori* reasons otherwise, for example thyroid cancer related to a previous release of radioactive iodine). Of course, any analysis must be carried out using a structure which is independent of the data used in the analysis to be scientifically meaningful.

CANADA

A study instigated by the Atomic Energy Control Board of Canada [6, 31] investigated childhood leukaemia around five nuclear facilities in Ontario. These facilities consisted of the research and development establishment at Chalk River (together with a nearby research reactor at Rolphton), a uranium refinery at Port Hope, uranium mining and milling facilities at Elliot Lake, and Candu reactor power stations at Pickering and Douglas Point. These facilities commenced operations in 1944, 1935, 1954, 1971 and 1967 respectively. Mortality data for the 0-14 year age group was available from 1950 to 1987, and registration data between 1964 and 1986. The periods analysed were the longest for which data were available since facility start-up. The areas studied were census sub-divisions, having the majority of their area within 25 km of a facility, although counties were also examined. Mortality and registration ratios were calculated for children born near a facility and for children dying or diagnosed while resident near a facility.
The childhood leukaemia mortality rate ratio among those born near a nuclear facility was O/E = 54/46.1 = 1.17 with a 95% confidence interval (CI) from 0.88 to 1.53, while for the population of children resident near a facility, O/E = 88/82.2 = 1.07 (95% CI: 0.86-1.3). The registration rate ratio for children born near a nuclear facility was O/E = 95/88.4 = 1.07 (95% CI: 0.87-1.3). These results are not unusual.
For individual facilities, rate ratios tended to be low for the Chalk River facility, although not significantly so, but high for the power stations: for those born near the two stations O/E = 36/25.7 = 1.40 (95% CI: 0.98-1.9) and for those dying near a station O/E = 66/59.8 = 1.10 (95% CI: 0.84-1.4). For Pickering Power Station, mortality ratios could be compared before and after the start of operations in 1971. For those born near Pickering during the period 1950-70, O/E = 80/74.1 = 1.08 (95% CI: 0.86-1.34), and for 1971-87, O/E = 33/24.6 = 1.34 (95% CI: 0.92-1.89). The difference between these two ratios is not statistically significant (p = 0.26). For those dying near Pickering, for 1950-70, O/E = 91/83.9 = 1.08 (95% CI: 0.87-1.33), and for 1970-87, O/E = 51/46.4 = 1.10 (95% CI: 0.82-1.45).
Taking the results which are most closely analogous to the findings of studies carried out in Britain - leukaemia mortality among children resident near a nuclear facility - does not produce a particularly remarkable ratio, O/E = 1.07 (95% CI: 0.86-1.3), and a

similar ratio is obtained for the two power stations, O/E = 1.10 (95% CI: 0.84-1.4). For those dying in a county containing a nuclear facility, O/E = 155/150.6 = 1.03 (95% CI: 0.86-1.2). Higher rate ratios are obtained for children born near a nuclear facility, in particular near a power station, but the evidence from this study for a raised risk of childhood leukaemia associated with the area around Canadian nuclear facilities is no more than weak.

As a result of the findings of the study by Gardner et al. [15] carried out around the Sellafield nuclear facility in West Cumbria, England, which found a statistical association between relatively high doses received by fathers while working at Sellafield before the conception of their children and leukaemia in these children, McLaughlin et al. [30, 32] conducted a case-control study of leukaemia among children born near a nuclear facility in Ontario. TThestudy included all deaths from leukaemia during 1950-63, and all incident cases of leukaemia diagnosed during 1964 88, among 0-14 year old children born to mothers living near an operating nuclear facility. The eight control children per case were individually matched by date and region of birth. Of the 112 cases of childhood leukaemia included in the study, six were linked to paternal exposure to radiation before the conception of the child as opposed to 53 of the 890 controls, giving an odds ratio of 0.87 (95% CI: 0.32-2.34). No case but five controls were associated with cumulative paternal preconceptional doses ≥100 mSv (the dose category for which Gardner et al. [15] obtained a statistically significant association), giving an odds ratio of 0.0 (95% CI: 0 9.72). Five cases and 41 controls were associated with paternal exposure to radiation in the six months immediately preceding conception, giving an odds ratio of 0.96 (95% CI: 0.34-2.77), and no case but seven controls were associated with a paternal dose during this period of ≥10 mSv (again a dose category giving a statistically significant association in the study of Gardner et al. (1990)), giving an odds ratio of 0.0 (95% CI: 0-5.86). Paternal exposure to tritium (associated with the operation of Candu reactors) was also assessed in this study. No case but 14 controls were associated with paternal exposure to tritium before conception, producing an odds ratio of 0.0 (95% CI: 0-2.39). The Ontario case-control study, therefore, provides no support for the hypothesis that paternal preconceptional irradiation materially increases the risk of childhood leukaemia in offspring, or that such irradiation plays any role in determining the level of childhood leukaemia in areas around nuclear facilities in the province.

UNITED STATES OF AMERICA

A large number of nuclear facilities are operational or have operated across the US. Thus the study of cancer in populations living near US nuclear facilities carried out by the National Cancer Institute, the results of which were published in 1990 [21] included 62 nuclear facilities, of which 52 are commercial nuclear power stations based upon light water reactors, the great majority of the remaining facilities being Department of Energy sites mainly concerned with the nuclear weapons programme. As noted in the Introduction, when dealing with such a large number of facilities, it is important to ensure that scientifically meaningful studies are conducted which are not influenced by prior knowledge of the data concerning a particular facility or facilities. Where such knowledge is available, unless care is taken to deal with this in the study methodology, results are liable to uninterpretable, particularly if analysis boundaries are constructed with the data in mind. When reviewing results of studies carried out in the US, particularly where individual facilities are concerned, this problem must be kept under consideration.

Early Studies (pre-1980)

A number of geographical correlation studies were carried out around nuclear facilities in the US prior to concerns arising in the UK over childhood leukaemia. These small studies have been reviewed by Patrick [37] who critically assessed eight early studies of populations living near nuclear facilities in the US, as well as carrying out an analysis around Oak Ridge, Tennessee. Tokuhata and Smith [42] reviewed the studies considered by Patrick [37] and a further two studies. Interestingly, the earliest of the studies reviewed was conducted by Moshman and Holland in 1949 [36] who examined cancer incidence around Oak Ridge where nuclear operations had started in 1943. Patrick [37] concluded in his review that

„All but one of these studies have been unable to show adverse health effects in the local population that might related to radiation exposure. The one study that purports to find an adverse effect has severe methodological limitations, which preclude any meaningful interpretation of the data."

Tokuhata and Smith [42] similarly concluded

„Existing studies of human populations living near nuclear facilities have been unable to establish any direct relationship between radiation and adverse health risks, mostly in terms of cancer mortality and infant mortality. When seemingly high rates have been observed in target populations, either similarly high rates have also been observed in control populations removed from the influence of radiation, or the high rates were already in existence in the same area before nuclear facilities went into operation. Otherwise, the results of data analyses have often been inconsistent, suggesting random variations due to small sample size, inadequate study design, and/or inaccurate or incomplete data."

A further study of the effect upon cancer mortality of uranium mill tailings used as construction fill material in Colorado found no evidence for an increased risk [33].

Later Studies (1980 onwards)

A number of studies around individual sites were carried out in the 1980s. Lambert and Cornell [26] examined various health statistics for Charlevoix County, Michigan, containing the Big Rock Point nuclear power station, and found no significant change for any of the variables studied when comparing rates before (1950-62) and after (1963-71) the station became operational. For the four adjacent counties, a marginally significant increase in the combined leukaemia and lymphoma mortality rate for all ages was reported. Stebbings and Voelz [40] examined cancer mortality during 1950-69 and incidence during 1969-74 in Los Alamos County, New Mexico in comparison with control counties. Overall, cancer rates were not unusual, but the white male leukaemia and lymphoma mortality rate was raised and of borderline significance. However, the leukaemia and lymphoma mortality rate for white females was low, and leukaemia and lymphoma incidence rates for white males for the later period were not unusual. Enstrom [11, 12] investigated cancer mortality around the San Onofre nuclear power plant (start-up year 1968) for the period 1960-78. There was no difference in the patterns of cancer or leukaemia in three counties around San Onofre, when compared with either California or US rates. He also examined in detail the pattern of childhood leukaemia mortality around San Onofre, and found no indication that the risk of childhood leukaemia was raised near this plant.

Johnson [23] carried out a study of cancer incidence around the Rocky Flats nuclear weapons plant near Denver, Colorado, during 1969-71. He compared a suburban area of Denver „most contaminated“ with plutonium with an „unexposed“ area, and claimed that cancer incidence was 24% higher in males and 10% higher in females in the former area. The excess was due to a variety of cancers including leukaemia. The methodology of this study has been criticised (for example by Reissland and Darby [39]) because, among other things, of the way that areas were selected for analysis, and because no account was taken of urban and socioeconomic factors. When Crump et al. [9] re-analysed the cancer incidence data for 1969-71, using the same areas as Johnson [23] but taking into account urbanisation, the statistically significant associations disappeared. When a similar analysis was performed with cancer incidence data for 1979-81, a similar pattern was found which was also attributed to urbanisation rather than contamination from Rocky Flats. This is not particularly surprising since Cobb et al. [7], in a study of plutonium in tissues sampled at autopsy, had found that while a small body burden of plutonium could be attributed to Rocky Flats, overall levels around the plant were not distinguishable from those found elsewhere in the US.

Goldsmith [17] examined childhood leukaemia mortality in the three decades between 1950 and 1979 in two counties adjacent to the Hanford facility, Washington State, and two counties adjacent to Oak Ridge. There was a significant excess in the 1950s, a non significant excess in the 1960s, and a non-significant deficit in the 1970s. Milham [34] suggested that, for Hanford at least, the expected number of deaths in the 1950s may have been underestimated by Goldsmith, because of population changes.

Clapp et al. [5] reported an increased incidence of adult (not childhood) leukaemia (particularly myeloid leukaemia in men) during 1982-84 in a five town area of Massachusetts near the Pilgrim nuclear power plant. Subsequently, Poole et al. [38] noted that this excess of adult leukaemia had not persisted into 1985-86, and that the leukaemia incidence rate for the entire period 1982-86 was not unusual. Leukaemia mortality rates for the five towns during 1969-86 were at expected levels. Wilson [44] noted that in Plymouth County, which contains the Pilgrim plant, the number of leukaemia deaths during 1977-86 was less than expected on the basis of Massachusetts rates. Morris and Knorr [35] conducted a case-control study of incident adult leukaemia cases during 1978-86 among persons resident at diagnosis in 22 communities situated near the Pilgrim plant. They found that individuals with the highest assessed potential for exposure to Pilgrim emissions, based upon place of residence and work and meterological and emissions data, had a relative risk of almost 4 when compared with those having the lowest potential for exposure. Unfortunately, the misclassification bias due to this crude exposure assessment has not been quantified by comparison with more rigorous dose reconstruction methods.

Nevada Test Site

Lyon et al. [28] investigated the effect of fallout during 1953-57 from the Nevada nuclear weapons testing site upon childhood leukaemia mortality in southern Utah and claimed that the level relative to northern Utah had increased during the tests and then decreased after the testing period. Land et al. [27] could not confirm these findings from mortality data for 1950-78, and suggested that an anomalously low childhood leukaemia mortality rate in southern Utah during 1944-49 might have been responsible for the findings of Lyon et al. [28]. Johnson [24] carried out a study of cancer incidence among Mormons in south western Utah, and reported levels higher than those expected for all Utah Mormons, particularly for leukaemia and thyroid cancer. Consequently, Machado et al. [29] investigated cancer mortality in south western Utah among those born before 1958. They examined deaths from leukaemia and bone cancer during 1955-80, and from other cancers during 1964-80. They found no excess risk of cancer mortality apart from leukaemia when comparing with rates for the remainder of Utah. The relative risk of leukaemia was 1.45 (95% CI: 1.18-1.79) which included a relative risk for childhood leukaemia of 2.84 (95% CI: 1.65-4.90). Machado et al. [29] concluded that the excess of childhood leukaemia mortality could be the result of weapons testing fallout, but urged caution in the interpretation of the results of a geographical correlation study. Stevens et al. [41] reported the results of a case-control study of leukaemia mortality in Utah among Mormons born before 1959 and dying during 1952-81. A careful programme of dose reconstruction for exposure to fallout was carried out for this study. A weak association between bone marrow dose and all types of leukaemia, all ages and all time periods after exposure was found. However, a significant association was found for acute leukaemia among those who were less than 20 years of age at exposure and died during 1952-63, suggesting that the excess of childhood leukaemia mortality was related to exposure to fallout. The excess risk of childhood leukaemia found in this study is consistent with that predicted from the experience of the Japanese atomic bomb survivors, but it is of interest that an excess risk is apparently discernible among children exposed to low doses (less than 30 mGy). A cohort study of thyroid disease among 4,818 schoolchildren from south western Utah, south eastern Nevada, and south eastern Arizona, potentially exposed to radioiodine from fallout during 1951 58, has been carried out by Kerber et al. [25]. A detailed reconstruction of thyroid doses due to radioiodine in fallout was carried out, the average thyroid dose in Utah being 170 mGy, with a few individuals receiving thyroid doses of almost 5 Gy. A significant association between all (malignant and benign) thyroid neoplasms and thyroid dose was found, but this association was only marginally significant ($p<0.1$) for malignant neoplasms alone. The results were consistent with those reported from other studies of thyroid neoplasms following exposure to radiation.

Three Mile Island

The accident at the Three Mile Island (TMI) nuclear power plant in March 1979 led to small exposures to radiation in the surrounding population. A number of studies have been carried out into the health of the general public following the accident. Berkheiser [1, 2, 3] studied leukaemias and lymphomas, thyroid cancer and breast cancer among patients attending a clinic in Harrisburg near the TMI plant before and after the accident. He found no increase in these malignant diseases during the five years after the accident. Hatch et al. [18] studied cancer incidence among those living within 10 miles of the TMI plant during 1975-85, paying particular attention to leukaemia and childhood cancers. Doses due to emissions during the accident were reconstructed and validated using data from environmental dosimeters. For neither leukaemia nor childhood cancer was an association with assessed exposure evident, although a non-significantly raised risk of childhood leukaemia was observed, based on a handful of cases. Non-Hodgkin's lymphoma (all ages) did show a marginally significant association with assessed exposure level, although this was partly due to depressed incidence ratios in the lowest exposure categories. For all cancers combined, a marginally significant raised risk was found which was entirely accounted for by lung cancer. However, lung cancer incidence was unusually low in the period 1975-79 preceding the accident, and the significance of the lung cancer association disappears when this is accounted for. This may be due to an effect of smoking which is very difficult to deal with in geographical correlation studies. These authors concluded „Overall, the pattern of results does not provide convincing evidence that radiation releases from the Three Mile Island nuclear facility influenced cancer risk during the limited period of follow-up". Hatch et al. [19] went on to consider the role that stress might have had on the risk of cancer around the TMI plant. This study took into account radiation exposure as assessed in the previous study. Some evidence for an effect of stress was found, although the authors were cautious in their conclusions, pointing to the possible impact on their results of improved surveillance of cancer near the TMI plant.

National Cancer Institute Study

The most extensive study of cancer near nuclear facilities in the Unnited States has been carriedout by Jablon et al. [21, 22] from the National Cancer Institute. Cancer mortality during 1950-84 for counties in which 62 nuclear facilities were located (and certain adjacent counties) was studied together with that for three control counties for each facility county, selected from the same geographical area. Standardised mortality ratios (SMRs) were calculated for 16 classes of cancer for each facility and associated control areas before and after the start-up of each facility, and relative risks were computed from the ratio of SMRs. In addition, cancer registration data from the Surveillance, Epidemiology and End Results (SEER) program were available for five counties associated with four nuclear power plants and their matched control counties. Counties are the smallest areas for which population estimates and the numbers of cause-specific deaths are available at a national level. Control counties were matched with facility counties on the basis of racial and certain other socioeconomic factors.

For leukaemia mortality under the age of 10 years, the relative risk (RR) for all facilities combined after start-up was 1.01/0.97 = 1.03 while before start-up RR = 1.07/0.99 = 1.08. Given the results of the study in England and Wales reported by Forman et al. [13] where a raised relative risk was found for the older nuclear facilities rather than the nuclear power plants, Jablon et al. [21] gave separate results for the group of Department of Energy (DoE) facilities, and for childhood leukaemia this group gave, after start-up, RR = 1.01/0.96 = 1.06, and before start-up, RR = 1.18/0.84 = 1.45. Consequently, there is no confirmation from this large study carried out in the US of a raised risk of childhood leukaemia associated with nearness to a nuclear facility. A similar pattern of results is obtained for leukaemia mortality at all ages. For mortality from all cancers except leukaemia at all ages, for all facilities combined, after start-up, RR = 1.02/1.02 = 1.01, and before start-up, RR = 0.99/1.01 = 1.00, and for the DoE facilities, after start-up, RR = 1.06/0.99 = 1.04 and before start-up, RR = 1.04/0.96 = 1.06. Therefore, there is little evidence from this study that the operation of nuclear facilities has influenced the risk of cancer at the county level.

One facility, the Millstone nuclear power plant in New London County, Connecticut, did show a significantly raised risk of childhood leukaemia incidence after start-up: RR = 1.55/0.51 = 3.04. However, as discussed in the Introduction, the concentration upon one result in a large survey such as this can be misleading, and Jablon et al. [22] have noted that the increase in childhood leukaemia started before the commencement of operations at the Millstone plant.

The authors of this large study appreciated the limitations of the study in that it is a geographical correlation study, primarily based upon mortality data, and conducted at the county level. However, they did point out that a similarly designed study carried out in England and Wales [13] did find a raised relative risk of childhood leukaemia mortality near older nuclear installations. Jablon et al. [22] concluded that the study „does not prove the absence of any effect. If, however, any excess cancer risk was present in US counties with nuclear facilities, it was too small to be detected with the methods employed."
Howe [20], commenting upon this study, concluded

„Thus, in view of these and the other limitations discussed by the authors, this study cannot be regarded as definitive. It is, however, important in defining one more piece of the puzzle. This study, in conjunction with the extrapolated results from high-dose studies, provides substantive evidence that the normal operation of nuclear facilities in the United States does not lead to any undue risk of cancer in those residents living near such facilities."

CONCLUSIONS

Viewed alone, the epidemiological studies of cancers near nuclear facilities in Canada and the United States of America provide no evidence that the assessed risk of cancer from discharges of radioactive material have been underestimated. The only persuasive evidence of a discernible effect of radiation exposure is from areas downwind of the Nevada nuclear weapons test site, particularly for childhood leukaemia. However, these findings are compatible with risk estimates derived from high dose studies. Studies carried out in Britain have suggested that the risk of childhood leukaemia is raised near nuclear facilities. This suggestion is not supported by studies carried out by McLaughlin et al. [31] in Ontario, Canada, and by Jablon et al. [22] in the US.
As noted in this article, most of the epidemiological studies of cancer around nuclear facilities in North America have been geographical correlation studies, and therefore cannot be regarded as definitive. The case-control and cohort studies which have been carried out in Canada and the US have not revealed any unexpected effect of radiation exposure. A number of dose reconstruction projects are currently underway in the US in relation to several nuclear facilities, for example Hanford. The doses produced by these projects will be used in individual-based studies, which will provide firm foundations for the detailed epidemiological assessment of the effects of radioactive releases from these facilities.

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