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CHILDHOOD LEUKAEMIA AROUND CANADIAN NUCLEAR FACILITIES - PHASE II

FINAL REPORT

by

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Report

CHILDHOOD LEUKÆMIA AROUND CANADIAN FACILITIES — PHASE II

A report prepared by Drs. E.A. Clarke and J. McLaughlin, Ontario Cancer Treatment and Research Foundation, Division of Epidemiology and Statistics, and Dr. T.W. Anderson, University of British Columbia, under contract to the Atomic Energy Control Board.

ABSTRACT

Recent studies in the United Kingdom have demonstrated an increased occurrence of childhood leukæmia in the vicinity of some nuclear facilities. In particular, these studies have reported relatively high rates of leukæmia among children born in the vicinity of a nuclear fuel reprocessing facility (Sellafield). Prompted by the findings in the United Kingdom, this study aimed to investigate whether the frequency of leukæmia among children born to mothers residing in the vicinity of nuclear facilities in Ontario differed from the provincial average.

The Ontario Cancer Registry was used to identify children, aged 0-14 years, who died from leukæmia between 1950 and 1987, or who were diagnosed with leukæmia between 1964 and 1986. A total of 1894 children who died from leukæmia were eligible for the mortality analysis and 1814 children were eligible for the incidence analysis. Residence at birth and death was obtained from birth and death certificates, respectively.

Analyses were performed separately for each of three general types of nuclear facilities (nuclear research and development facilities; uranium mining, milling and refining facilities; and nuclear generating stations), and for two levels of geographic area around each facility (county and "nearby" area within a 25-kilometre radius).

Relative risk estimates were calculated for each facility and each geographic area as the ratio of the observed (O) number of events over the expected (E) number. For the calculation of mortality ratios by residence at death, the expected values referred to the number of deaths that would be expected, on the basis of provincial rates, in a given population of children aged 0-14 years. For the calculation of mortality and incidence ratios by residence at birth, the expected values referred to the number of events that would be expected for a given number of live births.

The statistical analysis included the calculation of confidence intervals which indicate the range of values in which the true relative risk is likely to lie. If the confidence interval includes a value of 1.0 then it is likely that the difference between the observed and expected numbers was due to chance.

The observed number of children with leukæmia in the vicinity of the nuclear research and development facility in Renfrew County was less than the expected number. The mortality ratio by residence at birth was 0.33 (O=2, E=6.1) for the area "nearby" the research and development facility from 1950 to 1987. Results of the analyses of

differences between these mortality ratios could have been due to chance. Therefore, these results do not constitute proof that there was a true difference in the risk of leukæmia during the periods before and after the facility opened.

In summary, in the vicinity of nuclear research and development facilities, the rate of leukæmia was, in fact, less than expected and within the bounds of chance variation. In the areas around the uranium mining, milling and refining facilities, leukæmia occurred slightly more frequently than expected; however, due to small frequencies these differences may have arisen by chance. In the vicinity of nuclear generating stations in Ontario, a greater than expected occurrence of leukæmia was also detected, which may have been due to chance. Confidence intervals were wide for some facilities because of the small observed and expected numbers.

Large differences between the observed and expected rates, such as the ninefold excess reported near the Sellafield facility in the United Kingdom, were not detected around any of the Ontario facilities. This study was large enough to detect excess risks of the magnitude reported in the United Kingdom, but it was not large enough to discriminate between the observed relative risks and a chance finding.

This study did not detect levels of childhood leukæmia in the vicinity of nuclear facilities that were significantly different from the expected level; however, the levels that were detected in the vicinity of the nuclear generating stations indicate the need for further investigation.

RÉSUMÉ

De récentes études au Royaume-Uni ont révélé qu'il y avait davantage de cas de leucémie infantile au voisinage de certaines installations nucléaires. Ces études font notamment état d'un nombre relativement élevé de cas de leucémie chez des enfants nés dans le voisinage d'installations nucléaires qui retraitent le combustible (Sellafield). La présente étude, entreprise à la lumière des conclusions de l'étude menée au Royaume-Uni, a pour objectif de vérifier si la fréquence des cas de leucémie chez des enfants nés de mères habitant à proximité d'installations nucléaires en Ontario diffère de la moyenne provinciale.

Grâce au fichier des cas de cancer de l'Ontario (Ontario Cancer Registry), on a pu établir une liste des enfants de 14 ans et moins qui sont morts de leucémie entre 1950 et 1987 ou chez qui on a diagnostiqué la leucémie entre 1964 et 1986. Au total, 1894 enfants morts de leucémie ont été retenus pour l'analyse du taux de mortalité et 1814 enfants pour l'analyse d'occurrence. On a pu retracer leur lieu de résidence à la naissance à partir des certificats de naissance et leur lieu de résidence au décès à partir des certificats de décès.

On a analysé séparément chacun des trois types généraux d'installations nucléaires (installations de recherche nucléaire; mines, usines de concentration et raffineries d'uranium; centrales nucléaires) et deux différentes zones géographiques autour de chaque

«avoisinantes», selon le lieu de résidence à la naissance. Comme les intervalles de fiabilité de toutes les estimations pour les mines et les installations de concentration et de raffinage comprenaient une valeur de 1,0, il se peut que les écarts entre les fréquences observées et prévues soient dus au hasard.

Les cas de leucémie infantile à proximité des centrales nucléaires étaient plus nombreux que prévu, bien que les écarts observés puissent être attribuables au hasard. Dans la région «avoisinante» de la centrale nucléaire de Pickering, le taux de mortalité selon le lieu de résidence à la naissance était de 1,34, avec des valeurs de O=33 et de E=24,6 pour la période 1971-1987. Dans la région «avoisinante» de la centrale nucléaire de Douglas Point, le taux de mortalité de 2,78 selon le lieu de résidence à la naissance a été obtenu à partir d'un tout petit nombre de cas (O=3, E=1,1) entre 1967 et 1987. Pour ce qui est des deux centrales nucléaires, les ratios de mortalité selon le lieu de résidence à la naissance étaient supérieurs aux ratios de mortalité selon le lieu de résidence au décès et aux ratios d'occurrence. L'estimé du ratio global de mortalité selon le lieu de résidence à la naissance pour la région «environnante» de l'une ou l'autre des deux centrales nucléaires était de 1,40 (O=36, E=25,7) et la limite inférieure de l'intervalle de fiabilité (0,98) se rapprochait de 1,0. Les limites de fiabilité pour l'ensemble des estimations de risque relatif près des centrales nucléaires comprenaient la valeur 1,0, de telle sorte que la différence entre les nombres de cas observés et prévus peut être attribuable au hasard, comme dans le cas des mines, des usines de concentration et des raffineries d'uranium, bien que les résultats de l'analyse regroupée se rapprochent des limites de variations dues au hasard.

Au cours de la période qui a précédé la mise en service de la centrale électronucléaire de Pickering (1950-1970), le taux de mortalité selon le lieu de résidence à la naissance pour la région «avoisinante» était de 1,08 (O=80, E=74,1); après la mise en service de la centrale, ce taux est passé à 1,34 (O=33, E=24,6). Comme l'écart entre ces ratios de mortalité pourrait être dû au hasard, les résultats ne doivent donc pas constituer la preuve d'un écart véritable entre des risques de leucémie au cours des périodes ayant précédé et suivi la mise en service des installations.

En résumé, les cas de leucémie près des installations de recherche nucléaire ont été moins nombreux que prévus et dans les limites d'une variation attribuable au hasard. Aux alentours des mines et des installations de concentration et de raffinage de l'uranium, les cas de leucémie ont été un peu plus nombreux que prévu, mais vu le nombre minime de cas observés, il est possible que ces résultats soient dus au hasard. À proximité des centrales nucléaires de l'Ontario, on a décelé un nombre plus élevé que prévu de cas de leucémie et ce résultat pourrait être dû au hasard. Les intervalles de fiabilité étaient prononcés pour certaines installations en raison du petit nombre de cas observés et prévus.

L'étude n'a pas permis de constater d'écarts importants entre les taux observés et prévus à proximité des installations nucléaires ontariennes, comme le risque excessif de leucémie neuf fois supérieur

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Erratum

The sentence on page 8 reading:

> "Separate analyses could not be performed for the Rolphton facility because, in addition to the overlapping boundaries, the area had a very small population and a single work-force operated both the Chalk River and Rolphton facilities.",

should read:

> "Separate analyses could not be performed for the Rolphton facility because, in addition to the overlapping boundaries for the "nearby area", the area had a very small population and the work-force for both the Chalk River and Rolphton facilities came from a single population base.".

CHILDHOOD LEUKAEMIA AROUND CANADIAN NUCLEAR FACILITIES - PHASE II

A. INTRODUCTION

An elevated frequency of leukaemia in children living in Seascale, a village near the nuclear fuel reprocessing plant in Sellafield on the west coast of England, was reported in a television program in 1983. This report generated intense interest and an independent enquiry was undertaken by the British Government. The enquiry concluded that there was an excess of leukaemia in the Sellafield area, but that on the basis of current knowledge the radiation doses received by the population in the area could not account for this excess. [Ref. 1,2]

Subsequently, Gardner et al. [Ref. 3,4] examined cancer mortality and incidence in two groups of children: those who were born to mothers who resided in Seascale and those who attended school in Seascale but were born elsewhere. This study confirmed the excess mortality from childhood leukaemia but it was noted that the excess risk was confined to children who were born to mothers residing in Seascale at the time of the child's birth. Five leukaemia deaths had occurred among this "birth cohort" of children who were born between 1950 and 1983, resulting in a mortality ratio of 9.4 (observed (O)=5, expected (E)=0.53; 95% confidence interval of 3.0 to 21.8). No increased risk was detected for children who attended school in Seascale but were born elsewhere (O=10, E=12.7; mortality ratio of 0.8; 95% confidence interval of 0.4 to 1.5).

An association between leukaemia incidence in young people and residence near the other British reprocessing plant (Dounreay, in northern Scotland) was reported by Heasman et al. [Ref. 5] and discussed in detail in the second COMARE report. [Ref. 6] For the period 1968 to 1984 there were five leukaemia deaths in the 0-24 year age group, compared to 1.5 expected, resulting in a mortality ratio of 3.3. However, the Dounreay experience was not as consistent over time as that at Seascale. From 1968 to 1978 there were no leukaemia deaths (versus 1.1 expected), while from 1979 to 1984 there were five leukaemia deaths versus 0.5 expected. No study has yet been reported that focused on the risk among children whose mothers resided in Dounreay at the time of birth.

Other studies in the United Kingdom (U.K.) have examined leukaemia rates around nuclear weapons establishments in addition to those around nuclear power stations. In the study by Roman et al. [Ref. 7], an increased death rate from leukaemia was detected in children aged 0-4 years in the vicinity of nuclear weapon research and manufacturing facilities at Aldermaston and Burghfield (O=29, E=14.4).

A detailed study of cancer incidence and mortality around all nuclear installations was conducted by the Office of Population Census and Surveys in the U.K. This large study, which has been summarized by Forman et al. [Ref. 8], and Cook-Mozaffari et al. [Ref 9], confirmed the increased occurrence of childhood leukaemia in the Sellafield area and identified an increased risk of childhood leukaemia around nuclear facilities that began operating prior to 1955. Forman et al. and Cook-Mozaffari et al. also reported that for nuclear power stations that began operation after 1955 the leukaemia rates in the 0-24 age group were, in fact, slightly lower than expected.

The associations that have been demonstrated in the U.K. between childhood leukaemia and proximity to some nuclear installations have been difficult to explain. On one hand, the consistency with which elevated rates have been found argues in favour of it being more than a set of chance findings. On the other hand, even at Sellafield, where the known emissions have been much greater than at any other site, the potential radiation exposures of the population were too low to explain the abnormal leukaemia patterns. [Ref. 1] In a recent report by Cook-Mozaffari et al. [Ref. 10], which extended their earlier work in the U.K. [Ref. 8,9], communities where future nuclear facilities were planned were found to have the same level of excess risk as the areas around existing nuclear facilities, which suggests that the excess cancer may have been due to unrecognized risk factors other than environmental radiation pollution. In addition, it has been difficult to explain the "birth cohort" effect seen at Seascale, but possible mechanisms that have been proposed include (1) a pre-conception exposure of sperm or ova, (2) in-utero exposure of the mother, and (3) a hand-to-mouth pathway for radioactive dust in the first year or two of life (perhaps due to dust on parental clothing being brought into the home). [Ref. 6]

A recent report by Gardner et al. [Ref. 11] provided important evidence about potential causes of the excess of childhood leukaemia in the vicinity of Sellafield. This case-control study examined whether the observed excess of leukaemia was associated with established risk factors, such as in-utero exposure to x-ray, or with factors related to the plant. The most important finding was that the external dose of whole body ionizing radiation to fathers during employment at Sellafield was associated with the development of leukaemia among their children. For example, children of workers who had a lifetime dose of $\geq$ 100 milli-Sieverts before conception were at more than a six-fold excess risk of leukaemia.

As a possible mechanism, Gardner et al. speculated that an effect of ionizing radiation on fathers may be a mutation in sperm that is leukaemogenic in offspring. Other explanations have also been proposed, including that the fathers who received a high whole body exposure to radiation may also have received work-place exposure to other factors, such as chemicals or internally incorporated radionuclides. In addition, it must be noted that the paternal exposure result was based on small numbers (e.g., the relative risk of 6 was based on four exposed cases). Nevertheless, the observation made by Gardner et al. is important since it suggests that the most likely cause of the leukaemia cluster around Sellafield was an occupational exposure of fathers, rather than an environmental contamination that affected the general population. The hypothesis that paternal exposure to radiation is a cause of childhood leukaemia must now be tested by studies in other settings, such as those that are under way in the U.K.

Canada has neither fuel reprocessing plants nor weapons research and manufacturing facilities. However, it does have reactor research establishments at Chalk River, Ontario, and Pinawa, Manitoba, where experimental processes could give rise to a wide range of potential emissions. There are also uranium mines, mills and refineries in Ontario and other parts of Canada that could potentially release radioactive dust into the environment. Finally, there are nuclear power generating stations in Ontario, Quebec and New Brunswick which may release low levels of radioactive waste into the environment.

The present study used a population-based cohort approach within Ontario, the only province that has all three types of Canadian nuclear activity. Childhood leukaemia risk was initially examined in the vicinity of the nuclear research facility as a test of the hypothesis relating to Sellafield; then in the areas around the uranium mining, milling and refining facilities to explore the hypothesis that radioactive dust might be involved. Finally, even though there was no prior evidence from the U.K. of there being an adverse health effect, an exploratory analysis was performed in the vicinity of the nuclear generating stations.

The study examined the occurrence of leukaemia in subjects who died from the disease (mortality) and those who were diagnosed with the disease (incidence). An advantage of using incidence rather than mortality as a study outcome, as has been previously recognized [Ref. 7], is that since advances in treatment have occurred during the study period [Ref. 12], mortality has become a less sensitive outcome, while incidence has not been affected. Both incidence and mortality have been used in this study, which is similar to the approach used by Gardner et al. [Ref 3,4] and differs from others that included only mortality. [Ref. 8,9]

B. OBJECTIVES

The primary objective of this study was to investigate whether the frequency of leukaemia among children born to mothers residing in the vicinity of nuclear facilities in Ontario differed from the provincial average. The secondary objective of the study was to determine whether the relative risk of leukaemia was greater when examined in terms of residence at time of birth (i.e., the "birth cohort"), than by residence at time of death. A tertiary objective was to assess, where possible, whether the relative risk of leukaemia was different in the periods before and after the opening of a nuclear facility.

The observed numbers of leukaemia deaths and incident leukaemia cases were compared with the numbers that were expected on the basis of provincial leukaemia rates. Analyses of the occurrence of childhood leukaemia were performed for three components of the study: first, around the research facility at Chalk River (primary hypothesis); second, around the Port Hope uranium refinery and the Elliot Lake uranium mining and milling facility (secondary hypothesis); and third, around the power generating stations at Pickering and in Bruce County (exploratory investigation).

The study was performed in two phases. In Phase I, the occurrence of leukaemia was studied in children aged 0-4 years, because this age group had the highest mortality ratios in the British studies. The Phase I report concluded that slightly more leukaemia cases and deaths occurred than were expected, that the excess could have arisen due to chance and that the study should be expanded to include a wider age range to improve the statistical reliability of the results. [Ref. 13] In Phase II, therefore, leukaemia rates were examined among children aged 0-14 years, which approximately doubled the total number of children in the study. The present report therefore summarizes the work performed in both Phases I and II.

C. METHODS

C.1 Overview of Study Methods

Leukaemia deaths and incident cases among children aged 0-14 years were identified from the Ontario Cancer Registry (OCR). The OCR, which is operated by the Ontario Cancer Treatment and Research Foundation, is described in detail in Appendix A. Wherever possible, the residence of the mothers at the time of birth and of the children at time of death was determined. The number of subjects residing at birth or death in each of the areas under study was also determined. Analyses were performed at the county level and for the areas within a 25 kilometre (km) radius ("nearby" area) around each of the five nuclear facilities. For the primary and secondary objectives, the period of observation started in the year each nuclear facility began operation or when leukaemia data became available, whichever was most recent. All analyses continued to 1987 for mortality and 1986 for incidence. For the subanalysis of leukaemia patterns before and after the nuclear facilities began operation (tertiary objective), it was only feasible to examine mortality in the vicinity of Pickering Nuclear Generating Station. Ratios of the observed number of deaths and incident cases over the expected number were calculated in order to detect whether the frequency of leukaemia differed from the provincial rate. Details of subject selection, record linkage, data collection and statistical methods are summarized.

C.2 Subject Selection and Data Collection

Using the OCR, death records were located for 2181 children aged 0-14 years who resided in Ontario and who died from leukaemia between 1950 and 1987. Similarly, the OCR was used to identify 2374 children aged 0-14 years who resided in Ontario and who were first diagnosed with leukaemia between 1964 and 1986, since incidence data from the OCR are available only for these years. Children aged 0-14 years who died from leukaemia between 1964 and 1986 were eligible for inclusion in both the mortality and incidence analyses.

The criteria for inclusion in the study were: leukaemia (International Classification of Diseases, Ninth Revision (ICD-9), 204-208) [Ref. 14] registered from 1950 to 1987 for deaths, and 1964 to 1986 for incident cases; 0-14 years of age at the time of death or diagnosis; resident in Ontario at the time of death or diagnosis; and a match of OCR information with birth certificate data. The final criterion was necessary in order to identify maternal residence at the time of a child's birth as recorded on the birth certificate. A definite match of OCR and birth records was defined as complete agreement of full name (as available in the OCR), full date of birth and sex. For subjects with insufficient identifying information in the OCR, original records, such as death certificates and hospital charts, were searched for more complete information.

To perform the birth certificate linkage, data collection forms were developed and pre-printed with identifying information from the database of the OCR. With the permission of the Registrar General of Ontario, birth certificates of the children were located and details of maternal residence at time of birth were obtained. Death certificates were also examined in order to obtain additional identifying and residence information. To demonstrate the nature of the data and the way they were abstracted, copies of birth and death certificates are attached as Appendix B, and a copy of the Phase II data collection form is attached as Appendix C.

Residence at the time of the child's birth was assigned the Standard Geographic Code (1981 revision). [Ref. 15] In addition, residence at the time of death was available from the OCR for the subjects who died from leukaemia. Details of the residence coding procedures are described in Appendix D.

Table 1 lists the number of subjects who were initially identified for the mortality analysis (n=2181) and the number who met the selection criteria to be included in the study (n=1894). Two children were classified as "probable" matches because of inconsistencies between OCR and birth certificate information: the order of given names differed in the OCR and on the birth certificates, and since they died outside Ontario, death certificates could not be used for verification. The birth certificates with which these two children were linked indicated that the residence was outside the counties under study.

The following 251 children were excluded from the mortality analysis based on additional information: 214 children who were born outside Ontario; 32 adopted children for whom identifying information regarding the birth parents was deleted from the birth certificates; three children born in Ontario whose maternal residence was outside Ontario; one child who had a duplicate death registration; and one subject with an incorrect date of birth where the actual age at death was greater than 14 years.

Thirty-six subjects were excluded from the mortality analysis because birth certificate records could not be linked with the OCR information: for 33 subjects birth certificates could not be traced (there is some evidence that two of these were born outside Ontario); for three subjects the OCR contained inadequate identifying information (e.g., missing name or date of birth, invalid death certificate number). The proportion of records that were successfully linked in the mortality study was therefore 98% (2145/2181).

The numbers of subjects initially identified for (n=2374) and finally included in (n=1814) the incidence analysis are listed in Table 2. Among the subjects whose records were linked, 497 were excluded from the study. Records were not linked for 63, or 3% (63/2374), of incident cases because all efforts to identify birth records failed. (There is some evidence that eight of these cases were born outside Ontario). More difficulty was experienced in locating the birth certificates of children in the incidence study than in the mortality study. First, for those children who did not die, death certificates could not be used as an additional source of information. Second, identifying information for many cases was incomplete in the OCR during the early years of registration because of the practice of truncating names and entering incomplete dates of birth.

The following 497 children were excluded from the incidence analysis: 193 children who were born outside Ontario; 157 children whose diagnosis was confirmed not to be leukaemia; 54 children whose diagnosis could not be confirmed; 50 adopted children for whom parents' identifying information was removed from the birth certificate; 14 cases who had duplicate cancer registrations; 10 who were prevalent cases (i.e., diagnosed before 1964); seven children who were born in Ontario but maternal residence was outside Ontario; seven cases who were not residents of Ontario at the time of diagnosis; and five who had incorrect dates of birth and their actual age at diagnosis was found to be greater than 14 years.

The most important reason for exclusion was uncertainty about the diagnosis of leukaemia. The OCR has previously detected over-reporting of childhood cancer and there is an ongoing effort to confirm the diagnosis of childhood leukaemia. [Ref. 16] Therefore, for this study, it was necessary to review hospital charts in order to confirm the leukaemia diagnoses.

Incidence data are only available in the OCR from 1964; therefore, leukaemia incidence could not be studied for the whole period of operation for all the nuclear facilities. Mortality data, on the other hand, are available in the OCR from 1950. To ensure that the study outcomes were both sensitive (e.g., to changes in survival) and available for the relevant time periods, both mortality and incidence were therefore employed. It must be noted, however, that the two outcomes were not independent. Of the 1814 incident childhood leukaemia cases (1964-1986), 1102 died (61%) within the age range and time period of the study and were therefore included in both the mortality and incidence analyses.

Figures 1 and 2 display leukaemia mortality and incidence rates per 100,000 person-years from birth as five-year moving averages for three age groups (0-4, 5-9, 10-14). Figure 1 shows that mortality rates are highest in the youngest age group and, in each age group, have declined since the early 1970s. Figure 2 shows a similar pattern for incidence rates among the age groups; however, unlike mortality, there has not been a decline in recent years. The incidence rates shown in Figure 2 have a similar interpretation to the standard incidence rates which are expressed per 100,000 population. The leukaemia rates per 100,000 population for both sexes combined in 1986 were 9.3 for ages 0-4, 3.3 for ages 5-9 and 3.9 for ages 10-14.

Table 3 shows the number of children in each of three age groups who were included in the mortality and incidence analyses. The frequencies in the 0-4 age group in Table 3 are slightly greater than those in the Phase I report because an extra year of mortality and incidence data became available from the OCR. The youngest age group contributed more to the total than the other age groups (e.g., 43% of mortality subjects and 55% of incidence subjects are in the 0-4 age group), which is a reflection of the progressive decline in age-specific leukaemia rates per 100,000 live births as illustrated in Figures 1 and 2.

The distribution of the types of leukaemia in the 1894 children included in the mortality analysis is listed in Table 4a. For each of the three age groups, the majority of cases were classified as ICD-9 site 208 (unspecified cell type), followed by ICD-9 site 204 (lymphoid leukaemia). With increasing age there was a decreasing proportion of cases with unspecified cell type.

Table 4b shows frequencies by type of leukaemia for the cases included in the incidence analysis. In contrast to the mortality data, the proportion of cases diagnosed with leukaemia of unspecified cell type (ICD-9 208) is relatively constant across the age groups. In a more detailed analysis in the five areas under study, it was observed that the proportion of incident cases who were classified as unspecified cell type (ICD-9 208) was 14.0%, which was similar to the range that was observed in the three age groups in Table 4b (i.e., 15.3 to 19.8%). This finding indicates that in the areas under study the proportion of cases classified as unspecified cell type was similar to that of the province.

Leukaemia type was examined in more detail for the 1102 children who were included in both the mortality and incidence analyses. This revealed that the primary reason for the apparent discrepancies in Tables 4a and 4b was that 27% (166/609) of the children who were diagnosed with lymphocytic leukaemia (ICD-9 204), were classified on the death certificate as leukaemia of unspecified cell type (ICD-9 208). This indicates that the primary reason for the large number of nonspecific diagnoses in Table 4a was that detailed diagnostic information was lacking on death certificates.

C.3 <u>County and Community Level Data</u>

Two levels of geographic area were used in this study: counties and "nearby" areas that were within the counties. "County" is used in this report to refer to census divisions, one of which is a "district" (Algoma) and one a "regional municipality" (Durham). However, in this report, Durham Regional Municipality refers to Durham Regional Municipality excluding Newcastle Town and including Markham Town and Scarborough Borough. As well, Newcastle Town has been included in the definition of Northumberland County. These adjustments were necessary in order to define complete "nearby" areas (Appendix E). The counties under study are described in Table 5 in terms of their nuclear facilities and populations. The differences in the date of initial operation, the type of facility, and the population in each county should be noted. As shown in Table 5, two nuclear power facilities have operated in Bruce County; first the Douglas Point station and later the Bruce Nuclear Power Development station. The term "Douglas Point" in the remainder of this report refers to the location of both these installations.

"Nearby" areas were defined by census subdivisions (i.e., from township up to city) within 25 km of nuclear facilities. Maps of the five counties under study are presented in Appendix E. Both rural and urban areas were included in the definition of the "nearby" area. As shown on the map of Renfrew County, the areas within 25 km of the Chalk River facility overlapped considerably with the 25 km circle around Rolphton. The Rolphton facility was a small experimental reactor for power generation that was in operation from 1962 to 1988. Separate analyses could not be performed for the Rolphton facility because, in addition to the overlapping boundaries, the area had a very small population and a single work-force operated both the Chalk River and Rolphton facilities. Therefore, in addition to the analyses of the "nearby" Chalk River area, a secondary analysis was performed on a pooled area within 25 km of either facility.

The use of a 25 km radius as the focus of the "nearby" analysis in this study was necessitated by the low population densities close to most facilities. The smallest geostatistical unit for which vital statistics and census data are reported is the census subdivision, which is relatively large in area. As shown on the maps (Appendix E), the circle around each of the facilities was close to the boundary of the census subdivision in which the facility was located. The use of a shorter radius, as had been used in the U.K., was therefore inappropriate for Ontario. It must be emphasized that the county level analyses cannot be strictly interpreted as an indication of whether there is a radial gradient of effect because of the great diversity in the sizes and shapes of the counties.

The population of children aged 0-14 years was determined for each area from census publications [Ref. 17] and was used to interpolate the annual population between census years. Annual live birth totals were obtained from published vital statistics for the above counties from 1950 to 1987. [Ref. 18] In addition, annual birth totals were obtained for "nearby" communities, using published data where possible.

Unfortunately, for some years, live birth totals were not available for communities or rural areas that fell within several of the "nearby" areas. For example, in Renfrew County data were unavailable for several communities (e.g., Deep River Town, Chalk River Village from 1954 until 1961) and for several townships (e.g., Petawawa from 1949 until 1973). There were two reasons why data were unavailable. First, these communities (e.g., townships, villages) had small populations; therefore they were not consistently included as a unit for the reporting of vital statistics and were classified as "county-other". Second, the boundaries for several of these communities have changed over time, so that the enumeration of live births has also required a careful review of the historical development of small Ontario communities during the past three decades. Details of the boundary changes are presented in Appendix F.

There were three strategies that could be followed in order to obtain the unavailable live birth frequencies by maternal residence for these small communities. First, the actual number of live births by maternal residence could have been obtained for each of the communities with missing data by reviewing every certificate for live births classified by maternal residence in "county-other". This was not feasible because it would require searching potentially thousands of birth certificates over the first 24 years (i.e., 1950-1973) of this study. Second, only data that were available from published sources could have been used, but this would have allowed the analyses to be performed for all "nearby" areas from 1974 only. Third, the number of live births in each census subdivision with unavailable data could be estimated by multiplying the birth rate in "county-other" areas by the best available estimate of the population in the census subdivision. In this report, the third option has been chosen. Details of this estimation procedure are given in Appendix G and the magnitude of the potential bias is examined in Section E.6.9.

C.4 Methods of Analysis

Relative risk estimates were obtained as the ratio of the observed number of events (O) over the expected number of events (E) for each area under study. The expected numbers of events were based on the rates of childhood leukaemia in Ontario. The province of Ontario was used as the basis for comparison because its large population provided the greatest level of numerical stability that could be achieved. For the mortality analysis, a mortality ratio was calculated, whereas in the analysis of incidence an incidence ratio was calculated. The mortality ratios were calculated on the basis of both the subject's residence at time of death and the maternal residence at time of the subject's birth. The incidence ratios were calculated using only maternal residence at time of the subject's birth. For the remainder of this report, the term "residence at birth" will refer to the mother's residence at time of the child's birth.

The mortality ratio is the ratio of the observed number of deaths to the number that would be expected to occur in an area under study. The expected numbers were products of the population of children in each of the three age groups in the areas under study and the leukaemia mortality rate in Ontario children of the same age and over the same period of time. By obtaining observed and expected numbers of events in each of the five-year age groups and time periods, the analysis adjusted for the variation in age- and period-specific leukaemia rates. No adjustment was made for sex because no sex differential has previously been detected. [Ref. 3,4]

The mortality ratios were initially examined for all age and time periods combined and also separately where numbers permitted. Whether there was "significant" variation in the relative risk across age groups and time periods was tested by likelihood ratio tests obtained from Poisson regression models as developed for cohort studies. [Ref. 19] The primary statistical assumptions of the analyses are that the Poisson model holds and that the Ontario rates are appropriate for calculating the expected number of cases.

In addition to the estimated mortality ratio, it is important to recognize the potential effect of random variability in data and to estimate the range of values between which the true mortality ratio is likely to lie. The conventional level of alpha (i.e., 0.05) was chosen for the calculation of confidence intervals to conform with standard statistical practice. Approximate 95% confidence intervals were obtained using Byar's method. [Ref. 19]

A 95% confidence interval is a range between which the value of the true mortality ratio is expected to lie 95% of the time. The lower bound of a 95% confidence interval around a mortality ratio that is greater than 1.0 can be used to assess whether the observed excess risk is greater than that which is due to chance. If the lower bound is less than 1.0, then it can be concluded that the detected difference between observed and expected numbers of events is probably due to chance. A final feature of confidence intervals is that their width provides an indication of the precision of an estimate. A large relative risk with a wide confidence interval is based on a small number of expected events and should therefore be interpreted with caution.

Studies in the U.K. [Ref. 3,4] demonstrated that residence at birth may be more important than residence at death; therefore, mortality ratios by residence at birth were calculated, and are presented as the main analytic approach in this report. The choice of how residence should be classified in the calculation of mortality ratios is dependent on when an exposure is suspected to have its effect. If an exposure had its effect near the time of birth, then the mortality ratio by residence at birth would be the analytic method of choice. If an exposure had its effect later in life, then the mortality ratio by residence at death would be preferred.

The mortality ratio by residence at birth is the ratio of the observed number of deaths to the number that would be expected to occur in an area with an equal number of live births, tabulated by year of birth and by the residence at the time of the child's birth. Because of the difficulty in estimating the number of live births prior to 1950, only those deaths occurring in children born in 1950 or later were eligible for this style of analysis. A total of 248 children born between 1935 and 1949 were therefore excluded, leaving 1,646 deaths for the mortality analysis by residence at birth. The expected value was the product of the provincial rate of leukaemia deaths per number of live births and the number of live births in the area under study over the same time period. Confidence intervals were calculated using the method described above for the mortality ratio by residence at death.

The mortality ratio by residence at birth is a valid estimate of relative risk under the assumption that the rate of migration out of the province is equal for the areas under study and for the Ontario population. The possible impact of migration on the mortality ratios was examined, as described in Section E.6.1.

Pooled estimates of relative risk were calculated for facilities of similar type. For the secondary hypothesis of this study, the results were pooled for the areas near the mining, milling and refining facilities at Port Hope and Elliot Lake. For the exploratory study of power stations, results were pooled for the areas near Pickering and Douglas Point. Such pooling of results is valid under the assumption that each component of a pooled estimate is a measure of the same phenomenon. [Ref. 20] Under this homogeneity assumption, it is assumed that the two nuclear generating stations, for example, give rise to a similar type of potential exposure and result in a similar level of relative risk. The homogeneity assumption was tested statistically using the normal approximation, and results were pooled since the hypothesis that relative risks were equal for the two facilities could not be rejected at the 0.05 level of significance. Due to the diverse nature of the three general types of facilities, each of which could result in different types of emissions, it is not totally appropriate to pool the results across all facility types since detailed information on emissions has not been examined in this study. However, in spite of these differences, a pooled estimate across all five facilities is presented for the sake of completeness.

For leukaemia incidence, a similar analysis was performed to obtain incidence ratios by residence at birth, confidence intervals and area- and period-specific values. The complementary analysis of incidence by residence at time of diagnosis was not performed because the main focus of the study was on the detection of a potential excess risk associated with an exposure near the time of birth. It was not feasible to perform the incidence analysis by residence at time of diagnosis because the residence information in the OCR is classified using a different coding system. In addition, exact addresses were not available for resolving discrepancies between the two coding systems.

For the comparison of relative risk estimates in two time periods, this study would ideally consider the periods before and after the initial operation of each facility. For such a comparison to be reasonable, cancer data would be needed for many years in the "before" period, which is true only for cancer mortality and for the areas around nuclear power stations. For such a comparison to be meaningful, it must be based on large populations so that the two relative risk estimates are reasonably precise. Since the population around Douglas Point is relatively small, a comparison of the relative risk of leukaemia could only be performed for mortality in the vicinity of the Pickering facility (which began operation in 1971). This was accomplished by calculating the relative risk of leukaemia death from 1950 to 1970 for the "county" and "nearby" geographic areas. The relative risk estimates for the "before" and "after" periods were compared using the method described by Ederer and Mantel which assumes that the ratio of two Poisson variables follows the binomial distribution. [Ref. 21]

Several factors were identified as being potential threats to the validity of this study: migration; the effects of the selection criteria for cases; and the method used to estimate values where data were missing. The methods and results of the analyses that were performed to identify the magnitude and direction of these potential biases are explored in Section E.6.

Leukaemia mortality and incidence data, and the live birth frequencies and populations for each area were entered into a microcomputer. The database management and descriptive analyses were performed using SAS [Ref. 22,23], the person-years analysis was performed using PYRS [Ref. 24] and the regression analysis for Poisson models and capture-recapture models was performed using GLIM. [Ref. 25]

D. RESULTS

For each area under study, the observed and expected number of events, the ratio of observed over expected (O/E) and the 95% confidence interval of O/E are listed in Tables 6 to 10. The results are presented first for the area that was the subject of the primary hypothesis of this study (Chalk River), second for the facilities of the secondary hypothesis (Port Hope and Elliot Lake), and third for the facilities of the exploratory hypothesis (Pickering and Douglas Point).

In Table 6 results are presented for Renfrew County and the area "nearby" the Chalk River facility. In the mortality analyses that classified subjects according to their residence at death, the resultant mortality ratios were 0.56 for the "nearby" area (O=4, E=7.2) and 0.86 for the county (O=23, E=26.6), which indicated that the leukaemia risk in each area was lower than expected. By classifying subjects according to their residence at birth, even lower mortality ratio estimates were obtained, ranging from 0.33 (O=2, E=6.1) to 0.71 (O=17, E=23.9), for the "nearby" and county areas respectively. It should be noted that over the 38 years of observation, only two deaths occurred among children born in the "nearby" area, which highlights the rarity of leukaemia in children aged 0-14 years and the relatively small population residing in the area. The analysis of incidence by residence at birth resulted in ratios that were virtually identical to the mortality analysis by residence at birth. All of the confidence intervals in Table 6 encompass 1.0; therefore, at the conventional level of statistical significance, the differences between observed and expected may well be due to chance and not to any "beneficial" effect of living close to that facility.

For the pooled area within 25 km of either Chalk River or Rolphton, the relative risk estimates were unchanged. This occurred because the sparsely populated area within 25 km of the latter contributed nothing to the number observed and contributed minimally to the number expected in the "nearby" Chalk River area. For example, the expected number of incident cases for the area "nearby" Chalk River was 4.25 between 1962 and 1986, whereas the expected number for the pooled area "nearby" Chalk River or Rolphton was 4.32.

The results listed in each row of Table 6 are not from independent analyses, as emphasized by the fact that 32 individual children were the source of all the observed events listed in the table. Details of the overlapping subject inclusion for the different methods of analysis for all areas under study are presented in Appendix H.

Tables 7 and 8 present results for the areas that contain the two mining, milling and refining facilities. In Northumberland County (i.e., the location of the Port Hope facility) ratios ranged from 0.95 (O=22, E=23.0) to 1.14 (O=20, E=17.5) for mortality ratios by residence at death and residence at birth respectively (Table 7). The levels observed "nearby" the Port Hope facility were slightly higher than for the county level analysis and were similar for the two methods of classifying residence, with mortality ratios of 1.32 and 1.20 for residence at death and birth respectively. The incidence analysis resulted in ratios that were very similar to the mortality ratios obtained when children were classified according to residence at birth. As shown by the inclusion of 1.0 in the confidence intervals listed in Table 7, the observed elevations in risk could be due to chance alone.

Leukaemia risks in Algoma District and in the area "nearby" the Elliot Lake uranium mines and mills are examined in Table 8. The ratio values ranged from 0.80 (O=4, E=5.0) for the "nearby" incidence ratio, to 1.38 (O=38, E=27.6) for the county level mortality ratio by residence at birth, and had confidence intervals that, again, indicated that differences between the observed and expected could be due to chance alone. Although the number of leukaemia deaths was the same in the two calculations, the slight variation in the number of expected deaths gave rise to mortality ratios that were slightly greater for residence at birth than for residence at death. Also, it should be noted that for each style of analysis the ratios were lower for the "nearby" areas than for the county.

Pooling the results of the two mining, milling and refining facilities gave rise to a mortality ratio by residence at birth in the "nearby" area of 1.11 (O=16, E=14.4, 95% CI =(0.6, 1.8)). Due to the small frequencies, it was not informative to perform more detailed analyses for specific age groups and time periods.

Tables 9 and 10 present results for the areas around the two nuclear generating stations. In Table 9, the period of observation for both the mortality and incidence analyses began in 1971, since this was the year the Pickering facility began operation. The large frequencies for this analysis, which covered a relatively short period of time, are an indication of the presence of a large population. The frequencies for the county and "nearby" areas are almost identical, because the majority of the county's population lives in the "nearby" area. It is also noteworthy that the frequencies of observed and expected deaths were much greater when residence was classified according to time of death rather than time of birth. This is due to the restrictions on subject selection and the relatively recent opening of the facility. For the "nearby" area the ratios were lowest for the analysis of mortality by residence at death, with a value of 1.09 (O=63, E=57.6), intermediate for the incidence ratio by residence at birth, with a value of 1.15 (O=72, E=62.8), and highest for the mortality ratio at birth, with a value of 1.34 (O=33, E=24.6). With these large frequencies the confidence intervals were relatively narrow, although, as indicated by the inclusion of 1.0 in the intervals, the excesses could have been due to chance.

In Bruce County (Table 10) and "nearby" the generating stations, the mortality ratios ranged from 0.91 (O=6, E=6.6) for the county level by residence at death, to 2.78 (O=3, E=1.1) for the "nearby" area by residence at birth. The incidence ratios by residence at birth were lower than the mortality ratios by residence at birth for the same areas, but greater than the mortality ratio by residence at death. The ratios for the "nearby" areas were greater than for the county. For example, the mortality ratios by residence at birth were 2.78 (O=3, E=1.1) for the "nearby" area and 1.55 (O=5, E=3.2) for the county. The statistical instability of these ratios is indicated by the wide confidence intervals. The widths of the confidence intervals, in turn, are due to the small number of expected deaths or cases (e.g., 1.1 to 2.6 for "nearby" area) over the 21 years of observation.

Table 11 presents the pooled results for the nuclear generating stations at Pickering and Douglas Point. The pooled mortality ratio by residence at birth in the "nearby" areas was 1.40 (O=36, E=25.7, 95% CI = (0.98, 1.9)). Table 11 also presents the pooled data in further detail by listing the frequencies of observed and expected deaths by age group and time period. The results for the Pickering and Douglas Point facilities were pooled because of the relatively small frequencies in each of the "nearby" areas (e.g., 33 and 3 observed cases for Pickering and Bruce respectively). Table 11 shows that the largest number of leukaemia deaths occurred in the 0-4 age range and that with increasing age the number of expected deaths declined, which was largely due to the differences in age-specific leukaemia rates. The mortality ratios by age were lowest in the 0-4 age group (O/E = 1.37) and highest in the 10-14 age group (O/E = 1.51). Table 11 shows that the mortality ratio was highest among children born in the early time period (O/E = 1.71 for 1967-1973) and lowest in the most recent period (O/E = 0.94 for 1979-1987). Again, for each of the age groups and time periods the differences between the observed and expected numbers of leukaemia deaths may be due to chance as indicated by the inclusion of 1.0 in the confidence intervals. Poisson regression models were used to assess whether there was significant variation or trend in the mortality ratios for the different age groups and time periods. Across the categories of both age and time period there was no significant variation in the mortality ratios as shown by the likelihood ratio test (for age, chi-squared = 0.03, 2 degrees of freedom, p = 0.87; for period, chi-squared = 1.64, 2 degrees of freedom, p = 0.20).

Table 12 presents the mortality ratios for the periods before (1950-1970) and after (1971-1987) the initial operation of the Pickering Nuclear Generating Station. For the analysis with residence classified at the time of death, the mortality ratios were virtually identical in the "before" and "after" periods. For example, in the "nearby" area, 91 leukaemia deaths were observed in the "before" period while 83.9 were expected, giving a ratio of 1.08, which is similar to the ratio of 1.10 in the "after" period. The observed and expected values for the "after" period differ from Table 9 because children diagnosed before 1971 were included in the "before" period. A slightly different pattern was detected in the analysis by residence at birth. The mortality ratios by residence at birth for the period after 1971 were slightly higher than in the "before" period. For example, in the "nearby" area the mortality ratios were 1.08 (O=80, E=74.1) and 1.34 (O=33, E=24.6) before and after 1971 respectively. The differences between the mortality ratios of the periods before and after facility start-up could have been due to chance, as indicated by the overlapping confidence intervals and the Ederer-Mantel test (p=0.26). Finally, Table 12 shows that in the "before" period the mortality ratios by residence at death were almost identical to the mortality ratios by residence at birth.

The primary results presented in Tables 6 to 12 are shown graphically in Figures 3 to 5. Figure 3 is a plot of the mortality ratios by residence at birth for the "nearby" areas around each of the five facilities. Figure 4 is a similar plot for incidence ratios by residence at birth. Figure 5 plots the mortality ratios by residence at death and birth in the periods before and after the opening of the Pickering facility.

E. DISCUSSION

E.1 Risk Estimates in the Vicinity of the Nuclear Research Facility

The occurrence of leukaemia in the area surrounding the Chalk River and Rolphton facilities was lower than expected for each area analysed and for each style of analysis. The ratio of observed over expected obtained by the traditional method of classifying events according to their residence at death resulted in mortality ratios of 0.86 (O=23, E=26.6) for the county analysis and 0.56 (O=4, E=7.2) for the area "nearby" Chalk River. By classifying observed and expected numbers of deaths by residence at birth, the mortality ratios were even lower than the ratios by residence at death for both the county and "nearby" areas. The incidence ratios were virtually identical to the mortality ratios for residence at birth. Regarding the primary hypothesis of this study, these data indicate that the occurrence of childhood leukaemia was less than expected and within the bounds of chance variation in the vicinity of the nuclear research facilities in Renfrew County. The mortality and incidence ratios that were observed in these areas were much smaller than the values reported in the studies that prompted this study to be undertaken (e.g., a mortality ratio of 9.4 (O=5, E=0.53) was observed in the birth cohort at Sellafield).

Although there were no meaningful differences between the relative risk estimates obtained in the mortality and incidence analyses (e.g., by residence at birth), there were systematic changes in the estimates obtained using the different ways of classifying geographic area and residence. The ratios were smaller for the "nearby" area than for the county and when residence was classified at birth rather than at death. The small number of observed and expected deaths "nearby" the Chalk River research and development facility prevented any more detailed analysis of age- or period-specific variation in the relative risk estimates.

The gradient of effect in relation to distance and time is one of the most important features of the British evidence for an association between nuclear facilities and childhood leukaemia. As explained earlier, it was not possible in this study to test for risk gradients by distance as in the U.K. studies, where fixed radii of shorter lengths (e.g., 10 km) were applied. [Ref. 7,8] Due to the diversity in the sizes and shapes of the Ontario counties, the county level analysis can be considered only as a crude indication of gradient. For the Chalk River facility the mortality and incidence ratios in the "nearby" area were less than in the larger county area, which suggests that there was no greater risk with closer proximity to the nuclear facility.

A gradient of effect in terms of time can be examined by comparing the mortality ratios by residence at birth and by residence at death. The mortality ratios by residence at birth were less than the ratios by residence at death, which is evidence against there being a "birth cohort" phenomenon as was reported by Gardner et al. [Ref. 4] It is possible that a smaller differential should be expected between the two forms of analysis because, by including children with leukaemia up to age 15 years only, this study has followed individuals for a substantially shorter length of time than Gardner et al. who followed the birth cohort up to a maximum age of 36 years.

E.2 Risk Estimates in the Vicinity of Uranium Mining, Milling and Refining Facilities

In the mortality analysis of Northumberland County, the ratios of observed to expected were higher for the residence at birth analysis than for the residence at death analysis (1.14 (O=20, E=17.5) versus 0.95 (O=22, E=23.0) respectively). This apparent pattern of higher mortality ratios when residence was classified at birth rather than at death did not occur in the "nearby" area (e.g., 1.20 (O=12, E=10.0) by birth; 1.32 (O=14, E=10.6) by death). For each style of analysis, the ratios in the "nearby" area were, however, slightly higher than in the county, as shown for the mortality ratio by residence at birth of 1.20 (O=12, E=10.0) for the "nearby" area and 1.14 (O=20, E=17.5) for the county. Again the estimates obtained in the incidence analysis for residence at birth were similar to the birth residence analysis of mortality.

In Algoma District, which contains the Elliot Lake uranium mine and mill, slightly different patterns were observed. The most striking features of the data for Algoma District are that the mortality and incidence ratios in the "nearby" area are all less than 1.0 and they are all less than the ratios for the "county" level analysis (e.g., the mortality ratio by birth residence was 0.92 (O=4, E=4.4) for "nearby" and 1.38 (O=38, E=27.6) for the county). In Algoma District the mortality ratios were slightly higher when residence was classified at birth rather than at death, which is somewhat similar to the results for the area around Port Hope. The incidence analyses by residence at birth gave similar but slightly lower relative risk estimates as the mortality analyses by residence at birth.

The pooled analysis for the "nearby" areas of the two mining, milling and refining facilities resulted in a mortality ratio of 1.11 (O=16, E=14.4, CI = (0.63, 1.80)) for residence classified at birth. Due to the small numbers it was not possible to calculate mortality ratios for specific age groups and time periods.

The differences between the observed and expected numbers of leukaemia deaths and incident cases could have been due to chance in the analyses of Northumberland and Algoma counties. It should be noted that several of the estimates in the "nearby" and pooled analyses were based on the observation of a small number of events (< 5) over a long period of time. The data suggest that there may be an increased risk of childhood leukaemia in the area "nearby" the Port Hope uranium refinery and in Algoma District, but not in the area "nearby" the uranium mines and mills at Elliot Lake. All of the differences between the observed and expected numbers detected in the vicinity of the uranium mining, milling and refining facilities could be due to chance.

E.3 Risk Estimates in the Vicinity of Nuclear Power Generating Stations

In Durham Regional Municipality and in the area "nearby" the Pickering Nuclear Generating Station, the observed leukaemia mortality rates were similar to the expected for both the county and "nearby" areas when analysed according to residence at death (i.e., mortality ratio of 1.0). In the analysis of mortality by residence at birth, higher estimates of relative risk were obtained, with a value of 1.34 (O=33, E=24.6) in the "nearby" area.

Lower values were observed in the analysis of incidence for the birth cohorts (e.g., for "nearby" O/E = 1.15; O=72, E=62.8). Because the majority of the population in Durham Regional Municipality reside within 25 km of the Pickering facility, the results of the county and "nearby" areas were virtually identical.

The relative risk estimates obtained for Bruce County were higher than for Durham Regional Municipality, with values that ranged from 0.91 (O=6, E=6.6) to 2.78 (O=3, E=1.1). It must be noted that for both the Bruce County and "nearby" area analyses, the estimates were based on a very small number of observed events, ranging from 3 to 9, and an even smaller number of expected events, which gave rise to wide confidence intervals.

A direct comparison of the results for the Pickering and Bruce facilities demonstrates some interesting patterns. First, the expected numbers of deaths were greater when residence was classified at death rather than at birth, due to the subject selection and time period restrictions. Second, the magnitude of the excess risks was smallest for the mortality analysis by residence at death, largest for the mortality analysis by residence at birth and intermediate for the incidence ratios. Third, the mortality and incidence ratios were greater for the "nearby" area than for the Bruce County analysis, while around Pickering, there were no differences between the results for the "nearby" and county areas.

A pooled estimate for the "nearby" areas around both the Pickering and Bruce facilities was 1.40 (O=36, E=25.7) for the mortality analysis by residence at birth. The lower bound of the confidence interval for the pooled estimate (0.98) was close to 1.0. Subgroup analyses demonstrated that there was no significant variation in the mortality ratios across three age groups or birth periods. In general, these results of the analysis of leukaemia risk around the nuclear generating stations are suggestive of an increased risk but this could be due to chance. Because the result for these areas was close to the bounds of chance variation, further research may be warranted.

Mortality ratios were examined for the periods before and after the opening of the Pickering Nuclear Generating Station. During the "before" period the number of leukaemia deaths was slightly greater in the "nearby" area than was expected on the basis of provincial rates. There was no difference between the mortality ratios by residence at death in the "before" and "after" periods. The analysis of mortality by residence at birth revealed a slightly different pattern, with the mortality ratio in the period after 1971 (1.34; O=33, E=24.6) being greater than in the period before 1971 (1.08; O=80, E=74.1). The difference between the mortality ratios in the "before" and "after" periods is small but the direction of the effect is consistent with the birth cohort phenomenon reported by Gardner et al. [Ref. 4,11] The fact that there was a difference only in the mortality ratios by residence at birth suggests that if there was a true excess risk after 1971, it could be due to some factor that had its effect close to the time of birth.

E.4 The Power to Detect Effects Similar to Previously Reported Relative Risks

The ability of this study to detect important excesses of risk was determined by calculating power*. [Ref. 19] The study had sufficient power (> 80%) to detect excess risks of the magnitude observed in the Sellafield study (O/E = 9.4) [Ref. 4] in all areas. As well, risk estimates of the magnitude observed in the Dounreay study (O/E = 3.3) [Ref. 5] could be detected with greater than 80% power if 2.4 or more events were expected (i.e., all areas except "nearby" Douglas Point). In an effort to enhance the power of the study, pooled estimates of relative risk were obtained.

In each of the pooled analyses, at least 2.4 deaths were expected; however, the relative risk estimates were all less than 3.3. For the uranium mining, milling and refining facilities (Port Hope, Elliot Lake), the power to detect the pooled estimate of O/E = 1.11 (O=16, E=14.41) as being significantly different from 1.0, was 6%. In other words, in order for a mortality ratio of 1.11 to be detectable with 80% power, 684 expected deaths would be required. For the two generating stations (Pickering, Douglas Point), the pooled relative risk estimate of 1.40 (O=36, E=25.7) was associated with 39% power. Therefore, although this study was large enough to detect excess risks of the magnitude observed in the British studies, it was unable to discriminate between the observed relative risks and a chance observation.

A slightly different approach for interpreting study results when there is a prior hypothesis of elevated risk, is to test whether or not the two relative risk estimates are equal. The method described by Ederer and Mantel [Ref. 21] was used to test whether the relative risks observed in Ontario were compatible with those in the British studies. For the analysis of mortality by residence at birth, p values for the tests of equality with the Sellafield relative risks ranged from as low as 0.00006 for "nearby" Chalk River, to a maximum of 0.004 for "nearby" Douglas Point. These p values indicate that for each area the hypothesis that the relative risks are equal to those seen at Sellafield can be rejected with a high degree of probability. Tests of equality with the Dounreay figures (O/E = 3.3) gave rise to p values of 0.005 for "nearby" Chalk River, 0.04 for the pooled area "nearby" the uranium mining, milling and refining facilities, and 0.06 for the pooled areas "nearby" power stations. These results demonstrate that a relative risk of the magnitude observed in the Dounreay study is not likely to have occurred in the vicinities of the Chalk River facility or the Elliot Lake and Port Hope facilities. Such a relative risk cannot be formally ruled out in the vicinity of the nuclear power stations since the p value of 0.06 was not less than the standard level of significance (i.e., 0.05).

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*Power is the probability that a true difference of a specified size would be detected by a test. [Ref. 26]

Table H-1: Frequency of Subjects by Analysis Method and Geographic Region.

ANALYSIS	Renfrew		Northumberland		Algoma		Durham		Bruce	
METHOD	County	"Nearby"	County	"Nearby"	County	"Nearby"	County	"Nearby"	County	"Nearby"
A	10	4	7	4	5	1	40	37	3	0
B	1	0	1	1	2	0	0	0	0	0
C	5	0	7	5	12	1	42	39	4	1
D	5	0	5	3	5	1	0	0	0	0
E	3	2	4	1	3	1	7	7	2	0
F	8	0	10	7	28	2	26	26	3	3
Total	32	6	34	21	55	6	115	109	12	4

4.1% of the Ontario population moved to another province between the 1976 and 1981 censuses. (Note: no information is available for people who emigrated from Canada.) The proportion of emigrants from each of the counties under study was similar to the value for Ontario, except for Renfrew County. This county had a 7.3% emigration rate, and the largest relative amount of emigration with a rate that was 1.78 times greater than the province. The census subdivision in the "nearby" Renfrew area with the highest emigration rate was Petawawa Township, with 42.0%. This significant proportion can be explained by the existence of a Canadian Armed Forces Base, which has a large transient population.

The 1981 census also reported that 1.7% (32,841/1,886,500) of Ontario children aged 0-14 years emigrated from the province in the previous year. [Ref. 28] By multiplying the provincial emigration rate for children aged 0-14 years by the ratio noted above for all ages, an estimate of the proportion of children of this age group in Renfrew County who leave the province annually is 3% (1.7% x 1.78).

The total number of children aged 0-14 years who were born in Renfrew County and who emigrated from the province aged 0-14 years during the 38 year period of observation was then estimated to be 1,795, by using the county live birth figures and the 3% emigration rate derived above. The total number of person-years at risk among these emigrant children after they left the province is approximately 12,723. For these calculations the provincial mortality rate for the entire age range and time period, 2.67 per 100,000 person-years, was used to estimate that 0.34 leukaemia deaths would have been missed due to emigration.

The potential bias of the mortality ratios by residence at birth due to emigration can be examined by adding these estimated out-of-province leukaemia deaths to the number of observed deaths reported for the county level analysis in Table 6. For the analysis by residence at birth, a mortality ratio of 0.71 (O=17, E=23.9) was reported. A mortality ratio adjusted for interprovincial emigration would be at worst 0.75 (O=17+1, E=23.9), resulting in a 5.6% shift in the mortality ratio. For the other counties under study, the emigration effect would be smaller because interprovincial emigration did not occur with the same high relative frequency as it did for Renfrew County.

The above process of examining the impact of interprovincial migration was based on several assumptions. First, it assumed that the interprovincial emigration rates from the 1981 data were representative of the entire time period. This assumption was necessary because interprovincial emigration was only reported from the 1981 census. These rates may in fact overestimate interprovincial emigration, since in this time period many people were moving west to take advantage of the oil boom. A second and less critical assumption was that the leukaemia mortality rate observed in Ontario was appropriate for emigrant children.

It is possible that migration may have affected this study in another way. Since residence information was available only at the time of birth and death, it was not possible with these data to detect whether children lived in an area under study for only a short period (e.g., moving there during childhood but moving away before the occurrence of their disease). Given that the majority of study subjects are in the younger age groups, it is likely that only a small number of children would have been affected by such additional moves and that the potential bias would be minimal.

E.6.2 Urban-Rural Differences in Leukaemia Risk

Urban-rural differences in childhood leukaemia rates have been demonstrated in some but not all previous studies. Residence in an urban area was shown to be associated with increased risk in a study of nuclear facilities in the U.K. [Ref. 29] The Danish Cancer Registry, however, failed to detect an urban-rural differential in leukaemia risk. [Ref. 30]

An urban-rural differential may be important in this study because a small proportion of the populations in some of the counties under study live in urban areas. Algoma, Durham and Northumberland counties have large urbanized populations (75-80%), which are similar to the provincial total (82%). [Ref. 17] Renfrew County has a smaller urban population (57%), whereas Bruce County is largely rural with an urban population of only 42%. If leukaemia rates were lower in urban areas, then the inclusion of a large urban area like Metropolitan Toronto would cause an under-estimation of the expected values for rural areas, and therefore an over-estimation of the relative risk. An exploratory analysis was performed in Phase I to assess the impact of a possible urban-rural differential in risk, by excluding Metropolitan Toronto (except Scarborough) from the calculation of both the numerators and denominators of the relative risk estimates. The impact of this adjustment was that the county level relative risk estimates for mortality varied by at most 3.0%. Therefore, it is not likely that the relative risk estimates obtained in this study are seriously biased due to the urban-rural differences.

E.6.3 The Inclusion of Prevalent Cases in the Mortality Analysis

The objective of the primary analyses (Section D) was to determine the relative risk of leukaemia in the vicinity of each facility only for the period beginning at the time of each facility's initial operation. The results that have been reported for the analyses of mortality by residence at death suffer from a potential bias. With leukaemia death as the study outcome and residence classified at death, it was possible for children to be included in the mortality analysis even if their leukaemia was actually diagnosed before the facility opened. For example, a child who died from leukaemia in 1972 would have been included in the mortality analysis of the Pickering facility even if the diagnosis was made before the facility began operation in 1971. The inclusion of such children could produce spurious associations because it is not possible for the occurrence of leukaemia to be associated with the operation of a nuclear facility when the diagnosis of the disease predated the facility.

For consistency throughout the study such prevalent cases were not excluded from the mortality analysis because it was not possible to identify them for facilities that opened before 1964 (i.e., the beginning of the incidence data). The magnitude of the potential bias was examined for the facilities that began operation after 1964, which were the two nuclear power generating stations. The county analysis for the Pickering facility included 13 children who died after but were diagnosed prior to the 1971 start-up date. If these 13 children were excluded from the analysis, the county level mortality ratio by residence at death that is shown in Table 9 to be very close to 1.0 (O/E = 1.05; O=66, E=62.6) would be unchanged (O/E = 1.05; O=53, E=50.5). The mortality ratio was also unchanged when this adjustment was made for the "nearby" Pickering area. The county level analysis around the Douglas Point facility included two children who were diagnosed between 1964 and 1967 (note: neither were resident in the "nearby" area at death). If these two children were excluded from the analysis the county level mortality ratio by residence at death, which is shown in Table 10 to be less than 1.0 (O/E = 0.9; O=6, E=6.6), would be slightly lower (O/E = 0.7; O=4, E=5.8).

It must be noted that this potential bias does not affect analyses that used residence classified at birth, which were the primary methods of analysis used in this study. Based on the results of the two facilities that opened after 1964, it appears that the exclusion of children who died after but were diagnosed before the start-up would be unlikely to bias the mortality ratios for the other three facilities for which data are unavailable.

E.6.4 Exclusions from the Mortality Analysis due to Birth Outside Ontario and Missing Birth Records

The analyses of mortality by residence at death were performed on the 1894 children for whom residence information was available at both death and birth. There were 283 children for whom residence at birth was either missing or outside Ontario but who had complete residence information at death. As shown in Table 1, these 283 children included: 214 who were born outside Ontario; 33 for whom birth records could not be found; 32 who were adopted and for whom identifying information regarding the birth parents was deleted from the birth certificates; three whose mothers' residences at time of the child's birth were outside Ontario; and one of the three subjects with incomplete identifying information. These 283 children, 15 of whom resided in the counties under study at death, were added to the original 1894 children included in the study and the analysis of mortality by residence at death was repeated to determine whether their initial exclusion had biased the results.

The addition of the 283 children caused the expected number of deaths to increase in each county. The county level mortality ratio was therefore slightly reduced for the single county in which no change occurred in the observed number (e.g., for Bruce County a decline from 0.91 to 0.78, with O=6, E=7.7 and 95% CI = (0.29, 1.7)). The additional deaths that were observed in the other four counties resulted in only slight decreases in the mortality ratios. These ranged from a decline of 0.13 in Algoma District (from 1.20 to 1.07, with O=39, E=36.6 and 95% CI = (0.76, 1.46)) to a decline of 0.01 in Renfrew County (from 0.86 to 0.85, with O=26, E=30.6 and 95% CI = (0.56, 1.25)). The "nearby" relative risk estimates were also reduced for the counties in which no change occurred in the observed number (e.g., 1.06 in Northumberland County, 1.17 in Bruce County and 0.75 in Algoma District). For Renfrew County, the single additional death caused the mortality ratio to rise to 0.61 from 0.56 (95% CI = (0.20, 1.42)), while the addition of 10 cases to "nearby" Pickering left the mortality ratio unchanged. Therefore, there was no important bias in the results of the residence at death analysis due to the exclusion of children who were born outside Ontario or for whom residence at birth could not be determined.

E.6.5 Case Exclusions due to Failure to Trace Birth Records

Tables 1 and 2 show that 36 (2%) leukaemia deaths and 63 (3%) incident cases were excluded from the analysis because birth certificates could not be traced and therefore maternal residence at birth could not be identified. An estimate of the potential bias due to the failure to trace birth records was calculated under two assumptions. First, it was assumed that the excluded cases were as likely to reside in the counties under study as the original subjects who were included in the mortality analyses. Second, it was assumed that all of the excluded cases were born in Ontario.

The number of children for whom birth certificates could not be found and who may have resided in each of the "nearby" areas is calculated in Table 14. This table lists the proportion of all subjects included in the analysis who were born in the "nearby" areas and the number of excluded children who were born during each facility's period of observation. The estimated number of these excluded children who may have been born in each area is the product of these two figures. For both mortality and incidence analyses, less than one excluded case may have been born in any of the "nearby" areas, except for the incidence analysis for "nearby" Pickering. Due to the large population, a total of 3.5 of the excluded incident cases may have been born in this area.

The size of the potential bias was examined for the "nearby" Pickering area by adding 4 (i.e., rounding 3.5) to the observed number reported in Table 9 for the incidence analysis (O/E = 1.13; O=72, E=63.5). The expected number was not adjusted because the inclusion of 39 additional cases would have a very small effect on the Ontario rate that is used in its calculation. The adjusted incidence ratio for "nearby" Pickering would be slightly higher, with a value of 1.20 (O=72+4, E=63.5) and a 95% confidence interval ranging from 0.94 to 1.50. This demonstrates that, if cases who resided in the areas under study were excluded because of a failure to trace their birth certificates, the relative risk estimates could be slightly underestimated.

There is no reason to believe that the unavailability of birth records or OCR identifying information would occur selectively for the counties surrounding the nuclear facilities. The assumption that all subjects excluded as untraced were born in Ontario is conservative since there is evidence that some were born outside Ontario. Therefore, the bias due to case exclusion is likely to be small.

E.6.6 Exclusions from the Incidence Analysis due to Unconfirmed Incident Leukaemia

In order to assess the impact on the incidence analysis of excluding cases with unconfirmed incident leukaemia, a detailed review was undertaken of the cases who were excluded from the incidence analysis because their leukaemia diagnosis was unconfirmed (54 cases; see Table 2). Information regarding residence at birth was obtained from birth certificates, where possible. For 26 of the unconfirmed cases, the identifying information was so incomplete that a birth certificate could not be found and, therefore, these cases would have been excluded as untraced, even if the diagnoses had been confirmed. For the remaining 28, birth certificates were obtained and the review of the residence information and the dates of birth indicated that none resided in an area under study at birth after a facility began operation. The impact of including unconfirmed cases on the incidence ratio would be to cause a slight increase in the provincial rate that was used to calculate the expected numbers, while the number of observed cases would be unchanged. This would give rise to a minute decrease in the incidence ratios. Therefore, the results that have been reported are not significantly biased by the exclusion of cases with unconfirmed incident leukaemia.

E.6.7 Indicators of Ontario Cancer Registry Incidence Data Quality

Relative risk estimates can be biased if the outcome of interest is misclassified. The estimate will be biased towards 1.0 in the presence of random (non-differential) misclassification.* The direction of the bias is less predictable when misclassification is systematic (differential). A preliminary assessment of whether differential or nondifferential misclassification was active in this study was made by comparing indicators of OCR data quality for the counties under study and the province. These indicators can suggest whether leukaemia diagnoses were made with the same degree of certainty.

The two principal indicators of OCR data quality are the percentage of registrations that have been histologically verified (%HV) and the percentage that have been based on death certificates only

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*Misclassification is "the erroneous classification of an individual, a value or an attribute into a category other than that to which it should be assigned. The probability of misclassification may be the same in all study groups (non-differential misclassification) or may vary between groups (differential misclassification)". [Ref. 26]

(%DCO). These indicators for the registration of leukaemia (ICD-9 204-208) in Ontario for all ages for the entire time period were %HV=68 and %DCO=5.2. Confirmation rates in children aged 0-14 years were better, with %HV=87 and %DCO=3.49. In the five counties under study, for all ages, similar values to the province were obtained: %HV=63 and %DCO=5.2. The values for the children aged 0-14 years in these counties were: %HV=86 and %DCO=2.4. In general, the quality of leukaemia classification was, therefore, similar in Ontario and the areas examined in this study. The higher indices of registration quality for leukaemia in children reflect the results of the chart review for indefinite diagnoses, which was undertaken by OCR staff in view of the known over-reporting of childhood cancer in the OCR.

E.6.8 Estimation of the Number of Missed Leukaemia Cases

It is possible that cancer cases are missed by the OCR due to the passive nature of cancer registration in Ontario. An analysis was therefore performed to estimate the number of cases which were possibly not detected by the sources of information used for cancer registration (e.g., clinic records, pathology reports, hospital records and death certificates). The 193 incident cases who were incorrectly reported were excluded, leaving a total of 2181 cases for this analysis. The excluded cases were: confirmed not leukaemia, duplicate registrations, prevalent cases, non-resident in Ontario, or with incorrect age.

The probable number of missing cases was estimated by log-linear modeling using GLIM [Ref. 25] and the capture-recapture methods for estimating the size of a closed population as described by Bishop et al. [Ref. 31] Since pathology reports have only been used by the OCR since 1970, models for three data sources were examined in the earlier period and models for four data sources were used for the period after 1970. Separate regression analyses were performed for each of the three five-year age groups.

The estimate of the total number of missing incident cases that was obtained from these models was 29, which indicates that the reporting of childhood leukaemia was 98.7% complete (29/2210). This demonstrates that childhood leukaemia has been registered with a high level of completeness. The proportion of missed cases is therefore small and should have caused less bias than other factors that have been examined. Earlier work on the completeness of registration of all cancers by the OCR for all ages in a single year found that completeness by site varied between 94.5 and 99.0%. [Ref. 32]

E.6.9 Estimation of Unavailable Live Birth Data

The evaluation of the procedure that was used to estimate missing live birth frequencies is described in detail in Appendix G. This evaluation indicated that the estimation procedure may result in an underestimation of the live birth frequency for the "nearby" area in Northumberland County by an average of 2.4 live births per year. Over the 38 years of observation in Northumberland County, live birth estimation was required in 24 years, which would result in an underestimation of the total number of live births by 57.6 (24 x 2.4).

Following the addition of 2.4 to the number of live births for the area "nearby" Port Hope in each of the required years, "corrected" values were obtained for the number of expected deaths and the mortality ratio. The "corrected" mortality ratio was 1.193, as compared with the value of 1.196, which is reported in Table 7. Similarly, for all areas, the mortality ratios were affected only in the third decimal point. Therefore, the magnitude of the potential bias resulting from the estimation procedure is likely to be negligible.

E.6.10 Summary of Potential Biases

Many potentially biasing factors were examined in the previous sections, including several that relate to data quality, possible risk factors and statistical methodology.

All of the potentially biasing factors caused very small shifts in the relative risk estimates. Factors that showed no consistent pattern in relative risk shift included: urban-rural differences; the inclusion of prevalent cases in the mortality analysis by residence at death; the impact of under-registration of leukaemia and the impact of the estimation of the number of missing live births. Two factors demonstrated that the results may slightly underestimate the true relative risks: migration out of the province (e.g., Renfrew County); and the failure to trace birth certificates (e.g., Durham Regional Municipality). Finally, two factors were shown to cause the results to slightly overestimate the true relative risks: the exclusion from the mortality analysis of cases born outside Ontario; and the exclusion of unconfirmed leukaemia cases from the incidence analysis.

In general, only small deviations in the relative risk estimates were detected and it can be concluded that the results are not significantly biased by any of these factors.

E.7 Study Limitations

This study has two major limitations. First, the study was not large enough to distinguish between a chance occurrence and relative risks of the magnitude observed in the vicinity of the Ontario facilities. Although the study's power was sufficient to detect the relative risks of the magnitude reported at Sellafield and Dounreay, it was not adequate for relative risks in the observed range.

The second limitation is that, since this study was essentially a comparison of leukaemia rates for various geographic regions, it was not possible to study specific causal agents. If a significant excess (or deficit) of leukaemia had been detected, it could not have been directly attributed to the proximity of a nuclear facility or to some other environmental, genetic or behavioural factor in that population. More detailed studies that employ data from individuals, rather than reported summary statistics, would be required to distinguish between these possible causal factors.

F. CONCLUSION

The occurrence of leukaemia deaths and incident leukaemia cases was studied among children, aged 0-14 years, who were born to mothers residing in the vicinity of nuclear facilities in Ontario. High levels of excess risk, of the magnitude observed by Gardner et al. [Ref. 4] for children born to mothers resident in the vicinity of the Sellafield facility, were not detected in the areas around any of the nuclear facilities in Ontario. In the vicinity of the nuclear research facility, the rate of leukaemia was, in fact, less than expected but still within the bounds of chance variation. In the areas around uranium mining, milling and refining facilities, the rates were slightly greater than expected, but because of small numbers, these results may have arisen due to chance. In the areas around nuclear generating stations the difference between the observed and expected numbers was greater but still may have been due to chance.

Unlike the large difference seen around Sellafield, there was no consistent pattern of higher relative risk when residence was classified at the time of birth rather than death. For example, in the mortality analyses of "nearby" areas the relative risk estimates were higher for three facilities but lower for two facilities when residence was classified at birth rather than at death. For the Pickering Nuclear Generating Station, the mortality ratio by residence at birth was slightly greater after the facility opened than before; however, the difference was within the bounds of chance variation. The examination of the impact of several potential biases demonstrated that the results were not significantly affected.

G. RECOMMENDATION FOR FUTURE STUDIES

This study was specifically designed to detect whether the type of birthplace pattern in leukaemia rates that was seen by Gardner et al at Seascale [Ref. 4] has occurred in Ontario. It is of interest that, with the exceptions of the facilities at Chalk River and Port Hope, the estimates of relative risk for mortality in "nearby" areas around the nuclear facilities were indeed higher for residence at birth than at death, but the differences were small.

Even though this study did not detect levels of childhood leukaemia in the vicinity of nuclear facilities in Ontario that were significantly different from the expected level, further research is justified in order to confirm or refute the hypothesis regarding paternal radiation exposure that was proposed by Gardner et al. [Ref. 11] It is also important that future studies are designed to distinguish between factors related to the nuclear industry and other factors that may influence the occurrence of childhood leukaemia. Two large prospective case-control studies of childhood leukaemia, which will examine a variety of many risk factors (including the effect of electromagnetic fields), are scheduled to commence in 1990. One study will be conducted in five provinces (R. Gallagher, personal communication) and the other will be conducted in part of Southern Ontario (L. Green, personal communication). These prospective studies will aim to distinguish between a wide range of risk factors; however, due to the extremely low prevalence in the general population of being exposed to radiation as a nuclear worker, it is unlikely that these studies will be able to fully explore the hypothesis regarding nuclear industry exposure of fathers.

It is therefore recommended that, as a complement to the large prospective case-control studies described above, a study be undertaken that focuses specifically on the paternal exposure hypothesis proposed by Gardner et al. A retrospective case-control study of the association between childhood leukaemia and the exposure of fathers to radiation in the work-place should be undertaken. Such a study could employ birth certificates, the Ontario Cancer Registry and the National Dose Registry as the primary data sources. By focusing on children born in the vicinity of nuclear facilities, the study would have a higher prevalence of exposure than can be achieved in the previously mentioned prospective studies. Hence, such a retrospective case-control study would be more efficient for the examination of whether work-place exposures have had an effect among Ontario nuclear workers.

Table 1: Leukaemia deaths in children aged 0-14 years in Ontario, 1950-1987: The number included in the study, reasons for exclusions and reasons for unsuccessful linkages between the Ontario Cancer Registry and birth records.

TOTAL SUBJECTS SEARCHED			**2181**
Records not linked			
Untraced - birth records not found	33		
Incomplete Registry information	3		
Total records not linked		36	
Records linked			
Born outside Ontario	214		
Adopted	32		
Maternal residence outside Ontario	3		
Duplicate death registration	1		
Incorrect date of birth	1		
Total excluded from study after records linked		251	
Total excluded from study			287
Records linked			
Definite match	1892		
Probable match	2		
TOTAL CASES INCLUDED IN STUDY			**1894**

Table 2: Incident leukaemia cases in children aged 0-14 years in Ontario, 1964-1986: The number included in the study, reasons for exclusion and reasons for unsuccessful linkages between the Ontario Cancer Registry and birth records.

TOTAL SUBJECTS SEARCHED			**2374**
Records not linked			
Untraced - birth records not found	60		
Incomplete Registry information	3		
Total records not linked		63	
Records linked			
Born outside Ontario	193		
Confirmed not leukaemia	157		
Unconfirmed leukaemia	54		
Adopted	50		
Duplicate incidence registration	14		
Prevalent cases	10		
Maternal residence outside Ontario	7		
Not Ontario resident at date of diagnosis	7		
Incorrect date of birth	5		
Total excluded from study after records linked		497	
Total excluded from study			560
Records linked			
Definite match	1813		
Probable match	1		
TOTAL CASES INCLUDED IN STUDY			**1814**

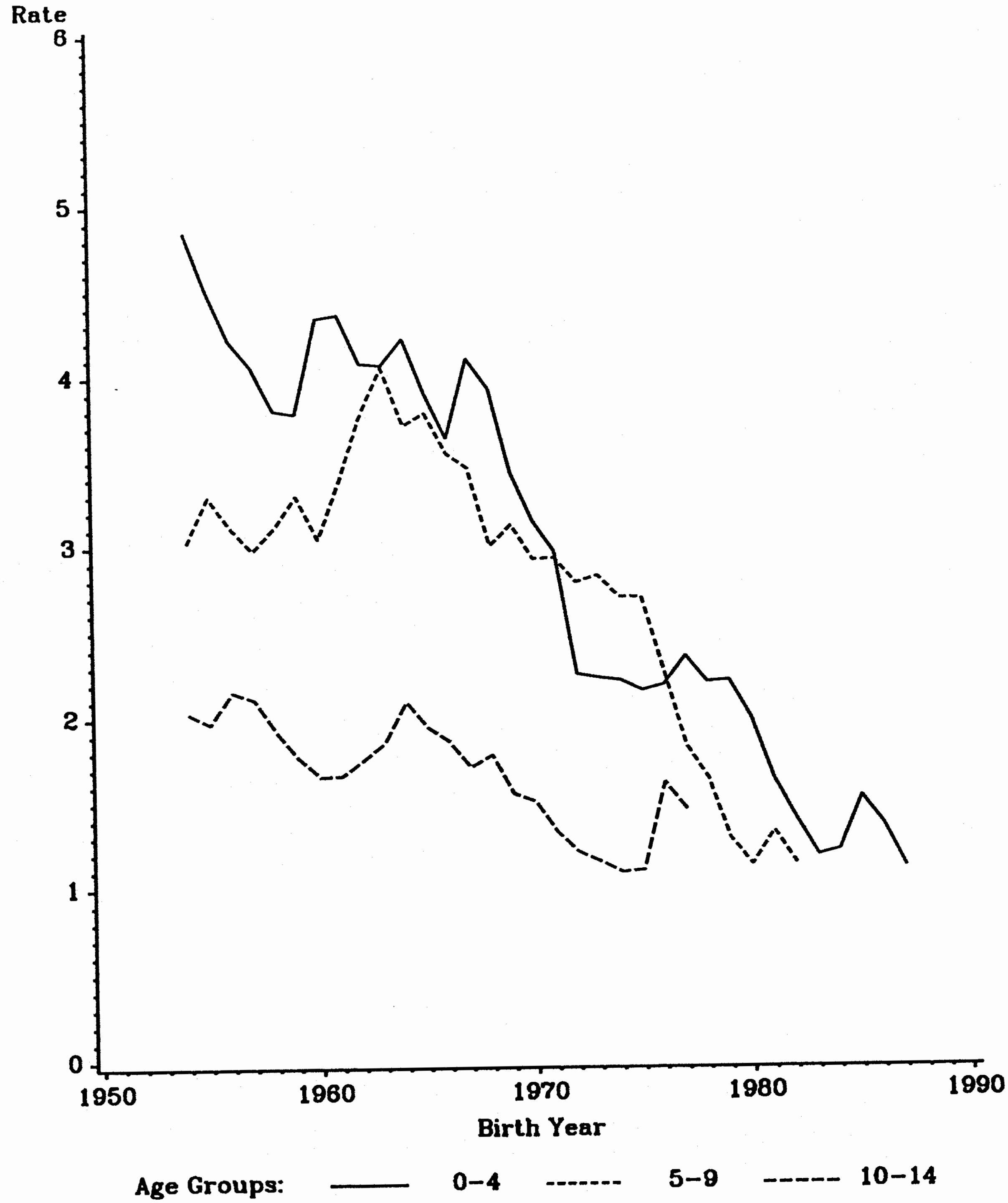

Figure 1: Provincial age-specific leukaemia mortality rates by birth year (per 100,000 person-years from birth; five-year moving average).

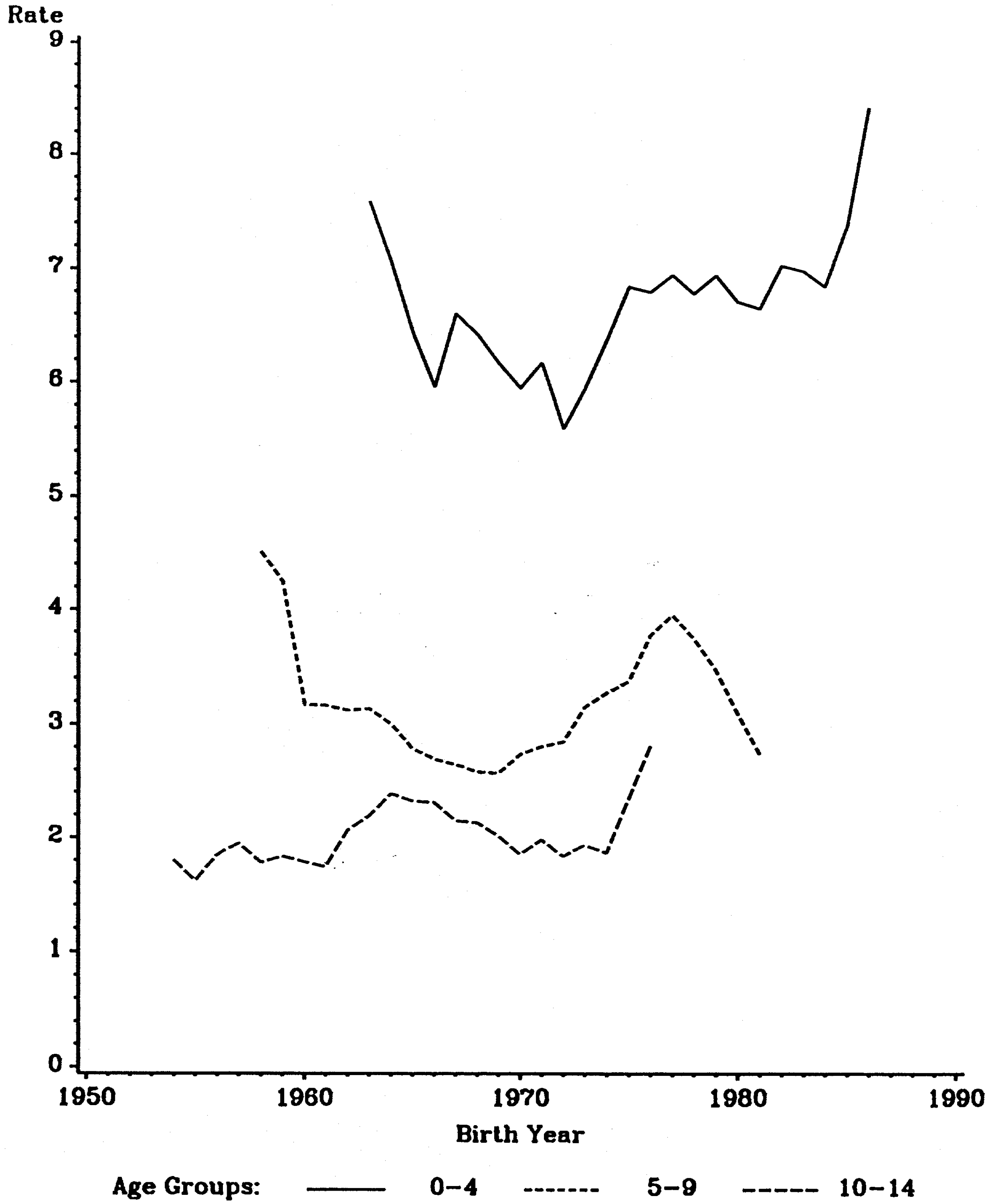

Figure 2: Provincial age-specific leukaemia incidence rates by birth year (per 100,000 person-years from birth; five-year moving average).

Table 3: The number of leukaemia deaths and leukaemia cases included in the study among children aged 0-4, 5-9 and 10-14 years in Ontario.

Outcome	Period	Age Group			Total
		0-4 yrs	5-9 yrs	10-14 yrs	
Mortality	1950-1987	809	684	401	1894
Incidence	1964-1986	999	494	321	1814

Table 4a: Distribution of type of leukaemia in cases included in the mortality analysis among children aged 0-4, 5-9 and 10-14 years, who died in Ontario, 1950-1987.

		Age Group					
		0-4 yrs		5-9 yrs		10-14 yrs	
Leukaemia	ICD-9*	Number	%	Number	%	Number	%
Lymphoid Leukaemia	204	186	23.0	257	37.6	151	37.7
Myeloid Leukaemia	205	88	10.9	48	7.0	64	16.0
Monocytic Leukaemia	206	6	0.7	5	0.7	7	1.7
Other Specified Leukaemia	207	3	0.4	1	0.2	0	0.0
Unspecified Cell Type	208	526	65.0	373	54.5	179	44.6
		809	100.0	684	100.0	401	100.0

* International Classification of Diseases, Ninth Revision.

Table 4b: Distribution of type of leukaemia in cases included in the incidence analysis among children aged 0-4, 5-9 and 10-14 years, who were diagnosed in Ontario, 1964-1986.

		Age Group					
		0-4 yrs		5-9 yrs		10-14 yrs	
Leukaemia	ICD-9*	Number	%	Number	%	Number	%
Lymphoid Leukaemia	204	699	70.0	330	66.8	178	55.5
Myeloid Leukaemia	205	102	10.2	58	11.7	90	28.0
Monocytic Leukaemia	206	5	0.5	3	0.6	2	0.6
Other Specified Leukaemia	207	9	0.9	5	1.0	2	0.6
Unspecified Cell Type	208	184	18.4	98	19.9	49	15.3
		999	100.0	494	100.0	321	100.0

* International Classification of Diseases, Ninth Revision.

Table 5: Ontario Counties with Nuclear Facilities: Population, Facility Name, Year of First Operation and Facility Type.

County	Population* All Ages	Population* 0-14 yrs	Nuclear Facility		Year of First Operation	Facility Type
Renfrew	87,485	19,575	Chalk River		1944	Research & Development
			Rolphton		1962	Nuclear Power Demonstration
Northumberland	64,965	14,090	Port Hope		1935	Uranium Processing
Algoma	133,550	33,390	Elliot Lake		1954	Uranium Mining
Durham	283,640	70,505	Pickering	A	1971	Power Generation
				B	1982	Power Generation
Bruce	60,020	14,835	Douglas Point		1967	Power Generation
			Bruce Nuclear Power Development	A	1976	Power Generation
				B	1984	Power Generation

* from 1981 census

Table 6: Leukaemia mortality and incidence in children aged 0-14 years in Renfrew County (Chalk River - nuclear research facility) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% CI
MORTALITY (1950-1987)				
By Residence at Death				
County *	23	26.6	0.86	(0.55, 1.30)
Nearby *	4	7.2	0.56	(0.15, 1.43)
By Residence at Birth				
County *	17	23.9	0.71	(0.41, 1.14)
Nearby *	2	6.1	0.33	(0.04, 1.19)
INCIDENCE (1964-1986)				
By Residence at Birth				
County *	16	23.0	0.70	(0.40, 1.13)
Nearby *	2	6.3	0.32	(0.04, 1.14)

* Rows do not constitute independent analyses. A total of 32 individuals contribute to observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 7: Leukaemia mortality and incidence in children aged 0-14 years in **Northumberland** County (Port Hope - uranium refinery) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% CI
MORTALITY (1950-1987)				
By Residence at Death				
County *	22	23.0	0.95	(0.60, 1.45)
Nearby *	14	10.6	1.32	(0.72, 2.21)
By Residence at Birth				
County *	20	17.5	1.14	(0.70, 1.76)
Nearby *	12	10.0	1.20	(0.62, 2.09)
INCIDENCE (1964-1986)				
By Residence at Birth				
County *	21	18.8	1.11	(0.69, 1.70)
Nearby *	13	11.7	1.11	(0.59, 1.91)

* Rows do not constitute independent analyses. A total of 34 individuals contribute to observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 8: Leukaemia mortality and incidence in children aged 0-14 years in **Algoma** District (Elliot Lake - uranium mining and milling) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% CI
MORTALITY (1954-1987)				
By Residence at Death				
County *	38	31.8	1.20	(0.85, 1.64)
Nearby *	4	4.6	0.87	(0.23, 2.24)
By Residence at Birth				
County *	38	27.6	1.38	(0.98, 1.89)
Nearby *	4	4.4	0.92	(0.25, 2.35)
INCIDENCE (1964-1986)				
By Residence at Birth				
County *	43	33.7	1.27	(0.92, 1.72)
Nearby *	4	5.0	0.80	(0.22, 2.05)

* Rows do not constitute independent analyses. A total of 55 individuals contribute to observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 9: Leukaemia mortality and incidence in children aged 0-14 years in **Durham** Regional Municipality (Pickering - nuclear generating station) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% CI
MORTALITY (1971-1987)				
<u>By Residence at Death</u>				
County *	66	62.6	1.05	(0.82, 1.34)
Nearby *	63	57.6	1.09	(0.84, 1.40)
<u>By Residence at Birth</u>				
County *	33	25.7	1.28	(0.88, 1.80)
Nearby *	33	24.6	1.34	(0.92, 1.89)
INCIDENCE (1971-1986)				
<u>By Residence at Birth</u>				
County *	75	65.7	1.14	(0.90, 1.43)
Nearby *	72	62.8	1.15	(0.90, 1.44)

* Rows do not constitute independent analyses. A total of 115 individuals contribute to observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 10: Leukaemia mortality and incidence in children aged 0-14 years in Bruce County (Douglas Point - nuclear generating stations) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% CI
MORTALITY (1967-1987)				
By Residence at Death				
County *	6	6.6	0.91	(0.33, 1.98)
Nearby *	3	2.2	1.35	(0.27, 4.00)
By Residence at Birth				
County *	5	3.2	1.55	(0.50, 3.63)
Nearby *	3	1.1	2.78	(0.56, 8.13)
INCIDENCE (1967-1986)				
By Residence at Birth				
County *	9	7.2	1.24	(0.57, 2.36)
Nearby *	4	2.6	1.57	(0.42, 4.01)

* Rows do not constitute independent analyses. A total of 12 individuals contribute to observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 11: Observed (O) and expected (E) leukaemia mortality in children by age group and time period in the area "nearby" the nuclear power generating stations (Pickering and Bruce) by residence at time of birth.

	Frequency Observed	Frequency Expected	O/E	95% CI
Age Group (Years)				
0-4	19	13.9	1.37	(0.82, 2.1)
5-9	13	9.1	1.43	(0.76, 2.4)
10-14	4	2.7	1.51	(0.41, 3.9)
Period of Birth				
1967-1973	15	8.8	1.71	(0.96, 2.3)
1974-1978	15	10.5	1.43	(0.80, 2.2)
1979-1987	6	6.4	0.94	(0.34, 2.1)
Overall	36	25.7	1.40	(0.98, 1.9)

O/E - ratio of observed over expected

CI - confidence interval

Table 12: Leukaemia mortality in children aged 0-14 years in Durham Regional Municipality before and after the year of initial operation of the Pickering Nuclear Generating Station.

	Before (1950-1970)				After (1971-1987)			
	O	E	O/E	95% CI	O	E	O/E	95% CI
By Residence at Death								
County *	95	90.2	1.05	(0.85, 1.29)	53	50.3	1.05	(0.79, 1.38)
Nearby *	91	83.9	1.08	(0.87, 1.33)	51	46.4	1.10	(0.82, 1.45)
By Residence at Birth								
County *	84	78.4	1.07	(0.85, 1.33)	33	25.7	1.28	(0.88, 1.80)
Nearby *	80	74.1	1.08	(0.86, 1.34)	33	24.6	1.34	(0.92, 1.89)

* Rows do not constitute independent analyses. A total of 177 individuals contribute to observed frequencies.

O/E - ratio of observed over expected

CI - confidence interval

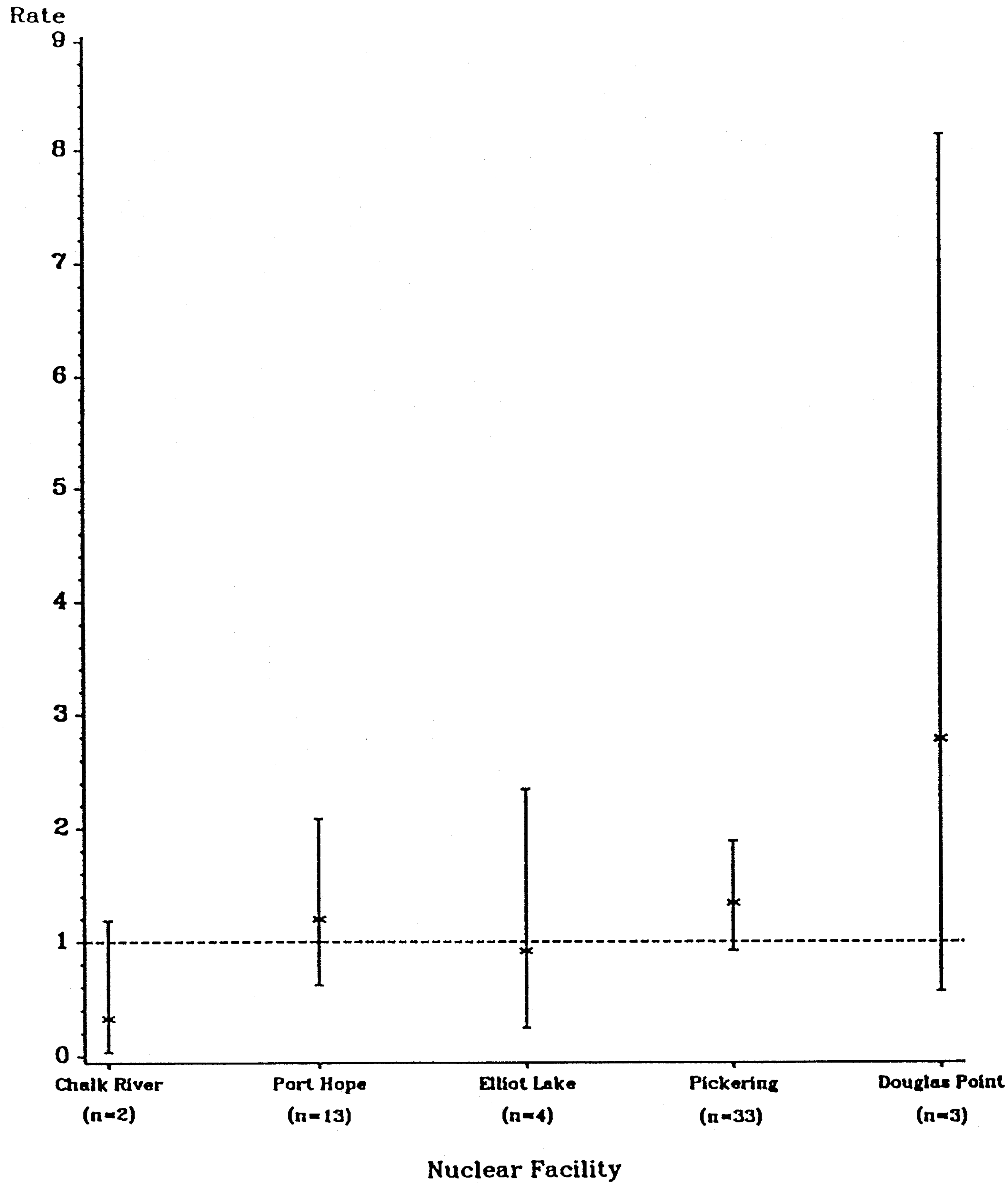

Figure 3: Mortality ratios by residence at birth for "nearby" areas (showing ratio, confidence interval and number (n) of leukaemia deaths observed).

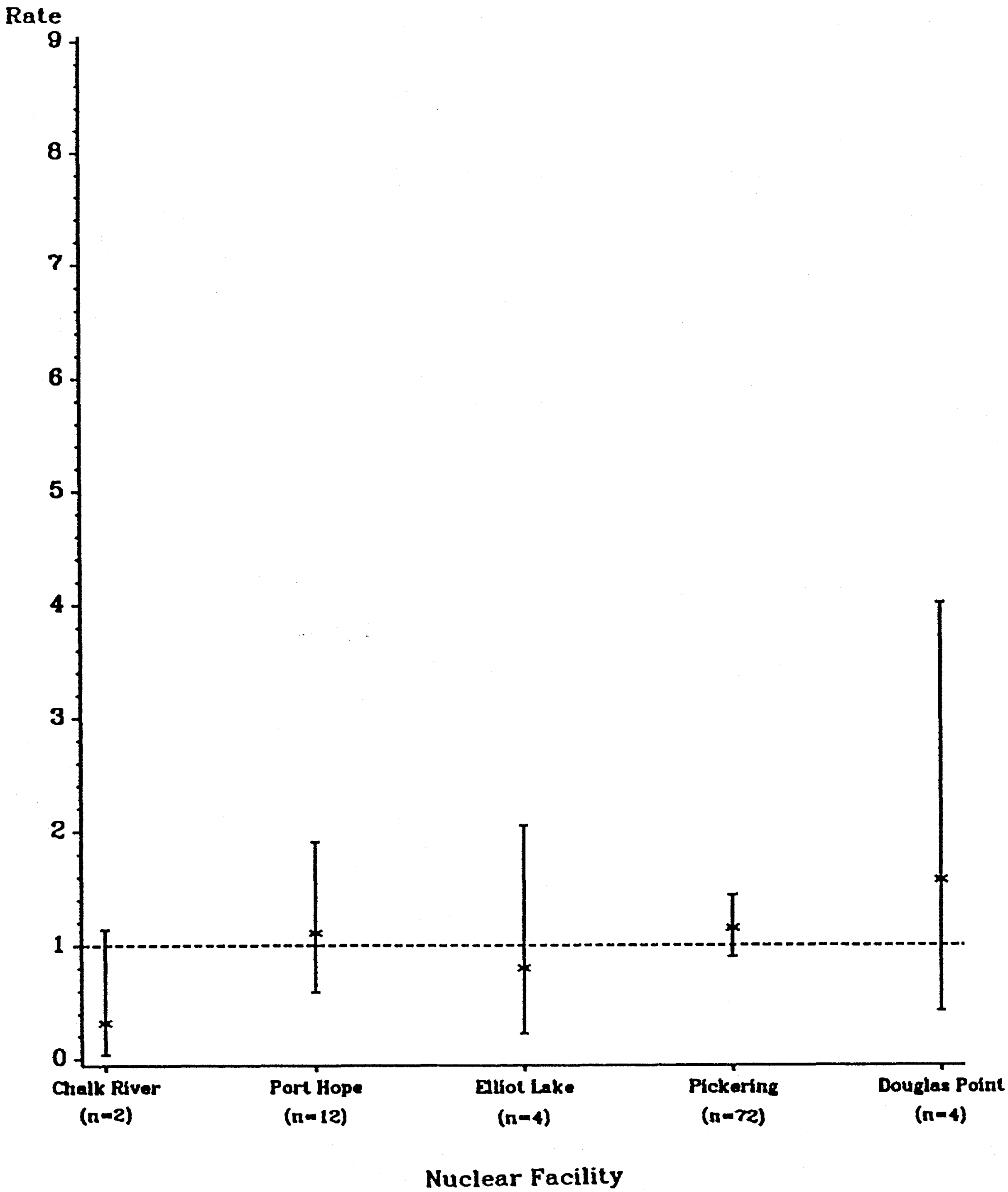

Figure 4: Incidence ratios by residence at birth for "nearby" areas (showing ratio, confidence interval and number (n) of leukaemia cases observed).

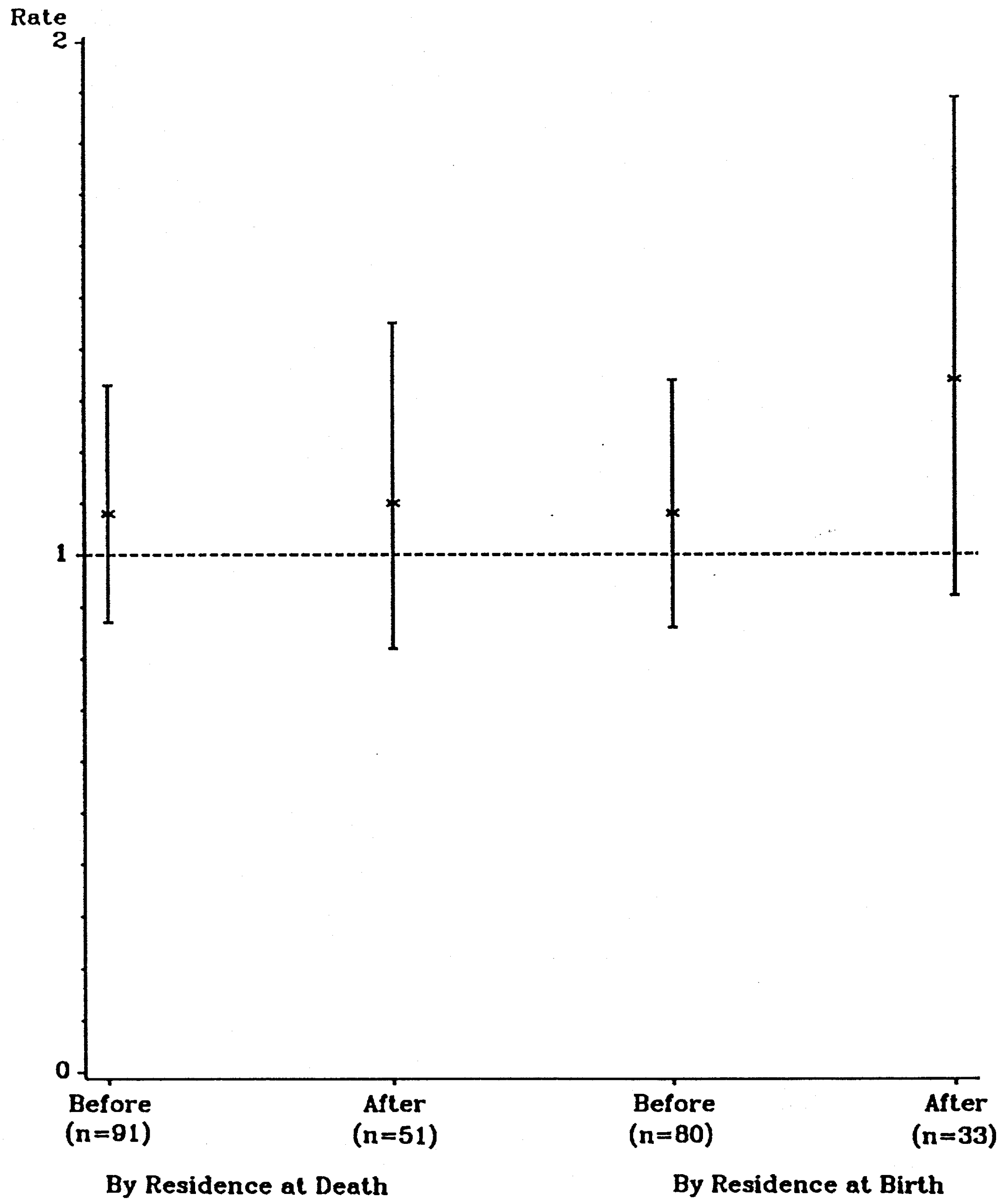

Figure 5: Mortality ratios in the "nearby" area before and after the opening of the Pickering Nuclear Generating Station (showing ratio, confidence interval and number (n) of leukaemia deaths observed).

Table 13: Migration out of the province for Ontario and selected census divisions and subdivisions during the 5 year period prior to the 1981 census. (Source: Ref. 25)

	Population > 5 yrs	% out-migration to other province
ONTARIO	7932965	4.1
RENFREW COUNTY	79945	7.3
- Petawawa Vl	4845	6.5
- Petawawa Twp	6850	42.0
- Deep River T	4735	5.7
- other "nearby"	2585	6.0
NORTHUMBERLAND CTY	59255	5.2
- Cobourg T	10170	6.6
- Port Hope T	9035	4.4
- Newcastle T	29625	3.3
- other "nearby"	14565	8.7
ALGOMA DISTRICT	121960	3.9
- Elliot Lake T	14835	3.9
- other "nearby"	2005	5.0
DURHAM REGION	736900	2.4
- Pickering T	33910	2.5
- Ajax T	23175	1.8
- Whitby T	32920	2.2
- Oshawa C	107210	3.2
- Markham T *	70240	2.6
- Scarborough Bor *	408815	2.1
BRUCE COUNTY	54515	3.9
- Kincardine T	5225	4.7
- Port Elgin T	5530	7.7
- Southampton T	2575	5.0
- other "nearby"	6840	2.3

* Markham and Scarborough are added to Durham Regional Municipality for this study.

Table 14: Estimation of the number of subjects whose mother's residence may have been in "nearby" areas among all subjects who were excluded due to failure to trace birth records.

"Nearby" Area	Ontario Number of untraced exclusions	"Nearby" Percentage of all cases (*)	Estimated number of untraced exclusions
MORTALITY			
- Renfrew	25	0.1 (2/1646)	0.03
- Northumberland	25	7.3 (12/1646)	0.18
- Algoma	20	0.3 (4/1405)	0.06
- Durham	5	9.2 (33/358)	0.46
- Bruce	9	0.6 (3/508)	0.05
INCIDENCE			
- Renfrew	63	0.1 (2/1813)	0.07
- Northumberland	63	7.2 (13/1813)	0.45
- Algoma	63	0.2 (4/1788)	0.14
- Durham	39	9.0 (72/802)	3.50
- Bruce	52	0.4 (4/1079)	0.19

* the number of leukaemia deaths and cases who were born in the area (from Tables 6-10) divided by the total number of children included in the analysis.

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APPENDIX A

THE ONTARIO CANCER REGISTRY

The Ontario Cancer Registry (OCR) is one of the largest population-based cancer registries in the world, containing more than 6 million diagnostic and treatment records on approximately 533,000 cases of cancer in Ontario. Site-specific cancer incidence data is currently available for the years 1964-1987 and cancer mortality data is available for the period 1950-1988.

The OCR is operated by the Ontario Cancer Treatment and Research Foundation (OCTRF). The Division of Epidemiology and Statistics of the OCTRF is responsible for the adequate reporting of cases and the recording and compilation of data, one of the mandates of the OCTRF under the Cancer Act. However, there is no legal requirement to register a case of cancer in Ontario and to make the OCR a population-based registry it has been necessary to collect information from multiple sources.

The OCR employs a system of registration that is based on computerized record linkage on cancer cases collected routinely for other purposes and provided to the Foundation. The Registry receives more than 200,000 such records annually. The following province-wide data are routinely forwarded to the Registry:

1. Hospital discharges with a mention of cancer collected by the Hospital Medical Records Institute (HMRI) and supplied by the Ontario Ministry of Health; 140,000 computerized records per year.

2. Pathology reports with a mention of cancer submitted voluntarily by hospital pathology laboratories; approximately 65,000 paper records per year.

3. Reports on patients referred to the Regional Cancer Centres of the OCTRF and the Ontario Cancer Institute/Princess Margaret Hospital; 20,000 computerized records per year.

4. Deaths from all causes supplied by the Registrar General of Ontario; 65,000 computerized records per year.

To link together the large volume of data, the Foundation staff have developed a sophisticated computer record linkage system based on the Generalized Iterative Record Linkage Systems (GIRLS), designed by Statistics Canada in conjunction with the Epidemiology Unit of the National Cancer Institute of Canada.

Once source files are preprocessed, cancer incidence data are created in two major phases. First, sequential computer linkage of the source files is carried out to bring all records pertaining to an individual together. Then, a set of computerized rules called "case resolution" is applied to the linked records, to determine site of disease, histology, and date and method of diagnosis. Manual resolution is carried out routinely to deal with problems arising as a result of either linkage or case resolution and to ensure that the data is of good quality.

The OCR provides a direct service to many different components of the cancer control system and the general community and provides accurate and timely information and assistance in interpreting the data. Numerous studies of cancer etiology (case-control and cohort) have been conducted utilizing information from the OCR.

APPENDIX B

BIRTH CERTIFICATE

TYPE OR PRINT

Form 2
(VSA 1970)

PROVINCE OF
ONTARIO (Canada)
Office of the Registrar-General

STATEMENT OF

LIVE BIRTH

Registration No. *(Department use only)*

THIS IS A PERMANENT LEGAL RECORD
TYPE OR PRINT PLAINLY AND COMPLETE ALL ITEMS
IMPORTANT: See reverse side for instructions

SPECIMEN

CHILD LAST NAME	1.	2. SEX OF CHILD
GIVEN NAMES		
DATE OF BIRTH	3. Month *(by name)*, day, year of birth	4. Please state if mother is: Married, widowed, divorced or single *(The term "common law" or "separated" not to be used)*
PLACE OF BIRTH	5. Name of hospital *(If not in hospital give exact location where birth occurred)* Borough, city, town, village, township *(by name)* — Regional municipality, county or district	
DEPARTMENT USE ONLY		For office use only

	FATHER	MOTHER
PARENTS NAME	6. SURNAME of child's father All given names	10. MAIDEN NAME *(name before marriage)* All given names
BIRTHPLACE	7. City, town or other place of birth *(by name)* Province *(or country if outside Canada)* — For office use only	11. City, town or other place of birth *(by name)* Province *(or country if outside Canada)* — For office use only
BIRTHDATE	8. Month *(by name)*, day, year of birth — 9. AGE *(at time of this birth)*	12. Month *(by name)*, day, year of birth — 13. AGE *(at time of this birth)*
USUAL RESIDENCE OF MOTHER	14. Complete street address. If rural give exact location, not Post Office or Rural Route address Borough, city, town, village, township *(by name)* — Regional municipality, county or district Province, *(or country)*	For office use only Postal code
MAILING ADDRESS OF MOTHER	15. Complete mailing address *(if different from item 14)* if rural give Post Office or Rural Route address.	Postal code

OTHER BIRTH PARTICULARS	16. Duration of pregnancy *(in weeks)*	17. Number of children ever born to this mother *(including this birth)* Number Liveborn — Number Stillborn *(after 20 wks pregnancy)*	18. Weight of child at birth Grams .... or ...... lb. .... oz.	19. KIND OF BIRTH single ☐ twin ☐ triplet ☐	20. If twin, triplet, state whether this child was born 1st, 2nd, 3rd.

ATTENDANT	21. Name of attending physician *(or other attendant)* Complete mailing address	☐ Physician ☐ Nurse ☐ Other
CERTIFICATION OF INFORMANT	22. I certify the foregoing to be true and correct to the best of my knowledge and belief: — Signature of informant X ...... 23. Relationship of informant to child — 24. Date signed — Month *(by name)*, day, year	

DO NOT WRITE BELOW THIS LINE — OFFICE USE ONLY

CERTIFICATION OF DIVISION REGISTRAR	I am satisfied as to the correctness and sufficiency of this statement and register the birth by signing this statement: Signature of Division Registrar		
	Registration Number	Code Number	Date: Month, day, year

For Department use only:

8-2300-33.4: 2-3-83

DEATH CERTIFICATE

Form 15
(VSA 1970)

Province of
ONTARIO (Canada)
Office of the Registrar-General

STATEMENT OF
DEATH

Registration (*Department use only*)

THIS IS A PERMANENT LEGAL RECORD
OR WRITE PLAINLY AND COMPLETE ALL ITEMS
(see reverse for Instructions and legal requirements under the Vital Statistics Act)

NAME OF DECEASED	1. Surname of deceased (*print or type*)			Social Insurance Number or Old Age Security (if available)
	All given names			2. SEX
DATE OF DEATH	3. Month (*by name*), day, year of death			
PLACE OF DEATH	4. Name of hospital or institution (*otherwise give exact location where death occurred*)			
	Borough, city, town, village, township, (*by name*)		Regional municipality, county, or district	
FOR DEPART-MENT USE ONLY				For Office Use Only
BIRTHDATE	5. Month (*by name*), day, year of birth	6. AGE (years)	If under 1 year (*Months*) (*Days*)	If under 1 day (*Hours*) (*Minutes*)
BIRTHPLACE	7. City or place of birth	Province (or country)		For Office Use Only
MARITAL STATUS	8. Single, married, widowed or divorced (*Specify*)	9. If married, widowed or divorced, give full name of husband or full maiden name of wife		
OCCU-PATION	10. Type of work done during most of working life	11. Type of business or industry in which deceased worked during most of working life		
FATHER	12. Surname and all given names of father (*print or type*)	13. BIRTHPLACE – City or place, province (*or country*)		
MOTHER	14. Maiden surname and all given names of mother (*print or type*)	15. BIRTHPLACE – City or place, province (*or country*)		
USUAL RESIDENCE	16. Complete address. If rural give exact location (*not Post Office or Rural Route address*)			For Office Use Only
	Borough, city, town, village, township, (*by name*)	Regional municipality, county, or district	Province (or country)	Postal Code
SIGNATURE OF INFORMANT	17. Signature of informant X		18. Relationship to deceased	
	19. Address of informant		20. Date: Month (*by name*), day, year	

(Items 21 -25 to be completed only by the funeral director)

DIS-POSITION	21. Burial, cremation or other disposition (*Specify*)		22. Proposed date of burial or dispostion (month, day, year)	
	23. Name and address of proposed cemetery, crematorium or place of disposition			
FUNERAL DIRECTOR	24. Name and address of funeral home (*or person in charge of remains*) (*print or type*)			Postal Code
	25. Signature of funeral director (*or responsible officer*) X	Business Code No.	Date: Month (*by name*), day, year	
CERTIFI-CATION OF DIVISION REGISTRAR	Burial Permit Issued by –	Address	Date issued (*m, d, yr*)	
	I am satisfied as to the correctness and sufficiency of this statement and the medical certificate of death, and I register the death by signing the statement and the medical certificate of death –		Signature of Division Registrar	
	Registration Number	Code Number	Date: Month (*by name*), day, year	

This form and Form 16 Medical Certificate of Death must be filed with a Division Registrar before a Burial Permit can be issued.

For Department Use Only

8-2370-34.1: 17-11-86

Form 16
(VSA 1970)

PROVINCE OF
ONTARIO (Canada)
Office of the Registrar-General

To be completed by attending physician or coroner

MEDICAL CERTIFICATE OF DEATH

Registration No. (Department use only)

THIS IS A PERMANENT LEGAL RECORD

TYPE OR PRINT PLAINLY AND COMPLETE ALL ITEMS

(See reverse for instructions and legal requirements under the Vital Statistics Act)

PERSONAL PARTICULARS OF DECEASED

NAME OF DECEASED

1. Surname of deceased *(print or type)* — All given names

2. SEX

DATE OF DEATH

3. Month *(by name)*, day, year of death

4. AGE *(years)*

If under 1 year: *(Months)* | *(Days)*

If under 1 day: *(Hours)* | *(Minutes)*

PLACE OF DEATH

5. Name of hospital or institution *(otherwise give exact location where death occurred)*

CHECK (√) IF D.O.A. ☐

Borough, city, town, village or township *(by name)*

Regional municipality, county or district

Do Not Write In This Space

MEDICAL CERTIFICATE OF DEATH

CAUSE OF DEATH

6.

Part I — I — Approx. interval between onset & death — 52 55

Immediate cause of death (a) ....

due to, or as a consequence of

Antecedent causes, if any, giving rise to the immediate cause (a) above, stating the *underlying cause last*

(b) ....

due to, or as a consequence of

(c) ....

Part II — II — 56 59

Other significant conditions contributing to the death but not causally related to the immediate cause (a) above

....

....

7. If deceased was a female, did the death occur either during pregnancy (including abortion and ectopic pregnancy) or within 42 days thereafter? .... (Yes or No) — 60

AUTOPSY PARTICULARS

8. Autopsy being held? Yes ☐ No ☐

9. Does the cause of death stated above take account of autopsy findings? Yes ☐ No ☐

10. May further information relating to the cause of death be available later? Yes ☐ No ☐ — 61 63

ACCIDENTAL OR VIOLENT DEATH *(if applicable)*

11. If accident, suicide, homicide or undetermined *(specify)*

12. Place of injury *(e.g. home, farm, highway, etc.)*

13. Date of injury *(Month (by name), day, year)* — 64

14. How did injury occur? *(describe circumstances)*

CERTIFICATION *(attending physician, coroner, etc.)*

15. I certify that to the best of my knowledge and belief, the above named person died on the date and from the causes stated herein:

Signature *(attending physician, coroner, etc.)*

X

16. Designation: Attending physician ☐ Coroner ☐ Other *(specify)* ☐ .... — 65

17. Name of physician or coroner *(print or type)*

Date signed – Month *(by name)*, day, year

Address

This form and Form 15, Statement of Death, must be filed with a Division Registrar before a Burial Permit can be issued.

CERTIFICATION OF DIVISION REGISTRAR

I am satisfied as to the correctness and sufficiency of this medical certificate of death and the statement of death and I register the death by signing this certificate and the statement of death.

....
Signature of Division Registrar

Registration Number

Code Number

Date: Month *(by name)*, day, year

For Departmental Use Only

APPENDIX C

DATA COLLECTION FORM

AECB STUDY OF CANCER IN CHILDREN

Study Number: 204168 **Birth Cert No:** 026159 **Link:** 1

Surname: MACPHERSON **Firstname(s):** BRIAN JAMES

Date of Birth: 11/16/60 **(Registry)** MM DD YY **Sex:** M

Place of Birth: (Hosp) SUDBURY GENERAL **Date of Birth:** 11/16/60 **(Birth Cert)** MM DD YY

(City) SUDBURY

Mother's Surname: MACPHERSON **Firstname(s):** MARGARET JULIA

Maiden Name: CARTWRIGHT

Mother's Address: 356 JUNIPER AVENUE #3 **Residence Code:** 53007

SUDBURY **RG Code:** 20447

Postal Code: ---

Mother's Occupation: HOUSEWIFE **Mother's Age:** 22

Father's Surname: MACPHERSON **Firstname(s):** DANIEL KENNETH

Father's Address: SAME **Residence Code:** 53007

RG Code: 20447

Postal Code: ---

Father's Occupation: TRUCK DRIVER

Group No: 112651876 **Date of Dx:** 05/12/64 DD MM YY **Age at Dx:** 4

Death Certificate No: 026133

Date of Death: 30/12/71 DD MM YY **Age at Death:** 11

Cause of Death: 2040 **Residence at Death:** 53007

ALL IDENTIFYING INFORMATION IS FICTITIOUS

APPENDIX D

SUMMARY OF RESIDENCE CODING PROCEDURES

In order to facilitate the analysis by maternal residence at the time of subject's birth, it was necessary to use a consistent residence coding system for information obtained from birth certificates. Thus, all residences were coded according to the 1981 Standard Geographic Classification (SGC): a five-digit code with the first two digits indicating the county and the last three indicating the location within the county.

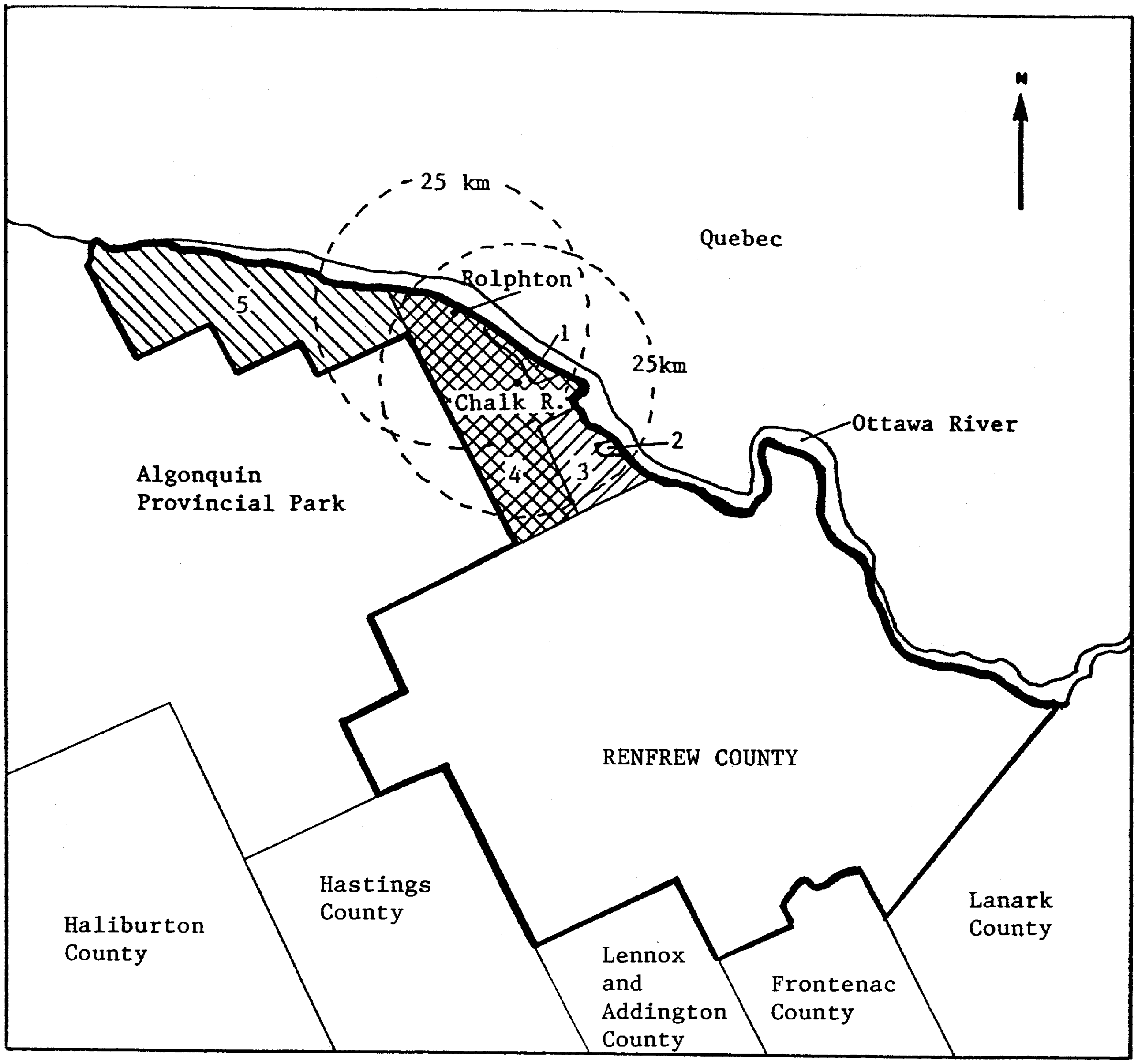
In order to be consistent with the number of live births published annually in Vital Statistics [Ref.17], the residence code assigned by the Registrar General was followed for all cases except when the birth certificate code was unspecified. In this case, an investigation of the maternal address was undertaken in order to record an accurate code. In addition, all maternal addresses in the counties under study were individually reviewed to ascertain their exact location in order to determine if cases should be included in both the county level and "nearby" analyses or the county level analysis only. For example, an address indicating only rural route information was investigated through the local post office in order to assign a specific township code for that location. Both the assigned codes and the Registrar General codes were recorded and entered into an IBM-AT compatible microcomputer.

In order to correctly interpret the Registrar General codes for verification purposes, it became clear that a thorough understanding of the complex changes in SGC coding over time was necessary. A careful search of historical documents revealed that the codes for all counties in Ontario have undergone two complete revisions since 1950. Codes for specific locations within counties changed in 1954, 1957 and 1971, in addition to several individual modifications as communities increased in size from villages to towns to cities, etc. The boundary changes which accompanied such coding modifications are described in Appendix F.

APPENDIX E

RENFREW COUNTY
(Chalk River Research Facility and
Rolphton Nuclear Power Demonstration Facility)

from: Standard Geographic Classification 1981, Volume 1A



		Population (1981)
	Chalk River Vl	1010
1	Deep River T	5095
2	Petawawa Vl	5520
3	Petawawa Twp	7720
4	Rolph, Buchanan Wylie and McKay Twp	1743
5	Head, Clara and Maria Twp	372

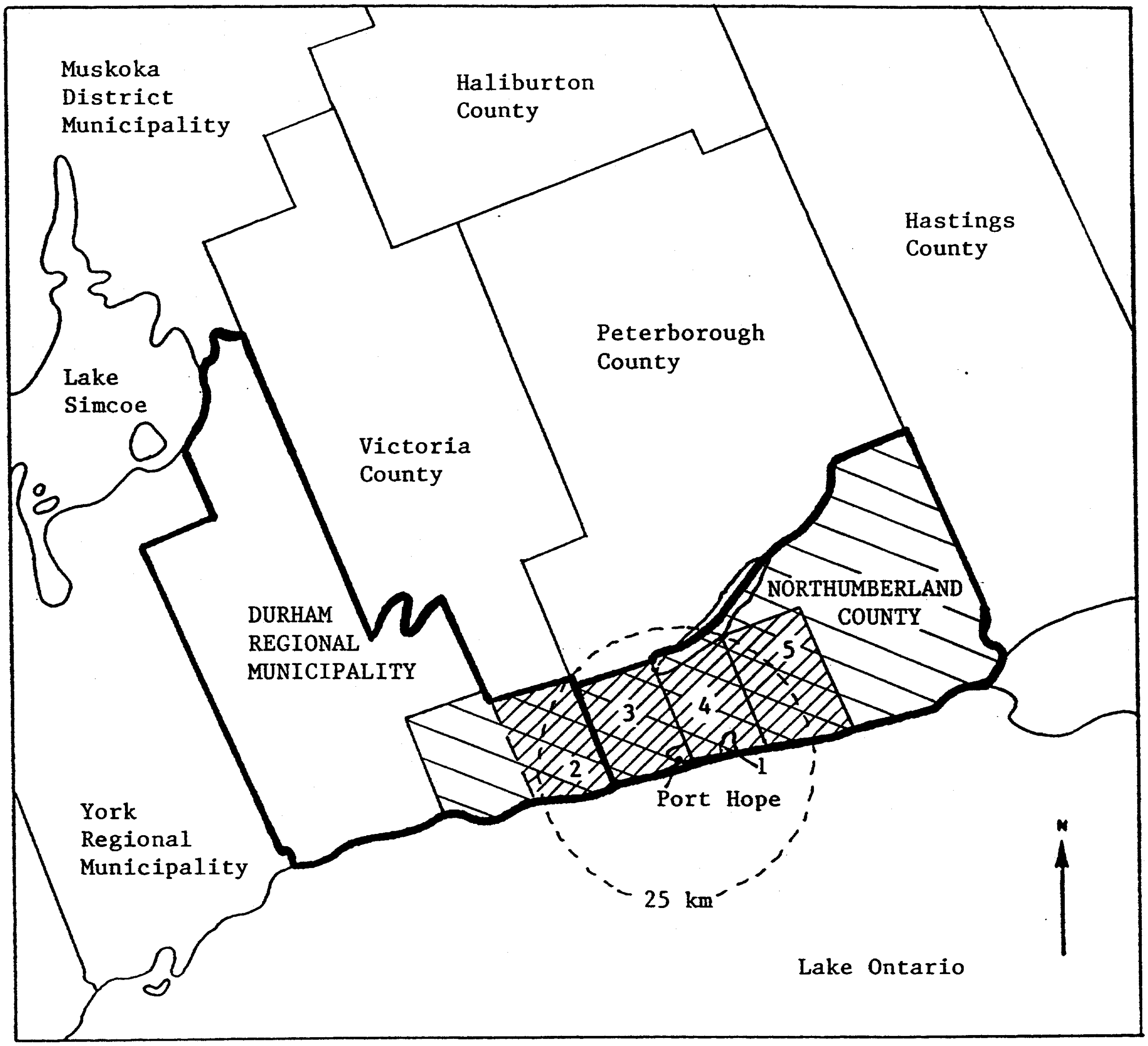
Area of "Nearby" Analysis for Chalk R.

Area of "Nearby" Analysis for Rolphton

0 10 20 30 km

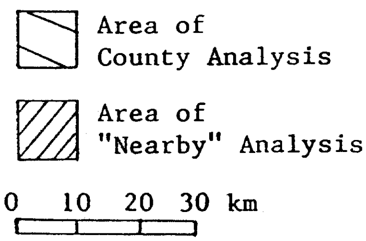
DURHAM REGIONAL MUNICIPALITY AND NORTHUMBERLAND COUNTY
(Port Hope Uranium Refining Facility)

from: Standard Geographic Classification 1981, Volume 1A



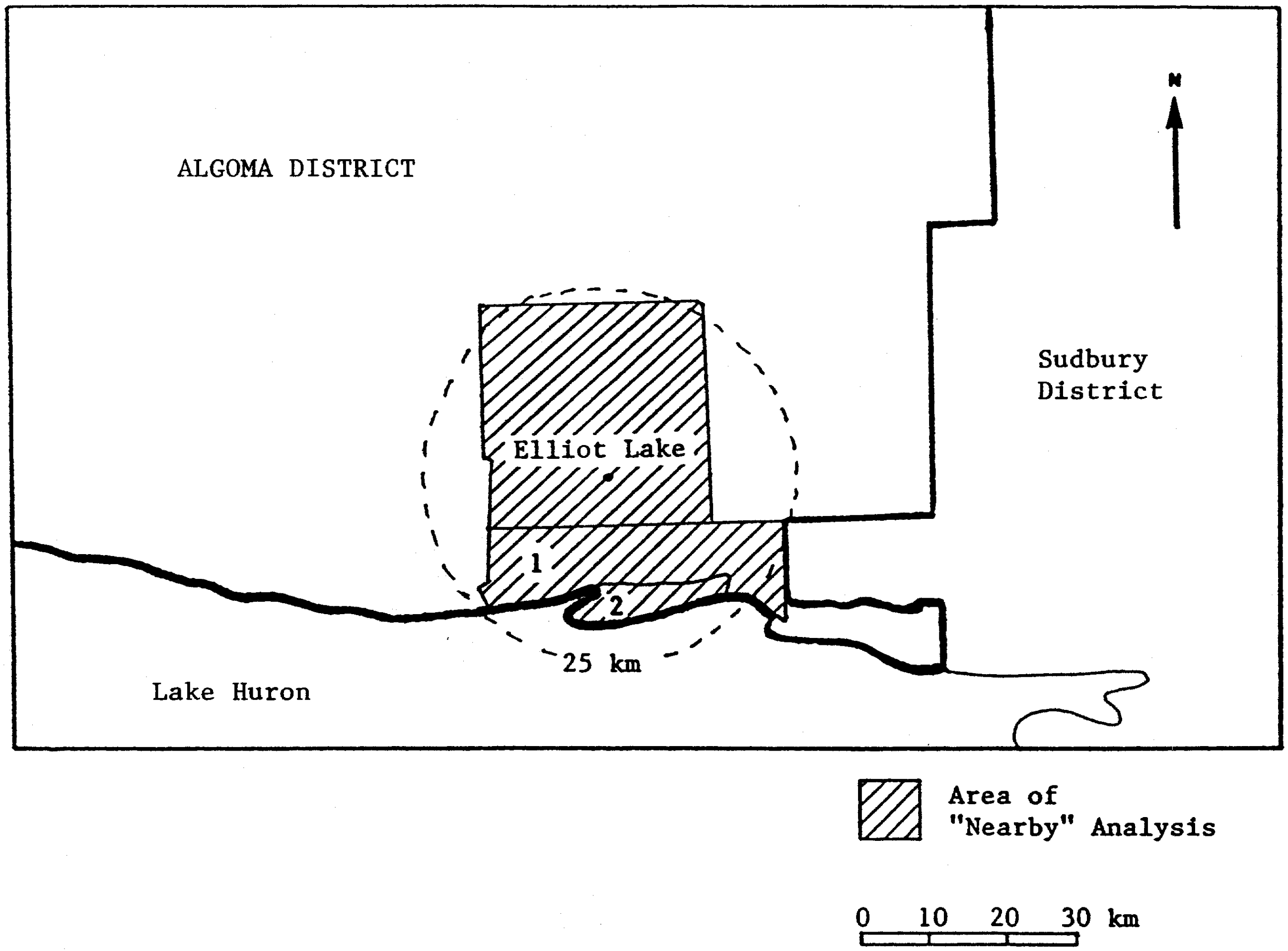
The area of the county analysis is emphasised as it differs from the geographic county boundary.

		Population (1981)
	Port Hope	9992
1	Cobourg T	11385
2	Newcastle T	32229
3	Hope Twp	3438
4	Hamilton Twp	8809
5	Haldimand Twp	3433

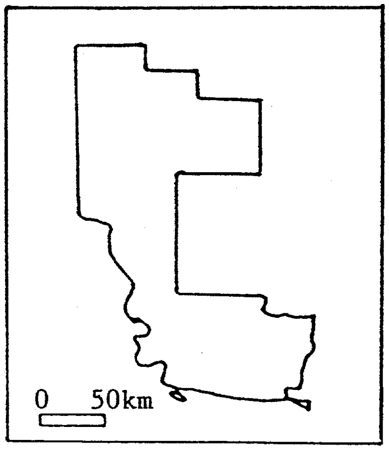


ALGOMA DISTRICT
(Elliot Lake Uranium Mine and Mill)

from: Standard Geographic Classification 1981, Volume 1A



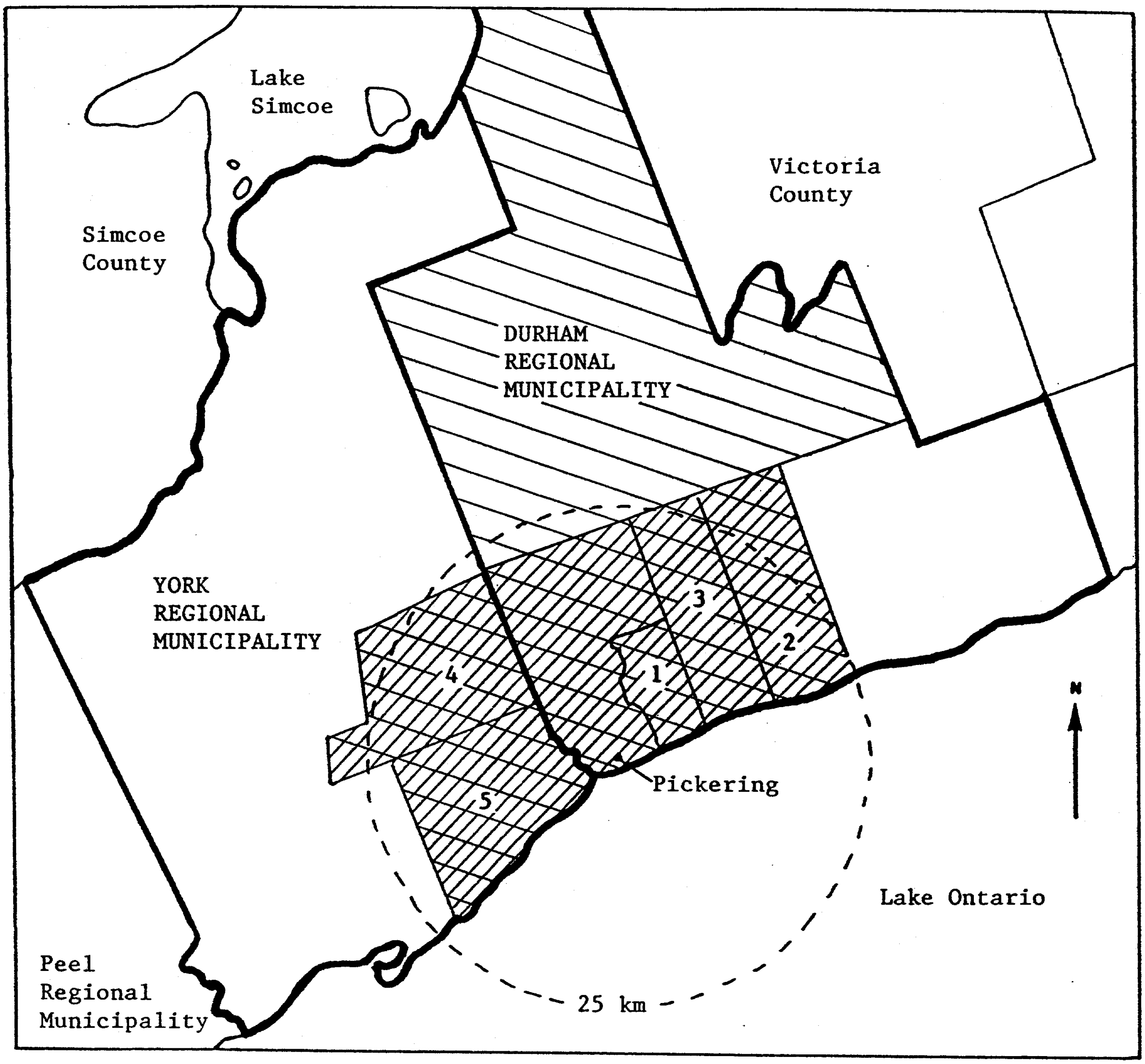
		Population (1981)
	Elliot Lake T	16723
1	North Shore Twp	2039
2	Serpent River 7 R	172



Algoma District

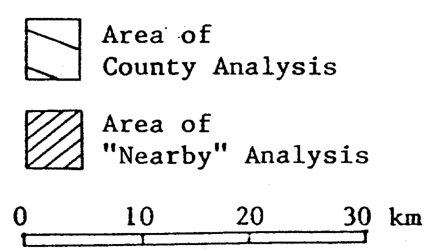
YORK AND DURHAM REGIONAL MUNICIPALITIES
(Pickering Nuclear Generating Station)

from: Standard Geographic Classification 1981, Volume 1A



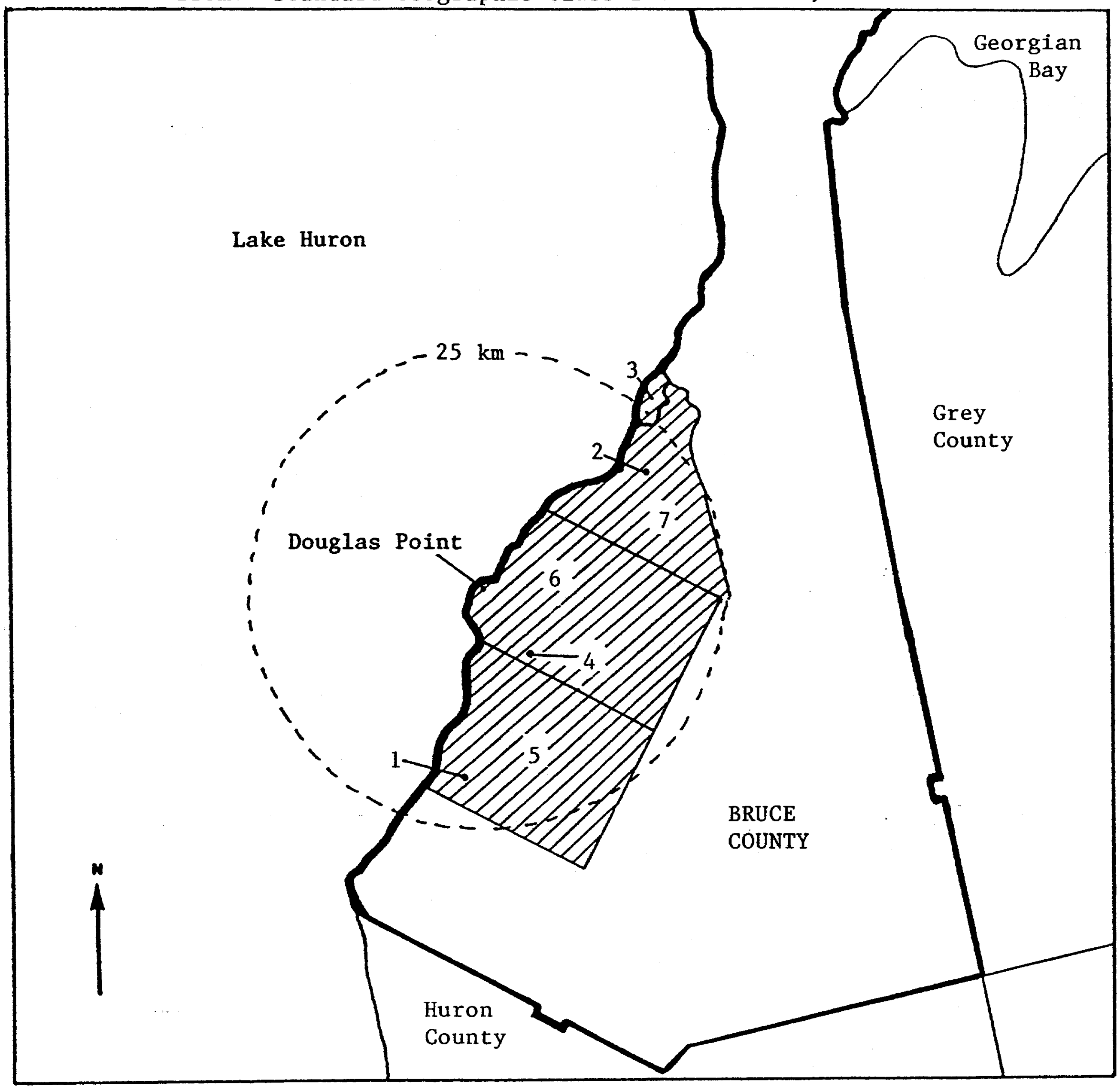
The area of the county analysis is emphasised as it differs from the geographic county boundary.

		Population (1981)
	Pickering T	37754
1	Ajax T	25475
2	Oshawa C	117519
3	Whitby T	36698
4	Markham T	77037
5	Scarborough Bor	443353



BRUCE COUNTY
(Douglas Point and Bruce Nuclear Power Development)

from: Standard Geographic Classification 1981, Volume 1A



		Population (1981)
1	Kincardine T	5778
2	Port Elgin T	6131
3	Southampton T	2830
4	Tiverton Vl	806
5	Kincardine Twp	3175
6	Bruce Twp	1773
7	Saugeen Twp	1720

Area of "Nearby" Analysis

0 10 20 30 km

APPENDIX F

SUMMARY OF BOUNDARY CHANGES AND ESTIMATION METHODS

For each county under study the chronology of boundary changes is listed from the year the nuclear facility began operation. The specific areas that were included in the county level and "nearby" analyses are listed (C=city; Bor=borough; T=town; Vl=village; Twp=township; R=Indian Reserve). The years for which data were not available from published reports are then listed, followed by detailed notes regarding the delineation of the counties and "nearby" areas under study and the methods of estimating populations and live birth frequencies.

RENFREW COUNTY (Chalk River and Rolphton)

Chronology

- 1904 - Petawawa Armed Forces Base opened as a training camp.
- 1944 - Chalk River Laboratory Facility opened in Rolph, Buchanan, Wylie and McKay Twp.
- 195? - Sometime in the 1950's, Petawawa Base became a permanent base, resulting in a large population increase.
- 1954 - Chalk River Vl. was incorporated from Rolph, Buchanan, Wylie and McKay Twp.
- 1956 - Deep River T. was incorporated from Rolph, Buchanan, Wylie and McKay Twp.
- 1961 - Petawawa Vl. was incorporated from Petawawa Twp.
- 1962 - Rolphton Power Facility opened in Rolph, Buchanan, Wylie and McKay Twp.
- 1980 - Petawawa Vl. annexed part of Petawawa Twp.
- 1988 - Rolphton was closed and dismantled.

County Level Analysis: Renfrew County

"Nearby" Analysis (Chalk River): Deep River T.; Chalk River Vl.; Petawawa Vl.; Rolph, Buchanan, Wylie and McKay Twp.; Petawawa Twp. A final analysis included Head, Clara and Maria Twp. post 1962, since this area was within 25 km of the Rolphton generating station.

Estimated Births:

- 1950-1968: Petawawa Twp.
- 1972-1973: Petawawa Twp.
- 1950-1973: Rolph, Buchanan, Wylie and McKay Twp., Head, Clara and Maria Twp.
- 1954-1961: Deep River T., Chalk River Vl.
- 1959-1961: Petawawa Vl.

Notes:

1. Births were estimated using the percentage of the population aged 15-44 years from 1949 to 1958 and the percentage of females aged 15-44 years (% F15-44) from 1959 to 1973. Birth figures are available for Petawawa Twp. for 1969 to 1971 from the annual Vital Statistics Report, but missing for 1972 and 1973.

2. Live births were only estimated back to 1950, even though the Chalk River facility opened earlier. The birth estimation before 1950 would be much more complex due to the absence of a census in 1946.

3. The Chalk River 25 km circle covers the Twp. of Sheen, Esher, Aberdeen and Malakoff in Pontiac County in Quebec. The Rolphton circle also covers this township, as well as Rapides-des-Joachims Twp. It is not feasible to obtain the relevant Quebec incidence and mortality data and, since the total population in these two townships is small (n=498 by the 1966 census) relative to the population of the "nearby" area (20,278 in 1966), the exclusion of this area could only have a minor effect on the study results.

4. Although Petawawa Vl. was incorporated in 1961, births had to be estimated for 1959-1961 because the village was listed separately from Petawawa Twp. in the 1961 census. A similar problem existed with Deep River T. and Chalk River Vl. in Rolph, Buchanan, Wylie and McKay Twp. from 1959 to 1961. The following procedure of estimation was used for all three areas, but is illustrated with Petawawa Vl.

a) Calculate percentage of women aged 15-44 in Petawawa Vl., using Petawawa Vl. and all "county-other" places in the denominator from the 1961 census.

b) Calculate the number of births expected in Petawawa Vl. in 1959-1961. Subtract this from the total "county-other" births.

c) Calculate % F15-44 in the remaining places to be estimated, using all "county-other" places in the denominator. Use these figures for the entire 1959-1963 pericensal period, and multiply by the annual "county-other" births.

NORTHUMBERLAND COUNTY (Port Hope)

Chronology

1935 - Port Hope Processing Plant opened.
1963 - Port Hope Vl. annexed part of Hope Twp.
1964 - Trenton T. (Hasting County) annexed part of Murray Twp.
1965 - Cobourg T. annexed part of Hamilton Twp.
1968 - Trenton T. (Hastings County) annexed part of Murray Twp.
1974 - Port Hope Vl. became a town (status change only)
- Port Hope T. and Hope Twp. from Durham County joined Northumberland County.
- South Monaghan Twp. from Northumberland County joined Peterborough County.
- Darlington Twp., Clarke Twp., Bowmanville T. and Newcastle Vl. became Newcastle T. in Durham Regional Municipality.

1983 - Cobourg T. annexed part of Hamilton Twp.

County Level Analysis: Northumberland County as defined in 1974, plus Newcastle T.

"Nearby" Analysis: Port Hope T., Cobourg T., Newcastle Vl., Clarke Twp., Hope Twp., Haldimand Twp., Hamilton Twp.

Estimated Births:

1950-1956: Newcastle Vl.
1950-1973: Clarke Twp., Hope Twp., Hamilton Twp., Haldimand Twp., South Monaghan Twp., Darlington Twp.

Notes:

1. Births were estimated using the percentage of the population aged 15-44 years from 1950 to 1958 and the percentage of women aged 15-44 years from 1959 to 1973. Since several of the "nearby" areas were part of Durham County during the period of estimation, the appropriate "county-other" births and population data were used.

2. Live births were only estimated back to 1950, even though the plant opened earlier. The birth estimation before 1950 would be much more complex due to the absence of a census in 1946.

3. Rationale for county level area: The available figures from 1974 to 1986 for Northumberland County can be used with that part of Durham Regional Municipality not used in the Pickering analysis. The number of live births in South Monaghan Twp. was estimated so that this number could be subtracted from Northumberland County figures prior to 1974; Darlington Twp., Clarke Twp. and Newcastle Vl. were added to the county figures. Exact figures were available for Bowmanville T.

4. Since only Clarke Twp. and Newcastle Vl. of the post-1974 Newcastle T. were to be included in the "nearby" analysis, it was necessary to estimate their birth figures. Since 27.15% of the population of Newcastle T. lived in Clarke Twp. and Newcastle Vl. in 1971, this percentage of the post-1974 births were considered to have occurred in the area under study. The exact location of residence of post-1974 cases occurring in Newcastle T. was individually checked.

5. Separate birth figures are available from Colborne Vl. from 1952. To be consistent through the 1949-1953 pericensal period, Colborne Vl. was included in both the "county-other" births and the % F15-44.

6. Separate births figures are available for Newcastle Vl. from 1957 to 1973. The following estimation procedure was used for 1954 to 1956.

a) Calculate % F15-44 in Newcastle Vl., using Newcastle Vl. and all "county-other" places in the denominator from the 1956 census.

b) Calculate the number of births expected in Newcastle Vl. in 1954-1956. Subtract this from the total "county-other" births.

c) Calculate % F15-44 in the remaining places to be estimated, using all "county-other" places in the denominator. Use these figures for the entire 1954-1958 pericensal period, and multiply by the annual "county-other" births.

ALGOMA DISTRICT (Elliot Lake)

Chronology:

1954 - Elliot Lake Uranium Mines opened.
1955 - Elliot Lake Improvement District was created from Algoma District Unorganized, North Part.
1966 - Elliot Lake Improvement District became a township.
1967 - Victoria Twp. (Unorganized) in Algoma District and May, Harrow, Salter & Hallam Twps. in Sudbury District became Spanish River Twp. in Sudbury District.
1974 - Shedden, Lewis, Spragge, Long, and part of Striker Twps. (Unorganized) became North Shore Improvement District.
1976 - Elliot Lake Twp. became a town.
1978 - North Shore Improvement District became a township.
1985 - Shedden Improvement District was incorporated from North Shore Twp.

County Level Analysis: Algoma District

"Nearby" Analysis: Elliot Lake T., North Shore Twp., and Serpent River 7 R.

Estimated Births:

1954-1963: Elliot Lake T.
1972-1973: Elliot Lake T.
1954-1973: Shedden, Lewis, Spragge, Long and part of Striker Twp.
1954-1986: Serpent River 7 R.

Notes:

1. Elliot Lake T. experienced a population boom and subsequent decline during the period when it was necessary to estimate the births. The following method was used:

1954-1956: The birth rate for Algoma "county-other" areas (per 1,000 population for every year) was multiplied by the census year total population.

1957-1963: The assessment population was available for Elliot Lake T. This was used instead of the census year total population with the "county-other" birth rate.

1964-1971: Exact figures were available from the annual vital statistics reports.

1972-1973: Elliot Lake T. is missing from the vital statistics reports. In order to make the estimates as accurate as possible, the following procedure was used:

a) Calculate % F15-44 in Elliot Lake T., using Elliot Lake T. and all "county-other" places in the denominator from the 1971 census.

b) Calculate the number of births expected in Elliot Lake T. in 1972-1973 by multiplying a) by the annual total "county-other" live births. Subtract this from the total "county-other" births.

c) Recalculate the "county-other" birth rate, using all "county-other" places in the denominator.

2. Due to the extremely small numbers, population figures by sex and age groups are not available for North Shore Twp. over the period requiring estimation. Therefore for the period 1954-1973, the number of live births was estimated by multiplying the birth rate for Algoma "county-other" areas (per 1,000 population for every year) by the census year total population for pericensal periods.

3. A variety of methods were used to estimate the births in Serpent River 7 R.:

1954-1958: The total population living on Indian Reserves is available from the 1956 census. To determine the population of Serpent River 7 R., the percentage from the 1961 census was used. In 1961, 13.54% of the Indian Reserve population in Algoma District lived in Serpent River 7 R. In 1956 the Indian Reserve population was 1704. Therefore, it was estimated that 13.54% of this population (231) lived in Serpent River 7 R. The births were calculated using the birth rate for Algoma "county-other" areas.

1959-1973: The birth rate for Algoma "county-other" (per 1,000 population for every year) was used with the census year total population for pericensal periods.

1974-1978: The number of births on Indian Reserves was available. This was used with the percentage of total Indian Reserve population that lived in Serpent River 7 R. as listed in the Census.

1979-1986: Age and sex breakdown was available for Serpent River 7 R. Therefore the births were calculated using the number of births on Indian Reserves and the percentage of Indian Reserve females aged 15-44 years who lived in Serpent River 7 R.

4. Population figures are given separately for Shedden Improvement District and North Shore Twp. in the 1986 Census, but they are reported as a single unit for the live births statistics.

5. Approximately half of the area of Striker Twp. was included in North Shore Twp. Since no information is available regarding the population distribution, it was decided that half the population of Striker Twp. be included when amalgamating the townships which formed North Shore Twp.

DURHAM REGIONAL MUNICIPALITY (Pickering)

Chronology

1971 - Pickering Nuclear Generating Station opened in Pickering Twp., Ontario County.
- Stouffville T., Richmond Hill T. and Markham T. annexed part of Markham Twp., York Regional Municipality.

1974 - Ontario County was dissolved. Rama and Mara Twps. joined Simcoe County. All other villages, towns, cities, and townships became part of the Durham Regional Municipality.
- Scott Twp. and Uxbridge T. joined Uxbridge Twp.
- Thorah Twp. and Cannington Vl. joined Brock Twp.
- Whitby East Twp. joined Oshawa C.
- Pickering Vl., Ajax T. and part of Pickering Twp. became Ajax T. The remainder of Pickering Twp. became Pickering T.
- Scott Twp., Port Perry Vl., and Cartwright Twp. from Durham County joined Scugog Twp.

1983 - Scarborough Bor. became a city.

County Level Analysis: Ontario County, minus Rama Twp. and Mara Twp., plus Cartwright Twp., Markham T., and Scarborough Bor.

"Nearby" Analysis: Pickering T., Ajax T., Whitby T., Oshawa C., Markham T. and Scarborough Bor.

Estimated Births:

1972-1973: Pickering Twp.
1971-1973: East Whitby Twp., Rama Twp., Mara Twp., Cartwright Twp.

Notes:

1. Since population figures were available by sex and age group, births were estimated using the number of births occurring in "county-other" areas of Ontario County and the percentage of woman aged 15-44 living in the areas which required estimation. Cartwright Twp. figures were estimated using the appropriate figures from Durham County. For Pickering Twp. birth figures are available in 1971 but are unavailable in 1972 and 1973.

2. Rationale for the county analysis area: Rama and Mara Twps. are the most northerly townships and relatively sparsely populated. By including Cartwright Twp., the figures from 1974 could be used without modification, and it was only necessary that 3 years of data be adjusted for the county level analysis.

3. Markham T. and Scarborough Bor. were included in the "nearby" and county analyses so that the "nearby" figures are a subset of the county figures.

4. For the analysis that examined mortality in the period before the opening of the Pickering facility, it was necessary to estimate births for the following years and places:

1950-1970: Rama Twp., Mara Twp., Cartwright Twp., East Whitby Twp.

1950-1953: Markham Twp., Scarborough Twp., Ajax T., Pickering Twp.

1950-1968: Whitby Twp.

1954-1956: Pickering Vl.

BRUCE COUNTY **(Douglas Point)**

Chronology

1967 - Douglas Point Power Plant opened in Bruce Twp.
1969 - Port Elgin T. annexed part of Saugeen Twp.
1971 - Southampton T. annexed part of Saugeen Twp.
- Port Elgin T. annexed part of Saugeen Twp.
1976 - Units 1 and 2 of Bruce Nuclear Power Development A began operation.
1977 - Port Elgin T. annexed part of Saugeen Twp.
1984 - Douglas Point Power Plant closed. Bruce Nuclear Power Development B opened: a total of 6 reactors in service.

County Level Analysis: Bruce County

"Nearby" Analysis: Kincardine T., Port Elgin T., Southampton T., Tiverton Vl., Kincardine Twp., Bruce Twp., Saugeen Twp.

Estimated Births:

1967-1973: Kincardine Twp., Tiverton Vl., Bruce Twp., Saugeen Twp.

Notes:

1. Since population figures are available by sex and age group, births were estimated using the number of births occurring in "county-other" areas of Bruce County and the percentage of women aged 15-44 living in the areas which required estimation.

APPENDIX G

LIVE BIRTH DATA AND ESTIMATION OF MISSING VALUES

Live births were calculated for the time periods and census subdivisions described in Appendix F. This was necessary because the published reports gave births only for incorporated places with a population over 1,000 as of the most recent census. Thus, a method for estimating live births had to be devised. In order of preference, the following estimation methods have been used:

a) "county-other" births multiplied by % population female, aged 15-44;
b) "county-other" births multiplied by % population, aged 15-44;
c) "county-other" births multiplied by % total population

"County-other" births are those births which are known to have occurred to a mother resident in a county under study, but in a census subdivision too small to have been reported separately. The advantage of using the annual "county-other" births is that if births had to be calculated for all of the "county-other" subdivisions, they would equal the total births known to have occurred to mothers in those subdivisions.

The three different percentages used attempt to give an increasingly more accurate indication of the segment of the population which is actually bearing children. The percentage population aged 15 to 44 was used for all estimation in the years 1950-1958, due to the limitations of the available census data. For some areas and time periods in Algoma District (see Appendix F), only total population was available. Therefore, for a given pericensal period, the most accurate percentage possible was calculated and used with the annual "county-other" births to estimate the live births. Complications occurred when live births for a census subdivision under study were available for only part of a pericensal period. Appendix F describes the method used for these calculations.

To investigate the accuracy of the estimation method, it was applied for the period when live birth frequencies were known (1974-1986), for Northumberland County. Prior to 1974, live birth frequencies had to be estimated for three townships (Haldimand, Hamilton, Hope), as shown in Table G-2. For these three townships, estimates were obtained after 1974 by adding their known values to the "county-other" value, and then applying the estimation procedure a) described above. For the three townships, estimates were obtained for each of 13 years, and these were compared with the true values (e.g., observed minus estimated). The box plots in Figure G-1 show that the median difference between true and estimated number of live births was -3.6 for Haldimand Township, -4.1 for Hamilton Township and 0 for Hope Township. It can also be noted that the range of differences was greatest for Hamilton Township, which had the largest number of live births (mean of true values = 115.2 per year). By examining the difference between the total births in the three townships together and the total estimated ("All"), an indicator of the overall effect of the estimation procedure was obtained. The box plot for "All", which has a median of 1.2 and a mean of 2.4 indicates that, on average, the live birth frequencies are an underestimation of the "nearby" area live births. Under the assumption that the effect of the estimation procedure is equal in all counties and over all years in which it was applied, this figure is used in Section E-5.5 to assess the potential bias effect on the major results of the study. Tables G-1 to G-5 give the live birth data that were used. The estimates are indicated by asterisks.

Table G-1: Renfrew County: Number of Live Births for "Nearby" Subdivisions

	Petawawa Twp.	Petawawa Vl.	Rolph, Buchanan Wylie & McKay Twp.	Chalk River Vl.	Deep River T.	Head Clara & Maria Twp.
1949	238*		138*			
1950	257*		149*			
1951	252*		146*			
1952	283*		165*			
1953	290*		168*			
1954	326*		52*	31*	128*	
1955	319*		51*	31*	126*	
1956	329*		52*	32*	129*	
1957	328*		52*	32*	129*	
1958	332*		53*	32*	131*	
1959	255*	144*	55*	34*	181*	
1960	250*	141*	54*	33*	177*	
1961	266*	150*	58*	36*	189*	
1962	266*	189	58*	52	147	13*
1963	252*	175	55*	43	139	12*
1964	235*	128	55*	44	133	12*
1965	197*	153	46*	23	116	10*
1966	163*	94	38*	21	84	8*
1967	159*	106	37*	24	97	8*
1968	158*	107	37*	20	82	8*
1969	186	104	33*	27	75	7*
1970	181	107	32*	27	105	7*
1971	189	119	31*	21	91	6*
1972	144*	116	31*	26	99	6*
1973	141*	90	30*	19	92	6*
1974	130	133	24	23	82	6
1975	113	119	38	27	90	10
1976	108	141	26	24	66	7
1977	128	120	30	23	71	3
1978	140	132	31	21	65	3
1979	145	122	31	22	68	5
1980	124	115	26	23	58	6
1981	124	111	18	22	73	2
1982	148	123	30	15	65	2
1983	144	129	25	22	64	5
1984	128	174	23	16	66	8
1985	168	141	16	18	70	2
1986	152	124	24	17	66	1
1987	97	195	20	12	49	2

* Estimated values.

Table G-2: Northumberland County: Number of Live Births for "Nearby" Subdivisions

	Haldimand Twp.	Hamilton Twp.	Cobourg T.	Hope Twp.	Port Hope T.	Newcastle Vl.	Clarke Twp.
1949	45*	62*	150	58*	182	21*	60*
1950	49*	67*	155	52*	137	19*	54*
1951	53*	73*	163	60*	181	21*	62*
1952	55*	74*	169	69*	159	25*	72*
1953	49*	67*	193	79*	167	28*	83*
1954	58*	89*	226	71*	175	29*	89*
1955	63*	97*	260	67*	166	27*	84*
1956	56*	87*	259	74*	189	30*	93*
1957	57*	88*	225	71*	169	27	89*
1958	58*	90*	225	74*	187	31	93*
1959	56*	110*	241	67*	186	21	96*
1960	52*	104*	237	62*	176	33	90*
1961	52*	103*	269	62*	182	31	89*
1962	46*	90*	229	62*	172	31	90*
1963	49*	97*	255	62*	157	31	90*
1964	49*	115*	269	58*	161	31	99*
1965	51*	118*	207	47*	135	33	81*
1966	45*	105*	177	45*	133	33	77*
1967	44*	103*	193	41*	146	29	71*
1968	38*	88*	182	43*	133	26	74*
1969	43*	99*	180	41*	134	25	83*
1970	46*	106*	199	45*	143	35	91*
1971	39*	91*	207	41*	133	38	84*
1972	46*	106*	184	40*	124	35	82*
1973	41*	93*	163	42*	163	23	86*
1974	37	119	184	44	152	130*	
1975	39	140	167	40	150	131*	
1976	39	114	146	35	169	125*	
1977	40	136	151	55	149	126*	
1978	60	106	154	43	163	126*	
1979	43	134	142	53	154	118*	
1980	49	110	142	43	177	112*	
1981	43	99	140	45	132	108*	
1982	48	114	157	58	170	114*	
1983	36	101	170	23	146	117*	
1984	43	112	162	39	147	115*	
1985	41	99	168	53	133	113*	
1986	39	113	158	58	161	133*	
1987	57	95	163	41	129	127*	

* Estimated values

Note: Please refer to Appendix F, Page F3, for an explanation of the estimated values for Newcastle Village 1974-1987.

Table G-3: Algoma District: Number of Live Births for "Nearby" Subdivisions

	North Shore Twp.	Elliot Lake T.	Serpent River 7 R.
1954	62*	121*	7*
1955	62*	122*	7*
1956	60*	118*	7*
1957	56*	376*	7*
1958	67*	765*	8*
1959	152*	980*	12*
1960	161*	1063*	12*
1961	129*	538*	10*
1962	122*	361*	9*
1963	114*	321*	9*
1964	131*	318	8*
1965	63*	160	4*
1966	58*	167	4*
1967	61*	154	4*
1968	58*	199	4*
1969	58*	267	4*
1970	49*	192	3*
1971	51*	207	3*
1972	44*	182*	3*
1973	40*	168*	3*
1974	23	129	6*
1975	29	121	5*
1976	37	154	6*
1977	43	175	5*
1978	55	298	6*
1979	40	305	3*
1980	45	344	3*
1981	43	388	3*
1982	37	462	2*
1983	29	450	2*
1984	37	446	2*
1985	30	384	2*
1986	31	348	4*
1987	34	290	2*

* Estimated values

Table G-4: Durham Regional Municipality: Number of Live Births for "Nearby" Subdivisions

	Pickering T.	Ajax T.	Whitby T.	Oshawa C.	Markham T.	Scarborough Bor.
1971	517	260	349	1716*	570	5546
1972	547*	268	358	1750*	687	5199
1973	513*	275	396	1667*	817	5461
1974	384	333	413	1727	913	5369
1975	378	325	400	1750	895	5627
1976	460	296	418	1747	833	5538
1977	602	366	400	1875	850	5714
1978	687	386	476	1890	896	5576
1979	707	402	540	1978	989	5807
1980	729	425	601	1896	1170	6240
1981	721	375	622	1869	1239	6464
1982	761	412	678	1843	1347	6636
1983	816	507	707	1926	1487	6654
1984	900	615	767	1964	1764	6981
1985	966	742	713	2052	1805	6920
1986	1024	773	824	1867	1974	7335
1987	1128	931	796	1955	2121	7272

* Estimated values

Table G-5: Bruce County: Number of Live Births for "Nearby" Subdivisions

	Kincardine Twp.	Kincardine T.	Bruce Twp.	Tiverton Vl.
1967	29*	31	20*	5*
1968	28*	36	19*	5*
1969	27*	30	23*	8*
1970	33*	46	28*	10*
1971	31*	50	27*	10*
1972	33*	53	28*	10*
1973	34*	54	29*	11*
1974	51	63	32	16
1975	64	73	52	17
1976	53	80	36	19
1977	57	81	38	18
1978	54	104	43	9
1979	54	113	30	11
1980	45	104	26	18
1981	62	114	31	15
1982	57	98	19	8
1983	56	154	22	18
1984	77	119	21	12
1985	52	104	24	14
1986	43	88	15	16
1987	29	90	16	8

	Saugeen Twp.	Port Elgin T.	Southampton T.
1967	17*	32	23
1968	17*	32	24
1969	15*	46	27
1970	19*	43	29
1971	18*	56	31
1972	19*	82	34
1973	20*	70	43
1974	17	76	27
1975	28	93	45
1976	26	109	40
1977	24	111	51
1978	34	115	50
1979	14	126	41
1980	34	125	36
1981	16	127	41
1982	29	131	43
1983	29	124	46
1984	25	119	52
1985	18	127	41
1986	21	112	35
1987	14	87	50

* Estimated values

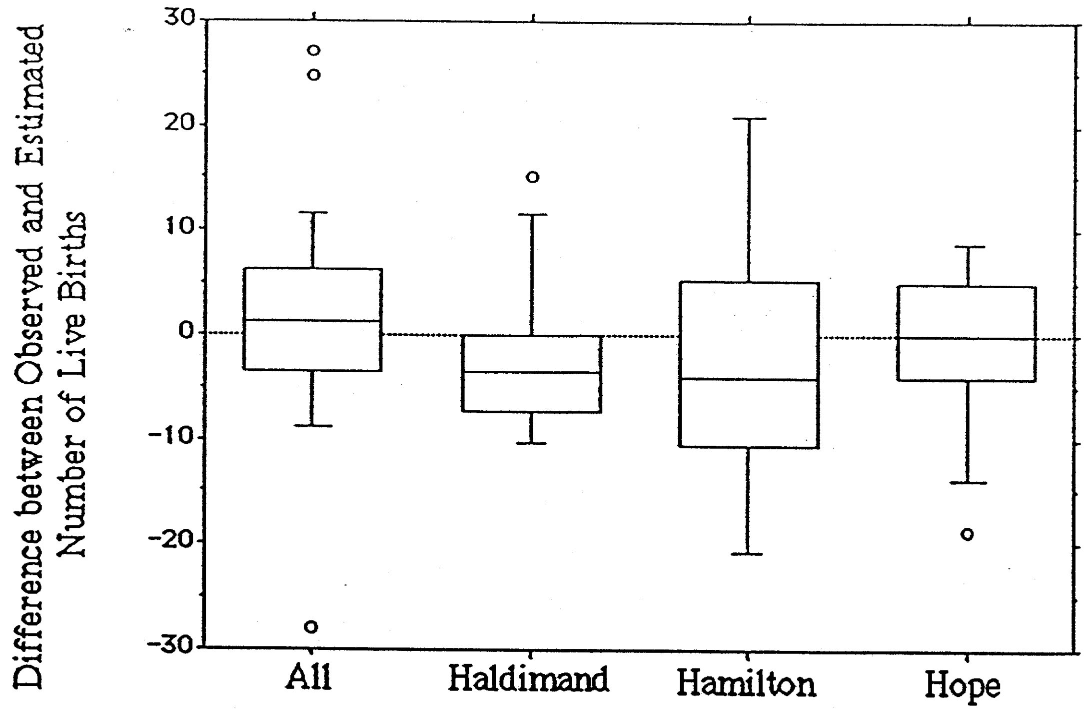


Figure G-1: Boxplots of the Difference Between Observed and Estimated Numbers of Live Births for Townships in Northumberland County.

APPENDIX H

THE INTERDEPENDENCE OF THE ANALYSIS METHODS

This appendix explains the interdependencies between the three styles of analysis presented in Tables 6 to 10. It is possible for a subject to be included in all three analyses at both the county and "nearby" levels, or to be included only once at the county level. Table H-1 gives the total number of individuals included for each method, level of analysis, and geographic region. While there are subjects included in two or three analyses, between 35% and 71% of subjects are included in only one style of analysis in a given county. Overlap has had the greatest effect in Algoma District, where 51% of subjects have been included in all three styles.

For individuals to be included in a specific combination of analyses, they must meet criteria, which are based on when the incidence and mortality data became available, when the facility opened, and migration. For each combination of analyses, these criteria are:

- Mortality by Residence at Death Only (A): Subject was born either before 1950, before the facility opened, or outside the county under study.

- Mortality by Residence at Birth Only (B): Subject was born between 1950 and 1963 inclusive, died outside the county under study and either died before 1964 or was diagnosed before 1964.

- Incidence Only (C): Subject was born either after 1950 or after the facility opened, was diagnosed after 1964 and either did not die or did not die of leukaemia under age fourteen years.

- Mortality by Residence at Birth and Death (D): Subject was born either after 1950 or after the facility opened, and either died before 1964 or was diagnosed before 1964.

- Mortality by Residence at Birth and Incidence (E): Subject was born either after 1950 or after the facility opened, was diagnosed after 1964 and died outside the county under study.

- Mortality by Residence at Birth and Death and Incidence (F): Subject was born and died in the county under study either after 1950 or after the facility opened, and was diagnosed after 1964.

Table H-1: Frequency of Subjects by Analysis Method and Geographic Region.

ANALYSIS	Renfrew		Northumberland		Algoma		Durham		Bruce	
METHOD	County	"Nearby"	County	"Nearby"	County	"Nearby"	County	"Nearby"	County	"Nearby"
A	10	4	7	4	5	1	40	37	3	0
B	1	0	1	1	2	0	0	0	0	0
C	5	0	7	5	12	1	42	39	4	1
D	5	0	5	3	5	1	0	0	0	0
E	3	2	4	1	3	1	7	7	2	0
F	8	0	10	7	28	2	26	26	3	3
Total	32	6	34	21	55	6	115	109	12	4