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INFO-0300-1

CHILDHOOD LEUKAEMIA AROUND CANADIAN NUCLEAR FACILITIES - PHASE I

FINAL REPORT

by

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A report prepared for the
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Ottawa, Canada

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May 1989

Canada

Report

EXECUTIVE SUMMARY

Recent studies in the United Kingdom have demonstrated an increased occurrence of childhood leukaemia in the vicinity of nuclear facilities that are involved in fuel reprocessing and weapon manufacturing. The general objective of this study was to investigate whether or not there exist clusters of leukaemia among children born to mothers resident in the vicinity of nuclear facilities in Ontario.

Seven hundred and ninety-five children, aged 0-4 years, who died of leukaemia between 1950 and 1986, and 951 children who were diagnosed with leukaemia between 1964 and 1985, were identified from the Ontario Cancer Registry. Residence at the time of birth was obtained from birth certificates. Residence at the time of death was obtained from Ontario Cancer Registry records or death certificates. Analyses were performed separately for each of three general types of nuclear facilities (nuclear research facilities; uranium mining, milling and refining facilities; and nuclear power generating stations), and for two levels of geographic area around each facility (county, and a "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) over the expected (E) number of events for each area. For the calculation of mortality ratios by residence at time of 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 0-4 years. For the calculation of mortality and incidence ratios by residence at time of birth, the expected values referred to the number of events that would be expected for a given number of live births.

The observed number of children with leukaemia in the vicinity of the nuclear research facilities in Renfrew County was less than the expected number, with county level mortality ratios of 0.83 (O = 9, E = 10.8) and 0.77 (O = 8, E = 10.4) for the residence at death and residence at birth analyses respectively. Results of the analyses of leukaemia incidence by residence at time of birth were similar to those of mortality by residence at time of birth. In the area "nearby" the research facility at Chalk River, an even lower level of relative risk was detected, with incidence and mortality ratios ranging from 0.31 (O = 1, E = 3.2) to 0.37 (O = 1, E = 2.7). These results demonstrated that the ninefold risk that was previously noted in the British study of leukaemia in the vicinity of the reprocessing facility at Sellafield (O = 5, E = 0.53) was not observed in the vicinity of the Chalk River nuclear research facility.

In general, the frequency of childhood leukaemia was slightly higher than expected in the vicinity of the two facilities involved in uranium mining, milling and refining; however, different patterns were observed for each of the facilities. Relative risk estimates were higher by residence at time of birth than by residence at time of death around the Port Hope facility [e.g., 1.6 (O = 7, E = 4.5) versus 1.4 (O = 6, E = 4.3) respectively], whereas the opposite was true for the Elliot Lake area [e.g., 1.1 (O = 2, E = 1.8) versus 1.8 (O = 3, E = 1.7)]. In the area "nearby" Port Hope, the relative risk estimates were slightly higher than for the county [e.g., for incidence 1.7 (O = 9, E = 5.2) versus 1.4 (O = 14, E = 9.8) respectively], but generally the "nearby" Elliot Lake estimates were lower than the county values [e.g., for incidence 0.4 (O = 1, E = 2.4) versus 1.0 (O = 18, E = 17.5) respectively]. The lower bounds of the confidence intervals for all of these estimates encompassed 1.0, therefore the degree of excess risk detected could have been due to chance.

The occurrence of leukaemia in children in the vicinity of nuclear power generating stations was slightly higher than expected. Essentially, there was little difference between the county and "nearby" analyses for the facility at Pickering as the two geographic areas were almost identical. The relative risk estimates for the "nearby" area were 1.2 (O = 50, E = 41.3) for the analysis of incidence and 1.4 (O = 17, E = 12.4) for the analysis of mortality by residence at birth, whereas for the analysis of mortality by residence at death the relative risk estimate was approximately 1.0 (O = 19, E = 18.6). The relative risk estimates for the "nearby" area around the facilities in Bruce County were elevated by all three methods of analysis and were higher than for the county analyses. For the "nearby" area, the mortality ratios were 2.5 (O = 2, E = 0.8) and 3.5 (O = 2, E = 0.6) for residence at death and birth respectively, while the incidence ratio was 2.5 (O = 4, E = 1.6). However, it must be emphasized again that the confidence limits for all of the estimates of relative risk in the vicinity of nuclear power generating stations also encompassed 1.0 so that, as in the case of the uranium processing facilities, the results could be due to chance.

In conclusion, a ninefold excess risk of leukaemia, as observed in the vicinity of the Sellafield facility, was not observed amongst children born to mothers residing in the areas around nuclear research facilities and uranium mining, milling and refining facilities in Ontario. In the vicinity of nuclear research facilities, the rate of leukaemia was, in fact, less than expected. In the areas around the uranium mining, milling and refining facilities, leukaemia occurred slightly more frequently than expected; however, due to small frequencies these results may have arisen by chance. A slightly greater than expected occurrence of leukaemia was also detected, which may well have been due to chance, in an exploratory study of the areas around nuclear power generating stations in Ontario.

In order to increase the precision of the relative risk estimates detected in this study, it is recommended that this study be expanded in Ontario to include children aged 5-14 years who were diagnosed with or died from leukaemia, and that the focus of the expanded study be residence at the time of birth. Such a study would be relatively simple to perform and could be completed in a short period of time.

DISCLAIMER

The opinions expressed in this document are those of the authors and do not necessarily reflect those of the Atomic Energy Control Board.

This work was produced by Dr. E.A. Clarke, Mr. J. McLaughlin and staff of the Division of Epidemiology and Statistics of the Ontario Cancer Treatment and Research Foundation with the assistance of Dr. T.W. Anderson of the University of British Columbia, under contract to the Atomic Energy Control Board; contract no. 87055-8-4043/01-SS.

RÉSUMÉ

De récentes études au Royaume-Uni ont révélé qu'il y avait plus de cas de leucémie infantile au voisinage des installations nucléaires qui retraitent le combustible et qui fabriquent des armes. L'objectif principal de la présente étude est de vérifier s'il existe un nombre accru de cas de leucémie chez les enfants nés de mères demeurant à proximité d'installations nucléaires en Ontario.

À partir du fichier des cas de cancer de l'Ontario (Ontario Cancer Registry), on a pu retrouver 795 enfants âgés de quatre ans et moins qui sont morts de leucémie entre 1950 et 1986, ainsi que 951 enfants chez qui on a diagnostiqué la leucémie entre 1964 et 1985. On a pu ensuite retracer leur lieu de résidence à la naissance à partir de leur certificat de baptême, et leur lieu de résidence au décès à partir du fichier des cas de cancer de l'Ontario ou du certificat 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 électronucléaires) et deux différentes zones géographiques autour de chaque installation (comté et région «avoisinante» dans un rayon de 25 km). On a estimé le risque relatif de chaque installation et de chaque zone géographique comme le ratio entre le nombre d'événements observés (O) et le nombre d'événements prévus (E) pour chaque zone. Pour calculer les ratios de mortalité par lieu de résidence au décès, on a établi les valeurs prévues selon le nombre de décès prévisibles à partir des taux provinciaux pour une population donnée d'enfants âgés de quatre ans et moins. Pour calculer les ratios de mortalité et d'occurrence par lieu de résidence à la naissance, on a établi les valeurs prévues selon le nombre d'événements prévisibles pour un nombre donné d'enfants nés vivants.

Le nombre observé d'enfants leucémiques à proximité des installations de recherche nucléaire dans le comté de Renfrew s'est avéré inférieur au nombre prévu; les ratios de mortalité du comté étaient de 0,83 (O = 9, E = 10,8) et de 0,77 (O = 8, E = 10,4) pour les analyses selon les lieux de résidence au décès et à la naissance respectivement. Les résultats des analyses de cas de leucémie selon le lieu de résidence à la naissance sont semblables à ceux des analyses de mortalité selon le lieu de résidence à la naissance. Dans la région «avoisinante» de l'installation de recherche de Chalk River, le niveau de risque relatif s'est avéré encore plus faible; les ratios d'occurrence et de mortalité varient entre 0,31 (O = 1, E = 3,2) et 0,37 (O = 1, E = 2,7). Ces résultats démontrent que le risque neuf fois supérieur qui avait été observé dans l'étude britannique sur les cas de leucémie dans le voisinage de l'usine de retraitement à Sellafield (O = 5, E = 0,53) n'a pas été observé près de l'installation de recherche nucléaire de Chalk River.

En général, la fréquence des cas de leucémie infantile était légèrement plus élevée que prévu à proximité des deux installations d'exploitation minière, de concentration ou de raffinage de l'uranium. Toutefois, on a observé différents modèles pour chacune des installations. Les estimations de risque relatif étaient supérieures selon le lieu de résidence à la naissance par rapport au lieu de résidence au décès près de l'installation de Port Hope [soit 1,6 [O = 7, E = 4,5) par rapport à 1,4 (O = 6, E = 4,3) respectivement], tandis que c'était le contraire dans la région d'Elliot Lake [soit 1,1 (O = 2, E = 1,8) par rapport à 1,8 [O = 3, E = 1,7)]. Dans la région «avoisinante» de Port Hope, les estimations de risque relatif étaient légèrement supérieures à celles du comté [soit une occurrence de 1,7 (O = 9, E = 5,2) par rapport à 1,4

(O = 14, E = 9,8) respectivement], mais en général, les estimations pour la région «avoisinante» d'Elliot Lake étaient inférieures aux valeurs établies pour le comté [soit une occurrence de 0,4 (O = 1, E = 2,4) par rapport à 1,0 (O = 18, E = 17,5) respectivement]. Comme les limites inférieures des intervalles de fiabilité de toutes ces estimations comprenaient 1,0, il se peut que le degré de risque excessif qui a été decelé soit dû au hasard.

Les cas de leucémie infantile à proximité des centrales électronucléaires étaient légérement plus élevés que prévu. Il y a foncièrement peu de différence entre les analyses pour le comté et la région «avoisinante» de l'installation de Pickering, puisque les deux zones géographiques sont pratiquement identiques. Les estimations de risque relatif pour la région «avoisinante» étaient de 1,2 (O = 50, E = 41,3) pour l'analyse d'occurrence et de 1,4 (O = 17, E = 12,4) pour l'analyse de mortalité selon le lieu de résidence à la naissance, tandis que l'estimation de risque relatif pour l'analyse de mortalité selon le lieu de résidence au décès était d'environ 1,0 (O = 19, E = 18,6). Les estimations de risque relatif pour la région «avoisinante» des installations nucléaires dans le comté de Bruce étaient élevées selon les trois méthodes d'analyse et étaient supérieures à celles des analyses pour le comté. Dans le cas de la région «avoisinante», les ratios de mortalité étaient de 2,5 (O = 2, E = 0,8) et de 3,5 (O = 2, E = 0,6) selon le lieu de résidence au décès et à la naissance respectivement, tandis que le ratio d'incidence était de 2,5 (O = 4, E = 1,6). Toufefois, il faut souligner une fois de plus que les limites de fiabilité de toutes les estimations de risque relatif à proximité des centrales électronucléaires comprenaient 1,0 et que, comme dans le cas des installations de traitement d'uranium, les résultats pourraient être attribuables au hasard.

En conclusion, le risque excessif de leucémie neuf fois supérieur qui a été observé dans le voisinage de l'installation nucléaire de Sellafield n'a pas été observé chez les enfants nés de mères demeurant près des installations de recherche nucléaire, ou des mines, usines de concentration et raffineries d'uranium de l'Ontario. Près des installations de recherche nucléaire, les cas de leucémie observés étaient, en fait, moins nombreux que prévu. Aux alentours des mines, des usines de concentration et des raffineries d'uranium, les cas de leucémie étaient légèrement plus fréquents que prévu, mais, vu le nombre minime de cas qui a été observé, il est possible que ces résultats soient dus au hasard. On a aussi décelé un nombre de cas de leucémie légèrement plus élevé que prévu dans une étude exploratoire des régions entourant les centrales électronucléaires de l'Ontario, mais ces résultats pourraient très probablement aussi être attribuables au hasard.

Pour améliorer la précision des estimations de risque relatif calculées dans la présente étude, les auteurs recommandent que l'étude soit étendue en Ontario à tous les enfants âgés de 5 à 14 ans qui sont morts de leucémie ou chez qui on a diagnostiqué la maladie, et que l'étude se concentre surtout sur la lieu de résidence à la naissance. Il serait relativement simple d'entreprendre une telle étude et de l'achever en peu de temps.

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CHILDHOOD LEUKAEMIA AROUND
CANADIAN NUCLEAR FACILITIES

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 not born there. 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) has also been 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 for a mortality ratio of 3.3. However, the Dounreay experience was not as consistent over time as that at Seascale. Thus, 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 as well as around nuclear power stations. In the study by Roman et al [Ref. 7], an increased death rate from leukaemia was found 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 very detailed study of cancer incidence and mortality around nuclear installations has been conducted by the office of Population Census and Surveys in the U.K. This large study has been summarized by Forman et al. [Ref. 8] The increased occurrence of childhood leukaemia was confirmed for the Sellafield area, but around nuclear power stations 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 are difficult to explain. On the 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 environmental contamination has been much greater than at any other site [Ref. 1], the known radiation exposures are too low to explain the abnormal leukaemia patterns. Furthermore, there is no obvious reason for the "birth cohort" effect seen at Seascale, but possible mechanisms that have been proposed include (a) an in-utero mechanism, and (b) a hand-to-mouth pathway for dust in the first year or two of life (perhaps due to dust on parental clothing being brought into the home). [Ref. 6]

Canada has neither fuel reprocessing plants nor weapons research and manufacturing facilities. However, it does have two research establishments at Chalk River, Ontario, and Pinawa, Manitoba, which are the only ones that could be considered similar to the reprocessing facilities in the U.K. There are also potentially dusty environments at uranium mines, mills and refineries in Ontario and other parts of Canada. Finally, there are nuclear power stations in Ontario, Quebec and New Brunswick.

The present study used a population-based cohort approach within Ontario, the province that has all three types of Canadian nuclear activity: (1) research, (2) uranium mines, mills and refineries, and (3) power generation. Each of the three types of facilities were examined separately. In the vicinity of the research facilities, leukaemia risk was examined in order to test for the occurrence of excesses of the magnitude observed at Sellafield. The occurrence of childhood leukaemia was assessed in the areas around the uranium mining, milling and refining facilities as a preliminary test of the hypothesis that radioactive dust was the exposure source, as proposed in the COMARE report. [Ref. 6] In an exploratory analysis, the risk of childhood leukaemia was also examined in the vicinity of the generating stations. The diagnosis of leukaemia and the 0-4 age group were selected for initial study since these were the diagnosis and age group with the highest mortality ratios in the British studies.

The study examined the occurrence of leukaemia in subjects who died from the disease (mortality) and those who were diagnosed with the disease (incidence). Incidence was employed in the Sellafield study only from 1971, although the facility began operation in 1950. [Ref. 3,4] An advantage of using incidence rather than mortality as a study outcome, as has been previously recognized [Ref. 7], is that if advances in treatment occurred during the study period then mortality would become a less sensitive outcome, whereas incidence would be unaffected. On the other hand, an advantage of studying mortality is the availability of data for a longer period of time.

B. OBJECTIVES

The general objective of this study was to investigate whether or not there exist clusters of leukaemia among children born to mothers resident in the vicinity of nuclear facilities in Ontario. The specific objectives of the study were to determine (a) whether or not there have been elevated frequencies of leukaemia in children who were born to mothers residing in the vicinity of nuclear facilities in Ontario, and (b) whether frequencies have been greater by residence at time of birth than by residence at time of death. In each case, the observed number of leukaemia deaths and incident leukaemia cases were compared with the numbers that were expected on the basis of provincial rates. Analyses of the occurrence of childhood leukaemia were performed for three components of the study: first, around the research facilities 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).

C. METHODS

The frequencies of leukaemia deaths and incident cases among children aged 0-4 years were obtained 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, residences of the mother at the time of birth and of the child at time of death were determined. The OCR does not have complete information on residence at time of diagnosis. The numbers of subjects residing at birth or death in each of the areas of interest were also determined. Analyses were performed at the county level and for the areas within a 25 km radius around each of the five nuclear facilities. The period of observation commenced in the year each nuclear facility began operation, unless leukaemia data were unavailable. In this case, the period of observation began when leukaemia data became available and continued to 1986 for the mortality analyses and 1985 for the incidence analyses. Ratios of the observed number of deaths and incident cases over the expected number were then calculated in order to detect the presence of above average frequency of leukaemia. Details of subject selection, record linkage, data collection and statistical methods are summarized.

1. Subject Selection and Data Collection

Using the OCR, records were located for 870 children aged 0-4 years who resided in Ontario and who died of leukaemia between 1950 and 1986. Similarily, the OCR was used to identify children aged 0-4 years who resided in Ontario and who were first diagnosed as having leukaemia between 1964 and 1985, as incidence data from the OCR are only available from 1964. Children aged 0-4 years, inclusive, who died with leukaemia as a certified cause of death between 1964 and 1985 were included in both the mortality and incidence studies.

The criteria for inclusion in the study were: leukaemia (International Classification of Diseases, Ninth Revision (ICD-9), 204-208) [Ref. 9] registered in Ontario from 1950 to 1986 for deaths, and 1964 to 1985 for incident cases; 0-4 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 residence at the time of birth of the child as listed 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 preprinted 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 residence at time of birth were obtained. 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 copies of the data collection forms are attached as Appendix C.

Table 1 lists the number of subjects who were initially identified for the mortality analysis (n = 870) and the number who met the selection criteria to be included in the study (n = 795). Two children, both of whom lived outside the counties of interest, were classified as "probable" matches because of inconsistencies between OCR and birth certificate information. These children were defined as "probable" matches because 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 following 62 children were excluded from the analysis by residence at time of birth based on additional information: 48 children born outside Ontario; 10 adopted children for whom identifying information regarding the birth parents was deleted from the birth certificates; one case for whom leukaemia as a cause of death could not be confirmed; one child born in Ontario for whom the mother's place of residence was outside Ontario; one child with a duplicate death registration; and one subject with an incorrect date of birth where the actual age was greater than four years.

Thirteen subjects were excluded for whom records were not linked: for seven subjects birth certificates could not be found (there is some evidence that two of these were born outside Ontario); for six subjects the OCR contained inadequate identifying information (missing name and date of birth, invalid death certificate number). The proportion of records that was successfully linked in the mortality study was therefore 99% (857/870).

The number of subjects initially identified for (n = 1181) and finally included in (n = 951) the incidence analyses are listed in Table 2. More difficulty was experienced in locating the birth certificates of children in the incidence study than in the mortality study because death certificates could not be used as an additional source of information for subjects who did not die. Identifying information was incomplete in the OCR for many cases because of the practice, during the early years of registration, of truncating names and entering incomplete dates of birth. Among the subjects whose records were linked, 203 were excluded from the study. Records were not linked for 27, or 2% (27/1181), of incident cases because all efforts to identify birth records failed. (There is some evidence that six of these were born outside Ontario).

The primary reason for excluding subjects was uncertainty regarding the diagnosis of leukaemia. It should be noted that the OCR previously detected over-reporting of childhood cancer and that the problem had been corrected for the period beginning in 1975. [Ref. 10] In 89 children it was confirmed that the diagnosis was definitely not leukaemia, and in a further 12 their diagnosis could not be confirmed (none of these 12 resided in the counties of interest). To confirm the leukaemia diagnoses it was necessary to review hospital charts.

Incidence data are available in the OCR from 1964; therefore, leukaemia incidence cannot be studied for the whole period of operation for all of the nuclear facilities. Mortality, on the other hand is available in the OCR back to 1950. To ensure that the study outcomes were both sensitive (e.g., to changes in survival) and available for the relevant time period, both mortality and incidence were therefore employed. It must be noted, however, that the two outcomes are not independent, since children who died with leukaemia could be included in both the mortality and incidence analyses. Of the 753 incident childhood leukaemia cases (1964-1980) who reached five years of age by 1985, 349 died (46%) and were therefore included in both the mortality and incidence analyses.

The distribution of the type of leukaemia in the 795 children included in the mortality analysis is listed in Table 3. For all leukaemia cases in Ontario, the majority were classified as ICD-9 site 208 (unspecified cell type), followed by ICD-9 site 204 (lymphoid leukaemia). In the counties of interest, the distribution by cell type of leukaemia was similar to the provincial total.

Residence at the time of the child's birth was assigned the Standard Geographic Code (1981 revision). [Ref. 11] In addition, residence at the time of death was available from the OCR for the subjects who died of leukaemia. Details of the residence coding procedures and how subjects were allocated to the areas of interest are described in Appendix D.

2. <u>County and Community Level Data</u>

Two levels of geographic areas were used in this study: counties and "nearby" areas that are within the counties. "County" is used in this report to refer to census divisions, of which one is now a "regional municipality" (Durham) and one is a "district" (Algoma). The counties of interest are described in Table 4 in terms of their nuclear facilities and populations. The differences in the starting dates of operation, the type of facility, and the population in each county should be noted. As shown in Table 4, 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 of interest 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, which was the subject of the primary hypothesis of this study, 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. In isolated locations in Algoma, Bruce and Renfrew counties, analyses were also performed on "extended nearby" areas that included the "nearby" areas and communities in which workers at the facilities may have lived. (See Appendix F for detailed definition.)

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 25 km radius 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. The effect of employing a longer radius was approximated by the county level analysis.

The population of children aged 0-4 years was determined for each area from census publications [Ref. 12] and was used to estimate the annual population for pericensal periods. Annual live birth totals were obtained from published vital statistics for the above counties from 1949 to 1986. [Ref. 13] In addition, annual birth totals were obtained for "nearby" communities, using published data where possible. To demonstrate the magnitude and variation of the live births for the components of the "nearby" areas of interest, the annual birth totals are listed in Appendix G, Tables G-1 to G-5.

Unfortunately, live birth totals were not available in some years for communities that fell within several "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, Pembroke from 1949 until 1973). These missing data were important because the nuclear facilities in Renfrew County were opened in 1944 and 1962. Similar problems occurred in all counties; however, where the facilities opened later, the problem was not as severe.

There were two reasons why data were unavailable for many of the communities that fell within our "nearby" areas. First, these communities (e.g., townships, villages) had small populations and therefore they were not consistently included as a unit for which vital statistics were reported 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 classifying potentially thousands of birth certificates over the 33 years 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 only from 1974. Third, the number of live births in each census subdivision with missing data could be estimated by multiplying the number of births 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 any potential bias is examined in Section 5.

3. Estimation of Relative Risk

The mortality ratio is the ratio of an observed number of deaths to the number that would be expected to occur in an area of interest. The expected numbers were multiples of the population of children aged 0-4 years in the areas of interest and the leukaemia mortality rate in Ontario children aged 0-4 years (over the same time period). No adjustment was made for age or sex because of the small age range and because no sex differential has previously been detected. [Ref. 3,4] Due to the small frequencies of events, time trends could not be analyzed, therefore, relative risks were estimated only for the whole period of observation.

Approximate 95% confidence intervals were obtained using Byar's method. [Ref. 14] The conventional level of alpha = 0.05 was chosen for the confidence intervals to conform with standard practice. It should be noted, however, that the existence of the prior hypothesis of increased risk in the vicinity of nuclear facilities calls for the use of a one-tailed, rather than a two-tailed, test of statistical significance. For this reason, 90% confidence intervals are also reported where appropriate (e.g., for the areas of the primary and secondary hypotheses).

The lower bound of a 95% confidence interval around a relative risk estimate 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 such a confidence interval includes a value of 1.0, then it must be concluded that the detected difference between observed and expected numbers of events may be 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.

The U.K. studies [Ref. 3,4] demonstrated that residence at time of birth may be more important than residence at time of death; therefore, live birth mortality ratios were calculated, and are presented as the main analytic approach in this report. The live birth mortality ratio is the ratio of the observed number of deaths to the number that would be expected to occur in an area with as many live births, tabulated by year of birth and by the residence at the time of the child's birth. The expected value was a multiple 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. This mortality ratio is a valid estimate of relative risk under the assumption that the rate of migration out of the province is equal for the areas of interest and for the Ontario population (i.e., for leukaemia to be detectable by the OCR). Again, because of the small age range and the absence of a sex effect, it was not necessary to adjust this measure for age or sex. Confidence intervals were calculated using the same method as for the mortality ratio.

Pooled estimates of relative risk were calculated for facilities of similar type. Due to the diversity in the nature of the three general types of facilities, each of which would result in different potential exposures, it is not appropriate to pool the results across all facility types. For the secondary hypothesis of this study (regarding dust), the results for the areas near the Port Hope and Elliot Lake facilities were pooled, and 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. 15] Under this homogeneity assumption, it must be assumed that the two nuclear generating stations, for example, give rise to a similar type and degree of exposure. The homogeneity assumption was tested statistically using the normal approximation, and results were pooled only if the assumption could not be rejected.

For leukaemia incidence, the same analysis was used for birth residence incidence ratios, confidence intervals, and area and time-specific values. A complimentary analysis by residence at time of diagnosis could not be performed due to incomplete residence information in the OCR. Leukaemia mortality and incidence data and the live birth frequencies for each area were entered into an IBM-PC. All analyses were performed using SAS. [Ref. 16,17]

D. RESULTS

For each area of interest, the observed and expected number of events, the ratio of the observed over expected (O/E) and the 95% confidence intervals of O/E are listed in Tables 5 to 9. 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 5 results are presented for Renfrew County in the area "nearby" the Chalk River facility. In the mortality analyses that allocated subjects according to their residence at time of death, the resultant mortality ratios ranged from 0.3 (O = 1, E = 3.1) to 0.8 (O = 9, E = 10.8), which indicated that the risk in each area of interest was slightly lower than expected. However, it should be noted that over the 36 years of observation, only one death occurred in the "nearby" area, whereas 3.1 were expected. By allocating subjects according to their residence at time of birth the mortality ratios ranged from 0.37 (O = 1, E = 2.7) to 0.77 (O = 8, E = 10.4). The analysis of incidence by residence at time of birth resulted in ratios that were slightly lower than in the mortality analysis. All of the confidence intervals in Table 5 encompass 1.0, therefore the differences between observed and expected may be due to chance.

In secondary analyses (not shown in Table 5) of the "extended nearby" area, relative risk estimates fell between the county and "nearby" values, with mortality ratios of 0.81 (O = 4, E = 5.0) and 0.63 (O = 3, E = 4.8) for residence at death and birth respectively, and an incidence ratio of 0.55 (O = 3, E = 5.4). Finally, 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 Rolphton 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 3.24, whereas the expected number for the pooled area "nearby" Chalk River or Rolphton was 3.28.

The results listed in each row of Table 5 are not from independent analyses, as emphasized by the fact that 15 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 are presented in Appendix H.

Tables 6 and 7 present results for the areas that contain the two facilities that may produce radioactive dust. In Northumberland County and "nearby" the Port Hope facility (Table 6), ratios at the county level ranged from 0.97 (O = 9, E = 9.3) to 1.49 (O = 12, E = 8.1), whereas the levels observed in the "nearby" area were slightly higher, but not statistically significant. For the "nearby" area, the mortality ratio for residence at time of death was approximately 1.4 (O = 6, E = 4.3), whereas slightly higher values were obtained for residence at time of birth (1.6; O = 7, E = 4.5) and in the incidence analysis (1.7; O = 9, E = 5.2). Again, as shown by the inclusion of 1.0 in the confidence intervals, the observed elevation in risk could be due to chance alone.

Leukaemia risks in Algoma District and in the "nearby" area around the Elliot Lake uranium mines and mills are examined in Table 7. The ratio values ranged from 0.41 (O = 1, E = 2.4) for the "nearby" incidence ratio, to 1.79 (O = 3, E = 1.7) for the "nearby" mortality ratio by residence at death, and had confidence intervals that again indicated that the values were not statistically significant. For analyses of the "extended nearby" area (not shown in Table 7), the relative risk estimates did not fall consistently between the county and "nearby" values, with mortality ratios of 1.42 (O = 3, E = 2.1) and 0.86 (O = 2, E = 2.3) for residence at death and birth, respectively, and an incidence ratio of 0.64 (O = 2, E = 3.1).

Tables 8 and 9 present results of the analyses in which the risk around nuclear power generating stations was explored. In Table 8, the period of observation for both the mortality and incidence analyses begins in 1971, since this was the year the Pickering nuclear power facility began operation. The high frequencies for this analysis, even over a relatively short period of time, are an indication that a large population resides in the area. The relative risk was increased to a similar extent in the analyses by residence at birth for both incidence and mortality with values ranging from 1.21 (O = 50, E = 41.3) to 1.37 (O = 17, E = 12.4) for the "nearby" areas. However, even with the large frequencies, these results are not statistically significant although the confidence limits are relatively narrow.

In Bruce County (Table 9), and "nearby" the power generating stations, even higher ratio values were observed, ranging from 0.89 (O = 2, E = 2.3) for the county level mortality ratio by residence at death; to 3.49 (O = 2, E = 0.6) for the "nearby" mortality ratio by residence at birth. The magnitude of the ratios in the "nearby" areas, which range from 2.46 (O = 2, E = 0.8) to 3.49 (O = 2, E = 0.6) is noteworthy, however the instability of these values as represented by the wide confidence intervals must also be noted. The width of the confidence intervals, in turn, are due to the small number of expected cases (e.g., 0.6 to 1.6 for "nearby" areas) over the 19 years of observation. The analysis of the "extended nearby" area for the facilities in Bruce county resulted in ratios that fell between the county and "nearby" values (i.e., as in Table 5), with mortality ratios of 1.64 (O = 2, E = 1.2) and 2.30 (O = 2, E = 0.9) for residence at death and birth respectively, and an incidence ratio of 2.02 (O = 5, E = 2.5).

E. DISCUSSION

1. Risk in the Vicinity of Nuclear Research Facilities

The occurrence of leukaemia in the area surrounding the Chalk River and Rolphton facilities was lower than expected for each area of analysis 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 the time of death resulted in mortality ratios of 0.8 (O = 9, E = 10.8) for the county analysis and 0.3 (O = 1, E = 3.1) for the area "nearby" Chalk River. By classifying observed and expected numbers of deaths by time and residence at time of birth, the mortality ratios were virtually unchanged for both the county and "nearby" area analyses. By then focusing on incidence by residence at time of birth, estimates of relative risk were similar. These data suggest that, for the primary hypothesis of this study, there was no increased occurrence of leukaemia in the vicinity of the nuclear research facilities in Renfrew County. The observed relative risk in the birth cohort at Sellafield was 9.4 (O = 5, E = 0.53), which is much larger than that observed in this study. The 90% confidence interval, which is relevant when a prior hypothesis exists, was (0.01, 1.76) for the analysis of mortality by residence at birth for the "nearby" area, as compared with the slightly wider 95% interval of (0.005, 2.07). Also, no systematic change was observed in the estimates obtained using mortality or incidence, or death versus birth residence. In this analysis, the relative risk observed in the "nearby" areas was actually less than at the county level.

The gradient of effect in relationship to distance and time is one of the most important features of the British evidence for an association between nuclear facilities and childhood leukaemia. Such a gradient was not observed in this study. First, the ratio of observed to expected in the "nearby" area was not greater than in the larger county area. However, it must be noted that in Ontario it was impossible to apply radii as short as were used in the U.K. studies (e.g., approximately 10 km). [Ref. 7,8] Second, the ratio by residence at time of birth was not greater than residence at time of death. It should be noted, however, that only a slight differential could be expected between subjects classified by birth versus death residence since this study followed subjects for only five years, over which time a relatively small number would be likely to move. In Appendix H, a large proportion of children is shown to have been included in the mortality analysis by both place of birth and death. In the studies by Gardner et al [Ref. 3,4] the period of follow-up was 30 years.

2. <u>Risk in the Vicinity of Uranium Mining, Milling and Refining Facilities</u>

In the mortality analysis of Northumberland County, the ratios of observed to expected were higher for the residence at time of birth analysis than for the residence at time of death analysis [1.5 (O = 12, E = 8.1) versus 1.0 (O = 9, E = 9.3) respectively]. The mortality ratios were slightly higher in the "nearby" area analysis. The estimates obtained in the incidence analysis for residence at time of birth were similar to the birth residence analysis of mortality. The estimates were greater in the "nearby" areas than in the counties for each method of analysis. In Algoma District, which contains the Elliot Lake uranium mine, slightly different patterns were observed. In general, the estimates were lower than in Northumberland County. Also, in contrast to Northumberland, in Algoma the estimates were higher by residence at time of death than by residence at time of birth [e.g., "nearby" mortality ratios of 1.8 (O = 3, E = 1.7) and 1.1 (O = 2, E = 1.8) for residence at death and birth respectively]. The residence at time of birth analysis, both for mortality and incidence, indicated minimal increases or even lower levels than expected in each of the areas. The 90% confidence intervals for the analyses of mortality by place of birth for the areas "nearby" the Port Hope and Elliot Lake facilities were (0.74, 2.95) and (0.19, 3.50), respectively, as compared to 95% intervals of (0.63, 3.23) and (0.12, 4.02). A pooled estimate for the area "nearby" either of the two facilities was 1.43 (O = 9, E = 6.3) for the mortality analysis by residence at time of birth.

Statistical significance was not achieved in the analyses of Northumberland and Algoma counties, but it should be noted that several of the estimates were based on the observation of a small number of events (< 5) over a long period of time. Therefore, in the areas surrounding the uranium mining, milling and refining facilities, there is some evidence of an increased leukaemia risk, particularly in Northumberland County. However the observed excess could be due to chance. Further research is therefore needed to test the dust hypothesis that was generated by the British studies.

3. Risk in the Vicinity of Nuclear 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 (i.e., mortality ratio of 1.0). In the analysis of mortality by residence at time of birth, slightly higher estimates of relative risk were obtained, with a value of 1.4 (O = 17, E = 12.4) in the "nearby" area. Slightly lower values were observed in the analysis of incidence for the birth cohorts (e.g., for "nearby" O/E = 1.2; O = 50, E = 41.3). 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 0.9 (O = 2, E = 2.3) to 3.5 (O = 2, E = 0.6). It must be noted that for both the Bruce County and "nearby" area analyses, the estimates were based on a very small number of events (< 5), and an even smaller number of expected events, which is indicated by the width of the confidence intervals. A pooled estimate for the "nearby" area around either of the generating stations was 1.46 (O = 19, E = 13) for the mortality analysis by residence at time of birth. In general, these results of the exploratory studies of leukaemia risk around nuclear power generating stations are suggestive of a slight increased relative risk that may well be due to chance. Additional research is necessary to examine this further.

4. The Power to Detect Significant Increases in Risk

The ability of this study to detect significant excesses of risk was determined by calculating power. [Ref. 14] 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, risks 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" Elliot Lake and Douglas Point). In an effort to enhance the power of the study, pooled estimates of relative risk were obtained for the sites with similar exposures. For the uranium mining, milling and refining facilities (Port Hope, Elliot Lake), the power to detect the pooled estimate of O/E = 1.43 (O = 9, E = 6.3) as being significantly different from 1.0, was still less than 38%. For the two generating stations (Pickering, Douglas Point), the pooled relative risk estimate of 1.46 (O = 19, E = 13) was associated with less than 60% power. In the pooled analyses, more than 2.4 deaths were observed; however, the relative risk estimates were all less than 3.3. 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 a true relative risk of 1.4 and a chance observation.

A related 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, which assumes that the ratio of two Poisson variables follows the binomial distribution [Ref. 18], was used to test whether the relative risks observed in Ontario equalled those from the British studies. For the analysis of mortality by residence at birth, p values for the tests of equality with the Sellafield relative risks were 0.0006 for "nearby" Chalk River, 0.003 for the pooled areas "nearby" dust generating facilities, and 0.011 for the pooled areas "nearby" power stations. These p values indicate that for each area the hypothesis of the equality of relative risks can be rejected. Tests of equality with the Dounreay figures (O/E = 3.3) gave rise to p values of 0.002 for "nearby" Chalk River, 0.11 for the pooled area "nearby" dust generating facilities, and 0.21 for the pooled areas "nearby" power stations. These figures demonstrate that a relative risk of the magnitude observed in the Dounreay study did not occur in the vicinity of the Chalk River facility, whereas such a relative risk cannot be ruled out in the vicinity of the uranium mining, milling and refining facilities and the nuclear power stations.

5. Potential Biases

5.1 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. as leukaemia mortality rates were greater than expected in rural areas [standardized mortality ratio (SMR) = 1.2], but equal to expected in urban areas (SMR = 1.0). [Ref. 19] The Danish Cancer Registry, however, failed to detect an urban-rural differential in leukaemia risk.

An urban-rural differential may be important in this study because a small proportion of the populations in some of the counties of interest live in urban areas. Algoma, Durham and Northumberland counties have large urbanized populations (75-80%), which are similar to the provincial total (82%). [Ref. 12] Renfrew County has a smaller urban population (57%), whereas Bruce County is largely rural with an urban population of only 42%. It was expected that if leukaemia rates were higher in urban areas, then the inclusion of a large urban area like Metropolitan Toronto would cause an over-estimation of the expected values for rural areas, and therefore an under-estimation of the relative risk. An exploratory analysis was performed 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, such a biased estimate is not likely to have occurred in this study.

5.2 The Effect on Mortality Analysis of Case Exclusions due to Birth Outside Ontario and Missing Birth Records

The analyses of mortality were performed on the 795 children for whom residence information was available at the time of both death and birth. There were 66 children for whom residence at the time of birth was either missing or outside Ontario but who had complete residence information at the time of death. As shown in Table 1, there were 48 who were born outside Ontario, 10 who were adopted, seven for whom birth records could not be found and one whose mother's residence was outside Ontario. These 66 children, two of whom resided in the counties of interest, were added to the original 795 children included in the study and the analysis of mortality by place of death was repeated to determine whether their initial exclusion had biased the results. The addition of the 66 children caused the expected number of deaths to increase in each county. The county level relative risk estimates were therefore slightly reduced for the counties in which no change occurred in the number observed (e.g., 0.89 in Northumberland; 1.14 in Algoma; 0.82 in Bruce). The additional death that was observed in each of two counties resulted in only slight changes in the results. For Renfrew

County the mortality ratio rose to 0.85 from 0.83 (90% CI = 0.46 to 1.45), whereas for Durham Regional Municipality the ratio fell to 0.95 from 0.97 (90% CI = 0.63 to 1.38). Therefore, there was no significant bias in the results of the residence at death analysis due to the exclusion of children who were born outside Ontario or for whom maternal residence at the time of birth could not be determined.

5.3 The Effect of Case Exclusions due to Failure to Trace Birth Records

Tables 1 and 2 show that 13 (2%) of the leukaemia deaths and 27 (2%) of the incident cases were excluded from the analysis because birth certificates could not be traced and therefore maternal residence at time of birth could not be identified. A crude estimate of the potential bias was calculated under the assumption that the excluded cases were twice as likely to reside in the counties of interest as the original 795 subjects who were included in the mortality study. From Table 6, the total number of subjects who lived in Northumberland County was 12, or 1.5% (12/795) of all subjects. If the 13 excluded subjects were twice as likely to reside in the study areas (2 x 0.015 = 0.03), then less than one (0.03 x 13 = 0.39) additional case would be observed. As the addition of 13 cases would not affect the provincial rates that were used to estimate the expected frequencies, a crude "adjusted" mortality ratio can be obtained. Again, from Table 6, for the county analysis the observed number of deaths by residence at time of birth resulted in a mortality ratio of 1.49. With the addition of the expected number of additional "cases" (0.39), a mortality ratio that is "adjusted" for the potential misclassification of missed "cases" would be 1.53 (12.39/8.1). This demonstrates that if cases who resided in the counties of interest were excluded, the relative risk estimates could be slightly under-estimated. There is no reason to believe that unavailability of birth records or OCR identifying information would occur selectively for the counties surrounding the nuclear facilities. Therefore, the bias due to case exclusion is likely to be small.

5.4 Indicators of Ontario Cancer Registry Incidence Data Quality

Relative risk estimates can be biased if the outcome of interest is misclassified, with an attenuating bias occurring in the presence of nondifferential misclassification and a less predictable bias occurring with differential misclassification. 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 of interest 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 that have been based on death certificates only (% DCO). These indicators for the registration of the leukaemia (ICD-9 204-208) in Ontario for all ages for the 1979-1983 period, were % HV = 74% and % DCO = 1.3%. In the five counties of interest, for all ages, similar values were obtained: % HV = 72% and % DCO = 1.5%. In general, the certainty of the classification of the leukaemias is similar in both Ontario and the areas examined in this study. The values for these counties for the children aged 0-4 years (n = 18) were: % HV = 94% and % DCO = 0%. The higher indices of quality of registration for leukaemia in this study may reflect the results of the chart review for indefinite diagnoses, which was undertaken in view of the known over-reporting of childhood cancer in the OCR.

5.5 The Effect of the Estimation of Missing Values

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 of 2.4 live births per year on average. Over the 36 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 this figure to the total number of live births for the area "nearby" Port Hope, "corrected" values were obtained for the number of expected deaths and the mortality ratio. The "corrected" mortality ratio was 1.564, as compared with the value of 1.568, which is reported in Table 6. 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.

6. Recommendation for Future Studies

North American families are generally believed to be more mobile than families in the U.K. This could result in a greater likelihood of failing to detect a true excess risk if a study were to analyse risk factors later rather than earlier in life. This study was specifically designed to detect a birthplace pattern as seen by Gardner et al [Ref. 3,4] in their study of children in Seascale. In spite of the narrow age range of this study, it is of interest that, with the exception of the facility at Elliot Lake, the estimates of relative risk for mortality in "nearby" areas around the nuclear facilities were all higher for residence at time of birth than at time of death.

At this time, it is not warranted to undertake a detailed study designed to quantify the risk of childhood leukaemia in relation to the radiation doses and exposure to chemicals in the environment in the vicinity of nuclear facilities. Instead, it is recommended that further studies be designed to detect a birthplace pattern. Strategies for increasing the sample size and hence the power of the current study include expanding to other age groups and/or to other provinces. For each type of expansion, power and the number of additional cases that could be included are estimated in order to assess the expected workload.

6.1 Study Expansion to Age 14

Estimates of the number of additional leukaemia cases (i.e., children aged 5-14 years) were obtained from the OCR. An additional 1282 deaths, which occurred from 1950 through 1986, and 1083 incident cases, which occurred from 1964 to 1985, would be available resulting in 2.5 and 1.9 fold increases in the sample sizes of the mortality and incidence studies respectively. An advantage of this expansion would be a reduction of the lowest detectable relative risk. Also, if in the expanded study the relative risk estimates are similar to those observed in this study, then narrow confidence intervals and a possible twofold increase in power would be obtained. Even with such an expansion, 80% power is still unlikely to be achieved by all of the analyses.

To expand the study to age 14 years will require an additional nine months. The time-consuming task of tracing and matching birth and death certificates for a further 2365 subjects must be performed. In addition, for the residence at time of birth, it will be necessary to collect data for a 15 year period prior to 1949 in order to obtain and estimate the number of live births, and it may be necessary to calculate age-adjusted relative risk estimates for the residence at time of birth analyses.

6.2 Expansion to Other Provinces

Three other provinces have nuclear facilities. Quebec and New Brunswick each have one power station and Manitoba has a facility that is a research centre (Whiteshell at Pinawa is similar to Chalk River). The estimated number of deaths and incident cases obtained by expanding the study of leukaemia in children aged 0-4 years to these provinces was based on the relative sizes of the populations of each province. Under the assumption that the leukaemia mortality and incidence rates in each province over the time period of interest are equal to those of Ontario, the number of additional subjects in each province can be estimated, as shown in Table 10.

By expanding the study to three other provinces, Table 10 shows that an additional 1657 subjects would need to be analyzed, with approximately a twofold increase in the number of children for the mortality and incidence studies. Such an increase in the total number of children who must be included in such an expanded study will have no effect on the observed or expected frequencies in the vicinity of a particular nuclear facility. Therefore, the problem of low power that arose in each stage of the analysis in the study would not be resolved by expanding to other provinces.

Prior to even considering such an expansion, estimates of the feasibility and time required must be obtained in consultation with representatives of each province. For example, it is possible that access to death certificate information is not as straightforward in some provinces as in others and that the populations living near the installations may be even smaller than those observed in Ontario. Problems similar to those experienced in this study in determining the population at risk may also be encountered due to boundary changes and the lack of published information.

F. CONCLUSION

The occurrence of leukaemia deaths and incident leukaemia cases was studied among children, aged 0-4 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 observed in the areas around nuclear research facilities and uranium mining, milling and refining facilities in Ontario. In the vicinity of nuclear research facilities, the rate of leukaemia was, in fact, less than expected. In the areas around uranium mining, milling and refining facilities, the rates were slightly greater than expected; however, due to small frequencies, these results may have arisen due to chance. A slightly greater than expected occurrence of leukaemia was also detected, which may well have been due to chance, in an exploratory study of the areas around nuclear power generating stations in Ontario. With the exception of one facility, a consistent pattern of higher relative risk was detected for mortality analyses in "nearby" areas performed by residence at time of birth versus residence at time of death. Such a differential can be expected to be even greater in a study encompassing larger age ranges.

It would be possible to reduce the uncertainty of the relative risk estimates obtained in each component of the study by expanding to other ages. It is recommended that the study first be expanded in Ontario to include children aged 5-14 years. Such a study would be relatively simple to perform, could be completed in a short period of time (nine months) and would increase the precision of the relative risk estimates detected in this study.

Table 1: Leukaemia deaths in children aged 0-4 years in Ontario, 1950 - 1986: The number included in the study, reasons for exclusions and reasons for unsuccessful linkages between Ontario Cancer Registry and birth records.

	Frequency
RECORDS LINKED	
Included in Study	
Definite matches	793
Probable matches *	2
Total Included in Study	**795**
Excluded from Study	
Born outside Ontario	48
Adopted (birth parents unidentifiable)	10
Leukaemia cause of death unconfirmed	1
Maternal residence outside Ontario	1
Incorrect date of birth	1
Duplicate death registration	1
Total Excluded from Study after Records Linked	62
TOTAL RECORDS LINKED	**857**
RECORDS NOT LINKED	
Birth records not found	7
Incomplete Registry information	6
TOTAL RECORDS NOT LINKED	13
TOTAL CASES SEARCHED	**870**

*See text for details.

Table 2: Incident leukaemia cases in children aged 0-4 years in Ontario, 1964 - 1985: The number included in the study, reasons for exclusion and reasons for unsuccessful linkages between Ontario Cancer Registry and birth records.

	Frequency
RECORDS LINKED	
Included in Study	
Definite matches	945
Probable matches *	4
Possible matches *	2
Total Included in Study	**951**
Excluded from Study	
Diagnosis confirmed not to be leukaemia	89
Born outside Ontario	60
Adopted (birth parents unidentifiable)	30
Leukaemia diagnosis unconfirmed	12
Duplicate incidence registration	8
Maternal residence outside Ontario	2
Incorrect date of birth	2
Total Excluded from Study after Records Linked	203
TOTAL RECORDS LINKED	**1154**
RECORDS NOT LINKED - Birth records not found	27
TOTAL CASES SEARCHED	**1181**

*See text for details.

Table 3: Distribution of type of leukaemia in cases eligible for study among children aged 0-4 years who died in Ontario and selected counties, 1950 - 1986.

Leukaemia	ICD-9*	Ontario Frequency	(%)	Five County Total Frequency	(%)
Lymphoid Leukaemia	204	179	(22.5)	13	(23.6)
Myeloid Leukaemia	205	86	(10.8)	11	(20.0)
Monocytic Leukemia	206	6	(0.8)	0	
Other Specified Leukemia	207	3	(0.4)	1	(1.8)
Unspecified Cell Type	208	521	(65.5)	30	(54.5)
		795	(100.0)	55	(100.0)

* International Classification of Diseases, Ninth Revision.

Table 4: Ontario Counties with Nuclear Facilities: Population, Facility Name, Year of First Operation and Facility Type.

County	Population* All Ages	Population* 0-4 yrs	Nuclear Facility		Year of First Operation	Facility Type
Renfrew	87,485	6,165	Chalk River		1944	Research & Development
			Rolphton		1962	Nuclear Power Demonstration
Northumberland	64,965	4,400	Port Hope		1935	Uranium Processing
Algoma	133,550	10,740	Elliot Lake		1954	Uranium Mining
Durham	283,640	22,895	Pickering	A	1971	Power Generation
				B	1982	Power Generation
Bruce	60,020	4,895	Douglas Point		1967	Power Generation
			Bruce Nuclear Power Development	A	1976	Power Generation
				B	1984	Power Generation

* from 1981 census

Table 5: Leukaemia mortality and incidence in children aged 0-4 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% C.I.
MORTALITY (1950-1986)				
By Residence at Death				
County *	9	10.8	0.83	(0.38, 1.58)
Nearby *	1	3.1	0.32	(0.004, 1.80)
By Residence at Birth				
County *	8	10.4	0.77	(0.33, 1.52)
Nearby *	1	2.7	0.37	(0.005, 2.07)
INCIDENCE (1964-1985)				
By Residence at Birth				
County *	8	11.4	0.70	(0.30, 1.39)
Nearby *	1	3.2	0.31	(0.004, 1.72)

* Rows do not constitute independent analyses. A total of 15 individuals contribute to the observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 6: Leukaemia mortality and incidence in children aged 0-4 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% C.I.
MORTALITY (1950-1986)				
By Residence at Death				
County *	9	9.3	0.97	(0.44, 1.84)
Nearby *	6	4.3	1.38	(0.50, 3.01)
By Residence at Birth				
County *	12	8.1	1.49	(0.77, 2.60)
Nearby *	7	4.5	1.57	(0.63, 3.23)
INCIDENCE (1964-1985)				
By Residence at Birth				
County *	14	9.8	1.43	(0.78, 2.39)
Nearby *	9	5.2	1.72	(0.78, 3.26)

* Rows do not constitute independent analyses. A total of 20 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 0-4 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% C.I.
MORTALITY (1954-1986)				
By Residence at Death				
County *	16	12.9	1.24	(0.71, 2.01)
Nearby *	3	1.7	1.79	(0.36, 5.22)
By Residence at Birth				
County *	14	11.6	1.21	(0.66, 2.02)
Nearby *	2	1.8	1.11	(0.12, 4.02)
INCIDENCE (1964-1985)				
By Residence at Birth				
County *	18	17.5	1.03	(0.61, 1.63)
Nearby *	1	2.4	0.41	(0.005, 2.31)

* Rows do not constitute independent analyses. A total of 27 individuals contribute to the 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 0-4 years in Durham Regional Municipality (Pickering - power generating station) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% C.I.
MORTALITY (1971-1986)				
By Residence at Death				
County *	19	19.5	0.97	(0.59, 1.52)
Nearby *	19	18.6	1.02	(0.61, 1.59)
By Residence at Birth				
County *	17	13.0	1.31	(0.76, 2.09)
Nearby *	17	12.4	1.37	(0.80, 2.19)
INCIDENCE (1971-1985)				
By Residence at Birth				
County *	52	43.1	1.21	(0.90, 1.58)
Nearby *	50	41.3	1.21	(0.90, 1.60)

* Rows do not constitute independent analyses. A total of 58 individuals contribute to the 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 0-4 years in Bruce County (Douglas Point - power generating stations) by residence at time of death and birth, and by geographic region.

	Frequency Observed	Frequency Expected	O/E	95% C.I.
MORTALITY (1967-1986)				
By Residence at Death				
County *	2	2.3	0.89	(0.09, 2.82)
Nearby *	2	0.8	2.46	(0.28, 8.89)
By Residence at Birth				
County *	3	1.6	1.87	(0.38, 5.47)
Nearby *	2	0.6	3.49	(0.39, 12.60)
INCIDENCE (1967-1985)				
By Residence at Birth				
County *	6	4.6	1.31	(0.48, 2.85)
Nearby *	4	1.6	2.46	(0.66, 6.30)

* Rows do not constitute independent analyses. A total of 6 individuals contribute to the observed frequencies. See Appendix H for details.

O/E - ratio of observed over expected

CI - confidence interval

Table 10: Estimation of the number of children aged 0-4 years who died from or were diagnosed with leukaemia in other Canadian provinces.

Province	Population aged 0-4 years 1976*	% of Ontario Population	Expected No. of deaths**	Expected No. of incident cases**
Ontario	607.2	1.00	795	951
Manitoba	72.3	0.12	95	114
Quebec	442.7	0.73	580	694
New Brunswick	58.3	0.10	79	95
Total			1549	1854

*population in thousands (source: 1976 Census)

**expected number = (expected number in Ontario) x (% of Ontario population)

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ACKNOWLEDGEMENTS

This study would not have been possible in the relatively short time period without the dedicated efforts and attention to detail of Mrs. V. Hunter, Project Co-ordinator, Miss P. Clarke, Research Assistant and Mrs. D. Nishri, Biostatistician.

The authors wish to express their thanks to Mrs. Despina Georgas, Mr. Carl Holness and their staff at the Office of the Registrar General of Ontario for their co-operation in searching birth and death records. They also wish to thank Mr. John Silins and his staff in the Vital Statistics and Disease Registries Section of Statistics Canada for their help in identifying numbers of live births in small areas of Ontario. The assistance and support of the Division of Epidemiology and Statistics of the Ontario Cancer Treatment and Research Foundation are gratefully acknowledged. In particular, special thanks are due to Miss D. Dale and Mrs. Mary Nemes for their help in obtaining information from hospital medical record departments and Regional Cancer Centres, Miss M. Kreller, for hospital chart review and Ms. S. Wing for secretarial assistance. The advice and comments of the Review Panel, Dr. A. Arsenault, Dr. G.B. Hill, Dr. G.R. Howe and Dr. D. Meyerhof, have been invaluable.

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 1964-1985 and cancer mortality data is available for the period 1950-1987. The OCR is a highly automated and cost-efficient system utilizing state-of-the-art computerized record linkage techniques, and medical and epidemiologic expertise.

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 unique system of registration, 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; 100,000 computerized records per year.

2. Pathology reports with a mention of cancer submitted voluntarily by hospital pathology laboratories; approximately 35,000 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 not only accurate and timely information, but 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.

GIVEN NAMES

2. SEX OF CHILD

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

PARENTS — FATHER — MOTHER

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; For office use only; Borough, city, town, village, township (by name); Regional municipality, county or district Province, (or country); 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; 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:

8-2300-23.1: 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*)

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 DEPARTMENT 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		
OCCUPATION	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

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)

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

DISPOSITION	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

CERTIFICATION 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

					Do Not Write In This Space
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			

MEDICAL CERTIFICATE OF DEATH

CAUSE OF DEATH

6.

Part 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 — 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

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

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

For Departmental Use Only

APPENDIX C

DATA COLLECTION FORMS

MORTALITY AECB STUDY OF CANCER IN CHILDREN

Study No: 101488 BIRTH CERT NO: 026159 LINK: 1

Surname: MACPHERSON Firstname(s): BRIAN JAMES

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

PLACE OF BIRTH: (Hospital) SUDBURY GENERAL DATE OF BIRTH: 11 /16 /60
(Birth Cert) MM DD YY

(City) SUDBURY

MOTHER'S SURNAME: MACPHERSON FIRSTNAME(S): MADELENE JULIA

MAIDEN NAME: CARTWRIGHT OTHER NAME: ---

Marital Status: ___

MOTHER'S ADDRESS: RESIDENCE CODE: 53007
356 JUNIPER AVE. #3
SUDBURY RG CODE: 20447
Postal Code: ________

MOTHER'S OCCUPATION: HOUSEWIFE AGE OF MOTHER: 19

FATHER'S SURNAME: MACPHERSON FIRSTNAME(S): DANIEL KENNETH

FATHER'S ADDRESS: RESIDENCE CODE: 53007
SAME
RG CODE: 20447
Postal Code: ________

FATHER's OCCUPATION: TRUCK DRIVER

Group No: ________ Date of DX: __/__/__ Age at DX: _____
DD MM YY

Death Cert No: 026133

Date of Death: 01/12/62 Age at Death: 2
DD MM YY

Cause of Death: 2040 Residence at Death: 20447

ALL IDENTIFYING INFORMATION IS FICTITIOUS

DATA COLLECTION FORMS

INCIDENCE   AECB STUDY OF CANCER IN CHILDREN

Study No: 002441   BIRTH CERT NO: 101251   LINK: 1

Surname: INGRAM   Firstname(s): LOUISE ARLENE

Date of Birth: 04/26/73   Sex: F
(Registry)   MM DD YY

PLACE OF BIRTH: (Hospital) TORONTO GENERAL   DATE OF BIRTH: 04/26/73
(Birth Cert) MM DD YY

(City) TORONTO

MOTHER'S SURNAME: INGRAM   FIRSTNAME(S): ELIZABETH ARLENE

MAIDEN NAME: CHAMBERS   OTHER NAME: ---

Marital Status: ___

MOTHER'S ADDRESS: RESIDENCE CODE: 20004
11 BLACKTHORN DRIVE
TORONTO   RG CODE: 20041
Postal Code:

MOTHER'S OCCUPATION: n/a   AGE OF MOTHER: 22

FATHER'S SURNAME: INGRAM   FIRSTNAME(S): TOBY MICHAEL

FATHER'S ADDRESS: RESIDENCE CODE: ---
n/a
RG CODE: ---
Postal Code:

FATHER's OCCUPATION: n/a

Group No: 116251039   Date of DX: 30/06/76   Age at DX: 3
DD MM YY

Death Cert No: 016253

Date of Death: 15/08/80   Age at Death: 7
DD MM YY

Cause of Death: Residence at Death:

ALL IDENTIFYING INFORMATION IS FICTITIOUS

APPENDIX D

SUMMARY OF RESIDENCE CODING ISSUES

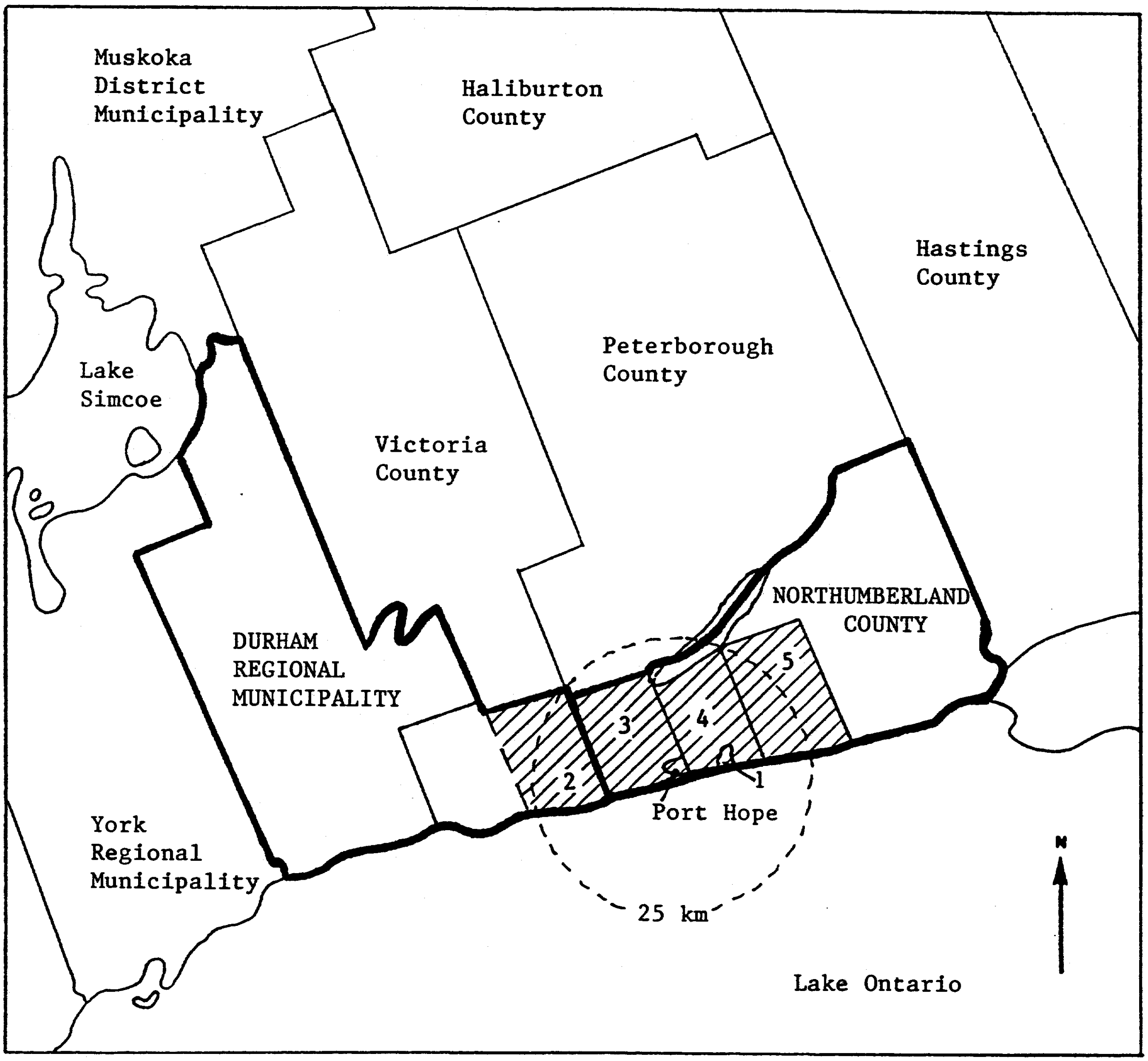
In order to facilitate the analysis by maternal residence at the time of subject's birth, it was necessary to use a consistent residence coding system. Thus, all residences were coded according to the 1981 Standard Geographic Classification (SGC): a five-digit code with the first two digits indicating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

In most cases, the residence was coded to the most specific location in the address. For example, an address such as Bowmanville, Darlington Township would be coded to Bowmanville. Residence codes were compared with those assigned by the Registrar General on the Birth Certificate, and all cases where the assigned code and the Registrar General code differed were noted. However, in order to be consistent with the number of live births published in vital statistics, the code assigned by the Registrar General was followed if coding more specifically placed the location in a different county. All places of residence in the counties of interest, particularly rural routes, were individually reviewed to ascertain their exact location in order to determine if cases should be included in the "nearby" analysis or the county level analysis only. Both the assigned codes and the Registrar General codes were recorded and entered into the IBM-PC.

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 H.

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

from: Standard Geographic Classification 1981, Volume 1A



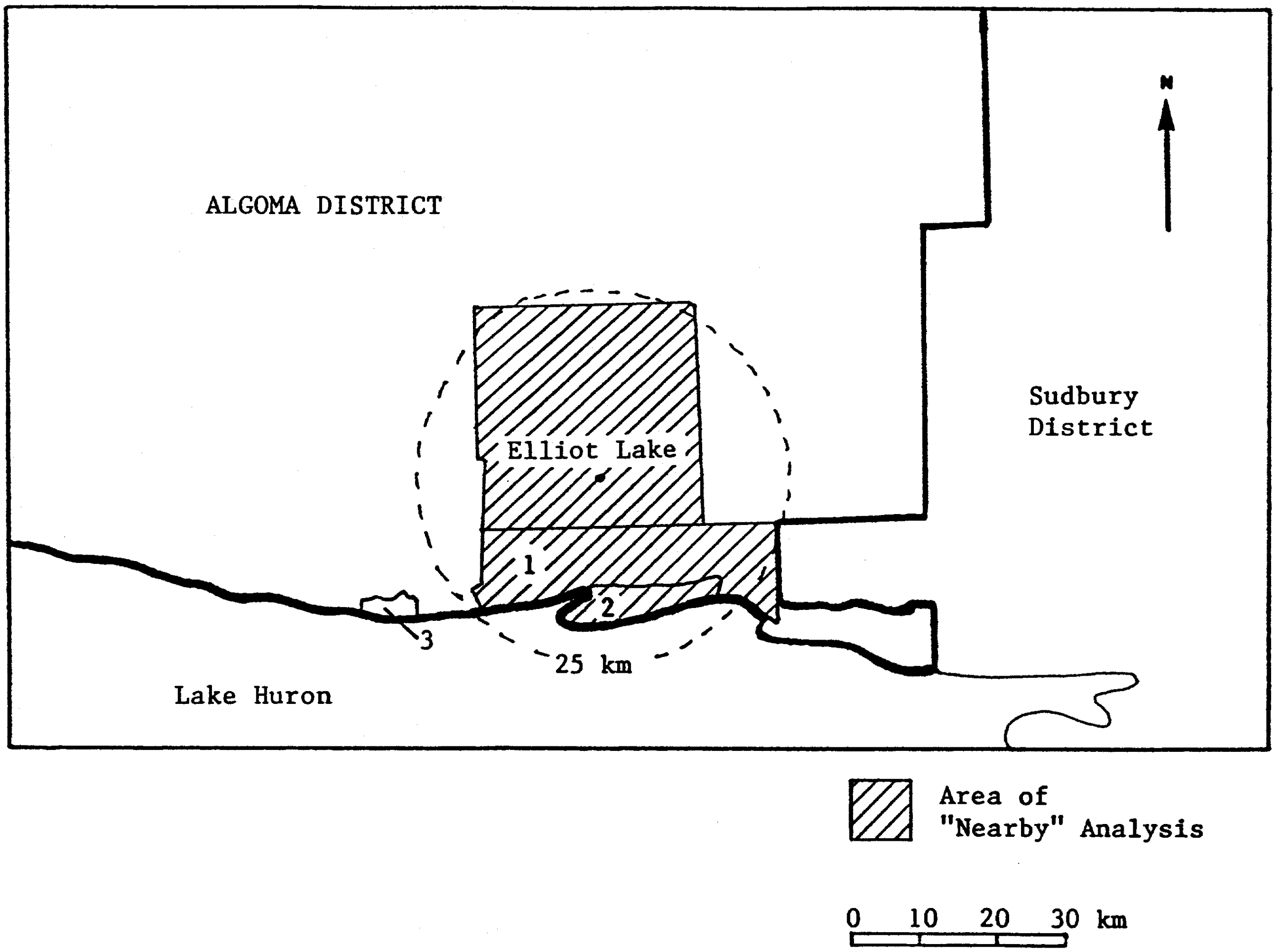
		Population (1981)
	Port Hope	9992
1	Cobourg T	11385
2	Newcastle T	32229
3	Hope Twp	3438
4	Hamilton Twp	8809
5	Haldimand Twp	3433

Area of "Nearby" Analysis

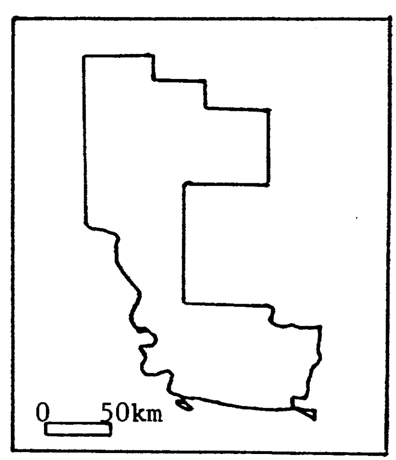
0 10 20 30 km

ALGOMA DISTRICT
(Elliot Lake Uranium Mine and Mill)

from: Standard Geographic Classification 1981, Volume 1A



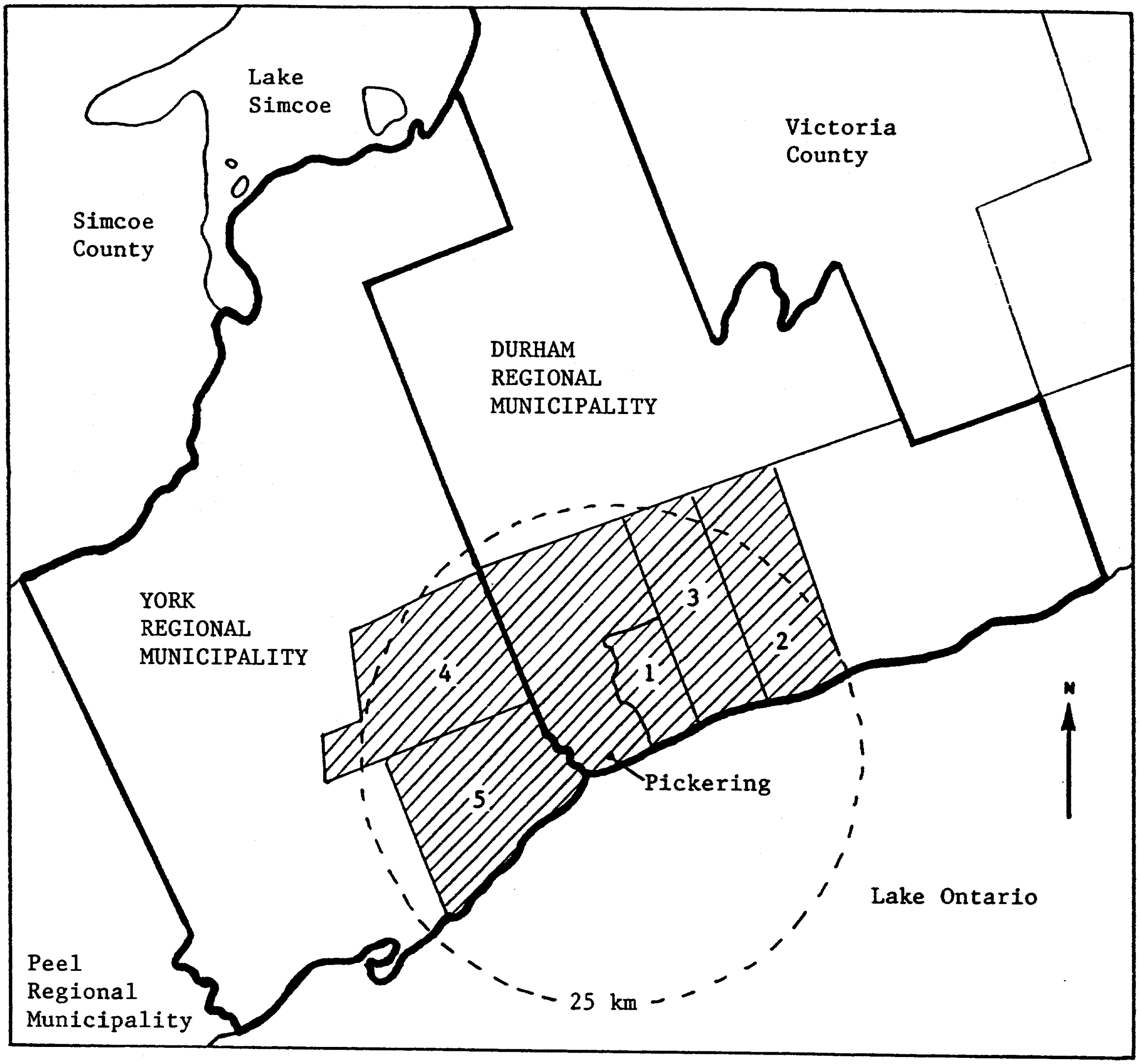
		Population (1981)
	Elliot Lake T	16723
1	North Shore Twp	2039
2	Serpent River 7 R	172
3	Blind River T	3444



Algoma District

YORK AND DURHAM REGIONAL MUNICIPALITIES
(Pickering Nuclear Generating Station)

from: Standard Geographic Classification 1981, Volume 1A



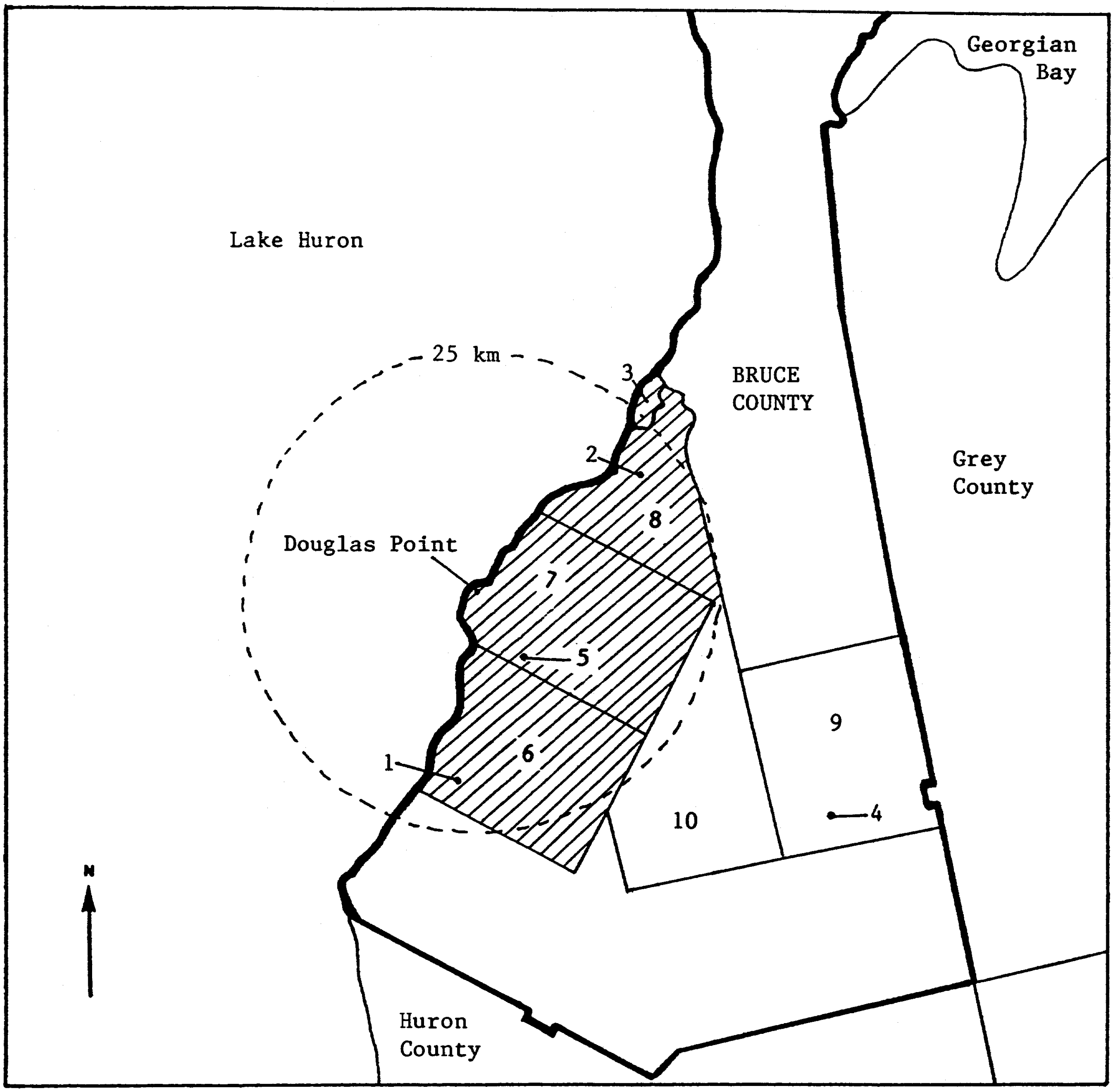
		Population (1981)
	Pickering T	37754
1	Ajax T	25475
2	Oshawa C	117519
3	Whitby T	36698
4	Markham T	77037
5	Scarborough Bor	443353

Area of "Nearby" Analysis

0 10 20 30 km

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	Walkerton T	4682
5	Tiverton Vl	806
6	Kincardine Twp	3175
7	Bruce Twp	1773
8	Saugeen Twp	1720
9	Brant Twp	3454
10	Greenoch Twp	1875

Area of "Nearby" Analysis

0 10 20 30 km

APPENDIX F

SUMMARY OF BOUNDARY CHANGES AND ESTIMATION METHODS

For each county of interest the chronology of boundary changes is listed from the year the nuclear facility began operation. The specific areas that were included in the 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 statistics are then listed, followed by detailed notes regarding the delineation of the areas of interest 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.
- 1971 - Pembroke T. became a city (status change only).
- 1980 - Petawawa Vl. annexed part of Petawawa Twp.
- 1984 - Pembroke C. annexed part of Stafford Twp.
- 1988 - Rolphton was closed and dismantled.

County Analysis: Renfrew County

"Nearby" Analysis (Chalk River): Deep River T.; Chalk River Vl.; Petawawa Vl.; Rolph, Buchanan, Wylie and McKay Twp.; Petawawa Twp. An "extended nearby" analysis included Pembroke C. and Pembroke 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:

1949 - 1968: 1972-1973: Petawawa Twp.
1949 - 1973: Pembroke Twp, 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 1949, even though the Chalk River plant opened earlier. The birth estimation before 1949 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 covers this township also, as well as Rapides-des-Joachims Twp. The total population in these two townships was small (n = 498 by the 1966 census). Also, it is unlikely that people living in Quebec would have been working in Chalk River or Rolphton facilities.

4. Although Petawawa Vl. was incorporated in 1961, births had to be estimated for 1959-1961 because the village appeared separately from Petawawa Twp. in the 1961 census. The same situation 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.

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 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:

1949-1956: Newcastle Vl.

1949-1973: 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 1949 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 1949, even though the plant opened earlier. The birth estimation before 1949 would be much more complex due to the absence of a census in 1946.

3. Rationale for county analysis: The available figures from 1974 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 lived in these two areas in 1971, this percentage of the post-1974 births were considered to have occurred in the portion of interest. 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.

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.
- 1972 - Blind River T. annexed part of Cobden Twp. (Unorganized).
- 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. An "extended nearby" analysis included Blind River T.

Estimated Births:

1954-1963; 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 percentage F15-44 in Elliot Lake T., using Elliot Lake T. and all "county-other" places in the denominator.

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

c) Calculate 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. To determine the population of Serpent River 7 R., the percentage from 1961 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. Blind River T. was included in an "extended nearby" analysis, since it is the largest "nearby" town.

5. 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.

6. 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 Power Plant 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.

County 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.

<u>BRUCE COUNTY</u> (Douglas Point)

<u>Chronology</u>

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.
- Walkerton T. annexed part of Brant Twp.
- Hanover T. (Grey County) annexed part of Brant Twp.

1976 - Units 1 and 2 of Bruce Nuclear Power Development A began operation.
1977 - Port Elgin T. annexed part of Saugeen Twp.
1981 - Hanover T. (Grey County) annexed part of Brant Twp.
1984 - Douglas Point Power Plant closed. Bruce Nuclear Power Development B opened: a total of 6 reactors in service.

<u>County Analysis</u>: Bruce County

<u>"Nearby" Analysis</u>: Kincardine T., Port Elgin T., Southampton T., Tiverton Vl., Kincardine Twp., Bruce Twp., Saugeen Twp. An "extended nearby" analysis included Walkerton T., Brant Twp. and Greenock Twp., because Ontario Hydro operated an employee shuttle bus service that started in Walkerton T.

<u>Estimated Births:</u>

<u>1967 - 1973:</u> Kincardine Twp., Tiverton Vl., Bruce Twp., Saugeen Twp., Brant Twp., Greenock Twp.

<u>Notes:</u>

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 of interest, 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 1949 - 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 of interest 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

	Pembroke Twp.	Pembroke C.	Petawawa Twp.	Petawawa Vl.	Rolph, Buchanan, Wylie & McKay Twp.	Chalk River Vl.	Deep River T.	Head, Clara & Maria Twp.
1949	14*	349	238*		138*			
1950	15*	380	257*		149*			
1951	14*	399	252*		146*			
1952	16*	420	283*		165*			
1953	17*	422	290*		168*			
1954	26*	445	326*		52*	31*	128*	
1955	26*	464	319*		51*	31*	126*	
1956	27*	518	329*		52*	32*	129*	
1957	26*	548	328*		52*	32*	129*	
1958	27*	480	332*		53*	32*	131*	
1959	28*	546	255*	144*	55*	34*	181*	
1960	27*	598	250*	141*	54*	33*	177*	
1961	29*	535	266*	150*	58*	36*	189*	
1962	29*	505	266*	189	58*	52	147	13*
1963	28*	531	252*	175	55*	43	139	12*
1964	30*	484	235*	128	55*	44	133	12*
1965	25*	331	197*	153	46*	23	116	10*
1966	20*	300	163*	94	38*	21	84	8*
1967	20*	266	159*	106	37*	24	97	8*
1968	20*	279	158*	107	37*	20	82	8*
1969	22*	293	186	104	33*	27	75	7*
1970	21*	259	181	107	32*	27	105	7*
1971	20*	271	189	119	31*	21	91	6*
1972	20*	254	144*	116	31*	26	99	6*
1973	19*	214	141*	90	30*	19	92	6*
1974	32	219	130	133	24	23	82	6
1975	14	197	113	119	38	27	90	10
1976	24	217	108	141	26	24	66	7
1977	27	189	128	120	30	23	71	3
1978	21	169	140	132	31	21	65	3
1979	34	170	145	122	31	22	68	5
1980	25	177	124	115	26	23	58	6
1981	13	199	124	111	18	22	73	2
1982	20	184	148	123	30	15	65	2
1983	26	202	144	129	25	22	64	5
1984	30	234	128	174	23	16	66	8
1985	30	195	168	141	16	18	70	2
1986	35	182	152	124	24	17	66	1

* 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 T.	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	478	
1975	39	140	167	40	150	483	
1976	39	114	146	35	169	461	
1977	40	136	151	55	149	464	
1978	60	106	154	43	163	464	
1979	43	134	142	53	154	434	
1980	49	110	142	43	177	411	
1981	43	99	140	45	132	398	
1982	48	114	157	58	170	418	
1983	36	101	170	23	146	431	
1984	43	112	162	39	147	423	
1985	41	99	168	53	133	415	
1986	39	113	158	58	161	488	

* Estimated values

Note: Newcastle T. 1974 - 1986 includes Clarke Twp., Darlington Twp. and Bowmanville T.

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

	Blind River T.	North Shore Twp.	Elliot Lake T.	Serpent River 7 R.
1954	103	62*	121*	7*
1955	160	62*	122*	7*
1956	180	60*	118*	7*
1957	224	56*	376*	7*
1958	233	67*	765*	8*
1959	258	152*	980*	12*
1960	189	161*	1063*	12*
1961	177	129*	538*	10*
1962	182	122*	361*	9*
1963	158	114*	321*	9*
1964	156	131*	318	8*
1965	109	63*	160	4*
1966	107	58*	167	4*
1967	92	61*	154	4*
1968	96	58*	199	4*
1969	108	58*	267	4*
1970	88	49*	192	3*
1971	87	51*	207	3*
1972	90	44*	182*	3*
1973	78	40*	168*	3*
1974	65	23	129	6*
1975	71	29	121	5*
1976	63	37	154	6*
1977	62	43	175	5*
1978	73	55	298	6*
1979	59	40	305	3*
1980	69	45	344	3*
1981	56	43	388	3*
1982	73	37	462	2*
1983	109	29	450	2*
1984	90	37	446	2*
1985	98	30	384	2*
1986	99	31	348	4*

* Estimated values

Table G-4: Durham County: 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

* Estimated values

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

	Kincardine Twp.	Kincardine T.	Bruce Twp.	Tiverton Vl.	Greenock Twp.
1967	29*	31	20*	5*	26*
1968	28*	36	19*	5*	25*
1969	27*	30	23*	8*	20*
1970	33*	46	28*	10*	24*
1971	31*	50	27*	10*	23*
1972	33*	53	28*	10*	24*
1973	34*	54	29*	11*	25*
1974	51	63	32	16	34
1975	64	73	52	17	24
1976	53	80	36	19	36
1977	57	81	38	18	31
1978	54	104	43	9	43
1979	54	113	30	11	29
1980	45	104	26	18	43
1981	62	114	31	15	30
1982	57	98	19	8	40
1983	56	154	22	18	27
1984	77	119	21	12	31
1985	52	104	24	14	26
1986	43	88	15	16	22

	Brant Twp.	Walkerton T.	Saugeen Twp.	Port Elgin T.	Southampton T.
1967	49*	57	17*	32	23
1968	47*	74	17*	32	24
1969	46*	79	15*	46	27
1970	57*	72	19*	43	29
1971	55*	73	18*	56	31
1972	58*	78	19*	82	34
1973	61*	81	20*	70	43
1974	60	71	17	76	27
1975	58	73	28	93	45
1976	48	76	26	109	40
1977	51	60	24	111	51
1978	53	75	34	115	50
1979	59	84	14	126	41
1980	68	77	34	125	36
1981	60	71	16	127	41
1982	64	77	29	131	43
1983	64	71	29	124	46
1984	83	87	25	119	52
1985	50	72	18	127	41
1986	68	57	21	112	35

* Estimated values

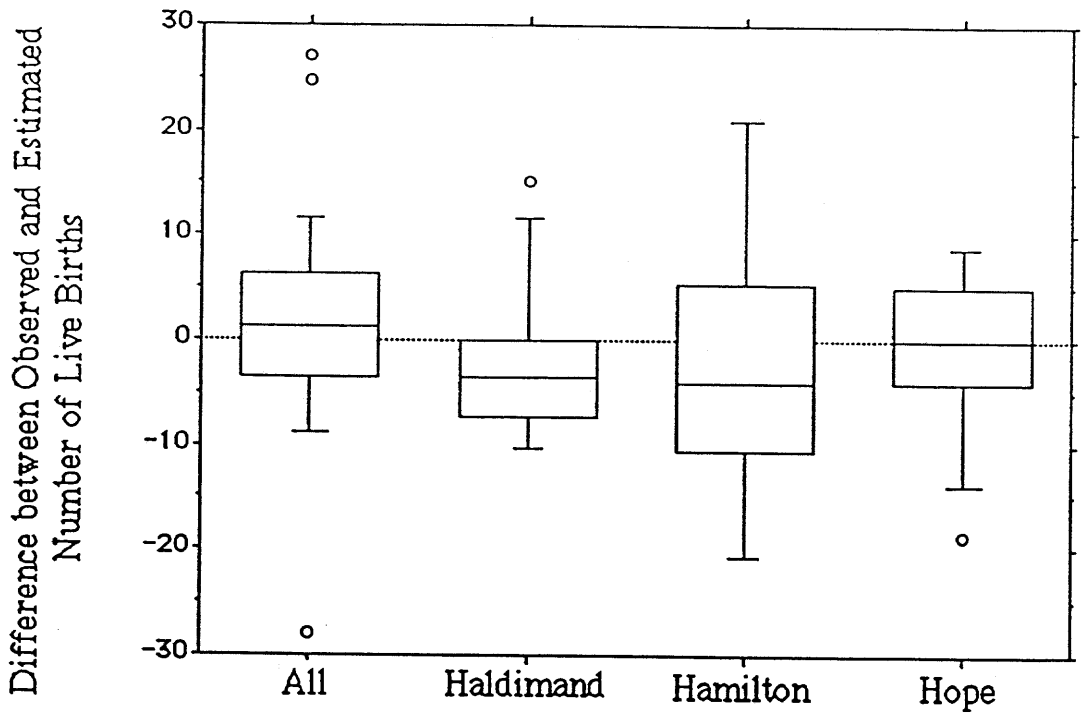


Figure G-7: Boxplots of the Difference Between Observed and Estimated Numbers of Live Births for Townships in Northumberland County.

APPENDIX H

THE INTERDEPENDENCE OF THE ANALYSIS METHODS

This appendix explains the interdependencies between the three styles of analysis presented in Tables 5 to 9. It is possible for a subject to be included in all three analyses at either the county or "nearby" level, or to be included only once. Table H-1 gives the total number of individuals for each method of analysis and for each geographic region. While there are subjects included in two or three analyses, in all counties at least 50% of the subjects are included in only one style of analysis.

For individuals to be included in a specific combination of analyses, they must meet criteria, which in general, 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 Death Residence Only (A): subject was born before 1950 or before the facility opened or was born outside the county of interest.

- Mortality by Birth Residence Only (B): subject was born before incidence data began (1964) and died outside the county of interest.

- Incidence Only (C): subject did not die, or died over four years of age.

- Mortality by Birth and Death Residence (D): both birth and death occurred after 1950, and prior to 1964.

- Mortality by Birth Residence and Incidence (E): subject was born after 1964 and died outside the county of interest.

- Mortality by Birth and Death Residence and Incidence (F): both birth and death occurred in a county of interest after 1964.

Table H-1 indicates that 12 subjects were analyzed at county level by residence at death only (Row A). However, 10 of these children probably resided in counties of interest all their lives, since their mothers resided in these counties at the time of their births. They have only been excluded due to restrictions on the beginning of the time period.

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	2	1	0	0	4	1	6	6	0	0
B	1	0	2	1	1	0	0	0	0	0
C	5	0	8	6	9	0	35	33	3	2
D	4	0	4	3	4	1	0	0	0	0
E	0	1*	1	0	1	0	4	4	1	0
F	3	0	5	3	8	1	13	13	2	2
Total	15	2	20	13	27	3	58	56	6	4

*Subject died in Renfrew County, but not in "nearby" area.

A = Mortality by death residence only
B = Mortality by birth residence only
C = Incidence only
D = Mortality by birth and death residence
E = Mortality by birth and incidence
F = Mortality by birth and death and incidence