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Foreword

This report incorporates public comments received by CDC on the draft version of the report. CDC released the draft report to the public during the March 18, 1998 meeting of the Fernald Health Effects Subcommittee in Harrison, Ohio. The lung cancer risk information originally released in the March 1998 draft report entitled "Estimation of the Impact of the Former Feed Materials Production Center (FMPC) on Lung Cancer Mortality in the Surrounding Community" remains unchanged. However, this final report contains two new sections as requested by public comment. The two new sections are: Chapter IV, Section E, "Estimates of the number and the percentage increase in lung cancer deaths by year of first exposure," (page 37) and Chapter V, Section E, "Percentage increase in the number of lung cancer deaths due to FMPC-related radiation exposure outside the assessment domain" (page 47).

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APPENDICES

I. Summary

A. FERNALD RISK ASSESSMENT PROJECT

The Fernald Risk Assessment Project was undertaken to characterize human health risk for the community surrounding the former Feed Materials Production Center (FMPC) near Ross, Ohio resulting from exposures to contaminants released from the site during its years of operation. The FMPC was a government-owned; contractor operated uranium-processing facility that was part of the United States (U.S.) weapons production complex. Draft results of the Fernald Dosimetry Reconstruction Project, sponsored by the Centers for Disease Control and Prevention (CDC) and reported in August 1996, indicated that during the its production years, 1951 through 1988, the FMPC released radioactive materials from the site. These materials primarily included radon and its decay products released into the atmosphere from stockpiles of radium contained in two waste storage facilities (the K-65 silos) and uranium and thorium isotopes released as a result of processing operations. A computer algorithm was developed in the Fernald Dosimetry Reconstruction Project to allow estimation of organ-specific doses for the population residing within 10 kilometers (6.2 miles) from the center of the FMPC production area during the plant's operating years. This geographic area is referred to in this report as the assessment domain. Results of the Fernald Dosimetry Reconstruction Project revealed that the primary exposure to residents of the surrounding community resulted from breathing radon decay products. These results also indicated a potential for increased cancer risk, specifically lung cancer in the community.

The Fernald Risk Assessment Project was initiated to respond to residents concerns about their potential health risks resulting from exposure to radioactive materials released from the FMPC site and to assist in evaluating the feasibility of an epidemiologic study within that community. Because the potential exists for significant exposures to radon and radon progeny in this community and because of the relationship between radon exposure and lung cancer, the first phase of our risk analysis focuses on an evaluation of the effect of FMPC-related radiation exposures on lung cancer mortality. The study population consisted of persons living within the assessment domain for some period of time from 1951 to 1988. This population was further subdivided based on location of residence within one of 160 geographic cells defined by compass direction and distance from the site. We included only those exposures occurring during the years of plant operations. We could not include exposures incurred as a result of working at the FMPC in this analysis because the Fernald Dosimetry Reconstruction Project was not designed to estimate occupational dose. Environmental exposures to radon, uranium, thorium, and their decay products and other radionuclides released from the site were accounted for in our estimation of lung dose. We have characterized the effect of these exposures on lung cancer mortality in terms of (1) the estimated number of lung cancer deaths occurring from 1951 through 2088 among residents of the community that may be due to exposures to radioactive material released from the site; and (2) the estimated percentage increase in the number of lung cancer deaths over the number that would be expected in the absence of these exposures. Estimates are projected through the year 2088 in order to allow the group of residents first exposed in the final year of plant operation (1988) the opportunity to reach 100 years of age.

We used mathematical models and pertinent data sources to estimate the components needed to make these risk predictions. These components included (1) gender-, age-specific population size within geographic cells of the assessment domain during years of plant operations; (2) time period-specific cumulative lung dose from radon, uranium and other radionuclides; and (3) lung cancer mortality risk in five year time intervals from 1951 through 2088 resulting from these exposures (using models developed from radon-exposed underground miners for radon-related risk and from atomic bomb survivors for the risk resulting from uranium exposure.). Life-table methodology was used to estimate the possible number of FMPC-related lung cancer deaths and the background number of deaths due to lung cancer and all other causes through the year 2088. Age-, gender-, geographic cell- and time period-specific groups, or cohorts were defined. The survival of these cohorts was modeled through age 100 years. The mortality experience of each cohort was summed to obtain the total number of lung cancer deaths in the population. The estimated percentage increase in lung cancer mortality that may be due to FMPC exposure was obtained by dividing the total estimated number of FMPC-related lung cancer deaths by the estimated total number of background lung cancer deaths and then multiplying by 100. The number of possible FMPC-related lung cancer deaths and the resulting percentage increase were estimated for the total population and by smoking status (ever vs. never smokers), gender, time period (1951-2000; 2001-2088), geographic location (0-<4 km, 4-<7 km, and 7-10 km from the site in the four geographic quadrants of the assessment domain) and year of first exposure (1951-1979; 1980-1988).

Because the components of the lung cancer mortality risk estimation process are uncertain, the resulting estimates of the number and percentage increase in FMPC-related lung cancer deaths and the number of background lung cancer deaths are uncertain. We attempted to quantify the uncertainty associated with this estimate using a technique called Monte Carlo simulation. By applying the Monte Carlo procedure, we obtained a collection of possible values for the total number and the percentage increase in lung cancer deaths that may result from FMPC-related radionuclide exposures. The range of possible values represented in these collections represents the uncertainty about the true values of the components used in the risk estimation process. These collections are summarized using the median value and the 90% credibility interval. The median is that value that is greater than half of the estimates produced in the Monte Carlo simulation and less than the other half. The 90% credibility interval is defined by an upper and lower limit so that 90% of the estimates produced in the Monte Carlo simulation fall between these values.

1. Results

We estimate that approximately 40,000 to 53,000 people resided within the assessment domain for some period between 1951 and 1988. The median estimates for the average lung dose equivalent, among this population resulting from exposure to all radioactive material released from the site was 0.45 sieverts with a 90% credibility interval of 0.12 to 1.7 sieverts. Exposure to radon decay products accounted for approximately 90% of the estimated total lung dose. Based on our life table modeling, the estimated range of possible excess lung cancer deaths resulting from this exposure had a median of about 85 deaths and a 90% credibility interval ranging from 25 deaths to 309 deaths. We estimate that the percentage increase in the number of lung cancer deaths that may be due to FMPC exposure ranged from 1% to 12% with a median value of 3%. In other words, we estimate that exposure to radioactive material released from the FMPC during its years of operation may have increased the number of lung cancer deaths among the population residing within the assessment domain by 1% to 12% over the number of lung cancer deaths we would expect in this population in the absence of FMPC-related exposure.

When examined by smoking status, we estimate that the majority of FMPC-related lung cancer deaths will occur among ever smokers as opposed to never smokers (median values of 65 deaths for ever smokers and 20 for never smokers). This is to be expected since studies of underground miners exposed to radon have shown that smoking appears to increase the risk of lung cancer death associated with radon exposure. We accounted for this interaction in our estimation of lung cancer mortality risk. In contrast, the estimated percentage increase in lung cancer deaths that may be due to FMPC exposures is more than twice as high among never smokers (2– 24%) as compared to ever smokers (1-10%). These results reflect how the increase in the number of lung cancer deaths that may be due to exposure to radioactive materials from the FMPC can have a proportionally greater impact among never smokers whose background rates of lung cancer are much less than the background rates for ever smokers.

The estimated number of FMPC-related lung cancer deaths among males is about 40% higher than the estimated number of FMPC-related lung cancer deaths among females. However, the percentage increase was comparable in both genders (median values of about 3% for both males for females). These results likely reflect the higher background rates of lung cancer among males.

The total number of estimated lung cancer deaths that may be related to FMPC radiation exposure was subdivided into those deaths predicted to occur between 1951 and 2000 and those predicted to occur from 2001 through 2088. We found that about half of the estimated number of FMPC-related lung cancer deaths are predicted to have occurred by the year 2000. This represents about a 2% to 22% increase during this time period in the number of lung cancer deaths that may be due to exposure to radioactive materials from the FMPC. While the actual number of estimated lung cancer deaths that may be due to FMPC-related exposure is comparable in the time periods up through and after the year 2000, the percentage increase in lung cancer deaths estimated to be due to FMPC exposures is about 3 times less among the population living past the year 2000 (median value of 6% through the year 2000 and 2% after the year 2000). This decrease in the estimated proportional effect on FMPC-related exposures on lung cancer mortality reflects the fact that as the population exposed from 1951 through 1988 ages, their background risk of lung cancer increases as does their risk of dying of causes other than lung cancer. Thus, the increase in the number of lung cancer deaths that may be related to FMPC exposure proportionately has less impact in this later time period.

Further analyses by geographic location showed that the percentage increase in the possible number of FMPC-related lung cancer deaths declined as the distance of residence from the site increased. Additionally, we predicted higher percentage increases among those who resided east of the site, in the direction of prevailing winds, as opposed to those who resided west of the site. These predicted geographic patterns in lung cancer mortality correspond to those in the estimated average lung dose.

The installation of containment measures to the K-65 silos in 1979 greatly reduced the amount of radon and radon decay products released from the site (RAC, 1998). Analysis of two subsets of the population, those who lived in the assessment domain from 1951 through 1979 and those who were born or first moved into the assessment domain after 1979, showed that virtually all the estimated increase in lung cancer deaths occurred among those first exposed before 1980.

The limitations of a model-based approach should be kept in mind when interpreting the lung cancer mortality estimates presented in this report. Many factors may affect the validity of these estimates. For example, the primary contributor to the estimated lung cancer risk for the population estimated to have resided within the assessment domain was exposure to radon decay products. We estimated the risk resulting from these exposures based on epidemiological evidence observed in several collections of underground miners exposed to much higher concentrations of radon. By using this evidence obtained at higher exposures to make estimates in this report, we are assuming a consistent, linear trend of risk with exposure beyond the realm observed in the underground miners' studies. Moreover, we are assuming a model developed using data primarily on adult males is applicable to the general population. These assumptions have been examined and accepted by the National Academy of Sciences, in its most recent evaluation of the likely impact of indoor exposure to naturally-occurring radon in the United States (NAS, 1998). Another important factor to keep in mind when interpreting these results is the uncertainty in the components of the risk assessment model, that is uncertainty concerning the actual lung dose, the risk resulting from that dose, and the number of individuals experiencing that risk. While we have attempted to model this uncertainty, it is highly unlikely that the full extent of the uncertainty about the true number of FMPC-related lung cancer deaths is adequately reflected in our estimated ranges. The magnitude of our estimates of FMPC-related lung cancer mortality, however, imply an approximate lifetime risk that is consistent with the range of estimates independently developed for a less representative portion of the population within the assessment domain in the Fernald Dosimetry Reconstruction Project.

2. Conclusion

In summary, our analysis indicated that the number of lung cancer deaths among the population that resided within 10 kilometers (6.2 miles) of the FMPC site for some period of time from 1951 through 1988, may be increased from 1% to 12% due to exposure to radioactive material released from the site during those years. The number of excess lung cancer deaths in this population resulting from these exposures is estimated to approximately range from 25 to 309 deaths, with a median expected number of FMPC-related lung cancer deaths of 85 over a period of 138 years (1951-2088). Analyses by smoking status, gender, time-period, and location indicate that some subgroups of this population are likely at greater risk than others, specifically smokers, persons who resided to the east and close to the site during its years of operation, and persons who lived near the site prior to 1980.

II. INTRODUCTION

A. HISTORY OF THE FEED MATERIALS PRODUCTION CENTER (FMPC)

The Fernald Feed Materials Production Center (FMPC) near Ross, Ohio (now known as the Fernald Environmental Management Project, FEMP) was a Department of Energy (DOE) facility that was part of the United States' nuclear weapons production complex from 1951 to 1988. The FMPC's primary purpose was to produce uranium metal for the United States defense program. A 1000-acre site located about 15 miles northwest of Cincinnati, Ohio, the FMPC processed uranium ore concentrates and compounds recycled from other stages of nuclear production into either uranium oxides or ingots of uranium metal. These materials were machined into tubular form for reactor fuel cores and target-fuel element fabrication. Production activities at the FMPC ended in 1988.

During the FMPC's production years (1951-1988), radioactive material was released from the site into the air during processing, from waste material stored in two large silos (the K-65 silos), and from waste burned or buried in pits and incinerators.

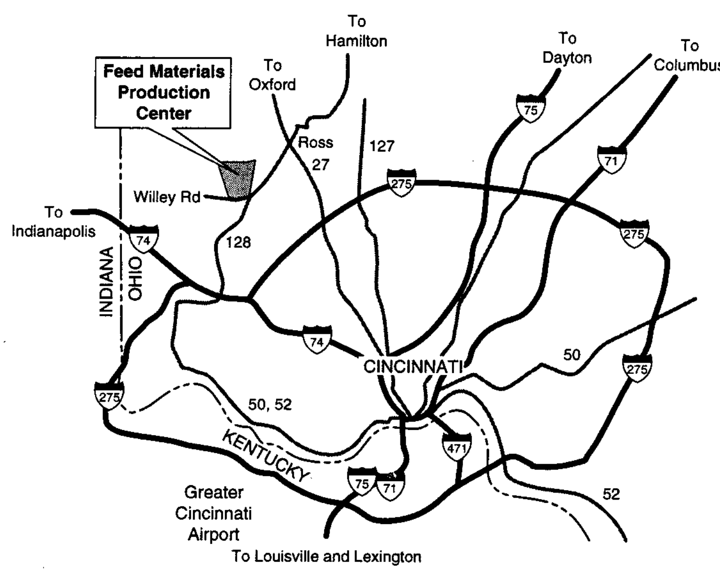

Figure 1 – Location of the Fernald Feed Materials Production Center

Particulate releases from the FMPC were primarily comprised of uranium (natural, depleted, and slightly enriched) and thorium. In addition, the two K-65 silos held waste material produced in the uranium extraction process by the FMPC and by the Mallinckrodt Chemical Works facility in St. Louis, Missouri. This waste material contained very high concentrations of radium and served as an emission source for radon and its decay products. Radioactive liquid waste was also released from the FMPC in water used for processing uranium and in water that ran into sewers and storm drains. At least three offsite water wells were contaminated with uranium after 1967.

B. CENTERS FOR DISEASE CONTROL AND PREVENTION (CDC) INVOLVEMENT

In 1988, the United States Congress requested that CDC's National Center for Environmental Health consider an epidemiologic study of the community surrounding the FMPC. CDC replied that such a study would have little chance of success without adequate estimation of radiation doses in the community and concluded that assessment of the feasibility of such a study was necessary before its initiation. We determined that the appropriate first step in assessing potential FMPC-related health effects was to estimate off-site radiation exposure through a dose reconstruction project. In addition, we proposed that a community-based risk assessment was needed in order to evaluate the FMPC's effect on the health of people who lived in the surrounding community. By estimating the community dose and the number of selected health outcomes that may have occurred in the area, we determined that a scientifically sound decision could be made concerning the feasibility of conducting a full epidemiologic study in the Fernald area.

Since then, CDC's National Center for Environmental Health (NCEH), in partnership with the Fernald Health Effects Subcommittee, CDC's National Institute for Occupational Safety and Health (NIOSH) and the Agency for Toxic Substances and Disease Registry (ATSDR), has continued to investigate the public health effect of historic radionuclide and chemical contamination from the Fernald site.

1. The Fernald Dosimetry Reconstruction Project

The CDC initiated the Fernald Dosimetry Reconstruction Project in 1990. CDC's National Center for Environmental Health and its contractor, Radiological Assessments Corporation (RAC), performed a thorough review of historical records and conducted extensive interviews with former and current employees and residents to reconstruct routine plant operations, document unintentional releases, and evaluate unmonitored emission sources. RAC then estimated the quantities of radioactive materials released into air, surface water and groundwater; developed the methodology and mathematical approaches for modeling how this material moved through the environment; and produced methods for estimating the resulting radiation doses to specific organs in the body. In addition, RAC estimated the risk of fatal cancers from these exposures and the likelihood of toxic effects from uranium on the kidneys for nine hypothetical exposure scenarios.

Initial draft project findings of the Fernald Dosimetry Reconstruction Project were released during two public meetings held in August 1996. Since that time, the draft report (RAC, 1996) has undergone lengthy scientific and public review. The final Fernald Dosimetry Reconstruction Report was released in September 1998.

a. The assessment domain for the Fernald Dosimetry Reconstruction Project

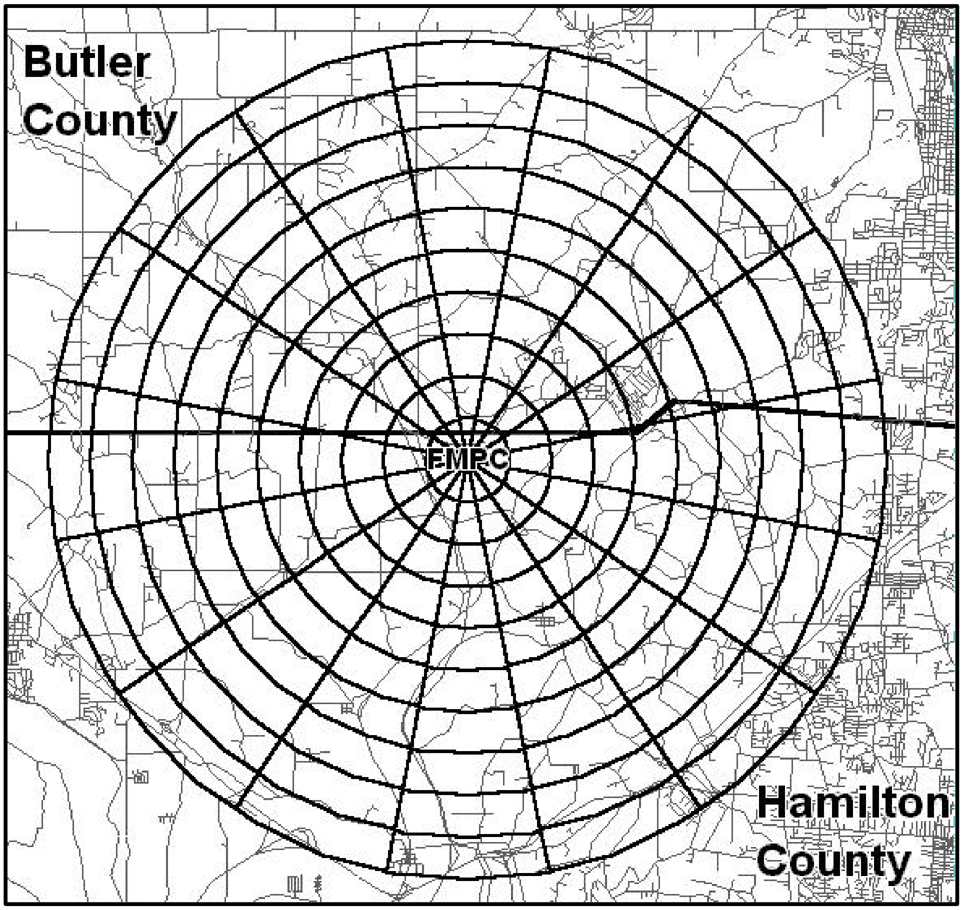

Figure 2 – The assessment domain for the Fernald Dosimetry Reconstruction Project

The study area, referred to as the assessment domain, for the Fernald Dosimetry Reconstruction Project was defined as the geographic region contained within a radius of 10 kilometers (6.2 miles) from the center of the FMPC production area. A grid containing 16 sectors representing possible wind directions subdivided this domain. Each of those sectors was then further divided into 10 geographic cells ranging from 1 kilometer to 10 kilometers from the center of the plant. The resulting grid consisted of 160 cells. This grid includes portions of three townships in Butler County, Ohio (Ross, Morgan and Fairfield) and four townships in Hamilton County (Crosby, Colerain, Harrison and Whitewater). (See Figure 2).

b. The use of nine hypothetical scenarios

In the Fernald Dosimetry Reconstruction Project, radiation dose could not be measured directly in individuals who lived in the surrounding community. Instead, mathematical models were used to estimate the possible doses to hypothetical people. Exposures among residents of the assessment domain were summarized by nine hypothetical "exposure scenarios." These scenarios were developed to describe typical people who might have lived, gone to school, or worked in the area and they were used to demonstrate the effect of location, distance from the site, diet, and lifestyle on the estimated doses that people living in the assessment domain could have received.

Nine scenarios describe representative people and their lifestyles to estimate likely ranges in their radiation doses

Scenario number	Years of exposure	Key feature	Home	School	Work
1	38	Received inhalation exposure close to site	Family farm	Elda Elementary, Ross Middle and High Schools	Family farm
2	38	Lived close to K-65 silos	Family farm	Elda Elementary, Ross Middle and High Schools	Hamilton
3	38	Drank well water	Family farm	Elda Elementary, Ross Middle and High Schools	Family dairy farm
4	18	Received typical inhalation exposure	Ross	Elda Elementary, Ross Middle and High Schools	Moved away
5	38	Worked outside the area	Near Layhigh	Morgan Elementary, Ross Middle and High Schools	Hamilton
6	38	Irrigated using water near the site	Family farm	Elda Elementary, Ross Middle and High Schools	Family farm
7	38	Irrigated using water farther from the site	Miamitown	Elda Elementary, Ross Middle and High Schools	Miamitown
8	13	Received exposure as a child in Ross	Ross	Elda Elementary, Ross Middle and High Schools	Family farm
9	18	Attended school in Ross and then left area	Near Route 128	Elda Elementary, Ross Middle and High Schools	Moved away

Figure 3 – The nine hypothetical exposure scenarios used in the Fernald Dosimetry Reconstruction Project

Results from the Fernald Dosimetry Reconstruction Project indicated that most of the estimated dose of radiation to the public occurred through breathing radon and radon decay products. (Although the decay products of radon are the radionuclides of concern, for simplicity we refer to lung dose resulting from exposure to radon progeny as radon dose.) The most important factors affecting the estimated radiation dose a person may have received were length of time a person lived in the assessment domain and the location of his or her residence relative to the site. Thus, estimated doses were larger for persons living close to the site over the 38-year period (1951-1988) and, in general, for persons living to the east of the site as opposed to the west.

c. Radon was found as the major release, with some uranium and other radionuclides

Findings from the Fernald Dosimetry Reconstruction Project indicated that exposure to residents within the assessment domain was mainly from radon and uranium. In examining past operations, it was determined that the largest releases of uranium occurred in the 1950s and 1960s. Radon and radon decay products released from the K-65 silos to the atmosphere were highest in the 1950s, 1960s and 1970s. In 1979, protective structural changes to the K-65 silos significantly decreased the amount of radon and radon decay products released to the atmosphere.

The final report (RAC, 1998) shows that the body organs receiving the greatest estimated radiation doses, were the lung, bone surfaces, red bone marrow, kidney, and liver. For all nine exposure scenarios used in the Fernald Dosimetry Reconstruction Project, the estimated radon lung dose was significantly higher than the dose to the lung from uranium and thorium isotopes or their decay products, or doses to any other organs.

d. Risk estimates were provided for the nine hypothetical exposure scenarios

The Fernald Dosimetry Reconstruction Project demonstrated that there is an increased lifetime risk of fatal cancer, almost entirely due to lung cancer, for each of the nine exposure scenarios. The median values (50^{th} percentiles) of the excess lifetime risk of fatal lung cancer that may be due to exposure to all radionuclides ranged across the scenarios: from 0.1% (or about 1 chance in 1000) for Scenario 8 to 1.3% (or about 1 chance in 100) for Scenario 1 (unadjusted for smoking). (See Table A14, Appendix A). [1]

The risk estimates made for the representative individuals in these nine exposure scenarios are subject to a variety of uncertainties. For example, for Scenario 1 (a hypothetical person who lived 1.7 km northeast of the site), the median estimate of the excess risk of fatal lung cancer is 1.3%, but a risk as low as 0.24% (the 5^{th} percentile value) or as high as 9.6% (the 95^{th} percentile value) are possible values of the excess lifetime risk for this hypothetical person because of the uncertainties involved in estimating lung cancer mortality risk.

[1] Median values of the risk estimates in the Final Fernald Dosimetry Reconstruction report (RAC, 1998) are lower than those reported in the Draft Fernald Dosimetry Report (RAC, 1996) due to the elimination of age and gender adjustments to the estimated lung cancer mortality risk. However, due to the inclusion of a broader range of uncertainties, the 90% credibility intervals for the estimates are similar in the Draft and Final reports.

It was not within the scope of the Fernald Dosimetry Reconstruction Project to provide risk estimates for the entire community surrounding the Fernald site. Dose and risk estimates were determined for the nine hypothetical exposure scenarios in an attempt to provide residents with some context for understanding what exposures they may have received, and how those exposures translate into dose and organ-specific cancer risk. However, the risks estimated for the nine exposure scenarios did not provide a comprehensive summary of the potential health effect of the FMPC on all residents in the surrounding community. Many individuals, who could not relate their own experiences to those defined in the nine exposure scenarios, were left with questions about their risk.

We proposed to analyze and characterize human health risk for the community surrounding the FMPC using a model-based risk assessment. We determined that this approach would provide a summary estimate of the number of selected disease outcomes that could potentially occur due to exposure to radioactive materials released from the FMPC during its operating years (1951-1988). However, this approach only provides estimates of the FMPC-related risk at the community-level and it can not be used to estimate risk for specific individuals. The results from this type of risk assessment will also allow us to determine the scientific feasibility of an epidemiologic study of selected disease outcomes, as well as assess the need for other public health activities.

1. Part of assessing the feasibility of an epidemiologic study

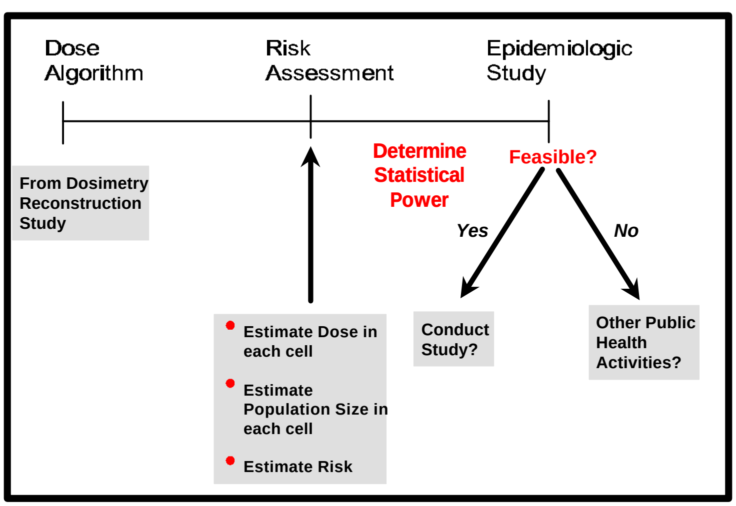

Figure 4 – Decision-making flow diagram for determining the feasibility of conducting an epidemiologic study at Fernald

As illustrated in Figure 4, the results of a risk assessment are part of a process for determining the feasibility of conducting an epidemiologic study. Risk assessment can provide an estimate of the number of cancers of selected sites/types or other health outcomes that may have occurred in the community.

Estimates of size of the population that resided within the assessment domain from 1951 through 1988 and estimates of the dose to geographic cells in the Fernald assessment domain are essential to developing these projected number of outcomes. Thus, risk estimation is necessary for determining epidemiologic feasibility because it provides the components needed to calculate the statistical power of a study: knowledge of the size of the study population, the level of exposure and the likely number of cases of disease is needed to estimate the probability that if an epidemiologic study were conducted in this population, it would be able to detect a true relationship between FMPC exposure and disease.

2. Response to community concerns

Work completed in the Fernald Dosimetry Reconstruction Project indicated that exposure to radon and its decay products provided the greatest contribution to lung dose estimated for the nine exposure scenarios. It also demonstrated that lung cancer dominates the contributions of various site-specific cancers to overall cancer risk. Because results of the Fernald Dosimetry Reconstruction Project and data in the scientific literature indicate that lung cancer is the most likely health outcome from exposure to radon, we proposed to the community that we conduct a lung cancer risk assessment for use in determining the feasibility of conducting an epidemiologic study of lung cancer. While this decision was not meant to exclude other health effects, it was considered a scientifically valid approach since an epidemiologic study of lung cancer in a population with potentially high radon exposures would likely have the greatest statistical power to detect a relationship between exposure and disease. However, this plan did not adequately address the immediate needs of the community. Through meetings with the Fernald Health Effects Subcommittee (FHES) (an advisory group composed of community residents, health care providers, and local and state health officials) and with residents not part of the FHES, it was determined that community needs were three-fold:

- To better understand the risk of a broad range of health effects in the community;
- To determine what public health interventions may be necessary to mitigate risk on the community level; and
- To understand what efforts to mitigate risk can be made at the individual level.

In its August 1997 meeting, the Fernald Health Effects Subcommittee recommended to CDC that it "hold in abeyance its evaluation of the feasibility of an epidemiologic study and proceed with an evaluation of the risk of diseases of community concern, such as but not limited to, cancers of the lung, kidney, breast and colon, and birth defects." The purpose of this recommendation "was not to negate any future epidemiologic study, but to delay [the completion of the feasibility study]" (minutes, FHES meeting, August 1997). We agreed that completion of risk assessments of multiple health outcomes prior to assessment of the feasibility of an epidemiological study, specifically for those outcomes where an association with radioactive materials emitted from FMPC is biologically plausible, was a scientifically credible means of addressing the community concern highlighted by this recommendation.

D. FOCUS OF THIS REPORT

The purpose of the Fernald Risk Assessment Project is to estimate the number of cancers and other health outcomes that may have been caused by exposure to radioactive materials released from the FMPC in the surrounding community during the plant's operating years, 1951-1988. This report provides the results of the first phase of this project: estimates of the number of lung cancer deaths among residents of the Fernald assessment domain that may be attributable to exposures from the FMPC site and estimates of the percent increase in the number of lung cancer deaths over the number that may be expected in the absence of these exposures. As noted previously, lung cancer is the most likely health outcome associated with radionuclides released to the environment during FMPC operations. Future reports will likely focus on additional health outcomes such as kidney and bone cancer, and the toxic effects of uranium on the kidneys.

In general, the methods developed to conduct these analyses for lung cancer are applicable for other health outcomes. We have utilized model-based approaches to estimate the:

- Gender- and age-specific population size within each geographic cell of the assessment domain during the years of plant operations;
- Time period-specific, cumulative dose from radon, uranium, thorium and their decay products for each of these populations;
- Lung cancer mortality risk through the year 2088 using a life-table approach and risk models developed in analysis of radon-exposed underground miners and atom bomb survivors. (Other risk models would be used for other health outcomes.); and
- The number of lung cancer deaths using a life table approach.

Because the estimates are model-based rather than actual "counts" and because information used in this analysis may be incomplete (for example, data on local smoking prevalence), we have made some simplifying assumptions in determining risk. In addition, we have emphasized the use of all available information to realistically quantify the uncertainty associated with the estimates produced in the model-based approach.

E. ADDRESSING OTHER HEALTH CONCERNS & COMMUNITY NEEDS

Because of public requests, CDC's National Center for Environmental Health is planning to allocate more time and resources to this risk assessment project—expanding the work to other health outcomes. Area residents have asked CDC for more information about whether exposures from the FMPC may have caused other health problems such as cancers of the kidney, breast and colon, miscarriages, birth defects or learning disabilities. Physicians in the Fernald area say that people with current health problems cannot afford to wait for a multi-year epidemiologic study, especially one that focuses exclusively on lung cancer. Physicians have asked for quick, specific information about what to look for when treating patients who lived near the FMPC.

In response, CDC's National Center for Environmental Health has delayed its current assessment of the feasibility of a epidemiologic study of lung cancer until the risk assessment work needed to address community concerns is completed. Future reports will be similar to this one--providing Fernald area residents and health care providers with information regarding health risks for other health outcomes.

III. METHODS

In this section, we provide a brief overview of the methods used to estimate the number of lung cancer deaths that may have or may yet occur as a result of historic environmental exposure to radioactive materials released from the FMPC. These estimates apply only to the population that resided within 10 kilometers (6.2 miles) of the site for some period of time during the years of plant operations, 1951 through 1988. Our goal was to estimate the lung cancer mortality experience of this population, from the period of first potential exposure, 1951, until the last group of potentially exposed citizens (first exposed in 1988) have the opportunity to reach the age of 100 years in 2088. We made these estimates based on existing epidemiologic evidence concerning the lung cancer mortality risks associated with exposure to the radionuclides released from the site (radon, radon progeny and uranium and thorium isotopes and their decay products). We applied this knowledge by using a mathematical modeling approach called life table estimation.

A. DESCRIPTION OF THE LIFE TABLE ESTIMATION APPROACH

A life table is a method by which mathematical models are used to assess the mortality experience of a specific group of individuals as the group ages through time. In our analyses, we estimated the number of lung cancer deaths that may be due to FMPC-related exposures, the number of lung cancer deaths that would occur in the absence of these exposures (called the background number), and the number of deaths due to all causes other than lung cancer.

To estimate the total number of lung cancer deaths related to FMPC radiation exposures, the population that resided within the assessment domain was divided into smaller groups, which we call cohorts, and the deaths within each cohort was modeled separately using the life table approach. Cohorts were defined by year of first exposure to site contaminants, age at that first exposure, gender and location of residence relative to the site, as defined by each of the 160 cells in the assessment domain. Within each cohort, the time-specific number of FMPC-related lung cancer deaths was estimated using modeled values for the time- and age-dependent cumulative lung dose resulting from FMPC-related exposures, the risk of lung cancer death resulting from that dose, and the size of the population at risk of dying of lung cancer during the time interval being considered[2]. The number of FMPC-related lung cancer deaths, the number of

[2] Based on available epidemiological evidence, we assumed a 5-year interval or "latency period" between time of exposure to radon and the beginning of the time at risk of lung cancer death due to this exposure. Similarly, for uranium exposure, we assumed a 10-year latency period.

lung cancer deaths due to background risk, and the number of deaths due to causes other than lung cancer were estimated within five-year age and time periods for each cohort. The mortality experience for each cohort was modeled from age at first exposure until members of the cohort had the opportunity to reach the age of 100 years. Therefore, our estimates reflect not only the influence of FMPC-exposure on lung cancer deaths that may already have occurred, but also its influence on the population's future risk. The estimated total number of lung cancer deaths resulting from historic releases of radioactive material from the FMPC site was obtained by adding together the number of lung cancer deaths estimated to occur within each of the time and age of first exposure, location, and gender-specific cohorts. In addition, the estimated total number of lung cancer deaths that would occur in the population in the absence of FMPC exposures was obtained by adding together estimated background number of lung cancer deaths estimated to occur in each cohort. By dividing the total estimated number of FMPC-related lung cancer deaths by the estimated total background number, we derived an estimate for the percentage increase in lung cancer deaths within the population due to historic releases of radioactive material from the FMPC site.

In addition to estimating the total number of lung cancer deaths that may result from exposures to FMPC-related radioactive materials, we were also able to use the life table approach to estimate the average lifetime lung dose within the affected community. The lifetime lung dose is defined as the radiation dose to the lung resulting from exposure to radioactive material released from the site between 1951 and 1988 from the time a person is first exposed through his or her death or 2088, whichever comes first. The average dose estimates are expressed in units called sieverts. Expressing average lung dose in these units allows the dose resulting from exposure to radon to be combined with that resulting from exposure to uranium and other radionuclides to produce a total estimated lifetime lung dose.

We obtained estimates of the average lifetime lung dose by multiplying the number of individuals predicted to die during a given time interval in the life table by the cumulative radon and uranium lung dose received up to and including that interval. These products of the estimated cumulative lung dose and the number of individuals for whom that cumulative dose is a lifetime dose were then summed across all time periods. We obtained the estimated average lifetime dose by dividing this sum by the total estimated population size. To illustrate how average lifetime lung dose varies with location of residence, we estimated the average dose separately for 12 geographic areas within the assessment domain. These areas were defined by combining the geographic cells within the assessment domain into distance categories of 0 to 4 kilometers from the site, 4 to 7 kilometers from the site, and 7 to 10 kilometers from the site in each of four directions. Figure 5 shows the locations of the 12 areas for which average lifetime lung dose equivalent was estimated for the illustration. It also shows how the cells within the assessment domain were combined into the larger areas. To illustrate how the estimated effect of FMPC exposures varied with location relative to the site, we also estimated the percentage increase in lung cancer deaths due to FMPC-related exposure separately for each of the 12 geographic areas.

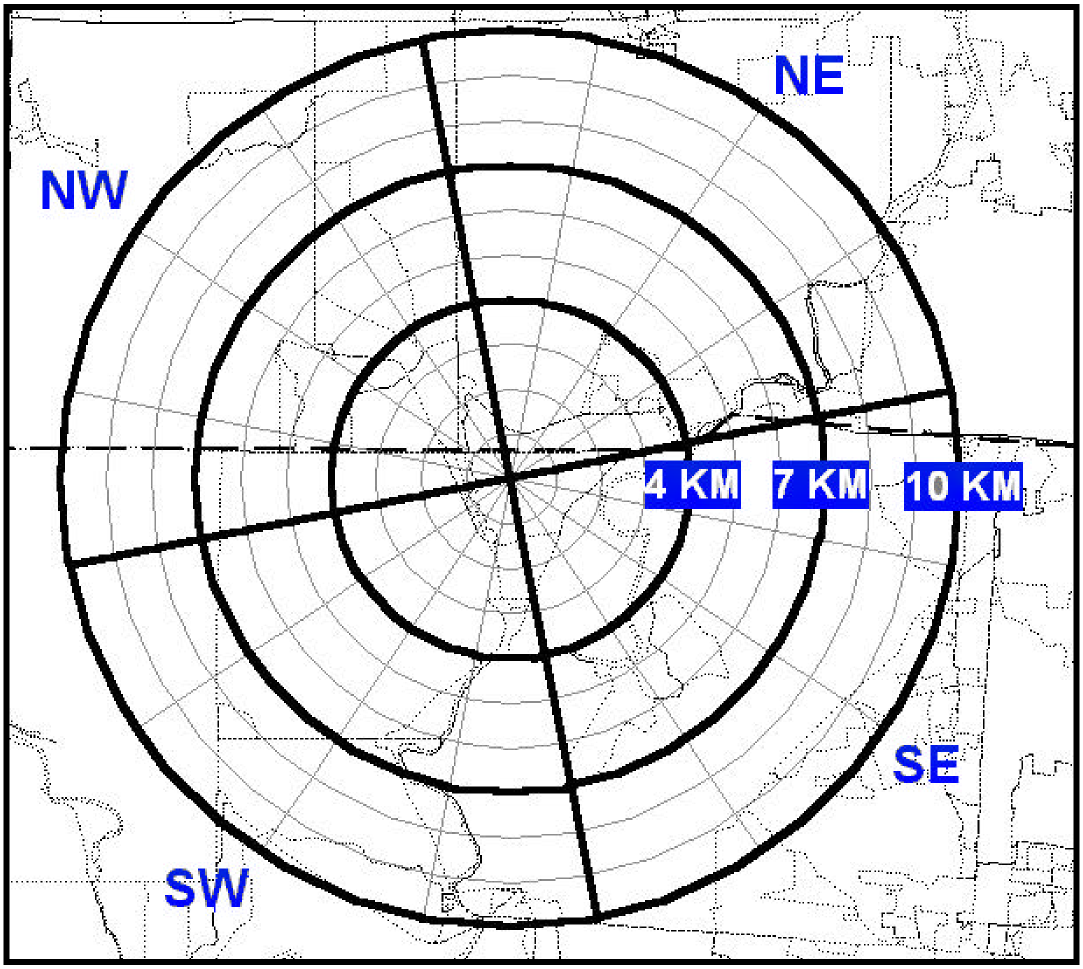

Figure 5 – Location of 12 areas within the assessment domain used to summarize the results in this report.

B. QUANTIFYING THE UNCERTAINTY ASSOCIATED WITH THE ESTIMATED TOTAL NUMBER OF FMPC-RELATED LUNG CANCER DEATHS

Estimation of the total number of lung cancer deaths potentially caused by past releases of radioactive material from the FMPC site depends on a variety of components. These components include: (1) estimates of the cumulative lung dose within cohorts at different points in time; (2) estimates of the risk of lung cancer death that may result from these doses; and (3) estimates of the number of persons experiencing that risk at different time periods. The values used for these components in our risk estimation were uncertain in that their true values were not directly measurable. As a result, estimates for these components were derived using mathematical models and all pertinent data sources. For example, although U.S. Census data provides counts of residents in geographic areas around the FMPC site over time, summary population counts reported by the U.S. Census do not correspond to the cells within the assessment domain used in our risk estimation. As a result, we used U.S. Geological Survey maps to enumerate the number of residential structures in the cells of the assessment domain around 1950 and 1980, county real estate tax databases to quantify the uncertainty in these structure counts, U.S. Census data to estimate household occupancy rates, and mathematical models to estimate the number of residents in each geographic cell of the assessment domain.

Because the components of the lung cancer mortality risk estimation process are uncertain, the resulting estimate of the number of FMPC-related lung cancer deaths is also uncertain. We modeled the uncertainty associated with this estimate using a technique called Monte Carlo simulation (Vose, 1996). In the Monte Carlo approach, estimation of the total number of FMPC-related lung cancers is repeated many times leading to a collection of possible values for this total. Within each repetition, possible estimates for the lung dose, the lung cancer mortality risk resulting from that dose, and the number of individuals alive and at risk for lung cancer death are sampled from a collection of plausible values for these components. The collection of plausible values for the components is determined based on the uncertainty estimated to be associated with each of these parameters. By applying the Monte Carlo procedure we obtained a collection of possible values for the total number of lung cancer deaths that may result from FMPC-related exposures, the background number of lung cancer deaths, and the percentage increase in lung cancer deaths over that expected in the absence of these exposures. These collections of estimates are summarized using the median value and the 90% credibility interval. The median is that value that is greater than half of the estimates produced in the Monte Carlo simulation and less than the other half. The 90% credibility interval provides a measure of the range of possible estimates about the median. The interval is defined by an upper and lower bound where the values for these bounds are determined so that 90% of the estimates produced in the Monte Carlo simulation fall between the lower and upper values. Conversely, this means that 5% of the possible values fall below this range and 5% of the possible values fall above this range. A detailed description of the life table estimation approach and our approach towards quantifying the uncertainty associated with the final estimates is provided in Appendix B of this report.

IV. RESULTS

A. ESTIMATES OF THE TOTAL NUMBER OF LUNG CANCER DEATHS FROM 1951 THROUGH 2088 THAT MAY BE DUE TO EXPOSURE TO RADIOACTIVE MATERIALS RELEASED FROM THE FMPC SITE DURING ITS YEARS OF OPERATION, 1951-1988

Estimates of the possible number of exposed citizens, the average lifetime lung dose, and the number of lung cancer deaths that may result from exposures to radioactive material released from the FMPC site were produced in this evaluation. These estimates do not reflect exposures incurred by portions of the population while employed at the site. Rather, the estimates are intended to provide an assessment of the effect on lung cancer mortality that might be due to exposure to radioactive materials resulting from residing near the site during the FMPC's years of operation, 1951-1988.

To reflect the uncertainty about the true number of lung cancer deaths potentially caused by site-related exposure; we used a Monte Carlo procedure to produce a collection of 500 possible values for this health outcome. This collection represents the uncertainty about the components of the risk estimation process. In general, we summarize the collection of estimates using the median, the value less than half of the possible estimates and greater than the other half, and the 90% credibility interval (sometimes called the uncertainty range). In some cases, we also present histograms representing a more complete description of the range of possible values produced by the Monte Carlo process. These histograms indicate the likelihood of specific ranges within the collection of possible values given the uncertainty considered.

Estimates of the number of persons that resided within 12 geographic areas surrounding the FMPC site for some period of time from 1951 through 1988 are shown in Table 1.

Table 1 - Estimated Number of Persons who Resided in 12 Geographic Areas * Surrounding the FMPC for Some Period of Time from 1951 through 1988

Direction from FMPC	Distance (kilometers) from FMPC	Estimated Population: Median ** #	90% Credibility Interval *** (lower limit)	90% Credibility Interval *** (upper limit)
Northeast	0-4	4,431	2,691	7,863
	4-7	3,795	2,345	6,549
	7-10	2,884	2,094	4,463
Southeast	0-4	894	529	1,671
	4-7	3,488	2,529	4,761
	7-10	8,039	5,706	11,991
Southwest	0-4	1,358	662	2,384
	4-7	2,195	1,490	3,134
	7-10	5,528	3,877	7,702
Northwest	0-4	825	349	1,912
	4-7	3,752	2,486	5,111
	7-10	6,939	4,832	10,634
Total Population in Entire Assessment Domain		**45,631**	**40,240**	**53,224**

* See Figure 5 for the geographic locations of the 12 distance areas from the FMPC

** 500 estimates for the total number of residents were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

*** 90% of the 500 estimates of the possible value for the true number of residents fall between the upper and lower bound of the 90% credibility interval.

\# The sum of the medians within categories will not necessarily equal the median for the entire population.

We estimate that approximately 40,000 to 53,000 individuals resided within the assessment domain for some period during the years of FMPC operation. Estimates for the average lifetime lung dose equivalents received by these individuals are shown in Table 2. Using the computer software developed in the Fernald Dosimetry Reconstruction Project (RAC, 1998), we estimate that the median average lifetime lung dose resulting from exposures during plant operations was 0.45 sieverts with a 90% credibility interval of 0.12 to 1.74 sieverts for the entire population within the assessment domain. This lung dose resulted primarily from radon, which accounted for approximately 90% of the total lung dose. The average lifetime dose estimates for both radon and uranium tend to be greater among persons who resided to the east of the FMPC as compared to those who resided west of the facility. In addition, both the average lung dose due to radon exposure and the dose due to uranium exposure tend to lower among those who resided further from the plant site.

Table 2 - Estimated Average Lifetime Lung Dose Equivalent (Sieverts) Resulting from Exposure to Radioactive Material Released from the FMPC from 1951 through 1988 Among Persons who Resided in 12 Geographic Areas * Surrounding the Site for any Period of Time During that Period.

		Dose (Sv) Resulting from Exposure to:		Total Lung Dose (Sv)		
Direction from FMPC	Distance (kilometers) from FMPC	RADON Median ** #	URANIUM & THORIUM Median ** #	Median ** #	90% Credibility Interval *** (lower limit)	(upper limit)
Northeast	0-4	0.86	0.06	0.95	0.22	4.16
	4-7	0.47	0.04	0.51	0.15	2.15
	7-10	0.33	0.02	0.36	0.10	1.34
Southeast	0-4	1.44	0.09	1.56	0.42	6.13
	4-7	0.76	0.06	0.84	0.23	3.19
	7-10	0.53	0.04	0.58	0.16	2.24
Southwest	0-4	0.38	0.02	0.41	0.09	1.69
	4-7	0.29	0.03	0.34	0.09	1.32
	7-10	0.14	0.01	0.16	0.04	0.61
Northwest	0-4	0.40	0.02	0.44	0.10	1.89
	4-7	0.12	0.01	0.12	0.03	0.47
	7-10	0.08	0.004	0.09	0.02	0.40
Entire Assessment Domain		0.41	0.03	0.45	0.12	1.74

* See Figure 5 for the geographic locations of the 12 distance areas from the FMPC

** 500 estimates for the average lung dose were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

*** 90% of the 500 estimates of the possible value for the average lung dose fall between the upper and lower bound of the 90% credibility interval.

\# The sum of the medians within categories will not necessarily equal the median for the entire population.

The number of lung cancer deaths estimated to occur in the population that resided within the assessment domain is shown in Table 3. Using the life table approach, we predict that the median number of lung cancer deaths occurring from 1951 through 2088 that may be due to exposure to radioactive material released from the FMPC is about 85 deaths-- with the 90% credibility interval ranging from 25 to 309 deaths.

Table 3 - Estimated Total of Lung Cancer Deaths that may be due to FMPC Exposures and Background Lung Cancer Deaths, from 1951 through 2088 ***

	FMPC-Related Lung Cancer Deaths			Background Lung Cancer Deaths ****		
	Median * #	90% Credibility Interval **		Median * #	90% Credibility Interval **	
		(lower limit)	(upper limit)		(lower limit)	(upper limit)
Entire Population	**85**	**25**	**309**	**2,601**	**2,257**	**3,014**
Ever Smokers	**65**	**19**	**238**	**2,302**	**1,997**	**2,666**
Never Smokers	**20**	**6**	**71**	**298**	**258**	**347**
Males	**49**	**14**	**187**	**1,692**	**1,496**	**1,978**
Females	**36**	**11**	**135**	**889**	**780**	**1,041**

*** 500 estimates for the total numbers of lung cancer deaths were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.**

**** 90% of the 500 estimates of the possible value for the true number of FMPC-related lung cancer deaths fall between the upper and lower bound of the 90% credibility interval.**

***** Based on a population at risk of approximately 40,000 to 53,000 individuals who resided within the assessment domain between 1951 and 1988.**

****** The estimated number of lung cancer deaths predicted to occur if there were no releases of radioactive materials from the FMPC.**

 # The sum of the median within categories will not necessarily equal the median for the entire population.

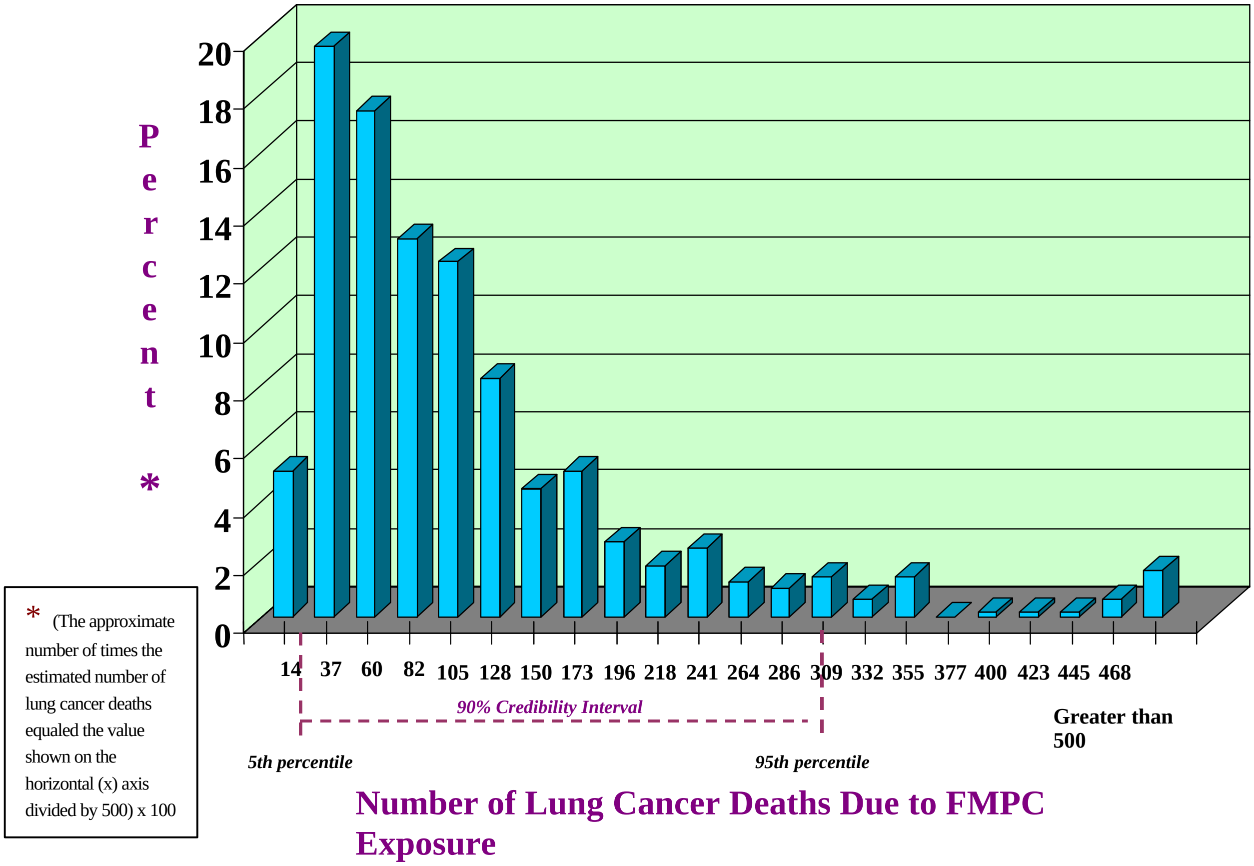

Figure 6 – Uncertainty Distribution for Predicted Total Number of Lung Cancer Deaths (for the Years 1951 through 2088) that May be Related to Exposures to Radioactive Materials from the Fernald Feed Materials Production Center (FMPC).

Figure 6 shows a histogram illustrating the full range of the uncertainty associated with FMPC-related lung cancer deaths. It illustrates that while the range of possible values for the number of lung cancer deaths that may be related to FMPC exposures as measured by the 90% credibility intervals is large, the distribution of possible values is quite skewed, with the majority of realizations closer to the median as opposed to the upper limit of the credibility interval.

The estimated number of background lung cancer deaths predicted to occur in the population within the assessment domain between 1951 and 2088 is also included in Table 3. We estimate that, about 2300 to 3000 background lung cancer deaths may occur in the study population. This range reflects the lung cancer mortality we may expect in the population if there were no radiation exposures from the FMPC site. Because we are not modeling FMPC-related dose and risk when estimating this background number, the uncertainty in the estimated number of background lung cancer deaths reflects our lack of precise knowledge on the true number of individuals who resided within the assessment domain during plant operations.

1. Estimates of the number of FMPC-related lung cancer deaths by smoking status

Because smoking was modeled as a modifier for the potential risk resulting from exposure to FMPC-related radioactive material (see Appendix B of this report), we also developed estimates of the number of FMPC-related lung cancer deaths among ever smokers (persons who ever smoked greater than or equal to 100 cigarettes) and never smokers (persons who never smoked or smoked less than a total of 100 cigarettes). Epidemiologic evidence suggests that the risk of lung cancer resulting from exposure to radon (NAS, 1998) is increased among those with a history of smoking. An interaction may also exist between smoking and exposure to uranium. (RAC, 1998). We incorporated the interaction between radiation exposure and smoking risk into our life table models using the methodology suggested in the most recent assessment of the underground miners' data (NAS, 1998). As a result, we estimate that the number of lung cancer deaths that may be related to FMPC exposures among ever smokers (median 65 deaths, 90% credibility interval 19-238 deaths) is approximately three times greater than the number of FMPC-related lung cancer deaths among never smokers (median 20 deaths, 90% credibility interval 6 to 71 deaths). As an illustration of the general impact of smoking on lung cancer risk, the reader should note that the estimated number of background lung cancer deaths among ever smokers is approximately 8 times greater than the corresponding estimate among never smokers.

2. Estimates of the total number of FMPC-related lung cancer deaths by gender

The estimated number of FMPC-related lung cancer deaths among males is approximately 40% greater than the corresponding estimate among females. This difference likely reflects the higher proportion of ever smokers among males and is the larger background rate of lung cancer. The estimated number of background lung cancer deaths among males is almost twice that of females in this population.

B. ESTIMATES OF THE PERCENTAGE INCREASE IN THE NUMBER OF LUNG CANCER DEATHS FROM 1951 THROUGH 2088

While the actual number of lung cancer deaths potentially related to FMPC releases provides one measure of the potential effect from these exposures, the percentage increase in the number of these events over that which we would expect in the absence of FMPC exposures is perhaps more meaningful. As stated previously, the percentage increase is defined as the number of lung cancer deaths estimated to be related to FMPC exposures divided by the estimated background number of lung cancer deaths. This resulting proportion is then multiplied by 100. The estimated percentage increase can be used to put the estimates of the actual number of lung cancer deaths into perspective relative to the number of lung cancers predicted to occur if there was no radiation exposure. Table 4 shows the estimated median and 90% credibility interval for the percentage increase in lung cancer deaths that may be due to FMPC-related exposure for the same groups as in Table 3. The median percentage increase in the number of lung cancer deaths predicted in the Monte Carlo estimation was 3% with a 90% credibility interval of 1% to 12%. In other words, we predict that exposure to radioactive material released from the site during its years of operation potentially increased the number of lung cancer deaths in the population residing in the assessment domain by about 1% to 12% over the number of lung cancer deaths that may have occurred in the absence of plant-related radiation exposures. Figure 7 contains a histogram providing a more detailed representation of the modeled uncertainty in the percentage increase in lung cancer deaths.

Table 4 - Estimated Percentage (%) Increase in the Number of Lung Cancer Deaths from 1951 through 2088 that may be due to FMPC Exposures ***

	Median * #	90% Credibility Interval ** (lower limit)	(upper limit)
Entire Population	**3 %**	**1 %**	**12 %**
Ever Smokers	**3 %**	**1 %**	**10 %**
Never Smokers	**7 %**	**2 %**	**24 %**
Males	**3 %**	**1 %**	**10 %**
Females	**3 %**	**1 %**	**12 %**

*** 500 estimates for the percentage (%) increase of lung cancer deaths were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.**

**** 90% of the 500 estimates of the possible value for the percentage (%) increase of FMPC-related lung cancer deaths fall between the upper and lower bound of the 90% credibility interval.**

***** Based on a population at risk of approximately 40,000 to 53,000 individuals who resided within the assessment domain between 1951 and 1988.**

 # The sum of the medians within categories will not necessarily equal the median for the entire population.

1. Estimates of the percentage increase in lung cancer deaths by smoking status

Because background lung cancer mortality is quite low for never smokers, the estimated relative impact of the FMPC-exposure on lung cancer mortality, as measured by the percentage increase in lung cancer deaths, is approximately 2 times greater among never smokers than among ever smokers. This does not mean that the actual risk at a given dose is greater for never smokers. To the contrary, as stated previously, epidemiologic evidence indicates that the risk of lung cancer death per a given level of exposure to radon progeny is actually greater among ever smokers. (Lubin and Steindorf, 1995). Rather, these results reflect how the increase in the number of lung cancer deaths due to exposure to radioactive material can proportionally have a much greater impact among never smokers whose background rates of lung cancer are much less that the background rates for ever smokers.

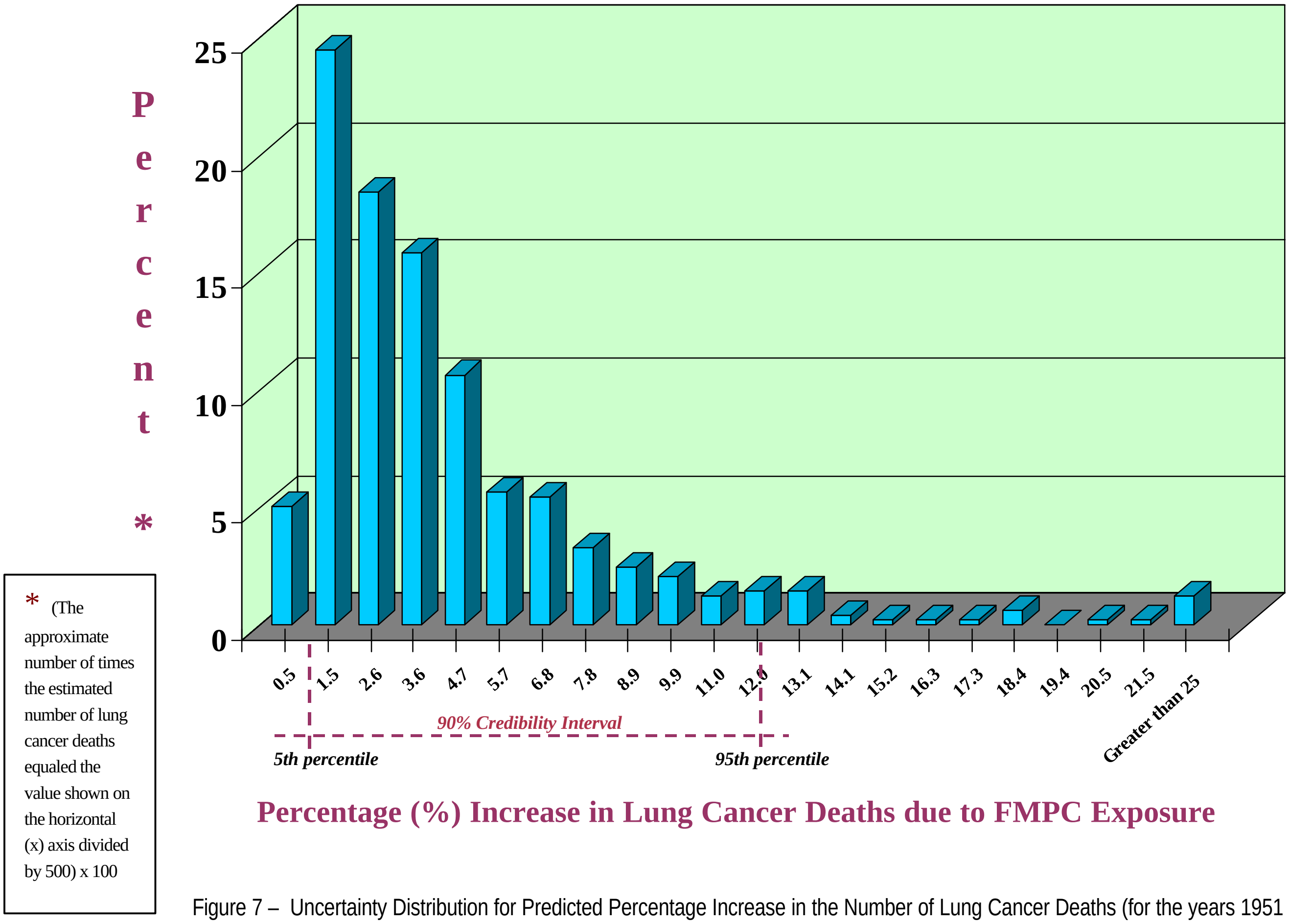

Figure 7 – Uncertainty Distribution for Predicted Percentage Increase in the Number of Lung Cancer Deaths (for the years 1951 through 2088) that May be Due to Exposure to Radioactive Materials Released from the Fernald Feed Materials Production Center (FMPC)

2. Estimates of the percentage increase in the number of lung cancer deaths by gender

The percentage increase in lung cancer deaths that may be due to FMPC-related exposure was comparable for males and females. This similarity in the proportionate increase primarily reflects the higher background lung cancer mortality among males as compared to females.

C. ESTIMATES OF THE NUMBER OF LUNG CANCER DEATHS AND THE PERCENTAGE INCREASE BY TIME PERIOD

We also partitioned the estimates of the number of lung cancer deaths to reflect the modeled occurrence of the events over time. This is shown in Tables 5 and 6 in which the estimated number of cancers and percentage increase is separated into two time intervals. The first interval corresponds to years from the first time period of potential exposure until the present while the second reflects projections from the present through the final period considered in this risk estimation. Roughly, half of the total numbers of FMPC-related lung cancer deaths are estimated to have occurred for the period through to the year 2000. The median percentage increase represented by the estimated number of FMPC-related lung cancer deaths is 6% (90% credibility interval, 2% to 22%) in the first time period as compared to an estimated median percentage increase of 2% (90% credibility interval, 1% to 8%) for the latter time period, 2001 to 2088. This lower predicted percentage increase in the 2001-2088 period reflects the fact that we are modeling a population that is aging and nearing the end of life expectancy during the period of 2001 to 2088. Consequently, the population's background rates of lung cancer and mortality due to other causes are increasing as they age. Thus, the modeled decline in the percentage increase in the number of lung cancer deaths attributable to FMPC-related exposure is expected.

Table 5 - Total Number of Lung Cancer Deaths that may be due to FMPC Exposures and Background Lung Cancer Risk by Time Period ***

	FMPC-Related Lung Cancer Deaths			Background Lung Cancer Deaths ****		
Time Period	Median * #	90% Credibility Interval ** (lower limit)	(upper limit)	Median * #	90% Credibility Interval ** (lower limit)	(upper limit)
1951-2000	45	14	165	748	653	869
2001-2088	39	11	150	1,848	1,588	2,157

Table 6 - Percentage (%) Increase in Lung Cancer Deaths that may be due to FMPC Exposures by Time Period ***

Time Period	Median * #	90% Credibility Interval ** (lower limit)	(upper limit)
1951-2000	6 %	2 %	22 %
2001-2088	2 %	1 %	8 %

* 500 estimates for the total number of lung cancer deaths and percentage (%) increase were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

** 90% of the 500 estimates of the possible value for the true number of FMPC-related lung cancer deaths and percentage (%) increase fall between the upper and lower bound of the 90% credibility interval.

*** Based on a population at risk of approximately 40,000 to 53,000 individuals who resided within the assessment domain between 1951 and 1988.

**** The estimated number of lung cancer deaths predicted to occur if there were no radioactive releases from the FMPC.

The sum of the median within categories will not necessarily equal the median for the entire population.

D.

ESTIMATES OF THE PERCENTAGE INCREASE IN LUNG CANCER DEATHS BY LOCATION OF RESIDENCE DURING PLANT OPERATIONS, 1951 THROUGH 1988

In Figure 8, we illustrate geographic variation in the estimated percentage increase in the number of lung cancer deaths that may be due to FMPC-related exposure. In this figure, we show the median of the estimated area-specific percentage increase in the number of lung cancer deaths that may result from FMPC exposure for the 12 geographic areas in the assessment domain (shown previously in Figure 5). The geographic patterns of the estimated percentage increase in the number of lung cancer deaths corresponded to those of the dose estimates in Table 2. That is, we estimate a decline in the percentage increase in the number of lung cancer deaths that may be related to FMPC exposures for areas more removed from the site and higher percentage increases in areas to the east of the site as compared to the west.

Because of the small estimated number of residents in some of these geographical areas, (see Table 1), the results illustrated in Figure 8 need to interpreted cautiously. Small population estimates are associated with an increased uncertainty in the estimates of the percentage increase in lung cancer deaths that may be due to FMPC-related exposure. To illustrate this uncertainty, in Table 7 we show the median estimates on which Figure 8 is based, as well as the associated area-specific 90% credibility intervals.

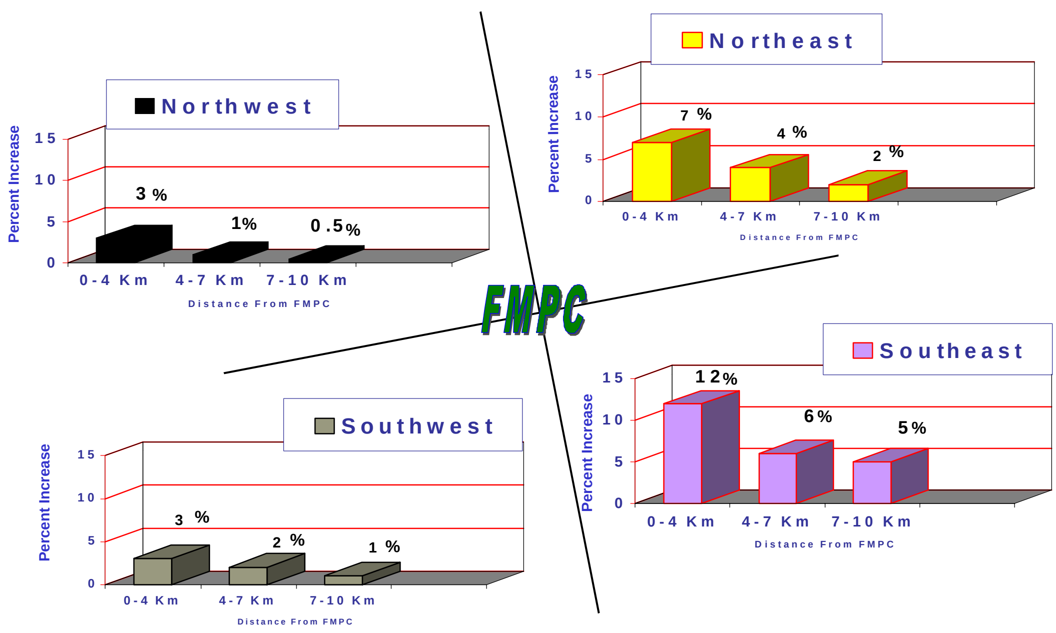

Figure 8 – Estimated Percentage Increase in the Number of Lung Cancer Deaths from 1951 through 2088 that may be due to FMPC Exposures, by Geographic Area

Table 7 - Estimated Percentage Increase in the Number of Lung Cancer Deaths that may be Due to FMPC Exposures for 12 Areas * within the Assessment Domain

Direction from FMPC	Distance (kilometers) from FMPC	Median ** #	90% Credibility Interval *** (lower limit)	(upper limit)
Northeast	0-4	7 %	2 %	26 %
	4-7	4 %	1 %	15 %
	7-10	2 %	1 %	10 %
Southeast	0-4	12 %	3 %	54 %
	4-7	6 %	2 %	25 %
	7-10	5 %	1 %	19 %
Southwest	0-4	3 %	1 %	10 %
	4-7	2 %	1 %	11 %
	7-10	1 %	0.3 %	4 %
Northwest	0-4	3 %	1 %	12 %
	4-7	1 %	0.2 %	3 %
	7-10	0.5%	0.1 %	2 %

* See Figure 5 for the geographic locations of the 12 distance areas from the FMPC.

** 500 estimates for the total numbers of percentage increase of lung cancer deaths were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

*** 90% of the 500 estimates of the possible value for the percentage increase of FMPC-related lung cancer deaths fall between the upper and lower limits of the 90% credibility interval.

\# The sum of the medians within categories will not necessarily equal the median for the entire population.

E. ESTIMATES OF THE NUMBER AND THE PERCENTAGE INCREASE IN LUNG CANCER DEATHS BY YEAR OF FIRST EXPOSURE

The results of the Fernald Dosimetry Reconstruction Project indicated that, due to containment measures applied to the K-65 silos in 1979, the amount of radon and radon decay products released from the site was greatly reduced from 1980 onward (RAC, 1998). Because exposure to radon and radon decay products was the major contributor to the estimated lung dose, it is likely that those who were born, or who first moved into the assessment domain, after 1979 will have a lower FMPC-related lung dose than those who were first exposed earlier. As a result, the estimated percentage increase in the number of lung cancer deaths that may result from FMPC-related radiation exposure will likely be lower among those first exposed after 1979 than among those first exposed before 1980.

To examine the effect of time of first exposure, the life table estimation approach used to produce the estimates given in this report was repeated twice. We first estimated the number and percentage increase in lung cancer deaths among the population that resided in the assessment domain for any period of time from 1951 through 1979. This group corresponds to those first exposed to FMPC radiation exposure in 1979 or earlier. We then produced similar estimates for the population that first resided in the assessment domain for any length of time between 1980 and 1988. This second group corresponds to those whose first exposure occurred after the implementation of the silo containment measures.

Table 8 shows the estimated number of lung cancer deaths that may result from FMPC-related radiation exposures among the population first exposed any time from 1951 through 1979 and those first exposed between 1980 and 1988. Among those first exposed before 1980, we estimate that a median of 80 lung cancer deaths may result from FMPC exposures with a 90% credibility interval of about 20 to 300 lung cancer deaths. The effect of the lower exposures to radon and radon decay products in the latter years of plant operations is illustrated by the fact that we estimate a median of one FMPC-related lung cancer death among those first exposed after 1980. The reader should keep in mind that due to the uncertainty in these estimates, the sum of the median estimated number of deaths among those first exposed during these two time periods will not necessarily add up to the median estimate of 85 FMPC-related lung cancer deaths, shown in Table 3, for the entire population exposed any time from 1951 through 1988.

Table 8 - Total Number of Lung Cancer Deaths that may be due to FMPC Exposures and Background Lung Cancer Risk by Year of First Exposure

	FMPC-Related Lung Cancer Deaths			Background Lung Cancer Deaths***		
Year of First Exposure	Median*	90% Credibility Interval **		Median*	90% Credibility Interval**	
1951 - 1979	80	20	301	1662	1450	2000
1980 - 1988	1	0	5	939	569	1464

* 500 estimates for the total number of lung cancer deaths were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

** 90% of the 500 estimates of the possible value for the true number of FMPC-related lung cancer deaths fall between the upper and lower bound of the 90% credibility interval.

*** The estimated number of lung cancer deaths predicted to occur if there were no releases of radioactive materials from the FMPC.

Table 9 contains the estimated percentage increase in the number of lung cancer deaths that may result from FMPC-related radiation for the two groups. The median percentage increase estimate among those first exposed before 1980 is 5% with a 90% credibility interval of 1% to 18%. The estimated percentage increase in the number of lung cancer deaths among those first exposed any time from 1980 through 1988 is much lower, 0.1%. Thus, FMPC-related radiation exposure has very little impact on the estimated risk of lung cancer death among those who were born, or who first moved in to the area, after 1979. It is important to note that the median estimated percentage increase in lung cancer deaths among those first exposed before 1980 is larger than the median percentage increase estimated for the entire population first exposed anytime during the entire period of plant operations, 1951 through 1988, given in Table 4. The reason for this difference is due to the fact that virtually all of the lung cancer deaths estimated to occur among the population that resided in the assessment domain for any length of time from 1951 through 1988 actually occur among those first exposed before 1980. In addition, because the subset made up of those first exposed before 1980 is smaller than the total number of people exposed from 1951 through 1988, the number of background lung cancer deaths estimated to occur among those first exposed before 1980 is smaller than the estimated number of background cancers for the entire assessment population shown in Table 3. Thus, the percentage increase in the number of lung cancer deaths is greater in those first exposed before 1980.

Table 9 - Percentage (%) Increase in Lung Cancer Deaths that may be due to FMPC Exposures by Year of First Exposure

Year of First Exposure	Median * #	90% Credibility Interval ** (lower limit)	(upper limit)
1951 - 1979	5 %	1 %	18 %
1980 - 1988	0.1 %	0 %	1 %

* 500 estimates for the total number of lung cancer deaths and percentage (%) increase were produced to reflect the uncertainty in the components used to estimate this value. The median is that value greater than one half of the estimates and less than the other half.

** 90% of the 500 estimates of the possible value for the percentage (%) increase fall between the upper and lower bound of the 90% credibility interval.

The sum of the median within categories will not necessarily equal the median for the entire population.

F. SUMMARY

In summary, we estimated that approximately 40,000 to 53,000 individuals resided within 10 kilometers (6.2 miles) of the FMPC site for some period during the years of plant operation, 1951-1988. In addition, we estimate the average lung dose among this population resulting from exposures to radioactive material released from the site to be approximately 0.12 to 1.74 sieverts. The majority of this lung dose resulted from exposure to radon and radon progeny.

As a possible result of these exposures, we estimate that the number of lung cancer deaths may be 1% to 12% higher among this population that would be expected if the FMPC-related exposures had not occurred. The estimated range in the number of lung cancer deaths that may have resulted from FMPC exposures has a median of 85 deaths and a 90% credibility interval of 25 to 309 deaths. Thus, we estimate that FMPC-related exposure may have resulted in approximately 25 to 309 additional lung cancer deaths over the time period from 1951 through 2088-- above the 2,300 to 3,000 lung cancer deaths estimated to occur in the study population in the absence of FMPC-related exposures. In addition, the estimated percentage increase in lung cancer deaths that may result from exposure to radioactive material released from the site was approximately 2 times higher among never smokers than among those who ever smoked. Also, the estimated effect of FMPC-related exposures tended to decrease for residences located further from the site and was more pronounced among those who resided to the east of the facility between 1951 and 1988 as opposed to those who lived west of the site.

INTERPRETING THE ESTIMATES OF FMPC-RELATED LUNG CANCER MORTALITY

A. LIMITATIONS OF THE APPROACH

The estimated number of lung cancer deaths that may have resulted from exposures to radioactive material released from the FMPC site during its years of operation presented in this report are based on mathematical modeling of the lung dose, the risk resulting from that dose, and the number of persons experiencing that risk during different time periods. Our goal was to use current epidemiologic information about the health risks resulting from the types of radionuclides released from the plant to predict the potential magnitude of the health effect resulting from these releases. We used this modeling approach because comprehensive measurements of the size and lung cancer mortality experience of the population within the assessment domain are not available. Therefore, it is necessary to keep the limitations of this model-based approach in mind when interpreting the estimates.

1. Estimating lung cancer mortality risk using a model developed from the experience of underground miners.

A potential limitation in our approach is that the major contributor to the estimated lung cancer mortality risk, the risk resulting from exposure to radon and radon decay products, is estimated using a model developed from epidemiologic investigations of underground miners. One critical issue concerns the fact that the average exposure level to radon progeny among the miners was substantially larger than that estimated to have occurred in the community surrounding the FMPC site. As a result, there may be a question as to whether the model developed to reflect the increase in the lung cancer mortality rate per unit exposure in the miners is applicable at lower exposure levels. While no conclusive evidence is currently available to either corroborate or refute the assumption that the miners' rate model is relevant at lower exposure levels, a recent re-analysis of the miners' data by Lubin et al (1997) lends credence to our use of this approach. In their re-analysis, Lubin et al (1997) used the rate model we use in our analysis to estimate lung cancer mortality for the subset of the original miners group that had the lowest levels of exposure. The estimated lung cancer mortality among the miners with relatively low exposures was then compared to the observed number of lung cancer deaths in this group. Under an assumption of a 5 year interval between the time of exposure and the initiation of lung cancer risk, the results of this analysis indicated that the rate model provided an "excellent fit" (Lubin et al., 1997) to the observed mortality among the low exposure miners. While the average level of exposure in the subgroups considered in this analysis was still greater than the estimated exposure to the population within the assessment domain, this analysis provides evidence for consistent patterns in lung cancer risk across the exposure levels considered.

Other differences exist between underground miners and the target population that calls into question the ability to generalize miner-based risk models. Underground miners were more likely to have ever smoked and were exposed to other lung carcinogens in the mining environment such as silica, arsenic, and diesel fuel. In addition, the miner cohorts include males only and provide very limited data on childhood exposure. Biases due to changes in smoking patterns and other exposures among underground miners cannot be quantified due to inadequate data on these factors. However, the National Academy of Sciences has attempted to examine the issue of differences in risk due to age at exposure. Using available data, primarily from Chinese tin miners, they found no evidence that the risk of lung cancer resulting from children exposed to radon is different from the risk among adult underground miners. (NAS, 1998) Lending further credence to our use of the rate model derived from the miners' studies are the results of epidemiologic investigations of the lung cancer risk resulting from indoor exposure to naturally occurring radon. The population at risk and the level of exposure is more similar in these investigations to the population within the assessment domain than are the underground miner cohorts. As described by Boice (1997), the results of these studies on the health effects of exposure to indoor radon "remain somewhat equivocal" but "the patterns of risk over categories of indoor radon concentrations are appearing remarkably consistent with those estimated from the studies of miners." Based on this evidence, other groups have used an earlier version of the rate model derived from the miners studies to estimate the level of lung cancer mortality due to indoor radon exposures both in the United States (Lubin et al., 1995) and in West Germany (Steindorf et al., 1995). In addition, the National Academy of Sciences has used the radon rate model we use in this report in a recent re-evaluation of the magnitude of lung cancer mortality arising from exposures to indoor radon in the United States. (NAS, 1998)

2. Underestimation of the uncertainty inherent in the estimates of lung cancer deaths

A second consideration to keep in mind when evaluating these estimates is the level of uncertainty inherent in model-based estimation of the lung cancer deaths. We have attempted to incorporate information about the uncertainty associated with the components that contribute to the final estimates.

These components include: uncertainty about the true level of dose, uncertainty associated with the risk resulting from that dose and uncertainty concerning the true size of the population experiencing that risk. This list, however, is by no means exhaustive of all the potential uncertainties associated with estimation of the number of lung cancer deaths. For example, we have assumed that the State-level mortality rates for background lung cancer and for causes other than lung cancer are representative of the rates expected in the absence of FMPC-related exposure within the assessment domain. For those components of uncertainty included in the final estimates, we used mathematical models to estimate the magnitude of the lack of precision. While these models use empirical evidence whenever possible (see Appendix B), they are themselves uncertain. Therefore, the range of estimates provided, as summarized by the 90% credibility interval, should be viewed as a minimum estimate for the actual uncertainty associated with the number of FMPC-related lung cancer deaths.

3. Impact of using current level of lung cancer mortality to predict future background lung cancer mortality rates

Modeling all cohorts through age 100 years requires projection of future mortality rates due to background lung cancer and all other causes. We used age-, gender- and time-period- specific rates to estimate these numbers during FMPC production years. However, because future rates are unknown, we had to assume that the mortality rates observed in 1990 would remain constant through the year 2088. This assumption is contradicted by what we know nationally of current trends in lung cancer mortality. Declines in lung cancer mortality rates for males have been observed since the late 1980s. Because smoking is estimated to cause 85% to 90% of lung cancers and national estimates show decreases in smoking prevalence, changing rates of lung cancer have been attributed to changes in smoking patterns. Decreases in lung cancer mortality for males are predicted to continue through the year 2000 (Miller et al, 1993).

Since the early 1990s, lung cancer mortality rates for males in the state of Ohio have also declined (CDC, 1990-1995). However, this trend has varied by age group. For example, from 1990 through 1995, lung cancer mortality rates for men ages 20 to 45 and aged 65 and older remained relatively constant. In contrast, for males aged 45-65, lung cancer mortality decreased about 15 % in the state.

Lung cancer mortality rates for females are continuing to increase; however, they are also expected to decrease after the turn of the century. (Miller et al, 1993). How long the downward trend continues for both genders is unknown. However, if this trend continues, use of 1990 rates to project the mortality experience of our population through 2088 may lead to an overestimation of the background lung cancer mortality rates from 1991 through 2088.

B. COMPARISON OF THE ESTIMATED LUNG CANCER MORTALITY RATE WITHIN THE ASSESSMENT DOMAIN TO THE OBSERVED RATE IN BUTLER COUNTY, 1962-1990

In light of these caveats, however, we should indicate that the risk estimation procedure leads to estimates that were plausible when compared to available external comparison values. For example, using our approach, we estimated an average annual lung cancer mortality rate within the assessment domain of approximately 41 to 49 lung cancer deaths per 100,000 population for the years from 1962 through 1990. This estimated range is approximately consistent with the observed annual lung cancer mortality rate for Butler County of roughly 40 lung cancer deaths per 100,000 population during the same interval. (CDC, 1962-1990). In addition, using the median estimates of the total number of background lung cancers deaths and the total number of individuals estimated to be in the assessment domain population, we estimate an average background lifetime probability of dying from lung cancer to range from approximately 0.05 (5 in 100) to 0.07 (7 in 100). This range is consistent with the estimated average lifetime probability of dying from lung cancer for the United States of about 0.06 (6 in 100) produced by the National Cancer Institute. (Ries et al, 1997).

C. COMPARISON WITH ESTIMATED LUNG CANCER DEATHS THAT MAY OCCUR DUE TO INDOOR EXPOSURE TO NATURALLY OCCURRING RADON

In addition to radon released from the Fernald site, residents of the assessment domain are exposed to radon from naturally occurring sources. Naturally occurring radon comes from the breakdown of uranium in soil, rocks, and water. This uranium has been in the ground since the time the earth was formed (NAS, 1998) and is not the result of human activities. Radon is found throughout the United States (U.S.), though its concentration varies with the amount of uranium occurring naturally in the soil. Naturally occurring radon seeps from the soil and into homes where concentrations can build up.

Numerous epidemiologic studies have attempted to quantify the risk of lung cancer due to indoor exposures to naturally occurring radon. However, as noted earlier, results remain "equivocal" (Boice, 1997) due to difficulties in quantifying exposures to individuals over time and the low levels of risk associated with these low radon exposures (NAS, 1998). Recently, the National Academy of Sciences has published a report on the *Health Effects of Exposure to Radon*, known as the BEIR VI Report. (NAS, 1998). In this report, mathematical models developed using data from underground miners exposed to radon were applied to the U.S. population to estimate the number of lung cancer deaths that are due to exposure to indoor radon. Based on the same model that was used in our risk estimation, results of this analysis indicate that the attributable risk, that is the percentage of what we refer to as background lung cancer deaths that can be attributed to indoor radon exposure, is about 10% with a 95% credibility interval of about 8 to 20%. This differs by smoking status. For ever smokers, about 9% of lung cancer deaths can be attributed to indoor radon exposure; however, for never smokers, about 19% of lung cancer deaths may be attributed to indoor radon exposure.

We can use these estimates of the proportion of background lung cancer deaths that may be due to natural radon exposure to derive a rough approximation of the number of lung cancer deaths due to indoor radon exposure in the population that resided in the assessment domain. Using the estimated median number of 2,600 background lung cancer deaths from Table 3, we can estimate that the number of lung cancer deaths among the assessment domain population that may result from exposure to naturally occurring radon could range from approximately 200 (2,601 x 0.08) to 500 (2,601 x 0.2) deaths. Note that this range is roughly 2 to 6 times larger than the median number of lung cancer deaths that we estimate may have resulted from exposure to radioactive material released from the FMPC site.

D. HOW CAN THESE RESULTS BE INTERPRETED IN TERMS OF THE PROBABILITY THAT A MEMBER OF THE FERNALD POPULATION WILL DIE OF LUNG CANCER?

Based on lung doses estimated using methodology developed in the Fernald Dosimetry Reconstruction Project (RAC, 1998), the epidemiologic evidence regarding the lung cancer mortality experience of those exposed to radon progeny and the exposure experience of atom bomb survivors, and the estimated number of persons assumed to be at risk, we estimate that the number of lung cancer deaths among those who resided within 10 kilometers (6.2 miles) of the plant (an estimated population of 40,000 to 53,000) during its years of operations may be increased by about 1% to 12%. In terms of the actual number of lung cancer deaths, this percentage increase translates in to an estimated 25 to 309 additional cases of fatal lung cancer for the years 1951 through 2088 with a median estimated number of FMPC-related lung cancer deaths of 85. Using our life table approach, we estimate that the average lung cancer mortality rate resulting from exposures to FMPC-related radioactive material has a 90% credibility interval of 1 to 12 deaths per 100,000 population. This estimate reflects an estimated 90% credibility interval of from approximately 2,230,000 to 2,960,000 person years of exposure incurred by the 40,000 to 53,0000 persons estimated to comprise the assessment domain population between 1951 and 2088. The average lifetime risk of dying from lung cancer as a result of exposure to radioactive material released from the FMPC was estimated by dividing the estimated total number of FMPC-related lung cancer deaths produced in each realization of the Monte Carlo process by the corresponding realization of the estimated size of the assessment population. By average lifetime risk, we mean the probability of dying from a fatal lung cancer at some point during a person’s lifetime averaged over the age, time, gender and exposures within the population. The median estimate for the average lifetime risk of dying from a fatal lung cancer due to FMPC-related exposure is 0.002 (2 in 1000) with a 90% credibility interval of 0.0006 (0.6 in 1000) to 0.007 (7 in 1000). Note that these estimates are consistent with the range of median lifetime risks of fatal FMPC-related lung cancer estimated for nine hypothetical exposure scenarios in the Fernald Dosimetry Reconstruction Project (see Table A14 in Appendix A of this report). The actual increase in the probability of a fatal lung cancer due to FMPC-related exposure to radioactive materials among those persons who did reside in the assessment domain will vary depending on factors such as the length of time of residence in the domain, the location of residence, gender, and smoking history. As stated previously, the National Cancer Institute estimates that the average American has a lifetime risk of dying from a fatal lung cancer of approximately 0.06 (6 in 100). Thus, we estimate that exposure to radioactive material released from FMPC from 1951 through 1988 may have increased the lifetime risk of fatal lung cancer among members of the assessment population from 0.06 to between 0.0606 to 0.067. This range represents an estimated 1% to 12% increase in the lifetime risk of dying from a fatal lung cancer that may have resulted from exposure to radioactive material released from the FMPC.

Our estimates of the lung cancer mortality impact of FMPC-related releases of radioactive material had to be made at the population level. We can not provide estimates of the risk that a specific individual will develop lung cancer as a result of his or her history of FMPC-related exposure due to our inability to measure and/or account for individual-level factors that could confound the effect of exposure, such as genetic susceptibility to cancer, individual smoking history, and exposure to other potentially carcinogenic contaminants.

E. PERCENTAGE INCREASE IN THE NUMBER OF LUNG CANCER DEATHS DUE TO FMPC-RELATED RADIATION EXPOSURE OUTSIDE THE ASSESSMENT DOMAIN

As is shown in Figure 8, we predict that a median 2% increase may occur in the number of lung cancer deaths among persons who resided 7 to 10 kilometers northeast of the site for some period of time from 1951 through 1988 due to FMPC-related radiation exposure. In addition, we estimate that the population that resided 7 to 10 kilometers to the southeast of the plant during this period may experience a 5% increase in the number of lung cancer deaths due to these exposures. Based on these estimates for areas on the boundary of the current assessment domain, it seems reasonable to assume that there may be an increase in the number of lung cancer deaths among persons who resided at distances greater than 10 kilometers from the site during the years of plant operations.

This issue of potentially elevated lung cancer mortality at distances beyond the current domain was discussed by the Fernald Health Effects Subcommittee in their review of the draft of this report that was released in March 1998. Based on this discussion, the committee recommended that, “a screening calculation should be made before a commitment is made to a larger and expensive project to evaluate risk beyond the current 10 kilometer domain.” In this context, we define a screening-level calculation as a rough approximation of the increase in the number of lung cancer deaths that may be due to FMPC-related radiation exposure where the approximation does not require estimation of the lung dose and the size of the population for distances beyond the boundary of the current domain. The committee suggested this screening-level approach because the Fernald Dosimetry Reconstruction Project did not provide methods for estimating FMPC-related radiation doses outside the current assessment domain (RAC, 1998) and because we did not have population estimates developed for these areas. As a result, we could not use the same approach in estimating the potential percentage increase in lung cancer deaths for areas outside the assessment domain as was used for the population who resided within 10 kilometers of the site. The screening-level estimates for areas outside the current domain were developed using an estimation approach called extrapolation. Using this approach, we extended the trend with distance of our estimates of the percentage increase in lung cancer deaths within the domain to distances outside the domain boundary. To do this, four separate lines, one for each of the directions from the site as shown in Figure 8, were fit to, or drawn through, the median percentage increase estimates within the domain. This fitted line was then extended to predict the percentage increase in lung cancer deaths at distances greater than 10 kilometers. Because these estimates were developed simply by extending the trend in the FMPC-related percentage increases estimated within the domain, they should be thought of only as rough approximations of the percentage increases at further distances.

The screening-level estimates for the median percentage increase in the number of lung cancer deaths that may occur among those who resided at various distances from the FMPC site are shown in Figure 9. These estimates apply only to persons who resided at the given distances for some period of time from 1951 through 1988 and provide rough approximations of the percentage increase in lung cancer deaths that may occur in this group from 1951 though 2088. Estimates to the northeast of the site, range from a 0.6% increase at 15 kilometers (approximately 9 miles) to a 0.04 % at a distance of 30 kilometers (approximately 19 miles). This means that, if 100 hypothetical persons lived at a distance of 15 kilometers from the site for some period of time from 1951 through 1988, we estimate that 0.6, or approximately one, additional lung cancer death may occur among this hypothetical group sometime between 1951 and 2088 due to radiation exposure from the FMPC site. The screening-level estimates of the median percentage increase in the number of lung cancer deaths due to FMPC radiation exposure to the southeast of the site range from a 2% increase at 15 kilometers to a 0.3% increase at a distance of 30 kilometers. To the west of the site, however, the estimated median percentage increases in the number of lung cancer deaths are 0.4% or lower for all distances beyond the current assessment domain.

It is important to remember that the uncertainty associated with the estimated percentage increase in the number of FMPC-related lung cancer deaths among citizens who resided within the assessment domain was quite large. For example, in Table 7, we show that the 90% credibility interval for the percentage increase was 1% to 19% for those who resided in the area 7 to 10 kilometers southeast of the site. Because the screening-level estimates of the percentage increase in lung cancer deaths beyond the assessment domain are based on the uncertain estimates within the assessment area, the screening-level estimates are also highly uncertain. In addition, the extrapolation approach used to produce the estimates beyond the domain will add more uncertainty to the screening–level approximations. Therefore, the estimates of the percentage increase in the number of lung cancer deaths for areas beyond the domain should be interpreted as an approximate indication of the size of the FMPC-related risk the may result among those who resided more than 10 kilometers from the site during the years of plant operations.

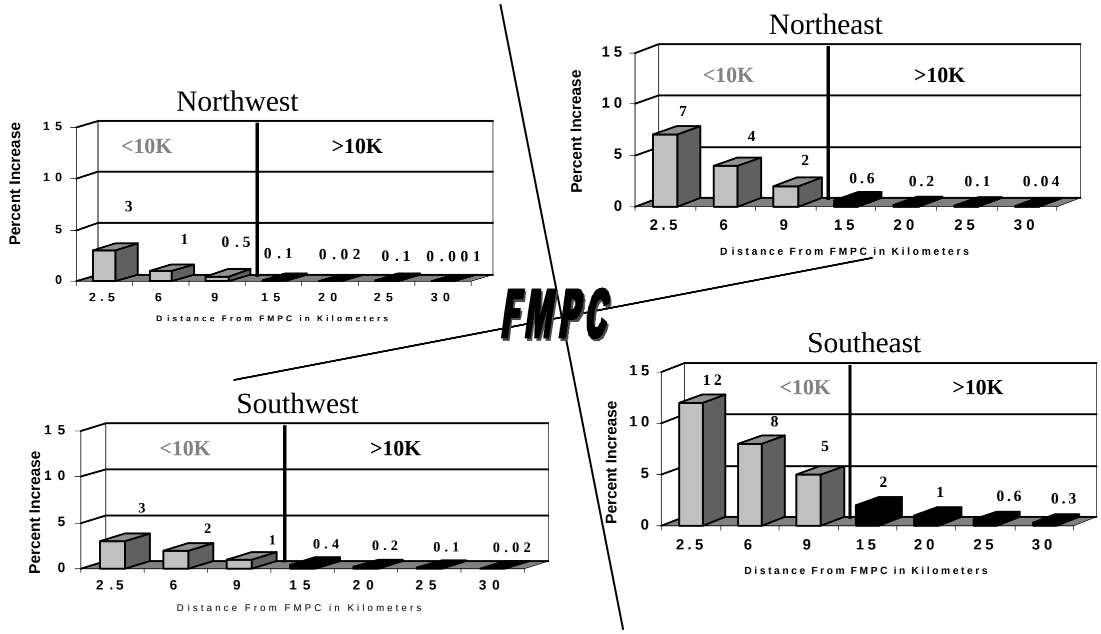

Figure 9 – Estimated Percentage Increase in the Number of Lung Cancer Deaths from 1951 Through 2088 that may be due to FMPC Exposures Within the 10 Kilometer Assessment Domain and Screening-Level Approximations of the Percentage Increase in Lung Cancer Deaths for Various Distances beyond the 10 Kilometer Domain

F. WHAT IS THE NEXT STEP?

In consultation with the Fernald Health Effects Subcommittee, we will attempt to estimate the potential magnitude of other health effects resulting from environmental exposure to contaminants released from the FMPC site during its years of operation. Health outcomes to be considered in the future include but are not limited to: kidney and bone cancer and kidney disease resulting from the toxicological effects of uranium ingestion. Quantitation of the risks for these outcomes may be more difficult than the estimation of the risk of lung cancer mortality presented in this report due to limited epidemiologic evidence of the dose risk relationship for some of these other potential outcomes. Finally, epidemiologists within the CDC's Radiation Studies Branch will use the lung cancer mortality estimates presented in this report as part of the continuing assessment of the feasibility of conducting epidemiologic investigations in the community exposed due to proximity to the FMPC. This work is part of our broad research agenda—the goal of which is to understand the health effects of environmental radiation exposure.

There is currently no way to reduce the exposures from the FMPC site that occurred in this population between 1951 and 1988. However, the CDC recommends actions that citizens can take now to lower their risk of lung cancer. First, if they smoke they should quit, and second, they should test their homes for naturally occurring radon. If the radon concentration in their home from natural sources exceeds the U.S. Environmental Protection Agency's recommended limit, then they should act to lower these levels. Information on reducing the level of naturally occurring radon in your home can be obtained by calling the Ohio Environmental Protection Agency's Ohio Radon Information line at (800) 523-4439 or by calling the Ohio Department of Health at (614) 466-0061.

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