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Report

Assessment of Radiation Dose and Cancer Risk for Emissions from 1951 Through 1984

Feed Materials Production Center
Fernald, Ohio

Submitted To:

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Oak Ridge, Tennessee

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RESPONSIVE TO THE NEEDS OF ENVIRONMENTAL MANAGEMENT

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REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AMAD	Activity median aerodynamic diameter
CDC	Centers for Disease Control
Ci	Curie
DOE	U.S. Department of Energy
U.S. EPA	U.S. Environmental Protection Agency
FMPC	Feed Materials Production Center
GAO	General Accounting Office
ICRP	International Commission on Radiological Protection
ISC	Industrial Source Complex
IT	IT Corporation
kg	Kilogram
LET	Linear energy transfer
μCi/cc	Microcuries per cubic centimeter
MeV	Million electron volts
MPBB	Maximum permissible body burden
NCRP	National Council on Radiation Protection and Measurements
NLO	National Lead of Ohio
ORNL	Oak Ridge National Laboratory
Q	Quality factor
RMI	Reactive Metals, Inc.
UF_4	Uranium tetrafluoride
UF_6	Uranium hexafluoride
UO_3	Uranium trioxide
WL	Working level
WLM	Working level month
WMCO	Westinghouse Materials Company of Ohio

LIST OF DEFINITIONS

Absorbed dose - The quantity of energy deposited in matter (usually the human body) by ionizing radiation per unit mass of irradiated matter at the location of interest. The common units for absorbed dose are the rad and the gray.

Activity median aerodynamic diameter - The diameter of a unit density sphere with the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.

Committed dose equivalent - The total dose equivalent averaged throughout a tissue in a specified time period after intake of a radionuclide into the body. For this assessment, a 70-year time period is specified.

Committed effective dose equivalent - The sum over specified tissues of the products of the committed dose equivalent in a tissue and the weighting factor for that tissue.

Dose equivalent - The quantity used to express the amount of effective absorbed dose caused by ionizing radiation. It is obtained by multiplying the absorbed dose by the quality factor and other modifying factors. The common units for dose equivalent are the rem and the sievert.

Effective dose equivalent - The sum over specified tissues of the products of the dose equivalent in a tissue and the weighting factor for that tissue.

Linear energy transfer - The linear rate of energy absorption by an absorbing medium (usually the human body) as an ionizing particle traverses the medium.

Lung class - A classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung.

Maximum permissible body burden - The activity of a radionuclide which if continuously present in the body will deliver the maximum permissible dose equivalent to the critical organ.

Quality factor - The principal modifying factor (which depends on the collision stopping power for charged particles) that is employed to derive dose equivalent from absorbed dose.

Selected individual - A hypothetical individual residing continuously at the point in the environment where the maximum exposure conditions have been calculated and where there are people assigned in the population distribution.

Working level - A working level is defined as any combination of short-lived radon progeny in one liter of air that will result in the ultimate emission of 1.3×10^5 million electron volts (MeV) of alpha particle energy.

Working level month - Cumulative exposure to radon progeny is expressed in working level months (WLMs). Cumulative exposure in WLMs is equal to exposure to a concentration of radon progeny in working levels times exposure duration in multiples of the 170-hour occupational month.

EXECUTIVE SUMMARY

In April 1985, Senator John Glenn asked the U.S. General Accounting Office (GAO) to review the effectiveness of the U.S. Department of Energy (DOE) in protecting its workers, the community, and the environment at three defense production facilities in Ohio, including the Feed Materials Production Center (FMPC) in Fernald, Ohio. As a result of the findings of the GAO and concerns of other federal and state agencies, Senator Glenn asked the Center for Environmental Health, Centers for Disease Control (CDC) to determine if an epidemiological study of the population surrounding the FMPC is warranted.

In 1985, the CDC initiated an effort to assess the feasibility of conducting an epidemiological study of the possible health effects from exposure to radiation among residents of communities near the FMPC. This effort was prompted by preliminary data indicating that large quantities of uranium were released to the environment during past operations of this plant, and that residents who may have been exposed to the radiation may experience negative health effects. The CDC assessment is dependent upon the successful reconstruction of population radiation doses from uranium. The DOE agreed to provide reconstructed radiation dose estimates. A DOE report completed in June 1988, under a contract with International Technology Corporation (IT), provided radiation dose estimates which CDC was to use in completing the feasibility study. However, additional radioactive material emission data have recently been discovered. This discovery prompted DOE to perform further analysis and review of the source-term estimates in order to achieve a more accurate reconstruction of radiation doses.

The CDC now plans to conduct an independent review and assessment of DOE source-term estimates, a modeled reconstruction of radiation doses to the population near the FMPC, and a study of the feasibility of carrying out an epidemiological study of possible health effects.

The DOE requested that IT reassess the estimated radiation doses using the latest estimates of airborne radionuclide emissions. The scope of work called for IT to simulate the atmospheric transport and dispersion of radionuclides released to the atmosphere and to predict their intake by the exposed population. The results of this modeling study include estimated radiation doses to the selected individual and to the population surrounding the FMPC from all radionuclides released into the atmosphere. The modeling results also include estimated risks of fatal cancers.

Data were compiled on airborne radionuclide emissions from the FMPC for the period from 1951 through 1984. Uranium is the major radionuclide contributing to these emissions. Thorium, fission products, and transuranic elements are present to a lesser degree. Radon emissions for the K-65 silos located west of the production area of the plant were also estimated. Data were compiled on radon emissions for the period from 1953 to 1984.

AIRDOS-EPA, an Environmental Protection Agency (EPA) computer code, was used with airborne emissions estimates and local meteorological data to estimate radionuclide concentrations in air and intake rates via inhalation of air and ingestion of meat, milk and fresh vegetables. The AIRDOS-EPA code uses a modified Gaussian plume equation to estimate both horizontal and vertical dispersion of the radionuclides emitted from the FMPC.

The DARTAB computer code combined estimates of environmental radionuclide exposure with dosimetric and health effects data in the RADRISK computer code to generate tabulations of predicted radiation doses and health effects for each of 34 years of FMPC operation (1951 through 1984). The appendices contain summary tables of estimated radiation doses and cancer risks for the emissions of radon and its progeny (32 years) and of other radionuclides (34 years).

Chapter 1.0 presents background information on the FMPC to familiarize the reader with the operating history of this facility and the function of the various production units. Before making any radiation dose and risk estimates, a modeling protocol was developed and a peer review committee was formed to review the protocol (Chapter 2.0). Chapter 3.0 describes the AIRDOS-EPA and DARTAB codes. Chapter 4.0 discusses the data compiled for input to the AIRDOS-EPA and DARTAB codes. Chapter 5.0 presents the results obtained from the DARTAB code. Chapter 6.0 discusses the results, particularly in terms of doses and risks from other sources, to which the population surrounding the FMPC is exposed. References are listed in Chapter 7.0.

The results indicate that the highest 70-year committed effective dose equivalent to the selected individual was approximately 730 millirems as a result of production area emissions from the FMPC in 1955. If the airborne production area emissions are averaged over 34 years, the calculated committed effective dose equivalent to the selected individual from one year of emissions from the FMPC is approximately 100 mrem. The organ receiving the highest calculated committed dose equivalent is the lung.

For comparison purposes, the average annual effective dose equivalent received by a member of the general public from natural background is 300 millirems. For a 70-year lifetime, the total effective dose equivalent due to natural background radiation would be 21,000 millirems.

The risk associated with the committed effective dose equivalents calculated for the emissions from the FMPC would be 8×10^{-4} to the selected individual living within 20 miles of the plant. Approximately half of this risk is associated with radon and its progeny. The remaining half is associated with production area emissions. This risk is comparable to that attributable to natural background. For the

population surrounding the FMPC, the model predicts approximately 12 hypothetical lung cancer deaths attributed to emissions from 1951 through 1984. This compares with more than 30,000 lung cancer deaths which should occur in the same population from all causes other than FMPC's emissions.

1.0 INTRODUCTION

1.1 PURPOSE OF THIS ASSESSMENT

In April 1985, Senator John Glenn asked the GAO to review the effectiveness of the DOE in protecting its workers, the community, and the environment at three defense production facilities in Ohio, including the FMPC in Fernald, Ohio. As a result of the findings of the GAO (GAO, 1985) and concerns of other federal and state agencies, the Center for Environmental Health, CDC was asked by Senator John Glenn to determine if an epidemiological study of the population surrounding the FMPC is warranted (Glenn, 1985).

In 1985, the CDC initiated an effort to assess the feasibility of conducting an epidemiological study of the possible health effects from exposure to radiation among residents of communities near the FMPC. The DOE agreed to provide reconstructed dose estimates. A DOE report completed in June 1988, under a contract with International Technology Corporation (IT), provided radiation dose estimates which CDC was to use in completing the feasibility study. However, additional radioactive material emissions data have recently been discovered, prompting DOE to perform further analysis and review of the source-term estimates (WMCO, 1989a). The latest source-term estimates were used in a computer simulation of the atmospheric transport, dispersion, and intake of airborne radionuclides released from the FMPC. The results of this computer modeling study provide estimates of the radiation doses to the population from airborne radionuclide releases from the FMPC (1951 through 1984). The modeling results also provide estimates of the risks of fatal cancers from estimated airborne radionuclide releases. Funding for this radiation dose and risk assessment was provided by DOE.

1.2 DESCRIPTION OF THE FACILITY

The FMPC is located on a 1,050-acre site in a rural agricultural area approximately 16 miles northwest of Cincinnati, Ohio (Figure 1). The villages of Fernald, Ross, New Haven, and Shandon are within a few miles of the site. The production facilities occupy approximately 136 acres in the center of the site (Figure 2). Topographically, the facilities are on a relatively level plain at approximately 580 feet above sea level. Vegetative cover of the site includes deciduous forests and grasslands. Surrounding land use includes several residences, small industries, and farms which support the major economic activities in the area.

The FMPC is a government-owned, contractor-operated federal facility for the production of pure uranium metals for DOE. This facility has been a key element in DOE's weapons production system since it began operating in 1951, when the U.S. Atomic Energy Commission (AEC) completed a long-term plan to establish an in-house integrated production complex for processing uranium and its compounds from natural uranium ore concentrates. Uranium ore concentrates and materials recycled from other stages of nuclear weapons production are converted to either uranium oxides or uranium ingots and billets. The uranium is then either machined or extruded into tubular form for production reactor fuel cores and target fuel element fabrication. The site was fully operational by the end of 1954.

In 1951, National Lead of Ohio (NLO, Inc.) (formerly National Lead Company of Ohio), a subsidiary of NL Industries (formerly the National Lead Company), New York, entered into a contract with DOE (formerly AEC) as operator of the FMPC. NLO, Inc., continued as the FMPC contract operator until January 1, 1986, when the Westinghouse Materials Company of Ohio (WMCO), a wholly-owned subsidiary of Westinghouse Electric Corporation, began contract responsibilities for management of the site operations and facilities for the next five years.

The principal product from FMPC operations is uranium metal in various physical forms having several different levels of enrichment (typically less than 1.25 percent U-235 by mass). Most of the production stream metal is cast into ingots for extrusion into tubes at the DOE extrusion press facilities located at Reactive Metals, Incorporated (RMI), Ashtabula, Ohio. Some of the extruded material is returned to the FMPC where tube blanks undergo heat treatment and fabrication into target element cores for DOE reactors. Other extruded material is further processed into fuel billets via an upset forge operation at RMI and is not returned to the FMPC. Both fuel cores and target elements are used in government reactors to generate electricity and to produce plutonium.

A wide variety of chemical and metallurgical processes are utilized at the FMPC to produce uranium metals. Large-scale chemical operations consist of processing enriched uranium scrap residues to produce a uranyl nitrate feed solution. Purified feed solution is concentrated and then denitrified to uranium trioxide (UO_3). UO_3 is converted to uranium tetrafluoride (UF_4) for reduction to metal. Scrap materials containing uranium which are generated in FMPC operations and those received from off site are recycled for reentry into the production process.

Six production units are involved in chemical operations. Chemical processing begins at the Sampling Plant (Plant 1) where depleted, normal, and enriched uranium materials are received, sampled, stored, and shipped. The Sampling Plant is responsible for accountability and control of fissionable materials processed at the FMPC. The Refinery (Plants 2 and 3) digests enriched uranium residues, concentrates pure uranium solution, and recovers uranium from waste solutions. The primary function of the Green Salt Plant (Plant 4) is to convert UO_3 to UF_4 (green salt). The principal functions of the Pilot Plant are the reduction of uranium hexafluoride (UF_6) to UF_4 and the purification and conversion of thorium nitrate solution to various thorium compounds.

The Scrap Recovery Plant (Plant 8) upgrades enriched uranium recycle materials to produce feed materials for processing in the Refinery Plants.

Metal production and fabrication is carried out in three plants: the Metals Production Plant (Plant 5), the Special Products Plant (Plant 9), and the Metals Fabrication Plant (Plant 6). Metal processing steps begin with the production of uranium metal (Plant 5). The Special Products Plant casts recycled metal into large diameter ingots and the Metals Fabrication Plant treats the ingots for extrusion.

These metal production and fabrication activities all result in airborne discharges of radioactive particulates, which are vented through emission control devices (wet scrubbers and/or bag-type dust collectors). These devices are normally very efficient in removing the radioactive particulates. Failures of these devices have occurred, however, which have resulted in increased emissions.

The most recent inventory of historic radionuclide emissions to the atmosphere estimates the total emissions of uranium to be 178,311 kilograms (kg) for the years from 1951 through 1984. These emissions occurred as either (1) a result of routine releases through filters in ventilation systems or wet scrubbers, which were constant or nearly constant over time; or (2) by accidental releases, which occurred over short periods (i.e., one hour to several days).

2.0 SELECTION OF ASSESSMENT METHODOLOGY

2.1 BASIS FOR SELECTION

Average annual radionuclide concentrations in the air and on ground surfaces are needed to estimate radiation doses and risks. When adequate environmental measurements of concentrations are unavailable (as is the case for the FMPC for most of the period from 1951 through 1984), computer modeling of the environmental fate of airborne releases may be used to estimate concentrations. Modeling expressions should account for building wake effects, meteorological conditions, particle settling velocities, particle sizes, and chemical forms of radionuclide emissions. Computer models considered for the estimation of radionuclide concentrations include the AIRDOS-EPA dispersion methodology (U.S. EPA, 1979) and the Industrial Source Complex (ISC) dispersion methodology (Bowers, et al., 1986).

A comparison of the AIRDOS-EPA and ISC radionuclide concentration predictions was performed to determine if predicted concentrations were significantly different when dispersion was modeled using AIRDOS-EPA versus the ISC model. Annual uranium concentrations were calculated at several points near the site boundary and off site. Results of these calculations are presented in Table 1.

Although the ISC configuration is a more realistic representation of emission stacks at the FMPC, the AIRDOS-EPA model predictions were generally higher than those predicted by the ISC. Thus, the AIRDOS-EPA dispersion model generates results that are conservative relative to the ISC model. At the receptor locations closest to the site boundary, the ratios of AIRDOS-EPA to ISC predictions were highest. At receptor locations farther downwind, there was less difference between model predictions.

2.2 PEER REVIEW OF SELECTED ASSESSMENT METHODOLOGY

At the beginning of the assessment study, personnel from CDC and IT met to discuss the overall approach to be taken. To ensure that the modeling approach adequately assessed the radiation dose and cancer risk from FMPC releases, the CDC recommended that a Peer Review Committee (Committee) be formed to review the dosimetry methodology. Individuals qualified to review the assessment approach were required to be familiar with the models used to estimate downwind radionuclide concentrations, radiation doses, and fatal cancer risks. Potential candidates were contacted, and five were invited to serve on the Committee. The five member Peer Review Committee consisted of:

Dr. Clayton S. Gist	U.S. Department of Energy Engineering Operations Oak Ridge, Tennessee
Mr. James M. Hardin	Office of Radiation Programs U.S. Environmental Protection Agency Washington, D.C.
Dr. H. Robert Meyer	Chem-Nuclear Systems Albuquerque, New Mexico
Dr. John E. Till	Radiological Assessments Corporation Neeses, South Carolina
Dr. John P. Witherspoon	Oak Ridge National Laboratory Oak Ridge, Tennessee

The Committee met once, in August 1987. Committee members discussed the selection of input parameters, computer models, and radiation dose and risk conversion factors; however, the Committee did not study or verify the source-term data used in the assessment. The Committee also reviewed drafts of the dose methodology in the June 1988 report, and provided comments to the authors.

The Committee felt that the use of a site-specific computer model (if one were available) would not lead to more accurate predictions of off-site airborne radionuclide concentrations, because site-specific data

(e.g., local meteorological measurements) are not available for the period under consideration (1951 through 1984).

The Committee made the following recommendations which were incorporated into the June 1988 assessment:

- Use the AIRDOS-EPA model for estimating atmospheric dispersion of radionuclides from the FMPC
- Use the DARTAB computer code for tabulating radiation doses and fatal cancer risks from calculated air concentrations
- Perform a review of the estimated annual discharges to the air from FMPC operations before the final assessment
- Include the estimated doses and risks from radon releases from the K-65 silos
- Perform an evaluation of the size of particulates which should be used in the dispersion and dose calculations
- Evaluate the chemical forms of radionuclide emissions whereby lung clearance classes may be assigned, consistent with the recommendation of the International Commission on Radiological Protection (ICRP) Publication 30 (ICRP, 1979)

The Committee also recommended that the uncertainties associated with the dosimetry methodology be addressed. In its background information document for the National Emission Standard for Hazardous Air Pollutants dealing with airborne radioactivity (U.S. EPA, 1984), the U.S. EPA states that the uncertainty associated with the AIRDOS-EPA/RADRISK/DARTAB methodology is approximately a factor of 10. This figure should be used in assessing the results of this assessment.

Westinghouse modified its radionuclide release estimates to include some additional sources (WMCO, 1989a). To account for these sources, DOE requested that a reassessment of the radiation dose and cancer risk

attributable to the FMPC air emissions be performed. This report documents this reassessment. Consistent with the earlier recommendations of the Peer Review Committee, the reassessment includes the following:

- Use of the AIRDOS-EPA model for estimating atmospheric dispersion of radionuclides from the FMPC
- Use of the DARTAB computer code for tabulating radiation doses and fatal cancer risks from calculated air concentrations
- Review and use of estimated annual discharges to the air from FMPC operations, as updated in the Addendum to FMPC-2082 (WMCO, 1989a)
- Use of estimated annual discharges of radon-222 to the air from the K-65 silos, as updated in Appendix F of this report
- A reevaluation of the size of particulates that should be used in the dispersion and dose calculations
- An evaluation of the chemical form of radionuclude emissions reported in the Addendum to FMPC-2082 so that lung clearance classes may be assigned, which are consistent with the recommendations of Publication 30 of the International Commission on Radiological Protection (ICRP, 1979)

A draft reassessment report was circulated to the five members of the Peer Review Committee who contributed to the June 1988 assessment. Comments on the draft reassessment were received from:

Dr. Clayton S. Gist
Mr. James M. Hardin
Dr. John P. Witherspoon

Dr. H. Robert Meyer and Dr. John E. Till chose not to participate in the review of the reassessment.

3.0 TECHNICAL DESCRIPTION OF ASSESSMENT METHODOLOGY

3.1 AIRDOS-EPA MODEL

The AIRDOS-EPA computer code was developed at Oak Ridge National Laboratory (ORNL) to be used by the U.S. Environmental Protection Agency (U.S. EPA) as part of a methodology to evaluate health risks to man from atmospheric radionuclide releases from facilities.

Both point sources and uniform area sources of atmospheric releases can be evaluated by AIRDOS-EPA. The code is used to estimate:

- Concentrations in air
- Rates of deposition on ground surfaces
- Ground surface concentrations
- Intake rates for humans via food ingestion and air inhalation

Release rates of radionuclides (in curies [Ci] per year) to the atmosphere from each point or area source are known collectively as the source term. The code is capable of modeling the dispersion of a source term comprised of up to 36 radionuclides from one to six point or area sources. The plume containing radionuclides is dispersed both horizontally and vertically as it travels downwind. Annual average frequencies of wind direction, wind speed, and atmospheric stability category are employed as input data to the dispersion model.

The code estimates the annual average concentration (microcuries per cubic centimeter [μCi/cc]) of each radionuclide in the source term in the air at ground level as a function of direction and distance from the source. The code calculates this estimate using a Gaussian plume expression to model downwind concentrations of particulate and gaseous emissions (U.S. EPA, 1979, Equation 1):

$$\chi = \frac{Q}{2p\ S_y\ S_z u} \exp\ [-(y/S_y)^2/2]\{\exp\ [-(Z-H)^2/2S_z^2] + \exp\ [-(Z+H)^2/2S_z^2]\} \quad (1)$$

where

χ = the modeled ambient concentration (μCi/cc) at X meters downwind, Y meters crosswind, and Z meters above ground,

Q = the emission rate from the release stack (Ci/sec),

u = mean wind speed (meter/second),

S_y = the horizontal dispersion coefficient (meters),

S_z = the vertical dispersion coefficient (meters),

H = the effective stack height (meters),

y = the crosswind distance (meters),

z = the vertical distance (meters), and

p = the constant pi.

Radionuclides in the form of particulates or reactive gases deposit on ground or water surfaces through scavenging processes, which primarily consist of washout by rainfall, and through dry deposition processes. The code estimates the deposition rate for each radionuclide in units of picocuries per square centimeter per second for each location for which estimated air concentrations are calculated. Air concentrations, ground deposition rates, and ground surface concentrations are average values at various distances over each of sixteen 22.5-degree sectors emanating from the center of the source.

Ingestion of radionuclides which have been deposited on crop and pastureland is estimated separately for vegetable, milk, and meat consumption. A terrestrial model within AIRDOS-EPA is used to calculate steady-state radionuclide concentrations in these three food types. Intake by man is calculated from input values assumed for daily consumption of each of the three types of food (ORNL, 1986).

Air and ground radionuclide concentrations and intake rates by man calculated by AIRDOS-EPA are input to the DARTAB computer code as shown

in Figure 3. As discussed in the next section, the DARTAB code is used to calculate radiation doses and health risks attributable to radionuclide releases.

3.2 DARTAB COMPUTER CODE

The DARTAB computer code (ORNL, 1981) was developed at ORNL at the request of the U.S. EPA to be used by the U.S. EPA as part of a methodology to evaluate health risks to man from atmospheric releases of radionuclides. The DARTAB computer code provides tabulations of predicted health impacts from radioactive airborne effluents by combining information on environmental concentrations from AIRDOS-EPA with dosimetric and health effects data generated by the RADRISK computer code (Section 3.3).

DARTAB reads a RADRISK data file containing dosimetric and health effects data (in the form of dose and risk conversion factors) that can be applied to the exposure data supplied by AIRDOS-EPA. The annual collective exposure or intake rate of each radionuclide in each exposure pathway operating at each location in the environment is input to the DARTAB code. These collective radionuclide exposure data are the product of the number of individuals residing at a given location and the air concentration, ground surface concentration, or intake rate for each radionuclide at that location. An exception is made for the short-lived progeny of radon-222. For radon-222 progeny, the AIRDOS-EPA code calculates exposure in units of the working level (WL)[1] instead of the concentrations of individual radionuclides. The assumed fractional equilibrium for the short-lived progeny used in the AIRDOS-EPA calculations is specified by the user. The input to DARTAB for radon-222 consists of the equilibrium fraction and the WL estimates rather than radon-222 concentrations and intake rates.

[1]A working level is defined as any combination of short-lived radon progeny in one liter of air that will result in the ultimate emission of 1.3×10^5 million electron volts (MeV) of alpha particle energy.

The dosimetric equations in the DARTAB code are linear (i.e., an intake of 10 μCi will result in dose rates ten times as large as those from an intake of 1 μCi). In similar fashion, exposure to ten times as large an air or ground surface concentration will increase the external dose by a factor of ten.

The approach to estimation of radiological health impacts used in DARTAB is applicable only to low-level chronic exposure. High-level acute exposures lead to health effects that are nonlinear with respect to exposure or intake. Therefore, DARTAB and RADRISK should not be used with either short-term or high-level intakes of radionuclides.

Finally, DARTAB permits assignment of a quality factor (Q) so that absorbed doses from different types of radiation can be combined to calculate total dose equivalent. A Q of 20 is used for alpha particle radiation [high linear energy transfer (LET) radiation], as opposed to a Q of 1 for beta and gamma radiation.

3.3 RADRISK COMPUTER CODE

The dosimetric and health effects data files were developed using the RADRISK computer code of Dunning, Leggett, and Sullivan (1984). The health effects data file developed from RADRISK contains data for each radionuclide and exposure pathway, assuming a continuous unit exposure rate.

The dosimetric data file from RADRISK includes consideration of internal exposure resulting from inhalation and ingestion of radionuclides, and external exposures from photons emitted by radionuclides outside the body, such as airborne and surface deposits of radioactive material. Low- and high-LET radiations are considered for internal exposures; however, high-LET radiations are neglected in the case of external exposures.

For internal exposures, organ dose rates increase with time because of the retention of inhaled and ingested radionuclides within the body under a constant rate of intake. The file contains absorbed dose rates for each organ per unit intake rate, inhaled or ingested, as a function of time for both low- and high-LET radiations. These values are expressed in units of mrad/year per μCi/year. Committed doses tabulated per unit intake are calculated for each year's emissions. The committed dose is a summation of the doses an individual will receive over the next 70 years as a result of retention of radioactivity taken in during a given year of emission. The internal dose conversion factors represent a 70-year committed dose equivalent and are calculated from metabolic factors and methodology similar to that presented in ICRP-30 (ICRP, 1979). The code uses a time span of 70 years because these calculations are being performed for members of the general public, whereas the ICRP methodology assumes an adult worker is exposed for 50 years. This causes the committed dose calculated by RADRISK methodology to be greater than the committed dose calculated by ICRP methodology.

For external exposures, the dosimetric data in the RADRISK code are drawn from the work of Kocher (1979), which tabulates factors relating absorbed dose rates for each organ to the airborne concentrations and surface concentrations of various radionuclides. The units of these factors are mrad/year per $\mu Ci/cm^3$ for airborne activity, and mrad/year per $\mu Ci/cm^2$ for ground surface concentrations of radionuclides.

The dosimetric data file is arranged by radionuclide. As such, the data for a given radionuclide correspond only to the dosimetric and health effects estimates associated with exposure to or intake of that radionuclide. In instances where radionuclides are members of decay chains (i.e., the nuclide decays to a daughter, which is also radioactive), no assumptions with regard to the relative exposure to or intake of the daughter have been included in the dosimetric data file. The ingrowth

of daughters and subsequent intake of or exposure to daughters during modeled air dispersion must be accounted for in the input data to the AIRDOS-EPA environmental transport code. After intake into the body, daughter ingrowth is considered in the development of the dosimetric data.

The RADRISK computer code utilizes the CAIRD computer code (Cook, 1978) as a subroutine to calculate the number of fatal cancers as a function of time in a hypothetical cohort of 100,000 persons. All persons in the cohort are assumed to be simultaneously liveborn and all are assumed to experience a constant exposure or intake rate throughout their lifetime. The cohort is processed through the life table methodology represented by CAIRD using risk factors for both high- and low-LET radiations (Dunning, et al., 1984), and risk factors for the baseline cancer mortality of the population.

3.4 INTERPRETATION OF RISK DATA

The risks computed using the RADRISK and DARTAB codes represent the effect of uniform exposure over the cohort's lifetimes. Since this study is looking at varying discharges over time, some adjustment to the RADRISK/DARTAB-generated risk figures for the selected individual is necessary. Since the life expectancy of the cohort is 70 years, one way to adjust for the difference in exposures is to divide the RADRISK/DARTAB risk figures by 70.

To determine if this adjustment is valid, the following analysis was conducted:

- Three types of data were tabulated from the RADRISK/DARTAB results:
  - The committed dose equivalents for radon-222 and for other radionuclides (primarily uranium) to the lung of the selected individual
  - The WLs of radon progeny to which the selected individual is exposed

- The lifetime risks of fatal lung cancer caused by radon-222, radon progeny, and other radionuclides

- The risks associated with the committed dose equivalents and the WLs were computed using risk factors obtained from ICRP (ICRP, 1977) and BEIR-IV (NAS, 1988)

- Ratios were obtained, comparing the RADRISK/DARTAB risks to the computed risks

The ratios obtained by this analysis are:

Radionuclide	Ratio
Radon-222	108
Radon progeny	87
Other (primarily uranium)	63

These ratios are consistent with the factor of 70 mentioned above. Therefore, the RADRISK/DARTAB risks associated with each year's emissions to the selected individual are reduced by a factor of 70 before being combined.

4.0 INPUT PARAMETERS

4.1 SOURCE TERM

4.1.1 Quantities Released

Periodic assessments of historical FMPC radionuclide discharges are made by the contractor operating the site. WMCO issued such a report in May 1987 (Boback, 1987). The information in the May 1987 historical discharge report has been updated by an addendum (WMCO, 1989a) dated March 1989. This addendum provides more recent estimates of uranium and thorium airborne emissions in kilograms released for each year of operation. Uranium and thorium emissions presented in the addendum (WMCO, 1989a) and emissions of other radionuclides published earlier (Boback, 1987) provide the basis for calculating estimated airborne releases in curies/year from the FMPC from 1951 through 1984.

Uranium

Emissions of uranium are summarized in Table 3 (WMCO, 1989a). Table 3 lists uranium emissions presented in the May 1987 discharge report and uranium emissions from gulping operations (WMCO, 1989b contains a description of this operation), other uranium processing operations, building exhausts, laboratory hoods, wind erosion of outdoor waste storage pits, and nonroutine events. The "Total Uranium Emissions" and "Uranium Gulping Emissions" columns in Table 3 are used to calculate estimated uranium activity released in curies for each year of operation.

Nine categories of uranium are included in the activity release inventory, three isotopes of uranium (U-234, U-235, U-238) in each of three lung clearance classes (Y, W, D) (ICRP, 1979). Uranium emissions are assigned to the ICRP lung clearance classes according to the solubility of the chemical forms in which they were emitted (ICRP, 1979). Uranium emissions from gulping operations are in the chemical

form uranyl nitrate, which is considered a Class D compound. All other uranium emissions are assigned to either Class Y or Class W according to the chemical forms found in these emissions.

Uranium activity release estimates are based on a methodology described in a manual of good health physics practices for uranium facilities (EGG, 1988). The manual presents a quantitative relationship between the specific activity of a mixture of U-234, U-235, and U-238 and the percent enrichment of U-235 (by mass) in the mixture (Figure 4). The manual also presents the fractional contribution of each of the three uranium radionuclides to the total uranium activity as a function of percent enrichment of U-235 in the mixture (Figure 5).

Annual activity release estimates for the three radioactive isotopes having lung clearance Class D (emitted from the gulping operations) are the product of:

- The specific activity of uranium emissions from the gulping operations
- The total mass of uranium released from the FMPC
- The fraction of total uranium releases contributed by Class D emissions from gulping operations
- The fraction of activity contributed by U-234, U-235, and U-238 in emissions from gulping operations

Annual activity release estimates for the three radioactive isotopes of uranium having lung clearance Class Y and three radioactive isotopes of uranium having lung clearance Class W from all other sources are the product of:

- The specific activity of all other uranium emissions
- The total mass of uranium released from the FMPC

- The fraction of total uranium releases having lung clearance Class Y or Class W
- The fraction of activity contributed by U-234, U-235, and U-238 from all other uranium emissions

Estimates of activity released for the nine categories of uranium are listed in Table 4 for each year of operation.

Thorium

Emissions of thorium are summarized in Table 3 (WMCO, 1989a). Table 3 lists thorium emissions from processing operations and from wind erosion of outdoor waste storage pits. The "Total Thorium Emissions" column in Table 3 is used to calculate estimated thorium activity released in curies for each year of operation.

Thorium activity release estimates are based on the assumptions that all material received at the FMPC for thorium processing was received as chemically pure thorium (WMCO, 1989c) and that the percent abundance of Th-232 is 100 percent. The Th-232 is very long-lived and does not decay appreciably over the period considered in the assessment. However, the half-lives of Th-232 daughters through Th-228 are relatively short. The relationship between parent and daughter half-lives causes Th-228 activity to reach 51 percent equilibrium with Th-232 activity in nine years. For the purposes of this assessment, it is assumed that Th-228 activity is in equilibrium with Th-232 activity; therefore, for each year in which Th-232 activity is released, it is assumed that an equal quantity of Th-228 activity is released (Table 4). The activity of Th-232 released each year is the product of the total mass of thorium released from the FMPC in that year and the specific activity of Th-232.

Radon

Radon is released from the K-65 storage silos, located approximately 800 meters west of the FMPC production area emission point. The silos contain residues from processing pitchblende ore. The residues contain

large quantities of Ra-226 which is the parent nuclide of Rn-222. Because radon activity equilibrates with Ra-226 activity in approximately 30 days, large quantities of radon have accumulated inside the K-65 storage silos. Two radon release pathways have been considered for the K-65 silos:

- Diffusion through the concrete domes of the silos (Borak, 1985)
- Free air exchange between the volume inside the domes and the outside atmosphere (Grumski, 1987)

The method of determining the release rate estimates for radon activity from the K-65 silos is described in detail in a separate document (Appendix F). The estimated total radon activity release is 1,083 Ci/year from both silos combined. The document in Appendix F is included for two reasons:

- It presents measured radon concentrations inside the silos (Grumski and Shanks, 1988).
- It describes the methodology behind the calculated 1,083 Ci/year radon activity release estimate, including calculations of radon flux and calculations of radon concentration inside the silos performed by Borak (1985). Measured radon concentrations (Grumski and Shanks, 1988) corroborate the concentrations calculated by Borak (1985).

Remaining Radionuclides

All other radionuclide release rates are calculated using radionuclide emission factors per total mass of uranium released from all FMPC sources other than gulping operations. Radionuclide emission factors in Table 5 are calculated based on data in Table 6 (Boback, 1987). Average emission factors for each radionuclide at each plant calculated from Table 6 are weighted by the fraction of total FMPC uranium emissions contributed by each plant. The sum of these weighted average plant emission factors represents the radionuclide emission factor for the entire FMPC site (Table 5).

4.1.2 Particle Size

Particle size information was obtained from 15 dust collectors at the FMPC during 1985 (Boback, 1987). An Andersen Mark III in-stack particle fractionating sampler was used to collect samples in the inlet duct to the dust collector and the outlet duct to the discharge stack. These data were used to determine the activity median aerodynamic diameter (AMAD) of particles released through the 15 collectors that were sampled. The AMADs are listed in Table 7.

To determine an average AMAD for the entire facility, the AMAD for each plant was weighted by the total emissions (1951 through 1984) for that plant. The results of this calculation are also presented in Table 7. The average AMAD for particles discharged from the dust collector stacks is 7.2 microns. According to FMPC personnel, the distribution of particle size from all processing activities has probably not changed substantially over the operating history of the plant. The particle size distributions estimated from dust collector samples taken in 1985 are probably representative of historic particle size distributions (Hibbitts, 1985).

Recently, information on emissions from a scrubber serving the gulping operations at the FMPC has become available (WMCO, 1989b). The particles emitted from this source tend to be smaller than those associated with the dust collectors.

Considering the distribution of particle sizes emitted from the FMPC's scrubber and dust collectors, it would be difficult, based on existing information, to establish a definitive particle size for these emissions. The ICRP (ICRP, 1979) recommends that, in the absence of definitive particle size data, a 1.0 micron AMAD particle size should be used for internal dose calculations from inhalation of radionuclides. Therefore, a uniform 1.0 micron AMAD particle size was assumed for all emissions. This assumption should provide an upper bound for this parameter

as it relates to dose calculations for emissions from the FMPC. Thus, selection of this particle size should lead to conservative estimates of doses and risks.

4.2 METEOROLOGICAL DATA

Data on meteorological conditions at the FMPC site are not available for the years from 1951 to 1984. Using the limited amount of on-site data (available from November 1985) for all years of interest could add considerable uncertainty to the analysis of plume behavior.

To provide input for the years of interest, two off-site sources of meteorological data were considered:

- The Greater Cincinnati Airport, located approximately 16 miles to the south of the FMPC
- The Dayton Airport, located approximately 50 miles to the northeast of the FMPC

A statistical test was prepared to compare measurements at the two airports with data collected at the FMPC during the period from November 1, 1985 to January 20, 1986. The test included a comparison of both wind speed and wind direction at the 10-meter level. The results of this test indicated that the data from the Greater Cincinnati Airport correlate better with site conditions than the data from Dayton (IT, 1986b). Therefore, the Greater Cincinnati Airport was selected as the source of meteorological information for the FMPC.

Annual frequency distributions of wind speed and direction by Pasquill stability class were obtained for the Greater Cincinnati Airport from the National Climatic Center for each of the 34 years from 1951 through 1984. The wind rose summarizing these distributions is shown in Figure 6 (U.S. Department of Commerce, 1985). The predominant wind direction is from the south-southwest. The atmospheric stability Class D is most often observed in this area, indicating stable conditions.

The meteorological data for each year from 1951 through 1984 and the particulate emission source term for that year comprise the input to the AIRDOS-EPA model. However, a different approach was used for the radon dose and risk assessment. Because radon is a gas, annual variations of wind speed and direction for the period from 1951 through 1984 have a much smaller impact on the transport model results for radon than for particulates. To simplify the analysis, therefore, the environmental transport of radon emissions was modeled using average meteorological conditions over the 34-year period.

4.3 POPULATION DISTRIBUTION

4.3.1 Changes Over Time

The population distribution within 20 miles of the FMPC is illustrated in Figure 7 (NLO, 1985). This distribution is based on 1970 census data.

Since the emissions of interest from the FMPC cover a time period which extends well before and beyond 1970, it is prudent to see how the population distribution has changed over time. Data on the populations of counties surrounding the FMPC are shown in Table 8 for 4 census years. According to the data, the total population for 1970 is greater than that for either 1950 or 1960, with the exception of Franklin County in Indiana. Since the estimated emissions from the FMPC were highest in the 1950s, using 1970 population data will lead to a conservative estimate of off-site population doses and risks.

Data for 1980 show a 1 percent higher population than in 1970. In Butler County in Ohio, which is in the prevailing downwind direction from the FMPC, the increase is 14 percent. Since the emissions from the FMPC in the 1980s were low, however, this increase should not significantly change the assessment results using the 1970 data. Any underestimate in population dose caused by use of the 1970 census data for

the emissions since 1970 should be more than compensated by the overestimate caused by using the same data for emissions in the years prior to 1970 (88 percent of the uranium and 75 percent of the thorium were emitted prior to 1970 for the period studied).

4.3.2 Distribution Selected for Assessment of Radionuclides Other than Radon

As mentioned in Section 4.3.1, population data for 1970 were used in the calculation of off-site doses. Off-site areas were broken into sixteen 22.5-degree sectors associated with the wind direction data described in Section 4.2. The population in a given sector was concentrated at a central point, in accordance with the following relationship:

SECTOR DISTANCE FROM FMPC (miles)	POPULATION CENTER (meters)
Site Boundary to 1.0	1,100
1.0 to 2.0	2,400
2.0 to 3.0	4,000
3.0 to 4.0	5,600
4.0 to 5.0	7,200
5.0 to 10.0	12,000
10.0 to 20.0	24,400

The populations at these distances were then used as input to the DARTAB code.

4.3.3 Distribution Selected for Radon Assessment

The source of radon at the FMPC site (the K-65 silos) is located approximately 800 meters to the west of the point where particulate emissions are centered (Section 4.4.1.1). In this location, the silos are closer to the FMPC site boundary than the source of particulate emissions. To account for this difference, 16 new sectors were established for the dose and risk assessment for radon. These sectors, centered at 500 meters from the production area emission point, account for the fact that there are individuals living closer to the silos than to the center of the production area, particularly in the southwest

direction. In assigning population estimates to the new sectors, the entire population in the 1,100-meter sector in the west-southwest direction was assigned to the new 500-meter sector. In the south, south-southwest, and southwest directions, half of the population in the 1,100-meter sector was assigned to the 500-meter sector. For all other sectors, the population distribution is assumed to stay the same.

4.4 OTHER INPUT PARAMETERS

4.4.1 AIRDOS-EPA Source Configurations

4.4.1.1 Location of the Source Center for Dispersion Modeling

The AIRDOS-EPA model can accept up to six point sources or six area sources, all of which are located at the center of the plant site. The FMPC contains approximately 459 exhaust vents or stacks located atop plant buildings (WMCO, 1989a). Previous studies (U.S. EPA, 1984) have combined these stacks into a single 10-meter stack located near the geometric center of the plant. This single stack configuration would concentrate plant emissions at one point and predicted off-site concentrations would be greater than if the physical location of each stack was considered.

A more reasonable approach, which would take into account the distance between sources, is to assume that the uranium emissions are spread over an area. The size of this area would be approximately equivalent to the area of the central portion of the FMPC where the majority of the sources are located. For this assessment, the area source is concentric with the geometric center of the plant.

4.4.1.2 Release Height of Area Sources

A release height (physical stack height plus plume rise) can be assigned to the area source. Most of the stacks at the FMPC exhaust air from plant ventilation systems. This ventilation air is exhausted at or near

ambient temperature and most of the stacks are equipped with rain caps. Because of these factors, very little plume rise can be expected; therefore, the physical stack height is a good estimate of the plume release height for these stacks.

The stack gas exit temperature from the old solid waste incinerator is approximately 550 degrees Centigrade and some plume rise because of buoyancy can be expected. However, emissions from this source represent a small fraction of the total FMPC emissions; therefore, plume rise for this source was considered negligible.

To determine the release height of the area source, the average stack height for each plant was weighted by the rate of total uranium emissions for that plant to the rate for the entire facility. This resulted in a weighted average release height of approximately 20 meters. A height of 20 meters was used as the release height for the area source.

For the assessment of radon releases, a different stack height was used. Because the K-65 silos are approximately 10 meters high, a 10-meter stack height was used for radon releases.

4.4.1.3 Size of Area Sources

The majority of uranium emission sources at the FMPC are located near the center of the production area. To determine the approximate area over which these emissions occur, a rectangle was drawn enclosing the plants in the central area. The dimensions of the rectangle are 490 meters by 180 meters. The diameter of a circle of equal area is 337 meters. This diameter is used for the area source.

For radon emissions, the area source was represented by a circle with an area equal to that of the two K-65 silo domes. This circle has a diameter of 34 meters.

4.4.2 Remaining Input Parameters

There are many other input parameters used by the AIRDOS-EPA code to model the transport of radioactivity through environmental pathways to man. A comprehensive listing of these parameters is contained in a listing of the input files in Appendices A and B.

5.0 RESULTS

5.1 RADON AND RADON PROGENY

The annual and 32-year doses and risks of fatal lung cancer to the selected individual and the exposed population from radon emissions and subsequent ingrowth of radon progeny have been calculated using the AIRDOS-EPA/RADRISK/ DARTAB computer modeling approach. These calculated doses and risks are presented in Table 9.

The computer code calculates average committed effective dose equivalents and risks, using average meteorological data for the years 1951 to 1984, to model radon transport and a constant radon activity release rate. Since radon emissions began in 1953, however, 32 years of radon emissions were modeled. Seventy-year committed effective dose equivalents and WLM exposures are calculated by multiplying the estimated values from one year of emissions in Table 9 by 32. In computing risks, the DARTAB code assumes steady-state intake for 70 years. As described in Section 3.4, to convert the risk figures to a 32-year total, the risks must be multiplied by 0.457 (32 divided by 70). A total of five hypothetical cancer deaths in the exposed population (total population of 1,164,402 out to 20 miles from the site) are estimated as a consequence of historical radon emissions from the FMPC. Examination of Table 9 reveals that the risk to the selected individual and the exposed population contributed by radon progeny from 32 years of radon-222 emissions is significantly greater than the risk contributed by radon-222 itself. The primary tissue at risk from inhalation of radon progeny is the epithelium of lung airways; therefore, these hypothetical deaths are associated with lung cancer.

5.2 OTHER RADIONUCLIDES

Doses and risks to the selected individual and the exposed population from all radionuclide emissions other than radon and radon progeny have been calculated using the AIRDOS-EPA/RADRISK/DARTAB approach.

Calculated 70-year committed effective dose equivalents to the selected individual and the exposed population are presented by year in Figures 8 and 9. Doses and risks of fatal lung cancer to the selected individual and to the exposed population are presented in Table 9 for one year of emissions and for 34 years of emissions.

The maximum 70-year committed effective dose equivalent is attributed to emissions from the year 1955 for both the selected individual and the exposed population. Seventy-year committed dose equivalents to six different organs from all 34 years of releases are presented for the selected individual and the exposed population in Figures 10 and 11. Examination of these two figures reveals that the calculated dose to the lungs constitutes 74 percent of the total dose to the six organs listed. This is true for both the selected individual and the exposed population. Appendices C and D present tabulated 70-year organ committed doses in 16 directions and at seven distance increments from the release point from all 34 years of releases for the selected individual and the exposed population. Appendix E presents calculated fatal cancer risks by organ in the exposed population in 16 directions and at seven distances from all 34 years of releases. A total of approximately seven hypothetical lung cancer deaths in the total population of 1,164,402 out to 20 miles from the site are estimated to be associated with historical emissions from the FMPC other than radon. Examination of the tables in Appendix E reveals that approximately 97 percent of the hypothetical cancer deaths are lung cancer deaths.

6.0 DISCUSSION

6.1 COMMITTED VERSUS ANNUAL DOSE EQUIVALENTS

Before discussing the results presented in Chapter 5.0, it is important to emphasize that the dose equivalents calculated in this report are not directly comparable with the limits imposed by DOE regulations during the period from 1951 through 1984. In this section, differences between the two types of dose equivalents will be discussed.

6.1.1 Behavior of Radionuclides in the Human Body

The dose equivalent caused by radionuclides inside the human body is a function of many variables:

- The activity of the radionuclides entering the body
- The route of entry into the body (e.g., inhalation, ingestion)
- The activity of the radionuclides retained in the body
- The activity of the radionuclides incorporated into a particular organ
- The rate at which the body eliminates the radionuclides once they are incorporated into an organ
- The physical decay of the radionuclides

Because uranium isotopes are so important to this assessment, a simplified description of their behavior in the body will be used as an example.

Assume that an individual inhales a quantity of uranium-bearing dust. Some of the uranium will remain in the inhaled air and be exhaled. Of the uranium that stays in the body, a fraction of the dust will be collected on the mucus in the nose and throat. This fraction will

ultimately be swallowed and will pass through the digestive tract. If the uranium is in a soluble chemical form, a fraction of it will be transferred to the blood stream via transport through the walls of the intestines. If the uranium is insoluble in body fluids, it will pass out of the body with the feces.

The fraction that was not collected in the nose and throat will reach the lungs. Once in the lungs, the uranium has four possible fates:

- Some of the uranium will be eliminated by the natural cleansing mechanisms of the lungs. This fraction will be swallowed and follow the route discussed above through the digestive tract.
- If the uranium's chemical form is soluble in body fluids, a fraction of it can pass into the blood stream through the lungs' air sacs (alveoli).
- Chemical forms of uranium that are relatively insoluble in body fluids will remain in the lungs, irradiating tissue there.
- Some of the insoluble uranium will be removed from the lungs and will be collected by the lymph glands serving them.

Once the soluble uranium reaches the blood stream, it tends to concentrate in two places:

- In bone, where it can irradiate both the bone matter itself and blood-producing bone marrow
- In the kidneys

As the body cleanses itself of the soluble uranium, it will pass through the urinary tract and be excreted. The amount of time spent in each organ is a factor in determining the dose equivalent that organ receives.

With this background, the differences between the two types of dose equivalents can be discussed.

6.1.2 Basis for DOE Regulations

Before January 1989, DOE regulations on control of internal exposure to radionuclides were based on the work of the ICRP's Committee II (ICRP, 1959). This committee considered the impact of constant exposure to either a soluble or an insoluble form of a particular radionuclide. They used a model of human metabolism to predict the behavior of the radionuclide in the body. The model predicted that concentrations of radionuclides would accumulate in various tissues and irradiate them. For some radionuclides, an equilibrium concentration was reached. For others, the accumulation time exceeded a human lifetime; therefore, an equilibrium concentration could not be achieved.

ICRP Committee II then considered exposure to the radionuclide over a period of 50 years (a working lifetime). The amount of the radionuclide accumulated by each organ in the 50-year period was defined as its "body burden." The amount of radioactivity that led to the annual dose equivalent limit for a particular organ within 50 years or after equilibrium was established became known as the "maximum permissible body burden" (MPBB).

Finally, the Committee compared the MPBBs for each organ of interest to determine which was the lowest. The organ with the lowest MPBB was declared the "critical organ." For a particular radionuclide, a critical organ was established for both the soluble and insoluble forms.

In establishing DOE's regulations, concentrations of radionuclides in air and in water were calculated that, if inhaled or ingested by an average individual over a 50-year period, would lead to the accumulation of an MPBB at the critical organ. These concentrations were the "concentration guides" contained in DOE's regulations. Internal exposure from radionuclides was controlled by a comparison of their intakes to the MPBBs on an annual basis. External exposure was controlled separately.

6.1.3 Committed Dose Methodology

In 1977, the ICRP issued new guidelines (ICRP, 1977) on internal and external radiation protection. This guidance was the result of several innovations, including:

- Incorporating the results of research on the uptake and fate of radionuclides in the body
- Modeling the human body's metabolism in more detail
- Modeling organ shapes more accurately, particularly to assess how they absorb radiation energy
- Defining three lung clearance classes for internal dose assessment, instead of the two previously defined
- Developing a system for combining internal and external dose equivalents into a single measure to improve protection

Another innovation was the development of a new system for assessing the impact of internally deposited radionuclides on the human body--the system of committed dose equivalents and committed effective dose equivalents.

Once a radionuclide is incorporated in an organ, it remains there, irradiating the organ until it decays or until the body eliminates it. The time spent in the organ can exceed one year, the time period for which most radiation standards are defined. To assess the impact on the body created over the entire residence time of the radionuclide in an organ, the ICRP developed a quantity which represents the cumulative dose equivalent associated with the radionuclide's residence time. This quantity is the committed dose equivalent. It is defined as the sum over time of all doses caused by an intake of a radionuclide. The ICRP recommends that the doses be summed over 50 years (a working lifetime) (ICRP, 1977).

In estimating the impact on the general population, the AIRDOS-EPA/RADRISK/DARTAB codes use a different version of the committed dose equivalent. The methodology assumes that the intake of the radionuclide occurs at birth and sums the dose equivalent over a 70-year lifetime. The resultant committed dose equivalent provides a conservative measure of the potential impact caused by the release of a radionuclide, because the entire population is not born at the time of release. This committed dose equivalent also can be used to determine the risk associated with that release.

To provide a means of combining the committed dose equivalents to various organs into a single measure, the ICRP developed the concept of committed effective dose equivalent. To compute the committed effective dose equivalent, the committed dose equivalent for the organ is multiplied by a weighting factor for that organ which represents the fractional cancer risk from irradiation of that organ relative to the total cancer risk assuming whole body irradiation (ICRP, 1977). The weighted committed dose equivalents are then added together. The resultant committed effective dose equivalent measures the effect of all sources of internal irradiation.

Because the committed dose equivalent and the committed effective dose equivalent measure the effect of irradiation over multiple years, they cannot be directly compared with the annual dose limits in DOE's regulations. In assessing the radiological hazards from the calculated emissions from the FMPC, the committed dose equivalent and committed effective dose equivalent provide a more appropriate measure of the risk to the general population. Therefore, this report will use committed dose equivalents and committed effective dose equivalents in the following discussions.

6.2 DOSE EQUIVALENTS RESULTING FROM FMPC EMISSIONS

6.2.1 Selected Individuals

The results of the AIRDOS-EPA/RADRISK/DARTAB models indicate that the individual receiving the highest committed effective dose equivalent from production area emissions resides 1,100 meters to the north-northeast of the FMPC site. This selected individual corresponds to the closest resident living in the prevailing wind direction from the site.

The committed effective dose equivalents received by this selected individual for each of the 34 years of radionuclide emissions from the FMPC are listed in Table 10. Listed are the contributions from Th-232 and Th-228, from uranium in compounds having lung clearance Classes W and Y (associated with particulate emissions), from uranium compounds having lung clearance Class D (associated with the emissions from gulping operations), and from other radionuclides. As the table shows, the thorium emissions and emissions from the gulping operations did not result in significant calculated committed effective dose equivalents to the selected individual. The largest contributor to the committed effective dose equivalent was insoluble uranium (clearance Class Y). This form of uranium is assumed to remain in the lungs for long periods of time following inhalation and causes the greatest potential detriment.

One of the key input parameters that influences the behavior of Class Y particulates is the assumed particle size. As discussed in Section 4.1.2, the particle size for uranium emissions was conservatively assumed to be 1.0 micron AMAD. The assumption of a larger particle size would reduce the calculated amount of uranium inhaled because less uranium is transported to the exposed off-site population. The larger particle size would also result in a reduction of the committed effective dose equivalent because the respiratory system removes larger particles more effectively.

Radon and its progeny are released from the K-65 silos, which are located approximately 800 meters to the west of the FMPC production area emission point. The effect of this different location and the different population distribution discussed in Section 4.3.3 is a change in the location of the selected individual. For radon and its progeny, the estimated selected individual resides 500 meters to the south of the K-65 silos. The calculated exposure of this individual is dominated by radon progeny. The highest individual exposure is 6.4×10^{-4} WL (3.3×10^{-2} WLM from one year of emissions).

6.2.2 Population

In calculating the population dose, the committed effective dose equivalents (rem) for each population sector are multiplied by the number of people in the sector. The resultant population doses (person-rem) for each sector are then summed. The smaller doses received in the 12,000-meter and 24,000-meter sectors are the highest contributors to the population dose. In particular, the population of Cincinnati to the southeast of the FMPC site adds significantly to the total population dose for each year, although the calculated individual doses in this area are extremely small and indistinguishable from variations in natural background doses.

6.2.3 Committed Effective Dose Equivalents in Perspective

Radiation doses calculated for emissions from the FMPC from 1951 through 1984 should be compared with average radiation doses received by the population of the United States from all sources. A summary of annual effective dose equivalents is given in Table 11. These data represent the most recent compilation of radiation dose information prepared by the National Council on Radiation Protection and Measurements (NCRP, 1987). The total of the annual effective dose equivalents for 70 years is obtained by multiplying the values in Table 11 by 70. Thus, over a 70-year lifetime, an average individual will receive an effective dose equivalent of 21,000 mrems due to natural background sources, including radon and its progeny.

The committed effective dose equivalents discussed in this section for emissions from the FMPC do not include the contribution of radon progeny. Because the detriment of radon progeny is expressed in WLMs, this result is not directly comparable with committed effective dose equivalents expressed in mrems. While the progeny detriment could be converted from WLMs to mrem by making assumptions about progeny equilibrium values, it is more important to assess the risk they represent. Their contribution to the overall risk will be discussed in Section 6.3.3.

The highest committed effective dose equivalent to an individual calculated in this report for production area emissions from the FMPC is approximately 730 mrem, which is calculated for emissions in 1955 for a person living 1,100 meters to the north-northeast of the site. This committed effective dose equivalent is roughly 3 percent of the 70-year total effective dose equivalent for a member of the United States population from natural background sources. If the airborne production area emissions are averaged over 34 years, the calculated committed effective dose equivalent to the selected individual from one year of emissions from the FMPC is approximately 100 mrem. This committed effective dose equivalent is roughly equal to 0.4 percent of the 70-year total effective dose equivalent for a member of the U.S. population from natural sources. In all cases, the largest component of the committed effective dose equivalent is the dose to the lung.

The maximum population dose calculated as a result of production area emissions from the FMPC is approximately 12,000 person-rem caused by releases in 1955. Over the 34-year period of emissions from the FMPC being studied, the average population dose calculated as a result of production area emissions from the FMPC is approximately 1,600 person-rem for each year's emissions. In all cases, the population dose represents a 70-year committed effective dose equivalent.

6.3 RISKS RESULTING FROM FMPC EMISSIONS

6.3.1 Selected Individuals

The population in the sector 1,100 meters to the north-northeast of the FMPC site has the greatest calculated risk of contracting cancer because of production area emissions from the FMPC. The calculated risk is greatest for lung cancer. The calculated increase in lifetime risk to an individual from lung cancer is 4×10^{-4}. This increase is the sum of calculated risks for all 34 years of radionuclide emissions from the FMPC production area.

Emissions of radon and its progeny also increase the risk to the off-site population. The organ at greatest risk is also the lungs. Because the K-65 silos are located to the west of the FMPC, the sector of greatest risk is located 500 meters to the south of the plant. The additional calculated risk associated with radon and its progeny is 5×10^{-4} at that location for the 32 years of emissions from the silos.

To calculate the total risk to the selected individual, the risks from the two sources would be combined as follows:

LOCATION	RADON AND PROGENY RISK	PRODUCTION AREA EMISSIONS RISK	TOTAL RISK
South (500 meters)	5×10^{-4}	2×10^{-4}	7×10^{-4}
North-northeast (1,100 meters)	4×10^{-4}	4×10^{-4}	8×10^{-4}

The maximum individual risk for all radionuclide emissions from the FMPC from 1951 through 1984, therefore, is approximately 8×10^{-4} lung cancers to an individual located 1,100 meters to the north-northeast of the site. It is important to note that this analysis assumes that the hypothetical individual remains at this location 24 hours per day, 365 days per year for 34 years.

6.3.2 Population

When risks are summed over the entire population within a 20-mile radius of the FMPC, a total of approximately 12 hypothetical lung cancer deaths are predicted as a result of radionuclide emissions from the FMPC. Of this total, approximately seven are calculated as a result of production area emissions. The remainder are associated with the exposure to radon and its progeny from the K-65 silos.

The collective risk of fatal lung cancer from radon emissions, and subsequently ingrown radon progeny, was assessed using a different methodology, which is described in Appendix F. This assessment was performed using environmental radon concentrations modeled by AIRDOS-EPA and revised values for other parameters including the radon release period, outdoor occupancy factor, outdoor radon progeny equilibrium factor, indoor occupancy factor, indoor radon progeny equilibrium factor, and radon progeny risk factor. This assessment results in a collective risk from radon emission that is comparable to the collective risk modeled by the AIRDOS-EPA/RADRISK/DARTAB risk assessment approach.

6.3.3 Risks in Perspective

The health risks associated with the FMPC's emissions can be compared to those associated with a number of industrial facilities that release similar radionuclides (Table 12). These facilities are required to meet federal and state regulations governing the release of and subsequent radiation doses from radioactive materials. The lifetime risk of lung cancer to the selected individual considered in this assessment is 8×10^{-4}, which is within the range of values for other industrial facilities given in Table 12.

Because the lifetime risk of suffering a fatal lung cancer in the United States is about 1 in 40 (2.6×10^{-2}) (NCI, 1984), there would be more than 30,000 fatal lung cancers from all causes for the population

surrounding the FMPC. In comparison, there are approximately 12 hypothetical fatal lung cancers predicted as a result of 34 years of radionuclide emissions from the FMPC.

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TABLES

TABLES

TABLE 1

COMPARISON OF AIRDOS-EPA AND INDUSTRIAL SOURCE COMPLEX DISPERSION MODEL PREDICTIONS

RECEPTOR LOCATION		CONCENTRATION (pCi/m^3)		RATIO, AIRDOS-EPA/ ISCLT
DIRECTION	DISTANCE (meters)	AIRDOS-EPA	ISCLT(a)	
N	1,500	0.102	0.068	1.5
N	2,500	0.053	0.039	1.4
N	3,500	0.033	0.026	1.3
N	4,500	0.023	0.019	1.2
N	7,500	0.010	0.010	1.0
E	1,500	0.048	0.037	1.3
E	2,500	0.023	0.019	1.2
E	3,500	0.014	0.012	1.2
E	4,500	0.010	0.009	1.1
E	7,500	0.004	0.004	1.0
S	1,500	0.043	0.035	1.2
S	2,500	0.022	0.018	1.2
S	3,500	0.013	0.012	1.1
S	4,500	0.009	0.011	0.8
S	7,500	0.004	0.004	1.0
W	1,500	0.047	0.036	1.3
W	2,500	0.024	0.019	1.3
W	3,500	0.015	0.013	1.2
W	4,500	0.010	0.009	1.1
W	7,500	0.005	0.005	1.0

(a)Industrial Source Complex Long-Term Model.

TABLE 2

RISK FACTORS FOR FATAL CANCERS FOR HIGH AND LOW LET RADIATION BY TYPE OF CANCER[a]

TYPE OF CANCER	RISK FACTORS LOW-LET RADIATION (deaths per 10^6 person-rad yr)	RISK FACTORS HIGH-LET RADIATION (deaths per 10^6 person-rad yr)
Leukemia	2.3	46
Bone	0.2	4
Lung	3.0	30
Breast	2.3	2.3
Liver	0.9	9
Stomach	0.5	5
Pancreas	0.7	7
Lower large intestine	0.4	4
Kidneys	0.2	2
Bladder	0.2	2
Upper large intestine	0.2	2
Small intestine	0.1	1
Ovaries	0.1	1
Testes	0.1	1
Spleen	0.1	1
Uterus	0.1	1
Thymus	0.1	1
Thyroid	0.4[b]	0.4[b]

[a]Dunning, et al., 1984.

[b]0.04 for ^{131}I and longer-lived radioiodine.

TABLE 3

ESTIMATED FMPC EMISSIONS SUMMARY IN KILOGRAMS

Year	1 Uranium FMPC-2082 Totals	2 Uranium Gulping Emissions	3 Other Uranium Process Emissions	4 Uranium Emissions Building Exhausts	5 Uranium Estimated Laboratory Emissions	6 Uranium Fugitive Emissions Waste Pits	7 Uranium Emissions Non-Routine Events	8 Total Uranium Emissions	9 Thorium Process Emissions	10 Thorium Fugitive Emissions Waste Pits	11 Total Thorium Emissions
1951	123.0	0	0	0	2	0	0	125	0	0	0
1952	499.0	0	0	0	2	0	42	543	0	0	0
1953	2,077.8	0	3	1	2	0	99	2,183	0	0	0
1954	15,119.2	210	8	5	2	0	142	15,486	815	0	815
1955	32,976.2	750	11	11	2	1	142	33,893	933	0	933
1956	13,595.4	1,750	12	16	2	2	142	15,519	0	0	0
1957	8,045.2	2,750	12	26	2	48	142	11,025	0	0	0
1958	5,513.4	3,300	14	31	2	95	100	9,055	0	0	0
1959	5,127.4	3,810	15	28	2	95	100	9,177	0	0	0
1960	4,872.8	4,020	17	33	2	108	100	9,153	0	0	0
1961	3,516.4	3,640	18	30	2	121	100	7,427	0	1	1
1962	4,568.0	2,070	19	26	2	125	132	6,942	0	2	2
1963	6,036.4	0	19	25	2	125	168	6,375	0	2	2
1964	5,253.4	0	22	20	2	129	157	5,583	246	2	248
1965	7,044.8	180	22	19	2	71	155	7,494	246	2	248
1966	3,048.5	460	12	16	2	49	143	3,731	335	2	337
1967	2,924.7	620	11	16	2	11	141	3,726	246	2	248
1968	4,655.2	1,110	7	14	2	12	85	5,885	246	2	248
1969	3,898.1	690	7	8	2	15	88	4,708	1030	2	1,032
1970	1,487.8	310	6	6	2	16	155	1,983	869	2	871
1971	772.0	280	5	2	2	16	15	1,092	356	2	358
1972	614.4	950	4	3	2	15	13	1,601	106	2	108
1973	496.0	1,210	5	3	2	15	8	1,739	38	2	40
1974	234.8	2,430	4	6	2	14	6	2,697	75	3	78
1975	318.0	2,780	4	7	2	18	9	3,138	2	3	5
1976	169.1	3,330	5	7	2	20	6	3,539	0	4	4
1977	191.9	750	5	2	2	20	7	978	292	4	296
1978	222.0	0	4	2	2	22	9	261	291	4	295
1979	154.7	0	4	1	2	31	7	200	291	4	295
1980	266.5	0	4	2	2	34	8	317	0	4	4
1981	587.2	30	5	2	2	42	9	677	0	4	4
1982	279.8	50	6	2	2	41	14	395	0	4	4
1983	181.2	130	6	4	2	40	13	376	0	4	4
1984	377.5	570	6	5	2	40	13	1,014	0	4	4
1985	121.3 *	130	6	4	2	40	12	315	0	4	4
1986	62.2 *	0	6	4	2	40	16	130	0	4	4
1987	42.3 *	200	5	2	2	41	10	302	0	4	4
Total	135,473.6	38,510	319	389	74	1,512	2,780 **		6417	79	
						TOTAL URANIUM		179,058 kg		TOTAL THORIUM	6,496 kg

NOTE: Numbers may not add due to round-off.

* The 1985, 1986 and 1987 totals are those reported in the Environmental Monitoring Annual Reports as corrected for dust collector round-off error.

** Includes 272 kgs U from estimated emissions not distributed over production years.

TABLE 4

CALCULATED ANNUAL RADIONUCLIDE EMISSIONS[a]

Nuclide	Th-232 Y (Ci)	Th-228 Y (Ci)	Th-234 Y (Ci)	Th-230 Y (Ci)	Sr-90 Y (Ci)	Tc-99 D (Ci)	Ru-106 D (Ci)	Cs-137 D (Ci)	Ra-226 W (Ci)	Ra-228 W (Ci)	Pa-234mY (Ci)	Np-237 W (Ci)
1951	0.00E+00	0.00E+00	0.00E+00	2.85E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-05	3.88E-05	0.00E+00	0.00E+00
1952	0.00E+00	0.00E+00	0.00E+00	1.24E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E-04	1.68E-04	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	4.98E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-04	6.77E-04	0.00E+00	0.00E+00
1954	8.88E-02	8.88E-02	0.00E+00	3.49E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.28E-03	4.73E-03	0.00E+00	0.00E+00
1955	1.02E-01	1.02E-01	0.00E+00	7.57E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.28E-03	1.03E-02	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	0.00E+00	3.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E-03	4.27E-03	0.00E+00	0.00E+00
1957	0.00E+00	0.00E+00	0.00E+00	1.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-03	2.57E-03	0.00E+00	0.00E+00
1958	0.00E+00	0.00E+00	0.00E+00	1.31E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-03	1.79E-03	0.00E+00	0.00E+00
1959	0.00E+00	0.00E+00	0.00E+00	1.23E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-03	1.66E-03	0.00E+00	0.00E+00
1960	0.00E+00	0.00E+00	0.00E+00	1.17E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-03	1.59E-03	0.00E+00	0.00E+00
1961	1.09E-04	1.09E-04	0.00E+00	8.65E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-03	1.17E-03	0.00E+00	0.00E+00
1962	2.18E-04	2.18E-04	1.98E+01	1.11E-01	3.16E-02	1.80E-01	3.34E-02	2.32E-02	1.36E-03	1.51E-03	6.93E+00	2.39E-03
1963	2.18E-04	2.18E-04	2.60E+01	1.46E-01	4.13E-02	2.35E-01	4.37E-02	3.03E-02	1.79E-03	1.98E-03	9.07E+00	3.12E-03
1964	2.70E-02	2.70E-02	2.27E+01	1.27E-01	3.62E-02	2.06E-01	3.83E-02	2.66E-02	1.56E-03	1.73E-03	7.94E+00	2.74E-03
1965	2.70E-02	2.70E-02	2.98E+01	1.67E-01	4.74E-02	2.70E-01	5.02E-02	3.48E-02	2.05E-03	2.27E-03	1.04E+01	3.58E-03
1966	3.67E-02	3.67E-02	1.33E+01	7.47E-02	2.12E-02	1.21E-01	2.24E-02	1.56E-02	9.16E-04	1.01E-03	4.65E+00	1.60E-03
1967	2.70E-02	2.70E-02	1.27E+01	7.09E-02	2.01E-02	1.15E-01	2.13E-02	1.48E-02	8.70E-04	9.63E-04	4.42E+00	1.52E-03
1968	2.70E-02	2.70E-02	1.94E+01	1.09E-01	3.09E-02	1.76E-01	3.27E-02	2.27E-02	1.34E-03	1.48E-03	6.79E+00	2.34E-03
1969	1.12E-01	1.12E-01	1.64E+01	9.17E-02	2.60E-02	1.48E-01	2.76E-02	1.91E-02	1.12E-03	1.25E-03	5.72E+00	1.97E-03
1970	9.49E-02	9.49E-02	6.82E+00	3.82E-02	1.08E-02	6.18E-02	1.15E-02	7.97E-03	4.69E-04	5.19E-04	2.38E+00	8.20E-04
1971	3.90E-02	3.90E-02	3.30E+00	1.85E-02	5.25E-03	2.99E-02	5.56E-03	3.86E-03	2.27E-04	2.51E-04	1.15E+00	3.97E-04
1972	1.18E-02	1.18E-02	2.66E+00	1.49E-02	4.23E-03	2.41E-02	4.47E-03	3.10E-03	1.83E-04	2.02E-04	9.28E-01	3.19E-04
1973	4.36E-03	4.36E-03	2.16E+00	1.21E-02	3.44E-03	1.96E-02	3.64E-03	2.53E-03	1.49E-04	1.65E-04	7.55E-01	2.60E-04
1974	8.50E-03	8.50E-03	1.09E+00	6.10E-03	1.73E-03	9.86E-03	1.83E-03	1.27E-03	7.48E-05	8.28E-05	3.80E-01	1.31E-04
1975	5.45E-04	5.45E-04	1.46E+00	8.17E-03	2.32E-03	1.32E-02	2.45E-03	1.70E-03	1.00E-04	1.11E-04	5.09E-01	1.75E-04
1976	4.36E-04	4.36E-04	8.51E-01	4.77E-03	1.35E-03	7.72E-03	1.43E-03	9.94E-04	5.85E-05	6.47E-05	2.97E-01	1.02E-04
1977	3.23E-02	3.23E-02	9.28E-01	5.20E-03	1.48E-03	8.42E-03	1.56E-03	1.08E-03	6.38E-05	7.06E-05	3.24E-01	1.12E-04
1978	3.22E-02	3.22E-02	1.06E+00	5.96E-03	1.69E-03	9.64E-03	1.79E-03	1.24E-03	7.31E-05	8.09E-05	3.71E-01	1.28E-04
1979	3.22E-02	3.22E-02	8.11E-01	4.54E-03	1.29E-03	7.35E-03	1.37E-03	9.47E-04	5.57E-05	6.17E-05	2.83E-01	9.75E-05
1980	4.36E-04	4.36E-04	1.29E+00	7.21E-03	2.05E-03	1.17E-02	2.17E-03	1.50E-03	8.85E-05	9.80E-05	4.50E-01	1.55E-04
1981	4.36E-04	4.36E-04	2.64E+00	1.48E-02	4.19E-03	2.39E-02	4.44E-03	3.08E-03	1.81E-04	2.01E-04	9.21E-01	3.17E-04
1982	4.36E-04	4.36E-04	1.40E+00	7.87E-03	2.23E-03	1.27E-02	2.37E-03	1.64E-03	9.66E-05	1.07E-04	4.91E-01	1.69E-04
1983	4.36E-04	4.36E-04	1.01E+00	5.64E-03	1.60E-03	9.12E-03	1.69E-03	1.18E-03	6.91E-05	7.65E-05	3.51E-01	1.21E-04
1984	4.36E-04	4.36E-04	1.81E+00	1.01E-02	2.88E-03	1.64E-02	3.05E-03	2.11E-03	1.24E-04	1.38E-04	6.32E-01	2.18E-04

[a]Radon emissions are 1083 curies/year from 1953 through 1984.

TABLE 4
(continued)

Nuclide	Pu-238 Y (Ci)	Pu-239 Y (Ci)	Pu-240 Y (Ci)	U-234 Y (Ci)	U-235 Y (Ci)	U-238 Y (Ci)	U-234 W (Ci)	U-235 W (Ci)	U-238 W (Ci)	U-234 D (Ci)	U-235 D (Ci)	U-238 D (Ci)
1951	0.00E+00	0.00E+00	0.00E+00	1.63E-02	7.97E-04	2.27E-02	1.39E-02	6.79E-04	1.93E-02	0.00E+00	0.00E+00	0.00E+00
1952	0.00E+00	0.00E+00	0.00E+00	7.09E-02	3.46E-03	9.86E-02	6.04E-02	2.95E-03	8.40E-02	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	2.85E-01	1.39E-02	3.96E-01	2.43E-01	1.18E-02	3.38E-01	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	0.00E+00	1.99E+00	9.73E-02	2.77E+00	1.70E+00	8.29E-02	2.36E+00	8.82E-02	4.94E-03	7.17E-02
1955	0.00E+00	0.00E+00	0.00E+00	4.33E+00	2.11E-01	6.02E+00	3.69E+00	1.80E-01	5.13E+00	3.03E-01	1.70E-02	2.47E-01
1956	0.00E+00	0.00E+00	0.00E+00	1.80E+00	8.77E-02	2.50E+00	1.53E+00	7.47E-02	2.13E+00	7.13E-01	4.00E-02	5.80E-01
1957	0.00E+00	0.00E+00	0.00E+00	1.08E+00	5.28E-02	1.50E+00	9.21E-01	4.49E-02	1.28E+00	1.12E+00	6.26E-02	9.08E-01
1958	0.00E+00	0.00E+00	0.00E+00	7.52E-01	3.67E-02	1.05E+00	6.41E-01	3.13E-02	8.91E-01	1.34E+00	7.51E-02	1.09E+00
1959	0.00E+00	0.00E+00	0.00E+00	7.01E-01	3.42E-02	9.75E-01	5.97E-01	2.91E-02	8.31E-01	1.55E+00	8.68E-02	1.26E+00
1960	0.00E+00	0.00E+00	0.00E+00	6.71E-01	3.27E-02	9.32E-01	5.71E-01	2.79E-02	7.94E-01	1.63E+00	9.16E-02	1.33E+00
1961	0.00E+00	0.00E+00	0.00E+00	4.95E-01	2.41E-02	6.88E-01	4.22E-01	2.06E-02	5.86E-01	1.48E+00	8.30E-02	1.20E+00
1962	1.27E-03	2.15E-02	2.15E-02	6.37E-01	3.11E-02	8.85E-01	5.42E-01	2.65E-02	7.54E-01	8.41E-01	4.72E-02	6.84E-01
1963	1.66E-03	2.81E-02	2.81E-02	8.33E-01	4.06E-02	1.16E+00	7.09E-01	3.46E-02	9.86E-01	0.00E+00	0.00E+00	0.00E+00
1964	1.45E-03	2.46E-02	2.46E-02	7.29E-01	3.56E-02	1.01E+00	6.21E-01	3.03E-02	8.64E-01	0.00E+00	0.00E+00	0.00E+00
1965	1.90E-03	3.23E-02	3.23E-02	9.55E-01	4.66E-02	1.33E+00	8.14E-01	3.97E-02	1.13E+00	7.31E-02	4.10E-03	5.95E-02
1966	8.51E-04	1.44E-02	1.44E-02	4.27E-01	2.08E-02	5.94E-01	3.64E-01	1.78E-02	5.06E-01	1.87E-01	1.05E-02	1.52E-01
1967	8.08E-04	1.37E-02	1.37E-02	4.06E-01	1.98E-02	5.64E-01	3.46E-01	1.69E-02	4.81E-01	2.51E-01	1.41E-02	2.04E-01
1968	1.24E-03	2.10E-02	2.10E-02	6.23E-01	3.04E-02	8.67E-01	5.31E-01	2.59E-02	7.38E-01	4.52E-01	2.54E-02	3.68E-01
1969	1.04E-03	1.77E-02	1.77E-02	5.25E-01	2.56E-02	7.29E-01	4.47E-01	2.18E-02	6.21E-01	2.81E-01	1.58E-02	2.29E-01
1970	4.35E-04	7.38E-03	7.38E-03	2.19E-01	1.07E-02	3.04E-01	1.86E-01	9.08E-03	2.59E-01	1.26E-01	7.05E-03	1.02E-01
1971	2.11E-04	3.57E-03	3.57E-03	1.06E-01	5.17E-03	1.47E-01	9.02E-02	4.40E-03	1.25E-01	1.14E-01	6.39E-03	9.27E-02
1972	1.70E-04	2.88E-03	2.88E-03	8.52E-02	4.15E-03	1.18E-01	7.26E-02	3.54E-03	1.01E-01	3.86E-01	2.17E-02	3.14E-01
1973	1.38E-04	2.34E-03	2.34E-03	6.93E-02	3.38E-03	9.64E-02	5.91E-02	2.88E-03	8.21E-02	4.92E-01	2.76E-02	4.00E-01
1974	6.94E-05	1.18E-03	1.18E-03	3.49E-02	1.70E-03	4.85E-02	2.97E-02	1.45E-03	4.13E-02	9.88E-01	5.54E-02	8.03E-01
1975	9.30E-05	1.58E-03	1.58E-03	4.67E-02	2.28E-03	6.50E-02	3.98E-02	1.94E-03	5.53E-02	1.13E+00	6.34E-02	9.19E-01
1976	5.43E-05	9.21E-04	9.21E-04	2.73E-02	1.33E-03	3.79E-02	2.32E-02	1.13E-03	3.23E-02	1.35E+00	7.59E-02	1.10E+00
1977	5.92E-05	1.00E-03	1.00E-03	2.98E-02	1.45E-03	4.14E-02	2.54E-02	1.24E-03	3.53E-02	3.05E-01	1.71E-02	2.48E-01
1978	6.79E-05	1.15E-03	1.15E-03	3.41E-02	1.66E-03	4.74E-02	2.90E-02	1.42E-03	4.04E-02	0.00E+00	0.00E+00	0.00E+00
1979	5.17E-05	8.78E-04	8.78E-04	2.60E-02	1.27E-03	3.61E-02	2.21E-02	1.08E-03	3.08E-02	0.00E+00	0.00E+00	0.00E+00
1980	8.22E-05	1.39E-03	1.39E-03	4.13E-02	2.01E-03	5.74E-02	3.52E-02	1.72E-03	4.89E-02	0.00E+00	0.00E+00	0.00E+00
1981	1.68E-04	2.85E-03	2.85E-03	3.13E-02	1.53E-03	4.35E-02	1.25E-01	6.11E-03	1.74E-01	1.21E-02	6.79E-04	9.85E-03
1982	8.97E-05	1.52E-03	1.52E-03	6.26E-02	3.05E-03	8.70E-02	2.09E-02	1.02E-03	2.90E-02	2.04E-02	1.14E-03	1.66E-02
1983	6.42E-05	1.09E-03	1.09E-03	3.29E-02	1.60E-03	4.57E-02	2.69E-02	1.31E-03	3.74E-02	5.29E-02	2.97E-03	4.30E-02
1984	1.15E-04	1.96E-03	1.96E-03	8.59E-02	4.19E-03	1.19E-01	2.15E-02	1.05E-03	2.99E-02	2.32E-01	1.30E-02	1.88E-01

TABLE 5

CALCULATED RADIONUCLIDE EMISSION FACTORS
(μCi/kg-U)

NUCLIDE	WEIGHTED AVERAGE[a]
PU-240	4.41
PU-239	4.41
PU-238	0.26
NP-237	0.49
TH-234	4,073.00
PA-234M	1,423.00
TH-230	22.83
RA-228	0.31
RA-226	0.28
CS-137	4.76
RU-106	6.86
TC-99	36.94
SR-90	6.48

[a]Based on average nuclide concentrations ($\bar{X}_i$) for Plants 1, 4, 5, 8, 9, the Pilot Plant, and Plant 8 scrubbers as calculated from Table 6, and emissions for these plants (w_i). For each nuclide, k, the weighted average emission factor, EF, is:

$$(EF)_k = \sum_{i=1}^{7} \bar{X}_i * w_i/W$$

where W is the total uranium emissions for Plants 1, 4, 5, 8, 9, the Pilot Plant, and Plant 8 scrubbers.

TABLE 6

RADIONUCLIDES IN FMPC DUST COLLECTOR SAMPLES[a]
(uCi/Kg-U)

Plant Number	Source	Plutonium 238	Plutonium 239+240	Neptunium 237	Thorium[b] 228	Thorium 230	Thorium[b] 232	Thorium 234
1	02-1	0.0110	0.100	0.0510	0.079	0.23	0.0120	440
1	02-172	0.2900	1.600	0.3300	5.500	26.00	8.8000	630
1	02-235	0.1100	0.180	0.0760	13.000	93.00	0.3200	500
1	02-64	8.7000	220.000	12.0000	8.700	3600.00	19.0000	380
1	02-76	0.3800	6.100	0.7900	1.800	30.00	1.4000	970
4	04-1	0.0280	0.300	0.2200	0.270	0.30	0.0980	720
4	04-12	0.0023	0.013	0.0035	0.049	0.05	0.0350	290
4	04-13	0.0086	0.048	0.1700	0.330	0.31	0.2200	780
4	04-14	0.0036	0.001	0.0070	0.033	0.13	0.0770	730
4	04-15	0.0390	0.460	0.0880	0.220	0.54	0.1600	720
4	04-2	0.0063	0.054	0.1000	0.053	0.09	0.0610	280
4	04-4	0.0170	0.190	0.0640	0.250	0.42	0.2300	540
4	04-5	0.0180	0.110	0.1400	0.300	0.32	0.0770	600
4	04-7	0.0470	0.630	0.1500	0.320	0.28	0.1700	610
5	BLDG-55	0.0290	0.180	0.2500	5.300	4.00	2.7000	24000
5	02-67	0.4700	5.200	1.5000	9.500	11.00	3.6000	2000
5	05-247	0.5200	3.100	1.4000	15.000	6.30	1.6000	1200
5	05-248	0.1000	0.400	0.2500	6.300	1.20	1.2000	33000
5	05-249	0.0030	0.015	0.0150	0.071	0.17	0.0730	880
5	05-250	0.0028	0.009	0.0180	0.210	0.35	0.1000	1200
5	05-251	0.0840	0.900	0.6000	1.400	6.00	0.3000	24000
5	05-253	0.0610	0.570	0.2200	0.270	2.30	0.6100	25000
5	05-254	0.0930	0.650	0.3300	0.930	1.10	0.7900	19000
5	05-256	0.1300	1.300	0.5300	1.100	1.90	0.9700	17000
5	05-260	0.0110	0.030	0.0150	0.120	0.26	0.0200	34000
5	05-261	0.0037	0.033	0.0150	0.060	0.07	0.0047	9200
5	05-262	1.0000	1.000	3.9000	140.000	45.00	68.0000	4700
5	05A-100	0.0620	0.170	0.3300	9.300	2.70	2.3000	2900
5	05A-101	0.0740	0.320	0.2400	6.500	1.80	1.9000	24000
8	8035	0.0370	0.160	0.0670	0.300	0.59	0.2800	410
8	043-27	0.2400	4.700	0.6400	1.700	100.00	1.1000	260
8	043-29	0.0830	0.640	0.3600	0.810	1.90	0.2300	380
9	09-1039	0.1300	1.700	0.4500	1.800	0.27	0.0590	14000
PP	PP-7050	4.9000	0.620	0.1800	8.600	9.10	11.0000	780
PP	PP/0-1	0.0023	0.002	0.0048	0.130	0.35	0.0730	81
PP	PP/0-2	0.0035	0.002	0.0099	0.130	0.19	0.1100	120
SCRUB	BOX-F	0.9500	71.000	1.5000	23.000	30.00	23.0000	320
SCRUB	OXD-F	0.0120	0.036	0.0360	3.600	1.20	1.0000	94
SCRUB	ROT-K	0.3300	3.000	0.7000	6.200	77.00	7.7000	610

[a]Data from Tables 52 through 87 in FMPC 2082.

[b]Emission factors for Th-232 and Th-228 were not used (see Section 4.1.1 for thorium emissions estimation method).

TABLE 6
(continued)

Plant Number	Source	Protactinium 234	Radium 226	Radium 228	Cesium 137	Ruthenium 106	Technetium 99	Strontium 90
1	Q2-1	380.0	0.0088	0.0120	0.030	0.280	1.100	0.0057
1	Q2-172	410.0	3.5000	5.5000	0.031	1.300	500.000	0.0420
1	Q2-235	350.0	0.5000	0.1200	0.220	0.800	54.000	0.3000
1	Q2-64	330.0	39.0000	11.0000	12.000	3.700	56.000	2.3000
1	Q2-76	610.0	2.0000	7.9000	30.000	7.200	7.900	24.0000
4	Q4-1	440.0	0.1600	0.0180	16.000	0.270	58.000	1.2000
4	Q4-12	250.0	0.0012	0.0027	0.097	0.130	2.100	0.0067
4	Q4-13	800.0	0.0130	0.0053	0.062	0.860	93.000	0.0320
4	Q4-14	380.0	0.0028	0.0044	0.038	0.260	0.046	0.0130
4	Q4-15	380.0	0.0150	0.0050	0.020	0.410	53.000	0.0140
4	Q4-2	260.0	0.0037	0.0026	0.026	0.084	82.000	0.0700
4	Q4-4	360.0	0.0051	0.0072	0.032	0.540	52.000	0.0440
4	Q4-5	410.0	0.0082	0.0150	0.028	0.028	97.000	0.2000
4	Q4-7	410.0	0.0047	0.0041	0.067	1.200	110.000	0.0280
5	BLDQ-55	9100.0	0.1500	0.0770	3.300	9.600	4.800	1.2000
5	Q2-67	1100.0	0.2100	1.8000	12.000	17.000	34.000	78.0000
5	Q5-247	650.0	0.5500	1.9000	11.000	14.000	18.000	94.0000
5	Q5-248	9500.0	0.1400	0.1500	5.600	27.000	2.300	1.1000
5	Q5-249	540.0	0.0052	0.0071	0.054	0.710	0.450	1.2000
5	Q5-250	670.0	0.0140	0.0058	0.041	0.580	0.170	0.3800
5	Q5-251	4600.0	0.1300	0.1300	4.900	11.000	8.700	4.1000
5	Q5-253	7600.0	0.1100	0.1800	10.000	19.000	1.300	76.0000
5	Q5-254	9300.0	0.0690	0.1900	18.000	14.000	3.000	79.0000
5	Q5-256	7700.0	0.1300	0.2100	21.000	8.100	4.900	4.5000
5	Q5-260	14000.0	0.0034	0.0054	0.024	6.100	0.280	0.0200
5	Q5-261	3700.0	0.0041	0.0041	0.017	0.027	0.280	0.0013
5	Q5-262	1500.0	0.9000	1.6000	66.000	270.000	0.340	9.1000
5	Q5A-100	1300.0	0.0580	0.1200	3.100	3.900	17.000	0.1900
5	Q5A-101	9400.0	0.0530	0.1100	4.200	16.000	1.300	3.9000
8	8035	390.0	0.0059	0.0580	0.260	1.100	13.000	0.0280
8	Q43-27	240.0	0.1800	0.2500	0.140	1.800	36.000	0.2600
8	Q43-29	360.0	0.0360	0.0350	0.220	0.290	32.000	0.0410
9	Q9-1039	720.0	0.4300	0.0130	0.720	0.900	68.000	0.2100
PP	PP-7050	410.0	0.4500	6.6000	6.170	8.200	2.100	0.4100
PP	PP/Q-1	210.0	0.0036	0.0023	0.200	0.270	0.096	0.0066
PP	PP/Q-2	240.0	0.0019	0.0028	0.210	0.130	0.170	0.0053
SCRUB	BOX-F	0.2	1.1000	0.5300	13.000	0.590	71.000	5.0000
SCRUB	OXD-F	0.0	0.0160	0.1500	1.300	0.027	5.800	0.2700
SCRUB	ROT-K	0.2	0.1200	0.2200	0.650	0.150	39.000	3.4000

TABLE 7

ACTIVITY MEDIAN AERODYNAMIC DIAMETER (AMAD) FOR PLANTS 4, 5, 8, AND 9[a]

PLANT	STACK IDENTIFICATION	AMAD INLET DUCT(μm)	AMAD OUTLET DUCT(μm)
4	G4-2	7.5	9.8
4	G4-5	4.4	6.2
4	G4-7	1.9	9.0
4	G4-12	10.5	8.0
4	G4-14	14.0	9.0
5	G5-249	10.3	6.7
5	G5-250	16.3	8.3
5	G5-251	0.48	7.8
5	G5-253	9.0	0.72
5	G5-254	7.6	5.2
5	G5-256	7.8	6.5
5	G5-260	7.0	1.1
5	G5-261	10.8	6.6
8	G43-27	7.4	8.8
9	G9N1-1039	5.0	1.3
	Weighted Mean AMAD	7.9	7.2

$$\text{Weighted Mean AMAD} = \frac{1}{W} \sum_{i=1}^{4} \bar{x}_i * w_i$$

where:

W = Total emissions from Plants 4, 5, 8, and 9,

$\bar{x}_i$ = Mean AMAD for Plant i, and

w_i = Emissions for Plant i.

[a]From Table 16 through Table 30 in FMPC-2082 (Boback, 1987).

TABLE 8

POPULATON HISTORY OF SELECTED COUNTIES IN THE VICINITY OF THE FMPC

COUNTY/STATE	YEAR 1950	1960	1970	1980
BUTLER/OHIO	147,203	199,076	226,207	258,787
HAMILTON/OHIO	723,952	864,121	924,018	873,224
DEARBORN/INDIANA	25,141	28,674	29,430	34,291
FRANKLIN/INDIANA	16,034	17,015	16,943	19,612
BOONE/KENTUCKY	13,015	21,940	32,812	45,842
KENTON/KENTUCKY	104,254	120,700	129,440	137,058
TOTAL	1,029,599	1,251,526	1,358,850	1,368,814

REFERENCE: U.S. Bureau of Census, 1952, et al.

TABLE 9

CALCULATED EXPOSURE AND RISK
FROM RADON, RADON PROGENY, AND URANIUM AND OTHER RADIONUCLIDES

		ONE YEAR OF EMISSIONS	32 YEARS OF EMISSIONS
RADON	Effective Dose Equivalent to the Selected Individual	2.08 mrem	66.6 mrem
	Effective Dose Equivalent to the Exposed Population	2.45×10^{1} person-rem	7.84×10^{2} person-rem
	Risk of Fatal Lung Cancer to the Selected Individual	1.20×10^{-7}	3.85×10^{-6}
	Risk of Fatal Lung Cancer to the Exposed Population	1.44×10^{-3} deaths	4.59×10^{-2} deaths
RADON PROGENY	Working Level Months to the Selected Individual	3.28×10^{-2} WLM	1.05 WLM
	Working Level Months to the Exposed Population	3.86×10^{2} person-WLM	1.24×10^{4} person-WLM
	Risk of Fatal Lung Cancer to the Selected Individual	1.42×10^{-5}	4.53×10^{-4}
	Risk of Fatal Lung Cancer to the Exposed Population	1.66×10^{-1} deaths	5.32 deaths

		ONE YEAR OF EMISSIONS	34 YEARS OF EMISSIONS
URANIUM AND OTHER RADIO-NUCLIDES	Effective Dose Equivalent to the Selected Individual	9.88×10^{1} mrem	3.36×10^{3} mrem
	Effective Dose Equivalent to the Exposed Population	1.56×10^{3} person-rem	5.29×10^{4} person-rem
	Risk of Fatal Lung Cancer to the Selected Individual	1.28×10^{-5}	4.37×10^{-4}
	Risk to Fatal Lung Cancer to the Exposed Population	2.05×10^{-1} deaths	6.98 deaths

NOTE: Effective dose equivalents include doses to the lung, red marrow, endosteal cells, testes, thyroid, breast, kidneys, liver, lower large intestinal wall, upper intestinal wall, and stomach wall.

TABLE 10

CONTRIBUTORS TO CALCULATED COMMITTED
EFFECTIVE DOSE EQUIVALENT TO THE SELECTED INDIVIDUAL
FROM RADIONUCLIDES OTHER THAN RADON
(mrem)

FMPC EMISSIONS FROM 1951 THROUGH 1984

YEAR	THORIUM-232+228	URANIUM CLASS Y	URANIUM CLASS W	URANIUM CLASS D	OTHER[a]	TOTAL
1951	0	1.8	0.1	0	0.2	2.1
1952	0	8.0	0.4	0	1.1	9.5
1953	0	37.8	1.9	0	5.4	45.1
1954	25.8	295	14.6	0.2	43.4	379
1955	27.1	585	28.8	0.6	85.5	727
1956	0	220	10.7	1.3	31.0	263
1957	0	131	6.4	2.0	19.6	159
1958	0	103	5.0	2.7	14.3	125
1959	0	113	5.5	3.7	15.8	138
1960	0	92	4.5	3.4	13.1	113
1961	0.03	67	3.3	3.0	9.6	82.9
1962	0.1	89	4.4	1.8	21.7	117
1963	0.1	151	7.4	0	36.5	195
1964	8.5	117	5.7	0	27.8	159
1965	9.0	162	8.0	0.2	39.8	219
1966	8.3	49.0	2.4	0.3	11.7	71.7
1967	7.1	54.4	2.8	0.5	12.8	77.6
1968	7.2	85.2	4.2	0.9	20.5	118
1969	27.3	65.2	3.2	0.5	15.8	112
1970	23.9	28.0	1.3	0.2	7.0	60.4
1971	10.2	14.1	0.7	0.2	3.5	28.7
1972	3.2	11.6	0.6	0.8	2.7	18.9
1973	1.4	11.7	0.6	1.2	2.9	17.8
1974	2.3	4.9	0.2	2.0	1.3	10.7
1975	0.2	6.8	0.3	2.5	1.6	11.4
1976	0.1	3.8	0.2	2.8	0.9	7.8
1977	8.4	4.0	0.2	0.6	0.9	14.1
1978	7.7	4.2	0.2	0	1.0	13.1

See footnote at the end of table.

TABLE 10
(Continued)

YEAR	THORIUM-232+228	URANIUM CLASS Y	URANIUM CLASS W	URANIUM CLASS D	OTHER[a]	TOTAL
1979	8.0	3.3	0.2	0	0.7	12.2
1980	0.1	5.4	0.3	0	1.3	7.1
1981	0.1	4.3	1.0	0.02	2.8	8.2
1982	0.1	8.4	0.2	0.04	1.5	10.2
1983	0.1	3.9	0.2	0.1	0.9	5.2
1984	0.2	15.9	0.2	0.6	2.6	19.5

[a]Includes Contributions from Uranium Daughters (Th-230/234, Pa-234m, Ra-226), Thorium Daughters (Ra-228), Transuranics (Np-237, Pu-238/239/240), and Fission Products (Sr-90, Tc-99, Ru-106, Cs-137).

TABLE 11

ANNUAL EFFECTIVE DOSE EQUIVALENT
IN THE U.S. POPULATION CIRCA 1980-82[a]

SOURCE	NUMBER OF PEOPLE EXPOSED (000s)	AVERAGE ANNUAL H_E[b] IN THE EXPOSED POPULATION (mrem)	ANNUAL COLLECTIVE EFFECTIVE DOSE EQUIVALENT (person-rem)	AVERAGE ANNUAL H_E IN THE U.S. POPULATION (mrem)
Natural Sources				
Radon	230,000	200	46,000,000	200
Other	230,000	100	23,000,000	100
Occupational	930[c]	230	200,000	0.9
Nuclear Fuel Cycle	-	-	13,600	0.05
Consumer Products				
Tobacco[d]	50,000	-	-	-
Other	120,000	5-30	1,200,000-2,900,000	5-13
Miscellaneous Environmental Sources	25,000	0.6	16,000	0.06
Medical				
Diagnostic X-rays	-[e]	-	9,100,000	39
Nuclear Medicine	-[f]	-	3,200,000	14
Rounded Total	230,000	-	83,500,000	360

[a]NCRP, 1987.

[b]H_E is the effective dose equivalent.

[c]Those nominally exposed total 1.68×10^6.

[d]Effective dose equivalent difficult to determine; dose to a segment of bronchial epithelium estimated to be 16 rem/yr.

[e]Number of persons exposed is not known. Number of examinations was 180 million and H_E per examination 50 mrem.

[f]Number of persons exposed is not known. Number of examinations was 7.4 million and H_E per examination 430 mrem.

TABLE 12

RADIOLOGICAL RISKS ASSOCIATED WITH FACILITIES WHICH RELEASE U-238 DECAY CHAIN RADIONUCLIDES[a]

FACILITY	MAXIMUM INDIVIDUAL OFF SITE (lifetime risk)	REGIONAL POPULATION[b] (risk/yr)
Coal-fired power plant[c]	4×10^{-6} - 4×10^{-5}	5×10^{-5} - 2×10^{-1}
Industrial boiler (coal)	1×10^{-6}	4×10^{-3}
Uranium mine	1×10^{-3}	3×10^{-2}
Uranium mill[d]	6.3×10^{-4}	1.4×10^{-2}
DOE uranium plants[e]	2×10^{-5} - 1×10^{-4}	1×10^{-3} - 3×10^{-2}
Phosphate rock processing plant	3×10^{-5}	3×10^{-3}
Phosphate fertilizer plant	5×10^{-6}	1×10^{-3}
Elemental phosphorus plant	1×10^{-4}	8×10^{-3}
Aluminum plant	2×10^{-5}	3×10^{-4}
Copper mine	1×10^{-4}	3×10^{-5}
Copper smelter	2×10^{-6}	6×10^{-5}
Copper mill	2×10^{-5}	1×10^{-5}
Zinc mine	2×10^{-3}	2×10^{-2}
Zinc smelter	1×10^{-7}	4×10^{-5}
Zinc mill	2×10^{-6}	8×10^{-5}
Lead smelter	2×10^{-7}	5×10^{-6}

[a]U.S. EPA, 1983.

[b]Regional population refers to the population living within 80 km of a source.

[c]Risks depend upon setting - rural or urban.

[d]NRC, 1979.

[e]U.S. EPA, 1984.

FIGURES

FIGURES

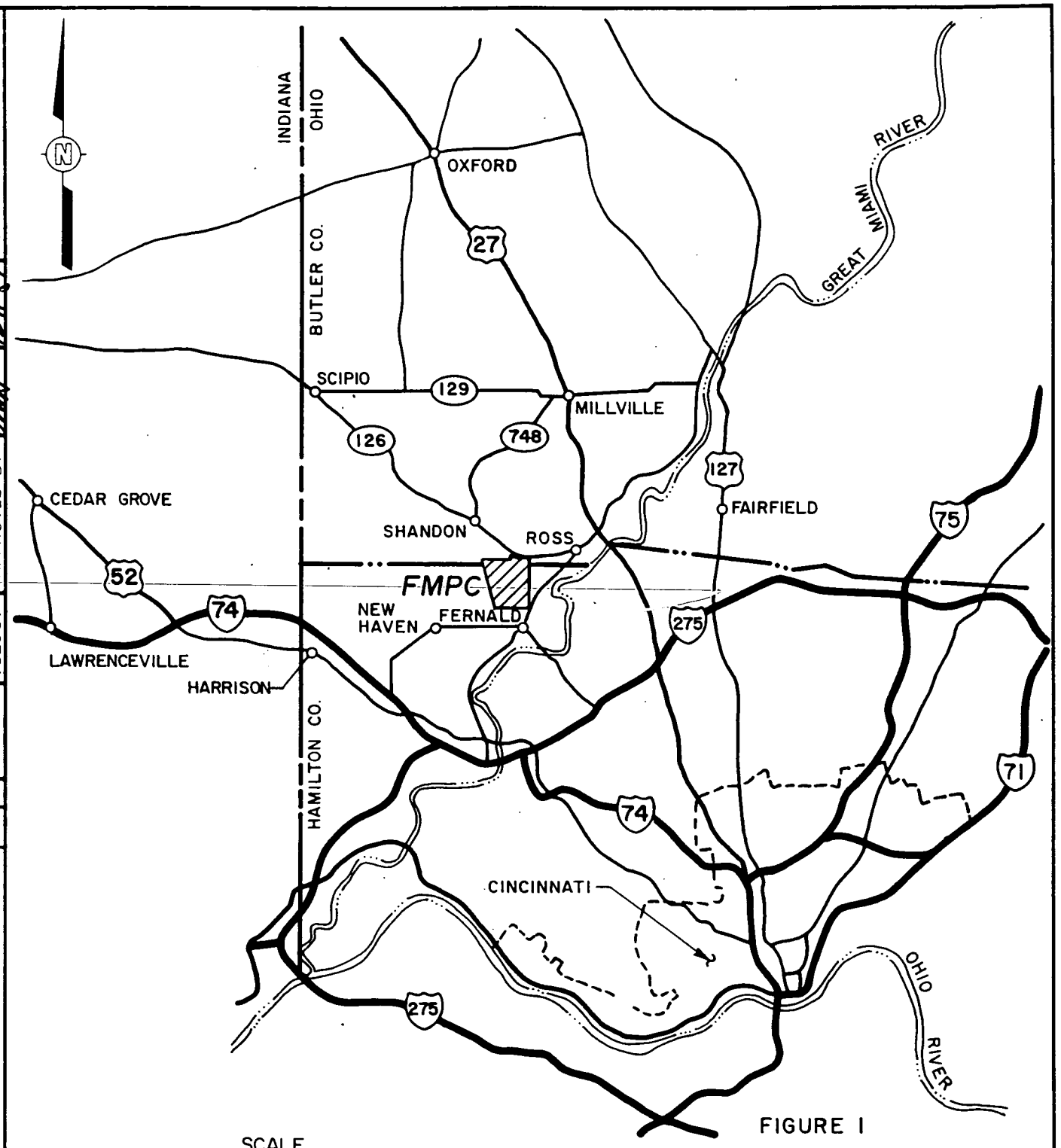

FIGURE I

SCALE
0 5 10 MILES

SCALE
0 5 10 15 KILOMETERS

REGIONAL LOCATION AND BOUNDARY FEATURES OF THE FMPC

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

REFERENCE:

AMERICAN AUTOMOBILE ASSOCIATION, STATE OF OHIO ROAD MAP, 1977-1978 EDITION.

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APPROVED BY TMH 12-11-87
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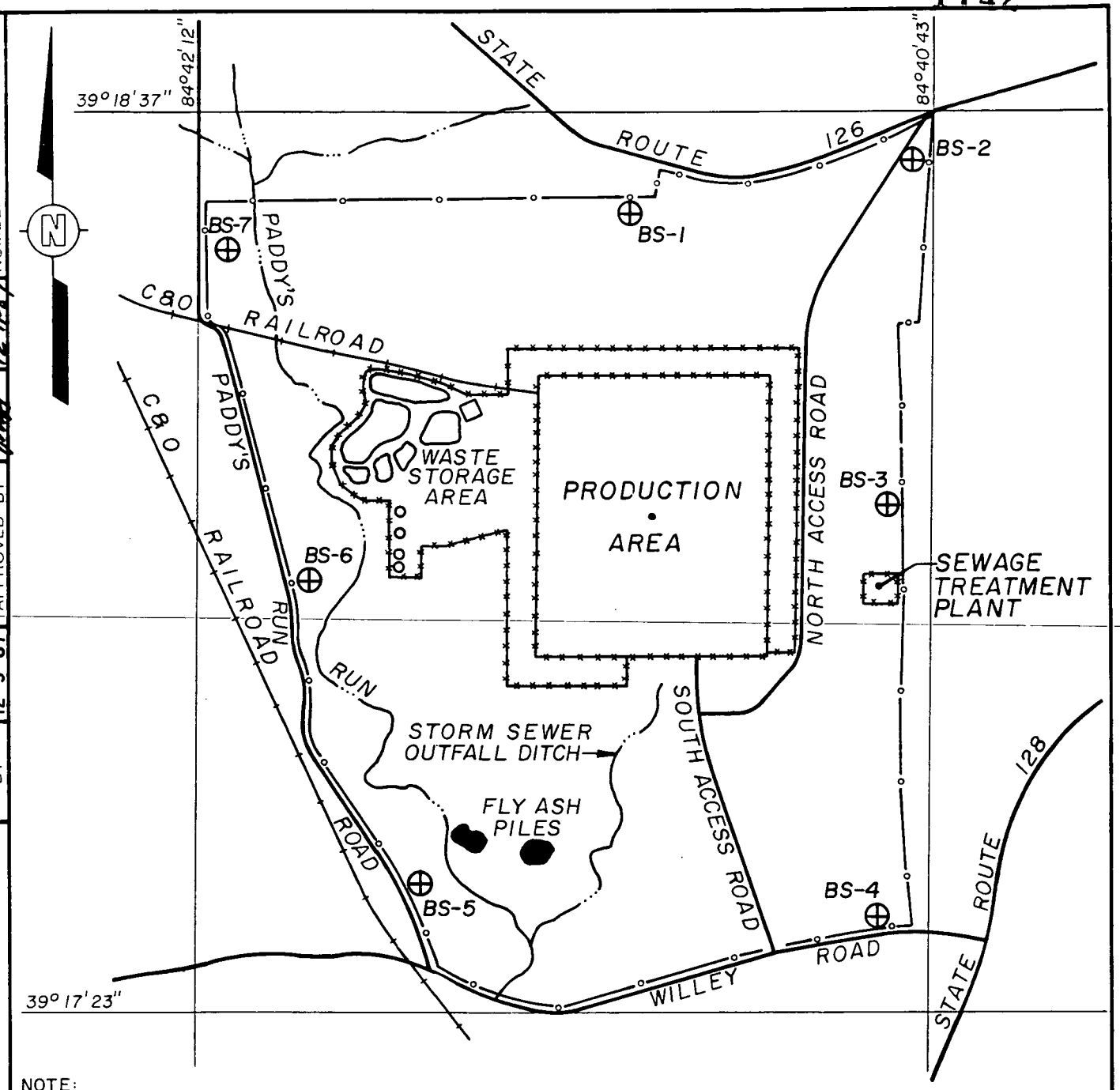

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		APPROVED BY	[illegible] 12-11-87	

NOTE:
COORDINATES AT CENTER OF PRODUCTION AREA:
LONGITUDE 84° 41' 19", LATITUDE 39° 17' 58".

LEGEND:
- SECURITY FENCE
- PROPERTY LINE FENCE
- GRID LINE
- BOUNDARY AIR MONITORING STATION

SCALE
0 1500 3000 FEET

SCALE
0 500 1000 METERS

REFERENCE:
IT CORPORATION, 1986a

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FIGURE 2

GENERALIZED
FMPC SITE LAYOUT

PREPARED FOR

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AND
CENTERS FOR DISEASE CONTROL

IT ... Creating a Safer Tomorrow

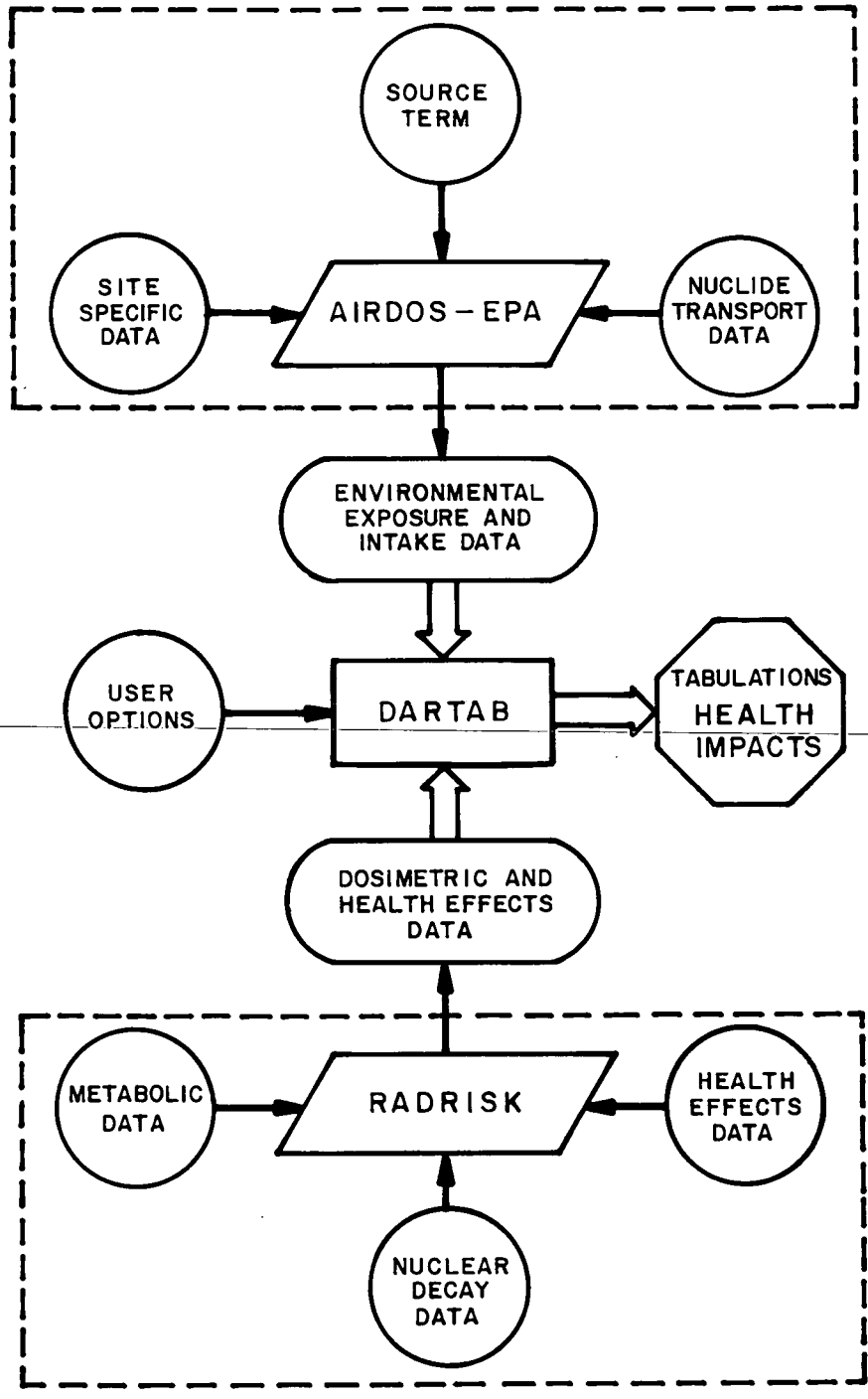

FIGURE 3

FLOWCHART FOR THE ASSESSMENT OF RADIOLOGICAL HEALTH IMPACTS

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

REFERENCE:

OAK RIDGE NATIONAL LABORATORY, 1986.

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	APPROVED BY 12-11-87	

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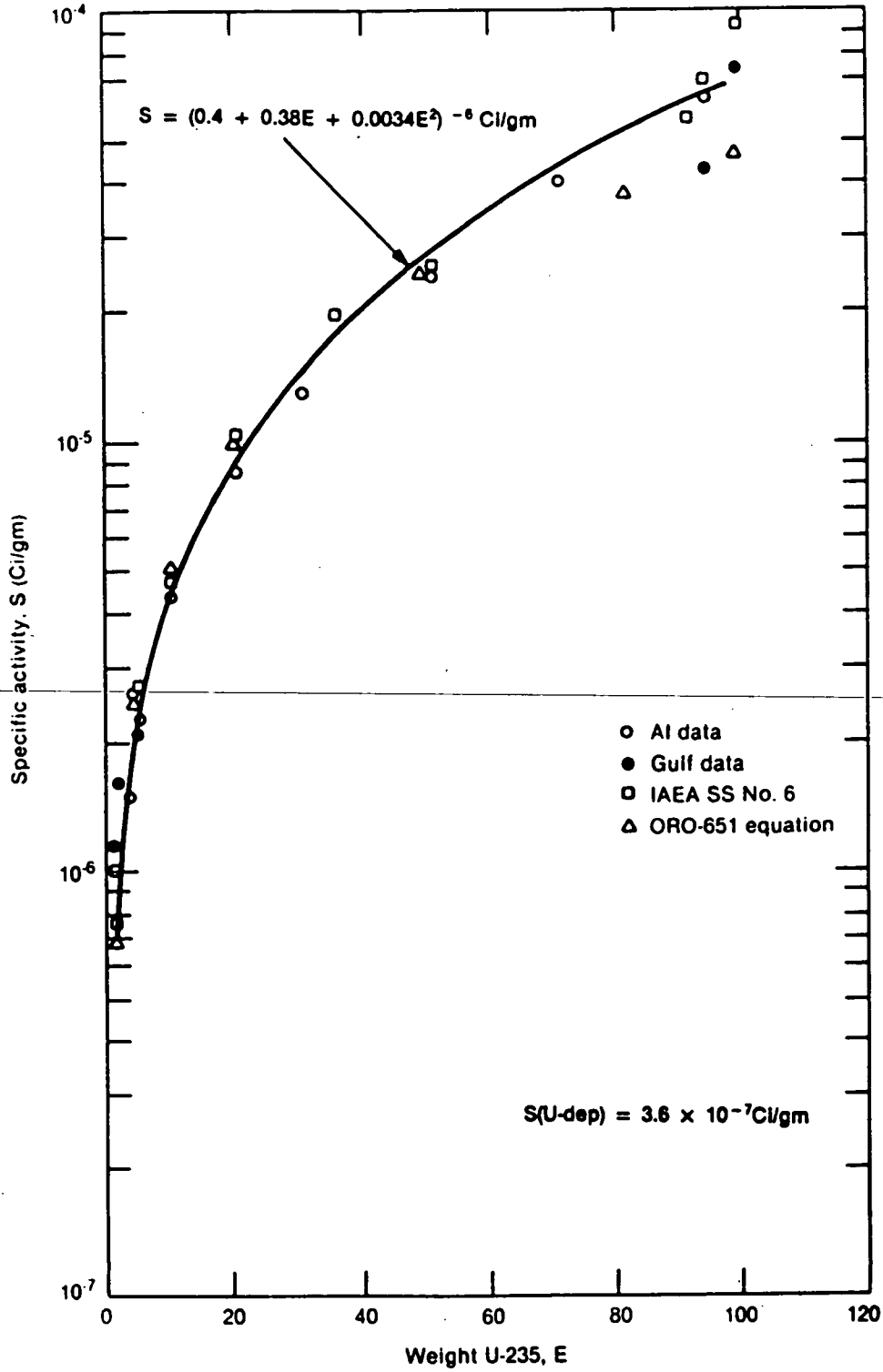

FIGURE 4
SPECIFIC ACTIVITY FOR MIXTURES
OF U-238, U-234, AND U-235

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

REFERENCE:
EG & G, 1988

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	3-27-89	APPROVED BY		303063-A1

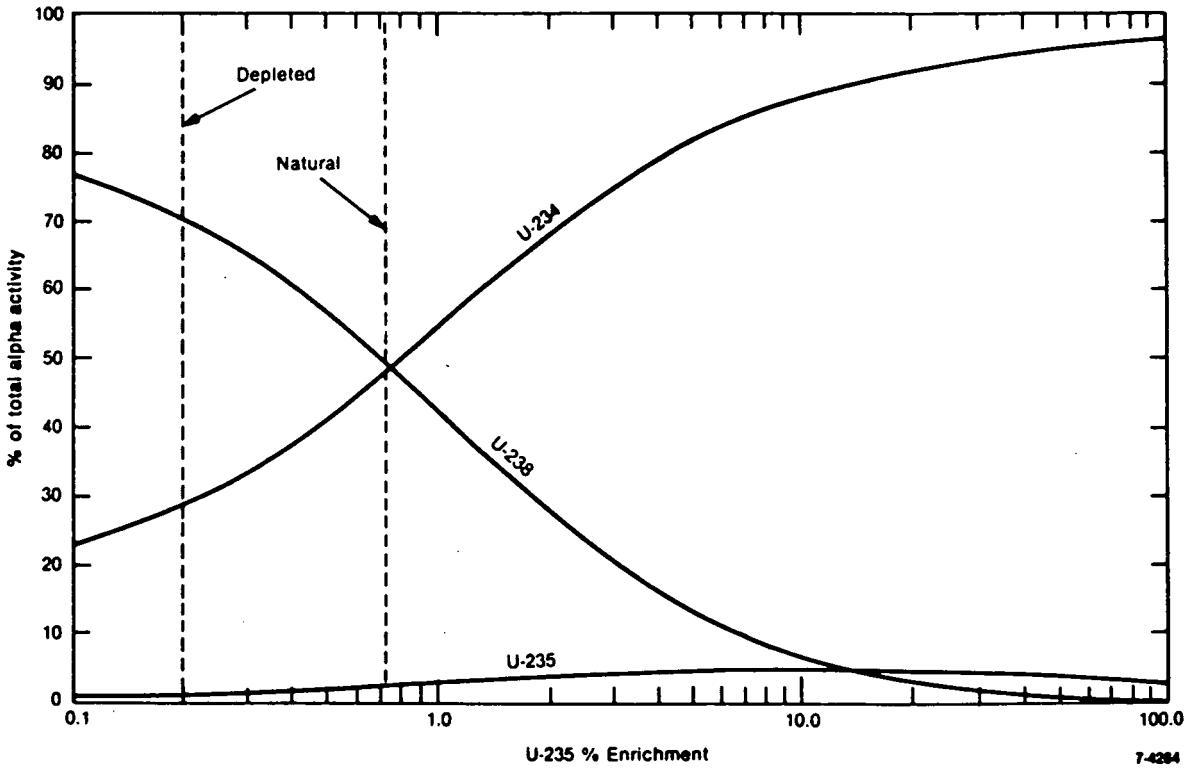

FIGURE 5
PERCENT OF TOTAL RADIOACTIVITY BY ISOTOPE vs. % WEIGHT U-235 ENRICHMENT CALCULATED FROM $S=(0.4+0.38E+0.0034E^2)\,10^{-6}$ Ci/g (GASEOUS DIFFUSION PROCESS)

PREPARED FOR

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AND
CENTERS FOR DISEASE CONTROL

REFERENCE:
EG & G, 1988

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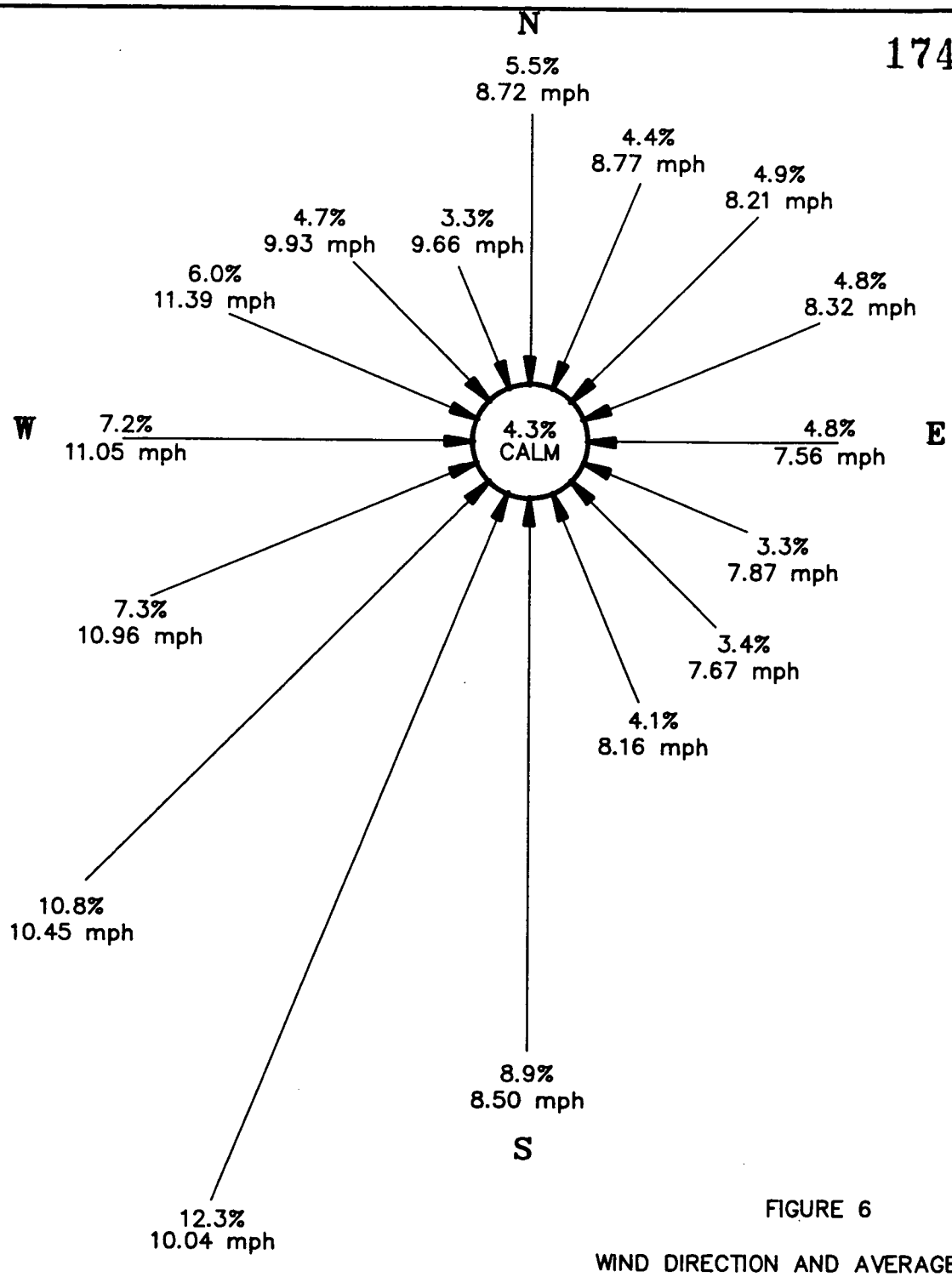

FIGURE 6

WIND DIRECTION AND AVERAGE SPEED BASED ON HOURLY DATA COLLECTED AT THE GREATER CINCINNATI AIRPORT FROM 1948 TO 1978

REFERENCE:

U.S. DEPARTMENT OF COMMERCE, 1985

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

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		APPROVED BY	3-30-89		

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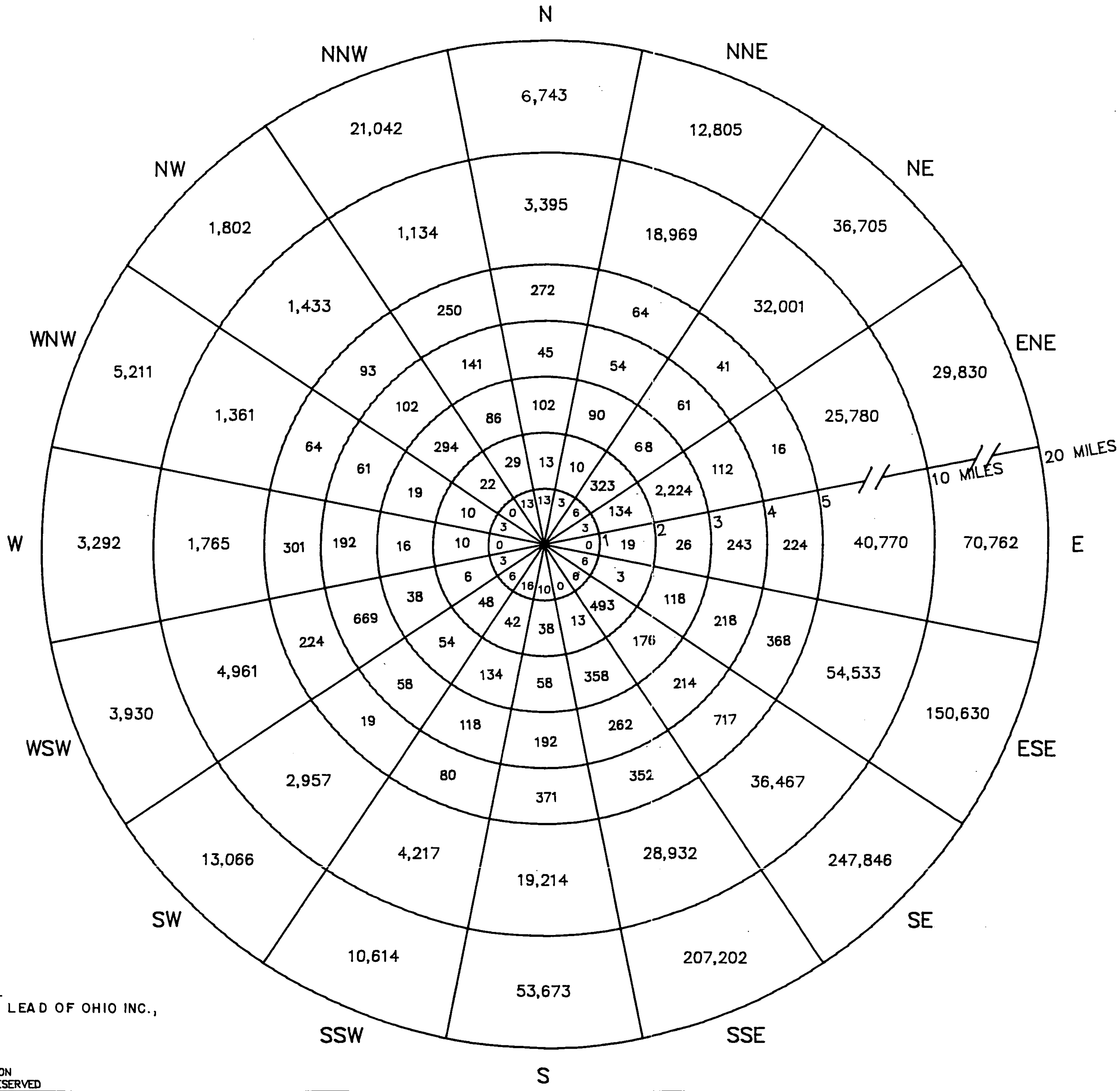

REFERENCE:
NATIONAL LEAD OF OHIO INC., 1985.

FIGURE 7

POPULATION DISTRIBUTION WITHIN 20 MILES OF THE FMPC

PREPARED FOR

DEPARTMENT OF ENERGY AND CENTERS FOR DISEASE CONTROL

INTERNATIONAL TECHNOLOGY CORPORATION

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R. Weible 11-17-87	TMH 12-1-87	[signature] 12-1-87	303063-B36

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	3-22-89	APPROVED BY			

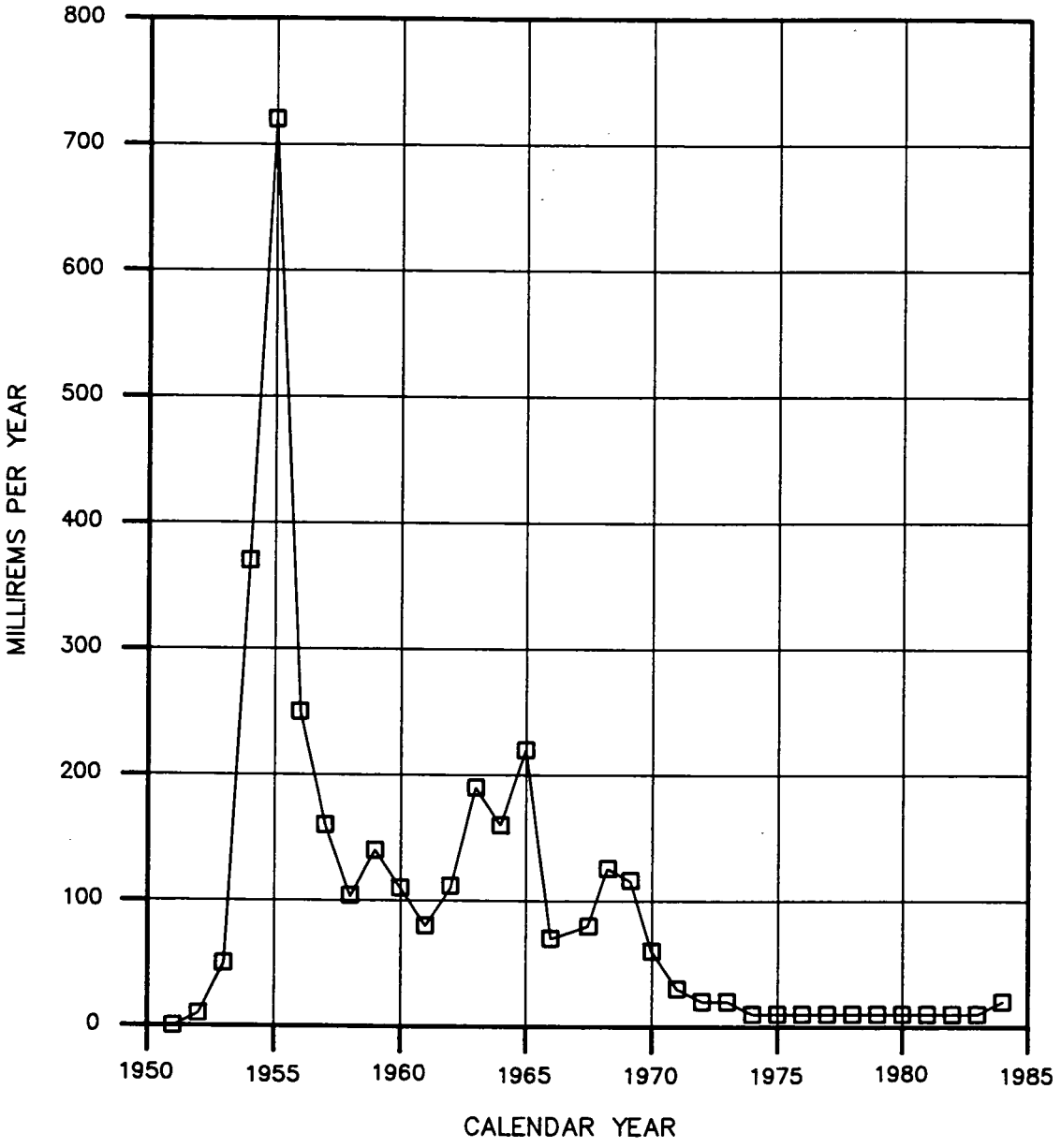

FIGURE 8

CALCULATED 70-YEAR COMMITTED EFFECTIVE DOSE EQUIVALENT FOR THE SELECTED INDIVIDUAL (1951-1984)

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

NOTE:

COMMITTED EFFECTIVE DOSE EQUIVALENTS DO NOT INCLUDE CONTRIBUTION FROM RADON OR RADON PROGENY.

EFFECTIVE DOSE EQUIVALENTS INCLUDE DOSES TO THE LUNG, RED MARROW, ENDOSTEAL CELLS, TESTES, THYROID, BREAST, KIDNEYS, LIVER, LOWER LARGE INTESTINAL WALL, UPPER LARGE INTESTINAL WALL, STOMACH WALL.

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	3-22-89	APPROVED BY	MLD	5-10-89		

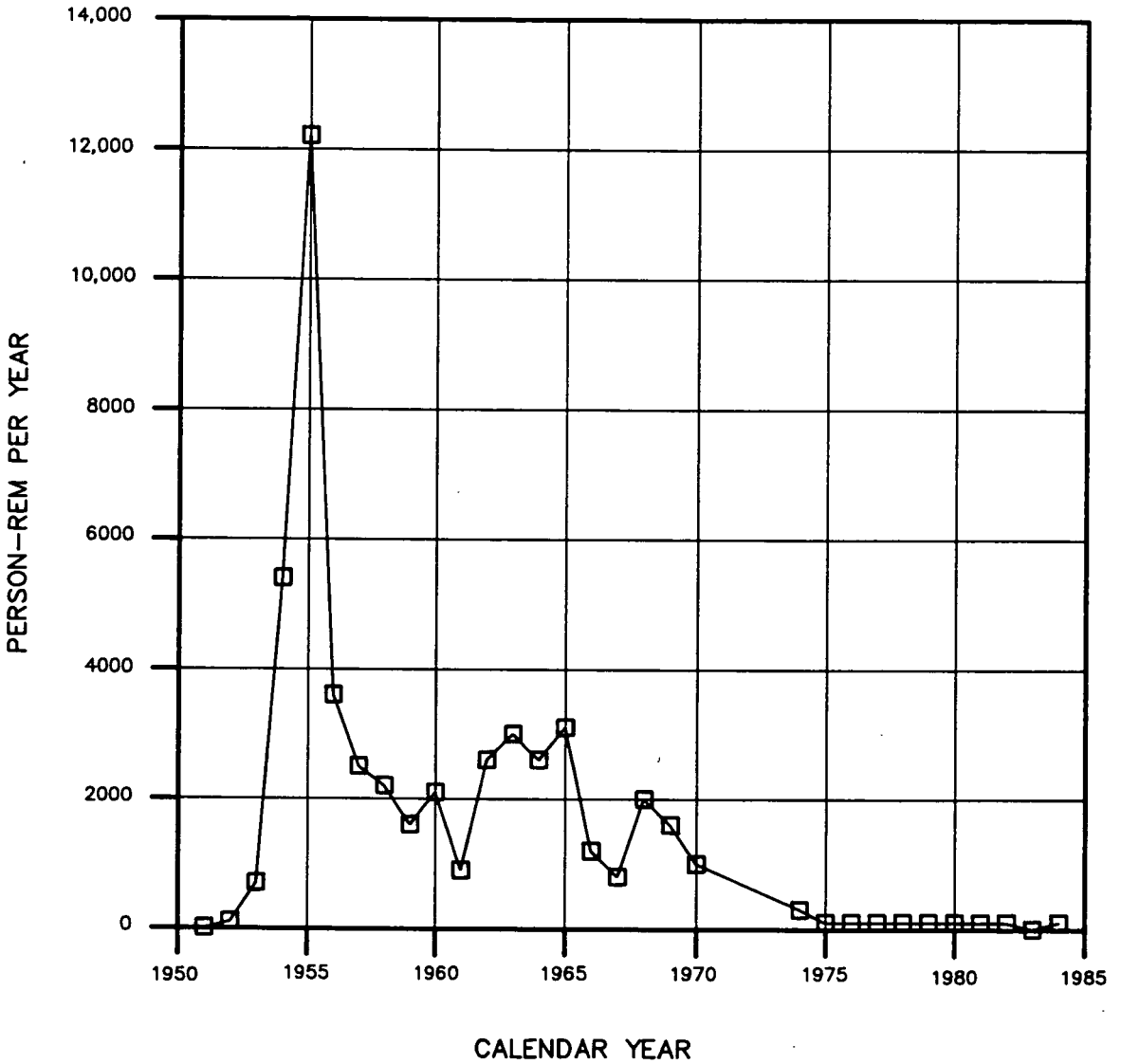

FIGURE 9

CALCULATED 70-YEAR COMMITTED EFFECTIVE DOSE EQUIVALENT FOR THE EXPOSED POPULATION (1951-1984)

PREPARED FOR

DEPARTMENT OF ENERGY
AND
CENTERS FOR DISEASE CONTROL

NOTE:

COMMITTED EFFECTIVE DOSE EQUIVALENTS DO NOT INCLUDE CONTRIBUTION FROM RADON OR RADON PROGENY.

EFFECTIVE DOSE EQUIVALENTS INCLUDE DOSES TO THE LUNG, RED MARROW, ENDOSTEAL CELLS, TESTES, THYROID, BREAST, KIDNEYS, LIVER, LOWER LARGE INTESTINAL WALL, UPPER LARGE INTESTINAL WALL, STOMACH WALL.

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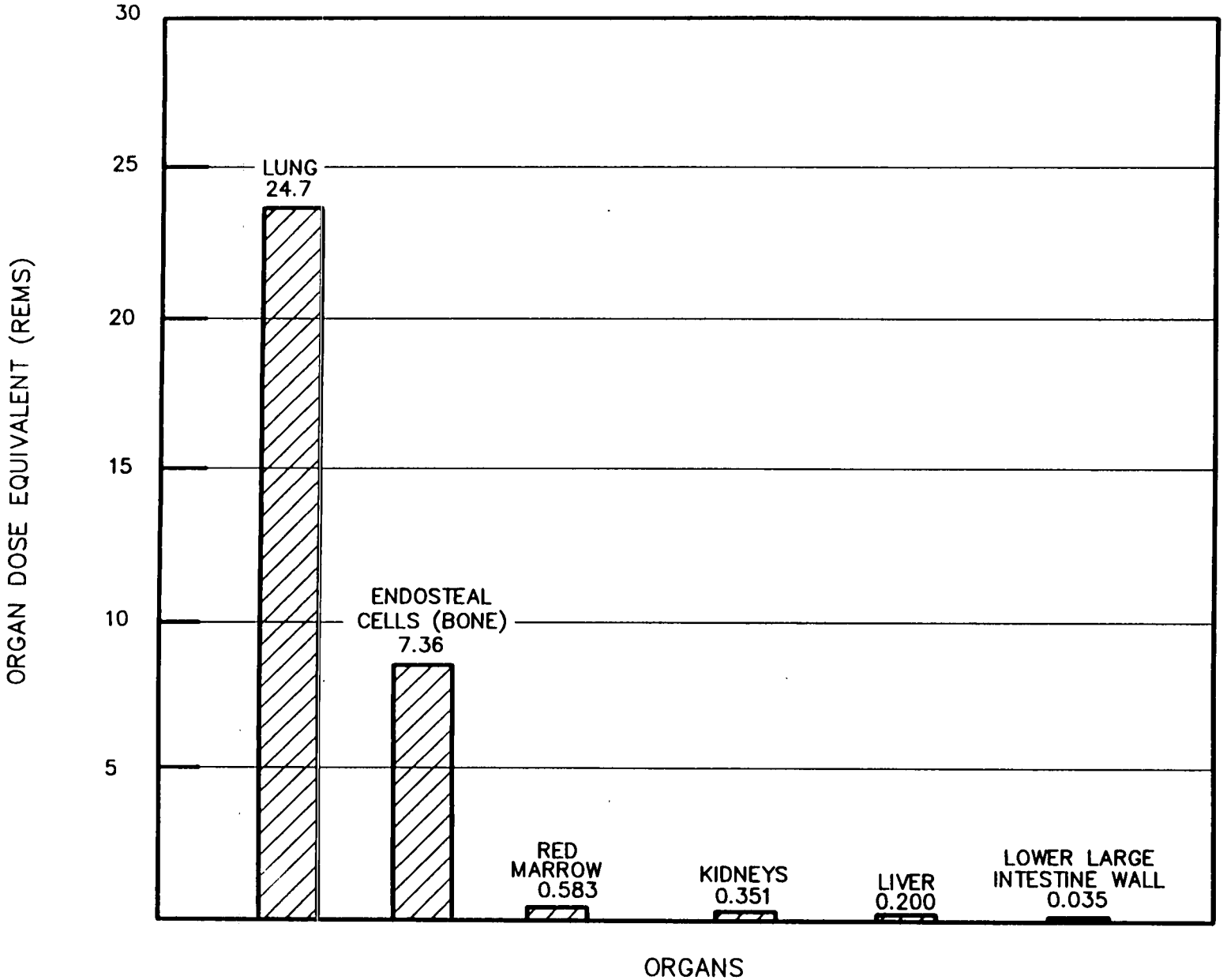


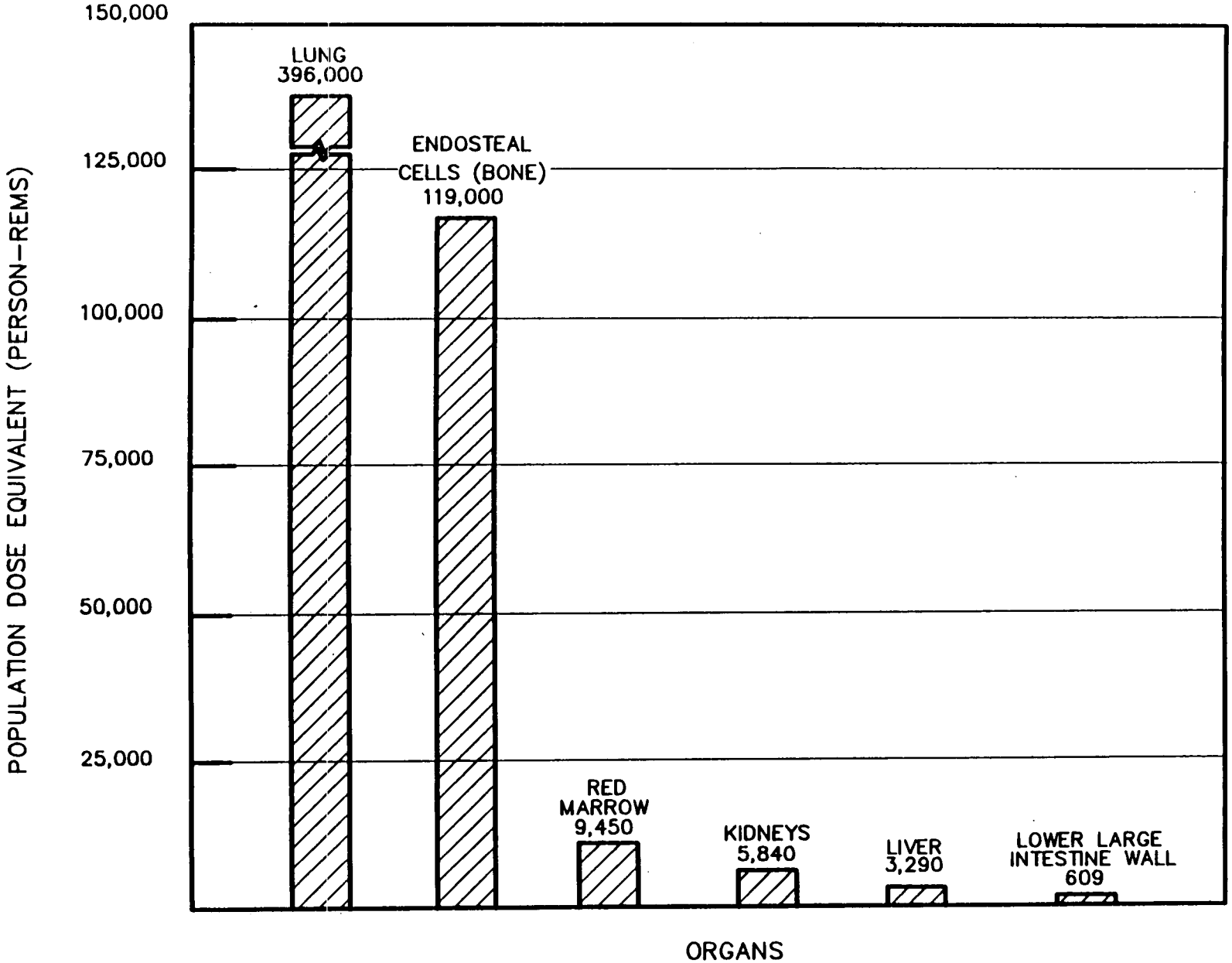
NOTE:

Dose Equivalents Do Not Include Contribution From Radon Daughters.

FIGURE 10

CALCULATED 70-YEAR COMMITTED ORGAN DOSE EQUIVALENT FOR THE SELECTED INDIVIDUAL (34-YEAR TOTAL, 1951-1984)

INTERNATIONAL TECHNOLOGY CORPORATION



NOTE:

Dose Equivalents Do Not Include Contribution From Radon Daughters.

FIGURE 11

CALCULATED 70-YEAR COLLECTIVE COMMITTED DOSE EQUIVALENT FOR THE EXPOSED POPULATION (34-YEAR TOTAL, 1951-1984)

INTERNATIONAL TECHNOLOGY CORPORATION

APPENDIX A

APPENDIX A

LISTING OF AIRDOS-EPA INPUT AND PREPROCESSOR INPUT FOR RADON-222

AIRDOS PREPROCESSOR
******** COMMENTS ********

```
RADON - 32 YEAR STAR DECK AVERAGE RUN
*
*** END OF USER DATA;  BEGIN PROCESSING ***
```

```
 MAIN OPTIONS:

OPTION(1)=0; CONCEN AND DOSEN

OPTION(2)=1; CIRCULAR GRID

 CONCEN OPTIONS:

OPTION(3)=0; SECTOR-AVERAGED

OPTION(4)=1; MOMENTUM-TYPE PLUME

OPTION(5)=0; FIXED DEPOSITION VELOCITY

OPTION(6)=0; NO PUNCH, CONCEN

OPTION(7)=1; AREA SOURCE

OPTION(8)=0; PRINT, CONCEN MAIN TABLE

OPTION(9)=1; NO PRINT, CONCEN CHI/Q TABLES

 DOSEN OPTIONS:

LIPO=1; POPULATION ASSESSMENT

NNTB=0; NO PRINT, DOSEN TABLES

NRTB=0; NO PUNCH, DOSES

NTTB=0; NO PRINT, DOSE SUMMARY

NSTB=2; DARTAB FILE ONLY

NUTB=1; 222-RN WORKING LEVELS

NVTB=1: READ, ORGAN NAMES

TSUBB= 1.000E+00 YEARS, T= 3.652E+02 DAYS; BUILDUP TIME IN SOIL

 GRID DATA:

NOL= 1, NOU=16; BOUNDS OF DIRECTION-INDICES
NRL= 1, NRU= 8; BOUNDS OF  DISTANCE-INDICES

 SQSD=2400.0 (M), COMPUTED FROM IDIST( 8)=24000 (M)

IDIST, THE ARRAY OF RADIAL DISTANCES (M);
   500  1100  2400  4000  5600  7200 12000 24000
```

```
DD1=0.500     FRACTION OF RADIOACTIVITY RETAINED ON VEGATABLES AFTER WASHING
UV=1.900E+02 (KG/Y), INGESTION OF PRODUCE
UM=1.100E+02 (L/Y),  INGESTION OF MILK
UF=9.500E+01 (KG/Y), INGESTION OF MEAT

UL=1.800E+01 (KG/Y), INGESTION OF LEAFY VEGETABLES

BRTHRT= 9.167E+05, (CM**3/H) BREATHING RATE IN MAN
        8.035E+03  (M**3/Y)


DILFAC=       1.0 (CM), DEPTH OF WATER
USEFAC=     0.000, FRACTION OF TIME SPENT SWIMMING
```

```
 NUMST=1, NUMBER OF SOURCES

 NNUCS= 1; NUMBER OF NUCLIDES

       SOURCE #:          1
PH,  HEIGHT (M)          10.0
DIA, DIAMETER (M)         0.00
VEL, EXIT VELOCITY
     (M/S)                0.
QH,  HEAT RELEASE RATE
     (CAL/S)              0.
DIM, SOURCE
     DIAMETER (M)        34.5
AREA (M**2)             934.0

OPTION(4)=1; MOMENTUM-TYPE PLUME
REL, NUCLIDE RELEASE RATE
     (CI/YR)
       1 RN-222          1.083E+03
```

AIRDOS PREPROCESSOR

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

INDEX	NAME	ANLAM 1/D	SC 1/S	VD M/S	VG M/S
1	RN-222	1.813E-01	3.319E-06	0.000E+00	0.000E+00

***NOTE: VG SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

***NOTE: ANLAM SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

FOR EACH STABILITY CLASS

UDCAT, HARMONIC AVERAGE WIND SPEEDS

	A	B	C	D	E	F	G	PERD, WIND FREQUENCY
N	1.367E+00	1.574E+00	2.685E+00	3.758E+00	3.087E+00	1.581E+00	7.717E-01	9.852E-02
NNW	1.319E+00	1.584E+00	2.569E+00	3.573E+00	2.994E+00	1.517E+00	7.717E-01	4.186E-02
NW	1.340E+00	1.599E+00	2.652E+00	3.349E+00	2.965E+00	1.538E+00	7.717E-01	3.805E-02
WNW	1.378E+00	1.800E+00	2.946E+00	3.353E+00	3.018E+00	1.599E+00	7.717E-01	3.811E-02
W	1.312E+00	1.746E+00	2.790E+00	3.453E+00	3.161E+00	1.652E+00	7.717E-01	5.464E-02
WSW	1.362E+00	1.757E+00	2.879E+00	3.493E+00	3.279E+00	1.726E+00	7.717E-01	5.133E-02
SW	1.273E+00	1.550E+00	2.751E+00	3.473E+00	3.336E+00	1.715E+00	7.717E-01	4.997E-02
SSW	1.300E+00	1.637E+00	2.825E+00	3.631E+00	3.402E+00	1.724E+00	7.717E-01	4.115E-02
S	1.217E+00	1.724E+00	2.820E+00	3.697E+00	3.434E+00	1.790E+00	7.717E-01	5.691E-02
SSE	1.565E+00	1.891E+00	3.026E+00	3.947E+00	3.407E+00	1.772E+00	7.717E-01	3.436E-02
SE	1.300E+00	1.756E+00	3.027E+00	4.131E+00	3.446E+00	1.805E+00	7.717E-01	4.763E-02
ESE	1.359E+00	1.903E+00	3.235E+00	4.610E+00	3.578E+00	1.723E+00	7.717E-01	6.159E-02
E	1.291E+00	1.844E+00	3.221E+00	4.475E+00	3.484E+00	1.732E+00	7.717E-01	7.689E-02
ENE	1.383E+00	1.977E+00	3.448E+00	4.499E+00	3.460E+00	1.681E+00	7.717E-01	7.417E-02
NE	1.245E+00	1.709E+00	3.131E+00	4.554E+00	3.327E+00	1.644E+00	7.717E-01	1.077E-01
NNE	1.463E+00	1.700E+00	2.962E+00	4.566E+00	3.296E+00	1.697E+00	7.717E-01	1.271E-01

UDAV, ARITHMETIC AVERAGE WIND SPEEDS

N	1.892E+00	2.458E+00	3.613E+00	4.914E+00	3.301E+00	2.089E+00	7.717E-01
NNW	1.839E+00	2.441E+00	3.495E+00	4.622E+00	3.189E+00	2.036E+00	7.717E-01
NW	1.863E+00	2.459E+00	3.496E+00	4.377E+00	3.151E+00	2.053E+00	7.717E-01
WNW	1.903E+00	2.687E+00	3.728E+00	4.382E+00	3.219E+00	2.103E+00	7.717E-01
W	1.831E+00	2.634E+00	3.708E+00	4.418E+00	3.387E+00	2.142E+00	7.717E-01
WSW	1.886E+00	2.698E+00	3.783E+00	4.625E+00	3.515E+00	2.194E+00	7.717E-01
SW	1.784E+00	2.432E+00	3.681E+00	4.627E+00	3.574E+00	2.187E+00	7.717E-01
SSW	1.817E+00	2.572E+00	3.847E+00	4.790E+00	3.638E+00	2.192E+00	7.717E-01
S	1.713E+00	2.610E+00	3.807E+00	4.769E+00	3.670E+00	2.235E+00	7.717E-01
SSE	2.076E+00	2.811E+00	3.973E+00	5.102E+00	3.643E+00	2.224E+00	7.717E-01
SE	1.817E+00	2.665E+00	3.929E+00	5.350E+00	3.681E+00	2.244E+00	7.717E-01
ESE	1.884E+00	2.795E+00	4.170E+00	5.841E+00	3.802E+00	2.192E+00	7.717E-01
E	1.806E+00	2.769E+00	4.159E+00	5.785E+00	3.716E+00	2.198E+00	7.717E-01
ENE	1.909E+00	2.920E+00	4.290E+00	5.745E+00	3.694E+00	2.163E+00	7.717E-01
NE	1.749E+00	2.695E+00	4.164E+00	5.797E+00	3.564E+00	2.136E+00	7.717E-01
NNE	1.987E+00	2.654E+00	3.938E+00	5.743E+00	3.533E+00	2.174E+00	7.717E-01

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

FOR EACH STABILITY CLASS

FRAW, FREQUENCIES OF STABILITY CLASSES

	A	B	C	D	E	F	G
N	4.568E-03	3.847E-02	7.897E-02	4.814E-01	1.576E-01	1.443E-01	9.460E-02
NNW	6.450E-03	5.566E-02	9.651E-02	4.955E-01	1.500E-01	1.242E-01	7.167E-02
NW	8.673E-03	7.543E-02	1.041E-01	4.712E-01	1.422E-01	1.204E-01	7.806E-02
WNW	9.184E-03	7.426E-02	1.204E-01	4.295E-01	1.396E-01	1.480E-01	7.898E-02
W	6.223E-03	6.424E-02	1.089E-01	4.337E-01	1.525E-01	1.534E-01	8.108E-02
WSW	8.182E-03	6.682E-02	1.223E-01	4.446E-01	1.492E-01	1.492E-01	5.961E-02
SW	9.606E-03	6.924E-02	1.133E-01	4.559E-01	1.425E-01	1.495E-01	6.004E-02
SSW	7.533E-03	6.950E-02	1.079E-01	5.113E-01	1.239E-01	1.278E-01	5.200E-02
S	7.732E-03	5.799E-02	1.147E-01	5.293E-01	1.269E-01	1.219E-01	4.147E-02
SSE	8.440E-03	7.014E-02	1.190E-01	5.978E-01	9.051E-02	8.120E-02	3.289E-02
SE	6.509E-03	5.732E-02	9.511E-02	6.160E-01	1.006E-01	8.986E-02	3.464E-02
ESE	5.520E-03	4.725E-02	9.531E-02	6.852E-01	8.394E-02	6.154E-02	2.127E-02
E	6.113E-03	4.890E-02	1.099E-01	6.542E-01	8.740E-02	6.698E-02	2.653E-02
ENE	5.123E-03	5.380E-02	1.286E-01	6.141E-01	9.263E-02	6.944E-02	3.627E-02
NE	3.251E-03	3.948E-02	1.111E-01	5.521E-01	1.162E-01	1.086E-01	6.929E-02
NNE	3.147E-03	3.100E-02	8.599E-02	5.125E-01	1.503E-01	1.402E-01	7.686E-02
TOTAL	5.930E-03	5.237E-02	1.046E-01	5.355E-01	1.262E-01	1.160E-01	5.934E-02

LIDAI= 900, HEIGHT OF LID (M)

RR= 99.2, RAINFALL RATE (CM/Y)

TA= 12.0, AVERAGE AIR TEMPERATURE (DEG C)
285.2 (K)

TG= 0.005 0.028 0.040, VERTICAL TEMPERATURE GRADIENT FOR STABILITIES E,F,G (K/M)

Z0= 0.030, SURFACE ROUGHNESS LENGTH (M)

Z= 10.0, HEIGHT OF WIND MEASUREMENTS (M)

UBAR= 4.12, AVERAGE WIND SPEED (M/S)

STAR INPUT, WIND FREQUENCIES

CLASS: A

N	2.100E-04	2.300E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	1.300E-04	1.800E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	2.100E-04	2.700E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	1.600E-04	2.600E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	1.400E-04	2.000E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	1.300E-04	2.200E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	1.300E-04	2.000E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	1.100E-04	1.600E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	1.700E-04	2.800E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	1.300E-04	2.700E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SW	1.600E-04	1.900E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	1.400E-04	2.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	2.000E-04	2.700E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	1.300E-04	2.100E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	1.300E-04	1.800E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	8.000E-05	2.100E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00

CLASS: B

N	8.600E-04	1.510E-03	9.300E-04	0.000E+00	0.000E+00	0.000E+00
NNE	8.500E-04	1.160E-03	8.500E-04	0.000E+00	0.000E+00	0.000E+00
NE	1.130E-03	1.470E-03	8.600E-04	0.000E+00	0.000E+00	0.000E+00
ENE	8.800E-04	1.430E-03	1.120E-03	0.000E+00	0.000E+00	0.000E+00
E	8.900E-04	1.610E-03	1.010E-03	0.000E+00	0.000E+00	0.000E+00
ESE	6.700E-04	1.310E-03	8.500E-04	0.000E+00	0.000E+00	0.000E+00
SE	8.700E-04	1.310E-03	6.900E-04	0.000E+00	0.000E+00	0.000E+00
SSE	7.200E-04	1.060E-03	5.500E-04	0.000E+00	0.000E+00	0.000E+00
S	1.200E-03	1.630E-03	9.600E-04	0.000E+00	0.000E+00	0.000E+00
SSW	1.090E-03	1.580E-03	1.270E-03	0.000E+00	0.000E+00	0.000E+00
SW	1.180E-03	1.600E-03	1.470E-03	0.000E+00	0.000E+00	0.000E+00
WSW	7.900E-04	1.640E-03	1.560E-03	0.000E+00	0.000E+00	0.000E+00
W	8.600E-04	1.630E-03	1.270E-03	0.000E+00	0.000E+00	0.000E+00
WNW	6.100E-04	1.330E-03	9.700E-04	0.000E+00	0.000E+00	0.000E+00
NW	6.900E-04	1.210E-03	8.300E-04	0.000E+00	0.000E+00	0.000E+00
NNW	5.200E-04	1.050E-03	8.400E-04	0.000E+00	0.000E+00	0.000E+00

CLASS: C

N	5.400E-04	1.860E-03	3.530E-03	5.800E-04	2.000E-05	0.000E+00
NNE	3.800E-04	1.180E-03	2.430E-03	4.500E-04	0.000E+00	0.000E+00
NE	4.900E-04	1.680E-03	3.150E-03	3.400E-04	0.000E+00	0.000E+00
ENE	4.700E-04	1.760E-03	3.600E-03	4.500E-04	0.000E+00	0.000E+00
E	4.800E-04	1.850E-03	3.190E-03	4.300E-04	0.000E+00	0.000E+00
ESE	2.800E-04	1.440E-03	2.620E-03	2.500E-04	0.000E+00	0.000E+00
SE	3.500E-04	1.400E-03	2.090E-03	1.200E-04	0.000E+00	0.000E+00
SSE	4.100E-04	1.420E-03	2.020E-03	1.900E-04	0.000E+00	0.000E+00
S	7.100E-04	2.480E-03	4.170E-03	4.100E-04	1.000E-05	0.000E+00
SSW	7.800E-04	2.860E-03	6.160E-03	1.030E-03	9.000E-05	1.000E-05

SW	7.700E-04	2.620E-03	6.800E-03	1.630E-03	1.200E-04	2.000E-05
WSW	3.900E-04	1.830E-03	5.900E-03	1.330E-03	9.000E-05	0.000E+00
W	4.400E-04	2.060E-03	4.720E-03	1.130E-03	8.000E-05	2.000E-05
WNW	3.100E-04	1.330E-03	3.420E-03	7.400E-04	5.000E-05	2.000E-05
NW	2.900E-04	1.180E-03	2.620E-03	4.300E-04	1.000E-05	0.000E+00
NNW	2.700E-04	1.040E-03	2.340E-03	4.200E-04	1.000E-05	1.000E-05

STAR INPUT, WIND FREQUENCIES

CLASS: D

N	1.080E-03	5.890E-03	1.360E-02	8.940E-03	5.400E-04	7.000E-05
NNE	8.900E-04	4.020E-03	9.130E-03	6.590E-03	3.800E-04	3.000E-05
NE	1.070E-03	5.000E-03	9.920E-03	6.400E-03	3.500E-04	4.000E-05
ENE	1.040E-03	4.870E-03	1.036E-02	6.080E-03	4.200E-04	5.000E-05
E	9.600E-04	5.530E-03	1.182E-02	5.180E-03	2.000E-04	1.000E-05
ESE	7.600E-04	4.090E-03	7.760E-03	3.570E-03	1.700E-04	2.000E-05
SE	8.800E-04	4.060E-03	9.140E-03	3.650E-03	1.600E-04	4.000E-05
SSE	8.200E-04	4.270E-03	1.000E-02	5.240E-03	3.500E-04	6.000E-05
S	1.740E-03	8.510E-03	2.110E-02	1.425E-02	1.470E-03	3.600E-04
SSW	1.290E-03	6.820E-03	2.394E-02	2.652E-02	5.400E-03	1.180E-03
SW	1.300E-03	6.590E-03	1.943E-02	2.628E-02	4.830E-03	1.010E-03
WSW	9.900E-04	5.470E-03	1.522E-02	1.941E-02	3.540E-03	9.200E-04
W	1.180E-03	6.160E-03	1.627E-02	2.116E-02	4.510E-03	1.020E-03
WNW	9.100E-04	4.450E-03	1.322E-02	1.952E-02	3.670E-03	4.300E-04
NW	8.500E-04	4.330E-03	1.073E-02	1.181E-02	1.430E-03	1.900E-04
NNW	6.400E-04	3.520E-03	7.990E-03	7.710E-03	6.200E-04	6.000E-05

CLASS: E

N	0.000E+00	2.820E-03	4.400E-03	0.000E+00	0.000E+00	0.000E+00
NNE	0.000E+00	2.080E-03	3.020E-03	0.000E+00	0.000E+00	0.000E+00
NE	0.000E+00	3.160E-03	3.960E-03	0.000E+00	0.000E+00	0.000E+00
ENE	0.000E+00	3.650E-03	4.010E-03	0.000E+00	0.000E+00	0.000E+00
E	0.000E+00	4.560E-03	3.770E-03	0.000E+00	0.000E+00	0.000E+00
ESE	0.000E+00	3.410E-03	1.910E-03	0.000E+00	0.000E+00	0.000E+00
SE	0.000E+00	3.670E-03	1.740E-03	0.000E+00	0.000E+00	0.000E+00
SSE	0.000E+00	4.130E-03	2.150E-03	0.000E+00	0.000E+00	0.000E+00
S	0.000E+00	9.240E-03	6.290E-03	0.000E+00	0.000E+00	0.000E+00
SSW	0.000E+00	8.910E-03	1.019E-02	0.000E+00	0.000E+00	0.000E+00
SW	0.000E+00	5.620E-03	6.890E-03	0.000E+00	0.000E+00	0.000E+00
WSW	0.000E+00	2.590E-03	4.280E-03	0.000E+00	0.000E+00	0.000E+00
W	0.000E+00	2.450E-03	4.270E-03	0.000E+00	0.000E+00	0.000E+00
WNW	0.000E+00	1.640E-03	3.530E-03	0.000E+00	0.000E+00	0.000E+00
NW	0.000E+00	1.840E-03	2.950E-03	0.000E+00	0.000E+00	0.000E+00
NNW	0.000E+00	1.260E-03	1.850E-03	0.000E+00	0.000E+00	0.000E+00

CLASS: F

N	1.300E-03	5.640E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	1.110E-03	4.150E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	1.600E-03	5.870E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	1.610E-03	6.050E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	2.000E-03	6.380E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	1.470E-03	4.170E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	1.320E-03	3.260E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	1.550E-03	3.650E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	3.820E-03	1.040E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	3.940E-03	1.388E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00

SW	2.830E-03	8.860E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	1.170E-03	3.980E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	1.070E-03	4.080E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	8.000E-04	2.990E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	7.800E-04	3.500E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	5.400E-04	2.250E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00

STAR INPUT, WIND FREQUENCIES

CLASS: G

N	2.360E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	2.140E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	3.000E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	3.060E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	4.430E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	3.010E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	2.970E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	3.000E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	9.320E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	9.770E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SW	7.460E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	2.690E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	2.040E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	1.310E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	1.650E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	1.130E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

INDEX	NAME	AMAD MICRONS	ISOL CLASS	DENSITY RHO G/CC	DIAMETER PDIA MICRONS	
1	RN-222	0.000	*	0.00	0.000	SEQWL=0.600

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

INDEX	NAME	UPTAKE-INH F1INH	UPTAKE-ING F1ING	DCF-AIR CFSBA (A)	DCF-H2O CFSBW (A)	DCF-SURFACE CFSUR (B)
1	RN-222	0.0000	0.0000	3.802E-01	8.271E-04	7.807E-05

(A) (REM-CM**3)/(MICROCI-H)
(B) (REM-CM**2)/(MICROCI-H)
(C) (REM-CM**3)/(PCI-YEAR)

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 4/18/89 11:59:25

FROG - EXTERNAL DOSE CORRECTION FACTOR

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	RN-222	5.140E-01	5.214E-01	5.958E-01	6.335E-01	6.335E-01	5.092E-01	4.682E-01	4.646E-01	4.748E-01	4.083E-01	4.948E-01

AIRDOS PREPROCESSOR DATE 4/18/89 11:59:25
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

CFINHA - DCF FOR INHALATION (REM/MICROCI)

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	RN-222	1.023E-01	9.200E-02	2.383E-01	1.082E-01	1.082E-01	1.121E-01	1.076E-01	1.075E-01	2.949E-02	1.082E-01	1.931E-01

AIRDOS PREPROCESSOR DATE 4/18/89 11:59:25
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

CFINGA - DCF FOR INGESTION (REM/MICROCI)

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	RN-222	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

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LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

INDEX	NAME	LAMRR 1/D	KFLAG	LAMSUR 1/D	LAMH2O 1/D	IFLAG	RD1	RD2	RW1	RW2
1	RN-222	1.813E-01	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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INDEX	NAME	PASTURE BSUBV1 DRY/SOIL	CROPS BSUBV2 FRESH/SOIL	MILK FSUBMI D/L	MEAT FSUBFI D/KG
1	RN-222	0.000E+00	0.000E+00	0.000E+00	0.000E+00

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

IMPFIX=0, FRACTIONS OF FOOD FROM OUTSIDE AREA CAN BE GREATER THAN FRACTIONS BELOW

RVEG=1.000E+00 VEG. ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3VEGM=7.000E-01 MINIMUM FRACTION VEG. INGESTED FROM OUTSIDE AREA

RBEF=1.000E+00 MEAT ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3BEFM=7.000E-01 MINIMUM FRACTION MEAT INGESTED FROM OUTSIDE AREA

RMLK=1.000E+00 MILK ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3MLKM=7.000E-01 MINIMUM FRACTION MILK INGESTED FROM OUTSIDE AREA

FOOD SUPPLY FRACTIONS:

	LOCAL	REGIONAL	EXTERNAL
VEGETABLES:	0.300	0.000	0.700
MEAT:	0.300	0.000	0.700
MILK:	0.300	0.000	0.700

LAMW=2.900E-03 REMOVAL RATE CONSTANT FOR WEATHERING (1/H)

TSUBH1=0.000E+00 TIME DELAY—INGESTION OF PASTURE (H)
TSUBH2=2.160E+03 TIME DELAY—INGESTION OF FEED (H)
TSUBH3=3.360E+02 TIME DELAY—INGESTION OF LEAFY VEGETABLES (H)
TSUBH4=3.360E+02 TIME DELAY—INGESTION OF PRODUCE (H)

TSUBE1=7.200E+02 PERIOD OF EXPOSURE—GRASS (H)
TSUBE2=1.440E+03 PERIOD OF EXPOSURE—CROPS (H)

YSUBV1=2.800E-01 PRODUCTIVITY: GRASS-MAN (KG/M**2)
YSUBV2=7.160E-01 PRODUCTIVITY: PRODUCE-MAN (KG/M**2)

FSUBP=4.000E-01 FRACTION OF YEAR ANIMALS GRAZE

FSUBS=4.300E-01 FRACTION OF FEED THAT IS PASTURE

QSUBF=1.560E+01 CONSUMPTION RATE BY ANIMAL (KG-DRY WEIGHT/D)

TSUBF=2.000E+00 TRANSPORT TIME FOR FEED-MILK-MAN (D)

TSUBS=2.000E+01 AVERAGE TIME FROM SLAUGHTER OF MEAT TO CONSUMPTION (D)

FSUBG=1.000E+00 FRACTION OF PRODUCE INGESTED GROWN IN GARDEN

FSUBL=1.000E+00 FRACTION OF LEAFY VEGETABLES GROWN IN GARDEN

P=2.150E+02 EFFECTIVE SURFACE DENSITY OF SOIL (KG/M**2)

TAUBEF=3.810E-03 FRACTION OF HERD SLAUGHTERED (1/D)

MSUBB=2.000E+02 MUSCLE MASS OF ANIMAL AT SLAUGHTER (KG)

VSUBM=1.100E+01 MILK PRODUCTION OF COW (L/DAY)

R1=5.700E-01 FALLOUT INTERCEPTION FRACTION-PASTURE

R2=2.000E-01 FALLOUT INTERCEPTION FRACTION-VEGETABLES

NOBCT, NUMBER OF BEEF CATTLE

	500	1100	2400	4000	5600	7200	12000	24000
N	311	311	311	311	311	311	311	311
NNW	311	311	311	311	311	311	311	311
NW	311	311	311	311	311	311	311	311
WNW	311	311	311	311	311	311	311	311
W	311	311	311	311	311	311	311	311
WSW	311	311	311	311	311	311	311	311
SW	311	311	311	311	311	311	311	311
SSW	311	311	311	311	311	311	311	311
S	311	311	311	311	311	311	311	311
SSE	311	311	311	311	311	311	311	311
SE	311	311	311	311	311	311	311	311
ESE	311	311	311	311	311	311	311	311
E	311	311	311	311	311	311	311	311
ENE	311	311	311	311	311	311	311	311
NE	311	311	311	311	311	311	311	311
NNE	311	311	311	311	311	311	311	311

NOMCT, NUMBER OF MILK CATTLE

N	47	47	47	47	47	47	47	47
NNW	47	47	47	47	47	47	47	47
NW	47	47	47	47	47	47	47	47
WNW	47	47	47	47	47	47	47	47
W	47	47	47	47	47	47	47	47
WSW	47	47	47	47	47	47	47	47
SW	47	47	47	47	47	47	47	47
SSW	47	47	47	47	47	47	47	47
S	47	47	47	47	47	47	47	47
SSE	47	47	47	47	47	47	47	47
SE	47	47	47	47	47	47	47	47
ESE	47	47	47	47	47	47	47	47
E	47	47	47	47	47	47	47	47
ENE	47	47	47	47	47	47	47	47
NE	47	47	47	47	47	47	47	47
NNE	47	47	47	47	47	47	47	47

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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INTFC, AREA OF VEGETABLE CROP PRODUCTION (M**2)

	500	1100	2400	4000	5600	7200	12000	24000
N	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NNW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
WNW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
W	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
WSW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SSW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
S	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SSE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
ESE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
E	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
ENE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NNE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06

INTPA, POPULATION

	500	1100	2400	4000	5600	7200	12000	24000
N	0	13	13	102	45	272	3395	6743
NNW	0	13	29	86	141	250	1134	21042
NW	0	0	22	294	102	93	1433	1802
WNW	0	3	10	19	61	64	1361	5211
W	0	0	10	16	192	301	1765	3292
WSW	3	0	6	38	669	224	4961	3930
SW	3	3	48	54	58	19	2957	13066
SSW	8	8	42	134	118	80	4217	10614
S	5	5	38	58	192	371	19214	53673
SSE	0	0	13	358	262	352	28932	207202
SE	0	6	493	176	214	717	36467	247846
ESE	0	6	3	118	218	368	54533	150630
E	0	0	19	26	243	224	40770	70762
ENE	0	3	134	2224	112	16	25780	29830
NE	0	6	323	68	61	41	32001	36705
NNE	0	3	10	90	54	64	18969	12805

INTWA, 1 DENOTES THE PRESENCE OF A SIGNIFICANT WATER AREA

N	1	1	1	1	1	1	1	1
NNW	1	1	1	1	1	1	1	1
NW	1	1	1	1	1	1	1	1
WNW	1	1	1	1	1	1	1	1
W	1	1	1	1	1	1	1	1
WSW	1	1	1	1	1	1	1	1
SW	1	1	1	1	1	1	1	1
SSW	1	1	1	1	1	1	1	1
S	1	1	1	1	1	1	1	1
SSE	1	1	1	1	1	1	1	1
SE	1	1	1	1	1	1	1	1
ESE	1	1	1	1	1	1	1	1
E	1	1	1	1	1	1	1	1
ENE	1	1	1	1	1	1	1	1
NE	1	1	1	1	1	1	1	1
NNE	1	1	1	1	1	1	1	1

APPENDIX
B

APPENDIX B

LISTING OF AIRDOS-EPA INPUT AND PREPROCESSOR INPUT FOR RADIONUCLIDES OTHER THAN RADON[a]

[a]Radionuclide No. 18 in the input data is listed as U-235. This is actually U-238.

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 .PREPAR.CAATMPLT.DATA 02/06/85. OLD XFR AND NEW EXTERNAL DCFS
 TYPE=3 DOSE EQUIVALENT FACTOR (REM) SELECTED WITH Q= 20.0 AND TIME= 70.
11 AIRDOS ORGANS PAIRED WITH DARTAB-RADRISK ORGANS:
W BODY   WT SUM
R MAR    R MAR
ENDOST   ENDOST
THYROID  THYROID
BREAST   BREAST
*PUL*    *PUL*
S WALL   S WALL
INT WALL INT WALL
LIVER    LIVER
PANCREAS PANCREAS
KIDNEYS  KIDNEYS
11 ORGANS AND WEIGHTS USED TO PRODUCE WEIGHTED-SUM
R MAR    1.552E-01
ENDOST   3.470E-03
THYROID  9.873E-02
BREAST   1.299E-01
*PUL*    2.075E-01
S WALL   8.401E-02
INT WALL 3.905E-02
LIVER    8.530E-02
PANCREAS 5.851E-02
KIDNEYS  2.481E-02
OTHER    1.136E-01
READING DATA TYPE= OPTI
READING DATA TYPE= GRID
READING DATA TYPE= METE
READING DATA TYPE= WIND
READING DATA TYPE= AG A
  FILE=  23
READING DATA TYPE= POPU
  FILE=  24
READING DATA TYPE= WATE
READING DATA TYPE= PHYS
READING DATA TYPE= RADI
READING DATA TYPE= AG D
READING DATA TYPE= USAG
READING DATA TYPE= COMM
```

AIRDOS PREPROCESSOR
******** COMMENTS ********

1969 FMPC
*
*** END OF USER DATA; BEGIN PROCESSING ***

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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MAIN OPTIONS:

OPTION(1)=0; CONCEN AND DOSEN

OPTION(2)=1; CIRCULAR GRID

CONCEN OPTIONS:

OPTION(3)=0; SECTOR-AVERAGED

OPTION(4)=1; MOMENTUM-TYPE PLUME

OPTION(5)=0; FIXED DEPOSITION VELOCITY

OPTION(6)=0; NO PUNCH, CONCEN

OPTION(7)=1; AREA SOURCE

OPTION(8)=1; NO PRINT, CONCEN MAIN TABLE

OPTION(9)=1; NO PRINT, CONCEN CHI/Q TABLES

DOSEN OPTIONS:

LIPO=1; POPULATION ASSESSMENT

NNTB=0; NO PRINT, DOSEN TABLES

NRTB=0; NO PUNCH, DOSES

NTTB=0; NO PRINT, DOSE SUMMARY

NSTB=2; DARTAB FILE ONLY

NUTB=0; NO 222-RN WORKING LEVELS

NVTB=1: READ, ORGAN NAMES

TSUBB= 1.000E+00 YEARS, T= 3.652E+02 DAYS; BUILDUP TIME IN SOIL

GRID DATA:

NOL= 1, NOU=16; BOUNDS OF DIRECTION-INDICES
NRL= 1, NRU= 7; BOUNDS OF DISTANCE-INDICES

SQSD=2400.0 (M), COMPUTED FROM IDIST(7)=24000 (M)

IDIST, THE ARRAY OF RADIAL DISTANCES (M):
1100 2400 4000 5600 7200 12000 24000

```
DD1=0.500      FRACTION OF RADIOACTIVITY RETAINED ON VEGATABLES AFTER WASHING
UV=1.900E+02 (KG/Y), INGESTION OF PRODUCE
UM=1.100E+02 (L/Y),  INGESTION OF MILK
UF=9.500E+01 (KG/Y), INGESTION OF MEAT

UL=1.800E+01 (KG/Y), INGESTION OF LEAFY VEGETABLES

BRTHRT= 9.167E+05, (CM**3/H) BREATHING RATE IN MAN
        8.035E+03  (M**3/Y)


DILFAC=       1.0 (CM), DEPTH OF WATER
USEFAC=     0.000, FRACTION OF TIME SPENT SWIMMING
```

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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NUMST=1, NUMBER OF SOURCES

NNUCS=24; NUMBER OF NUCLIDES

	SOURCE #:	1
PH,	HEIGHT (M)	20.0
DIA,	DIAMETER (M)	0.00
VEL,	EXIT VELOCITY (M/S)	0.
QH,	HEAT RELEASE RATE (CAL/S)	0.
DIM,	SOURCE DIAMETER (M)	337.0
AREA	(M**2)	89197.0

OPTION(4)=1; MOMENTUM-TYPE PLUME

REL, NUCLIDE RELEASE RATE (CI/YR)

1	TH-232	1.120E-01
2	TH-228	1.120E-01
3	TH-234	1.640E+01
4	TH-230	9.170E-02
5	SR-90	2.600E-02
6	TC-99	1.480E-01
7	RU-106	2.760E-02
8	CS-137	1.910E-02
9	RA-226	1.120E-03
10	RA-228	1.250E-03
11	PA-234M	5.720E+00
12	NP-237	1.970E-03
13	PU-238	1.040E-03
14	PU-239	1.770E-02
15	PU-240	1.770E-02
16	U-234	5.250E-01
17	U-235	2.560E-02
18	U-235	7.290E-01
19	U-234	4.470E-01
20	U-235	2.180E-02
21	U-238	6.210E-01
22	U-234	2.810E-01
23	U-235	1.580E-02
24	U-238	2.290E-01

AIRDOS PREPROCESSOR

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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INDEX	NAME	ANLAM 1/D	SC 1/S	VD M/S	VG M/S
1	TH-232	1.350E-13	3.319E-06	6.577E-04	3.551E-05
2	TH-228	9.919E-04	3.319E-06	6.577E-04	3.551E-05
3	TH-234	2.877E-02	3.319E-06	6.577E-04	3.551E-05
4	TH-230	2.464E-08	3.319E-06	6.577E-04	3.551E-05
5	SR-90	6.635E-05	3.319E-06	6.577E-04	3.551E-05
6	TC-99	8.914E-09	3.319E-06	6.577E-04	3.551E-05
7	RU-106	1.883E-03	3.319E-06	6.577E-04	3.551E-05
8	CS-137	6.288E-05	3.319E-06	6.577E-04	3.551E-05
9	RA-226	1.187E-06	3.319E-06	6.577E-04	3.551E-05
10	RA-228	3.301E-04	3.319E-06	6.577E-04	3.551E-05
11	PA-234M	8.533E+02	3.319E-06	6.577E-04	3.551E-05
12	NP-237	8.872E-10	3.319E-06	6.577E-04	3.551E-05
13	PU-238	2.163E-05	3.319E-06	6.577E-04	3.551E-05
14	PU-239	7.860E-08	3.319E-06	6.577E-04	3.551E-05
15	PU-240	2.904E-07	3.319E-06	6.577E-04	3.551E-05
16	U-234	7.763E-09	3.319E-06	6.577E-04	3.551E-05
17	U-235	2.697E-12	3.319E-06	6.577E-04	3.551E-05
18	U-235	2.697E-12	3.319E-06	6.577E-04	3.551E-05
19	U-234	7.763E-09	3.319E-06	6.577E-04	3.551E-05
20	U-235	2.697E-12	3.319E-06	6.577E-04	3.551E-05
21	U-238	4.247E-13	3.319E-06	6.577E-04	3.551E-05
22	U-234	7.763E-09	3.319E-06	6.577E-04	3.551E-05
23	U-235	2.697E-12	3.319E-06	6.577E-04	3.551E-05
24	U-238	4.247E-13	3.319E-06	6.577E-04	3.551E-05

***NOTE: VG SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

***NOTE: ANLAM SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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FOR EACH STABILITY CLASS

UDCAT, HARMONIC AVERAGE WIND SPEEDS

	A	B	C	D	E	F	G	PERD, WIND FREQUENCY
N	0.000E+00	1.786E+00	3.307E+00	3.345E+00	2.853E+00	1.785E+00	7.717E-01	1.067E-01
NNW	0.000E+00	2.208E+00	4.720E+00	3.085E+00	2.907E+00	1.641E+00	7.717E-01	3.950E-02
NW	2.572E+00	1.861E+00	2.564E+00	2.932E+00	2.803E+00	1.381E+00	7.717E-01	3.729E-02
WNW	2.572E+00	3.081E+00	2.498E+00	4.121E+00	2.725E+00	1.698E+00	7.717E-01	4.452E-02
W	2.572E+00	3.506E+00	3.972E+00	4.011E+00	3.020E+00	2.152E+00	7.717E-01	6.443E-02
WSW	0.000E+00	1.900E+00	2.835E+00	4.158E+00	3.389E+00	1.834E+00	7.717E-01	6.143E-02
SW	1.453E+00	1.631E+00	2.273E+00	3.838E+00	3.239E+00	1.875E+00	7.717E-01	4.707E-02
SSW	0.000E+00	1.066E+00	2.748E+00	4.183E+00	3.148E+00	1.698E+00	7.717E-01	3.853E-02
S	7.717E-01	2.572E+00	3.193E+00	4.481E+00	3.836E+00	2.106E+00	7.717E-01	7.075E-02
SSE	0.000E+00	3.542E+00	2.152E+00	3.934E+00	3.726E+00	2.279E+00	7.717E-01	2.823E-02
SE	0.000E+00	2.077E+00	3.390E+00	4.332E+00	3.545E+00	2.279E+00	7.717E-01	4.961E-02
ESE	0.000E+00	3.839E+00	3.223E+00	4.577E+00	3.613E+00	2.279E+00	7.717E-01	5.582E-02
E	2.572E+00	1.861E+00	3.739E+00	5.286E+00	3.784E+00	1.983E+00	0.000E+00	9.183E-02
ENE	0.000E+00	1.992E+00	3.106E+00	4.584E+00	3.196E+00	1.495E+00	7.717E-01	9.012E-02
NE	2.572E+00	2.181E+00	3.451E+00	4.333E+00	3.160E+00	1.548E+00	7.717E-01	9.067E-02
NNE	2.572E+00	1.635E+00	3.607E+00	4.235E+00	3.051E+00	1.712E+00	7.717E-01	8.351E-02

UDAV, ARITHMETIC AVERAGE WIND SPEEDS

N	0.000E+00	2.445E+00	3.766E+00	4.566E+00	3.003E+00	2.232E+00	7.717E-01
NNW	0.000E+00	2.776E+00	4.884E+00	4.255E+00	3.076E+00	2.135E+00	7.717E-01
NW	2.572E+00	2.572E+00	3.354E+00	3.733E+00	2.932E+00	1.907E+00	7.717E-01
WNW	2.572E+00	3.295E+00	4.169E+00	5.095E+00	2.818E+00	2.175E+00	7.717E-01
W	2.572E+00	3.737E+00	4.489E+00	4.661E+00	3.221E+00	2.422E+00	7.717E-01
WSW	0.000E+00	2.827E+00	3.835E+00	5.069E+00	3.626E+00	2.262E+00	7.717E-01
SW	1.978E+00	2.572E+00	3.196E+00	4.544E+00	3.473E+00	2.285E+00	7.717E-01
SSW	0.000E+00	1.978E+00	4.029E+00	4.735E+00	3.372E+00	2.175E+00	7.717E-01
S	7.717E-01	2.572E+00	4.215E+00	5.066E+00	4.013E+00	2.401E+00	7.717E-01
SSE	0.000E+00	3.770E+00	3.533E+00	4.980E+00	3.926E+00	2.473E+00	7.717E-01
SE	0.000E+00	2.572E+00	3.734E+00	5.343E+00	3.773E+00	2.473E+00	7.717E-01
ESE	0.000E+00	4.015E+00	4.020E+00	5.748E+00	3.832E+00	2.473E+00	7.717E-01
E	2.572E+00	2.847E+00	4.556E+00	6.095E+00	3.972E+00	2.343E+00	0.000E+00
ENE	0.000E+00	2.782E+00	4.110E+00	5.718E+00	3.426E+00	2.017E+00	7.717E-01
NE	2.572E+00	2.782E+00	4.234E+00	5.362E+00	3.385E+00	2.062E+00	7.717E-01
NNE	2.572E+00	2.687E+00	4.211E+00	5.429E+00	3.258E+00	2.184E+00	7.717E-01

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

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FOR EACH STABILITY CLASS

FRAW, FREQUENCIES OF STABILITY CLASSES

	A	B	C	D	E	F	G
N	0.000E+00	4.509E-02	5.877E-02	4.871E-01	1.478E-01	1.428E-01	1.185E-01
NNW	0.000E+00	7.823E-02	4.329E-02	5.142E-01	2.170E-01	9.165E-02	5.570E-02
NW	1.850E-02	4.586E-02	1.217E-01	3.974E-01	1.381E-01	1.459E-01	1.325E-01
WNW	7.637E-03	3.863E-02	4.650E-02	5.252E-01	1.696E-01	1.384E-01	7.412E-02
W	5.277E-03	9.049E-02	1.127E-01	4.271E-01	1.332E-01	1.800E-01	5.122E-02
WSW	0.000E+00	7.814E-02	1.182E-01	3.974E-01	2.289E-01	1.416E-01	3.581E-02
SW	2.188E-02	7.287E-02	1.190E-01	5.339E-01	1.020E-01	1.387E-01	1.168E-02
SSW	0.000E+00	5.346E-02	8.072E-02	5.173E-01	1.601E-01	1.599E-01	2.855E-02
S	4.806E-03	3.873E-02	7.830E-02	6.557E-01	9.696E-02	1.177E-01	7.774E-03
SSE	0.000E+00	7.297E-02	7.474E-02	7.070E-01	4.853E-02	7.722E-02	1.948E-02
SE	0.000E+00	5.523E-02	6.309E-02	7.277E-01	6.229E-02	5.846E-02	3.326E-02
ESE	0.000E+00	3.063E-02	9.871E-02	7.015E-01	6.145E-02	7.811E-02	2.956E-02
E	7.514E-03	4.846E-02	9.365E-02	6.468E-01	1.008E-01	1.027E-01	0.000E+00
ENE	0.000E+00	6.469E-02	1.580E-01	5.455E-01	7.235E-02	1.046E-01	5.482E-02
NE	3.750E-03	6.430E-02	1.029E-01	4.890E-01	1.172E-01	1.319E-01	9.088E-02
NNE	4.071E-03	6.562E-02	1.206E-01	3.869E-01	1.726E-01	1.779E-01	7.233E-02
TOTAL	4.110E-03	5.829E-02	9.635E-02	5.343E-01	1.262E-01	1.269E-01	5.385E-02

LIDAI= 900, HEIGHT OF LID (M)

RR= 99.2, RAINFALL RATE (CM/Y)

TA= 12.0, AVERAGE AIR TEMPERATURE (DEG C)
285.2 (K)

TG= 0.005 0.028 0.040, VERTICAL TEMPERATURE GRADIENT FOR STABILITIES E,F,G (K/M)

Z0= 0.030, SURFACE ROUGHNESS LENGTH (M)

Z= 10.0, HEIGHT OF WIND MEASUREMENTS (M)

UBAR= 4.09, AVERAGE WIND SPEED (M/S)

STAR INPUT, WIND FREQUENCIES

CLASS: A

N	3.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	3.400E-04	6.900E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	0.000E+00	3.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	0.000E+00	3.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	0.000E+00	6.900E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	0.000E+00	3.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SW	0.000E+00	3.400E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	0.000E+00	6.900E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

CLASS: B

N	0.000E+00	2.740E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	1.370E-03	0.000E+00	6.900E-04	0.000E+00	0.000E+00	0.000E+00
NE	1.030E-03	1.370E-03	1.030E-03	0.000E+00	0.000E+00	0.000E+00
ENE	1.030E-03	2.060E-03	1.710E-03	0.000E+00	0.000E+00	0.000E+00
E	0.000E+00	2.060E-03	3.770E-03	0.000E+00	0.000E+00	0.000E+00
ESE	0.000E+00	1.030E-03	6.900E-04	0.000E+00	0.000E+00	0.000E+00
SE	3.400E-04	1.030E-03	3.400E-04	0.000E+00	0.000E+00	0.000E+00
SSE	3.400E-04	2.060E-03	6.900E-04	0.000E+00	0.000E+00	0.000E+00
S	1.030E-03	3.090E-03	6.900E-04	0.000E+00	0.000E+00	0.000E+00
SSW	1.710E-03	1.710E-03	2.060E-03	0.000E+00	0.000E+00	0.000E+00
SW	6.900E-04	3.770E-03	1.370E-03	0.000E+00	0.000E+00	0.000E+00
WSW	1.030E-03	3.090E-03	1.710E-03	0.000E+00	0.000E+00	0.000E+00
W	1.030E-03	1.710E-03	1.710E-03	0.000E+00	0.000E+00	0.000E+00
WNW	0.000E+00	3.400E-04	1.370E-03	0.000E+00	0.000E+00	0.000E+00
NW	3.400E-04	2.060E-03	3.400E-04	0.000E+00	0.000E+00	0.000E+00
NNW	0.000E+00	6.900E-04	1.370E-03	0.000E+00	0.000E+00	0.000E+00

CLASS: C

N	3.900E-04	6.900E-04	3.770E-03	6.900E-04	0.000E+00	0.000E+00
NNE	3.700E-04	3.400E-04	2.060E-03	3.400E-04	0.000E+00	0.000E+00
NE	8.000E-04	2.060E-03	2.740E-03	0.000E+00	0.000E+00	0.000E+00
ENE	7.400E-04	6.900E-04	5.830E-03	0.000E+00	0.000E+00	0.000E+00
E	6.000E-05	1.370E-03	4.460E-03	1.370E-03	0.000E+00	0.000E+00
ESE	3.600E-04	0.000E+00	1.370E-03	3.400E-04	0.000E+00	0.000E+00
SE	4.300E-04	1.710E-03	2.400E-03	0.000E+00	0.000E+00	0.000E+00
SSE	0.000E+00	0.000E+00	1.370E-03	3.400E-04	0.000E+00	0.000E+00
S	1.000E-04	2.400E-03	3.430E-03	3.400E-04	0.000E+00	0.000E+00
SSW	1.300E-04	3.090E-03	5.140E-03	1.710E-03	0.000E+00	0.000E+00

SW	4.100E-04	1.370E-03	6.520E-03	1.030E-03	0.000E+00	0.000E+00
WSW	8.700E-04	3.770E-03	7.200E-03	2.400E-03	0.000E+00	0.000E+00
W	3.700E-04	3.400E-04	6.520E-03	1.370E-03	0.000E+00	0.000E+00
WNW	3.700E-04	3.400E-04	4.800E-03	0.000E+00	0.000E+00	0.000E+00
NW	4.000E-05	1.030E-03	2.060E-03	0.000E+00	0.000E+00	0.000E+00
NNW	3.900E-04	6.900E-04	6.900E-04	3.400E-04	0.000E+00	0.000E+00

STAR INPUT, WIND FREQUENCIES

CLASS: D

N	8.000E-05	6.520E-03	2.401E-02	1.475E-02	6.900E-04	3.400E-04
NNE	5.000E-05	3.770E-03	1.097E-02	4.800E-03	3.400E-04	0.000E+00
NE	1.000E-04	8.230E-03	9.600E-03	6.860E-03	3.400E-04	0.000E+00
ENE	4.000E-04	4.120E-03	1.097E-02	7.890E-03	1.030E-03	0.000E+00
E	9.000E-05	7.200E-03	1.235E-02	7.540E-03	3.400E-04	0.000E+00
ESE	4.000E-04	4.120E-03	1.063E-02	6.860E-03	1.030E-03	3.400E-04
SE	7.700E-04	6.170E-03	6.170E-03	1.710E-03	0.000E+00	0.000E+00
SSE	1.450E-03	4.800E-03	9.600E-03	4.460E-03	0.000E+00	0.000E+00
S	2.920E-03	1.132E-02	2.332E-02	1.303E-02	1.370E-03	0.000E+00
SSW	7.600E-04	4.800E-03	1.235E-02	1.166E-02	2.400E-03	3.400E-04
SW	7.800E-04	6.520E-03	1.715E-02	1.783E-02	1.370E-03	6.900E-04
WSW	4.700E-04	9.600E-03	1.097E-02	2.435E-02	2.740E-03	1.030E-03
W	7.000E-05	5.830E-03	1.715E-02	3.018E-02	5.140E-03	1.030E-03
WNW	7.500E-04	4.460E-03	1.337E-02	1.646E-02	4.120E-03	0.000E+00
NW	4.400E-04	7.200E-03	1.097E-02	1.612E-02	1.030E-03	3.400E-04
NNW	4.100E-04	4.800E-03	6.860E-03	7.200E-03	6.900E-04	0.000E+00

CLASS: E

N	0.000E+00	1.370E-03	5.490E-03	0.000E+00	0.000E+00	0.000E+00
NNE	0.000E+00	3.430E-03	2.740E-03	0.000E+00	0.000E+00	0.000E+00
NE	0.000E+00	2.400E-03	2.400E-03	0.000E+00	0.000E+00	0.000E+00
ENE	0.000E+00	5.830E-03	8.230E-03	0.000E+00	0.000E+00	0.000E+00
E	0.000E+00	5.490E-03	3.090E-03	0.000E+00	0.000E+00	0.000E+00
ESE	0.000E+00	6.520E-03	1.030E-03	0.000E+00	0.000E+00	0.000E+00
SE	0.000E+00	4.120E-03	1.030E-03	0.000E+00	0.000E+00	0.000E+00
SSE	0.000E+00	6.170E-03	2.400E-03	0.000E+00	0.000E+00	0.000E+00
S	0.000E+00	1.200E-02	3.770E-03	0.000E+00	0.000E+00	0.000E+00
SSW	0.000E+00	8.920E-03	5.490E-03	0.000E+00	0.000E+00	0.000E+00
SW	0.000E+00	5.830E-03	4.800E-03	0.000E+00	0.000E+00	0.000E+00
WSW	0.000E+00	3.430E-03	3.090E-03	0.000E+00	0.000E+00	0.000E+00
W	0.000E+00	2.060E-03	7.200E-03	0.000E+00	0.000E+00	0.000E+00
WNW	0.000E+00	1.030E-03	2.400E-03	0.000E+00	0.000E+00	0.000E+00
NW	0.000E+00	1.030E-03	2.060E-03	0.000E+00	0.000E+00	0.000E+00
NNW	0.000E+00	3.400E-04	1.030E-03	0.000E+00	0.000E+00	0.000E+00

CLASS: F

N	7.900E-04	7.540E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	1.360E-03	4.800E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	1.040E-03	5.490E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	1.500E-03	7.200E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	9.700E-04	1.063E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	1.360E-03	4.800E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	2.010E-03	3.430E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	8.800E-04	2.740E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	2.880E-03	1.235E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	3.200E-03	1.166E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00

SW	3.390E-03	8.570E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	2.910E-03	6.520E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	1.200E-03	8.230E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	2.400E-04	4.120E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	1.600E-04	2.740E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	1.200E-04	2.060E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

STAR INPUT, WIND FREQUENCIES

CLASS: G

N	5.500E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNE	1.100E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NE	5.500E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ENE	2.200E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
E	3.300E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ESE	3.300E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE	4.940E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSE	2.200E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
S	1.264E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SSW	6.040E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SW	8.240E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WSW	4.940E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
W	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
WNW	1.650E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NW	1.650E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NNW	5.500E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

AIRDOS PREPROCESSOR

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INDEX	NAME	AMAD MICRONS	ISOL CLASS	DENSITY RHO G/CC	DIAMETER PDIA MICRONS
1	TH-232	1.000	Y	1.00	1.000
2	TH-228	1.000	Y	1.00	1.000
3	TH-234	1.000	Y	1.00	1.000
4	TH-230	1.000	Y	1.00	1.000
5	SR-90	1.000	Y	1.00	1.000
6	TC-99	1.000	D	1.00	1.000
7	RU-106	1.000	D	1.00	1.000
8	CS-137	1.000	D	1.00	1.000
9	RA-226	1.000	W	1.00	1.000
10	RA-228	1.000	W	1.00	1.000
11	PA-234M	1.000	Y	1.00	1.000
12	NP-237	1.000	W	1.00	1.000
13	PU-238	1.000	Y	1.00	1.000
14	PU-239	1.000	Y	1.00	1.000
15	PU-240	1.000	Y	1.00	1.000
16	U-234	1.000	Y	1.00	1.000
17	U-235	1.000	Y	1.00	1.000
18	U-235	1.000	Y	1.00	1.000
19	U-234	1.000	W	1.00	1.000
20	U-235	1.000	W	1.00	1.000
21	U-238	1.000	W	1.00	1.000
22	U-234	1.000	D	1.00	1.000
23	U-235	1.000	D	1.00	1.000
24	U-238	1.000	D	1.00	1.000

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INDEX	NAME	UPTAKE-INH F1INH	UPTAKE-ING F1ING	DCF-AIR CFSBA (A)	DCF-H2O CFSBW (A)	DCF-SURFACE CFSUR (B)
1	TH-232	0.0002	0.0002	1.034E+00	2.612E-03	2.363E-03
2	TH-228	0.0002	0.0002	2.777E+00	6.625E-03	3.055E-03
3	TH-234	0.0002	0.0002	8.229E+00	1.958E-02	4.473E-03
4	TH-230	0.0002	0.0002	1.224E+00	3.064E-03	2.418E-03
5	SR-90	0.0100	0.3000	0.000E+00	0.000E+00	0.000E+00
6	TC-99	0.8000	0.8000	4.769E-04	1.110E-06	1.127E-07
7	RU-106	0.0500	0.0500	0.000E+00	0.000E+00	0.000E+00
8	CS-137	0.9500	0.9500	0.000E+00	0.000E+00	0.000E+00
9	RA-226	0.2000	0.2000	6.414E+00	1.431E-02	1.612E-03
10	RA-228	0.2000	0.2000	3.549E-06	8.904E-09	7.385E-09
11	PA-234M	0.0010	0.0010	1.118E+01	2.427E-02	2.245E-03
12	NP-237	0.0010	0.0010	2.967E+01	7.132E-02	2.338E-02
13	PU-238	0.0010	0.0010	1.372E+00	3.511E-03	3.304E-03
14	PU-239	0.0001	0.0001	5.655E-01	1.431E-03	1.270E-03
15	PU-240	0.0001	0.0001	1.304E+00	3.351E-03	3.144E-03
16	U-234	0.0020	0.0020	1.270E+00	3.233E-03	3.009E-03
17	U-235	0.0020	0.0020	1.443E+02	3.233E-01	3.988E-02
18	U-235	0.0020	0.0020	1.443E+02	3.233E-01	3.988E-02
19	U-234	0.0500	0.0500	1.270E+00	3.233E-03	3.009E-03
20	U-235	0.0500	0.0500	1.443E+02	3.233E-01	3.988E-02
21	U-238	0.0500	0.0500	1.038E+00	2.654E-03	2.519E-03
22	U-234	0.0500	0.0020	1.270E+00	3.233E-03	3.009E-03
23	U-235	0.0500	0.0020	1.443E+02	3.233E-01	3.988E-02
24	U-238	0.0500	0.0020	1.038E+00	2.654E-03	2.519E-03

(A) (REM-CM**3)/(MICROCI-H)
(B) (REM-CM**2)/(MICROCI-H)
(C) (REM-CM**3)/(PCI-YEAR)

FROG - EXTERNAL DOSE CORRECTION FACTOR

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	TH-232	7.933E-02	4.324E-02	1.150E-01	9.831E-02	2.207E-01	6.568E-02	5.507E-02	5.197E-02	5.793E-02	4.120E-02	6.201E-02
2	TH-228	3.337E-01	2.673E-01	5.179E-01	4.526E-01	5.635E-01	3.205E-01	2.825E-01	2.755E-01	2.916E-01	2.278E-01	2.992E-01
3	TH-234	4.263E-01	2.927E-01	7.330E-01	6.202E-01	7.586E-01	4.167E-01	3.593E-01	3.455E-01	3.757E-01	2.712E-01	3.906E-01
4	TH-230	1.444E-01	9.477E-02	2.243E-01	1.930E-01	3.143E-01	1.316E-01	1.127E-01	1.077E-01	1.182E-01	8.650E-02	1.237E-01
5	SR-90	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	TC-99	5.089E-01	3.662E-01	8.721E-01	7.332E-01	8.659E-01	4.997E-01	4.352E-01	4.214E-01	4.511E-01	3.343E-01	4.617E-01
7	RU-106	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	CS-137	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	RA-226	5.183E-01	4.820E-01	7.365E-01	6.708E-01	7.563E-01	5.005E-01	4.518E-01	4.469E-01	4.584E-01	3.860E-01	4.709E-01
10	RA-228	7.800E-03	1.913E-04	9.484E-04	3.696E-04	5.788E-02	5.847E-04	1.509E-04	1.222E-04	7.190E-06	4.314E-04	8.866E-07
11	PA-234M	5.396E-01	5.395E-01	5.961E-01	6.791E-01	6.451E-01	5.357E-01	4.980E-01	4.980E-01	5.018E-01	4.339E-01	5.282E-01
12	NP-237	3.535E-01	2.573E-01	5.758E-01	4.962E-01	6.383E-01	3.383E-01	2.943E-01	2.863E-01	3.042E-01	2.303E-01	3.213E-01
13	PU-238	2.606E-02	4.396E-03	1.737E-02	1.420E-02	1.500E-01	9.776E-03	6.518E-03	5.546E-03	5.933E-03	5.626E-03	6.671E-03
14	PU-239	6.506E-02	3.931E-02	8.056E-02	6.825E-02	2.014E-01	4.878E-02	4.177E-02	4.068E-02	4.132E-02	3.491E-02	4.199E-02
15	PU-240	2.690E-02	4.755E-03	1.879E-02	1.553E-02	1.520E-01	1.054E-02	7.116E-03	6.107E-03	6.631E-03	6.049E-03	7.537E-03
16	U-234	5.217E-02	2.478E-02	6.377E-02	5.447E-02	1.837E-01	3.687E-02	3.026E-02	2.861E-02	3.102E-02	2.375E-02	3.354E-02
17	U-235	5.166E-01	4.794E-01	7.395E-01	6.723E-01	7.542E-01	4.998E-01	4.502E-01	4.461E-01	4.560E-01	3.829E-01	4.677E-01
18	U-235	5.166E-01	4.794E-01	7.395E-01	6.723E-01	7.542E-01	4.998E-01	4.502E-01	4.461E-01	4.560E-01	3.829E-01	4.677E-01
19	U-234	5.217E-02	2.478E-02	6.377E-02	5.447E-02	1.837E-01	3.687E-02	3.026E-02	2.861E-02	3.102E-02	2.375E-02	3.354E-02
20	U-235	5.166E-01	4.794E-01	7.395E-01	6.723E-01	7.542E-01	4.998E-01	4.502E-01	4.461E-01	4.560E-01	3.829E-01	4.677E-01
21	U-238	4.245E-02	1.552E-02	4.958E-02	4.145E-02	1.703E-01	2.751E-02	2.182E-02	2.006E-02	2.267E-02	1.634E-02	2.406E-02
22	U-234	5.217E-02	2.478E-02	6.377E-02	5.447E-02	1.837E-01	3.687E-02	3.026E-02	2.861E-02	3.102E-02	2.375E-02	3.354E-02
23	U-235	5.166E-01	4.794E-01	7.395E-01	6.723E-01	7.542E-01	4.998E-01	4.502E-01	4.461E-01	4.560E-01	3.829E-01	4.677E-01
24	U-238	4.245E-02	1.552E-02	4.958E-02	4.145E-02	1.703E-01	2.751E-02	2.182E-02	2.006E-02	2.267E-02	1.634E-02	2.406E-02

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

CFINHA - DCF FOR INHALATION (REM/MICROCI)

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	TH-232	2.476E+02	2.889E+02	3.600E+03	1.289E+00	1.294E+00	9.105E+02	1.309E+00	1.403E+00	8.053E+00	1.315E+00	1.314E+00
2	TH-228	5.509E+02	2.890E+01	3.533E+02	8.122E-01	8.178E-01	2.624E+03	9.572E-01	2.609E+00	3.678E+00	8.319E-01	1.381E+00
3	TH-234	8.593E-02	8.927E-04	1.518E-03	4.462E-05	5.857E-05	4.046E-01	1.875E-03	4.201E-02	2.116E-04	8.025E-05	4.375E-05
4	TH-230	2.480E+02	2.824E+02	3.517E+03	6.466E-01	6.468E-01	9.214E+02	6.457E-01	7.003E-01	5.468E+00	6.467E-01	6.466E-01
5	SR-90	1.685E+00	1.112E-01	2.510E-01	9.808E-04	9.809E-04	7.922E+00	3.002E-02	5.298E-01	1.839E-03	9.808E-04	9.808E-04
6	TC-99	1.722E-03	1.755E-04	1.755E-04	4.536E-03	1.755E-04	1.805E-03	9.266E-03	4.198E-04	2.304E-04	1.755E-04	1.755E-04
7	RU-106	5.609E-02	5.348E-02	5.225E-02	5.394E-02	5.372E-02	7.623E-02	2.931E-02	4.959E-02	5.372E-02	5.324E-02	5.420E-02
8	CS-137	3.039E-02	2.901E-02	2.029E-02	3.378E-02	3.190E-02	3.394E-02	2.311E-02	1.871E-02	3.184E-02	2.952E-02	3.359E-02
9	RA-226	2.081E+01	2.754E+00	3.058E+01	6.088E-01	6.096E-01	9.593E+01	6.078E-01	6.951E-01	4.275E-01	6.095E-01	7.936E-01
10	RA-228	4.058E+00	1.332E+00	1.319E+01	4.487E-01	4.496E-01	1.679E+01	4.509E-01	4.885E-01	8.587E-01	4.514E-01	4.604E-01
11	PA-234M	4.492E-06	2.650E-09	1.972E-09	2.478E-09	2.703E-09	2.160E-05	9.680E-08	8.978E-09	4.290E-09	4.599E-09	1.990E-09
12	NP-237	4.007E+02	9.102E+02	1.125E+04	1.404E+01	1.406E+01	1.094E+02	1.396E+01	1.402E+01	2.227E+03	1.410E+01	1.409E+01
13	PU-238	3.572E+02	3.183E+02	3.925E+03	4.886E+00	4.886E+00	1.070E+03	4.867E+00	4.930E+00	8.155E+02	4.886E+00	4.886E+00
14	PU-239	3.728E+02	3.842E+02	4.731E+03	5.889E+00	5.889E+00	1.021E+03	5.864E+00	5.924E+00	9.565E+02	5.889E+00	5.889E+00
15	PU-240	3.724E+02	3.832E+02	4.719E+03	5.881E+00	5.881E+00	1.021E+03	5.856E+00	5.916E+00	9.543E+02	5.881E+00	5.881E+00
16	U-234	1.948E+02	2.751E-01	4.343E+00	9.855E-03	1.001E-02	9.382E+02	1.225E-02	6.762E-02	9.933E-03	9.872E-03	1.693E+00
17	U-235	1.803E+02	2.844E-01	4.213E+00	1.623E-02	2.131E-02	8.682E+02	3.557E-02	1.744E-01	2.788E-02	2.950E-02	1.574E+00
18	U-235	1.803E+02	2.844E-01	4.213E+00	1.623E-02	2.131E-02	8.682E+02	3.557E-02	1.744E-01	2.788E-02	2.950E-02	1.574E+00
19	U-234	2.001E+01	7.951E-01	1.256E+01	2.825E-02	2.826E-02	9.497E+01	3.024E-02	7.684E-02	2.826E-02	2.825E-02	4.857E+00
20	U-235	1.853E+01	7.821E-01	1.215E+01	2.790E-02	2.832E-02	8.789E+01	3.108E-02	9.108E-02	2.386E-02	2.873E-02	4.495E+00
21	U-238	1.775E+01	8.453E-01	1.091E+01	2.561E-02	2.571E-02	8.415E+01	2.785E-02	8.473E-02	2.254E-02	2.570E-02	4.339E+00
22	U-234	1.358E+00	2.645E+00	4.177E+01	9.397E-02	9.398E-02	1.656E+00	9.413E-02	1.084E-01	9.397E-02	9.397E-02	1.615E+01
23	U-235	1.288E+00	2.599E+00	4.041E+01	9.175E-02	9.224E-02	1.536E+00	9.120E-02	1.072E-01	7.609E-02	9.227E-02	1.495E+01
24	U-238	1.272E+00	2.797E+00	3.626E+01	8.450E-02	8.470E-02	1.463E+00	8.425E-02	9.755E-02	7.203E-02	8.458E-02	1.443E+01

AIRDOS PREPROCESSOR DATE 3/ 9/89 11:45:32

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

CFINGA - DCF FOR INGESTION (REM/MICROCI)

IN	NAME	W BODY	R MAR	ENDOST	THYROID	BREAST	*PUL*	S WALL	INT WALL	LIVER	PANCREAS	KIDNEYS
1	TH-232	2.152E-01	1.049E+00	1.310E+01	2.288E-03	2.291E-03	2.290E-03	5.726E-03	8.533E-02	1.900E-02	2.290E-03	2.262E-03
2	TH-228	7.716E-02	2.970E-01	3.635E+00	7.788E-03	7.873E-03	7.801E-03	1.265E-02	2.423E-01	3.429E-02	7.841E-03	9.547E-03
3	TH-234	3.743E-03	6.525E-05	7.303E-05	1.080E-06	1.186E-05	2.454E-06	3.694E-03	8.749E-02	1.445E-05	1.192E-05	1.231E-05
4	TH-230	2.362E-01	1.150E+00	1.433E+01	2.581E-03	2.581E-03	2.581E-03	6.614E-03	9.994E-02	2.183E-02	2.581E-03	2.581E-03
5	SR-90	1.118E-01	6.511E-01	1.478E+00	5.329E-03	5.329E-03	5.329E-03	3.555E-03	3.672E-02	5.710E-03	5.329E-03	5.329E-03
6	TC-99	1.916E-03	2.312E-04	2.312E-04	5.976E-03	2.312E-04	2.312E-04	1.255E-02	2.203E-03	3.035E-04	2.312E-04	2.312E-04
7	RU-106	1.123E-02	5.635E-03	5.407E-03	5.530E-03	5.597E-03	5.468E-03	9.109E-03	1.431E-01	5.573E-03	5.548E-03	5.654E-03
8	CS-137	4.446E-02	4.365E-02	3.052E-02	5.080E-02	4.799E-02	4.438E-02	3.568E-02	2.928E-02	4.786E-02	4.440E-02	5.055E-02
9	RA-226	7.391E-01	2.311E+00	2.723E+01	3.325E-01	3.333E-01	3.329E-01	3.348E-01	4.973E-01	3.237E-01	3.331E-01	3.327E-01
10	RA-228	4.714E-01	9.784E-01	9.611E+00	3.319E-01	3.326E-01	3.320E-01	3.294E-01	3.693E-01	3.946E-01	3.323E-01	3.379E-01
11	PA-234M	8.115E-06	3.779E-09	1.863E-09	4.133E-10	4.067E-09	4.179E-09	9.630E-05	3.941E-07	5.484E-09	3.810E-08	8.798E-09
12	NP-237	3.146E+00	7.510E+00	9.278E+01	1.158E-01	1.160E-01	1.162E-01	1.196E-01	2.216E-01	1.836E+01	1.164E-01	1.163E-01
13	PU-238	2.883E+00	6.765E+00	8.342E+01	1.038E-01	1.038E-01	1.038E-01	1.081E-01	2.169E-01	1.712E+01	1.038E-01	1.038E-01
14	PU-239	3.431E-01	8.091E-01	9.964E+00	1.240E-02	1.240E-02	1.240E-02	1.676E-02	1.189E-01	1.981E+00	1.240E-02	1.240E-02
15	PU-240	3.424E-01	8.072E-01	9.939E+00	1.239E-02	1.239E-02	1.239E-02	1.677E-02	1.193E-01	1.977E+00	1.239E-02	1.239E-02
16	U-234	8.436E-03	1.084E-02	1.712E-01	3.851E-04	3.854E-04	3.851E-04	4.501E-03	9.916E-02	3.851E-04	3.852E-04	6.619E-02
17	U-235	8.600E-03	1.087E-02	1.656E-01	3.767E-04	4.626E-04	3.870E-04	4.545E-03	1.061E-01	3.722E-04	4.683E-04	6.136E-02
18	U-235	8.600E-03	1.087E-02	1.656E-01	3.767E-04	4.626E-04	3.870E-04	4.545E-03	1.061E-01	3.722E-04	4.683E-04	6.136E-02
19	U-234	1.098E-01	2.709E-01	4.279E+00	9.626E-03	9.627E-03	9.627E-03	1.369E-02	1.036E-01	9.626E-03	9.627E-03	1.655E+00
20	U-235	1.056E-01	2.664E-01	4.139E+00	9.399E-03	9.527E-03	9.439E-03	1.344E-02	1.100E-01	7.847E-03	9.536E-03	1.532E+00
21	U-238	1.047E-01	2.864E-01	3.714E+00	8.652E-03	8.678E-03	8.664E-03	1.221E-02	9.527E-02	7.361E-03	8.666E-03	1.478E+00
22	U-234	8.436E-03	1.084E-02	1.712E-01	3.851E-04	3.854E-04	3.851E-04	4.501E-03	9.916E-02	3.851E-04	3.852E-04	6.619E-02
23	U-235	8.600E-03	1.087E-02	1.656E-01	3.767E-04	4.626E-04	3.870E-04	4.545E-03	1.061E-01	3.722E-04	4.683E-04	6.136E-02
24	U-238	7.905E-03	1.147E-02	1.486E-01	3.461E-04	3.537E-04	3.473E-04	3.984E-03	9.141E-02	2.980E-04	3.521E-04	5.915E-02

AIRDOS PREPROCESSOR

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INDEX	NAME	LAMRR 1/D	KFLAG	LAMSUR 1/D	LAMH2O 1/D	IFLAG	RD1	RD2	RW1	RW2
1	TH-232	1.350E-13	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
2	TH-228	9.919E-04	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
3	TH-234	2.877E-02	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
4	TH-230	2.464E-08	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
5	SR-90	6.635E-05	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
6	TC-99	8.914E-09	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
7	RU-106	1.883E-03	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
8	CS-137	6.288E-05	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
9	RA-226	1.187E-06	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
10	RA-228	3.301E-04	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
11	PA-234M	8.533E+02	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
12	NP-237	8.872E-10	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
13	PU-238	2.163E-05	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
14	PU-239	7.860E-08	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
15	PU-240	2.904E-07	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
16	U-234	7.763E-09	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
17	U-235	2.697E-12	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
18	U-235	2.697E-12	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
19	U-234	7.763E-09	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
20	U-235	2.697E-12	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
21	U-238	4.247E-13	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
22	U-234	7.763E-09	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
23	U-235	2.697E-12	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		
24	U-238	4.247E-13	0	0.000E+00	0.000E+00	0	0.000E+00	0.000E+00		

AIRDOS PREPROCESSOR

LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INDEX	NAME	PASTURE BSUBV1 DRY/SOIL	CROPS BSUBV2 FRESH/SOIL	MILK FSUBMI D/L	MEAT FSUBFI D/KG
1	TH-232	6.300E-03	3.500E-04	5.000E-06	1.600E-06
2	TH-228	6.300E-03	3.500E-04	5.000E-06	1.600E-06
3	TH-234	6.300E-03	3.500E-04	5.000E-06	1.600E-06
4	TH-230	6.300E-03	3.500E-04	5.000E-06	1.600E-06
5	SR-90	2.400E+00	2.200E-01	1.100E-03	3.000E-04
6	TC-99	2.200E+02	1.100E+00	9.900E-03	8.700E-03
7	RU-106	1.700E-01	1.600E-02	6.100E-07	1.800E-03
8	CS-137	1.400E-01	9.100E-03	5.600E-03	1.400E-02
9	RA-226	1.000E-01	2.000E-02	5.900E-04	5.000E-04
10	RA-228	1.000E-01	2.000E-02	5.900E-04	5.000E-04
11	PA-234M	1.000E-02	2.500E-03	5.000E-06	1.600E-06
12	NP-237	1.000E-01	4.280E-03	5.000E-06	5.500E-05
13	PU-238	6.700E-03	1.100E-03	5.300E-08	1.900E-08
14	PU-239	6.700E-03	1.100E-03	5.300E-08	1.900E-08
15	PU-240	6.700E-03	1.100E-03	5.300E-08	1.900E-08
16	U-234	2.100E-02	4.200E-03	1.400E-04	1.600E-06
17	U-235	2.100E-02	4.200E-03	1.400E-04	1.600E-06
18	U-235	2.100E-02	4.200E-03	1.400E-04	1.600E-06
19	U-234	2.100E-02	4.200E-03	1.400E-04	1.600E-06
20	U-235	2.100E-02	4.200E-03	1.400E-04	1.600E-06
21	U-238	2.100E-02	4.200E-03	1.400E-04	1.600E-06
22	U-234	2.100E-02	4.200E-03	1.400E-04	1.600E-06
23	U-235	2.100E-02	4.200E-03	1.400E-04	1.600E-06
24	U-238	2.100E-02	4.200E-03	1.400E-04	1.600E-06

```
IMPFIX=0, FRACTIONS OF FOOD FROM OUTSIDE AREA CAN BE GREATER THAN FRACTIONS BELOW

  RVEG=1.000E+00 VEG. ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3VEGM=7.000E-01 MINIMUM FRACTION VEG. INGESTED FROM OUTSIDE AREA

  RBEF=1.000E+00 MEAT ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3BEFM=7.000E-01 MINIMUM FRACTION MEAT INGESTED FROM OUTSIDE AREA

  RMLK=1.000E+00 MILK ING. RATIO-IMMEDIATE AREA/TOTAL WITHIN AREA
F3MLKM=7.000E-01 MINIMUM FRACTION MILK INGESTED FROM OUTSIDE AREA

FOOD SUPPLY FRACTIONS:
                LOCAL   REGIONAL  EXTERNAL
VEGETABLES:     0.300     0.000     0.700
      MEAT:     0.300     0.000     0.700
      MILK:     0.300     0.000     0.700

  LAMW=2.900E-03 REMOVAL RATE CONSTANT FOR WEATHERING (1/H)

TSUBH1=0.000E+00 TIME DELAY--INGESTION OF PASTURE (H)
TSUBH2=2.160E+03 TIME DELAY--INGESTION OF FEED  (H)
TSUBH3=3.360E+02 TIME DELAY--INGESTION OF LEAFY VEGETABLES (H)
TSUBH4=3.360E+02 TIME DELAY--INGESTION OF PRODUCE (H)

TSUBE1=7.200E+02 PERIOD OF EXPOSURE--GRASS (H)
TSUBE2=1.440E+03 PERIOD OF EXPOSURE--CROPS (H)

YSUBV1=2.800E-01 PRODUCTIVITY: GRASS-MAN (KG/M**2)
YSUBV2=7.160E-01 PRODUCTIVITY: PRODUCE-MAN (KG/M**2)

 FSUBP=4.000E-01 FRACTION OF YEAR ANIMALS GRAZE

 FSUBS=4.300E-01 FRACTION OF FEED THAT IS PASTURE

 QSUBF=1.560E+01 CONSUMPTION RATE BY ANIMAL (KG-DRY WEIGHT/D)

 TSUBF=2.000E+00 TRANSPORT TIME FOR FEED-MILK-MAN (D)

 TSUBS=2.000E+01 AVERAGE TIME FROM SLAUGHTER OF MEAT TO CONSUMPTION (D)

 FSUBG=1.000E+00 FRACTION OF PRODUCE INGESTED GROWN IN GARDEN

 FSUBL=1.000E+00 FRACTION OF LEAFY VEGETABLES GROWN IN GARDEN

     P=2.150E+02 EFFECTIVE SURFACE DENSITY OF SOIL (KG/M**2)

TAUBEF=3.810E-03 FRACTION OF HERD SLAUGHTERED (1/D)

 MSUBB=2.000E+02 MUSCLE MASS OF ANIMAL AT SLAUGHTER (KG)

 VSUBM=1.100E+01 MILK PRODUCTION OF COW (L/DAY)
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R1=5.700E-01 FALLOUT INTERCEPTION FRACTION-PASTURE

R2=2.000E-01 FALLOUT INTERCEPTION FRACTION-VEGETABLES

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INTFC, AREA OF VEGETABLE CROP PRODUCTION (M**2)

	1100	2400	4000	5600	7200	12000	24000
N	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NNW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
WNW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
W	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
WSW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SSW	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
S	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SSE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
SE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
ESE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
E	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
ENE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06
NNE	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06	8.530E+06

NOBCT, NUMBER OF BEEF CATTLE

	1100	2400	4000	5600	7200	12000	24000
N	311	311	311	311	311	311	311
NNW	311	311	311	311	311	311	311
NW	311	311	311	311	311	311	311
WNW	311	311	311	311	311	311	311
W	311	311	311	311	311	311	311
WSW	311	311	311	311	311	311	311
SW	311	311	311	311	311	311	311
SSW	311	311	311	311	311	311	311
S	311	311	311	311	311	311	311
SSE	311	311	311	311	311	311	311
SE	311	311	311	311	311	311	311
ESE	311	311	311	311	311	311	311
E	311	311	311	311	311	311	311
ENE	311	311	311	311	311	311	311
NE	311	311	311	311	311	311	311
NNE	311	311	311	311	311	311	311

NOMCT, NUMBER OF MILK CATTLE

N	47	47	47	47	47	47	47
NNW	47	47	47	47	47	47	47
NW	47	47	47	47	47	47	47
WNW	47	47	47	47	47	47	47
W	47	47	47	47	47	47	47
WSW	47	47	47	47	47	47	47
SW	47	47	47	47	47	47	47
SSW	47	47	47	47	47	47	47
S	47	47	47	47	47	47	47
SSE	47	47	47	47	47	47	47
SE	47	47	47	47	47	47	47
ESE	47	47	47	47	47	47	47
E	47	47	47	47	47	47	47
ENE	47	47	47	47	47	47	47
NE	47	47	47	47	47	47	47
NNE	47	47	47	47	47	47	47

AIRDOS PREPROCESSOR
LISTING OF AIRDOS INPUT AND PREPROCESSOR INPUT

DATE 3/ 9/89 11:45:32

INTPA, POPULATION

	1100	2400	4000	5600	7200	12000	24000
N	13	13	102	45	272	3395	6743
NNW	13	29	86	141	250	1134	21042
NW	0	22	294	102	93	1433	1802
WNW	3	10	19	61	64	1361	5211
W	0	10	16	192	301	1765	3292
WSW	3	6	38	669	224	4961	3930
SW	6	48	54	58	19	2957	13066
SSW	16	42	134	118	80	4217	10614
S	10	38	58	192	371	19214	53673
SSE	0	13	358	262	352	28932	207202
SE	6	493	176	214	717	36467	247846
ESE	6	3	118	218	368	54533	150630
E	0	19	26	243	224	40770	70762
ENE	3	134	2224	112	16	25780	29830
NE	6	323	68	61	41	32001	36705
NNE	3	10	90	54	64	18969	12805

INTWA, 1 DENOTES THE PRESENCE OF A SIGNIFICANT WATER AREA

N	1	1	1	1	1	1	1
NNW	1	1	1	1	1	1	1
NW	1	1	1	1	1	1	1
WNW	1	1	1	1	1	1	1
W	1	1	1	1	1	1	1
WSW	1	1	1	1	1	1	1
SW	1	1	1	1	1	1	1
SSW	1	1	1	1	1	1	1
S	1	1	1	1	1	1	1
SSE	1	1	1	1	1	1	1
SE	1	1	1	1	1	1	1
ESE	1	1	1	1	1	1	1
E	1	1	1	1	1	1	1
ENE	1	1	1	1	1	1	1
NE	1	1	1	1	1	1	1
NNE	1	1	1	1	1	1	1

APPENDIX C

APPENDIX C

CALCULATED 70-YEAR COMMITTED DOSE EQUIVALENTS TO THE SELECTED INDIVIDUAL FROM RADIONUCLIDE EMISSIONS OTHER THAN RADON (34-YEAR EMISSIONS, 1951 TO 1984)

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNGS
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	1.91E+04	2.47E+04	1.89E+04	1.24E+04	0.00E+00	1.02E+04	8.29E+03	0.00E+00
2400	8.57E+03	1.03E+04	7.46E+03	4.42E+03	3.85E+03	3.60E+03	3.11E+03	2.32E+03
4000	5.31E+03	6.00E+03	4.25E+03	2.34E+03	2.07E+03	1.87E+03	1.69E+03	1.28E+03
5600	3.77E+03	4.15E+03	2.91E+03	1.55E+03	1.38E+03	1.23E+03	1.13E+03	8.58E+02
7200	2.87E+03	3.11E+03	2.17E+03	1.13E+03	1.01E+03	8.86E+02	8.32E+02	6.32E+02
12000	1.58E+03	1.68E+03	1.17E+03	5.88E+02	5.28E+02	4.57E+02	4.39E+02	3.36E+02
24000	6.44E+02	6.86E+02	4.70E+02	2.33E+02	2.10E+02	1.80E+02	1.75E+02	1.34E+02

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNGS
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	1.11E+04	1.00E+04	1.28E+04	1.19E+04	0.00E+00	7.43E+03	0.00E+00	8.88E+03	1.30E+04
2400	4.52E+03	4.02E+03	5.23E+03	4.89E+03	4.37E+03	3.19E+03	3.23E+03	3.64E+03	4.79E+03
4000	2.61E+03	2.28E+03	2.98E+03	2.82E+03	2.66E+03	1.94E+03	1.89E+03	2.11E+03	2.76E+03
5600	1.80E+03	1.56E+03	2.04E+03	1.94E+03	1.87E+03	1.37E+03	1.31E+03	1.45E+03	1.90E+03
7200	1.35E+03	1.16E+03	1.52E+03	1.45E+03	1.42E+03	1.04E+03	9.83E+02	1.08E+03	1.41E+03
12000	7.30E+02	6.22E+02	8.19E+02	7.85E+02	7.82E+02	5.74E+02	5.35E+02	5.85E+02	7.63E+02
24000	2.96E+02	2.52E+02	3.34E+02	3.20E+02	3.19E+02	2.33E+02	2.17E+02	2.37E+02	3.09E+02

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : ENDOST
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	5.87E+03	7.36E+03	5.68E+03	3.74E+03	0.00E+00	3.02E+03	2.50E+03	0.00E+00
2400	2.64E+03	3.13E+03	2.29E+03	1.35E+03	1.23E+03	1.07E+03	9.31E+02	6.72E+02
4000	1.64E+03	1.85E+03	1.32E+03	7.23E+02	6.58E+02	5.55E+02	5.04E+02	3.65E+02
5600	1.17E+03	1.29E+03	9.12E+02	4.79E+02	4.37E+02	3.63E+02	3.37E+02	2.44E+02
7200	8.90E+02	9.67E+02	6.82E+02	3.50E+02	3.18E+02	2.62E+02	2.47E+02	1.79E+02
12000	4.92E+02	5.27E+02	3.69E+02	1.83E+02	1.67E+02	1.35E+02	1.30E+02	9.46E+01
24000	2.00E+02	2.15E+02	1.49E+02	7.29E+01	6.63E+01	5.35E+01	5.21E+01	3.78E+01

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : ENDOST
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	3.30E+03	2.86E+03	3.62E+03	3.46E+03	0.00E+00	2.29E+03	0.00E+00	2.70E+03	3.87E+03
2400	1.32E+03	1.16E+03	1.48E+03	1.42E+03	1.37E+03	9.88E+02	9.88E+02	1.11E+03	1.45E+03
4000	7.55E+02	6.57E+02	8.43E+02	8.19E+02	8.28E+02	6.02E+02	5.81E+02	6.44E+02	8.34E+02
5600	5.18E+02	4.49E+02	5.76E+02	5.62E+02	5.82E+02	4.24E+02	4.03E+02	4.43E+02	5.74E+02
7200	3.86E+02	3.34E+02	4.28E+02	4.20E+02	4.40E+02	3.22E+02	3.02E+02	3.31E+02	4.29E+02
12000	2.08E+02	1.80E+02	2.31E+02	2.27E+02	2.42E+02	1.77E+02	1.65E+02	1.79E+02	2.32E+02
24000	8.41E+01	7.30E+01	9.44E+01	9.27E+01	9.89E+01	7.22E+01	6.68E+01	7.26E+01	9.38E+01

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) * 30 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : R MAR
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	4.65E+02	5.83E+02	4.49E+02	2.96E+02	0.00E+00	2.39E+02	1.98E+02	0.00E+00
2400	2.09E+02	2.48E+02	1.81E+02	1.07E+02	9.77E+01	8.45E+01	7.37E+01	5.31E+01
4000	1.30E+02	1.46E+02	1.05E+02	5.72E+01	5.21E+01	4.39E+01	3.99E+01	2.89E+01
5600	9.27E+01	1.02E+02	7.21E+01	3.79E+01	3.46E+01	2.87E+01	2.67E+01	1.93E+01
7200	7.05E+01	7.66E+01	5.39E+01	2.77E+01	2.52E+01	2.08E+01	1.96E+01	1.42E+01
12000	3.90E+01	4.17E+01	2.91E+01	1.45E+01	1.32E+01	1.07E+01	1.03E+01	7.49E+00
24000	1.59E+01	1.70E+01	1.18E+01	5.76E+00	5.25E+00	4.23E+00	4.12E+00	2.99E+00

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : R MAR
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	2.61E+02	2.26E+02	2.86E+02	2.74E+02	0.00E+00	1.82E+02	0.00E+00	2.14E+02	3.06E+02
2400	1.05E+02	9.15E+01	1.17E+02	1.13E+02	1.08E+02	7.84E+01	7.83E+01	8.80E+01	1.15E+02
4000	5.97E+01	5.21E+01	6.67E+01	6.48E+01	6.56E+01	4.77E+01	4.60E+01	5.10E+01	6.60E+01
5600	4.10E+01	3.56E+01	4.56E+01	4.45E+01	4.62E+01	3.37E+01	3.19E+01	3.51E+01	4.54E+01
7200	3.05E+01	2.65E+01	3.39E+01	3.32E+01	3.49E+01	2.55E+01	2.39E+01	2.62E+01	3.39E+01
12000	1.64E+01	1.42E+01	1.83E+01	1.80E+01	1.92E+01	1.41E+01	1.31E+01	1.42E+01	1.83E+01
24000	6.66E+00	5.78E+00	7.46E+00	7.34E+00	7.84E+00	5.72E+00	5.29E+00	5.75E+00	7.43E+00

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	1.69E+02	2.00E+02	1.47E+02	9.96E+01	0.00E+00	7.75E+01	6.97E+01	0.00E+00
2400	7.94E+01	9.18E+01	6.23E+01	3.64E+01	3.93E+01	2.74E+01	2.56E+01	1.64E+01
4000	5.12E+01	5.72E+01	3.74E+01	1.97E+01	2.08E+01	1.42E+01	1.36E+01	8.52E+00
5600	3.70E+01	4.08E+01	2.62E+01	1.31E+01	1.38E+01	9.29E+00	9.00E+00	5.57E+00
7200	2.84E+01	3.11E+01	1.98E+01	9.60E+00	1.00E+01	6.71E+00	6.56E+00	4.03E+00
12000	1.59E+01	1.72E+01	1.08E+01	5.05E+00	5.23E+00	3.46E+00	3.43E+00	2.09E+00
24000	6.45E+00	7.04E+00	4.39E+00	2.02E+00	2.08E+00	1.37E+00	1.37E+00	8.30E-01

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	8.30E+01	6.51E+01	7.87E+01	8.14E+01	0.00E+00	6.67E+01	0.00E+00	8.10E+01	1.01E+02
2400	3.21E+01	2.74E+01	3.24E+01	3.39E+01	4.36E+01	2.97E+01	2.99E+01	3.43E+01	4.01E+01
4000	1.75E+01	1.60E+01	1.88E+01	1.98E+01	2.66E+01	1.84E+01	1.79E+01	2.02E+01	2.36E+01
5600	1.17E+01	1.11E+01	1.30E+01	1.37E+01	1.88E+01	1.31E+01	1.25E+01	1.40E+01	1.64E+01
7200	8.56E+00	8.29E+00	9.73E+00	1.03E+01	1.42E+01	9.98E+00	9.44E+00	1.05E+01	1.23E+01
12000	4.53E+00	4.51E+00	5.29E+00	5.59E+00	7.84E+00	5.53E+00	5.16E+00	5.70E+00	6.71E+00
24000	1.84E+00	1.84E+00	2.15E+00	2.29E+00	3.20E+00	2.26E+00	2.10E+00	2.32E+00	2.72E+00

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LLI WALL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	2.86E+01	3.47E+01	2.65E+01	1.73E+01	0.00E+00	1.37E+01	1.18E+01	0.00E+00
2400	1.31E+01	1.53E+01	1.11E+01	6.46E+00	6.29E+00	5.03E+00	4.49E+00	3.13E+00
4000	8.14E+00	9.19E+00	6.49E+00	3.52E+00	3.41E+00	2.67E+00	2.46E+00	1.70E+00
5600	5.81E+00	6.46E+00	4.52E+00	2.37E+00	2.29E+00	1.77E+00	1.65E+00	1.14E+00
7200	4.44E+00	4.89E+00	3.40E+00	1.75E+00	1.69E+00	1.30E+00	1.22E+00	8.45E-01
12000	2.48E+00	2.70E+00	1.87E+00	9.39E-01	9.02E-01	6.88E-01	6.56E-01	4.53E-01
24000	1.02E+00	1.12E+00	7.76E-01	3.89E-01	3.73E-01	2.84E-01	2.72E-01	1.88E-01

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LLI WALL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	1.51E+01	1.26E+01	1.59E+01	1.54E+01	0.00E+00	1.11E+01	0.00E+00	1.31E+01	1.80E+01
2400	6.07E+00	5.24E+00	6.63E+00	6.46E+00	6.90E+00	4.87E+00	4.92E+00	5.52E+00	6.96E+00
4000	3.44E+00	3.02E+00	3.82E+00	3.75E+00	4.17E+00	2.97E+00	2.92E+00	3.23E+00	4.06E+00
5600	2.35E+00	2.08E+00	2.63E+00	2.59E+00	2.94E+00	2.10E+00	2.03E+00	2.24E+00	2.81E+00
7200	1.75E+00	1.56E+00	1.97E+00	1.94E+00	2.23E+00	1.59E+00	1.53E+00	1.68E+00	2.11E+00
12000	9.52E-01	8.51E-01	1.08E+00	1.07E+00	1.24E+00	8.86E-01	8.46E-01	9.24E-01	1.16E+00
24000	3.97E-01	3.55E-01	4.51E-01	4.46E-01	5.15E-01	3.68E-01	3.51E-01	3.83E-01	4.81E-01

CALCULATED INDIVIDUAL DOSE EQ. RATE(MREM) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : KIDNEY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	2.81E+02	3.51E+02	2.88E+02	1.77E+02	0.00E+00	1.47E+02	1.21E+02	0.00E+00
2400	1.25E+02	1.48E+02	1.17E+02	6.44E+01	5.95E+01	5.23E+01	4.53E+01	3.24E+01
4000	7.63E+01	8.73E+01	6.83E+01	3.46E+01	3.19E+01	2.73E+01	2.47E+01	1.75E+01
5600	5.39E+01	6.07E+01	4.72E+01	2.30E+01	2.12E+01	1.79E+01	1.65E+01	1.17E+01
7200	4.08E+01	4.56E+01	3.54E+01	1.68E+01	1.55E+01	1.30E+01	1.22E+01	8.56E+00
12000	2.25E+01	2.49E+01	1.92E+01	8.85E+00	8.13E+00	6.71E+00	6.42E+00	4.52E+00
24000	9.19E+00	1.02E+01	7.79E+00	3.54E+00	3.26E+00	2.67E+00	2.58E+00	1.81E+00

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : KIDNEY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	AVE
1100	1.61E+02	1.36E+02	1.81E+02	1.63E+02	0.00E+00	1.06E+02	0.00E+00	1.21E+02	1.86E+02
2400	6.42E+01	5.35E+01	7.39E+01	6.66E+01	6.24E+01	4.47E+01	4.60E+01	4.99E+01	6.91E+01
4000	3.62E+01	3.00E+01	4.20E+01	3.80E+01	3.75E+01	2.65E+01	2.70E+01	2.91E+01	3.96E+01
5600	2.47E+01	2.03E+01	2.87E+01	2.60E+01	2.63E+01	1.85E+01	1.88E+01	2.01E+01	2.72E+01
7200	1.83E+01	1.51E+01	2.13E+01	1.94E+01	1.99E+01	1.39E+01	1.41E+01	1.51E+01	2.03E+01
12000	9.86E+00	8.07E+00	1.15E+01	1.05E+01	1.09E+01	7.60E+00	7.68E+00	8.20E+00	1.10E+01
24000	4.00E+00	3.28E+00	4.69E+00	4.29E+00	4.46E+00	3.10E+00	3.12E+00	3.33E+00	4.45E+00

APPENDIX D

APPENDIX D

CALCULATED 70-YEAR COMMITTED DOSE EQUIVALENTS TO THE EXPOSED POPULATION FROM RADIONUCLIDE EMISSIONS OTHER THAN RADON (34-YEAR TOTAL EMISSIONS, 1951 TO 1984)

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNGS
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	2.48E+02	7.41E+01	1.13E+02	3.71E+01	0.00E+00	6.09E+01	4.97E+01	0.00E+00
2400	1.12E+02	1.03E+02	2.41E+03	5.93E+02	7.31E+01	1.08E+01	1.53E+03	3.01E+01
4000	5.42E+02	5.40E+02	2.89E+02	5.21E+03	5.37E+01	2.21E+02	2.98E+02	4.57E+02
5600	1.70E+02	2.24E+02	1.78E+02	1.74E+02	3.34E+02	2.67E+02	2.42E+02	2.25E+02
7200	7.80E+02	1.99E+02	8.89E+01	1.80E+01	2.25E+02	3.26E+02	5.96E+02	2.23E+02
12000	5.37E+03	3.20E+04	3.73E+04	1.52E+04	2.15E+04	2.49E+04	1.60E+04	9.71E+03
24000	4.34E+03	8.78E+03	1.73E+04	6.96E+03	1.48E+04	2.71E+04	4.34E+04	2.78E+04
SUM	1.16E+04	4.19E+04	5.77E+04	2.82E+00	3.70E+04	5.30E+04	6.22E+04	3.84E+04

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNGS
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	1.11E+02	1.60E+02	7.67E+01	3.57E+01	0.00E+00	2.23E+01	0.00E+00	1.16E+02	1.10E+03
2400	1.71E+02	1.69E+02	2.51E+02	2.94E+01	4.37E+01	3.19E+01	7.11E+01	1.06E+02	5.74E+03
4000	1.52E+02	3.06E+02	1.61E+02	1.07E+02	4.25E+01	3.70E+01	5.56E+02	1.81E+02	9.15E+03
5600	3.46E+02	1.84E+02	1.18E+02	1.30E+03	3.60E+02	8.38E+01	1.34E+02	2.05E+02	4.54E+03
7200	5.01E+02	9.25E+01	2.88E+01	3.24E+02	4.27E+02	6.66E+01	9.14E+01	2.71E+02	4.26E+03
12000	1.40E+04	2.62E+03	2.42E+03	3.89E+03	1.38E+03	7.81E+02	7.66E+02	6.64E+02	1.89E+05
24000	1.59E+04	2.67E+03	4.36E+03	1.26E+03	1.05E+03	1.22E+03	3.90E+02	4.99E+03	1.82E+05
SUM	3.12E+00	6.21E+03	7.42E+03	6.90E+03	3.30E+03	2.24E+03	2.01E+03	6.53E+03	3.96E+05

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) • 30 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : ENDOST
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	7.63E+01	2.21E+01	3.41E+01	1.12E+01	0.00E+00	1.81E+01	1.50E+01	0.00E+00
2400	3.44E+01	3.13E+01	7.39E+02	1.81E+02	2.34E+01	3.20E+00	4.59E+02	8.73E+00
4000	1.68E+02	1.66E+02	9.00E+01	1.61E+03	1.71E+01	6.55E+01	8.89E+01	1.31E+02
5600	5.26E+01	6.95E+01	5.56E+01	5.37E+01	1.06E+02	7.91E+01	7.21E+01	6.39E+01
7200	2.42E+02	6.18E+01	2.79E+01	5.60E+00	7.13E+01	9.66E+01	1.77E+02	6.31E+01
12000	1.67E+03	9.98E+03	1.18E+04	4.72E+03	6.80E+03	7.38E+03	4.75E+03	2.74E+03
24000	1.35E+03	2.75E+03	5.47E+03	2.17E+03	4.69E+03	8.06E+03	1.29E+04	7.83E+03
SUM	3.59E+03	1.31E+04	1.82E+04	8.75E+03	1.17E+04	1.57E+04	1.85E+04	1.08E+04

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : ENDOST
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	3.30E+01	4.58E+01	2.17E+01	1.04E+01	0.00E+00	6.88E+00	0.00E+00	3.51E+01	3.30E+02
2400	5.02E+01	4.86E+01	7.11E+01	8.53E+00	1.37E+01	9.88E+00	2.17E+01	3.22E+01	1.74E+03
4000	4.38E+01	8.81E+01	4.55E+01	3.11E+01	1.32E+01	1.14E+01	1.71E+02	5.53E+01	2.79E+03
5600	9.94E+01	5.30E+01	3.34E+01	3.76E+02	1.12E+02	2.59E+01	4.11E+01	6.25E+01	1.36E+03
7200	1.43E+02	2.67E+01	8.15E+00	9.39E+01	1.32E+02	2.06E+01	2.81E+01	8.28E+01	1.28E+03
12000	3.99E+03	7.58E+02	6.83E+02	1.13E+03	4.28E+02	2.41E+02	2.36E+02	2.03E+02	5.75E+04
24000	4.52E+03	7.75E+02	1.23E+03	3.65E+02	3.26E+02	3.76E+02	1.20E+02	1.53E+03	5.45E+04
SUM	8.88E+03	1.80E+03	2.10E+03	2.01E+03	1.02E+03	6.92E+02	6.18E+02	2.00E+03	1.19E+05

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : R MAR
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	6.04E+00	1.75E+00	2.70E+00	8.89E-01	0.00E+00	1.43E+00	1.19E+00	0.00E+00
2400	2.72E+00	2.48E+00	5.84E+01	1.43E+01	1.85E+00	2.54E-01	3.63E+01	6.91E-01
4000	1.33E+01	1.32E+01	7.12E+00	1.27E+02	1.35E+00	5.18E+00	7.03E+00	1.03E+01
5600	4.17E+00	5.50E+00	4.40E+00	4.25E+00	8.39E+00	6.26E+00	5.71E+00	5.06E+00
7200	1.92E+01	4.90E+00	2.21E+00	4.43E-01	5.65E+00	7.64E+00	1.40E+01	4.99E+00
12000	1.33E+02	7.91E+02	9.32E+02	3.74E+02	5.38E+02	5.84E+02	3.76E+02	2.17E+02
24000	1.07E+02	2.18E+02	4.32E+02	1.72E+02	3.71E+02	6.37E+02	1.02E+03	6.19E+02
SUM	2.85E+02	1.04E+03	1.44E+03	6.93E+02	9.27E+02	1.24E+03	1.46E+03	8.57E+02

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : R MAR
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	2.61E+00	3.62E+00	1.72E+00	8.22E-01	0.00E+00	5.45E-01	0.00E+00	2.78E+00	2.61E+01
2400	3.97E+00	3.84E+00	5.62E+00	6.75E-01	1.08E+00	7.84E-01	1.72E+00	2.55E+00	1.37E+02
4000	3.47E+00	6.98E+00	3.60E+00	2.47E+00	1.05E+00	9.07E-01	1.35E+01	4.38E+00	2.21E+02
5600	7.87E+00	4.20E+00	2.64E+00	2.98E+01	8.86E+00	2.05E+00	3.25E+00	4.95E+00	1.07E+02
7200	1.13E+01	2.12E+00	6.44E-01	7.43E+00	1.05E+01	1.63E+00	2.23E+00	6.56E+00	1.01E+02
12000	3.16E+02	6.01E+01	5.41E+01	8.92E+01	3.39E+01	1.91E+01	1.87E+01	1.61E+01	4.55E+03
24000	3.57E+02	6.14E+01	9.75E+01	2.89E+01	2.58E+01	2.98E+01	9.54E+00	1.21E+02	4.31E+03
SUM	7.02E+02	1.42E+02	1.66E+02	1.59E+02	8.12E+01	5.49E+01	4.90E+01	1.58E+02	9.45E+03

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	2.20E+00	5.99E-01	8.82E-01	2.99E-01	0.00E+00	4.65E-01	4.18E-01	0.00E+00
2400	1.03E+00	9.18E-01	2.01E+01	4.88E+00	7.46E-01	8.23E-02	1.26E+01	2.14E-01
4000	5.22E+00	5.16E+00	2.54E+00	4.37E+01	5.42E-01	1.68E+00	2.40E+00	3.05E+00
5600	1.66E+00	2.20E+00	1.60E+00	1.47E+00	3.35E+00	2.02E+00	1.93E+00	1.46E+00
7200	7.74E+00	1.99E+00	8.11E-01	1.54E-01	2.25E+00	2.47E+00	4.71E+00	1.42E+00
12000	5.38E+01	3.26E+02	3.47E+02	1.30E+02	2.13E+02	1.88E+02	1.25E+02	6.03E+01
24000	4.35E+01	9.01E+01	1.61E+02	6.02E+01	1.47E+02	2.06E+02	3.40E+02	1.72E+02
SUM	1.15E+02	4.27E+02	5.34E+02	2.41E+02	3.68E+02	4.01E+02	4.88E+02	2.38E+02

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	8.30E-01	1.04E+00	4.72E-01	2.44E-01	0.00E+00	2.00E-01	0.00E+00	1.05E+00	8.70E+00
2400	1.22E+00	1.15E+00	1.56E+00	2.04E-01	4.36E-01	2.97E-01	6.59E-01	9.93E-01	4.71E+01
4000	1.01E+00	2.14E+00	1.02E+00	7.55E-01	4.26E-01	3.50E-01	5.26E+00	1.73E+00	7.70E+01
5600	2.25E+00	1.31E+00	7.55E-01	9.20E+00	3.61E+00	8.00E-01	1.28E+00	1.97E+00	3.69E+01
7200	3.18E+00	6.63E-01	1.85E-01	2.30E+00	4.28E+00	6.39E-01	8.77E-01	2.62E+00	3.63E+01
12000	8.71E+01	1.90E+01	1.56E+01	2.78E+01	1.38E+01	7.53E+00	7.40E+00	6.47E+00	1.63E+03
24000	9.85E+01	1.95E+01	2.82E+01	8.97E+00	1.05E+01	1.18E+01	3.78E+00	4.87E+01	1.45E+03
SUM	1.94E+02	4.49E+01	4.78E+01	4.94E+01	3.31E+01	2.16E+01	1.93E+01	6.35E+01	3.29E+03

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LLI WALL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	3.71E-01	1.04E-01	1.59E-01	5.17E-02	0.00E+00	8.23E-02	7.06E-02	0.00E+00
2400	1.70E-01	1.53E-01	3.57E+00	8.66E-01	1.20E-01	1.51E-02	2.21E+00	4.07E-02
4000	8.31E-01	8.27E-01	4.41E-01	7.84E+00	8.87E-02	3.16E-01	4.33E-01	6.10E-01
5600	2.62E-01	3.49E-01	2.75E-01	2.65E-01	5.56E-01	3.86E-01	3.54E-01	3.00E-01
7200	1.21E+00	3.13E-01	1.39E-01	2.80E-02	3.77E-01	4.78E-01	8.76E-01	2.97E-01
12000	8.42E+00	5.13E+01	5.98E+01	2.42E+01	3.67E+01	3.75E+01	2.39E+01	1.31E+01
24000	6.91E+00	1.44E+01	2.85E+01	1.16E+01	2.64E+01	4.28E+01	6.74E+01	3.90E+01
SUM	1.82E+01	6.74E+01	9.29E+01	4.48E+01	6.43E+01	8.16E+01	9.53E+01	5.33E+01

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LLI WALL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	1.51E-01	2.02E-01	9.56E-02	4.63E-02	0.00E+00	3.34E-02	0.00E+00	1.70E-01	1.54E+00
2400	2.31E-01	2.20E-01	3.18E-01	3.88E-02	6.90E-02	4.87E-02	1.08E-01	1.60E-01	8.34E+00
4000	1.99E-01	4.04E-01	2.06E-01	1.42E-01	6.68E-02	5.64E-02	8.57E-01	2.78E-01	1.36E+01
5600	4.51E-01	2.45E-01	1.53E-01	1.74E+00	5.64E-01	1.28E-01	2.07E-01	3.16E-01	6.55E+00
7200	6.49E-01	1.24E-01	3.75E-02	4.36E-01	6.71E-01	1.02E-01	1.42E-01	4.21E-01	6.30E+00
12000	1.83E+01	3.59E+00	3.19E+00	5.30E+00	2.18E+00	1.21E+00	1.21E+00	1.05E+00	2.91E+02
24000	2.13E+01	3.77E+00	5.90E+00	1.75E+00	1.69E+00	1.92E+00	6.33E-01	8.06E+00	2.82E+02
SUM	4.13E+01	8.55E+00	9.90E+00	9.45E+00	5.25E+00	3.49E+00	3.16E+00	1.04E+01	6.09E+02

CALCULATED COLLECTIVE DOSE EQ. RATE(PERSON REMS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : KIDNEY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	3.66E+00	1.05E+00	1.73E+00	5.31E-01	0.00E+00	8.83E-01	7.24E-01	0.00E+00
2400	1.63E+00	1.48E+00	3.79E+01	8.63E+00	1.13E+00	1.57E-01	2.23E+01	4.21E-01
4000	7.78E+00	7.85E+00	4.65E+00	7.69E+01	8.28E-01	3.22E+00	4.34E+00	6.26E+00
5600	2.43E+00	3.28E+00	2.88E+00	2.58E+00	5.15E+00	3.90E+00	3.54E+00	3.06E+00
7200	1.11E+01	2.92E+00	1.45E+00	2.70E-01	3.47E+00	4.77E+00	8.71E+00	3.01E+00
12000	7.63E+01	4.72E+02	6.15E+02	2.28E+02	3.32E+02	3.66E+02	2.34E+02	1.31E+02
24000	6.19E+01	1.30E+02	2.86E+02	1.05E+02	2.30E+02	4.02E+02	6.40E+02	3.75E+02
SUM	1.65E+02	6.18E+02	9.49E+02	4.23E+02	5.73E+02	7.81E+02	9.14E+02	5.18E+02

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : KIDNEY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	1.61E+00	2.17E+00	1.09E+00	4.90E-01	0.00E+00	3.18E-01	0.00E+00	1.58E+00	1.58E+01
2400	2.44E+00	2.25E+00	3.55E+00	4.00E-01	6.24E-01	4.47E-01	1.01E+00	1.45E+00	8.58E+01
4000	2.10E+00	4.01E+00	2.26E+00	1.44E+00	6.00E-01	5.03E-01	7.94E+00	2.50E+00	1.33E+02
5600	4.74E+00	2.40E+00	1.66E+00	1.74E+01	5.05E+00	1.13E+00	1.91E+00	2.84E+00	6.39E+01
7200	6.79E+00	1.21E+00	4.04E-01	4.34E+00	5.98E+00	8.88E-01	1.31E+00	3.77E+00	6.04E+01
12000	1.89E+02	3.41E+01	3.39E+01	5.19E+01	1.93E+01	1.03E+01	1.10E+01	9.29E+00	2.81E+03
24000	2.15E+02	3.48E+01	6.13E+01	1.69E+01	1.47E+01	1.61E+01	5.63E+00	7.00E+01	2.67E+03
SUM	4.22E+02	8.09E+01	1.04E+02	9.29E+01	4.62E+01	2.98E+01	2.88E+01	9.15E+01	5.84E+03

APPENDIX
E

APPENDIX E

CALCULATED 34-YEAR TOTAL FATAL CANCER RATE IN THE EXPOSED POPULATION FROM RADIONUCLIDE EMISSIONS OTHER THAN RADON

CALCULATED FATAL CANCER RATE (DEATHS) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNG
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	4.38E-03	1.31E-03	2.00E-03	6.55E-04	0.00E+00	1.08E-03	8.78E-04	0.00E+00
2400	1.97E-03	1.82E-03	4.26E-02	1.05E-02	1.29E-03	1.90E-04	2.70E-02	5.32E-04
4000	9.56E-03	9.54E-03	5.11E-03	9.22E-02	9.51E-04	3.90E-03	5.25E-03	8.05E-03
5600	3.00E-03	3.96E-03	3.14E-03	3.07E-03	5.91E-03	4.72E-03	4.27E-03	3.97E-03
7200	1.38E-02	3.51E-03	1.57E-03	3.19E-04	3.98E-03	5.76E-03	1.05E-02	3.93E-03
12000	9.50E-02	5.65E-01	6.59E-01	2.68E-01	3.80E-01	4.39E-01	2.82E-01	1.71E-01
24000	7.68E-02	1.55E-01	3.05E-01	1.23E-01	2.62E-01	4.79E-01	7.66E-01	4.89E-01
SUM	2.04E-01	7.41E-01	1.02E+00	4.97E-01	6.55E-01	9.30E-01	1.10E+00	6.77E-01

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LUNG
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	1.96E-03	2.82E-03	1.35E-03	6.30E-04	0.00E+00	3.94E-04	0.00E+00	2.04E-03	1.95E-02
2400	3.03E-03	2.98E-03	4.43E-03	5.18E-04	7.73E-04	5.63E-04	1.26E-03	1.87E-03	1.01E-01
4000	2.67E-03	5.39E-03	2.84E-03	1.89E-03	7.52E-04	6.53E-04	9.82E-03	3.20E-03	1.62E-01
5600	6.11E-03	3.24E-03	2.09E-03	2.29E-02	6.36E-03	1.48E-03	2.36E-03	3.61E-03	8.02E-02
7200	8.83E-03	1.63E-03	5.08E-04	5.72E-03	7.55E-03	1.18E-03	1.61E-03	4.78E-03	7.52E-02
12000	2.47E-01	4.63E-02	4.27E-02	6.86E-02	2.44E-02	1.38E-02	1.35E-02	1.17E-02	3.33E+00
24000	2.80E-01	4.72E-02	7.68E-02	2.22E-02	1.86E-02	2.15E-02	6.90E-03	8.81E-02	3.22E+00
SUM	5.50E-01	1.10E-01	1.31E-01	1.22E-01	5.84E-02	3.96E-02	3.55E-02	1.15E-01	6.98E+00

CALCULATED FATAL CANCER RATE (DEATHS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LEUKEMIA
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	6.06E-05	1.76E-05	2.72E-05	8.92E-06	0.00E+00	1.44E-05	1.19E-05	0.00E+00
2400	2.73E-05	2.48E-05	5.89E-04	1.44E-04	1.86E-05	2.55E-06	3.65E-04	6.95E-06
4000	1.33E-04	1.32E-04	7.17E-05	1.28E-03	1.36E-05	5.22E-05	7.07E-05	1.04E-04
5600	4.17E-05	5.50E-05	4.43E-05	4.27E-05	8.42E-05	6.31E-05	5.74E-05	5.10E-05
7200	1.92E-04	4.90E-05	2.23E-05	4.46E-06	5.66E-05	7.70E-05	1.41E-04	5.03E-05
12000	1.32E-03	7.90E-03	9.40E-03	3.76E-03	5.39E-03	5.88E-03	3.78E-03	2.19E-03
24000	1.07E-03	2.18E-03	4.36E-03	1.73E-03	3.73E-03	6.43E-03	1.03E-02	6.25E-03
SUM	2.85E-03	1.04E-02	1.45E-02	6.97E-03	9.29E-03	1.25E-02	1.47E-02	8.65E-03

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LEUKEMIA
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	2.63E-05	3.65E-05	1.74E-05	8.28E-06	0.00E+00	5.46E-06	0.00E+00	2.78E-05	2.62E-04
2400	4.01E-05	3.87E-05	5.68E-05	6.80E-06	1.08E-05	7.84E-06	1.72E-05	2.55E-05	1.38E-03
4000	3.50E-05	7.01E-05	3.63E-05	2.48E-05	1.05E-05	9.05E-06	1.35E-04	4.37E-05	2.22E-03
5600	7.94E-05	4.22E-05	2.67E-05	2.99E-04	8.84E-05	2.05E-05	3.26E-05	4.94E-05	1.08E-03
7200	1.14E-04	2.13E-05	6.50E-06	7.48E-05	1.05E-04	1.63E-05	2.23E-05	6.55E-05	1.02E-03
12000	3.19E-03	6.03E-04	5.45E-04	8.97E-04	3.38E-04	1.91E-04	1.87E-04	1.61E-04	4.57E-02
24000	3.60E-03	6.17E-04	9.83E-04	2.90E-04	2.58E-04	2.97E-04	9.54E-05	1.21E-03	4.34E-02
SUM	7.09E-03	1.43E-03	1.67E-03	1.60E-03	8.10E-04	5.47E-04	4.90E-04	1.58E-03	9.51E-02

CALCULATED FATAL CANCER RATE (DEATHS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : BONE
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	4.13E-05	1.20E-05	1.85E-05	6.09E-06	0.00E+00	9.82E-06	8.11E-06	0.00E+00
2400	1.86E-05	1.69E-05	4.01E-04	9.82E-05	1.27E-05	1.74E-06	2.49E-04	4.74E-06
4000	9.04E-05	8.98E-05	4.89E-05	8.71E-04	9.25E-06	3.56E-05	4.82E-05	7.09E-05
5600	2.83E-05	3.75E-05	3.02E-05	2.91E-05	5.73E-05	4.30E-05	3.91E-05	3.48E-05
7200	1.30E-04	3.33E-05	1.52E-05	3.04E-06	3.85E-05	5.24E-05	9.61E-05	3.43E-05
12000	9.00E-04	5.38E-03	6.41E-03	2.56E-03	3.67E-03	4.01E-03	2.58E-03	1.49E-03
24000	7.28E-04	1.48E-03	2.97E-03	1.18E-03	2.54E-03	4.38E-03	7.00E-03	4.26E-03
SUM	1.94E-03	7.05E-03	9.89E-03	4.75E-03	6.32E-03	8.53E-03	1.00E-02	5.89E-03

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : BONE
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	1.79E-05	2.49E-05	1.18E-05	5.65E-06	0.00E+00	3.72E-06	0.00E+00	1.90E-05	1.79E-04
2400	2.73E-05	2.64E-05	3.87E-05	4.64E-06	7.38E-06	5.33E-06	1.17E-05	1.73E-05	9.42E-04
4000	2.38E-05	4.78E-05	2.48E-05	1.69E-05	7.13E-06	6.16E-06	9.21E-05	2.98E-05	1.51E-03
5600	5.41E-05	2.87E-05	1.82E-05	2.04E-04	6.02E-05	1.39E-05	2.22E-05	3.36E-05	7.34E-04
7200	7.78E-05	1.45E-05	4.43E-06	5.09E-05	7.13E-05	1.11E-05	1.52E-05	4.46E-05	6.93E-04
12000	2.17E-03	4.11E-04	3.72E-04	6.11E-04	2.30E-04	1.30E-04	1.27E-04	1.10E-04	3.12E-02
24000	2.46E-03	4.20E-04	6.70E-04	1.98E-04	1.75E-04	2.02E-04	6.49E-05	8.23E-04	2.95E-02
SUM	4.83E-03	9.73E-04	1.14E-03	1.09E-03	5.51E-04	3.72E-04	3.33E-04	1.08E-03	6.48E-02

CALCULATED FATAL CANCER RATE (DEATHS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	8.28E-06	2.27E-06	3.35E-06	1.13E-06	0.00E+00	1.77E-06	1.58E-06	0.00E+00
2400	3.88E-06	3.45E-06	7.62E-05	1.85E-05	2.79E-06	3.13E-07	4.77E-05	8.16E-07
4000	1.95E-05	1.93E-05	9.59E-06	1.66E-04	2.03E-06	6.39E-06	9.07E-06	1.17E-05
5600	6.22E-06	8.23E-06	6.03E-06	5.56E-06	1.25E-05	7.71E-06	7.30E-06	5.62E-06
7200	2.88E-05	7.41E-06	3.05E-06	5.81E-07	8.39E-06	9.41E-06	1.78E-05	5.46E-06
12000	2.01E-04	1.22E-03	1.30E-03	4.93E-04	7.99E-04	7.18E-04	4.75E-04	2.33E-04
24000	1.62E-04	3.36E-04	6.06E-04	2.28E-04	5.52E-04	7.85E-04	1.29E-03	6.65E-04
SUM	4.30E-04	1.59E-03	2.01E-03	9.12E-04	1.38E-03	1.53E-03	1.85E-03	9.22E-04

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : LIVER
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	3.17E-06	4.01E-06	1.82E-06	9.37E-07	0.00E+00	7.53E-07	0.00E+00	3.95E-06	3.30E-05
2400	4.66E-06	4.40E-06	6.01E-06	7.80E-07	1.63E-06	1.11E-06	2.47E-06	3.72E-06	1.78E-04
4000	3.90E-06	8.18E-06	3.92E-06	2.88E-06	1.59E-06	1.31E-06	1.97E-05	6.49E-06	2.91E-04
5600	8.65E-06	4.99E-06	2.91E-06	3.51E-05	1.34E-05	3.00E-06	4.78E-06	7.37E-06	1.39E-04
7200	1.23E-05	2.53E-06	7.11E-07	8.80E-06	1.60E-05	2.39E-06	3.28E-06	9.80E-06	1.37E-04
12000	3.37E-04	7.25E-05	6.01E-05	1.06E-04	5.16E-05	2.82E-05	2.77E-05	2.42E-05	6.15E-03
24000	3.81E-04	7.44E-05	1.08E-04	3.43E-05	3.93E-05	4.40E-05	1.42E-05	1.82E-04	5.50E-03
SUM	7.50E-04	1.71E-04	1.84E-04	1.89E-04	1.24E-04	8.07E-05	7.21E-05	2.37E-04	1.24E-02

CALCULATED FATAL CANCER RATE (DEATHS) * 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : BOWEL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	1.60E-06	4.45E-07	6.73E-07	2.20E-07	0.00E+00	3.48E-07	3.02E-07	0.00E+00
2400	7.37E-07	6.60E-07	1.52E-05	3.69E-06	5.23E-07	6.37E-08	9.46E-06	1.71E-07
4000	3.63E-06	3.60E-06	1.89E-06	3.34E-05	3.87E-07	1.33E-06	1.84E-06	2.54E-06
5600	1.15E-06	1.52E-06	1.18E-06	1.13E-06	2.42E-06	1.63E-06	1.50E-06	1.25E-06
7200	5.29E-06	1.37E-06	5.97E-07	1.19E-07	1.65E-06	2.01E-06	3.72E-06	1.23E-06
12000	3.69E-05	2.25E-04	2.56E-04	1.03E-04	1.60E-04	1.58E-04	1.01E-04	5.43E-05
24000	3.03E-05	6.30E-05	1.22E-04	4.94E-05	1.15E-04	1.80E-04	2.86E-04	1.61E-04
SUM	7.96E-05	2.95E-04	3.98E-06	1.91E-04	2.80E-04	3.43E-04	4.04E-04	2.21E-04

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : BOWEL
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	6.33E-07	8.41E-07	3.94E-07	1.94E-07	0.00E+00	1.44E-07	0.00E+00	7.40E-07	6.54E-06
2400	9.65E-07	9.19E-07	1.31E-06	1.62E-07	3.02E-07	2.12E-07	4.71E-07	6.99E-07	3.55E-05
4000	8.29E-07	1.70E-06	8.52E-07	5.97E-07	2.93E-07	2.46E-07	3.73E-06	1.21E-06	5.81E-05
5600	1.87E-06	1.03E-06	6.32E-07	7.28E-06	2.48E-06	5.59E-07	9.04E-07	1.38E-06	2.79E-05
7200	2.69E-06	5.24E-07	1.55E-07	1.83E-06	2.95E-06	4.46E-07	6.22E-07	1.84E-06	2.70E-05
12000	7.56E-05	1.51E-05	1.32E-05	2.22E-05	9.60E-06	5.28E-06	5.29E-06	4.58E-06	1.25E-03
24000	8.78E-05	1.58E-05	2.43E-05	7.35E-06	7.45E-06	8.39E-06	2.76E-06	3.52E-05	1.20E-03
SUM	1.70E-04	3.60E-05	4.09E-05	3.97E-05	2.31E-05	1.53E-05	1.38E-05	4.57E-05	2.60E-03

CALCULATED FATAL CANCER RATE (DEATHS) • 34 YEAR TOTAL

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : URINARY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	N	NNE	NE	ENE	E	ESE	SE	SSE
1100	9.27E-06	2.67E-06	4.39E-06	1.35E-06	0.00E+00	2.24E-06	1.83E-06	0.00E+00
2400	4.12E-06	3.75E-06	9.61E-05	2.19E-05	2.86E-06	3.98E-07	5.66E-05	1.07E-06
4000	1.97E-05	1.99E-05	1.18E-05	1.95E-04	2.10E-06	8.16E-06	1.10E-05	1.58E-05
5600	6.14E-06	8.31E-06	7.31E-06	6.53E-06	1.31E-05	9.89E-06	8.97E-06	7.74E-06
7200	2.81E-05	7.40E-06	3.68E-06	6.83E-07	8.80E-06	1.21E-05	2.21E-05	7.63E-06
12000	1.93E-04	1.20E-03	1.56E-03	5.79E-04	8.41E-04	9.27E-04	5.94E-04	3.31E-04
24000	1.57E-04	3.30E-04	7.26E-04	2.68E-04	5.84E-04	1.02E-03	1.62E-03	9.50E-04
SUM	4.18E-04	1.57E-03	2.41E-03	1.07E-03	1.45E-03	1.98E-03	2.32E-03	1.31E-03

FOR RADIONUCLIDE : SUM
AND ORGAN/CANCER : URINARY
AND PATHWAYS : ALL

DIRECTIONS: DISTANCE (METERS):	S	SSW	SW	WSW	W	WNW	NW	NNW	SUM
1100	4.08E-06	5.50E-06	2.76E-06	1.24E-06	0.00E+00	8.06E-07	0.00E+00	4.00E-06	4.01E-05
2400	6.18E-06	5.69E-06	9.00E-06	1.01E-06	1.58E-06	1.13E-06	2.57E-06	3.66E-06	2.18E-04
4000	5.33E-06	1.02E-05	5.74E-06	3.66E-06	1.52E-06	1.27E-06	2.01E-05	6.34E-06	3.38E-04
5600	1.20E-05	6.08E-06	4.21E-06	4.41E-05	1.28E-05	2.85E-06	4.84E-06	7.19E-06	1.62E-04
7200	1.72E-05	3.05E-06	1.02E-06	1.10E-05	1.51E-05	2.25E-06	3.32E-06	9.54E-06	1.53E-04
12000	4.79E-04	8.62E-05	8.60E-05	1.32E-04	4.88E-05	2.62E-05	2.79E-05	2.35E-05	7.13E-03
24000	5.44E-04	8.81E-05	1.55E-04	4.27E-05	3.72E-05	4.09E-05	1.42E-05	1.77E-04	6.76E-03
SUM	1.07E-03	2.05E-04	2.64E-04	2.35E-04	1.17E-04	7.53E-05	7.30E-05	2.32E-04	1.48E-02

APPENDIX
F

APPENDIX F

RADON DOSE AND RISK ASSESSMENT FOR THE FEED MATERIALS PRODUCTION CENTER FERNALD, OHIO

APPENDIX F

RADON DOSE AND RISK ASSESSMENT FEED MATERIALS PRODUCTION CENTER, FERNALD, OHIO

F.1.0 INTRODUCTION

In 1988, IT prepared a technical report (IT, 1988) concerning radiation dose and cancer risk assessment for persons in the area surrounding the Feed Materials Production Center (FMPC), Fernald, Ohio. This appendix reviews the dose and cancer risk assessment presented for radon in the 1988 report and presents a reassessment of that risk based on a revision of input parameters.

F.2.0 RADON SOURCE HISTORY

The U.S. Department of Energy (formerly the U.S. Atomic Energy Commission) built two silos in 1951 and 1952 to store residues from pitchblende processing at the FMPC site. The two silos are located approximately 1,300 feet west of the main production area fence on the FMPC site (Figure F1). Boback (1987) reported that residues were added to the K-65 silos from 1953 to 1955.

Residues in the form of an aqueous slurry were pumped into the silos through pipelines. Excess water was decanted from the slurry in the silos and returned to processing plants to be reused in the slurrying process. Consequently, the residue material in the silos initially existed in a semidry state. When pipelines to the silos were removed, all openings were sealed except one small gooseneck pipe on each silo (Boback, 1987). In 1977, these remaining openings were permanently sealed (Boback, 1987). Core samples taken from the silos in 1972 contained dry powder at the surface of the residues and about 40 percent moisture in bottom residues (Boback, 1987).

The residues are estimated to contain from 9,300 kilograms (kg) to 11,500 kg of uranium (Grumski, 1987). A wide range of values of radium mass has been reported. These values range from 1,672 grams to 3,161 grams of radium (Litz, 1974; Grumski, 1987). The radium mass in the residues corresponds to 1,652 Ci to 3,123 Ci of radium-226, assuming that all the radium mass is radium-226 and using a specific activity of 0.988 Ci radium-226 per gram.

The K-65 residues contain radon-222 and radon progeny activities approximately equal to the radium-226 activity if the silos are sealed tightly enough to prevent radon leakage. Accumulation of radon in the silo dome airspace above the residues could present a radiation hazard to the public because the gaseous, chemically inert nature of radon facilitates its release from containment and dispersion to areas that may be inhabited by people.

F.3.0 RADON RELEASE FROM THE K-65 SILOS

Radon dose and cancer risk estimates for persons near the FMPC depend on estimated radon release rates from the K-65 silos. Two radon release pathways are presented for the K-65 silos: (1) diffusion through the concrete domes of the silos and (2) free air exchange between the void volume inside the domes and the outside atmosphere (Grumski, 1987). Radon release estimates for both pathways rely on calculated radon concentrations inside the domes (Borak, 1985).

Diffusion

Diffusion through the silo domes is reported to release 60 Ci/year to the atmosphere (Grumski, 1987; Borak, 1985). This annual release is based directly on calculations by Borak (1985). Borak employed one-dimensional, steady-state diffusion equations (Colle, et al., 1981) to calculate the release of radon from the residues in the silos. Solving a steady-state flux equation for the special case of the K-65 silos, Borak obtained the following:

$$\text{Flux} = J = E*k*l* \frac{[Rn]}{\sinh (L/l)} \qquad \text{(F-1)}$$

where

E = porosity of medium,

k = radon-222 decay constant in sec^{-1},

l = diffusion length in cm,

[Rn] = void volume radon-222 concentration in pCi/cm^3, and

L = dome thickness in cm.

The radon flux from the silo dome surfaces is calculated to be 2,400 picocuries per square meter per second ($pCi/m^2/sec$) (Borak, 1985). Borak employed an average radon flux of 2,000 $pCi/m^2/sec$ to calculate his annual release to the atmosphere of 60 Ci/year:

$$\text{flux} * \text{dome area} * \text{time} = \text{annual release} \qquad \text{(F-2)}$$

$$\frac{2{,}000 \text{ pCi}}{m^2 * \text{sec}} * 934 \text{ m}^2 * \frac{3.2 \times 10^7 \text{ sec}}{\text{year}} * \frac{1 \text{ Ci}}{1 \times 10^{12} \text{ pCi}} = 60 \frac{\text{Ci}}{\text{year}}$$

where

934 m^2 = the surface area of the two silo domes approximated by circles.

The flux in Equation (F-1) depends on the radon-222 concentration in the silo void volumes. Equation (F-3) was used to determine the radon-222 concentration (Borak, 1985).

$$[Rn] = \frac{0}{k} * \frac{E*l}{E*l + h} \qquad \text{(F-3)}$$

where

0 = the production of radon-222 in pore spaces of the residues in $pCi/cm^3/sec$, and

h = the effective height of void volume in cm.

Equation (F-3) is the product of the radon source term from the residues and the ratio of the residue pore volume to the sum of pore volume and silo void volume. The radon concentration in the silo void volumes is calculated to be 3×10^4 pCi/cm^3 (Borak, 1985). The calculated radon flux also depends on the radium-226 content of the residues because the radon concentration inside the silo domes is directly proportional to the radium-226 activity in the residues, as shown in Equation (F-4) (Borak, 1985).

$$O = \frac{[\text{Ra-226}]*ef*p*k}{E} \qquad \text{(F-4)}$$

where

[Ra-226] = radium-226 concentration in residues in pCi/gram,
ef = radon-222 emanation fraction, and
p = bulk density of the residues in grams/cm^3.

As stated earlier, reported values of the radium-226 content of the residues range from 1,652 to 3,123 Ci. Boback (1987) reported that Borak assumed 1,760 Ci of radium-226 in the residues to calculate the radon concentration in the silo void volumes above the residues. Uncertainty in the estimated radium-226 activity could proportionately affect the calculated radon source term and the radon concentration in the silo void volume. Until planned sampling of the residues to characterize the content of radium-226 is completed, there is no definitive value for the radium-226 content of the residue.

The modeled radon flux is also dependent on the dimensions of the void volume inside the silos because the effective height (h) of the void volume is related to the estimated radon concentration inside the silos Equation (F-3). The void volume is reported to range from 25,000 cubic feet (ft^3) per silo (Grumski, 1987) to 38,758 ft^3 in one silo and 48,758 ft^3 in the other silo (Grumski, 1987b, personal communication).

Free Air Exchange

The K-65 silos have a history of exchanging air with the outside atmosphere. Temperature changes monitored inside and outside the silos have led to the conclusion that there is an average 20 degrees Fahrenheit daily variation in the temperature of the gaseous material above the residues (Grumski, 1987). Pressure changes monitored inside the silos show that the domes are not capable of holding significant pressure increases. Therefore, each silo is estimated to exchange an average of 1,000 ft^3 of gas per day with the outside atmosphere (Grumski, 1987). Grumski (1987) calculates a radon release from both silos of about 600 Ci/year by free air exchange using the following relationship:

$$\text{concentration} * \text{exchange rate} * \text{time} = \text{annual release} \qquad \text{(F-5)}$$

$$\frac{3 \times 10^4 \text{ pCi}}{\text{cm}^3} * \frac{1{,}000 \text{ ft}^3}{\text{day}} * \frac{1 \text{ Ci}}{10^{12} \text{ pCi}} * \frac{28{,}328 \text{ cm}^3}{\text{ft}^3} * \frac{365 \text{ days}}{\text{year}} = \frac{310 \text{ Ci}}{\text{year} * \text{silo}}$$

A release of 1,000 ft^3 of gas per day per silo and a radon concentration of 3×10^4 pCi/cm^3 are assumed.

The accuracy of the 600 Ci/year radon release estimate depends on both the radon concentration calculated by Borak (1985) and the daily gas release due to thermal effects calculated by Grumski (1987). The annual gas release of 600 Ci assumes a dome void volume of 25,000 ft^3 (Grumski, 1987). Estimates of 48,758 ft^3 and 38,758 ft^3 have been presented by Grumski (1987b). The average of these two values is 43,758 ft^3. This average void volume increases the estimated gas release rate to approximately 1,650 ft^3 per day per silo, and increases the calculated radon activity released per day per silo by a factor of approximately 1.65. This increases the estimated annual release to 512 Ci/year/silo.

Both the radon concentration inside the silos and the daily gas releases due to thermal effects depend on the dimensions of the silo void volumes. Thus, radon release estimates by diffusion and by free air exchange are dependent on the size of the void volumes.

F.4.0 RADON MEASUREMENTS

Two types of radon measurements have been made concerning the K-65 silos: (1) measurements of the radon flux from the surfaces of the silo domes and (2) measurements of airborne radon at various points on and off the FMPC site.

Flux measurements on dome surfaces are reported to range from 13 $pCi/m^2/sec$ to 3×10^7 $pCi/m^2/sec$ (Grumski, 1987; Hagee, et al., 1985). These flux measurements were made in October 1984 by Monsanto Research Corporation (Hagee, et al., 1985). Charcoal canisters were fitted to the exterior surfaces of the domes using adaptor rings to hold the exposed charcoal adjacent to the exterior surface. The adapters were then sealed to the surface so that emanating radon would remain inside the seal. Twenty-four locations were sampled on each silo; 12 locations on intact concrete and 12 locations where the concrete was obviously cracked. Radon emanation rates were so high at some locations that short sampling periods had to be used to avoid saturating the charcoal detectors. The highest flux measurements are associated with cracked concrete surfaces as shown in Table F-1 (Hagee, et al., 1985). Interpretation of the charcoal canister measurements leads to the conclusion that the K-65 silos release less radon per year than a typical inactive uranium mill tailing pile (U.S. EPA, 1983).

Measurements of ambient radon concentrations were also made by Monsanto Research Corporation. Passive Environmental Radon Monitors (PERMs) containing lithium fluoride thermoluminescent dosimeters were employed for one- to two-week exposure periods and then read to calculate

airborne radon concentrations. The PERMs were deployed between September 20, 1984 and December 5, 1984, at locations immediately surrounding the K-65 silo fenceline and at various distances from the silos, as shown in Figure F2 (Hagee, et al., 1985). Average results of the PERM monitoring program are given in Table F-2 (Hagee, et al., 1985). The highest ambient radon concentrations were measured at the K-65 fenceline and just to the northeast of the K-65 site. Measurements ranged from 5.1 pCi/l at the silo fenceline to 0.24 pCi/l three quarters of a mile from the silos. Measured ambient radon concentrations in the FMPC production area are reported to be below the DOE guideline of 3.0 pCi/l above background in uncontrolled areas, and well below the 100 pCi/l guideline for occupational exposures (Hagee, et al., 1985). Average ambient radon concentrations in the northeast United States are reported to be 0.2 to 0.3 pCi/l (Hagee, et al., 1985).

An additional radon monitoring program has been implemented at the FMPC facility. This program is designed to monitor concentrations of radon (Rn-222) and thoron (Rn-220) to determine the levels to which people might be exposed from K-65 releases. Track-etch detectors mounted inside cups covered with membrane filters are used in this FMPC monitoring program. The membrane cover serves to screen out radon decay products while permitting the entry of radon (Grumski, 1987). Sites are equipped with two detectors: one sensitive to radon and thoron and one sensitive only to radon (Grumski, 1987). Thoron concentrations are obtained as the difference between the two detector measurements. Figure F-3 (Grumski, 1987) shows locations of the 14 track-etch detector sites. The locations selected are at FMPC boundary sites, two schools, a local business, and two local residences. Monitoring results are shown in Table F-3 (Grumski, 1987). Average values in Table F-3 are at or below 1 pCi/l. Relative standard deviations for environmental radon monitoring are typically about 20 percent (Grumski, 1987). No significant differences were found between the data for 1985 and 1986, and measured radon concentrations were not found to be associated with the prevailing wind direction (Grumski, 1987).

The Ohio Department of Health conducted indoor radon monitoring at nine locations around the FMPC site between July 1985 and July 1986 (Grumski, 1987). These indoor concentrations ranged from 1.1 pCi/l to 12.8 pCi/l. Measurements were not found to be correlated with distance from the K-65 silos, and the FMPC Health and Environmental Advisory Committee concluded that the higher concentrations measured in the study were not caused by releases from the K-65 silos (Grumski, 1987).

F.5.0 RISK REASSESSMENT

The risk from radon exposure off site has been reassessed. In this reassessment several input parameters are assigned revised values. These parameters include the radon activity release rate, the release period, outdoor and indoor occupancy factors, outdoor and indoor radon progeny equilibrium factors, and the risk factor for radon exposure. Table F-4 lists these input parameters, the values used in the June 1988 report, values selected for the reassessment, and references for the selected values.

Chapter F.3.0 of this appendix describes the assessment of radon releases from the K-65 silos. Two release pathways are considered: (1) diffusion through the concrete silo domes and (2) free air exchange between the void volume inside the domes and the outside atmosphere. Reassessment of the silo void volumes (Grumski, 1987b) leads to the estimation that the daily volume of silo gas released by free air exchange is 1,650 ft^3/day/silo rather than 1,000 ft^3/day/silo. This is an increase of about 65 percent. The following equation demonstrates the effect of this increase on the radon activity release per year per silo when compared with Equation (F-5):

$$\frac{3 \times 10^4 \text{ pCi}}{\text{cm}^3} * \frac{1{,}650 \text{ ft}^3}{\text{day}} * \frac{1 \text{ Ci}}{10^{12} \text{ pCi}} * \frac{28{,}328 \text{ cm}^3}{\text{ft}^3} * \frac{365 \text{ days}}{\text{year}} = \frac{512 \text{ Ci}}{\text{year} * \text{silo}} \qquad \text{(F-6)}$$

The radon activity release by free air exchange from both silos combined becomes 1,023 Ci/year. Adding the 60 Ci/year radon activity release by diffusion through both concrete domes brings the total radon activity release to 1,083 Ci/year.

In the June 1988 report the radon release period is 34 years (1951 to 1984). Boback (1987) reports that residues were first pumped into the silos in 1953; therefore, a release period of 32 years (1953 to 1984) is selected for the reassessment.

The risk assessment in the June 1988 report presumes that members of the public are continuously exposed to the ambient radon concentrations modeled by the AIRDOS-EPA computer code at off-site environmental locations. Further, the modeled ambient radon concentration in pCi/l is converted to working levels (WLs) based on a radon progeny equilibrium factor of 0.70. The reassessment separates exposure into the fraction of time an average individual spends outdoors and the fraction of time spent indoors. Different radon progeny equilibrium factors are used for outdoor versus indoor exposure, as shown in Table F-4. It is assumed that the indoor radon concentration attributable to releases from the K-65 silos is equal to the modeled radon concentration outdoors (U.S. NRC, 1980).

In 1988 the Committee on the Biological Effects of Ionizing Radiation (BEIR) released a report entitled "Health Risks of Radon and Other Internally Deposited Alpha-Emitters, BEIR IV" (NAS, 1988). In this report the Committee presents an excess lifetime lung cancer mortality from lifetime exposure to radon progeny of 350 deaths per 10^6 person-WLM. This most recent estimate of risk from radon/radon progeny exposure is used in this reassessment.

The revised input parameters in Table F-4 are used to recalculate the risk to the local population from radon releases. The AIRDOS-EPA computer code is used to model radon dispersion based on the revised radon activity release rate in Table F-4. Modeled average radon concentrations (pCi/cm^3) at environmental locations in 16 directions and at 8 distance increments are converted to cumulative radon progeny exposure in working level months (WLMs), and finally to collective risk from the 32-year release period as shown in Figure F4. The estimated total number of excess lung cancer deaths in the assessment population from 32 years of radon releases is calculated to be 3.79. The analogous number in the June 1988 report is 3.04 excess deaths in the assessment population from 34 years of radon release.

F.6.0 RADON MITIGATION EFFORTS

An interim stabilization project has been implemented at the FMPC K-65 site to comply with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) section of the Federal Facilities Compliance Agreement between DOE and U.S. EPA (Grumski, 1987c). Compliance requires that DOE control radioactive emissions from the FMPC. Work performed as part of the interim stabilization project for the K-65 silos included temporary operation of a radon gas treatment system and application of a layer of rigid polyurethane foam to the exterior dome surfaces (Grumski and Shanks, 1988).

The radon treatment system was built and operated between November 23, 1987 and December 6, 1987. The treatment system removed gas from the silos and utilized charcoal beds and calcium sulfate beds to adsorb radon and filters to remove radon progeny. Cleaned air was then recirculated into the silos (Grumski and Shanks, 1988). Operation of the radon treatment system was found to reduce penetrating radiation dose rates at the exterior surface of the silo domes by 60 to 70 percent without increasing ambient radon concentrations outside the silos (Grumski and Shanks, 1988).

The second phase of the interim stabilization project involved applying polyurethane foam to the exterior dome surfaces. The rigid foam was then covered with a thin urethane finish coating. This phase of the project provides: (1) protection against weathering for the concrete dome surfaces, (2) improved structural integrity for the domes, (3) insulation to reduce daily temperature fluctuations inside the domes, and (4) a reduced rate of radon diffusion through the domes (Grumski and Shanks, 1988).

Radon releases from the K-65 silos are expected to be reduced to negligible levels due to implementation of the interim stabilization project. This is because of two separate effects of the polyurethane foam on the exterior of the silo domes: (1) polyurethane foam has been shown to be an effective barrier to radon diffusion and (2) the polyurethane foam insulates the silo domes, reducing both daily temperature fluctuations inside the domes and the estimated gas release rate resulting from temperature fluctuations.

The ability of polyurethane foam to reduce radon diffusion was tested in a laboratory study (Grumski, 1987c). Charcoal canister radon detectors were sealed over containers of K-65 residue samples. Some containers had an unobstructed airspace above the residue material and other containers had a layer of polyurethane foam applied directly on top of the residue material. The activities on the charcoal canisters exposed to the residues with and without the foam were compared. Results showed that properly applied foam completely attenuated radon diffusion (Grumski, 1987c).

F.7.0 SUMMARY

Dose and cancer mortality risk estimates depend on the quantity of radon released from the K-65 silos and the quantity reaching people off site.

Radon releases depend on: (1) the radium-226 content of the residues, (2) the radon concentration generated inside silo void volumes by radium decay, and (3) the ability of radon gas to exit the concrete silo domes. Retrospective calculations of emission rates presented in the June 1988 technical report rely on radon concentration and flux calculations by Borak (1985). Borak's radon concentration estimates are corroborated by analyses of silo gas samples collected in November 1987, as shown in Table F-5 (Grumski and Shanks, 1988).

The risk to the off-site population from radon exposure has been reassessed. This reassessment is based on the revision of input parameters described earlier. The estimated total number of excess lung cancer deaths in the assessment population from 32 years of radon releases is calculated to be 3.79. The analogous number in the June 1988 report is 3.04 excess deaths in the assessment population from 34 years of radon release.

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TABLE F-1

SUMMARY OF RADON FLUX MEASUREMENTS MADE ON OCTOBER 24, 1984
FROM K-RESIDUE STORAGE TANKS
FERNALD, OHIO

NORTH TANK

LOCATION	DISTANCE FROM CENTER (feet)	QUADRANT	SAMPLING PERIOD (min)	CONDITION[a]	JA[b]	JL[c]
1	30	N/S line, north	114	I	2.2 (3)	1.6 (0)
2	20	N/S line, north	115	I	1.3 (2)	9.7 (-2)
3	10	N/S line, north	177	I	5.8 (1)	4.4 (-2)
3	10	N/S line, north	115	I	1.3 (1)	9.5 (-3)
4	21.7	Northeast	51	C	7.5 (2)	5.6 (-1)
5	22.6	Northeast	50	C	6.2 (2)	4.7 (-1)
6	32.6	Northeast	51	C	2.8 (2)	2.1 (-1)
7	30	E/W line, east	117	I	1.1 (2)	8.0 (-2)
8	20	E/W line, east	117	I	9.8 (1)	7.4 (-2)
9	10	E/W line, east	181	I	6.4 (1)	4.8 (-2)
9	10	E/W line, east	116	I	3.4 (2)	2.6 (-1)
10	21.1	Southeast	53	C	3.9 (3)	2.9 (0)
11	20.9	Southeast	52	C	3.7 (4)	2.8 (1)
12	33.8	Southeast	52	C	1.9 (7)	1.4 (4)
13	30	N/S line, south	117	I	4.3 (3)	3.2 (0)
14	20	N/S line, south	116	I	8.4 (2)	6.4 (-1)
15	10	N/S line, south	180	I	6.3 (1)	4.7 (-2)
15	10	N/S line, south	116	I	1.7 (3)	1.3 (0)
16	21.6	Southeast	182	C	7.7 (1)	5.8 (-2)
16	21.6	Southeast	52	C	1.1 (3)	8.0 (-1)
17	23.6	Southeast	53	C	3.1 (4)	2.3 (1)
18	29.9	Southeast	183	C	8.3 (6)	6.2 (3)
18	29.9	Southeast	53	C	2.5 (7)	1.8 (4)
19	30	E/W line, west	114	I	2.1 (2)	1.6 (-1)
20	20	E/W line, west	114	I	7.7 (1)	5.7 (-2)
21	10	E/W line, west	115	I	8.2 (1)	6.1 (-2)
22	23.2	Northwest	50	C	5.0 (2)	3.7 (-1)
23	23.4	Northwest	52	C	6.6 (2)	4.9 (-1)
24	36.4	Northwest	181	C	1.6 (7)	1.2 (4)
24	36.4	Northwest	52	C	2.8 (7)	2.1 (4)

See footnotes at the end of table.

TABLE F-1
(Continued)

SOUTH TANK

LOCATION	DISTANCE FROM CENTER (feet)	QUADRANT	SAMPLING PERIOD (min)	CONDITION[a]	JA[b]	JL[c]
25	30	M/S line, north	207	I	1.8 (2)	1.4 (-1)
25	30	M/S line, north	81	I	1.6 (3)	1.2 (0)
26	20	M/S line, north	84	I	1.3 (5)	9.5 (1)
27	10	M/S line, north	84	I	3.1 (4)	2.4 (1)
28	23.4	Northeast	206	C	2.4 (1)	1.8 (-2)
28	23.4	Northeast	56	C	1.4 (2)	1.0 (-1)
29	28.3	Northeast	56	C	1.1 (4)	7.9 (0)
30	34.9	Northeast	55	C	7.1 (1)	5.3 (-2)
31	30	E/W line, east	212	I	6.2 (1)	4.6 (-2)
31	30	E/W line, east	85	I	1.6 (2)	1.2 (-1)
32	20	E/W line, east	84	I	9.3 (1)	6.9 (-2)
33	10	E/W line, east	83	I	2.4 (3)	1.8 (0)
34	28.9	Southeast	50	C	9.0 (5)	6.7 (2)
35	34.0	Southeast	50	C	2.1 (5)	1.6 (2)
36	34.5	Southeast	212	C	6.9 (6)	5.2 (3)
36	34.5	Southeast	51	C	1.4 (7)	1.0 (4)
37	30	N/S line, south	85	I	3.3 (2)	2.5 (-1)
38	20	N/S line, south	85	I	5.3 (2)	3.9 (-1)
39	10	N/S line, south	85	I	1.3 (2)	9.4 (-2)
40	27.6	Southwest	209	C	1.7 (4)	1.3 (1)
40	27.6	Southwest	52	C	8.8 (4)	6.6 (1)
41	34.7	Southwest	52	C	3.2 (3)	2.4 (0)
42	35.0	Southwest	52	C	2.2 (2)	1.7 (-1)
43	30	E/W line, west	80	I	2.9 (1)	2.2 (-2)
44	20	E/W line, west	81	I	9.6 (1)	7.2 (-2)
45	10	E/W line, west	208	I	3.3 (1)	2.5 (-2)
45	10	E/W line, west	81	I	1.0 (2)	7.8 (-2)
46	23.2	Northwest	57	C	6.4 (3)	4.8 (0)
47	34.2	Northwest	55	C	2.3 (4)	1.7 (1)
48	35.5	Northwest	56	C	1.0 (2)	7.5 (-2)

[a]I - Intact concrete, C = Crack or fissures.
[b]JA is Radon Flus in units of $pCi/m^2/sec$. 2.2. (3) = 2.2×10^3 $pC/m^2/sec$.
[c]JL is in units of pCi/cm/sec. 1.6 (0) = 1.7×10^0 pCi/cm/sec.

Reference: Hagee et al., 1985.

TABLE F-2

SUMMARY OF DATA FOR FERNALD RADON MONITORING NETWORK
FOR THE PERIOD OF SEPTEMBER 20, 1984 TO FEBRUARY 5, 1985

LOCATION ABOVE RANGE OF BACKGROUND		NUMBER OF SAMPLES	RADON CONC. pCl/LITER AVE.	STD. ERROR	DATE INITIATED
#3	West perimeter K-65 fence	15	5.1	0.6	09/20/84
#1	East perimeter K-65 fence	15	3.6	0.5	09/20/84
#5	NE 30 meters	15	3.6	0.5	09/20/84
#4	North perimeter K-65 fence	15	3.0	0.4	09/20/84
#2	South perimeter K-65 fence	15	1.6	0.2	09/20/84
#12	Northwest 200 meters	13	1.7	0.2	09/27/84
#6	East 75 meters	15	1.3	0.1	09/20/84
#7	East production fence	14	1.2	0.1	09/27/84
#8	Southeast production fence	13	1.0	0.1	09/27/84
#11	North 300 meters	14	0.97	0.14	09/27/84
#9	Northeast production fence	14	0.82	0.11	09/27/84
#10	North-northeast production fence	13	0.71	0.08	09/27/84
#13	South 150 meters	11	0.60	0.09	10/18/84
#15	West Paddy's Run Road	12	0.46	0.05	10/18/84
LOCATION IN BACKGROUND RANGE					
#14	East sewage treatment plant	11	0.29	0.03	10/18/84
#18	Northeast route 126	5	0.24	0.04	12/05/84
#17	Southeast Wiley Road	5	0.24	0.04	12/05/84

Reference: Hagee, et al., 1985.

TABLE F-3

RADON IN AMBIENT AIR

RADON[a] pCi/P

SAMPLING LOCATION[b]	SET 1[c]		SET 2		SET 3		SET 4		SET 5		1986 AVERAGE		1985 AVERAGE	
AMS 1	0.31	(0.011)	0.14	(0.005)	0.83	(0.031)	0.50	(0.019)	1.40	(0.052)	0.64	(0.024)	0.81	(0.030)
AMS 2	0.37	(0.014)	0.61	(0.023)	1.12	(0.041)	0.50	(0.019)	1.60	(0.059)	0.84	(0.031)	0.82	(0.030)
AMS 3	0.60	(0.022)	1.04	(0.038)	0.54	(0.020)	0.50	(0.019)	0.70	(0.026)	0.68	(0.025)	0.28	(0.010)
AMS 4	0.55	(0.020)	0.40	(0.015)	0.70	(0.026)	0.50	(0.019)	0.60	(0.022)	0.55	(0.020)	0.56	(0.021)
AMS 5	0.43	(0.016)	0.18	(0.007)	0.91	(0.034)	1.00	(0.037)	0.40	(0.015)	0.58	(0.022)	0.80	(0.030)
AMS 6	0.33	(0.012)	0.81	(0.030)	0.91	(0.034)	0.70	(0.026)	0.50	(0.019)	0.65	(0.024)	0.67	(0.025)
AMS 7	0.31	(0.011)	0.98	(0.036)	1.51	(0.056)	1.40	(0.052)	0.60	(0.022)	0.96	(0.036)	1.01	(0.037)
AMS 8	-[d]		-		-		-		0.60	(0.022)	0.60	(0.022)	-	
AMS 9	-		-		-		-		0.50	(0.019)	0.50	(0.019)	-	
OS 1	0.19	(0.007)	1.29	(0.048)	0.50	(0.019)	0.40	(0.015)	0.60	(0.022)	0.60	(0.022)	0.59	(0.022)
OS 2	0.29	(0.011)	1.29	(0.048)	0.56	(0.021)	0.20	(0.007)	0.50	(0.019)	0.57	(0.021)	0.37	(0.014)
OS 3	-		-		-		-		0.80	(0.030)	0.80	(0.030)	-	
OS 4	-		-		-		1.10	(0.041)	0.70	(0.026)	0.90	(0.033)	-	
OS 5	-		-		-		0.60	(0.022)	0.80	(0.030)	0.70	(0.026)	-	

[a]See Figure F3.
[b]Bq/P in parentheses.
[c]Sets were replaced at about two-month intervals.
[d]"-" - No data collected.

Source: 1986 FMPC Environmental Monitoring Report.

TABLE F-4

REVISED INPUT PARAMETERS FOR RADON MODELING

PARAMETER	CDC REPORT VALUE (JUNE 1988)	REVISED VALUE	REFERENCE FOR REVISION
Release Rate	660 Ci/yr	1083 Ci/yr	This report
Release Period	1951 to 1984	1953 to 1984	Boback 1987
Outdoor Occupancy Factor	1.0	0.25	U.S. EPA 1986
Outdoor Equilib. Factor	0.70 Default	0.60	UNSCLEAR 1982, NCRP 1984
Indoor Occupancy Factor	NA	0.75	U.S. EPA, 1986
Indoor Equilib. Factor	NA	0.50	UNSCEAR 1977, 1982
Risk Factor		$\frac{350}{10^6 \text{WLM-person}}$	BEIR 1988

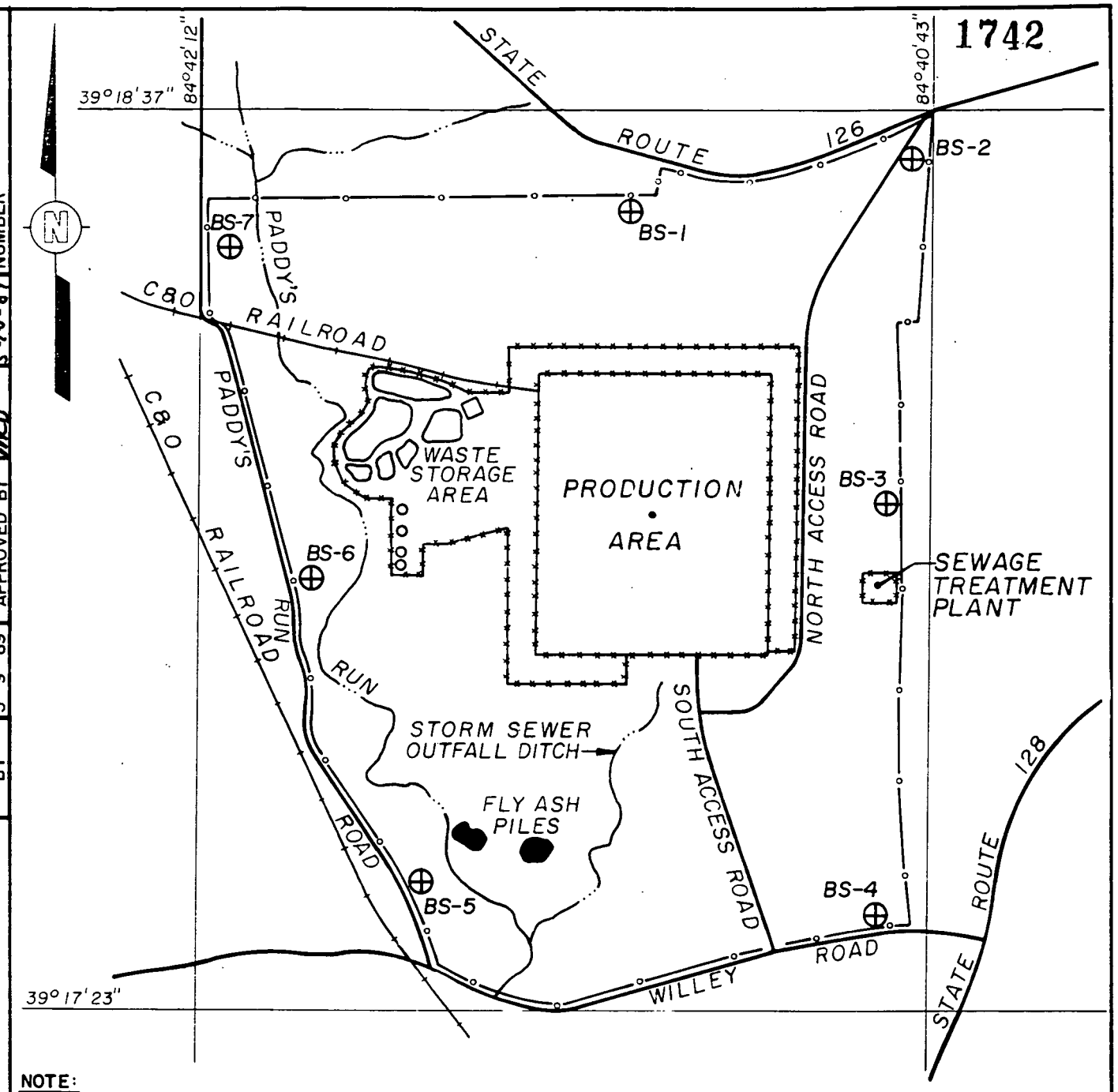
TABLE F-5

K-65 SILO GAS SAMPLING RESULTS

SAMPLE TYPE AND SILO	WMCO ANALYSIS (pCi/ℓ)	MOUND ANALYSIS (pCi/ℓ)
Sampling Bag, Silo 1	-	2.3×10^7
Sampling Bag, Silo 2	-	1.3×10^7
Glass Flask, Silo 1	2.6×10^7	2.5×10^7
Glass Flask, Silo 2	3.0×10^7	2.9×10^7

Reference: Grumski and Shanks, 1988.

DRAWN BY	D.E.S.	CHECKED BY	5-10-89	DRAWING NUMBER	303063-A54
	5-9-89	APPROVED BY	5-10-89		



NOTE:
COORDINATES AT CENTER OF PRODUCTION AREA:
LONGITUDE 84°41'19", LATITUDE 39°17'58".

LEGEND:
- SECURITY FENCE
- PROPERTY LINE FENCE
- GRID LINE
- BOUNDARY AIR MONITORING STATION

SCALE
0 1500 3000 FEET

SCALE
0 500 1000 METERS

REFERENCE:
IT CORPORATION, 1986

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Do Not Scale This Drawing

FIGURE F1

GENERALIZED
FMPC SITE LAYOUT

PREPARED FOR

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DRAWN BY	R. Weible	CHECKED BY	MLD	DRAWING NUMBER	303063-A51
	5-9-89	APPROVED BY	MLD		

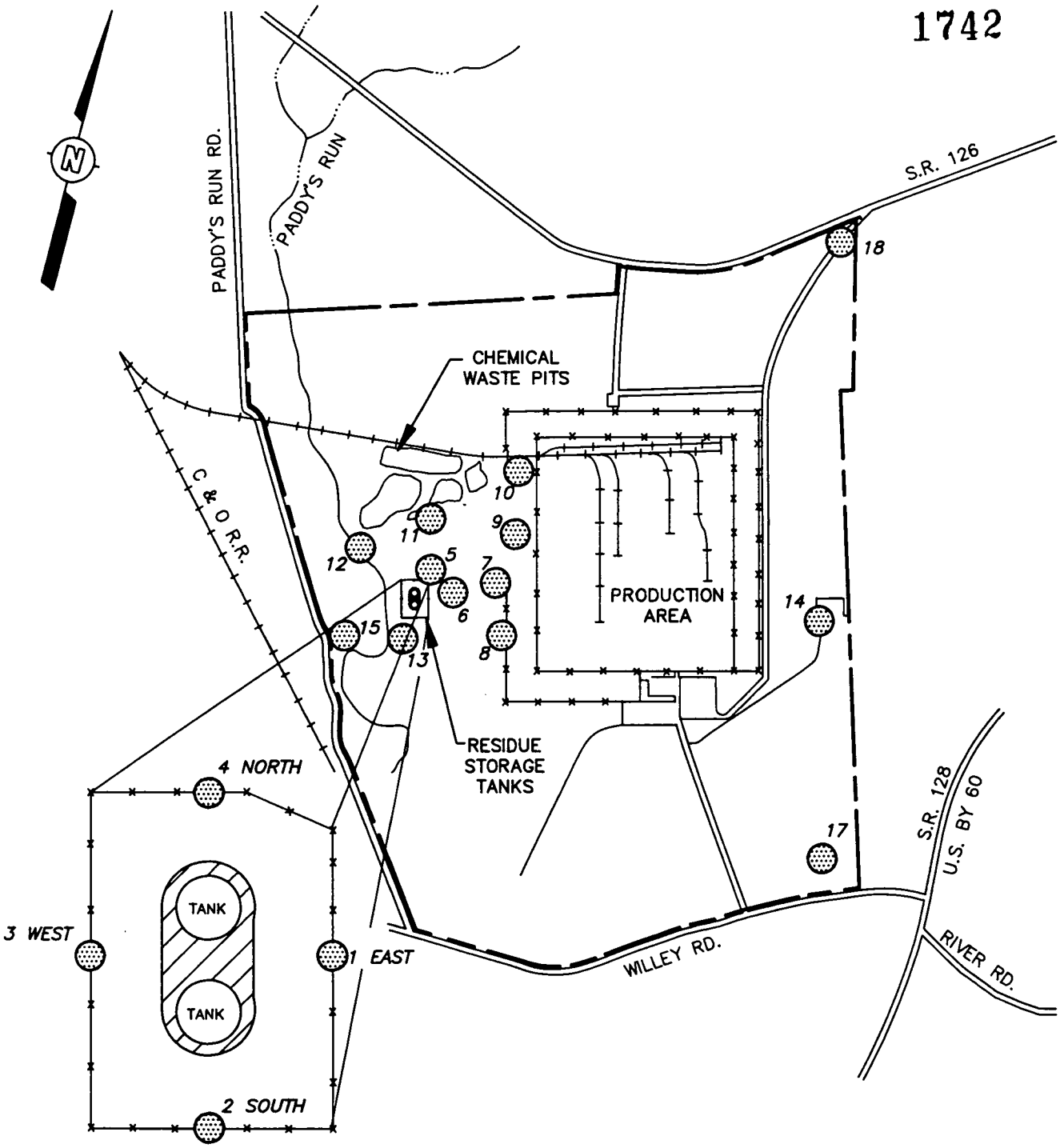

FIGURE F2

RADON MONITORING NETWORK ON FMPC SITE

PREPARED FOR

DEPARTMENT OF ENERGY AND CENTERS FOR DISEASE CONTROL

LEGEND

6 SAMPLING LOCATION. NUMBER IDENTIFIES LOCATION NUMBER APPEARING IN TABLE F-2.

REFERENCE:
ADAPTED FROM HAGEE et. al., 1985.

"NOT TO SCALE"

INTERNATIONAL TECHNOLOGY CORPORATION

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DRAWN BY	WAD	CHECKED BY	MLD	5-10-89	DRAWING NUMBER 303063-A50
	5/5/89	APPROVED BY	MLD	5-10-89	

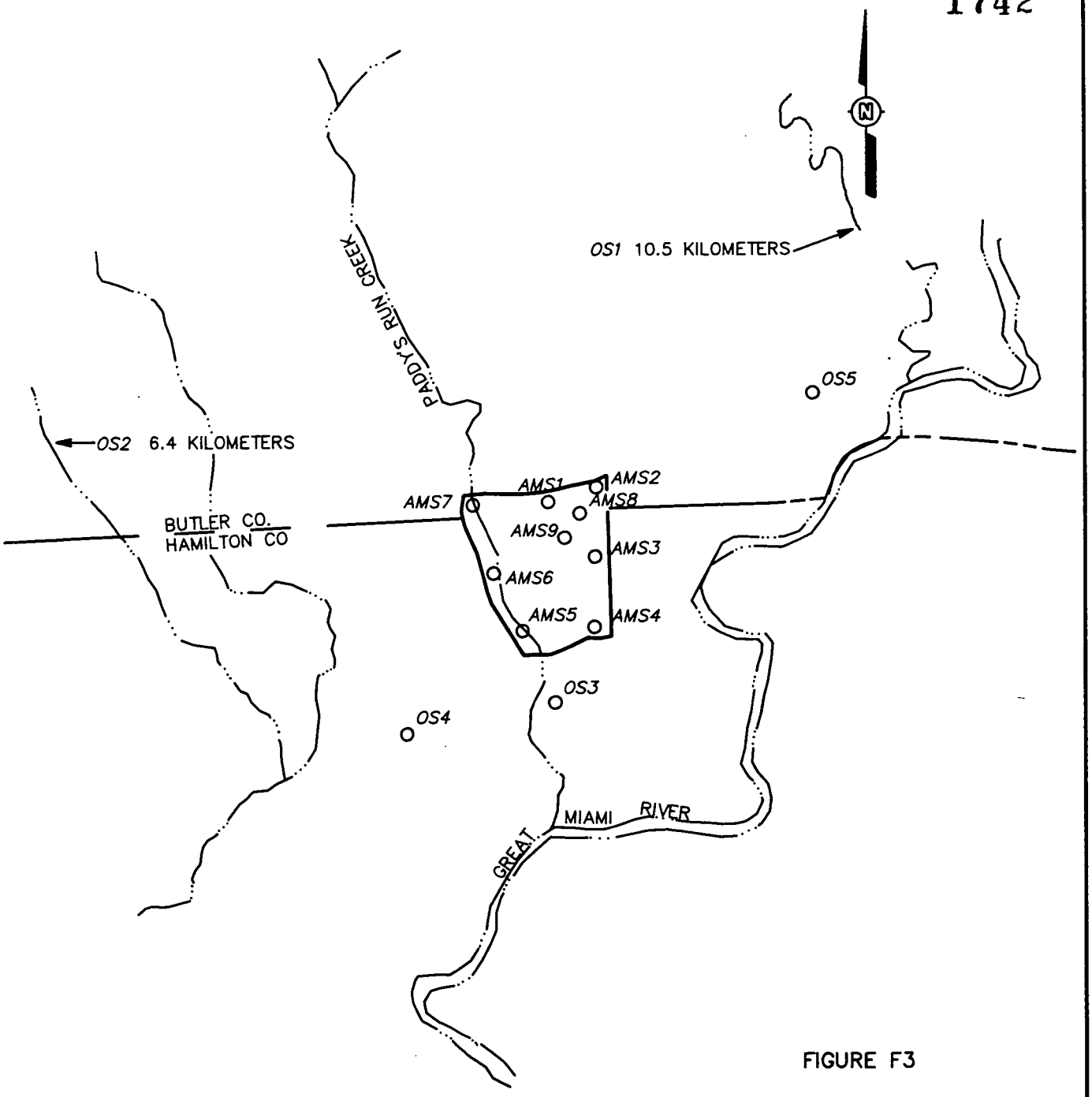

FIGURE F3

LEGEND

AMS1
O SAMPLING LOCATION. NUMBER IDENTIFIES LOCATION NUMBER APPEARING IN TABLE F-3.

"NOT TO SCALE"

REFERENCE:

ADAPTED FROM GRUMSKI, 1987

AIR MONITORING STATION LOCATIONS

PREPARED FOR

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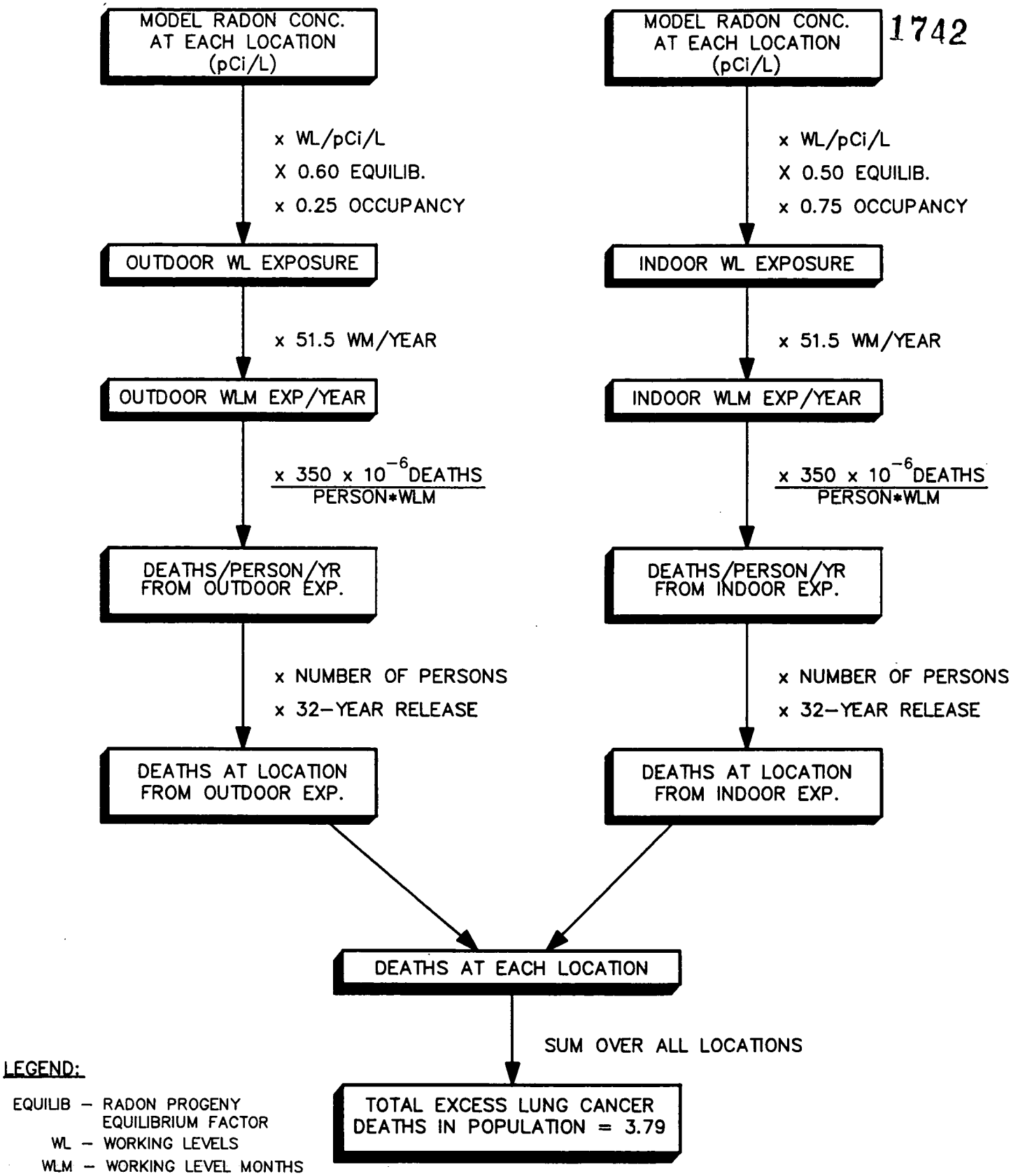

FIGURE F4

FLOWCHART DEPICTING THE CALCULATION OF COLLECTIVE RISK FROM 32 YEARS OF RADON RELEASES