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A Benchmark Comparison of EPA Computer Models for Demonstrating Compliance to the Regulatory Effluent Dose Constraint at a Radioactive Waste Processing Facility

Debra Ann McCroskey
University of Tennessee - Knoxville, dmccros2@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Debra Ann McCroskey entitled "A Benchmark Comparison of EPA Computer Models for Demonstrating Compliance to the Regulatory Effluent Dose Constraint at a Radioactive Waste Processing Facility." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

Laurence F. Miller, Major Professor

We have read this thesis and recommend its acceptance:

Ronald R. Pevey, Gloria T. Mei

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

A Benchmark Comparison of EPA Computer Models for Demonstrating Compliance to the Regulatory Effluent Dose Constraint at a Radioactive Waste Processing Facility

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC), or NRC agreement states, establish radiation dose limits to members of the public from airborne radionuclide emissions released from facilities licensed to use and/or handle radioactive material. These regulations specify that the licensee ensure that the individual member of the public likely to receive the highest dose shall not be expected to receive a total effective dose equivalent (EDE) in excess of 10 mrem (0.1 mSv) per year. Doses to members of the public from airborne effluents are evaluated using EPA-approved computer programs, such as COMPLY or CAP88. These are screening/compliance computer software programs, which make conservative modeling assumptions and require simple input data. COMPLY code, developed in 1989, is an extension of the National Council on Radiation Protection (NCRP) screening levels which are based on documented and well-known radiological assessment principles that combine environmental transport mechanisms, exposure pathways, and dosimetry components. The EPA no longer provides technical or administrative support for the COMPLY code, although it is still available for download and is still used by licensees. EPA's CAP88-PC program was developed to demonstrate compliance with the Clean Air Act as applied to radionuclide emissions from licensed facilities outlined in 40 CFR 61 Subpart H (Rad-NESHAP). CAP88-PC is now the only code for effluent emissions that the EPA supports and routinely updates in concert with model improvements. The purpose of this benchmark study was to determine if there is a significant difference between dose estimates obtained for a radioactive waste processing facility's annual radionuclide effluents using COMPLY-Level 4 and CAP88-PC software codes. Based on the comparison of the code results for one facility and its isotope emissions for the years 2004 to 2012, there was no significant difference found in the total dose results. However, CAP88-PC incorporates the latest science and is easier to use than COMPLY. Since the EPA allows the use of both codes for demonstrating compliance, it is ultimately up to the user on which to select.

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Chapter 1

1 Introduction and General Information

The facility is a licensed commercial low-level radioactive waste (LLRW, e.g., waste) processing operation, including the only commercially licensed radioactive metals recycling furnace and the largest waste incinerators in the United States (U.S.) It primarily receives waste from nuclear utilities, government agencies, industrial facilities, laboratories and hospitals.

1.1 Facility Description

The waste processing facility provides comprehensive, integrated services and solutions to the nuclear energy industry. The fully licensed, state-of-the-art facilities and staff process and manage waste safely, cost-effectively, perform decommissioning projects, and meet the significant fuel cycle and waste management challenges faced by government and commercial customers. This is the largest fixed-based facility in the U.S. for processing LLRW and for volume reduction or recycle of radioactive materials back into the industry. Thermal processes at the facility include incineration of dry active waste (DAW) and metal melting to convert waste into re-useable items such as shield blocks. Up to 30 million pounds (lbs.) of LLRW is processed annually at this facility.

The facility lies within the Great Valley of East Tennessee between the Cumberland and Great Smoky Mountains. The Cumberland Mountains are 16 km (10 miles) to the northwest; the Great Smoky Mountains are 51 kilometers (km) (31.6 miles) to the southeast. The facility encompasses about 44 acres on the southwestern perimeter of the Department of Energy (DOE) Oak Ridge Reservation. The site contains 141,998 square feet (ft^2) of indoor space for waste treatment and processing, and over 250,000 ft^2 of exterior radioactive storage space.

Municipalities within approximately 30 km (18.6 miles) of the facility include Oliver Springs, Clinton, Lake City, Lenoir City, Farragut, Kingston, and Harriman shown in Figure 1.1. Knoxville, the major metropolitan area nearest Oak Ridge, is located about 40 km (25 miles) to the east and has a population of about 183,550. The land within 8 km (5 miles) of the facility is semi-rural and is used primarily for residences, small farms, and cattle pasture. Fishing, hunting, boating, water skiing, and swimming are popular recreational activities in the area.

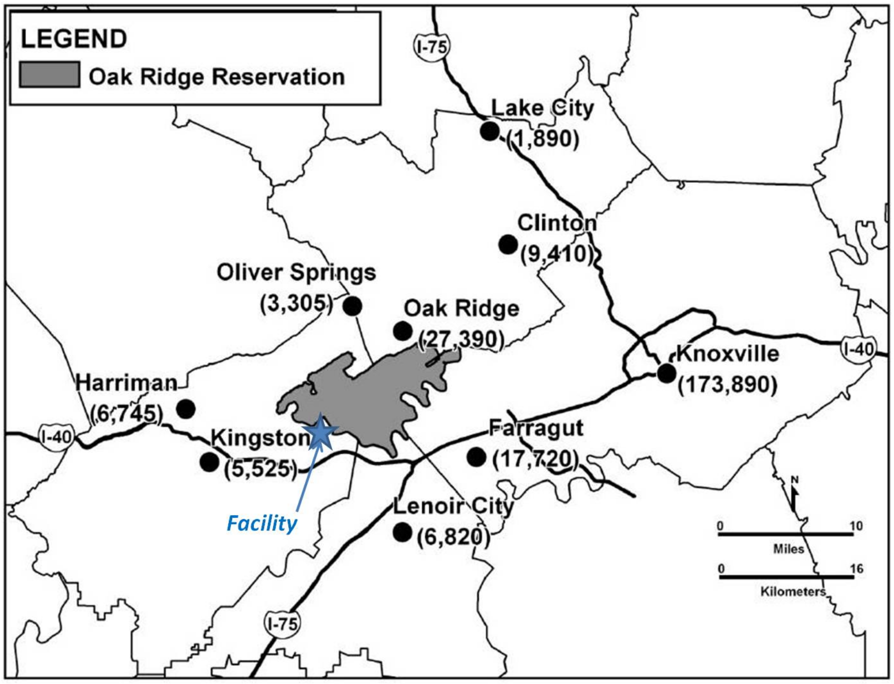

Figure 1.1 Locations and populations of towns nearest the facility.

1.1.1 Operational History

The facility was founded in 1985 and quickly grew to become the leading waste processor in the U.S. The initial processing technology was the super-compaction of waste drums and boxes of waste for disposal in the South Carolina LLRW landfill. Operational technologies were added over the years including two incinerators for combustible materials, metal melting, lead extraction and casting, compaction upgrades, shredding, decontamination, sorting, liquid evaporation, liquid/sludge solidification, resin dewatering, and other LLRW volume reduction or metal recycling methods. The facility has redundant systems designed and used to control emissions from the primary sources of radiological effluents generated/released from the thermal processes of incineration and metal recycling.

The LLRW incinerators are the only two licensed commercial incinerators in the U.S. See Figure 1.2 for a photo of one of the incinerators. Incineration is the most cost-effective treatment for the majority of dry active waste (DAW) and remains the primary choice for disposing non-hazardous radioactive waste oils and other liquids due to the disposal cost savings based on volume reduction. Each incinerator can process solid waste at up to 1,600 lbs and up to 30 gallons (gal) of waste oil per hour simultaneously. Since 1989, the facility has incinerated over four million cubic feet (ft^3) of DAW for clients such as nuclear power plants, hospitals, brokers, government facilities, and research centers. [1]

Figure 1.2 Commercial DAW and Radioactive Liquids Incinerator

The metal melt operation can process over 25 million lbs of radioactively contaminated metals per year. Since 1992 the facility has melted and recycled more than 58,000 tons of radioactively contaminated large components and metals (also lead) for recycle rather than disposed of as waste for utility, commercial and government clients. The smelter is a 20-ton, 7,200 kilowatt (kW) electric-induction furnace with a large capacity, constant feed process for both ferrous and non-ferrous metals. Using the melted contaminated metals, the facility recycles the metal by producing useable items, such as shield blocks (Figure 1.3) for exposure reduction, for other licensed users, which are outside of the public domain, thereby eliminating any potential generator liability. [2]

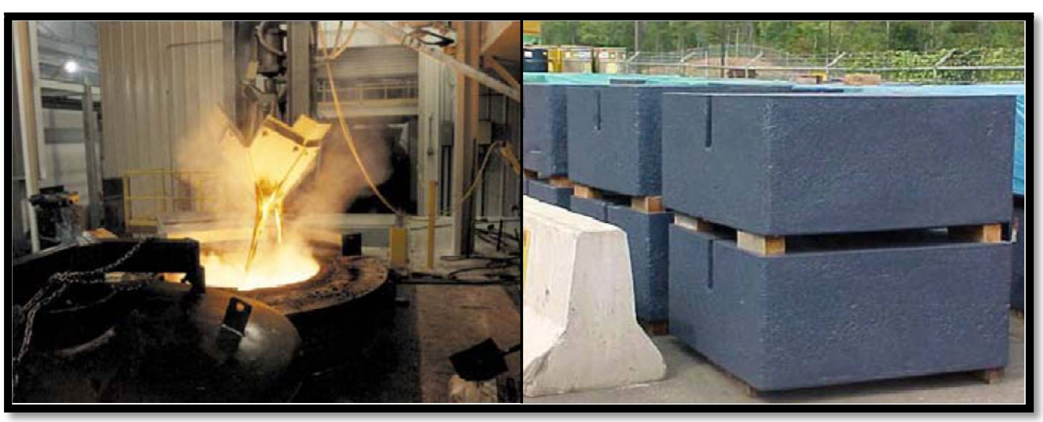

Figure 1.3 Metal Melt Furnace and Product Shield Blocks

One of the non-thermal processes at the facility is the super- or Ultra-compaction of DAW. Achieving maximum density is optimal and the key to cost-effective radioactive waste disposal at most burial sites. The compactor located at the facility is the world's largest commercial compactor available for LLRW. The unit compacts both metal 55-gal drums and 38 ft^3 boxes with the force of 44.5 mega-newtons (MN), similar to the thrust force from the Saturn V rocket at liftoff (35 MN). Typical waste this is processed includes paper, plastic, asbestos, metals, wood, filters, and other types of DAW. Other items successfully compacted include soils, motors, pumps, pipes, valves, and conduit. Volume reductions are on the order of 6:1 for DAW and 8:1 for asbestos. The primary radiological effluent observed over time from this process has been tritium (H-3) gas. However, the levels of radioactivity are far below those observed from the Incineration or Metal Melt processes. [3]

All other non-thermal processes, such as decontamination, sorting, liquid evaporation, liquid/sludge solidification, and resin dewatering do not significantly contribute to the radiological effluents from the facility, or are performed in the incineration or metal melt buildings, and therefore are not considered separately in this study.

1.1.2 Radionuclide Effluent Release Points

The facility presently has five effluent release stacks. These are associated with the different process buildings as follows:

- **Stack 1 - incineration operations;**
- **Stack 2 - metal melting operations;**
- Stack 3 - decontamination facility;
- Stack 4 - sorting operations; and
- Stack 5 - compaction operations.

The effluent control equipment uses a unique combination of carefully chosen technologies, with redundancy built-in throughout the system. In the case of the incineration process, effluents first go through a heat recovery boiler for off-gas temperature control. After the boiler the effluents are routed through a baghouse filter system for particulate control, including radiological particulates. The next stage is the wet scrubber system for acid gas removal and finally the effluents are filtered through a High Efficiency Particulate Air (HEPA) system before release through the stack. For the metal melt process, the effluents are filtered through a baghouse and a HEPA unit before release.

From years of direct monitoring of stack effluents, it has been determined that tritium (H-3) is the largest constituent of effluents from all the stacks. This is primarily due to the fact that tritium as a gas (H_2) is able to bypass all the particulate air filters. Also, it combines with any water vapor in the effluent gases and is expelled as tritiated water (T_2O). Carbon-14 (C-14) is the other significant constituent of the effluents, not because it is measured directly, but because it is administratively passed through the thermal processes based on the client's manifested values. There is currently no practical method for the Facility to monitor the radioactivity concentrations of C-14 in the effluent gases because of the overwhelming volumes of carbon dioxide (CO_2) in the emission that would saturate any monitoring system. Therefore, it is conservatively assumed that all C-14 activity manifested in for the DAW that is incinerated, or the metal that is melted, is exhausted through the stack(s). All other radionuclides are either not detected above the minimum detectable levels of the counting instrumentation, or are orders of magnitude lower than the H-3 and C-14. Even so, these others will be included in the suite of nuclides used for calculating off-site receptor dose.

Comparison of the effluent activity concentrations of C-14 and H-3 between stacks shows that Stack 1 and Stack 2 (in bold above) released significantly higher concentrations of radioactivity than any of the other facility stacks. This is logical since these stacks are for the operational areas where waste is thermally processed. As a result of the higher effluent activity concentrations, these two stacks are the primary contributors to the calculated effluent dose. Therefore, only these two facility stack effluents are considered for this comparative study of codes to calculate offsite maximum receptor dose.

1.1.3 Offsite Resident Locations (Maximally Exposed Individual)

The COMPLY-Level 4 code requirement for offsite resident locations (receptors) is to determine the straight-line distance (in meters) from the source (effluent stack) to the nearest receptors measured along the ground. When using a wind rose, the straight-line distance to the nearest receptor for each of the 16 compass sectors must be determined. For this study, the nearest offsite residents to the facility were identified using the internet application "Google Maps" [4] and street maps. The street address for each resident location identified through Google Maps was then entered into the online calculator provided by Stephen Morse, San Francisco, that converts street addresses to GPS coordinates [5].

Distances from the stacks to the offsite receptor were determined using another online application developed by Stephen P. Morse [6]. This application provides two distance computations. One distance computation is based on a spherical earth using the formula appearing at mathforum.com. The other distance calculations were based on an ellipsoidal earth using the formula developed by Thaddeus Vincenty. The spherical earth results were used for this study.

CAP88-PC estimates doses for the maximally-exposed individual (MEI) in population runs for the location, or sector-segment in the radial assessment grid, of highest risk where at least one individual actually resides. Therefore, the general distances of receptors determined for COMPLY were also used to generate model inputs for an individual assessment in CAP88-PC.

1.2 Radionuclide Emission Standards and Regulations

When Congress amended the Clean Air Act in 1977, it specifically addressed emissions of radioactive materials. Before that time, emissions of radionuclides were either regulated under the Atomic Energy Act or were not regulated at all. Section 122 of the Clean Air Act required the EPA Administrator to determine, after public notice and opportunity for public hearings, whether emissions of radionuclides cause or contribute to air pollution that may reasonably be expected to endanger public health. [7]

On February 6, 1985, the EPA issued standards under Section 112 of the Clean Air Act that limited airborne emissions of radionuclides to the atmosphere. In February 1989 these standards were re-proposed, and in November 1989 the final standards were to be promulgated. [8]

These standards applied to certain facilities which could emit radionuclides to the air, that are licensed by the NRC or it's Agreement States. The facilities are required to demonstrate compliance with one of the National Emission Standards for Hazardous Air Pollutants (NESHAP) by filing an annual report with the EPA.

The title of the Radionuclide NESHAP as published in 1989 was: "Subpart I—National Emissions Standards for Radionuclide Emissions From Facilities Licensed by the Nuclear Regulatory Commission and Federal Facilities not Covered by Subpart H." Radionuclide NESHAP regulations limit the annual radioactive dose from air emissions to the most exposed member of the public. In most cases, the facility is exempt from reporting or filing with the EPA if the facility's emissions lead to calculated doses that are a factor of ten lower than the standard. The EPA Regional Offices have the primary responsibility for implementing the radionuclides NESHAPs, with guidance from Agency Headquarters. During the following three years, there was a flurry of regulatory activity. EPA issued various stays of applicability for some NRC licensees and extended the stays various times. However, EPA was required by court order to withdraw the stays and Subpart I became fully effective on November 16, 1992.

On September 5, 1995, EPA amended the NESHAP to exempt only the nuclear power reactors which are licensed by the NRC. EPA did not change the title of the NESHAP at that time. On December 30, 1996, EPA significantly amended the 40 CFR 61 Subpart I—Radionuclide NESHAP. EPA was convinced at that point that the NRC licensee program protected public health as effectively as the NESHAP.

Therefore, the NESHAP no longer affected operations licensed by the NRC or their Agreement States. NRC licensees that were no longer affected by this rule included:

- Facilities licensed to use or possess nuclear materials such as hospitals, medical research facilities, radiopharmaceutical manufacturers, laboratories, etc.
- Facilities engaged in the conversion of uranium ore to produce electric power, e.g., uranium mills, fuel fabrication plants.

The title of this NESHAP, as amended on December 30, 1996, was changed to: "Subpart I—National Emission Standards for Radionuclide Emissions From Federal Facilities Other Than Nuclear Regulatory Commission Licensees and Not Covered by Subpart H"

Subsequent corrections and amendments are reflected in the latest version of the Code of Federal Regulations, Volume 40, Part 61, Subpart I.

1.2.1 EPA-NESHAP Compliance Requirements

All NRC and Agreement State Licensees, except Nuclear Power Plant Licensees, are required to evaluate their radionuclide air emissions and show compliance with the requirements of 40 CFR Part 61, Subpart I—NESHAPs for Radionuclides (NESHAPs). NESHAPs limits radionuclide emissions to the ambient air such that the most exposed individual must not receive in any year more than the effective dose equivalent (EDE) of 10 millirem (mrem), of which no more than three mrem EDE may be from radioiodines (§ 61.102). The standard specifically excludes doses caused by radon-220 or radon-222 and their decay products that are formed after release [9]. Radionuclide emissions can either be monitored, measured, or estimated using methodology referenced in §61.107.

Compliance with the limit of the standard may be demonstrated using EPA approved methods of determining emissions and EPA-approved procedures for estimating the resulting doses. The NESHAP includes approved calculational and analytical methods for determining emissions, and a number of alternative procedures for determining doses. Other methods and procedures (including those based on environmental measurements) must be submitted to the EPA for approval before they are used.

The chief ways to show compliance are by using an EPA supplied computer program, COMPLY or by the methods described in Appendix E of NESHAPs (Appendix E to Part 61—Compliance Procedures Methods for Determining Compliance With Subpart I). This Appendix provides simplified procedures that consist of a series of increasingly more stringent steps, depending on the facility's potential to exceed the standard. These procedures are described in the 1989 "Guide for Determining Compliance with the Clean Air Act Standards for Radionuclide Emissions From NRC-Licensed and Non-DOE Federal Facilities." [8]

The computer program called COMPLY was developed to reduce the burden on the regulated community. The Agency also prepared a "User's Guide for the COMPLY Code" to assist in using the code, and in handling more complex situations such as multiple release points. The basis for these compliance procedures are provided in 1989 "Background Information Document: Procedures Approved for Demonstrating Compliance with 40 CFR Part 61, Subpart I". The compliance model is the highest level in the COMPLY computer code and provides for the most realistic assessment of dose by allowing the use of site-specific information.

The EPA also allowed facilities to demonstrate compliance with the emission standard in Subpart I through the use of computer models that are equivalent to COMPLY, provided that the model has received prior approval from EPA headquarters. The EPA may approve an alternative model in whole or in part and may limit its use to specific circumstances.

1.2.2 NRC Compliance Requirements

In 1992 the EPA and the NRC signed the "Memorandum of Understanding Between the Environmental Protection Agency and Nuclear Regulatory commission concerning Clean air Act Standards for Radionuclide Releases from Facilities other than Nuclear Power Reactors Licensed by NRC or its Agreement States." EPA and NRC entered into this Memorandum of Understanding (MOU) to ensure that facilities other than nuclear power reactors, licensed by the NRC, would continue to limit their air emissions of radionuclides to levels that would result in the protection of the public health with an ample margin of safety. Through the MOU, the two agencies would avoid unnecessary duplicative or piecemeal regulatory requirements for NRC licensees, consistent with their legal responsibilities, and ensure that standards and regulations, when issued, would be effectively implemented.

Under the MOU plan, the EPA would issue generally applicable environmental limits on radiation exposure or levels, or concentrations or quantities of radioactive materials, in the general environment outside the boundaries of licensed facility locations, and NRC implements these standards by the use of its licensing and regulatory authority. The NRC agreed to develop and issue a regulatory guide on designing and implementing a radiation protection program to ensure that doses resulting from effluents from licensed facilities would remain as low as is reasonably achievable (ALARA) [10]. The NRC guide would establish the specific goal of 10 mrem per year total effective dose equivalent (TEDE) to the maximally exposed individual (MEI) from radionuclide air emission from licensed facilities and operations to match the EPA limit. The guide would also describe the types of administrative programs and objectives for environmental radiation protection programs that the NRC staff would find acceptable for satisfying the requirements of 10 CFR 20.1101(b).

Unlike the EPA, the NRC does not reference what methods or computer models the licensee should use to demonstrate compliance with the emission standard. Therefore, it is accepted industry practice to use the EPA computer models such as COMPLY, or those that are equivalent to COMPLY.

1.2.3 State of Tennessee Compliance Requirements

NRC provides assistance to States expressing interest in establishing programs to assume NRC regulatory authority under the Atomic Energy Act of 1954, as amended. Section 274 of the Act provides a statutory basis under which NRC relinquishes to the States portions of its regulatory authority to license and regulate byproduct materials (radioisotopes); source materials (uranium and thorium); and certain quantities of special nuclear materials. Regulation of nuclear power plants cannot be delegated to a state.

The mechanism for the transfer of NRC's authority to a State is an agreement signed by the Governor of the State and the Chairman of the Commission, in accordance with section 274b of the Act. The state is then called an NRC Agreement State. On March 26, 1962, the Commonwealth of Kentucky became the first Agreement State. Today, 37 States have entered into Agreements with NRC, and others are being evaluated. Tennessee became an Agreement State as of September 1, 1965.

As an Agreement State, Tennessee assumes most of the regulatory responsibilities that the NRC would have had within the state, including the regulation of Tennessee's LLRW processing facilities. Conducting this Agreement State program is the responsibility of the Tennessee Division of Radiological Health (or DRH). The DRH is responsible for protecting Tennesseans and the environment from the hazards associated with ionizing radiation. This responsibility encompasses regulating the use and possession of radioactive materials and radiation producing machines within the state, as well as responding to accidents involving radiation. In addition, the DRH monitors the environment for radiation, especially around nuclear facilities and other major radioactive material users.

In agreement with the NRC, Tennessee's DRH also incorporated regulations to ensure that doses resulting from effluents from licensed facilities would remain ALARA [11]. The Tennessee regulations also include the specific goal of 10 mrem per year TEDE to the maximally exposed individual (MEI) from radionuclide air emission from licensed facilities and operations to match the NRC and EPA limit.

The regulations also describe the types of administrative programs and objectives for environmental radiation protection programs that the Tennessee staff would find acceptable for satisfying the requirements of the Tennessee Standards for Protection Against Radiation (SFPAR) Chapter 0400-20-05-.40 (2).

As with the NRC, the DRH regulations do not reference what methods or computer models the licensee should use to demonstrate compliance with the emission standard. Therefore, the accepted industry practice for Tennessee licensees is to use the EPA computer models such as COMPLY, or those that are equivalent to COMPLY.

1.2.4 Regulatory ALARA Effluent Dose Constraint

The NRC, as part of its commitment to the EPA Memorandum of Understanding, prepared Regulatory Guide 4.20, "Constraint on Releases of Airborne Radioactive Materials to the Environment for Licensees Other than Power Reactors" [12] to provide guidance on the methods that the regulatory agencies (NRC or Agreement State) would consider acceptable for meeting the constraint on airborne emissions of radioactive material.

The dose limit established by regulation is a basic radiation protection standard that is the upper acceptable bound of radiation dose and should not be exceeded. The dose limit to members of the public found in SFPAR Chapter 0400-20-05 of 100 mrem per year includes doses from all pathways, including direct radiation, liquid effluents, and airborne emissions. The constraint, in the case of emissions, may be interpreted as that fraction of the public dose limit allocated to airborne emissions to ensure that doses are ALARA. The constraint serves as a starting point, or upper level, for ALARA assessments. If licensees exceed the constraint on airborne emissions, they are required to report the radiation dose to the NRC, or the Agreement State as appropriate, and to take corrective actions to lower the dose below the constraint value. [12]

The Tennessee SFPAR Chapter 0400-20-05-.40(4) specifies that licensees establish a constraint on air emissions of radioactive material to the environment, excluding radon-222 and its daughters, to ensure that the individual member of the public likely to receive the highest dose shall not be expected to receive a TEDE in excess of 10 mrem (0.1 mSv) per year from these emissions. This regulation stands in agreement with the requirements of the EPA and NRC Code of Federal Regulations (40 CFR Part 61 and 10 CFR 20, respectively).

The Maximally Exposed Individual (MEI) is defined as a hypothetical person who resides at the nearest location and has a lifestyle such that no other member of the public can receive a higher dose than this individual. The individual is assumed to reside 24 hours a day, 365 days a year at the location in the predominant downwind direction, and consumes local meat, vegetables, and milk during the year. In reality, it is a highly unlikely worst-case scenario that such a combination of maximized dose to any single individual would occur.

1.3 ICRP Internal Dosimetry Models

During the past 4 decades, the International Commission on Radiological Protection (ICRP), has published three different mathematical models to describe the deposition, clearance, and dosimetry of inhaled radioactive materials in the respiratory tract. The models make it possible to calculate the absorbed doses expected to be received from the environmental exposure to radionuclides by different parts of the respiratory tract and describe mathematically the expected absorption and translocation of portions of the deposited radionuclides to other organs and tissues beyond the respiratory tract.

As shown in the following sections, the structure and complexity of these models have increased with each version. These increases reflect both the expanded knowledge of the behavior and dosimetry of inhaled materials in the respiratory tract and an increased need for models having broader applications. Earlier models were used primarily for general prospective health protection planning purposes and routine workplace monitoring support. As these models have become more detailed and flexible, they have also been used for environmental applications as well. There were a number of significant changes to the form of ICRP recommendations between 1977 and 1990. These included a larger estimate of radiation detriment by increasing carcinogenic risk factors. More organs and tissues were specifically identified to be given their own tissue weighting factors. By 1990, the ICRP had moved away from the use of quality factors in favor of radiation weighting factors which were believed to be more biologically plausible and better related to measured radiation biological equivalencies. To accomplish this, the risk and detriment estimates were revised and justification for new dose limits was presented. The philosophical basis had broadened from a "system of dose limitation," to a "system of radiological protection." [13]

Since Publication 60, there has been a series of publications that have provided additional guidance for the control of exposures from radiation sources. However, the key principles of radiological protection from the 1990 recommendations were retained. In the 2007 Recommendations, the Commission sought to clarify and extend its previous recommendations. The system of protection was changed from a process-led (practice and intervention) to a situation-led (planned, emergency and existing) philosophy with a greater emphasis on source-related control compared to the 1990 concentration on the individual-related dose limits. More specifically, the Commission had now embraced the protection of the environment as a subject for radiological protection. [13]

For some radionuclides, dose coefficients given in the ICRP's series on environmental exposures vary substantially with age as a net result of the application of age-specific tissue masses and biokinetic parameter values. As these models have become more detailed and complex, so have the computational models that are required to use them.

1.3.1 Internal Dosimetry Model Development

Contemporary internal dosimetry models began with the single compartment models provided by the ICRP in publications 2 and 10 ([14], [15], [16]). The Committee on Medical Internal Radiation Dose of the Society of Nuclear Medicine (MIRD) Methodology [17] and ICRP publications 26 and 30 ([18], [19]) developed the concept of source and target organs. ICRP 26 defined the dosimetric quantities and dose limitation system and provided primary guidance for assessing radiation dose to workers. ICRP 30 recommended biokinetic and dosimetric models and provided secondary guidance in the form of limits on intake for occupationally exposed workers.

ICRP 60 and supporting publications including ICRP 66 ([20], [21]) superseded ICRP 26. The concept of effective dose as defined in Publication 60 differs little from that originally formulated in Publication 26, but Publication 60 revised and extended the list of tissue weighting factors used to calculate effective dose coefficients.

ICRP 68 [22] superseded ICRP 30. The updated respiratory model used in Publication 68 was introduced in Publication 66. That model involved greater detail and physiological realism than the respiratory model used in Publication 30 and produces considerably different predictions for some situations.

Age-specific dosimetric and biokinetic models, including gastrointestinal uptake fractions, for 31 environmentally important elements provided in ICRP 68 were taken from a series of ICRP documents, initiated in the late 1980s, on doses to members of the public from intake of radionuclides. The dosimetric models and methods used in ICRP 68 do not differ greatly from those used in ICRP 30, but many of the systemic biokinetic models and reference gastrointestinal absorption fractions (f1 values) were changed substantially. Systemic biokinetic models carried over from ICRP 30 generally had to be modified for use in Publication 68 because they did not explicitly address some tissues that were given weighting factors in ICRP 60 but not in ICRP 26. The respiratory model used in ICRP 30 is referred to as the Task Group Lung Model (TGLM), and the updated model used in ICRP 68 is referred to as the Human Respiratory Tract Model (HRTM), which was introduced in ICRP 66, where its basis and features are described. Although the TGLM was designed and intended for application to occupational intakes, it has also been applied to environmental exposures. In contrast to the TGLM, the HRTM model was designed to address environmental as well as occupational intakes.

Additional refinements to the biokinetic models are included in the ICRP 103 recommendations and supporting publications, which have not yet been adopted by regulatory agencies. [23]

1.3.2 Regulatory application of ICRP Internal Dosimetry Models

ICRP recommendations have been incorporated into national and international regulations for establishing public dose limits and ALARA constraints. For example, ICRP 26/30 form the basis for the U.S. ionizing radiation regulations (10 CFR 20 and 10 CFR 835), and ICRP 60/68 are the basis for current international regulations.

Over the past two decades the EPA has issued a series of Federal guidance documents for the purpose of providing the Federal and State agencies with technical information to assist their implementation of radiation protection and environmental compliance programs. The tabulations for currently recommended dose conversion factors and corresponding annual limits on intake (ALIs) and derived air concentrations (DACs) for intake of radionuclides in the Federal Guidance Report (FGR) No. 11 [24] were based on the radiation protection guidance given in ICRP 26 and ICRP 30. The guidance and models underlying FGR No. 11 were designed for application to occupational exposures to radionuclides, but have been applied to environmental exposures as well.

The dose coefficients of ICRP 30 and FGR No. 11, particularly the effective dose coefficient, have been applied to members of the public as well as to occupational radiation workers. While it is recognized by most investigators that dose per unit intake may often be greater for infants and children than for adults, it is considered that such difference with age may often be offset by lower usage (intake) of environmental media at younger ages.

1.3.3 ICRP 26/30

The biokinetic models of ICRP 30 generally are formulated as simple mathematical expressions and address only the initial distribution and net rate of decline of radionuclides in a few major organs. Retention of a radionuclide in the whole body or specific organ typically is described in terms of one to three removal half-times, with multiple half-times representing retention in multiple hypothetical compartments. With the exception of iodine, feedback of material from tissues to blood is not treated explicitly in ICRP 30, as material leaving an organ is assumed to move directly to excreta. The model for iodine is the only systemic biokinetic in ICRP 30 in which recycling of material is depicted explicitly.

In ICRP 30, decay chain members produced in the body generally are assigned the biokinetic model of the parent radionuclide, which is referred to as the assumption of "shared kinetics". However, experimental data on laboratory animals, and postmortem data on human subjects, indicate that many decay chain members produced *in vivo* behave much differently from the parent radionuclide. [25]

1.3.4 ICRP 66/68

The ICRP 66/68 model is a general update of that in ICRP 26/30, but is of wider scope. The fundamental difference in approach is that whereas the ICRP 30 model calculates only the average dose to the lungs, the new model takes account of the presumed differences in radiosensitivity of respiratory tract tissues, and the side range of doses they may receive, and calculates specific tissue doses. The new model also introduces a relatively detailed, physiologically realistic model of the respiratory tract. In contrast to the ICRP's previous respiratory model, the updated model addresses differences with age, gender, breathing rate, and other factors affecting deposition of inhaled material in the respiratory tract.

ICRP 66/68 applies explicitly to occupational radiation workers and all members of the public, with regards to the inhalation of gases, vapors and particles, and enables the evaluation of dose per unit intake or exposure and bioassay interpretation. For example, age-specific deposition fractions for different regions of the tract are provided for consideration of environmental intakes, and different patterns of deposition within the lung are also provided for occupational and environmental intakes by the adult to account for differences in breathing rates and mouth versus nose breathing. Along with the introduction of a new respiratory model, the ICRP changed its recommendation for a default particle size for assessment of occupational intake, from 1 micrometer or micron (μm) to 5 μm (activity median aerodynamic diameter, or AMAD). Depending to some extent on the half- life of the radionuclide and the types and energies of emitted radiations, the change in the default particle size sometimes leads to noticeable changes in dose estimates for occupational intakes due to differences in total or regional deposition of 1- and 5-μm particles in the respiratory tract.

1.3.5 ICRP 72

ICRP 72 was issued in 1996 and provided standard guidance used by international radiation protection community and by EPA in Federal Guidance Report 13, "Cancer Risk Coefficients for Environmental Exposure to Radionuclides." [26] The internal dose conversion factors (DCF) provided in ICRP 72 were derived from updated metabolic models and methodologies. The Effective Dose Equivalent (EDE) approach derived from summation of individual organ dose multiplied by organ weighting factor, giving stochastic dose, was similar to ICRP 30. The purpose of ICRP 72 was to summarize data on age dependent committed effective dose coefficients for members of the public from intakes by ingestion and inhalation of radioisotopes of the 91 elements described in ICRP Publications 56, 67, 68, 69 and 71. The publication does not give committed equivalent dose coefficients to tissues and organs. ICRP 72 methodologies and DCFs are the standard among the international community for radiation protection of the public. Use of ICRP 72 EDE DCFs is consistent with the stochastic EDE concept endorsed by the NRC in establishing 10 CFR 20 Appendix B effluent concentration limits.

1.4 EPA Computer Model Codes for Study

Doses to members of the public from airborne emissions must be evaluated with an EPA-approved model, such as CAP88, COMPLY or another approved method to demonstrate compliance (i.e., PRESTO, GENII-NESHAPS, AIRDOS-PC or DCAL). Emission monitoring and compliance procedures for Department of Energy (DOE) facilities (40 CFR 61.93(a)) require the use of the CAP88 or AIRDOS-PC computer models, or other approved procedures to calculate effective dose equivalents to members of the public. CAP88 and COMPLY are screening/compliance computer program models, which make conservative assumptions and require simple input data, for evaluating radiation exposure from atmospheric releases of radionuclides.

EPA approval of alternative computer codes is based on an evaluation of the meteorological and dosimetric models used in the code and on the exposure pathways that are included. The meteorological dispersion portion of the code must be appropriate for the situation that is being evaluated. For example, a code for treating area sources is not appropriate for releases from a stack or vent. The dosimetric models should closely approximate those in ICRP 26 and 30, and any differences should be explained and justified by the applicant. With respect to pathways, the code must consider air immersion, inhalation, ingestion, and ground-surface contamination. In addition, any request for approval of an alternative procedure that proposes modifying parameters that affect dose should be reviewed by EPA Headquarters prior to approval. [7]

1.4.1 COMPLY

The COMPLY computer code was the code developed and approved by the EPA to determine compliance with NESHAPs in 40 CFR 61, subpart I by determining the dose to members of the general public from emissions of radionuclides to the atmosphere [27]. When the COMPLY program is initiated, the first screen provides an introductory message with a brief description of the code as shown in Figure 1.4.

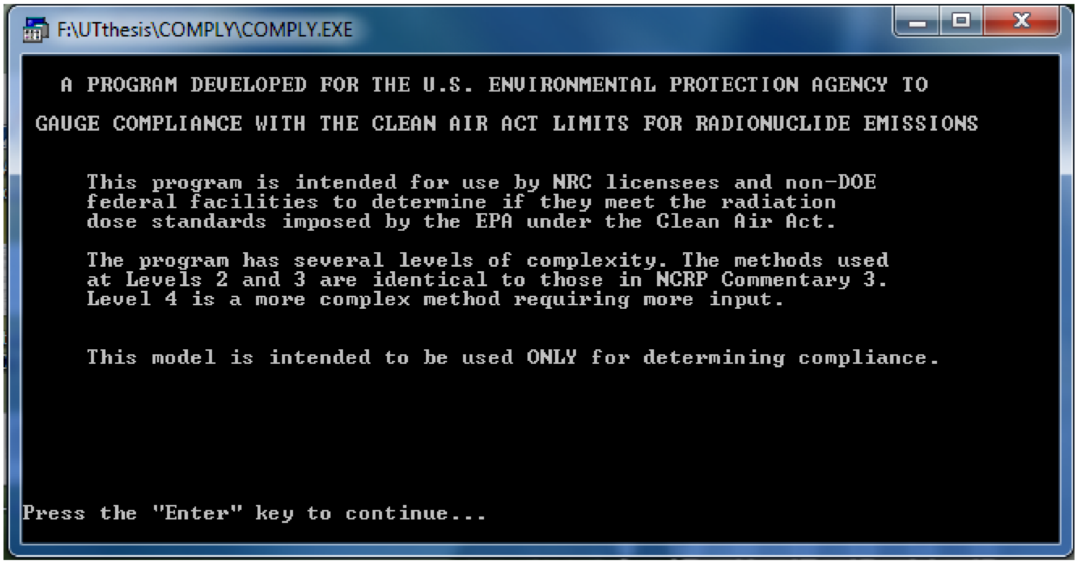

Figure 1.4 COMPLY Version 1.6 Opening Screen (MS-DOS)

In 1985, the EPA asked the National Council on Radiation Protection and Measurements (NCRP) to develop simple screening methods for assessing compliance with the Clean Air Act by users of small quantities of radionuclides. NCRP published these procedures in 1986 and 1989 in Commentary No. 3 [28]. EPA's COMPLY model was then developed based on the procedures provided in Commentary No. 3. [27]. The dose estimated by the COMPLY code is used to only demonstrate compliance with environmental standards and is not intended to represent actual doses to real people. The COMPLY code was also found by the NRC to be acceptable for demonstrating compliance with 10 CFR 20.1101(d) as the use of appropriate computer codes [12].

The code is designed to require only minimum input, using fixed data for environmental transport and food chain description to calculate the effective dose equivalent from radionuclides released from stacks and vents.

COMPLY includes 4 levels of complexity:

- Levels 1-2 request the least amount of information; however "worst case" assumptions are used in the dose estimates.
- Levels 3 and 4 request the most information, and use site specific meteorological and occupancy data instead of assuming the worst case.

At all levels, the program will determine whether a facility is in compliance with the standards, or whether it exceeds the standards. Level 4, used at the facility, is an extension of the NCRP screening levels, but produces a more accurate dose estimate by providing for more complete treatment of air dispersion, and a separate location for the production of each type of food.

The NCRP screening techniques are based on documented and well-known radiological assessment principles that combine environmental transport mechanisms, exposure pathways, and dosimetry components into a few calculational steps that require a minimum of site-specific data for the initial screening approach. In addition, the pathway parameters in Level 4 are less conservative. This method is the highest level in the COMPLY computer code, which is designed for facilities with continuously operating stacks.

Activity to dose conversion factors, fallout deposition velocities, food consumption rates and occupancy factors are fixed defaults. The atmospheric concentrations are estimated using a Gaussian plume model. The effective dose is calculated from the radionuclides released from one or more stacks, and releases from each stack are considered individually. The code also calculates radionuclide concentrations in various foods by coupling the output of the atmospheric transport models with the food chain models. The summary TEDE for the highest location is the only output and is primarily intended for comparison with environmental standards. [12]

However, although the EPA does make download of COMPLY available on the Internet as a DOS-based 16-bit code, the agency no longer provides revision or upgrades. In fact, with 64-bit environment operating systems (Windows 7 and Windows 8), attempts to run or install the program will result in an error message about compatibility because 16-bit programs cannot be run in a 64-bit environment. The model code CAP88 is now the only software revised as necessary by the EPA and will operate in 32 or 64-bit environments.

1.4.2 CAP88-PC

EPA's CAP88-PC (Clean Air Act Assessment Package-1988) computer model program was developed to demonstrate compliance with the Clean Air Act as applied to radionuclide emissions from licensed facilities outlined in 40 CFR 61, NESHAPs, Subpart H (Radionuclides). CAP88-PC is composed of modified versions of AIRDOS-EPA [29] and DARTAB [30]. The original CAP88 model was written in FORTRAN77 and was designed to be compiled and ran on an IBM 3909 under OS/VS2, using the IBM FORTRAN compiler at the EPA National Computer Center in Research Triangle Park, NC [31]. The code determines effective dose equivalent resulting from inhalation, immersion, ground deposition, and ingestion. Dispersion and environmental transport parameters are based on NRC Regulatory Guide 1.109 methodology. Dose conversion factors and organ weighting values are based on ICRP 26/30 methodology.

The first CAP88-PC software package, version 1.0, allowed users to perform full-featured dose and risk assessments in a DOS environment for the purpose of demonstrating compliance with 40 CFR 61.93 (a). There were a few differences between CAP88-PC and earlier mainframe versions of AIRDOS, PREPAR and DARTAB. In particular, population assessments were easier to perform. CAP88-PC provided the CAP88 methodology for assessments of both collective populations and MEIs. When performing population assessments, Population arrays are supplied to the program as a file, using the same format as the mainframe version of CAP88. The program uses the distances in the population array to determine the sector midpoint distances where the code calculates concentrations. One important point, CAP88-PC only uses circular grids as demonstrated in Figure 1.5.

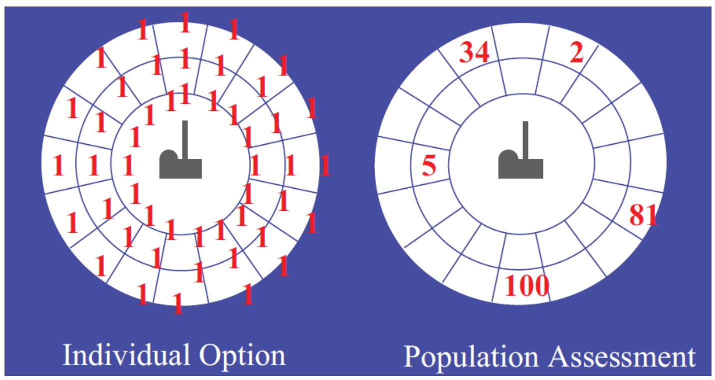

Figure 1.5 Example CAP88-PC Individual and Population Assessment Sector Grids

When an individual assessment is run, the sector midpoint distances are input by the user on the "Run Option" tab form. Direct user input of radionuclide concentrations at a specific receptor location is not an option in CAP88-PC.

The complete set of dose and risk factors used in mainframe CAP88 was provided in version 1.0 of CAP88-PC. This provided a major difference in CAP88-PC from the radionuclide emission dose assessment software AIRDOS-PC in that it estimated risk as well as dose. CAP88-PC also offered a wider selection of radionuclide and meteorological data, provided the capability for collective population assessments, and allowed users greater freedom to alter values of environmental transport variables. CAP88-PC version 1.0 was approved for demonstrating compliance with 40 CFR 61.93 (a) in February 1992.

CAP88-PC version 2.0 provided a framework for developing inputs to perform full-featured dose and risk assessments in a Windows® environment for the purpose of demonstrating compliance with 40 CFR 61.93 (a). The changes from version 2.0 to version 2.1 included the addition of more decay chains, improvements in the Windows code error handling, and a modified nuclide data input form.

CAP88-PC Version 3.0 (opening screen shown in Figure 1.6) marked a significant update to the version 2 system. Version 3 incorporated dose and risk factors from FGR 13 [26] in place of the RADRISK data that was used in previous versions. The FGR 13 factors were based on the methods in Publication 72 of the International Commission on Radiological Protection [32]. In addition, the CAP88-PC database, user interface, and input/output files were modified to accommodate the FGR 13 data formats and nomenclature.

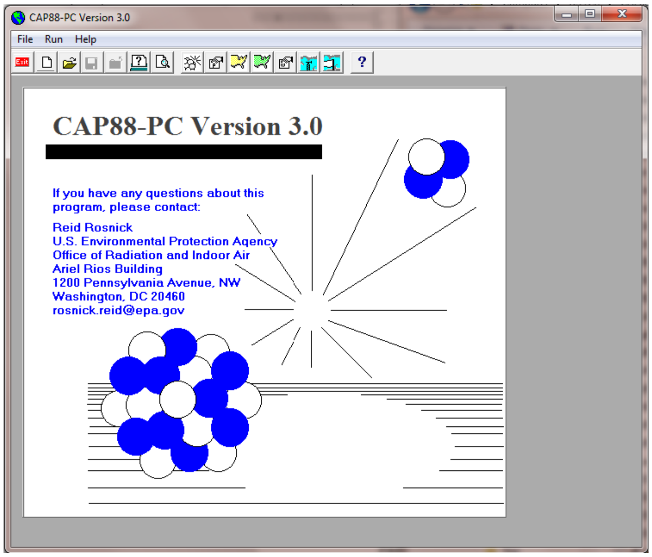

Figure 1.6 CAP88-PC Version 3.0 Opening Screen

CAP88-PC Version 4 was a significant modification to version 3 intended to improve usability, increase stability, update the datasets, and provide a more maintainable code base and documentation set for the future. Version 4 adopts age-dependent dose and risk factors and introduces a new code architecture that conforms to updated coding standards and data formats. The database of isotopic data is now in eXtensible Markup Language (XML) format to enhance portability [33].

The EPA allows the use of any version of CAP88 for enforcement purposes. Version 4.0.0.0 (production release) has just been added to the suite of models but was not used for this study. To allow for updates and refinement of the software, Subpart H of 40 CFR Part 61 does not specify any version. However, because Version 4 incorporates the latest science and is more versatile than the older versions, it is recommended. As with previous model versions, the version 4 modifications eliminate the errors discovered by the user community.

As with COMPLY, CAP88-PC uses a Gaussian plume model equation to estimate the average dispersion of radionuclides released from elevated stacks or diffuse sources. The program computes radionuclide concentrations in air, rates of deposition on ground surfaces, and concentrations in food (where applicable) to calculate a final value for projected dose at the specified distance from the release point. The program supplies both the calculated effective dose equivalent to the MEI and the collective population dose within a 50-mile radius of the emission source. For purposes of modeling the dose to the MEI, all emission points are located at the center of the referenced facility.

The CAP88-PC modeling program is explicitly designed to model continuous airborne radioactive emissions that occur over the course of a single year. Input parameters used in the model include radionuclide type, emission rate in curies per year, stack parameters such as height and diameter, and emission exhaust velocity. Site specific weather data is also used for the assessments. CAP88-PC requires the additional information of average temperature, precipitation rates, lid (mixing) height, and average humidity. The code calculates radionuclide concentrations in various foods by coupling the output of the atmospheric transport models with the food chain models.

Assessments are done for a circular grid of distances and directions for a radius of up to 80 km (50 miles) around the facility. The Gaussian plume model produces results that agree with experimental data as well as any model, is fairly easy to work with, and is consistent with the random nature of turbulence. The calculation of deposition velocity and the default scavenging coefficient is also modified to incorporate current EPA policy. The default scavenging coefficient is calculated as a function of annual precipitation. Activity to effective dose conversion factors are given as fixed default values [33].

While up to six stack or area sources can be modeled, all the sources are modeled as if located at the same point; that is, stacks cannot be located in different areas of a facility. The same plume rise mechanism (buoyant or momentum) is used for each source. Also, area sources are treated as uniform. Variation in radionuclide concentrations due to complex terrain cannot be modeled. Errors arising from these assumptions will have a negligible effect for assessments where the distance to exposed individuals is large compared to the stack height, area or facility size.

CAP88-PC models uniform area sources using a method described by Mills and Reeves, as modified by Christopher Nelson, EPA, and implemented by Culkowski and Patterson. [31] The method transforms the original area source into an annular segment with the same area. The transformation is dependent on the distance between the centroid of the area source and the receptor. At large distances (where the distance/diameter ratio is 2.5), the area source is modeled as a point source; at close distances it becomes a circular source centered at the receptor. A point source model is also used if the area source is 10 m in diameter or less.

For area sources, Chi/Q values are used to convert radionuclide release values (Q) to concentrations (Chi). The principle of reciprocity is used to calculate the effective Chi/Q. The problem is equivalent to interchanging source and receptor and calculating the mean Chi/Q from a point source to one or more sector segments according to the angular width of the transformed source. The mean value of Chi/Q for each sector segment is estimated by calculating Chi/Q at the distance which would provide the exact value of the mean if the variation in Chi/Q were proportional to $r^{-1.5}$ for distances from the point source to location within the sector segment. The Chi/Q for the entire transformed source is the sum of the Chi/Q values for each sector weighted by the portion of the total annular source contained in that sector.

The EPA's Office of Radiation and Indoor Air has made comparisons between the predictions of annual-average ground-level concentration to actual environmental measurements, and found very good agreement. In the paper "Comparison of AIRDOS-EPA Prediction of Ground-Level Airborne Radionuclide Concentrations to Measured Values" [34], environmental monitoring data at five DOE sites were compared to AIRDOS-EPA predictions. EPA concluded that as often as not, AIRDOS-EPA predictions are within a factor of 2 of actual concentrations.

CAP88-PC tabulates the effective dose equivalent for the maximally-exposed individual in mrem/yr for a 50 year exposure. Risk is estimated as total lifetime risk for a lifetime exposure. As with the COMPLY code, dose and risk estimates from CAP88-PC are applicable only to low-level chronic exposures, since the health effects and dosimetric data are based on low-level chronic intakes. CAP88-PC cannot be used for either short-term or high-level radionuclide intakes. Also, the dose estimated by this code at any given location is used for comparison with environmental standards as required by EPA and State of Tennessee regulations, and is not intended to represent actual doses to real people.

Collective population dose and risk are found by summing, for all sector segments, the intake and exposure rates multiplied by the appropriate dose or risk conversion factors determined using the Oak Ridge National Laboratory (ORNL5692 [30]) preprocessor which creates AIRDOS-EPA Input Data Sets. Collective population dose is reported by person-rem/yr (not millirem), and collective risk is reported in deaths/yr. Collective risk is reported as annual risk, while maximally-exposed individual risk is reported as lifetime risk.

Currently, CAP88 is now the only code the EPA provides support for, and will continue to update as new internal dose models are developed. The latest release is Version 4.0.0.0 (production release January 2014). CAP88-PC Version 4.0 has only been tested on Windows XP with Service Pack 3, Windows Vista, Windows 7, Windows 8, and Windows Server 2008, 2008 R2, and 2012. Windows versions before XP with SP3 are not supported. Also, CAP88-PC V4 requires the .NET Framework 4 to be installed. The User's Manual for CAP88-PC Version 4 is provided both on-line as context-sensitive help and in the installation file set. CAP88 v4 has undergone an internal EPA quality assurance review. The quality assurance review report and documentation are available at the Office of Radiation and Indoor Air (ORIA).

1.5 Other Computer Model Codes

The following models are also identified by the EPA to assess risk and dose: PRESTO, GENII-NESHAPS, and DCAL. These models are considered acceptable to demonstrate compliance with 40 CFR 61, Subpart H and I, but are not supported by the EPA.

1.5.1 PRESTO

PRESTO (Prediction of Radiological Effects Due to Shallow Trench Operations) is a computer model for evaluating radiation exposure from contaminated soil layers, including waste disposal, soil cleanup, agricultural land application, and land reclamation. It is a multimedia model typically used for assessing risk from low-level and low- activity wastes, NARM, and uranium mill tailings waste. [35]

This model was intended to support the development of EPA's environmental standards and criteria. The initial models, published in 1987, were developed for a mainframe computer. Subsequent versions were modified to operate on a personal computer in a DOS environment.

- PRESTO-EPA-CPG Operation System
  Version 2.0published in 1993
  Version 2.1 published in 1996
- PRESTO-EPA-POP Operation System
  Version 2.1 published in 1995

The current Version 4.2 of the PRESTO-EPA-CPG/POP Operation System combines these two systems and operates in a Windows environment. It also incorporates new features, including the addition of soil cleanup, agricultural land application, and land reclamation to the waste trench operation scenarios.

The models are designed to calculate the maximum annual committed effective dose to a critical population group and cumulative fatal health effects and genetic effects to the general population in several scenarios:

1. Near surface disposal trench containing low-level radioactive waste and/or naturally occurring or accelerator produced radioactive material (NARM)

2. Residual radionuclides remaining in soil layers after cleanup

3. Agricultural land application of technologically enhanced naturally occurring radioactive materials (TENORM) waste

4. Stripped land reclamation with applied TENORM waste

The models simulate the transport of radionuclides in air, surface water, and groundwater pathways, and evaluate exposures through ingestion, inhalation, immersion and external exposure pathways.

To avoid overly conservative results, EPA employed a dynamic approach for the infiltration sub-model; a multi-phase leaching concept for the release sub-model; realistic transition flow from vertical transport reach to horizontal transport reach for the groundwater sub-model; and plausible scenario assumptions for the well mechanics sub-model.

Theoretically, a one-dimensional model can produce a significant amount of error relative to a three dimensional model; however, the magnitude of this error depends largely on the conditions of the application. A recent study indicated that under normal applications, this relative error may range from zero to 10 percent for the PRESTO-EPA-CPG and virtually zero error for PRESTO-EPA-POP. [35]

1.5.2 GENII-NESHAPS

The GENII System provides a state-of-the-art, fully documented set of software for calculating radiation dose and risk from radionuclides released to the environment. The GENII-NESHAPs edition automatically incorporates specific requirements of the NESHAP regulations. However, EPA has not approved it for demonstrating compliance with NESHAP Subparts H and I. [36]

The DOE released GENII Version 1.0 in 1988. The EPA developed a new version of the software in 2002, GENII Version 2.0, incorporating improved transport models, exposure options, dose and risk estimation, and user interfaces.

In 2002, a new edition, GENII-NESHAPS, was developed as an alternative for demonstrating compliance with the dose limits specified in 40 CFR 61.93(a), the

National Emission Standards for Hazardous Air Pollutants for radionuclides. The GENII-NESHAPS edition offers limited capability to change parameters, but the advantage is that it automatically incorporates specific requirements of the NESHAP regulation. GENII-NESHAPS incorporates the internal dosimetry models recommended in ICRP 56-72 and the radiological risk estimating procedures of FGR 13 into updated versions of existing environmental pathway analysis models. These dosimetry and risk models are considered to be state of the art by the international radiation protection community and have been adopted by most national and international organizations as their standard dosimetry methodology. The software was designed with the flexibility to accommodate input parameters for a wide variety of generic sites. GENII-NESHAPS functions within the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES), which allows GENII to run in conjunction with and provide inputs to related software.

GENII-NESHAPS offers interactive, menu-driven user interfaces for entering data. It provides default exposure and consumption parameters for the maximally exposed individual. It accepts radionuclide source term information in formats appropriate for different exposure scenarios --as release quantities where transport is involved or as concentrations in environmental media (air, water, soil) in the absence of transport. The model also considers decay of parent radionuclides and in-growth of radioactive decay products prior to the start of the exposure scenario for either basic or derived concentrations. Because the system works sequentially on individual decay chains, unlimited numbers of radionuclides, including the source term and accumulated decay products, can be processed in a single run. The radial grid used in GENII-NESHAPS allows consideration of both the distance and direction to target individuals and populations. The model accommodates scenarios involving chronic releases to air from ground level and/or elevated sources. Exposure pathways include direct exposure from surface sources (soil) and air (semi-infinite cloud and finite cloud geometries) as well as inhalation and ingestion. The tritium model includes consideration of both gas and vapor, conversion of gas into vapor, and biological conversion of both into organically-bound tritium.

Radiation doses are calculated by the model using plume air transport calculations based on chronic atmospheric releases. This allows the use of an effective stack height or calculation of plume rise from buoyant or momentum effects (or both). The system then calculates the health risks to individuals or populations by applying appropriate risk factors to either the effective dose, the effective dose equivalent, or the organ dose. It also estimates cancer risk to specific organs or tissues using risk factors from FGR 13.

In 2003, the software was peer reviewed and the EPA has since decided not to support alternative models, such as GENII-NESHAPS, for compliance purposes. CAP88 remains the only model supported by the EPA for demonstrating compliance. [36]

1.5.3 AIRDOS-PC

The AIRDOS-PC software package was designed in the late 1980's to calculate the effective dose equivalent values to MEI, as required by 40 CFR Parts 61.93(a), and to prepare a two-page compliance report suitable for submission to the EPA. Organ dose equivalents are also calculated. Additional output tables which are produced by AIRDOS-EPA, but not required for determining compliance, may also be printed. The assessment scenario is designed to reflect the modeling used by EPA in the Background Information Document prepared for the NESHAP rulemaking. [29]

AIRDOS-EPA is one component of the CAP88 computer model specified in 40 CFR 61.93(a). The original AIRDOS-EPA computer code was designed for use on IBM-360 computers. The code computes air concentrations, ground surface deposition, and intake rats for the inhalation and ingestion pathways. This code incorporates a modified Gaussian plume equation which is used to estimate both horizontal and vertical dispersion of radionuclides released from one to six stacks or area sources.

Dose conversion factors are input to the code, DARTAB, which estimates doses to individuals at specified distances and directions for selected organs through the following exposure modes: (1) immersion in air containing radionuclides, (2) exposure to ground surfaces contaminated by deposited radionuclides, (3) immersion in water containing radionuclides, (4) inhalation of radionuclides in air, and (5) ingestion of food produced in the area.

In order for the AIRDOS-PC code to fit in the memory constraints of a personal computer while meeting the modeling requirements of NESHAPS, a number of options that available on the mainframe version of AIRDOS-EPA were not available for AIRDOS-PC. Also, there are a number of significant limitations in the original mainframe AIRDOS-EPA code that are also present in AIRDOS-PC. For example, while up to six (6) stacks or area sources can be modeled, all the sources are treated as collocated at the same point. Also there is no correction for the errors introduced by building wake effects, so the model is rested to distances of 300 m or greater. There is also a restriction on which radionuclides can be modeled with this version.

Additional limitations include the configuration of individual locations and food sources. Calculations are only done for a circular grid of directions and distances; a square grid option is not available. The food source is assumed to be 100% locally grown, unique agricultural arrays cannot be supplied. There is no provision for build-up of decay products in soil for the uranium and thorium decay series. Population assessments are not an option. Directions and distances to locations of maximum doses are not supplied in the compliance report. Calculations for risks or genetic effects are not an option. Dose conversion factors are not available for all combinations of particle size and solubility classes for some radionuclides.

References on AIRDOS-EPA, DARTAB, and supplementary computer codes for AIRDOS-PC are available from the National Technical Information Service.

1.5.4 DCAL

Dose and Risk Calculation (DCAL) is a comprehensive software system for the calculation of tissue dose and subsequent health risk from intakes of radionuclides or exposure to radionuclides present in environmental media. DCAL was developed for the EPA by ORNL and is documented in ORNL/TM-2001/190. The software runs on a PC under Windows 98/NT/2000/XP. The system includes extensive libraries of biokinetics and dosimetric data and models representing the current state of the art. DCAL may be used either in an interactive mode or in a batch mode and is intended for experienced users with knowledge of computational dosimetry. The system consists of a series of computational modules driven by a user interface. [37]

Under the sponsorship of the EPA, the Dosimetry Research Group (now the Biosystems Modeling Team in the Advanced Biomedical Science and Technology Group) at ORNL developed this comprehensive software system for the calculation of tissue dose and subsequent health risk from intakes of radionuclides or exposure to radionuclides present in environmental media. This system serves EPA's current needs in radiation dosimetry and risk analysis. DCAL has been used in the development of two federal guidance reports (FGR 12 and 13) and several publications of the ICRP, specifically in the computation of age-specific dose coefficients for members of the public (ICRP 1989, 1993, 1995a, 1995b, 1996).

DCAL uses metabolic models from ICRP Publications 68 and 72 with data from ICRP Publications 23 and 89 to calculate dose per unit intake of over 800 radionuclides and combines that with risk models from EPA 402-R-93-076 Estimating Radiogenic Cancer Risks and EPA 402-R-99-003 Estimating Radiogenic Cancer Risks, Addendum: Uncertainty Analysis to develop average lifetime risk estimates for a unit intake of a radionuclide by a member of the US population either by ingestion, or by inhalation, or by injection. A detailed discussion can be found in EPA 402-R-99-001 FGR No. 13, Cancer Risk Coefficients for Environmental Exposure to Radionuclides." [26]

Chapter 2

2 Code Mathematical Models

Both COMPLY and CAP88-PC determine effective dose equivalents from external sources, considering uptakes from both inhalation and ingestion. Exposure pathways include submersion in a cloud of airborne gases or particles, irradiation from a large ground plane contaminated with radioactive particles, and internally deposited radionuclides.

Both models use a modification of the Gaussian plume model for dispersion in the atmosphere to calculate airborne concentrations and ground deposition of radionuclides released from the source(s). However, they vary in regards to default input parameters.

2.1 Gaussian Plume Model

The Gaussian plume, straight-line trajectory model is one of the more commonly used models for estimating the ground-level concentration of a gaseous effluent from a point source, such as a stack. The standard Gaussian plume air dispersion model was developed in the mid-1930s and remains a simple model that produces a relatively accurate result for the input data required [38]. The term dispersion in this context is used to describe the combination of diffusion (due to turbulent eddy motion) and advection (due to the wind) that occurs within the air near the Earth's surface. Because most sources have an associated size (area/cross section/volume) at the release location, the Gaussian model is not considered to give reasonable results within a few hundred meters of the release location unless adjustments are made, such as in area and volume source adaptations. Also, this model determines ground level pollutant concentrations based on time-averaged atmospheric variables (e.g. temperature, wind speed). Therefore, an instantaneous "picture" of the plume's concentration cannot be obtained.

The model assumes that the contaminant concentration has a Gaussian distribution, meaning that it is normally distributed around the central axis of the plume as shown in Figure 2.1. This is also assuming that atmospheric stability and wind speed determine the atmospheric dispersion characteristics of the contaminant in the downwind direction [39]. The primary algorithm used in Gaussian modeling is shown in Equation (1) and is known as the Pasquill-Gifford equation:

$$\chi(x,y,z) = \frac{Q}{\pi \sigma_y \sigma_z \mu} exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2}\right)\right] \quad (1)$$

where

- $\chi(x,y)$ = ground level concentration at point x,y (Ci/m^3),
- x = downwind distance on plume center line (m),
- y = crosswind distance (m),
- Q = mass emitted per unit time,
- σ_y = horizontal standard deviation of contaminant concentration in plume (m),
- σ_z = vertical standard deviation of contaminant concentration in plume (m),
- μ = mean wind speed at level of plume center line (m/s),
- y = distance in horizontal direction (m),
- H = effective stack height (m).

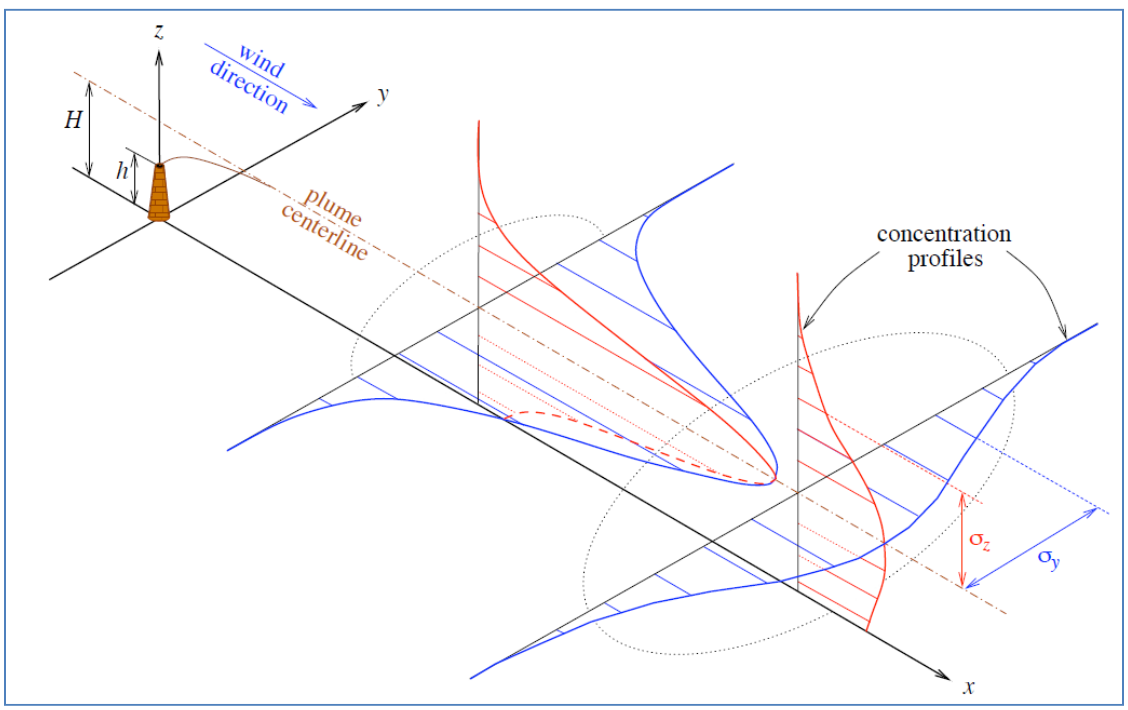

Figure 2.1 Contaminant plume emitted from a continuous point source with Gaussian cross-sections

For purposes of calculating ground-level concentrations with the use of Equation (1), Pasquill defined values for σ_y and σ_z by classifying stability conditions according to prevailing conditions of average wind speed and estimated radiation balance. References, such as Health Physics and Radiological Health, 4th edition [40] and other texts provide the σ_y and σ_z values for each of the stability categories. The most commonly used formulations are based on the Pasquill-Gifford curves or those suggested by Briggs [41] for rural (open country) or urban conditions. These standard deviations are characteristic of the size of the plume and become larger as the plume travels farther downwind.

If the effluent gas has a significant exit velocity or if it is at a high temperature, it will rise to a level higher than the stack. The effective stack height, therefore, is the sum of the actual stack height plus a factor that accounts for the exit velocity and temperature of the effluent gas as shown in Equation (2):

$$\boldsymbol{H = h + d\left(\frac{\nu}{\mu}\right)^{1.4}\left(1 + \frac{\Delta T}{T}\right)} \tag{2}$$

where

h = actual stack height (m),

d = stack outlet diameter (m),

ν = exit velocity of gas (m/s),

Q = mass emitted per unit time,

μ = mean wind speed (m/s),

ΔT = difference between ambient and effluent gas temperatures,

T = absolute temperature of effluent gas.

The Gaussian dispersion model itself can be supplemented by other models when downwind air concentrations are being calculated. Other factors to be considered include plume rise, buoyancy-induced dispersion, and plume depletion as a function of dry and wet deposition [38].

Except in the case of nonreactive gases, the total amount of contaminant in the plume decreases as the plume moves downwind because of chemical reaction, gravitational settling (dry deposition), impaction on surfaces protruding from the ground, and precipitation scavenging (wet deposition from rainout, washout). Gravitational settling is important for large particles, about 15 to 20 µm or larger; impaction and wet deposition are important mechanisms of plume depletion mainly for small particles.

2.2 COMPLY Mathematical Models

2.2.1 Air and Food Concentration Models

The meteorological model for determining air concentration for COMPLY levels 2 and 3 is the same as that used in NCRP Commentary 3 [28]. At level 4, the method is almost the same as levels 2 and 3 with three major differences. The first is that wind frequency *(f)* and average wind speed *(u)* are supplied for each of the16 sectors around the release point (a wind rose). The distance to the closest receptor also must be supplied in each of these sectors. If a wind rose was not supplied, then *f* is taken to be 0.25 just as at levels 2 and 3. With a wind rose, the code searches the sectors to find the receptor exposed to the highest concentration. The second difference from levels 2 and 3 is that plume rise (momentum or buoyant) is accounted for when the stacks are greater than 2.5 times the building height. The third difference is that the code uses the supplied distance to the farms producing vegetables, milk, and meat in the sector having the maximum value of *f/u* to estimate the concentration at each farm. However, this study uses "home" for food production so the concentration is calculated to be at the same location of the receptor, just as for levels 2 and 3.

The method for calculating the air concentration at the receptor's location *x* meters from the source depends upon the configuration of the stack and the location of the receptor relative to the building. There are two main subdivisions, one for tall stacks (> 2.5 times the building height) and one for short stacks where building wake effects are important. The stack and building information required by COMPLY specific with the stacks is provided in Table 2.1 below. Building and stack dimensions were confirmed by the Facility engineer.

Table 2.1 COMPLY Stack and Building Dimensions

	Stack 1	Stack 2
Building Data	meters	meters
Release Height	30	22
Building Height	15	16
Building Width	60	46
Building Length	20	107
Ratio Stack to Building	2	1.4
Building Area	1200 m^2	4922 m^2
Area Square Root	35 m	70 m
Closest Receptor	1600 m	1400 m
Ratio SqrtArea to Receptor	45.7	20

As shown in Table 2.1, the stacks of this Facility are not greater than 2.5 times the building height, so the code would use the algorithms for a short stack. Additionally, the receptor is on the same building as the stack. For this set of conditions the algorithms used are further divided into two cases, first where the distance to the receptor, *x*, is less than or equal to 2.5 times the square root of the building area, or when *x* is greater than 2.5 times the square root of the building area. As can be seen in Table 2.1, the distance to the receptor is many times greater than 2.5. Therefore, the modified Gaussian plume equation for determining air concentration at each receptor location is [27]:

$$C = 2.032\left(\frac{fQ}{ux\sigma_z}\right) \tag{3}$$

Where

- C = ground level concentration at point x (Ci/m^3),
- f = fraction of the time the wind blows from the source to the receptor
- Q = radionuclide release rate (Ci/yr),
- u = annual average wind speed (m/s),
- x = distance between the source and the receptor (m),
- σ_z = vertical standard deviation of contaminant concentration in plume (m),

The equation for vertical standard deviation, σ_z, is based on neutral atmospheric stability (Class D) as shown in Equation (4).

$$\sigma_z = \frac{0.06x}{\sqrt{1+0.0015x}} \tag{4}$$

The concentration at farms producing various foods is calculated the same way. By specifying that the food is produced at home, *x* for the farm is the same as the distance from the source to the receptor.

2.2.2 Plume Rise

Plume rise is used only when the stack height is greater than 2.5 times the building height (no building wake effects). Therefore, algorithms for plume rise were not used.

2.2.3 Dose Calculations

The dose calculations for COMPLY levels 2 and 3 are the same as those used in NCRP Commentary 3. At level 4, the methods are generally the same, but there are some differences. The contribution of daughter radionuclides to the dose from external exposure is handled internally by the program, rather than being built into the dose factors. Build-up of daughters in the food chain is also calculated by the program instead of being compensated for in the dose factors. The differential equations for determining radionuclide concentrations in food and water for the pathways provided in NCRP Commentary No. 3 are solved using the methods described by Ken Skrable's in a 1974 Health Physics Journal article [42].

The sources for the dose conversion factors are Federal Guidance Report No. 11 (internal) [24] and the external dose rate conversion factors provided by Federal Guidance Report No. 12 [43]. The soil to plant concentration ratios and animal product transfer factors are from the sources in NCRP Commentary No. 3.

2.2.4 Tritium and Carbon-14

Tritium and Carbon-14 at level 4 are treated slightly differently than in NCRP Commentary No. 3. The NCRP approach assumes that the specific activity of Carbon-14 and Tritium are the same in the food as in the atmosphere. For level 4, instead of assuming that the specific activity of tritium is the same in the food product as in the atmosphere, the level 4 method accounts for some dilution by non-tritiated water. In addition, level 4 uses equations directly from the Baker report [44], rather than using transfer factors.

2.2.5 Plume Depletion

Calculation of wet deposition follows the methods provided in the International Atomic Energy Agency's Safety Series No. 57 [45]. The total deposition is the sum of the wet and dry deposition velocities. The precipitation rate is taken as a default to be 1 meter per year. The

2.2.6 COMPLY Code Default Parameters

The values of the parameters used at level 4 are those from AIRDOS-EPA [29] and EPA Standards [46]. Table 2.2 provides a summary of these parameters as they are used in the level 4 COMPLY code.

Table 2.2 Parameters used in COMPLY

Symbol	Definition	COMPLY
RMCONR	Removal constant, 1/yr	0.015
DEPTIM	Period of long-term buildup in soil, yr	100
VDEP	Deposition velocity, m/day (noble gases)	0
VDEP	Deposition velocity, m/day (iodine)	860
VDEP	Deposition velocity, m/day (particulates)	210
FRVEG	Fraction of activity intercepted & retained (veg)	0.1
FRMLK	Fraction of activity intercepted & retained on forage or feed (milk)	0.18
FRMEA	Fraction of activity intercepted & retained on forage or feed (meat)	1.8
TWEATH	Weathering half-life, days	12
TEVEG	Period of above-ground exposure, days (veg)	60
TEMLK	Period of above-ground exposure, days (milk)	30
TEMEA	Period of above-ground exposure, days (meat)	30
YVEG	Edible crop per m^2 at harvest, kg/m^2 (veg)	1.0
YMLK	Edible crop per m^2 at harvest, kg/m^2 (milk)	1.0
YMLK	Edible crop per m^2 at harvest, kg/m^2 (meat)	1.0
PVEG	Areal density of effective root zone, kg/m^2	220
PMLK	Areal density of effective root zone, kg/m^2	220
PMEA	Areal density of effective root zone, kg/m^2	220
QMLK	Feed or forage consumption rate, kg/day (dairy)	16
QMEA	Feed or forage consumption rate, kg/day (meat)	12
QWMEA	Water consumption by dairy cow, kg/day (dairy)	60
QWMEA	Water consumption by beef cattle, kg/day	50
CH20	Concentration of water vapor in atmosphere, kg/m^3	0.008
CCARB	Concentration of carbon in atmosphere, kg/m^3	1.6e-4
FHVEG	Fraction of hydrogen in vegetables	0.1
FHMEAT	Fraction of hydrogen in meat	0.1
FHMILK	Fraction of hydrogen in milk	0.11
FHFEED	Fraction of hydrogen in animal feed or forage	0.07
FCVEG	Fraction of carbon in vegetables	0.09
FCMEAT	Fraction of carbon in meat	0.24
FCMILK	Fraction of carbon in milk	0.07
CVEG1	Human vegetable consumption, kg/yr	70
CMILK1	Human milk consumption, kg/yr	160
CMEAT1	Human meat consumption, kg/yr	75
BREATH	Breathing rate, m^3/yr	8000
DELVEG	Delay time, harvest to consumption, days	11
DELMLK	Delay time, milking to consumption, days	2
DELMET	Delay time, slaughter to consumption, days	17

2.3 CAP88-PC Mathematical Models

CAP88-PC incorporates a modified version of the AIRDOS-EPA [29] program to calculate environmental transport [31].

2.3.1 Air and Food Concentration Models

Plume dispersion is modeled in the subroutine CONCEN with the Gaussian plume equation of Pasquill, as modified by Gifford. The chronic implementation of the Gaussian puff model considers a continuous atmospheric release. For a receptor at ground level, the concentration downwind of a chronic source can be derived from Equation (5) by setting z = 0 and integrating over time from zero to infinity. The resulting equation calculates the chronic air concentration at a specific location downwind for a given set of meteorological conditions (i.e., weather stability category and wind speed and direction).

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\mu} exp\left(\frac{-y^2}{2\sigma_y}\right)\left[exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right] \tag{5}$$

Where

χ = air concentration of radionuclide *i* at *x* meters downwind, *y* meters cross wind, and *z* meters above ground (Ci/m^3) [ACON],
Q = release rate from stack (Ci/sec) [REL],
μ = wind speed (m/s) [U],
σ_y = horizontal dispersion coefficient (m),
σ_z = vertical dispersion coefficient (m),
H = effective stack height (m).
y = crosswind distance (m),
z = vertical distance (m),

The downwind distance *x* comes into Equation (5) through σ_y and σ_z, which are functions of *x* as well as the Pasquill atmospheric stability category applicable during emission from the stack for open country conditions. Horizontal and vertical dispersion coefficients (σ_y and σ_z) used for dispersion calculation in CONCEN and for depletion fraction determination in QY are taken from recommendations by G.A. Briggs of the Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee [29].

CAP88-PC converts χ in Equation (5) and other plume dispersion equations from units of curies per cubic meter to units of picocuries per cubic centimeter. Equation (5) is also modified at greater distances where plume reflection occurs off a stable upper layer or mixing layer. At these distances, uniform mixing between the ground and the upper air layer is assumed, and the Gaussian form of the equation is lost.

The annual-average meteorological data sets include frequencies for several wind-speed categories for each wind direction and Pasquill atmospheric stability category. CAP88-PC then uses reciprocal-averaged wind speeds in the atmospheric dispersion equations, which permit a single calculation for each wind-speed category. Ground-level concentrations in air are determined by setting *y* and *z* to zero in Equation (5), giving the sector-averaged Equation (6):

$$\chi = \frac{Q}{0.15871\pi x \sigma_z \mu} exp\left(\frac{-H^2}{2\sigma_z^2}\right) \tag{6}$$

This method of sector-averaging compresses the plume within the bounds of each of the sixteen 22.5° sectors for unstable Pasquill atmospheric stability categories in which horizontal dispersion is great enough to extend significantly beyond the sector edges. It is not a precise method, however, because the integration over the *y*-axis, which is perpendicular to the downwind direction, x, involves increasing values for *x* as *y* is increased from zero to infinity.

An average lid for the assessment area is provided as part of the input data. The lid is assumed not to affect the plume until *x* becomes equal to $2x_L$, where x_L is the value of *x* for which $\sigma_z = 0.47$ times the height of the lid. For values of *x* greater than $2x_L$, vertical dispersion is restricted and radionuclide concentration in air is assumed to be uniform from ground to lid. Values of the downwind distance greater than $2x_L$ dispersion can no longer be said to be represented by the Pasquill equation. The model is simply a uniform distribution with a rectangle of dimensions.

2.3.2 Plume Rise

CAP88-PC calculates plume rise in the subroutine CONCEN using Rupp's equation [47] for momentum dominated plume rise. CAP88-PC also accepts supplied values for plume rise for each Pasquill stability class (from downloaded ORNL meteorological data). The plume rise, Δh, is added to the actual physical stack height, *h* [PH], to determine the effective stack height, *H*. The plume centerline is shifted from the physical height, *h*, to *H* as it moves downwind. The plume centerline remains at *H* unless gravitational settling of particulates produces a downward tilt, or until meteorological conditions change.

The true-average wind speed for each Pasquill stability category is used in CAP88-PC to estimate plume rise, as it is greater than the reciprocal-averaged wind speed, and produces a smaller, more conservative plume rise. This procedure does not risk underestimating the significant contribution of relatively calm periods to downwind nuclide concentrations which could result from direct use of a plume rise calculated for each separate wind-speed category. This procedure avoids calculating an infinite plume rise when wind speed is zero (during calms), since both momentum and buoyancy plume rise equations contain wind speed in the denominator. CAP88-PC also accepts supplied plume rise values, for situations where actual measurements are available or the supplied equations are not appropriate. For example, plume rises of zero may be used to model local turbulence created by building wakes.

2.3.3 Dose Calculations

CAP88-PC uses a database of dose and risk factors provided in Federal Guidance Report 13 [26] for estimating dose and risk. Dose and risk conversion factors include the effective dose equivalent calculated according to the methods in ICRP Publication Number 72 [32]. Although FGR 13 contains age–dependent dose factors, CAP88-PC only uses the adult factors in order to retain consistency with previous versions. The risk factors used are those for lifetime fatal cancer risk (mortality) per FGR 13. Dose and risk factors for the pathways of ingestion and inhalation intake, ground level air immersion and ground surface irradiation are used. Factors are further broken down by particle size [SIZE], clearance category [FMSTYPE], chemical form [CHEMFORM], and gut-to-blood [GI_ING and GI_INH] transfer factors. These factors are stored in a database for use by the program.

For each assessment, CAP88-PC tabulates the frequency distribution of risk, or the number of people at various levels of risk (lifetime risk). Cancer risks for adults are estimated for individual exposures assuming the linear no threshold model is applicable to low values of individual and collective dose equivalents. The risk categories are divided into powers of ten, from 1 in ten to one in a million. The number of health effects is also tabulated for each risk category.

Doses for the maximally-exposed individual in population runs are estimated by CAP88-PC for the location, or sector-segment in the radial assessment grid, of highest risk where at least one individual actually resides. The effective dose equivalent for the maximally-exposed individual is tabulated in mrem/yr for a 50 year exposure. Risk is estimated as total lifetime risk for a lifetime exposure.

2.3.4 Tritium and Carbon-14

CAP88-PC gives special consideration to the radionuclides hydrogen-3 (tritium), carbon-14, and radon-222. The specific activity of tritium in air is calculated based on the input absolute humidity, which has a default value of 8 g/m^3. The specific activity of atmospheric carbon-14 is calculated for a carbon dioxide concentration of 330 ppm by volume. Concentrations of these nuclides in vegetation are calculated on the assumption that the water and carbon content in vegetation are from the atmosphere and have the same specific activity as in the atmosphere. Drinking water is assumed to be one percent (1%) tritiated.

For tritium in the vapor phase the inhalation dose and risk factors have been multiplied by 1.5 to account for the skin uptake pathway that is not specifically modeled in former versions of CAP88 or COMPLY. The ingestion dose and risk factors have been multiplied by 2.0 to account for the dose from organically bound tritium. Also for tritium dose and risk, CAP88-PC version 3 uses the FGR-13 vapor phase (HTO) dose factors when the organic form is selected in order to bring the code into conformance with the recommendations of the Environmental Monitoring for Radiation Safety working group, which recognizes that releases of the organic form must be converted to tritiated water or organically bond tritium in order to produce internal dose.

2.3.5 Plume Depletion

Radionuclides are depleted from the plume by precipitation scavenging, dry deposition and radioactive decay. Depletion is accounted for by substituting a reduced release rate, Q^1, for the original release rate Q for each downwind distance x . The ratio of the reduced release rate to the original is the depletion fraction. The overall depletion fraction used in CAP88-PC is the product of the depletion fractions for precipitation scavenging, dry deposition and radioactive decay, modeled in CONCEN. Defaults for deposition velocity used by CAP88-PC are 3.5E-2 m/sec for Iodine, 1.8E-3 m/sec for particulates and zero for gases.

Gravitational settling is handled by tilting the plume downward after it has leveled off at height H by subtracting $V_g\, x/\mu$ from H in the plume dispersion equations. For CAP88-PC V_g is set at the default value of zero and cannot be changed.

2.3.6 CAP88-PC Code Default Parameters

The CAP88-PC code uses various types of default data. The file, DEFAULT.DAT is divided into two segments. The first segment contains default values that can, with great caution, be changed by the user. The second segment contains permanent defaults which are values that must never be changed by the user since any changes would corrupt the assessments [31]. Table 2.3 provides a summary of the variable names whose values can be changed by the user. Also included are a brief description and default values.

Table 2.3 Parameters used in CAP88-PC

Symbol	Description	CAP88-PC
Meteorological		
TG	Vertical temperature gradient for Pasquill categories E, F, and G (°K/m)	0.0728, 0.1090, 0.1455
DILFAC	Depth of water for dilution for water immersion doses (cm)	1.0
USEFAC	Fraction of time spent swimming	0.0
ILOC	Direction index of the single location used for individual calculations	0
JLOC	Distance index of the single location used for individual calculations	0
PLOC	The percentile of the total risk to use in choosing the location for the exposure array used for the individual tables. When ILOC and JLOC are both 0, PLOC is used.	100.0
GSCFAC	A scaling factor used to correct ground surface dose factors for surface roughness	0.5
Default Rates		
BRTHRT	Inhalation rate of man (cm^3/hr)	9.167e+5
DD1	Fraction of radioactivity retained on leafy vegetables and produce after washing	0.5
UF	Ingestion rate of meat by man (kg/yr)	85.0
UL	Ingestion rate of leafy vegetables by man (kg/yr)	18.0
UM	Ingestion rate of milk by man (liter/yr)	112.0
UV	Ingestion rate of produce by man (kg/yr)	176.0
Agricultural Defaults		
FSUBG	Fraction of produce ingested grown in garden of interest	1.0
FSUBL	Fraction of leafy vegetables grown in garden of interest	1.0
FSUBP	Fraction of year animals graze on pasture	0.4
FSUBS	Fraction of daily feed that is pasture grass when animal grazes on pasture	0.43
LAMW	Removal rate constant for physical loss by weathering (hr^{-1})	2.9E-3
MSUBB	Muscle mass of animal at slaughter (kg)	200.0
P	Effective surface density of soil, dry weight, assumes 15 cm plow layer (kg/m^2)	215.0

Table 2.3 Continued

Symbol	Description	CAP88-PC
QSUBF	Consumption rate of contaminated feed or forage by an animal, dry weight (kg/day)	15.6
R1	Fallout interception fraction-pasture	0.57
R2	Fallout interception fraction-vegetables	0.2
TAUBEF	Fraction of animal herd slaughtered per day	3.81E-3
TSUBE1	Period of exposure during growing season—pasture grass (hr)	720.0
TSUBE2	Period of exposure during growing season—crops or leafy vegetables (hr)	1440.0
TSUBF	Transport time: animal feed-milk-man (day)	2.0
TSUBH1	Time delay—ingestion of pasture grass by animals (hr)	0.0
TSUBH2	Time delay—ingestion of stored feed by animals (hr)	2160.0
TSUBH3	Time delay—ingestion of leafy vegetables by man (hr)	336.0
TSUBH4	Time delay—ingestion of produce by man (hr)	336.0
TSUBS	Average time from slaughter of meat animal to consumption (day)	20.0
VSUBM	Milk production of cow (liter/day)	11.0
YSUBV1	Agricultural productivity by unite area, grass-cow-milk-man pathway (kg/m^2)	0.28
YSUBV2	Agricultural productivity by unit area, produce or leafy vegetables ingested by man (kg/m^2)	0.716
TSUBB	Period of long-term buildup for activity in soil (yr)	100.0

Chapter 3

3 Benchmark Materials and Methods

This benchmark study was performed to compare the results at an operating facility, using actual radionuclide emission data, between the CAP88-PC and COMPLY-Level 4 codes. The results from both codes for stack emissions for the years 2004 through 2012 were compared with the following general parameters:

1) COMPLY with specific source to receptor distances for each of the 16 sectors, and food stuff production set as home; and

2) CAP88-PC with general source to receptor distances for each of the 16 sectors with local food stuff production.

Annual weather (meteorological) data was obtained from the measurements at the DOE Oak Ridge Reservation Y-12 West 60-m meteorological tower through an online link. The ASCII files are linked from: http://www.ornl.gov/~das/web/page6.cfm. The wind rose files are linked from: http://www.ornl.gov/~das/web/page7.cfm. The data includes wind speed, direction, and frequency.

Annual data, including Wind Rose, nuclide release rates by stack, and other meteorological data (CAP88 includes average air temperature, precipitation rate, lid height and humidity), were the same for each scenario. Additionally, the dimensions of the facility buildings and stacks are the same for each year.

3.1 Hardware Requirements

3.1.1 Computer Codes

The COMPLY code was available for downloading on the Internet at the website: http://www.epa.gov/rpdweb00/assessment/comply.html#download. The COMPLY code runs on an IBM PC or PC-compatible computer. It is an MS-DOS program, but did run in the Windows 7 operating system as an executable program, as long as it is not a 64-bit operating environment. The code has been designed for users with limited computer experience. The program will ask for the information it needs and will produce most of the report. The user must decide initially which of the methods (levels) to use, but the program does all the numerical calculations.

The CAP88-PC Windows version 3.0 code was downloaded from the following EPA web site: http://www.epa.gov/radiation/assessment/CAP88/index.html. The installation package of CAP88-PC Version 3.0 ships with three pre-existing input files, named CAP88.dat, NUKETEST.dat, and MODTEST.dat, along with their associated output files for those input datasets.

3.2 Locating Offsite Receptors and Stacks

Receptor locations were determined using GPS coordinates, and distances from each facility stack's GPS coordinates were calculated using an online calculator. Offsite receptor locations were identified as shown below using the internet application Google Maps. After identification of the closest resident in each of the 16 sectors, the GPS coordinates for the resident were determined by driving to the location and using a portable GPS device. Latitude/Longitude coordinates were also confirmed using the physical street address and an online application that converted address to coordinates. Examples of the Google Earth views for all 16 sectors are provided in Figure 3.1, Figure 3.2, Figure 3.3, and Figure 3.4. Summaries of the receptors addresses and coordinate locations are provided in Table 3.1, Table 3.2, Table 3.3 and Table 3.4 below.

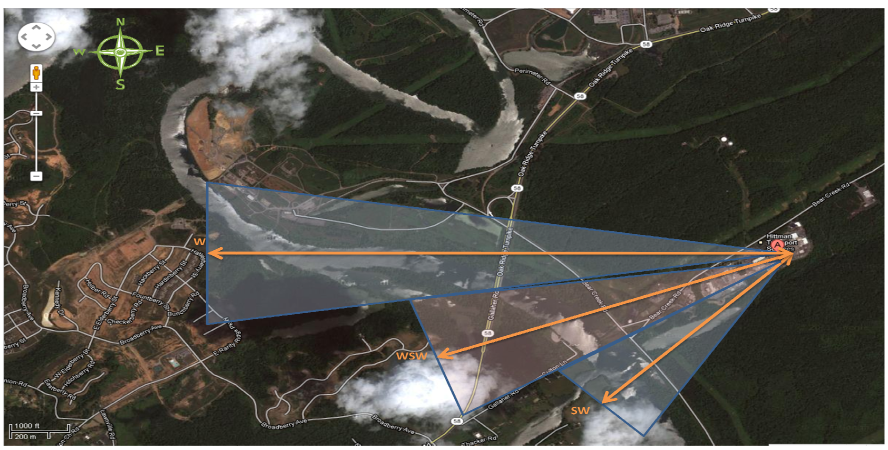

Figure 3.1 Identification of Closest Resident in directions West, West South West and South West

Table 3.1 Receptor Locations West, West Southwest and Southwest

Direction	Address	City	Latitude / Longitude
W – West	155 Hatleyberry St.	Oak Ridge	Lat: 35.912013 Lon: -84.415376
WSW – West-Southwest	100 Wallberry Rd	Oak Ridge	Lat: 35.906886 Lon: -84.40518
SW – Southwest	465 Smith Rd	Kingston	Lat: 35.902015 Lon:-84.39172

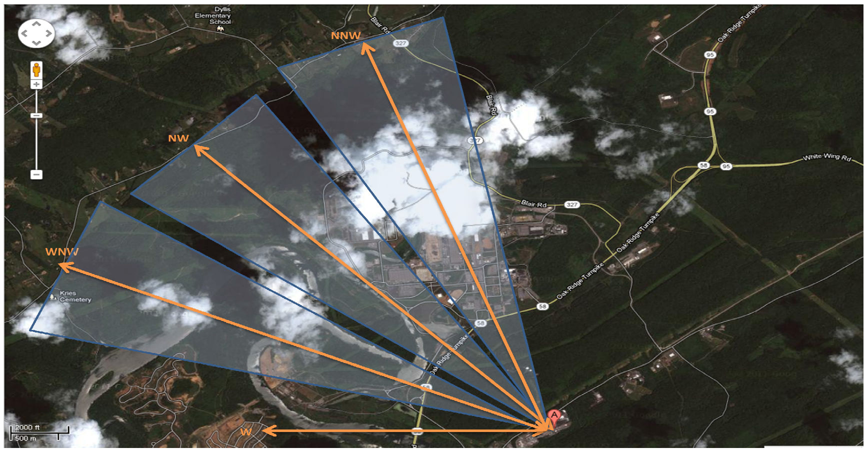

Figure 3.2 Identification of Closest Resident in directions West-North-West, North-West and North-North-West

Table 3.2 Receptor Locations West Northwest, Northwest and North Northwest

Direction	Address	City	Latitude / Longitude
WNW – West-Northwest	3331 Sugar Grove Valley Rd	Harriman	Lat: 35.9312067 Lon: -84.4395711
NW – Northwest	3593 Sugar Grove Valley Rd	Harriman	Lat: 35.946551 Lon: -84.429622
NNW – North-Northwest	127 Poplar Creek Rd	Harriman	Lat: 35.9557599 Lon:-84.41078

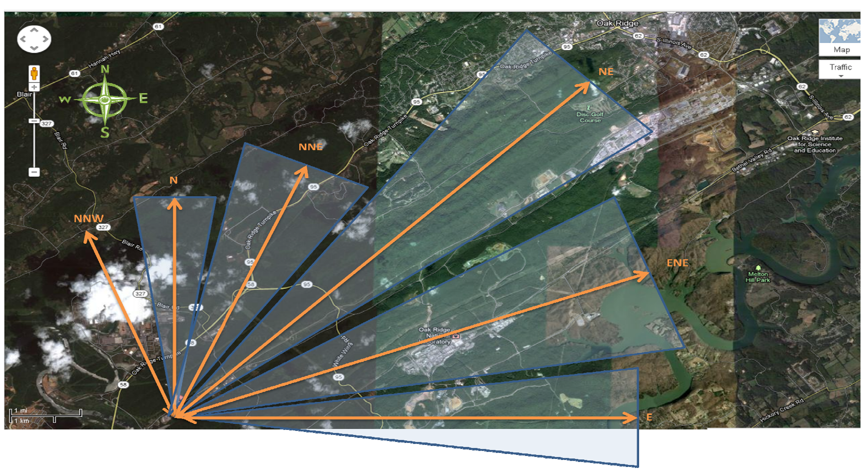

Figure 3.3 Identification of Closest Resident in directions North, North-North-East, North-East, East-North-East, East

Table 3.3 Receptor Locations North, North Northeast, Northeast, East Northeast, and East

Direction	Address	City	Latitude / Longitude
N – North	447 Poplar Creek Rd	Oliver Springs	Lat: 35.9649263 Lon: -84.3922976
NNE – North-Northeast	280 West Southwood Ln	Oak Ridge	Lat: 35.9705639 Lon: -84.342761
NE – Northeast	200 Hampton Rd	Oak Ridge	Lat: 35.9931979 Lon:-84.2669661
ENE – East-Northeast	3100 W. Gallaher Ferry Rd	Knoxville	Lat: 35.9301174 Lon: -84.2526246
E – East	2750 Pine Hill Dr	Knoxville	Lat: 35.909053 Lon: -84.2603906

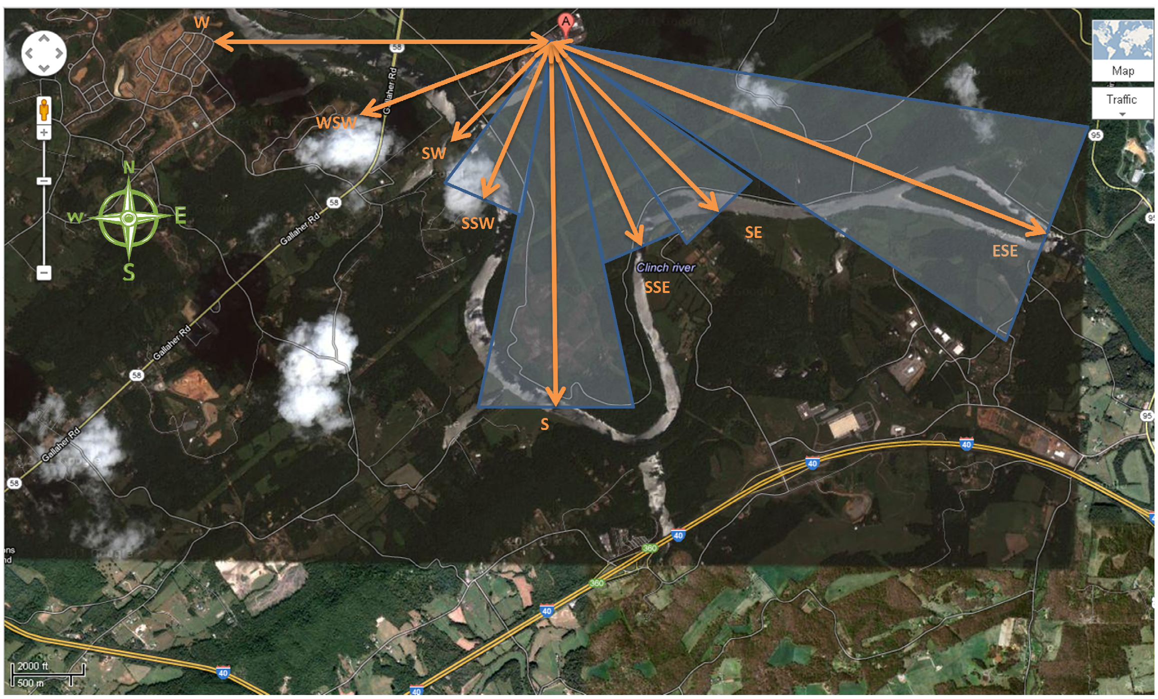

Figure 3.4 Identification of Closest Resident in directions East-South-East, South-East, South-South-East, South, South-Southwest

Table 3.4 Receptor Locations East Southeast, Southeast, South Southeast, South and South Southwest

Direction	Address	City	Latitude / Longitude
ESE – East-Southeast	2560 Upper Jones Road	Lenoir City	Lat: 35.8929803 Lon: -84.3358091
SE – Southeast	418 Blackburn Lane	Lenoir City	Lat: 35.895855 Lon: -84.3689349
SSE – South-Southeast	447 Blackburn Lane	Lenoir City	Lat: 35.8968236 Lon:-84.3714574
S – South	428 Speers Road	Kingston	Lat: 35.884124 Lon: -84.387468
SSW – South-Southwest	199 Cherry Point	Kingston	Lat: 35.8990034 Lon: -84.3911847

The coordinates of the two stacks studied were also determined with the hand-held GPS device as shown in Table 3.5.

Table 3.5 Stack 1 and 5 GPS Coordinates

Stack 1	35.913583 -84.3802667	Latitude Longitude
Stack 2	35.91155 -84.3823333	Latitude Longitude

Having both the Stack and Receptor location coordinates allowed the straight-line determination of the distance from Stack to Receptor using the online application. See Table 4.1 and Table 4.2 for the results of these measurements and calculations.

3.3 Annual Wind Rose Data

A wind rose is a graphic tool used by meteorologists to give a very succinct, but information-laden view of how wind speed and direction are typically distributed at a particular location over a specified time period. Wind roses use 16 cardinal directions, such as north (N), NNE, NE, etc. For each direction, a frequency (percentage of time that winds blow from a particular direction) and average speed in meters per second is provided. In terms of angle measurement in degrees, North corresponds to 0°/360°, East to 90°, South to 180°, and West to 270°. [48]

Both the COMPLY and CAP88-PC codes require wind rose data for model calculations. The wind rose data for each of the 16 directions was provided by the Oak Ridge National Laboratory environmental monitoring department and posted on their website: http://www.ornl.gov/~das/web/page7.cfm. Table 3.6 below provides a summary of the wind rose data by year.

Table 3.6 Wind Rose Data for Y-12 Tower West 60 meter

Wind Rose: Frequency / Speed (m/s)									
Dir	2004	2005	2006	2007	2008	2009	2010	2011	2012
N	0.037/2.2	0.028/1.73	0.024/1.83	0.026/1.9	0.025/1.85	0.024/1.91	0.041/1.79	0.023/1.81	0.024/1.80
NNE	0.047/2.0	0.051/2.32	0.048/2.39	0.047/2.3	0.047/2.21	0.052/2.56	0.066/2.28	0.040/2.40	0.048/2.14
NE	0.098/2.6	0.175/3.57	0.161/3.44	0.157/3.27	0.166/3.36	0.171/3.41	0.173/3.15	0.162/3.23	0.156/3.21
ENE	0.124/2.7	0.118/2.74	0.089/2.51	0.09/2.49	0.09/2.65	0.091/2.61	0.072/2.18	0.082/2.37	0.088/2.46
E	0.042/1.9	0.035/1.78	0.033/1.7	0.036/1.73	0.033/1.73	0.043/1.95	0.036/3.74	0.037/1.83	0.035/1.86
ESE	0.027/1.8	0.021/1.6	0.017/1.36	0.016/1.48	0.019/1.3	0.019/1.59	0.014/1.41	0.021/1.74	0.017/1.58
SE	0.021/1.8	0.018/1.41	0.017/1.42	0.016/1.43	0.019/1.22	0.015/1.51	0.016/1.57	0.018/1.44	0.018/1.45
SSE	0.023/2.0	0.018/1.48	0.016/1.44	0.014/1.56	0.019/1.36	0.018/1.64	0.020/1.65	0.018/1.72	0.017/1.52
S	0.033/2.5	0.023/1.83	0.029/1.67	0.025/1.87	0.023/1.94	0.023/1.89	0.018/1.90	0.024/2.09	0.026/1.82
SSW	0.068/3.1	0.047/2.88	0.051/2.61	0.052/2.75	0.054/3.29	0.052/3.19	0.058/2.94	0.058/3.46	0.060/2.84
SW	0.126/3.2	0.126/3.42	0.162/3.6	0.162/3.63	0.147/3.83	0.142/3.70	0.157/3.38	0.154/3.92	0.161/3.64
WSW	0.101/2.7	0.136/3.36	0.154/3.32	0.149/3.36	0.151/3.42	0.139/3.41	0.138/3.10	0.158/3.45	0.150/3.24
W	0.067/2.8	0.109/3.1	0.116/2.95	0.119/3.06	0.126/3.14	0.127/3.09	0.100/2.77	0.136/2.98	0.107/3.00
WNW	0.068/3.5	0.05/2.8	0.036/2.27	0.045/2.38	0.041/2.31	0.044/2.29	0.040/2.04	0.043/2.33	0.037/2.18
NW	0.072/4.0	0.024/2.11	0.025/2.23	0.025/2.18	0.027/2.14	0.022/1.94	0.028/1.87	0.019/1.87	0.030/1.99
NNW	0.044/2.7	0.022/1.76	0.02/1.97	0.021/1.82	0.023/1.77	0.019/1.64	0.022/1.69	0.019/1.79	0.026/1.77

Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions. The length of each "spoke" around the circle is related to the frequency of time that the wind blows from a particular direction. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. [48] Figure 3.5 shows the combined Wind Rose graphic for the years 2004-2012 at the Y-12 Tower "W." The wind roses shown in Figure 3.5 contain additional information, in that each spoke is broken down into discrete frequency categories that show the percentage of time that winds blow from a particular direction and at certain speed ranges. As can clearly be seen in the figure, the predominant wind directions averaged over this period of time are West-Southwest at 14.76% of the year, Southwest at 15.06% of the year and North-Northeast at 16.4% of the year. For the winds from the Southwest direction, the wind speed was observed over 17.8 mph (8 m/s).

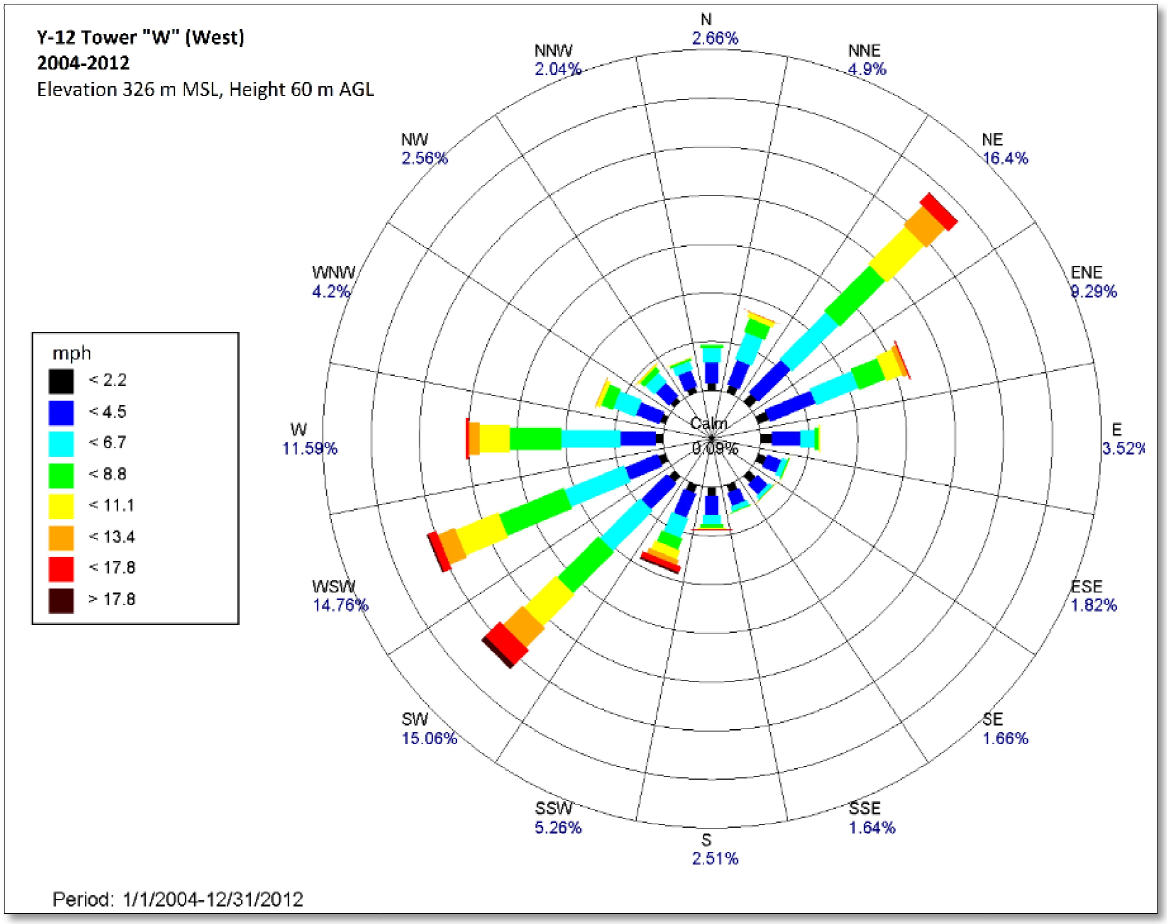

Figure 3.5 Wind Rose Graphic for Y-12 Tower "W" 2004-2012

3.4 Annual Radionuclide Emission Rates

The emission data used in this study was from stacks number 1 and number 2. The list of yearly effluent nuclides and their release rates are provided in text files by the facility radiochemistry lab in units of Ci/year. Table 3.7 and Table 3.8 below provide a summary of the data used in this study.

Table 3.7 Stack 1 Annual Nuclide Emission Rates

Stack 1									
Nuclide	**2004 Ci/y**	**2005 Ci/y**	**2006 Ci/y**	**2007 Ci/y**	**2008 Ci/y**	**2009 Ci/y**	**2010 Ci/y**	**2011 Ci/y**	**2012 Ci/y**
Ag-110m Y			2.96e-07			4.89e-07			
Ce-144 Y		5.03e-06	1.31e-05						
Co-57 Y		7.68e-06	8.29e-06						
Co-58 Y			2.61e-07						
Co-60 Y	2.31e-06	1.65e-06	1.68e-06	7.28e-04	5.74e-07	2.41e-06	7.74e-07		5.56e-06
Cr-51 Y	8.52e-07				6.02e-07				
Cs-134 D	2.49e-07					7.14e-07			
Cs-137 D	1.41e-05	5.57e-06	2.23e-05	1.04e-06	2.08e-06	2.27e-05	4.68e-06	4.79e-06	3.23e-06
I-125 D	1.97e-03	1.34e-02	1.38e-02	4.41e-03	8.98e-03	6.86e-03	2.51e-03	6.04e-03	2.85e-03
I-129 D			1.96e-06	1.59e-06			1.15e-05		2.24e-05
I-131 D	1.11e-06	8.13e-06	8.03e-06	2.11e-04	1.33e-04	1.29e-05	1.07e-04	5.91e-05	1.44e-07
K-40 D	3.18e-06	4.38e-06	6.01e-05	2.17e-04	8.21e-05	6.51e-05	2.53e-05	7.32e-06	4.31e-05
Nb-94 Y				1.98e-07					
Nb-95 Y								1.53e-07	
Ru-103 Y		1.88e-07		3.82e-07	1.69e-06	8.93e-07			
Ru-106 Y		5.0e-05			1.07e-06	8.78e-07			
Mn-54 W	9.76e-08	2.36e-07	4.33e-07				3.17e-07		
Se-75 W	2.3e-05	2.3e-04	4.99e-04	7.65e-06	3.51e-05	2.97e-05	3.46e-05	1.73e-05	7.16e-06
Sb-124 W							5.81e-03	5.54e-04	1.04e-03
Sb-125 W	6.62e-05	8.01e-05	1.6e-04	5.05e-05	2.1e-05	2.34e-05	1.38e-04	6.62e-05	1.02e-04
Sn-113 W				3.55e-07					
H-3 V	2.53e+01	4.17e+01	1.03e+02	1.03e+02	1.06e+02	8.07e+01	1.1e+02	1.02e+02	3.14e+02
C-14 1	4.09e+00	9.76e+00	8.36e+00	1.19e+01	1.46e+01	6.28e+00	1.52e+01	9.54e+00	9.04e+00
Pu-238 W	1.17e-07	3.82e-08	1.48e-08	8.61e-09	1.65e-08	4.2e-09	4.53e-10	5.91e-09	2.79e-10
Pu-239 W	2.18e-07	7.78e-08	2.56e-08	1.35e-08	1.51e-08	2.18e-09	2.19e-09	3.92e-09	2.15e-09
Pu-240 W	2.18e-07	7.78e-08	2.56e-08	1.35e-08	1.51e-08	2.18e-09	2.19e-09	3.92e-09	2.15e-09
U-233 Y	6.18e-07	1.98e-07	2.18e-07	3.83e-07	3.04e-07	1.38e-07	1.4e-07	1.84e-07	1.3e-07
U-234 Y	6.18e-07	1.98e-07	2.18e-07	3.83e-07	3.04e-07	1.38e-07	1.4e-07	1.84e-07	1.3e-07
U-235 Y	5.82e-08	1.58e-08	1.09e-08	3.22e-08	2.32e-08	4.12e-09	7.95e-09	9.63e-09	7.45e-09
U-236 Y	5.82e-08	1.58e-08	1.09e-08	3.22e-08	2.32e-08	4.12e-09	7.95e-09	9.63e-09	7.45e-09
U-238 Y	5.46e-07	1.68e-07	2.1e-07	3.53e-07	2.33e-07	1.57e-07	1.37e-07	1.77e-07	1.2e-05
Pu-241 W	6.87e-07		1.04e-07	1.24e-07	1.73e-07	1.16e-08	2.85e-08	6.26e-08	1.67e-07
Sr-89 Y	4.21e-07	6.64e-09	1.51e-08	1.87e-08		4.29e-08	1.37e-08	8.33e-08	
Sr-90 Y	4.02e-07	2.47e-08	3.01e-08	4.08e-08	3.9e-08	1.77e-08	5.01e-08	3.28e-07	3.47e-08
Fe-55 D	6.64e-06	2.76e-06	8.0e-05	6.76e-07	1.93e-06	5.29e-07	5.08e-07	2.62e-06	6.92e-07
Fe-59 D					9.91e-05				
Ni-63 V	2.68e-06	9.96e-07	2.71e-06	9.17e-07	5.17e-06	8.42e-06	4.07e-06	7.0e-06	2.24e-06
Tc-99 W	5.76e-06	4.57e-06	6.74e-06	5.88e-06	2.63e-04	3.59e-05	2.17e-04	3.11e-05	6.34e-06
Zn-65 Y	6.12E-07	2.63e-07				3.59e-07			

Table 3.8 Stack 2 Annual Nuclide Emission Rates

Stack 2									
Nuclide	**2004 Ci/y**	**2005 Ci/y**	**2006 Ci/y**	**2007 Ci/y**	**2008 Ci/y**	**2009 Ci/y**	**2010 Ci/y**	**2011 Ci/y**	**2012 Ci/y**
Co-57 Y		1.7e-05							
Co-58 Y			2.96e-07			2.48e-07			
Co-60 Y	2.11e-05	2.39e-07	2.69e-06	6.84e-05	1.77e-06	1.47e-05	4.34e-06	4.13e-07	
Cr-51 Y		5.39e-05	9.57e-07	4.39e-07					
Cs-137 D	4.67e-05	3.0e-06	8.0e-06	1.52e-06	8.51e-06	4.53e-06	5.96e-06	8.99e-06	3.22e-04
I-125 D									1.97e-05
I-129 D				9.02e-07					
I-131 D	9.45e-07	1.24e-07	3.28e-07	7.07e-08				2.38e-07	
K-40 D		1.77e-05			6.67e-05	7.45e-05		8.59e-07	3.32e-05
Nb-94 Y	1.13e-06	3.14e-07							
Nb-95 Y	1.51e-11	2.92e-06							
Ru-103 Y		1.21e-06		9.68e-08				9.58e-08	
Ru-106 Y	3.61e-06								
Mn-54 W			1.01e-07			5.01e-07			
Se-75 W									
Sb-124 W									
Sb-125 W	4.04e-07								
H-3 V	1.83e+00	4.82e-01	2.73e-01	9.26e+01	1.28e+00	4.4e-01	1.02e+00	7.02e+00	2.63e+00
C-14 1	4.95e-02	2.25e-02	2.45e-02	3.26e-01	9.92e-02	7.76e-02	5.22e-02	3.82e-02	3.26e-01
Pu-238 W	1.25e-08	8.59e-09	2.32e-09		1.02e-09	2.17e-09	2.07e-09	4.16e-10	7.45e-09
Pu-239 W	1.89e-09	2.46e-08	5.19e-09	3.85e-10		4.82e-09	6.47e-10	2.63e-10	1.76e-08
Pu-240 W	1.89e-09	2.46e-08	5.19e-09	3.85e-10		4.82e-09	6.47e-10	2.63e-10	1.76e-08
U-233 Y	6.54e-07	3.63e-07	2.45e-07	1.02e-07	1.54e-07	1.35e-07	1.39e-07	3.83e-08	3.72e-08
U-234 Y	6.54e-07	3.63e-07	2.45e-07	1.02e-07	1.54e-07	1.35e-07	1.39e-07	3.83e-08	3.72e-08
U-235 Y	6.6e-08	3.52e-08	1.12e-08	5.87e-09	1.13e-08	6.22e-09	4.59e-09	1.75e-09	8.55e-09
U-236 Y	6.6e-08	3.52e-08	1.12e-08	5.87e-09	1.13e-08	6.22e-09	4.59e-09	1.75e-09	8.55e-09
U-238 Y	6.34e-07	3.28e-07	2.11e-07	7.76e-08	1.71e-07	1.32e-07	1.38e-07	4.5e-08	2.65e-08
Pu-241 W	9.01e-07	1.95e-07	3.29e-08	6.0e-08	1.52e-07	5.26e-08	9.2e-08	6.09e-08	8.27e-08
Sr-89 Y	2.49e-07	2.3e-08	6.73e-09	1.55e-08	1.35e-07	7.31e-09	5.19e-09	1.28e-07	6.16e-07
Sr-90 Y	2.02e-07		6.73e-09	1.93e-08	7.98e-08	2.81e-08	1.03e-07	3.77e-08	1.37e-06
Fe-55 D	3.26e-06	1.31e-06	3.18e-05	1.75e-07	7.24e-07	2.19e-06	1.03e-06	1.53e-06	1.37e-06
Ni-63 V	1.42e-06	9.57e-07	1.08e-06	8.34e-07	9.27e-07	1.04e-06	9.74e-07	2.73e-07	1.45e-06
Tc-99 W	3.96e-07	3.34e-06	3.02e-07		3.97e-06		1.48e-07	1.34e-09	
Zn-65 Y									
Zr-95 D		7.36e-05							

3.5 COMPLY Code Parameters

The overall approach of the COMPLY code is a tiered set of methods intended to minimize the burden on those facilities covered by the standard. This approach begins with simple-to-use methods that are very conservative in terms of determining compliance. The methods become progressively less conservative but more complicated at succeeding levels. The simplest methods do not estimate the radiation dose directly. Instead, they determine whether your emissions could not cause a dose greater than the standard. [27]

Level 1, the "Possession Table," allows the user to determine compliance from the amount of radionuclides used annually at their facility. This method should only be used by facilities that handle small quantities of radioactive material and do not have measured stack emission concentrations. The annual quantities provided by COMPLY were calculated using assumptions that tend to overestimate the dose.

Level 2, the "Concentration Table," is for facilities that have measured stack effluent concentrations or have EPA approval to measure air concentrations at the receptor. The approach is generally based on the concentration of radionuclides in the emissions. For each radionuclide, the concentration limit ensures that a person exposed to that concentration for a full year would not receive a dose that exceeds the standard. This method assumes no dispersion from the point of release to where the most exposed person lives and assumes that all of the person's food is grown at his home.

Level 3, consists of three screening levels. This approach is used if a facility cannot satisfy the requirements using the possession or concentration tables. This method requires that user develop a small amount of site-specific data (quantities of nuclides released, the facility's physical configuration, and distance to the nearest person from the point of release). Detailed radionuclide, meteorological, and demographic information is not needed because the dose factors and dispersion models incorporate assumptions that tend to overestimate the dose.

Level 4, the "Compliance Model," is an extension of the NCRP Screening Levels but produces a more accurate dose estimate by providing for more complete treatment of air dispersion, and a separate location for the production of each type of food. In addition, the pathway parameters are less conservative. This greater precision requires some additional site-specific data. Only facilities that handle and release radionuclides having the potential to cause doses greater than 10% of the standard are required to use this method.

3.5.1 COMPLY Level 4 Parameters

Since the Level 4 method is the highest level in the COMPLY computer code, and the facility monitors stack emission concentrations, this was the level used for the study. Code output was sent to a file to allow repeated or delayed printing of the file. This also preserved a copy of the report for future reference.

With multiple release points, COMPLY Level 4 allows the assumption that all the radionuclides from the facility are released from the stack or vent having the potential for causing the highest dose. Similarly, it may be assumed that all the release points from a building can be replaced by a single stack or vent having the potential for causing the highest dose. However for this study, the two stacks evaluated were not consolidated, but were considered as separate sources to the receptors. Each release point is treated individually in regards to release rates, release heights, etc. for each point.

The wind rose data can be entered either manually or from a text file. Additionally, the distance to closest receptor (rounded to the nearest 100 meters from the distances calculated and shown in Table 4.1 and Table 4.2) for each direction must be entered as provided in Table 3.9.

Table 3.9 COMPLY Stack to Receptor Distances, 16 Sectors

	Stack 1	Stack 2
Direction	Distance meters	Distance meters
N	5800	6000
NNE	7200	7500
NE	13500	13800
ENE	11700	11800
E	10800	11000
ESE	4600	4700
SE	2200	2100
SSE	2000	1900
S	3300	3100
SSW	1900	1600
SW	1600	1400
WSW	2400	2100
W	3200	3000
WNW	5700	5600
NW	5700	5800
NNW	5400	5500

Level 4 also requires input of the distance from the source to the farm producing vegetables, meat and milk for the offsite receptor. The choice of "home" provides a higher level of conservatism since there is no data on the actual location of food production for the receptors.

3.5.2 COMPLY Input Data

The COMPLY program will ask for input as it is needed. Table 3.10 provides the input used for this study after starting the program in a MS-DOS command prompt window.

Table 3.10 COMPLY Benchmark Study Input Data

Parameter	Default	Value
TITLE	N/A	COMPLY Test *yyyy* (e.g., COMPLY Test 2012)
Company Name	N/A	Radioactive Waste Processing Facility
Facility Name	N/A	Benchmark Study
Facility Address	N/A	Oak Ridge, Tennessee
Contact Person	N/A	Debra McCroskey
Contact Person Phone Number	N/A	Master's Thesis
Report Output	F=FILE; P=PRINTER	F
File Name	*.LIS (8 char. max)	COMPyyyy.LIS (e.g., COMP2012.LIS)
Multiple Stacks	Y (Yes) or N (No)	Y

Table 3.10 Continued

Parameter	Default	Value
Number of Stacks	N/A	2
Nuclide Input by Stack Number	F=FILE K=KEYBOARD	F
Stack Nuclide File Name	*.DAT (8 char. max)	*Stack #1:* ST1NUC*yy*.DAT (e.g., ST1NUC12.DAT) *Stack #2:* ST2NUC*yy*.DAT (e.g., ST2NUC12.DAT)
Stack Nuclide List Review	OK? Y (Yes) or N (No)	Y or N *(as applicable)*
Compliance Level	1 Y (Yes) or N (No)	N
Choose Compliance Level	2, 3, or 4	4
Specify RELEASE RATE units	Y (Ci/yr) S (Ci/sec)	Y
Enter Release Rate values by Nuclide for each Stack	N/A	*(For each stack, total effluent activity by nuclide for the applicable year. See yearly nuclide data tables)*
Release Rates Review	OK? Y (Yes) or N (No)	Y or N *(as applicable)*
Stack Data: • Release Height • Building Height • Source/Receptor on same Building • Building Width • Building Length	After entering the Release, & Bldg Height, Source/Receptor question on the First Stack ONLY, the choice of using a Wind Rose.	*Stack #1* (meters): 30, 15, N, 60, 20 Wind Rose: Y *Stack #2* (meters): 22, 16, N, 46, 107

Table 3.10 Continued

Parameter	Default	Value
Stack to Receptor Distances	F=FILE K=KEYBOARD	F
Stack to Receptor Distances for 16 directions File Name	*.DAT (8 char. max)	*Stack #1:* ST1STACK.DAT *Stack #2 (MMF):* ST2STACK.DAT
Stack to Receptor Distances Review	OK? Y (Yes) or N (No)	Y or N *(for each stack as applicable)*
Wind Rose Input	F=FILE K=KEYBOARD	F
Wind Rose File Names	*.DAT (8 char. max)	WIND*yyyy*.DAT (e.g., WIND2012.DAT)
Wind Rose Values Review	OK? Y (Yes) or N (No)	Y or N *(as applicable)*
Distance from Source to Farm producing Vegetables, Milk, Meat **(After this entry, the program performs the dose estimate calculations, saves the output file to the name selected and closes. The report can be printed from the Notepad program)**	(meters) For Home type "H"	*Stack #1:* H *Stack #2:* H
Print Report	N/A	N/A

3.6 CAP88-PC Parameters

CAP-88 PC uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to six emitting sources. The sources may be either elevated stacks, such as a smokestack, or uniform area sources, such as a pile of uranium mill tailings. Plume rise can be calculated assuming either a momentum or buoyant-driven plume. The Gaussian plume model produces results that agree with experimental data as well as any model, is fairly easy to work with, and is consistent with the random nature of turbulence.

Although CAP88-PC version 4 has become available for download in 2014 from the EPA, this study was initiated with version 3 to generate the data for review. Significant upgrades were made in version 3 compared to its predecessors. For example, in versions 1 and 2, the equilibrium fractions were set to a constant of 0.7, and with version 3 the capability to vary equilibrium fractions has been added. The new method varies the equilibrium fractions depending on the distance from the source. Linear interpolation is then used to determine the equilibrium fractions for distances that do not match the set distances given. Starting with version 3, the code has also been modified to do either “Radon-only” or “Non-Radon” runs, to conform to the format of the 1988 Clean Air Act NESHAP Rulemaking.

Organs and weighting factors have been modified in Version 3 to follow the FGR 13 method. In accordance with the FGR 13 dose model, the code now calculates dose for 23 internal organs, rather than the 7 organs used in earlier versions. A ‘24th’ organ is also calculated, which is the total effective dose equivalent. The code now reports cancer risk for the 15 target cancer sites used in FGR 13. As was the case in version 2, changing the organs and weights will invalidate the results.

Some of the input parameters for version 3 have remained the same as in previous versions. For example, agricultural arrays of milk cattle, beef cattle and agricultural crop area are generated automatically. However, the code does give the option to override the default agricultural productivity values by entering the data directly on the Agricultural Data tab form. The calculation of deposition velocity and the default scavenging coefficient is defined by current EPA policy. These calculations have not been modified in Version 3; deposition velocity is set to 3.5e-2 m/sec for Iodine, 1.8e-3 m/sec for Particulate, and 0.0 m/sec for Gas. The default scavenging coefficient is calculated as a function of annual precipitation, which is input on the Meteorological Data tab form.

3.6.1 CAP88-PC Version 3.0 Parameters

When running Version 3.0 for the first time, no input datasets are included in the dropdown file selection list. After creating a new dataset, the file is saved to the "Datasets" subdirectory. See Figure 3.6 below for an example of the setup screen.

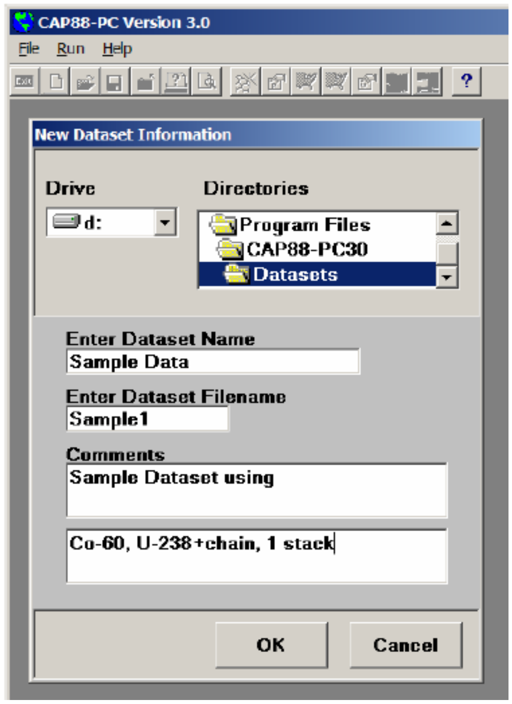

Figure 3.6 Example New Dataset Entry Information

3.6.1.1 Facility Data

The description of the facility and time period to be modeled is entered on the Facility Data tab. The State must be selected from the list provided. The State name is required because it is used by the program to establish values for agricultural arrays of beef cattle, milk cattle, and crop production according to EPA-accepted state-wide averages. Also included on this tab are two optional comments fields for additional information. See Figure 3.7 below for an example of the Facility Data screen.

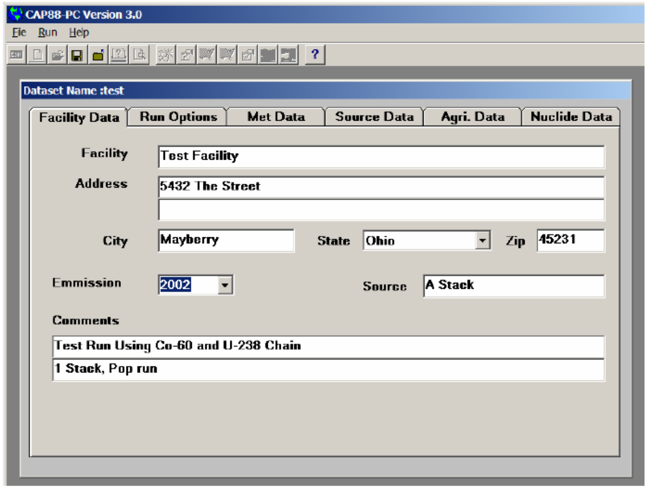

Figure 3.7 Example Facility Data entry screen.

3.6.1.2 Run Options

The “Run Type” must be selected to determine the source of the population data. If an “Individual Assessment” is chosen, the midpoint distances for the assessment areas must be entered. If a “Population Assessment” had been chosen, the data would have been read in from a Population file. Since the population distribution about the Facility is not recorded and it is in a rural location, “Individual” was chosen for this study. Figure 3.8 below provides an example of the Run Options entry screen.

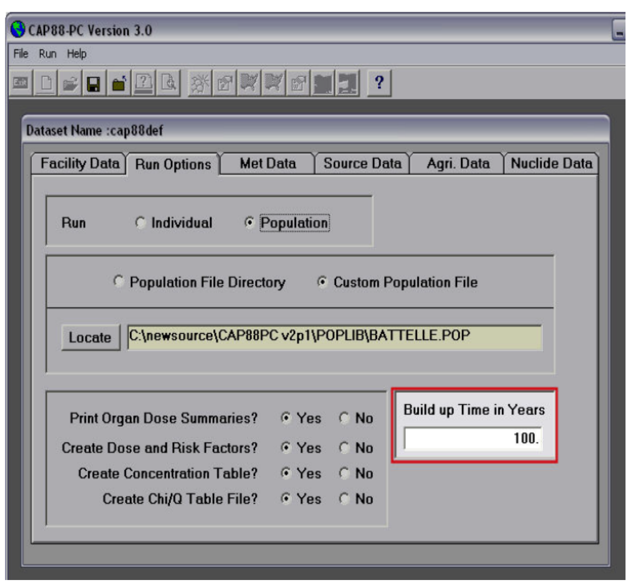

Figure 3.8 Example Run Options entry screen

With an “Individual Assessment,” a button labeled “Location Index of Exposed Individual” will show on the screen. After clicking this button to open the screen, there are two input boxes allowing the entry of a direction index and a distance index for the exposed individual. The default values for these indices are 0, which means that CAP88-PC calculates the maximally exposed individual. The default values were not changed for this study.

Midpoint distances are required for an “Individual Assessment.” These distances, in meters, are those for which the doses and risks are calculated. The distances must be integers between 1 and 80000 m (inclusive). If no distances are entered, the AIRDOS program component of CAP88-PC will abort. The distances entered in the table cells must be contiguous and ascending. There are twenty cells for entry in the table, but it is not required to enter values in all twenty. The cells at the end of the table may be left blank. For the Facility, previous and proposed stack to receptor distance values determined for the COMPLY code for all stacks were ranked and 20 representative values were chosen to complete the Midpoint Distance fields. Table 3.11 below provides the Midpoint Distances used in this study as they were entered in the code.

Table 3.11 CAP88-PC Individual Assessment Midpoint Distances

Distance meters	Distance meters	Distance meters	Distance meters	Distance meters
1400	1500	1600	1700	1800
1900	2000	2100	2200	2300
2400	3000	3100	3200	3300
4700	5800	7500	11700	13800

The Build-up time sets the analysis time period by defining the time period for calculating build-up factors. The entry field for Build-up time is set to a default value of 100 years when the dataset is started, which is consistent with previous versions of CAP88-PC. Previously, this value was not to be changed for cases being submitted to demonstrate NESHAPS compliance without permission of the EPA. With the inclusion of the FGR 13 dose and risk factors in version 3, a 1 year build-up time period will generate the 50-year dose and risk values resulting from annual facility releases.

3.6.1.3 Met Data

Meteorological wind rose data obtained from the files provided by the ORNL at http://www.ornl.gov/~das/web/page6.cfm are in a text file format which cannot be used directly by the CAP88-PC. The files had to be converted to a specific wind file format. The STAR Distribution Program within CAP88-PC is used to extract and process the site-specific meteorological data based on several popular methods. Each of the processing methods creates a Stability Array file (.STR) that is then used to create a Wind File for input to CAP88-PC. The downloaded text files are copied to the CAP88-PC30 folder labeled "Star." Using Windows file manager, the file extension was changed from *.txt to *.str. With this change, the CAP88-PC option "Star Distribution Program – Create Wind File for CAP88-PC" was used to convert the *.str file to a usable wind data file as *.wnd. After selecting custom wind file on the Meteorological Data entry tab, the appropriate file for the reference year was chosen. Figure 3.9 below provides an example of the Met Data entry screen.

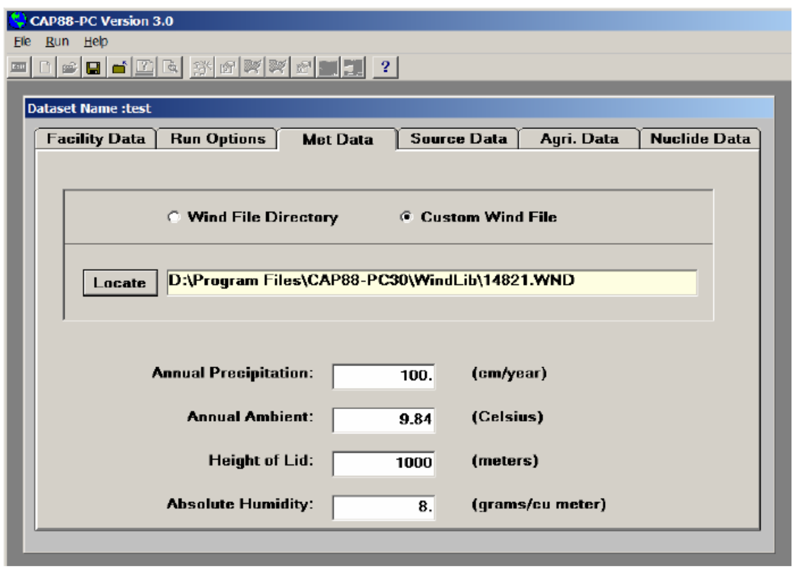

Figure 3.9 Example Met Data entry screen.

Additional weather data files were also downloaded from the ORNL site for the Y-12 West 60 m meteorological tower from the online link for the applicable year. This data provided the average ambient temperature, annual precipitation rate, and mixing lid height. The mixing lid height represents the height of the troposphere mixing layer (in meters) at or near the site. This field must contain a positive non-zero value. A zero value will cause the AIRDOS program to abort when the dataset is executed. The absolute humidity values were available for 2009 – 2012, however the 5-yr average was used for the years 2004 - 2008. The summary by year of the Additional weather data is provided below in Table 3.12. Actual data was downloaded for 2010 – 2012. Years 2004 – 2009 are averages based on the actual data since there were no files available from ORNL for those years.

Table 3.12 Additional Weather Data for Y-12 "West" 60-meter Tower

Additional Weather Data									
Metric	2004	2005	2006	2007	2008	2009	2010	2011	2012
Temp. (deg C)	15	15	15	16	15	14	15	16	16
Precip. (cm/y)	171	126	129	97	134	157	132	128	128
Humid. (g/m3)	10.2	10.2	10.2	10.2	10.2	10.2	10.3	10.2	10.3
Lid Height (m)	769	663	565	590	588	569	592	661	661

3.6.1.4 Source Data

For the dataset, the emitting sources were identified as "Stack." Up to six stack sources can be modeled, however, all the sources are modeled as if located at the same point. As noted before, this study used the two stacks from facility buildings that primarily involve thermal processes, Stacks 1 and 2. Figure 3.10 below provides an example of the Source Data entry screen.

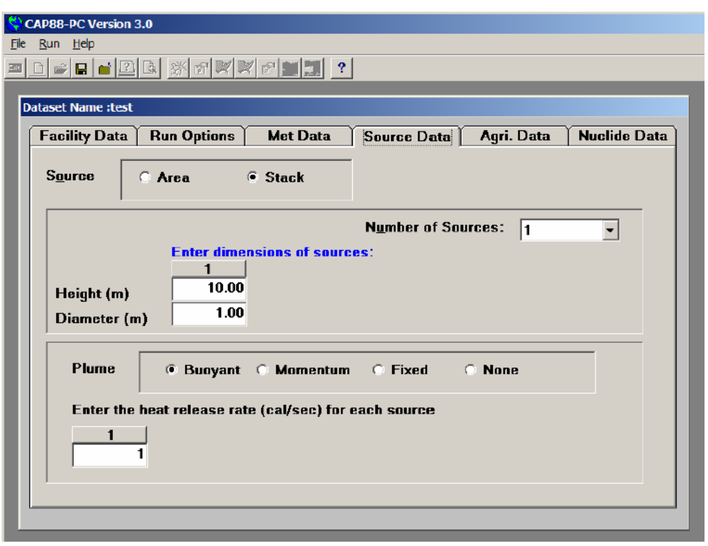

Figure 3.10 Example Source Data entry screen

Momentum was chosen as emission type since these are fan-forced stacks. The same plume rise mechanism was used for each stack (source). When this option is selected, a table appears to enter specific stack metrics. The height, diameter and average recorded volumetric exit flow rate in m^3/s for each stack was provided by the Facility ventilation engineer. The linear flow rate of m/s was then determined by dividing the volumetric flow rate by the calculated area of the stack opening. Table 3.13 below provides the values used for each stack.

Table 3.13 Stack Metrics

	Stack 1	Stack 2
Height, m	30	22
Diameter, m	2.69	2.74
exit flow, m^3/s	60.0	94.4
Flow velocity, m/s	10.54	15.97

3.6.1.5 Agri. Data

Selection of the EPA Food Source Scenario will result in different fractions appearing in the 9 cells which describe the fraction of Vegetable, Milk and Meat produced in the area. The choice of "Local" used in this study provided a level of conservatism since there is no data on the actual location of food production for the receptors. The Fraction of Home produced is displayed as "1." Sample distributions of beef and milk cattle density, and crop productivity are provided by EPA for the assessment area using average agricultural productivity data for each of the 50 states. Figure 3.11 below provides an example of the "Agri. Data" entry screen.

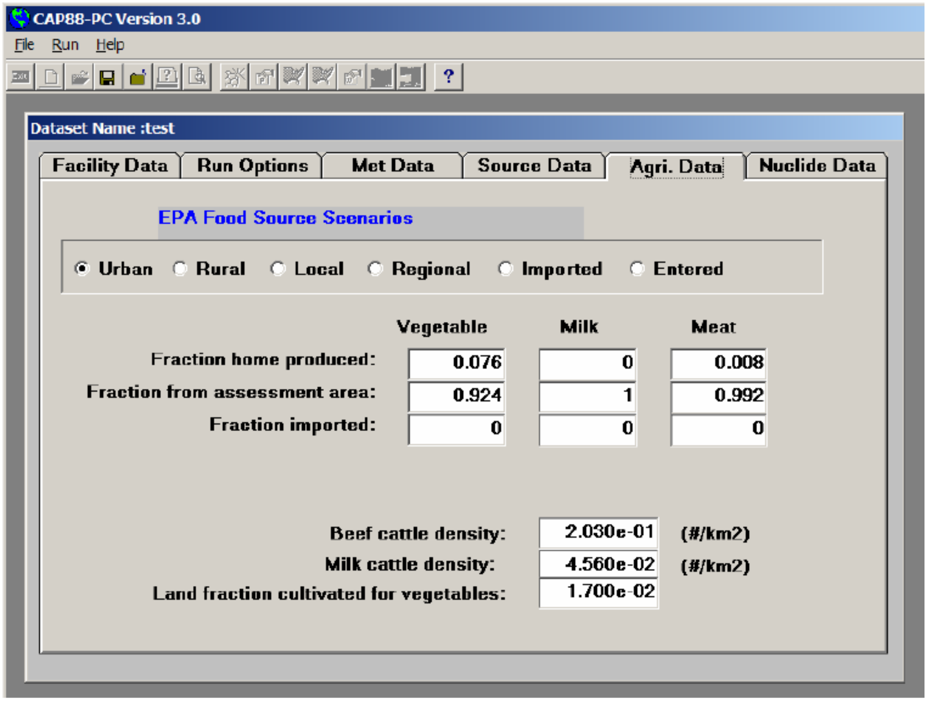

Figure 3.11 Example Agri. Data screen entry

3.6.1.6 Nuclide Data

On the Nuclide Data tab, "Time Step Days" is the number of days that will be used by the program for calculating build-up factors. The length of the time step should not be greater than 10% of the shortest half-life (in days) of the nuclides. I-131 was determined to have the shortest half-life for the significant releases, 8 days, for all three years. Therefore, the value was left at 1 day. If the check box under Limit Daughters is unchecked, all isotopes in each decay chain will be included in the build-up factor, dose and risk calculations. If checked, the user can select a shorter chain length. The default of 5 is consistent with older versions of CAP88-PC. Chain lengths less than 3 are strongly discouraged, therefore a chain length of 3 was chosen for this study. Figure 3.12 below provides an example of the Nuclide Data entry screen.

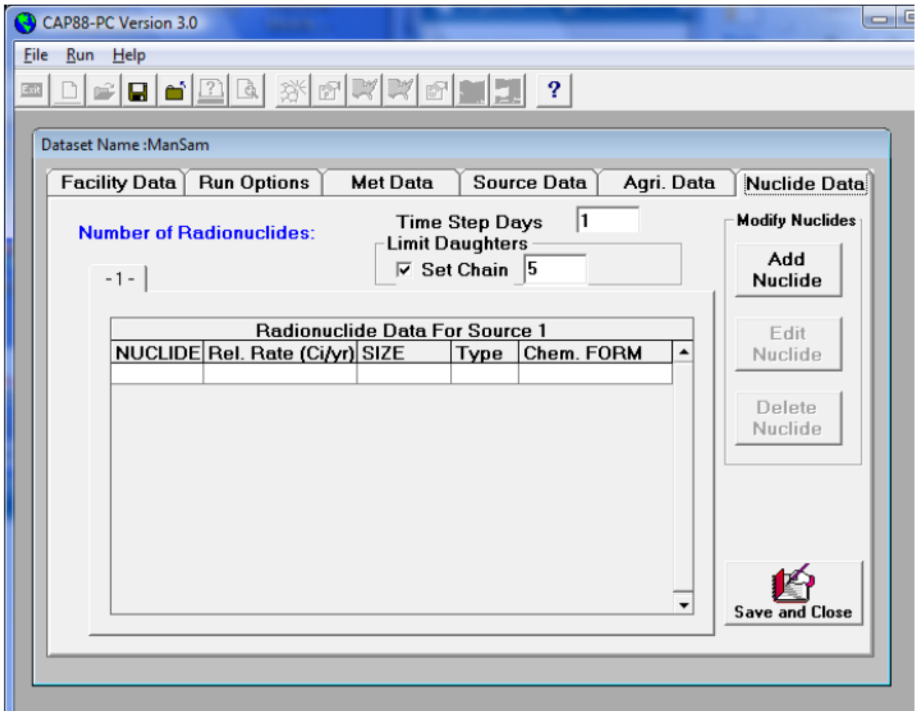

Figure 3.12 Example Nuclide Data entry screen

After clicking the Add Nuclide button, the nuclide is selected from the drop down menu of the pop-up window. The release rate is entered in Ci/year. Entry numbers must be in the Scientific notation format with 2 decimals for the exponent, e.g., 1.1E-01. If the "0" is not entered, the program will abort. The default particle size will appear for the selected nuclide. The particle size can be changed, if necessary, by selecting one of the allowed Activity Medium Aerodynamic Diameter Micrometers (AMAD) for particulates. Particle size (AMAD) in micrometers for inhaled particles is now limited to 1.0, according to the FGR 13 data model. Vapors and gases are assigned a particle size of 0. The type can also be modified as necessary (Slow – Medium – Fast). Figure 3.13 below shows an example of the Add/Edit Nuclide screen.

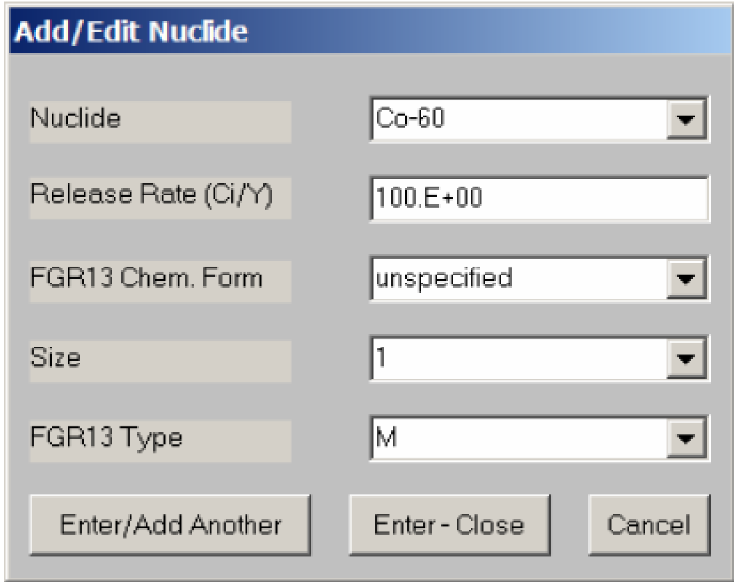

Figure 3.13 Example Add/Edit Nuclide entry screen

Entries can be edited after closing the pop-up window by selecting the nuclide and clicking the "Edit Nuclide" button. Entries can be deleted by selecting the nuclide and clicking the "Delete Nuclide" button.

Once data entry was completed, the "Save and Close" button was selected to process and save the dataset as the file name chosen with a *.DAT extension in the Datasets subdirectory. After the dataset had been saved and closed, the case was run by selecting <Run> and <Execute> from the menu bar and choosing the appropriate dataset name. Output files are written to the Output subdirectory, and are viewable within the code environment by clicking on the <print preview> icon on the button bar and selecting the Dataset name from the list. The output reports have the same filename as the dataset. For this study, the "Synopsis," "Weather Data," and "D/R Equiv. Summaries" reports were chosen for print.

3.6.2 CAP88-PC Input Data

The CAP88-PC program parameters are entered on the individual tabs displayed after a new dataset is started as explained in the previous sections. Table 3.14 provides the input values used for this study.

Table 3.14 CAP88-PC Input Summary Table

Parameter	Default	Value
Facility Data		
File – New Dataset Enter Dataset Name Enter File Name Comments 1 (opt) Comments 2 (opt)	(Dataset Name 20 char. Max, File Name 8 char. Max, no file extension required, Comment 1 50 char. Max, Comment 2 50 char. max)	 CAP88-PC Test *yyyy* CAP*yyyy* Benchmark Study *yyyy* 2 Stacks, complete nuclides
Facility Name	N/A (optional)	Radioactive Waste Processing Facility
Address	N/A (optional)	Benchmark Study
City	N/A (optional)	Oak Ridge
State	N/A (optional)	Tennessee
Zip	N/A (optional)	37831
Emission	Year (optional)	*yyyy*
Source	(optional)	2 Stacks
Run Options		
Run	• Individual • Population	• Individual

Table 3.14 Continued.

Parameter	Default	Value
Set Max Exposed Individual (button)	Let CAP88PC determine ILOC and JLOC.	*ILOC & JLOC No Entry* Click Button *(Let CAP88PC determine ILOC and JLOC.)*
Midpoint Distances	(meters)	1400, 1500, 1600, 1700, 1800 1900, 2000, 2100, 2200, 2300 2400, 3000, 3100, 3200, 3300 4700, 5800, 7500, 11700, 13800
Print Organ Dose Summaries? Create Dose and Risk Factors? Create Concentration Table? Create Chi/Q Table File?	• No • No • Yes • Yes	*No change, leave default options*
Build Up Time in Years	100	*Change to* 1 year
Met Data		
Wind File	Wind File Directory	Custom Wind File: ST*yy*W060.WND
Annual Precipitation Annual Ambient Height of Lid Absolute Humidity	(cm/year) (Celsius) (meters) 8 grams/m^3	*As provided in* Table 3.12
Source Data		
Source	• Area • Stack	*Select* "Stack"
Number of Sources	N/A	2

Table 3.14 Continued.

Parameter	Default	Value
Enter Dimensions of Sources	Height (meters) Diameter (meters)	*Stack #1:* 30 2.69 *Stack #2:* 22 2.74
Plume	• Buoyant • Momentum • Fixed • None	*Select* Momentum
Enter the Exit Velocity	(meters/sec)	*Stack #1:* 10.54 *Stack #2:* 15.97
Agri. Data		
EPA Food Source Scenarios	• Urban • Rural • Local • Regional • Imported • Entered	*Select* Local
Beef Cattle Density Milk Cattle Density Land Fraction for Vegetables	(depends on EPA Food Source Scenario selected)	*No change, left as default option for "Local"* 2.11e-01 #/km^2 2.00e-01 #/km^2 2.72e-03
Nuclide Data		
Time Step Days	1 day	*No change, left as default option*

Table 3.14 Continued.

Parameter	Default	Value
Limit Chain, Set Length	5	*Change to* 3
Modify Nuclides	N/A	*(For each stack, total effluent activity by nuclide for the applicable year. See* Table 3.7 *and* Table 3.8*)*
Save and Close	N/A	N/A
Menu Bar Options Case Execution and Report		
Run – Execute	N/A	N/A
File – Print Preview	N/A	*(Select applicable Dataset)*

Chapter 4

4 Results and Discussion

4.1 Source to Receptor Distance Summary

Table 4.1 and Table 4.2 below provide the distances between the nearest receptor and the respective stacks determined through the online calculator, no rounding.

Table 4.1 Stack 1 to Receptor Locations & Distances

Stack 1	35.913583 -84.3802667	Latitude Longitude
Direction	Receptor Lat/Lon	Distance, meters (miles)
N	35.9649263 -84.3922976	5793.6 (3.6)
NNE	35.9705639 -84.3421761	7193.8 (4.47)
NE	35.9931979 -84.2669661	13470.2 (8.37)
ENE	35.9301174 -84.2526246	11671.0 (7.22)
E	35.909053 -84.2603906	10782.6 (6.7)
ESE	35.8929803 -84.3358091	4602.7 (2.86)
SE	35.895855 -84.3689349	2220.9 (1.38)
SSE	35.8968236 -84.3714574	2027.8 (1.26)
S	35.884124 -84.387468	3331.3 (2.07)
SSW	35.8990034 -84.3911847	1899.0 (1.18)
SW	35.902015 -84.39172	1641.5 (1.02)
WSW	35.906886 -84.40518	2365.7 (1.47)
W	35.912013 -84.415376	3154.3 (1.96)
WNW	35.9312067 -84.4395711	5681.0 (3.53)
NW	35.946551 -84.429622	5745.4 (3.57)
NNW	35.9557599 -84.41078	5423.5 (3.37)

Table 4.2 Stack 2 to Receptor Locations & Distances

Stack 2	35.91155 -84.3823333	Latitude Longitude
Direction	Receptor Lat/Lon	Distance, meters(miles)
N	35.9649263 -84.3922976	5986.8 (3.72)
NNE	35.9705639 -84.3421761	7483.5 (4.65)
NE	35.9931979 -84.2669661	13759.9 (8.55)
ENE	35.9301174 -84.2526246	11828.7 (7.35)
E	35.909053 -84.2603906	10959.6 (6.81)
ESE	35.8929803 -84.3358091	4667.1 (2.9)
SE	35.895855 -84.3689349	2124.3 (1.32)
SSE	35.8968236 -84.3714574	1899.0 (1.18)
S	35.884124 -84.387468	3073.8 (1.91)
SSW	35.8990034 -84.3911847	1609.3 (1.00)
SW	35.902015 -84.39172	1351.8 (0.84)
WSW	35.906886 -84.40518	2124.3 (1.32)
W	35.912013 -84.415376	2977.3 (1.85)
WNW	35.9312067 -84.4395711	5584.4 (3.47)
NW	35.946551 -84.429622	5761.5 (3.58)
NNW	35.9557599 -84.41078	5536.1 (3.44)

The distances provided above are as exactly determined to 5 significant digits by the conversion calculator. However, for simplicity of data entry for both codes, the values were rounded to the nearest 100 m with no more than 3 significant digits. These are straight-line distances and do not take into account any terrain variances. For example, the facility lies between two ridgelines that go from Northeast to Southwest. As stated before, variation in radionuclide concentrations due to complex terrain cannot be modeled by either COMPLY or CAP88-PC.

As stated by the EPA in 40 CFR 61, if the maximally exposed individual (MEI) lives within 3 kilometers of all sources of emissions from the facility, EPA's COMPLY model and associated procedures may be used for determining dose for purposes of compliance. The stack-to-receptor distances for each of the 16 directions used with the COMPLY code are shown in Table 3.9. The total dose to the maximally exposed individual is based on the conservative assumptions that 100% of the individual's time is spent at this location and that his/her diet consists exclusively of vegetables with the calculated radionuclide concentration, and milk and meat from livestock fed on grasses with a calculated concentration.

The method for stack-to-receptor distance input is different for CAP88-PC. For modeling the dose to the MEI, all emission points are collocated at the center of the site. In each of the sixteen compass sectors, the assessment area is divided into concentric rings. Distances are not entered specific to a direction and the nearest receptor in that direction, but as a set of 20 values that define the concentric ranges of distances that closely approximate the nearest receptors, no matter in which specific direction they actually reside. The distances entered in the cells must be contiguous and ascending, that is, no cells can be skipped and the midpoint distances must increase from left to right in each row. However, if there are less than 20 values, the cells at the end may be left blank after the midpoint distances have been entered. Table 3.11 shows exactly how the midpoint distances were entered into CAP88-PC, using all 20 cells.

Linear interpolation between the inner and outer sector radii is applied to determine average concentrations and deposition of radioactive materials in each interval. Calculated parameters are assumed to be uniform within each of the annular areas defined by the concentric rings. Likewise, production and consumption rates of agricultural products are the same for all members of the population included in that interval. Therefore, everyone within a given set of boundaries receives the same dose equivalents from each exposure pathway.

The selection of the CAP88-PC distances was made to capture exact distances as comparable as possible to the COMPLY stacks for the closest receptors, and using representative distances for the farther receptors. As noted before, CAP88-PC does not treat each stack as an individual location on the site, but considers the effluence of all stacks as from one "combined" stack for the site.

Table 4.3 provides a summary comparison of the receptor distances used for both codes.

Table 4.3 Comparison of Stack to Receptor Distances for COMPLY and CAP88-PC

CAP88-PC Range Meters	COMPLY: Direction	Stack 1 Distance meters	Stack 2 Distance meters
1400			
1500	SW	1600	1400
1600			
1700			
1800	SSW	1900	1600
1900	SSE	2000	1900
2000			
2100	SE	2200	2100
2200	WSW	2400	2100
2300			
2400			
3000	W	3200	3000
3100	S	3300	3100
3200			
3300			
4700	ESE	4600	4700
	NNW	5400	5500
	WNW	5700	5600
5800	NW	5700	5800
	N	5800	6000
7500	NNE	7200	7500
	E	10800	11000
11700	ENE	11700	11800
13800	NE	13500	13800

4.2 Comparison of Code Mathematical Models

In either model, the Gaussian model for atmospheric dispersion is appropriate for flat terrain devoid of significant changes in elevation and heat sources. The chronic form is used to derive the source model in both COMPLY and CAP88-PC. CAP88-PC implements the rural Briggs coefficients. Equation (5) presents the basic Gaussian time-dependent dispersion equation for a discrete puff generated from a point source [49]. In this equation a second z-exponential term has been added to account for the fact that pollutant cannot diffuse downward through the ground at $z = 0$.

Initial plume rise due to thermal buoyancy is accounted for in CAP88-PC, but not in COMPLY. Growth of the plume during plume rise (buoyancy-induced dispersion) is a result of turbulent motion associated with plume release conditions and turbulent entrainment of ambient air. Neither COMPLY nor CAP88-PC accounts for buoyancy-induced dispersion if buoyant plume rise is considered. In COMPLY, buoyant plume rise is estimated using a simplified method suggested by Briggs [41] and is based on the equations given in that study.

According to the COMPLY users guide, the dispersion formula provided in Equation (3) is a simplification of the Pasquill-Gifford Gaussian plume model based on the building height and the ratio of the stack height to the building height. Building height is not even a required input value for CAP88-PC. However, the sector-averaged ground level concentration air concentration formula as shown in Equation (6) takes into account the vertical components as well as the downwind distance. Additionally, the wind frequencies are not directly shown in this averaged formula, but are handled within the CONCEN subroutine.

Most of the radioactive contaminants released from the Facility are in the form of particulates, which will be depleted from the plume because of dry and wet deposition. Both codes have different algorithms to estimate plume depletion resulting from dry deposition. CAP88-PC accounts for wet deposition with different algorithms. Defaults for COMPLY for deposition velocity are 860 m/day for iodine and 210 m/day for particulates, and zero for gases. Defaults for deposition velocity used by CAP88-PC are 3.5E-2 m/sec (3024 m/day) for Iodine, 1.8E-3 m/sec (155.5) for particulates and zero for gases.

For CAP88-PC, three meteorological parameters: annual precipitation, average temperature, and elevation of the inversion layer or "lid" must be supplied to estimate airborne concentrations and deposition rates of released materials. This input data is not required or used in the treatment of air concentration calculations by the COMPLY code.

COMPLY allows the entry of distances from a receptor for production of agricultural products (meat, vegetables and milk), whereas national or state average agricultural production and consumption rates are provided within CAP88-PC. Specific data, when known through population studies, can also be entered into CAP88-PC. For both programs the option of "home" (COMPLY) or "local" (CAP88-PC) provides the most conservative approach.

Table 4.4 below shows a side by side comparison of the meteorological, rates and agricultural default parameters used in the COMPLY and CAP88-PC codes.

Table 4.4 Comparison of COMPLY and CAP88-PC Default Parameters

Definition	COMPLY	CAP88-PC
Meteorological		
Removal constant, 1/yr	0.015	
Vertical temperature gradient for Pasquill categories E, F, and G (°K/m)		0.0728, 0.1090, 0.1455
Depth of water for dilution for water immersion doses (cm)		1.0
Fraction of time spent swimming		0.0
Direction index of the single location used for individual calculations		0
Distance index of the single location used for individual calculations		0
The percentile of the total risk to use in choosing the location for the exposure array used for the individual tables. When ILOC and JLOC are both 0, PLOC is used.		100.0
A scaling factor used to correct ground surface dose factors for surface roughness		0.5
Default Rates		
Breathing rate, m^3/yr	8000	8030 (9.167e+5 cm^3/hr)
Fraction of activity intercepted & retained (veg)	0.1	0.5
Fraction of activity intercepted & retained on forage or feed (milk)		0.18
Fraction of activity intercepted & retained on forage or feed (meat)		1.8
Human meat consumption, (kg/yr)	75	85.0
Ingestion rate of leafy vegetables by man (kg/yr)		18.0
Human milk consumption, (kg/yr)	160	112
Human vegetable consumption, (kg/yr)	70	176.0
Agricultural Defaults		
Fraction of produce ingested grown in garden of interest		1.0
Fraction of leafy vegetables grown in garden of interest		1.0
Fraction of year animals graze on pasture		0.4
Fraction of daily feed that is pasture grass when animal grazes on pasture		0.43

Table 4.4 Continued

Definition	COMPLY	CAP88-PC
Weathering half-life, days	12	14.4 (2.9E-3 hr^{-1})
Muscle mass of animal at slaughter (kg)		200.0
Areal density of effective root zone (veg), kg/m^2	220	215
Areal density of effective root zone (milk), kg/m^2	220	215
Areal density of effective root zone (meat), kg/m^2	220	215
Feed or forage consumption rate, kg/day (dairy)	16	15.6
Feed or forage consumption rate, kg/day (meat)	12	15.6
Water consumption by dairy cow, kg/day (dairy)	60	
Water consumption by beef cattle, kg/day	50	
Concentration of water vapor in atmosphere, kg/m^3	0.008	
Concentration of carbon in atmosphere, kg/m^3	1.6e-4	
Fraction of hydrogen in vegetables	0.1	
Fraction of hydrogen in meat	0.1	
Fraction of hydrogen in milk	0.11	
Fraction of hydrogen in animal feed or forage	0.07	
Fraction of carbon in vegetables	0.09	
Fraction of carbon in meat	0.24	
Fraction of carbon in milk	0.07	
Fallout interception fraction-pasture		0.57
Fallout interception fraction-vegetables		0.2
Fraction of animal herd slaughtered per day		3.81E-3
Period of above-ground exposure, days (veg)	60	60 (1440 hr)
Period of above-ground exposure, days (milk)	30	30 (720 hr)
Period of above-ground exposure, days (meat)	30	30 (720 hr)
Milk production of cow (liter/day)		11.0
Period of long-term buildup in soil, (yr)	100	100.0
Deposition velocity, m/day (noble gases)	0	0
Deposition velocity, m/day (iodine)	860	3024 (3.5E-2 m/s)
Deposition velocity, m/day (particulates)	210	155.5 (1.8E-3 m/s)
Edible crop per m^2 at harvest, kg/m^2 (veg)	1.0	0.716
Edible crop per m^2 at harvest, kg/m^2 (milk)	1.0	0.28
Edible crop per m^2 at harvest, kg/m^2 (meat)	1.0	

Table 4.4 Continued

Definition	COMPLY	CAP88-PC
Time delay—ingestion of pasture grass by animals (hr)		0.0
Time delay—ingestion of stored feed by animals (hr)		2160.0
Time delay—ingestion of leafy vegetables by man (hr)		336.0
Delay time, harvest to consumption (veg), days	11	14 (336 hr)
Delay time, milking to consumption, days	2	2.0
Delay time, slaughter to consumption, days	17	20

As the primary radionuclides emitted from the Facility are Tritium and C-14, another important parameter that needs to be considered when comparing the two codes are the dose conversion factors for these two radionuclides, as well as Iodine which is reported separately. As stated before the COMPLY code uses dose conversion factors provided in FGR 11 which are based on ICRP 30. CAP88-PC uses dose conversion factors from FGR 13 which are based on ICRP 68. Table 4.5 provides both the FGR 11 and FGR 13 dose conversion factors for H-3, C-14 and iodine, in units of mrem per microCurie.

Table 4.5 Comparison of ICRP 30 and ICRP 68 Iodine Dose Conversion Factors

	ICRP 30 mrem/μCi	ICRP 68 mrem/μCi
H-3	6.40E-02	6.66E-02
C-14	2.09E+00	2.15E+00
I-125	2.42E+01	2.77E+01
I-129	1.74E+02	1.89E+02
I-131	3.29E+01	4.07E+01

As can be seen in the table, the current factors of ICRP 68/72, which are accepted internationally, are somewhat higher.

4.3 Annual Maximally Exposed Individual Results

Table 4.6 summarizes the maximally exposed individual doses calculated by COMPLY-4 and CAP88-PC for the years 2004 to 2012 evaluated.

Table 4.6 Maximally Exposed Individual Results Summary

Year	COMPLY Level 4 Version 1.6	Distance / Direction	CAP88-PC Version 3	Distance / Direction
2004	0.1 mrem/yr Iodine: 3.0e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.0663 mrem/yr Iodine: 7.36e-3 mrem/yr	1400m SW
2005	0.2 mrem/yr Iodine: 1.3e-2 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.183 mrem/yr Iodine: 4.92e-2 mrem/yr	1400m SW
2006	0.2 mrem/yr Iodine: 1.3e-2 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.181 mrem/yr Iodine: 5.08e-2 mrem/yr	1400m SW
2007	0.2 mrem/yr Iodine: 4.4e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.217 mrem/yr Iodine: 1.63e-2 mrem/yr	1400m SW
2008	0.3 mrem/yr Iodine: 8.9E-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.245 mrem/yr Iodine: 3.31e-2 mrem/yr	1400m SW
2009	0.1 mrem/yr Iodine: 6.8e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.125 mrem/yr Iodine: 2.55e-2 mrem/yr	1400m SW
2010	0.3 mrem/yr Iodine: 3.0e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.229 mrem/yr Iodine: 1.00e-2 mrem/yr	1400m SW
2011	0.2 mrem/yr Iodine: 6.0e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.157 mrem/yr Iodine: 1.05e-2 mrem/yr	1400m SW
2012	0.2 mrem/yr Iodine: 3.1e-3 mrem/yr	ST1: 1600m SW ST2: 1400m SW	0.202 mrem/yr Iodine: 1.16e-2 mrem/yr	1400m SW

Annual doses from the COMPLY code are given with only 1 significant digit, while doses reported in the CAP88-PC output are given with 3 significant digits, as shown in the table above. For both codes and all years, the maximally exposed individual was in the southwest direction at the closest distance entered. For COMPLY, the distances from the stacks were reported separately. CAP88-PC, with the one combined stack model, gives a single distance.

4.4 Statistical Comparison of Results

Table 4.7 provides the percent difference between the annually effective dose as determined with COMPLY to the annual dose determined with CAP88-PC.

Table 4.7 Percent Difference Between COMPLY and CAP88-PC Total Dose

Year	COMPLY mrem/y	CAP88-PC mrem/y	unrounded % difference	CAP88-PC Rounded mrem/y	rounded % difference
2004	0.1	0.0663	-34%	0.1	0%
2005	0.2	0.183	-9%	0.2	0%
2006	0.2	0.181	-10%	0.2	0%
2007	0.2	0.217	8%	0.2	0%
2008	0.3	0.245	-18%	0.3	0%
2009	0.1	0.125	25%	0.1	0%
2010	0.3	0.229	-24%	0.2	-33%
2011	0.2	0.157	-22%	0.2	0%
2012	0.2	0.202	1%	0.2	0%

As can be seen in the difference analysis above, the difference between the annual dose results appears to be on the order of 9% to 34% lower for CAP88-PC than COMPLY, with two exceptions for the years 2007 and 2012 where the result is 8% and 1% higher, respectively. However, if the CAP88-PC results are rounded to one significant digit, as the COMPLY results are reported, there is no difference between the results except for the year 2010. For that year, rounding down from 0.229 to 0.2 mrem/y gives a 33% lower result for CAP88-PC.

The COMPLY report includes a single line item giving the effective dose equivalent due to Iodine (see Appendix A: COMPLY Output Reports). The reporting of the Iodine dose by the COMPLY code was to address the EPA regulatory limit of less than 3 mrem attributed to Iodine at the time of its development. For comparison of results, the Iodine dose from CAP88-PC was calculated by summing the individual nuclide results for I-125, I-129 and I-131 from the Dose and Risk Equivalent Summary reports (see Appendix B: CAP88-PC Output Reports). For CAP88-PC, the dose was calculated by summing all the Iodine isotopes dose contribution from the summary list showing the dose contribution for each nuclide. Table 4.8 provides the percent difference between the annually effective dose equivalents from Iodine as determined with COMPLY with the annual Iodine dose calculated from the individual Iodine isotopes reported by CAP88-PC.

Table 4.8 Percent Difference Between COMPLY and CAP88-PC Iodine Dose

Year	COMPLY I-mrem/y	CAP88-PC I-mrem/y	unrounded % difference	CAP88-PC Rounded I-mrem/y	rounded % difference
2004	3.0E-03	7.36E-03	145%	7.4E-03	147%
2005	1.3E-02	4.92E-02	278%	5.0E-02	285%
2006	1.3E-02	5.08E-02	291%	5.1E-02	292%
2007	4.4E-03	1.63E-02	270%	1.7E-02	286%
2008	8.9E-03	3.31E-02	272%	3.4E-02	282%
2009	6.8E-03	2.55E-02	275%	2.6E-02	282%
2010	3.0E-03	1.00E-02	233%	1.0E-02	233%
2011	6.0E-03	1.05E-02	75%	1.1E-02	83%
2012	3.1E-03	1.16E-02	274%	1.2E-02	287%

For all years, the total Iodine component of the effective annual dose determined with the CAP88-PC code is significantly higher than the result reported by the COMPLY code. The percent difference for the reported results ranges from 75% to 291%. As seen with the total dose, there was a difference between the significant digits reported by the codes. COMPLY reports the Iodine dose with 2 significant digits while CAP88-PC gives the dose in 3 significant digits. However, unlike with the total dose, rounding the CAP88-PC Iodine dose to 2 significant digits does not change the order of difference between the two results.

Chapter 5

5 Conclusions and Recommendations

5.1 Conclusions

Calculated doses from the Facility's airborne emissions using EPA-approved codes COMPLY and CAP88-PC for the years 2004 to 2012 were well below the 10 mrem/yr NESHAP dose standard. As shown in Table 4.6, the total calculated doses for both codes ranged from 0.1 mrem/yr to 0.3 mrem/yr to the MEI. The location of this hypothetical person is about 1400 m southwest of the Facility. Both codes calculate the dose assuming a person resides there 24 hours a day for the entire year, eats meat, milk and vegetables grown at their residence (see the agricultural parameters in Chapter 2), and drinks water from local wells contaminated with deposited airborne radionuclides. Thus the calculated dose to this hypothetical person, the MEI, is greater than the dose to an actual member of the public.

The basic air dispersion mathematical model to estimate radionuclide concentrations at the MEI locations for both codes was based on the Gaussian Plume dispersion model. However, with COMPLY, no treatment of plume rise was considered because neither stack was greater than 2.5 times the building height. Also, COMPLY only considers the D stability class for determination of the dispersion coefficients. Therefore, the final equation the code used was a very simplified form of the Gaussian model as given in Equation (3). For CAP88-PC, building height was not even an input parameter. The dispersion equation considers not only plume rise, but additional Pasquill stability classes as well.

Surprisingly, considering all the advancements in the basic internal dose models and a more refined air dispersion/concentration calculational model, the maximally exposed total individual doses calculated with CAP88-PC were almost identical to those calculated with COMPLY when the CAP88-PC doses were rounded with the same significant digits as COMPLY. As can be seen in Chapter 2, the codes not only differ in the equation used to estimate air concentration, but also in the default or built-in parameters that are used. Even with these significant differences between COMPLY and CAP88-PC, with the two total dose outputs being so similar it can be concluded that the codes performed as intended by the EPA developers.

One major differences observed between the outputs was in the contribution of Iodine to the total dose was notably higher for CAP88-PC. As was shown in Table 4.5 the dose conversion factors (DCF) were higher for the ICRP 68/72 dose models used by CAP88-PC. For the case of Iodine, the differences in the ICRP 68/72 DCFs can explain the difference between the values provided by COMPLY with those from CAP88-PC. With version 3.0 of CAP88-PC, dose and risk factors were incorporated from FGR 13 [26], which are based on the methods in Publication 72 of the ICRP [32]). COMPLY, based on NCRP Commentary No. 3, incorporates the dose and risk factors from FGR 11 [24] which are based on the methods in Publication 30 of the ICRP. Therefore, seeing higher Iodine results with the code that uses the most current dose models is not unexpected. ICRP 68 predicts much different rates of absorption from the respiratory tract to the blood. These differences in the biokinetic and dosimetric properties of the two respiratory models often lead to substantially different estimates of lung dose. The fact that the total annual effective dose is not significantly different between the two codes is a result of other factors that lower dose calculations with the ICRP 68 methods in comparison to ICRP 30. For example, ICRP 68 predicts a lower total deposition in the respiratory tract for most particle sizes than ICRP 30.

It was notable that the direction of the maximally exposed individual, Southwest, was the same for all years investigated. The wind rose provided in Figure 3.5 clearly shows that the annual average frequency for winds blowing towards the Southwest direction (from Northeast 16.4% of the time) was the most predominant. Therefore it wasn't unexpected that the maximally exposed individual would be identified to the Southwest for the most part, but the consistency between the years was surprising.

5.2 Recommendations

CAP88-PC represents one of the best available validated codes for the purpose of making comprehensive dose and risk assessments. EPA studies have shown that it produces results that agree with experimental data as well as any model, and is consistent with the random nature of turbulence. The Office of Radiation and Indoor Air made comparisons between the predictions of annual-average ground-level concentration to actual environmental measurements, and found very good agreement. In the paper "Comparison of AIRDOS-EPA Prediction of Ground-Level Airborne Radionuclide concentrations to Measured Values" [34] , environmental monitoring data at five DOE sites were compared to AIRDOS-EPA predictions. EPA concluded that as often as not, AIRDOS-EPA predictions were within a factor of 2 of actual concentrations.

Additionally, CAP88-PC has been updated over the years with the most current and internationally accepted dose assessment models/methods, and is the only model that will continue to be supported by the EPA. Version 4 of CAP88-PC, just released in 2014, includes updated ICRP dosimetric models and Federal Guidance Report-related risk factors. The separation of program files from data files introduced in Version 4 makes it easier to run under newer Windows operating systems, and the new case folder structure simplifies maintaining datasets and their associated report files.

Each new version of CAP88-PC incorporates the latest science while become somewhat more versatile. COMPLY code is no longer supported by the EPA. However, the EPA allows for facilities for which the maximally exposed individual lives within 3 kilometers of all sources of emissions in the facility, to continue to use the COMPLY model. Therefore, depending on the data or computer operating system available and the distance to the nearest receptors, the choice of COMPLY or CAP88-PC code for calculating the offsite maximally exposed individual to demonstrate compliance to regulations is entirely up to the user. Both codes are best suited for chronic releases and receptor distances greater than 100 m. As can seen by the results of this study, using either code will result in similar, if not practically identical, TEDE for the MEI for a facility whose stack effluent(s) are primarily comprised of typical mixed-fission and corrosion radionuclides.

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APPENDICES

Appendix A: COMPLY Output Reports

COMPLY Test 2004

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COMPLY: V1.6.                                        3/ 3/2014  11:44


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants




                    REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                 FROM THE COMPLY CODE - V1.6.




                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis




                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
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COMPLY Test 2004

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	2.310E-06
CR-51	Y	8.520E-07
CS-134	D	2.490E-07
CS-137	D	1.410E-05
I-125	D	1.970E-03
I-131	D	1.110E-06
K-40	D	3.180E-06
MN-54	W	9.760E-08
SE-75	W	2.300E-05
SB-125	W	6.620E-05
ZN-65	Y	6.120E-07
H-3	V	2.530E+01
C-14	1	4.090E+00
PU-238	W	1.170E-07
PU-239	W	2.180E-07
PU-240	W	2.180E-07
U-233	Y	6.180E-07
U-234	Y	6.180E-07
U-235	Y	5.820E-08
U-236	Y	5.820E-08
U-238	Y	5.460E-07
PU-241	W	6.870E-07
SR-89	Y	4.210E-07
SR-90	Y	4.020E-07
FE-55	D	6.640E-06
NI-63	V	2.680E-06
TC-99	W	5.760E-06

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	2.110E-05
CS-137	D	4.670E-05
I-131	D	9.450E-07
NB-94	Y	1.130E-06
NB-95	Y	1.510E-11
RU-106	Y	3.610E-06

SB-125	W	4.040E-07
H-3	V	1.830E+00
C-14	1	4.950E-02
PU-238	W	1.250E-08
PU-239	W	1.890E-09
PU-240	W	1.890E-09
U-233	Y	6.540E-07
U-234	Y	6.540E-07
U-235	Y	6.600E-08
U-236	Y	6.600E-08
U-238	Y	6.340E-07
PU-241	W	9.010E-07
SR-89	Y	2.490E-07
SR-90	Y	2.020E-07
FE-55	D	3.260E-06
NI-63	V	1.420E-06
TC-99	W	3.960E-07

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2004.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2004 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.032	0.69
NNE	0.054	0.97
NE	0.156	2.03
ENE	0.102	2.18
E	0.027	1.67
ESE	0.012	1.41
SE	0.011	1.33
SSE	0.011	1.35
S	0.013	1.46
SSW	0.030	1.89
SW	0.135	2.17
WSW	0.232	1.74
W	0.083	1.07
WNW	0.046	0.77
NW	0.031	0.73
NNW	0.025	0.64

```
     He produces his own VEGETABLES at home.
     Stack number 1.

     He produces his own MILK at home.
     Stack number 1.

     He produces his own MEAT at home.
     Stack number 1.

     He produces his own VEGETABLES at home.
     Stack number 2.

     He produces his own MILK at home.
     Stack number 2.

     He produces his own MEAT at home.
     Stack number 2.

 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.   Stack 1.
     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.   Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Windrose wind frequency is unusually HIGH.
         Windrose wind speed is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.1 mrem/yr.

     Effective dose equivalent:    3.0E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.


********** END OF COMPLIANCE REPORT **********
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COMPLY Test 2005

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COMPLY: V1.6.                                          3/ 3/2014  12:28


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



                    REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                 FROM THE COMPLY CODE - V1.6.



                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis



                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
```

COMPLY: V1.6.   3/ 3/2014 12:28

COMPLY Test 2005

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CE-144	Y	5.030E-06
CO-57	Y	7.680E-06
CO-60	Y	1.650E-06
CS-137	D	5.570E-06
I-125	D	1.340E-02
I-131	D	8.130E-06
K-40	D	4.380E-06
MN-54	W	2.360E-07
RU-103	Y	1.880E-07
RU-106	Y	5.000E-05
SE-75	W	2.300E-04
SB-125	W	8.010E-05
ZN-65	Y	2.630E-07
H-3	V	4.170E+01
C-14	1	9.760E+00
PU-238	W	3.820E-08
PU-239	W	7.780E-08
PU-240	W	7.780E-08
U-233	Y	1.980E-07
U-234	Y	1.980E-07
U-235	Y	1.580E-08
U-236	Y	1.580E-08
U-238	Y	1.680E-07
SR-89	Y	6.640E-09
SR-90	Y	2.470E-08
FE-55	D	2.760E-06
NI-63	V	9.960E-07
TC-99	W	4.570E-06

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-57	Y	1.700E-05
CO-60	Y	2.390E-07
CR-51	Y	5.390E-05
CS-137	D	3.000E-06
I-131	D	1.240E-07

K-40	D	1.770E-05
NB-94	Y	3.140E-07
NB-95	Y	2.920E-06
RU-103	Y	1.210E-06
ZR-95	D	7.360E-05
H-3	V	4.820E-01
C-14	1	2.250E-02
PU-238	W	8.590E-09
PU-239	W	2.460E-08
PU-240	W	2.460E-08
U-233	Y	3.630E-07
U-234	Y	3.630E-07
U-235	Y	3.520E-08
U-236	Y	3.520E-08
U-238	Y	3.280E-07
PU-241	W	1.950E-07
SR-89	Y	2.300E-08
FE-55	D	1.310E-06
NI-63	V	9.570E-07
TC-99	W	3.340E-06

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2005.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2005 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.028	1.73
NNE	0.051	2.32
NE	0.175	3.57
ENE	0.118	2.74
E	0.035	1.78
ESE	0.021	1.60
SE	0.018	1.41
SSE	0.018	1.48
S	0.023	1.83
SSW	0.047	2.88
SW	0.126	3.42
WSW	0.136	3.36
W	0.109	3.10
WNW	0.050	2.80
NW	0.024	2.11
NNW	0.022	1.76

He produces his own VEGETABLES at home.
Stack number 1.

He produces his own MILK at home.
Stack number 1.

He produces his own MEAT at home.
Stack number 1.

He produces his own VEGETABLES at home.
Stack number 2.

He produces his own MILK at home.
Stack number 2.

He produces his own MEAT at home.
Stack number 2.

NOTES:

```
    The receptor exposed to the highest concentration is located
         1600. meters from the source in the SW sector.   Stack 1.
    The receptor exposed to the highest concentration is located
         1400. meters from the source in the SW sector.   Stack 2.

    He produces his own VEGETABLES at his home.

    He produces his own MEAT at his home.

    He produces his own MILK at his home.

    Input parameters outside the "normal" range:

        Building (length) is unusually WIDE.
        Windrose wind frequency is unusually LOW.
        Receptor is unusually FAR.
        Stack file distance is unusually FAR.
```

RESULTS:

```
    Effective dose equivalent:        0.2 mrem/yr.

    Effective dose equivalent:    1.3E-02 mrem/yr due to Iodine.

    *** Comply at level 4.

    This facility is in COMPLIANCE.

    It may or may not be EXEMPT from reporting to the EPA.

    You may contact your regional EPA office for more information.
```

********** END OF COMPLIANCE REPORT **********

COMPLY Test 2006

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COMPLY: V1.6.                                        3/ 3/2014   1:05


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



                    REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                 FROM THE COMPLY CODE - V1.6.



                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis



                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
```

COMPLY: V1.6.   3/ 3/2014   1:05

COMPLY Test 2006

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
AG-110M	Y	2.960E-07
CE-144	Y	1.310E-05
CO-57	Y	8.290E-04
CO-58	Y	2.610E-07
CO-60	Y	1.680E-06
CS-137	D	2.230E-05
I-125	D	1.380E-02
I-129	D	1.960E-06
I-131	D	8.030E-06
K-40	D	6.010E-05
MN-54	W	4.330E-07
SE-75	W	4.990E-04
SB-125	W	1.600E-04
H-3	V	1.030E+02
C-14	1	8.360E+00
PU-238	W	1.480E-08
PU-239	W	2.560E-08
PU-240	W	2.560E-08
U-233	Y	2.180E-07
U-234	Y	2.180E-07
U-235	Y	1.090E-08
U-236	Y	1.090E-08
U-238	Y	2.100E-07
PU-241	W	1.040E-07
SR-89	Y	1.510E-08
SR-90	Y	3.010E-08
FE-55	D	8.000E-05
NI-63	V	2.710E-06
TC-99	W	6.740E-06

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-58	Y	2.960E-07
CO-60	Y	2.690E-06
CR-51	Y	9.570E-07
CS-137	D	8.000E-06

I-131	D	3.280E-07
MN-54	W	1.010E-07
H-3	V	2.730E-01
C-14	1	2.450E-02
PU-238	W	2.320E-09
PU-239	W	5.190E-09
PU-240	W	5.190E-09
U-233	Y	2.450E-07
U-234	Y	2.450E-07
U-235	Y	1.120E-08
U-236	Y	1.120E-08
U-238	Y	2.110E-07
PU-241	W	3.290E-08
SR-89	Y	6.730E-09
SR-90	Y	6.730E-09
FE-55	D	3.180E-05
NI-63	V	1.080E-06
TC-99	W	3.020E-07

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2006.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2006 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.024	1.83
NNE	0.048	2.39
NE	0.161	3.44
ENE	0.089	2.51
E	0.033	1.70
ESE	0.017	1.36
SE	0.017	1.42
SSE	0.016	1.44
S	0.029	1.67
SSW	0.051	2.61
SW	0.162	3.60
WSW	0.154	3.32
W	0.116	2.95
WNW	0.036	2.27
NW	0.025	2.23
NNW	0.020	1.97

He produces his own VEGETABLES at home.
Stack number 1.

He produces his own MILK at home.
Stack number 1.

He produces his own MEAT at home.
Stack number 1.

He produces his own VEGETABLES at home.
Stack number 2.

He produces his own MILK at home.
Stack number 2.

He produces his own MEAT at home.
Stack number 2.

```
 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.
     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.2 mrem/yr.

     Effective dose equivalent:    1.3E-02 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.


********** END OF COMPLIANCE REPORT **********
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COMPLY: V1.6.                                       3/ 3/2014   1:35


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



                   REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                FROM THE COMPLY CODE - V1.6.




                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis




                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
```

COMPLY: V1.6. 3/ 3/2014 1:35

COMPLY Test 2007

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	7.280E-04
CS-137	D	1.040E-06
I-125	D	4.410E-03
I-129	D	1.590E-06
I-131	D	2.110E-04
K-40	D	2.170E-04
NB-94	Y	1.980E-07
RU-103	Y	3.820E-07
SE-75	W	7.650E-06
SB-125	W	5.050E-05
SN-113	W	3.550E-07
H-3	V	1.030E+02
C-14	1	1.190E+01
PU-238	W	8.610E-09
PU-239	W	1.350E-08
PU-240	W	1.350E-08
U-233	Y	3.830E-07
U-234	Y	3.830E-07
U-235	Y	3.220E-08
U-236	Y	3.220E-08
U-238	Y	3.530E-07
PU-241	W	1.240E-07
SR-89	Y	1.870E-08
SR-90	Y	4.080E-08
FE-55	D	6.760E-07
NI-63	V	9.170E-07
TC-99	W	5.880E-06

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	6.840E-05
CR-51	Y	4.390E-07
CS-137	D	1.520E-06
I-129	D	9.020E-07
I-131	D	7.070E-08
RU-103	Y	9.680E-08

H-3	V	9.260E+01
C-14	1	3.260E-01
PU-239	W	3.850E-10
PU-240	W	3.850E-10
U-233	Y	1.020E-07
U-234	Y	1.020E-07
U-235	Y	5.870E-09
U-236	Y	5.870E-09
U-238	Y	7.760E-08
PU-241	W	6.000E-08
SR-89	Y	1.550E-08
SR-90	Y	1.930E-08
FE-55	D	1.750E-07
NI-63	V	8.340E-07

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2007.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2007 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.026	1.90
NNE	0.047	2.30
NE	0.157	3.27
ENE	0.090	2.49
E	0.036	1.73
ESE	0.016	1.48
SE	0.016	1.43
SSE	0.014	1.56
S	0.025	1.87
SSW	0.052	2.75
SW	0.162	3.63
WSW	0.149	3.36
W	0.119	3.06
WNW	0.045	2.38
NW	0.025	2.18
NNW	0.021	1.82

He produces his own VEGETABLES at home.
Stack number 1.

He produces his own MILK at home.
Stack number 1.

He produces his own MEAT at home.
Stack number 1.

He produces his own VEGETABLES at home.
Stack number 2.

He produces his own MILK at home.
Stack number 2.

He produces his own MEAT at home.
Stack number 2.

```
NOTES:
------

    The receptor exposed to the highest concentration is located
         1600. meters from the source in the SW sector.  Stack 1.

    The receptor exposed to the highest concentration is located
         1400. meters from the source in the SW sector.  Stack 2.

    He produces his own VEGETABLES at his home.

    He produces his own MEAT at his home.

    He produces his own MILK at his home.

    Input parameters outside the "normal" range:

        Building (length) is unusually WIDE.
        Windrose wind frequency is unusually LOW.
        Receptor is unusually FAR.
        Stack file distance is unusually FAR.

RESULTS:
--------

    Effective dose equivalent:        0.2 mrem/yr.

    Effective dose equivalent:    4.4E-03 mrem/yr due to Iodine.

    *** Comply at level 4.

    This facility is in COMPLIANCE.

    It may or may not be EXEMPT from reporting to the EPA.

    You may contact your regional EPA office for more information.

********** END OF COMPLIANCE REPORT **********
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COMPLY: V1.6.                                        3/ 3/2014   3:15


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



                    REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                 FROM THE COMPLY CODE - V1.6.



                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis



                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
```

COMPLY: V1.6.   3/ 3/2014   3:15

COMPLY Test 2008

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	5.740E-07
CR-51	Y	6.020E-07
CS-137	D	2.080E-06
FE-59	D	9.910E-05
I-125	D	8.980E-03
I-131	D	1.330E-04
K-40	D	8.210E-05
RU-103	Y	1.690E-06
RU-106	Y	1.070E-06
SE-75	W	3.510E-05
SB-125	W	2.100E-05
H-3	V	1.060E+02
C-14	1	1.460E+01
PU-238	W	1.650E-08
PU-239	W	1.510E-08
PU-240	W	1.510E-08
U-233	Y	3.040E-07
U-234	Y	3.040E-07
U-235	Y	2.320E-08
U-236	Y	2.320E-08
U-238	Y	2.330E-07
PU-241	W	1.730E-07
SR-90	Y	3.900E-08
FE-55	D	1.930E-06
NI-63	V	5.170E-06
TC-99	W	2.630E-04

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	1.770E-06
CS-137	D	8.510E-06
K-40	D	6.670E-05
H-3	V	1.280E+00
C-14	1	9.920E-02
PU-238	W	1.020E-09
U-233	Y	1.540E-07

U-234	Y	1.540E-07
U-235	Y	1.130E-08
U-236	Y	1.130E-08
U-238	Y	1.710E-07
PU-241	W	1.520E-07
SR-89	Y	1.350E-07
SR-90	Y	7.980E-08
FE-55	D	7.240E-07
NI-63	V	9.270E-07
TC-99	W	3.970E-06

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2008.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2008 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.025	1.85
NNE	0.047	2.21
NE	0.166	3.36
ENE	0.090	2.65
E	0.033	1.73
ESE	0.019	1.30
SE	0.019	1.22
SSE	0.019	1.36
S	0.023	1.94
SSW	0.054	3.29
SW	0.147	3.83
WSW	0.151	3.42
W	0.126	3.14
WNW	0.041	2.31
NW	0.027	2.14
NNW	0.023	1.77

```
     He produces his own VEGETABLES at home.
     Stack number 1.

     He produces his own MILK at home.
     Stack number 1.

     He produces his own MEAT at home.
     Stack number 1.

     He produces his own VEGETABLES at home.
     Stack number 2.

     He produces his own MILK at home.
     Stack number 2.

     He produces his own MEAT at home.
     Stack number 2.

 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.

     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.3 mrem/yr.

     Effective dose equivalent:    8.9E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.

********** END OF COMPLIANCE REPORT **********
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COMPLY: V1.6.                                              3/ 3/2014   3:47


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



                   REPORT ON COMPLIANCE WITH

        THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

                 FROM THE COMPLY CODE - V1.6.




                Prepared by:

                Radioactive Waste Processing Facility
                Benchmark Study
                Oak Ridge, TN

                Debra McCroskey
                Master's Thesis




                Prepared for:

                U.S. Environmental Protection Agency
                Office of Radiation and Indoor Air
                Washington, DC  20460
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COMPLY: V1.6.                                        3/ 3/2014   3:47


COMPLY Test 2009

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SCREENING LEVEL 4
-----------------

 DATA ENTERED:
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     RELEASE RATES FOR STACK    1.

                 Release Rate
         Nuclide  (curies/YEAR)
         ---------- -------------
         AG-110M   Y  4.890E-07
         CO-60     Y  2.410E-06
         CS-134    D  7.140E-07
         CS-137    D  2.270E-05
         I-125     D  6.860E-03
         I-131     D  1.290E-05
         K-40      D  6.510E-05
         RU-103    Y  8.930E-07
         RU-106    Y  8.780E-07
         SE-75     W  2.970E-05
         SB-125    W  2.340E-05
         ZN-65     Y  3.590E-07
         H-3       V  8.070E+01
         C-14      1  6.280E+00
         PU-238    W  4.200E-09
         PU-239    W  2.180E-09
         PU-240    W  2.180E-09
         U-233     Y  1.380E-07
         U-234     Y  1.380E-07
         U-235     Y  4.120E-09
         U-236     Y  4.120E-09
         U-238     Y  1.570E-07
         PU-241    W  1.160E-08
         SR-89     Y  4.290E-08
         SR-90     Y  1.770E-08
         FE-55     D  5.290E-07
         NI-63     V  8.420E-06
         TC-99     W  3.590E-05


     RELEASE RATES FOR STACK    2.

                 Release Rate
         Nuclide  (curies/YEAR)
         ---------- -------------
         CO-58     Y  2.480E-07
         CO-60     Y  1.470E-05
         CS-137    D  4.530E-06
         K-40      D  7.450E-05
         MN-54     W  5.010E-07
```

H-3	V	4.400E-01
C-14	1	7.760E-02
PU-238	W	2.170E-09
PU-239	W	4.820E-09
PU-240	W	4.820E-09
U-233	Y	1.350E-07
U-234	Y	1.350E-07
U-235	Y	6.220E-09
U-236	Y	6.220E-09
U-238	Y	1.320E-07
PU-241	W	5.260E-08
SR-89	Y	7.310E-09
SR-90	Y	2.810E-08
FE-55	D	2.190E-06
NI-63	V	1.040E-06

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR ---	Distance (meters) ---------
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: WIND2009.DAT

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2009 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.024	1.91
NNE	0.052	2.56
NE	0.171	3.41
ENE	0.091	2.61
E	0.043	1.95
ESE	0.019	1.59
SE	0.015	1.51
SSE	0.018	1.64
S	0.023	1.89
SSW	0.052	3.19
SW	0.142	3.70
WSW	0.139	3.41
W	0.127	3.09
WNW	0.044	2.29
NW	0.022	1.94
NNW	0.019	1.64

He produces his own VEGETABLES at home.
Stack number 1.

He produces his own MILK at home.
Stack number 1.

He produces his own MEAT at home.
Stack number 1.

He produces his own VEGETABLES at home.
Stack number 2.

He produces his own MILK at home.
Stack number 2.

He produces his own MEAT at home.
Stack number 2.

```
 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.

     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.1 mrem/yr.

     Effective dose equivalent:    6.8E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.


********** END OF COMPLIANCE REPORT **********
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COMPLY Test 2010

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COMPLY: V1.6.                                     2/20/2014   8:50


40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants



               REPORT ON COMPLIANCE WITH

      THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

             FROM THE COMPLY CODE - V1.6.



            Prepared by:

            Radioactive Waste Processing Facility
            Benchmark Study
            Oak Ridge, TN

            Debra McCroskey
            Master's Thesis



            Prepared for:

            U.S. Environmental Protection Agency
            Office of Radiation and Indoor Air
            Washington, DC  20460
```

COMPLY Test 2010

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	7.740E-07
CS-137	D	4.680E-06
I-125	D	2.510E-03
I-129	D	1.150E-05
I-131	D	1.070E-04
K-40	D	2.530E-05
MN-54	W	3.170E-07
SE-75	W	3.460E-05
SB-124	W	5.810E-03
SB-125	W	1.380E-04
H-3	V	1.100E+02
C-14	1	1.520E+01
PU-238	W	4.530E-10
PU-239	W	2.190E-09
PU-240	W	2.190E-09
U-233	Y	1.400E-07
U-234	Y	1.400E-07
U-235	Y	7.950E-09
U-236	Y	7.950E-09
U-238	Y	1.370E-07
PU-241	W	2.850E-08
SR-89	Y	1.370E-08
SR-90	Y	5.010E-08
FE-55	D	5.080E-07
NI-63	V	4.070E-06
TC-99	W	2.170E-04

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	4.340E-06
CS-137	D	5.960E-06
H-3	V	1.020E+00
C-14	1	5.220E-02
PU-238	W	2.070E-09
PU-239	W	6.470E-10
PU-240	W	6.470E-10

U-233	Y	1.390E-07
U-234	Y	1.390E-07
U-235	Y	4.590E-09
U-236	Y	4.590E-09
U-238	Y	1.380E-07
PU-241	W	9.200E-08
SR-89	Y	5.190E-09
SR-90	Y	1.030E-07
FE-55	D	1.030E-06
NI-63	V	9.740E-07
TC-99	W	1.480E-07

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.DAT

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: wind2010.dat

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2010 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.041	1.79
NNE	0.066	2.28
NE	0.173	3.15
ENE	0.072	2.18
E	0.036	3.74
ESE	0.014	1.41
SE	0.016	1.57
SSE	0.020	1.65
S	0.018	1.90
SSW	0.058	2.94
SW	0.157	3.38
WSW	0.138	3.10
W	0.100	2.77
WNW	0.040	2.04
NW	0.028	1.87
NNW	0.022	1.69

```
     He produces his own VEGETABLES at home.
     Stack number 1.

     He produces his own MILK at home.
     Stack number 1.

     He produces his own MEAT at home.
     Stack number 1.

     He produces his own VEGETABLES at home.
     Stack number 2.

     He produces his own MILK at home.
     Stack number 2.

     He produces his own MEAT at home.
     Stack number 2.

 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.

     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.3 mrem/yr.

     Effective dose equivalent:    3.0E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.

********** END OF COMPLIANCE REPORT **********
```

COMPLY Test 2011

COMPLY: V1.6. 2/20/2014 8:04

40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants

REPORT ON COMPLIANCE WITH

THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

FROM THE COMPLY CODE - V1.6.

Prepared by:

Radioactive Waste Processing Facility
Benchmark Study
Oak Ridge, TN

Debra McCroskey
Master's Thesis

Prepared for:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Washington, DC 20460

COMPLY: V1.6.   2/20/2014   8:04

COMPLY Test 2011

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CS-137	D	4.790E-06
I-125	D	6.040E-03
I-131	D	5.910E-05
K-40	D	7.320E-06
NB-95	Y	1.530E-07
SE-75	W	1.730E-05
SB-124	W	5.540E-04
SB-125	W	6.620E-05
H-3	V	1.020E+02
C-14	1	9.540E+00
PU-238	W	5.910E-09
PU-239	W	3.920E-09
PU-240	W	3.920E-09
U-233	Y	1.840E-07
U-234	Y	1.840E-07
U-235	Y	9.630E-09
U-236	Y	9.630E-09
U-238	Y	1.770E-07
PU-241	W	6.260E-08
SR-89	Y	8.330E-08
SR-90	Y	3.280E-07
FE-55	D	2.620E-06
NI-63	V	7.000E-06
TC-99	W	3.110E-05

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	4.130E-07
CS-137	D	8.990E-06
I-131	D	2.380E-07
K-40	D	8.590E-07
RU-103	Y	9.580E-08
H-3	V	7.020E+00
C-14	1	3.820E-02
PU-238	W	4.160E-10
PU-239	W	2.630E-10

PU-240	W	2.630E-10
U-233	Y	3.830E-08
U-234	Y	3.830E-08
U-235	Y	1.750E-09
U-236	Y	1.750E-09
U-238	Y	4.500E-08
PU-241	W	6.090E-08
SR-89	Y	1.280E-07
SR-90	Y	3.770E-08
FE-55	D	1.530E-06
NI-63	V	2.730E-07
TC-99	W	1.340E-09

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.dat

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.DAT

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, MODIFIED FILE: wind2011.dat

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2011 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.023	1.81
NNE	0.040	2.40
NE	0.162	3.23
ENE	0.082	2.37
E	0.037	1.83
ESE	0.021	1.74
SE	0.018	1.44
SSE	0.018	1.72
S	0.024	2.09
SSW	0.058	3.46
SW	0.154	3.92
WSW	0.158	3.45
W	0.136	2.98
WNW	0.043	2.33
NW	0.019	1.80
NNW	0.019	1.79

```
     He produces his own VEGETABLES at home.
     Stack number 1.

     He produces his own MILK at home.
     Stack number 1.

     He produces his own MEAT at home.
     Stack number 1.

     He produces his own VEGETABLES at home.
     Stack number 2.

     He produces his own MILK at home.
     Stack number 2.

     He produces his own MEAT at home.
     Stack number 2.

 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.

     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.2 mrem/yr.

     Effective dose equivalent:    6.0E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.

********** END OF COMPLIANCE REPORT **********
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COMPLY: V1.6.   2/20/2014 7:47

40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants

REPORT ON COMPLIANCE WITH

THE CLEAN AIR ACT LIMITS FOR RADIONUCLIDE EMISSIONS

FROM THE COMPLY CODE - V1.6.

Prepared by:

Radioactive Waste Processing Facility
Benchmark Study
Oak Ridge, TN

Debra McCroskey
Master's Thesis

Prepared for:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Washington, DC 20460

COMPLY Test 2012

SCREENING LEVEL 4

DATA ENTERED:

RELEASE RATES FOR STACK 1.

Nuclide		Release Rate (curies/YEAR)
CO-60	Y	5.560E-05
CS-137	D	3.230E-06
I-125	D	2.850E-03
I-129	D	2.240E-05
I-131	D	1.440E-07
K-40	D	4.310E-05
SE-75	W	7.160E-06
SB-124	W	1.040E-03
SB-125	W	1.020E-04
H-3	V	3.140E+02
C-14	1	9.040E+00
PU-238	W	2.790E-10
PU-239	W	2.150E-09
PU-240	W	2.150E-09
U-233	Y	1.300E-07
U-234	Y	1.300E-07
U-235	Y	7.450E-09
U-236	Y	7.450E-09
U-238	Y	1.200E-05
PU-241	W	1.670E-07
SR-90	Y	3.470E-08
FE-55	D	6.920E-07
NI-63	V	2.240E-06
TC-99	W	6.340E-06

RELEASE RATES FOR STACK 2.

Nuclide		Release Rate (curies/YEAR)
CS-137	D	3.220E-04
I-125	D	1.970E-05
K-40	D	3.320E-05
H-3	V	2.630E+00
C-14	1	3.260E-01
PU-238	W	7.450E-09
PU-239	W	1.760E-08
PU-240	W	1.760E-08
U-233	Y	3.720E-08

U-234	Y	3.720E-08
U-235	Y	8.550E-09
U-236	Y	8.550E-09
U-238	Y	2.650E-08
PU-241	W	8.270E-08
SR-89	Y	6.160E-07
SR-90	Y	1.370E-06
FE-55	D	1.370E-06
NI-63	V	1.450E-06

SITE DATA FOR STACK 1.

Release height 30 meters.

Building height 15 meters.

The source and receptor are not on the same building.

Building width 60 meters.

Building length 20 meters.

STACK DISTANCES, FILE: ST1STACK.dat

DIR	Distance (meters)
N	5800.0
NNE	7200.0
NE	13500.0
ENE	11700.0
E	10800.0
ESE	4600.0
SE	2200.0
SSE	2000.0
S	3300.0
SSW	1900.0
SW	1600.0
WSW	2400.0
W	3200.0
WNW	5700.0
NW	5700.0
NNW	5400.0

SITE DATA FOR STACK 2.

Release height 22 meters.

Building height 16 meters.

The source and receptor are not on the same building.

Building width 46 meters.

Building length 107 meters.

STACK DISTANCES, FILE: ST2STACK.dat

DIR	Distance (meters)
N	6000.0
NNE	7500.0
NE	13800.0
ENE	11800.0
E	11000.0
ESE	4700.0
SE	2100.0
SSE	1900.0
S	3100.0
SSW	1600.0
SW	1400.0
WSW	2100.0
W	3000.0
WNW	5600.0
NW	5800.0
NNW	5500.0

WINDROSE DATA, FILE: wind2012.dat

Source of wind rose data: Y12 WEST METEOROLOGICAL TOWER 60 METERS
Dates of coverage: 2012 (1 YEAR)
Wind rose location: OAK RIDGE, TN
Distance to facility: 0.25

Percent calm: 0.00

Wind FROM	Frequency	Speed (meters/s)
N	0.024	1.80
NNE	0.048	2.14
NE	0.156	3.21
ENE	0.088	2.46
E	0.035	1.86
ESE	0.017	1.58
SE	0.018	1.45
SSE	0.017	1.52
S	0.026	1.82
SSW	0.060	2.84
SW	0.161	3.64
WSW	0.150	3.24
W	0.107	3.00
WNW	0.037	2.18
NW	0.030	1.99
NNW	0.026	1.77

```
     He produces his own VEGETABLES at home.
     Stack number 1.

     He produces his own MILK at home.
     Stack number 1.

     He produces his own MEAT at home.
     Stack number 1.

     He produces his own VEGETABLES at home.
     Stack number 2.

     He produces his own MILK at home.
     Stack number 2.

     He produces his own MEAT at home.
     Stack number 2.

 NOTES:
 ------

     The receptor exposed to the highest concentration is located
          1600. meters from the source in the SW sector.  Stack 1.

     The receptor exposed to the highest concentration is located
          1400. meters from the source in the SW sector.  Stack 2.

     He produces his own VEGETABLES at his home.

     He produces his own MEAT at his home.

     He produces his own MILK at his home.

     Input parameters outside the "normal" range:

         Building (length) is unusually WIDE.
         Windrose wind frequency is unusually LOW.
         Receptor is unusually FAR.
         Stack file distance is unusually FAR.

 RESULTS:
 --------

     Effective dose equivalent:        0.2 mrem/yr.

     Effective dose equivalent:    3.1E-03 mrem/yr due to Iodine.

     *** Comply at level 4.

     This facility is in COMPLIANCE.

     It may or may not be EXEMPT from reporting to the EPA.

     You may contact your regional EPA office for more information.

********** END OF COMPLIANCE REPORT **********
```

Appendix B: CAP88-PC Output Reports

CAP88-PC Test 2004

```
                         C A P 8 8 - P C

                          Version 3.0


              Clean Air Act Assessment Package - 1988


                    S Y N O P S I S   R E P O R T

                  Non-Radon Individual Assessment
                       Mar  5, 2014  09:19 am



    Facility:  Radioactive Waste Processing Facility
     Address:  Benchmark Study
        City:  Oak Ridge
       State:  TN           Zip:    37831


    Source Category:  2 Stacks
        Source Type:  Stack
      Emission Year:  2004


    Comments:  Benchmark Study 2004
               2 Stacks, complete nuclides


               Effective Dose Equivalent
                      (mrem/year)
               _________________________

                       6.63E-02
               _________________________


   At This Location:   1400 Meters Southwest

       Dataset Name:  CAP88 Test 2004
       Dataset Date:  3/5/2014 9:16:00 AM
          Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f
```

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 1000 Meters Southwest
Lifetime Fatal Cancer Risk: 4.96E-08

RADIONUCLIDE EMISSIONS DURING THE YEAR 2004

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	2.3E-06	2.1E-05	2.3E-05
Cr-51	S	1	8.5E-07	0.0E+00	8.5E-07
Cs-134	F	1	2.5E-07	0.0E+00	2.5E-07
Cs-137	F	1	1.4E-05	4.7E-05	6.1E-05
I-125	F	1	2.0E-03	0.0E+00	2.0E-03
I-129	F	1	0.0E+00	0.0E+00	0.0E+00
I-131	F	1	1.1E-06	9.5E-07	2.1E-06
K-40	F	1	3.2E-06	0.0E+00	3.2E-06
Nb-94	S	1	0.0E+00	1.1E-06	1.1E-06
Nb-95	S	1	0.0E+00	1.5E-11	1.5E-11
Ru-103	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-106	S	1	0.0E+00	3.6E-06	3.6E-06
Mn-54	M	1	9.8E-08	0.0E+00	9.8E-08
Se-75	M	1	2.3E-05	0.0E+00	2.3E-05
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	6.6E-05	4.0E-07	6.7E-05
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	2.5E+01	1.8E+00	2.7E+01
C-14	G	0	4.1E+00	4.9E-02	4.1E+00
Pu-238	M	1	1.2E-07	1.3E-08	1.3E-07
Pu-239	M	1	2.2E-07	1.9E-09	2.2E-07
Pu-240	M	1	2.2E-07	1.9E-09	2.2E-07
U-233	S	1	6.2E-07	6.5E-07	1.3E-06
U-234	S	1	6.2E-07	6.5E-07	1.3E-06
U-235	S	1	5.8E-08	6.6E-08	1.2E-07
U-236	S	1	5.8E-08	6.6E-08	1.2E-07
U-238	S	1	5.5E-07	6.3E-07	1.2E-06
Pu-241	M	1	6.9E-07	9.0E-07	1.6E-06
Sr-89	S	1	4.2E-07	2.5E-07	6.7E-07
Sr-90	S	1	4.0E-07	2.0E-07	6.0E-07
Fe-55	F	1	6.6E-06	3.3E-06	9.9E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	2.7E-06	1.4E-06	4.1E-06
Tc-99	M	1	5.8E-06	4.0E-07	6.2E-06
Zn-65	S	1	6.1E-07	0.0E+00	6.1E-07
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	15 degrees C
Precipitation:	171 cm/y
Humidity:	10 g/cu m
Mixing Height:	769 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

C A P 8 8 - P C

Version 3.0

Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 5, 2014 09:19 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2004

Comments: Benchmark Study 2004
2 Stacks, complete nuclides

Dataset Name: CAP88 Test 2004
Dataset Date: 3/5/2014 9:16:00 AM
Wind File: C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	6.57E-02
INHALATION	6.21E-04
AIR IMMERSION	5.01E-08
GROUND SURFACE	2.82E-05
INTERNAL	6.63E-02
EXTERNAL	2.83E-05
TOTAL	6.63E-02

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	9.85E-06
Cr-51	7.25E-10
Cs-134	1.25E-09
Cs-137	7.93E-05
Ba-137m	3.04E-06
I-125	7.36E-03
I-129	0.00E+00
I-131	1.30E-06
Xe-131m	0.00E+00
K-40	1.21E-06
Nb-94	2.23E-07
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	5.61E-07
Rh-106	9.52E-08
Mn-54	1.21E-10
Se-75	5.81E-06
Sb-124	0.00E+00
Sb-125	3.63E-06
Te-125m	2.10E-08
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	6.01E-03

C-14	5.28E-02
Pu-238	4.32E-06
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	7.94E-06
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	7.94E-06
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	9.92E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	9.71E-06
U-235	7.71E-07
U-236	7.95E-07
U-238	7.74E-06
Th-234	5.96E-10
Pa-234m	8.57E-09
Pa-234	0.00E+00
Pu-241	1.15E-06
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	2.91E-08
Sr-90	6.65E-07
Y-90	3.77E-09
Fe-55	1.60E-07
Fe-59	0.00E+00
Ni-63	5.94E-09
Tc-99	3.20E-07
Zn-65	3.10E-07
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	6.63E-02

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	7.08E-10
Stomach	3.03E-09
Colon	6.98E-09
Liver	1.00E-09
LUNG	6.16E-09
Bone	6.12E-11
Skin	6.50E-11
Breast	2.89E-09
Ovary	8.06E-10
Bladder	1.60E-09
Kidneys	3.45E-10
Thyroid	6.41E-10
Leukemia	3.66E-09
Residual	9.83E-09
Total	3.78E-08
TOTAL	7.55E-08

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	3.74E-08
INHALATION	3.45E-10
AIR IMMERSION	1.41E-14
GROUND SURFACE	1.26E-11
INTERNAL	3.78E-08
EXTERNAL	1.26E-11
TOTAL	3.78E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	8.19E-12
Cr-51	6.10E-16
Cs-134	5.74E-16
Cs-137	4.02E-11
Ba-137m	1.64E-12
I-125	4.67E-10
I-129	0.00E+00
I-131	1.20E-13
Xe-131m	0.00E+00
K-40	1.12E-12
Nb-94	1.39E-13
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	6.61E-13
Rh-106	3.48E-14
Mn-54	9.43E-17
Se-75	4.43E-12
Sb-124	0.00E+00
Sb-125	2.42E-12
Te-125m	8.17E-15
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	3.73E-09
C-14	3.35E-08
Pu-238	7.52E-13
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.26E-12
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.26E-12
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Mar 5, 2014 09:19 am SUMMARY

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	7.10E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	6.97E-12
U-235	5.84E-13
U-236	6.03E-13
U-238	5.52E-12
Th-234	3.07E-16
Pa-234m	1.37E-15
Pa-234	0.00E+00
Pu-241	1.00E-13
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	3.25E-14
Sr-90	3.96E-13
Y-90	4.50E-16
Fe-55	1.14E-13
Fe-59	0.00E+00
Ni-63	3.30E-15
Tc-99	3.06E-13
Zn-65	2.19E-13
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	3.78E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	9.4E-03	8.8E-03	8.3E-03	7.9E-03	7.5E-03	7.2E-03	7.0E-03
NNW	6.5E-03	6.2E-03	5.8E-03	5.5E-03	5.3E-03	5.0E-03	4.8E-03
NW	9.1E-03	8.6E-03	8.2E-03	7.9E-03	7.6E-03	7.3E-03	7.0E-03
WNW	9.8E-03	9.3E-03	8.8E-03	8.3E-03	7.9E-03	7.5E-03	7.2E-03
W	1.7E-02	1.6E-02	1.5E-02	1.4E-02	1.3E-02	1.3E-02	1.2E-02
WSW	5.0E-02	4.7E-02	4.4E-02	4.2E-02	4.0E-02	3.8E-02	3.6E-02
SW	6.6E-02	6.3E-02	5.9E-02	5.6E-02	5.4E-02	5.1E-02	4.9E-02
SSW	2.1E-02	2.0E-02	2.0E-02	1.9E-02	1.8E-02	1.8E-02	1.7E-02
S	1.1E-02	1.1E-02	1.1E-02	1.0E-02	1.0E-02	9.7E-03	9.3E-03
SSE	7.5E-03	7.2E-03	6.9E-03	6.7E-03	6.4E-03	6.2E-03	5.9E-03
SE	1.0E-02	9.8E-03	9.5E-03	9.1E-03	8.8E-03	8.5E-03	8.2E-03
ESE	1.7E-02	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02
E	4.4E-02	4.2E-02	4.0E-02	3.9E-02	3.7E-02	3.6E-02	3.5E-02
ENE	5.9E-02	5.6E-02	5.3E-02	5.1E-02	4.9E-02	4.7E-02	4.5E-02
NE	5.5E-02	5.2E-02	4.9E-02	4.6E-02	4.4E-02	4.2E-02	4.0E-02
NNE	1.9E-02	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.4E-02	1.4E-02

Direction	Distance (m) 2100	2200	2300	2400	3000	3100	3200
N	6.7E-03	6.5E-03	6.3E-03	6.1E-03	5.3E-03	5.1E-03	5.0E-03
NNW	4.6E-03	4.4E-03	4.2E-03	4.1E-03	3.5E-03	3.3E-03	3.2E-03
NW	6.7E-03	6.5E-03	6.3E-03	6.1E-03	5.1E-03	4.9E-03	4.8E-03
WNW	6.9E-03	6.6E-03	6.3E-03	6.1E-03	4.9E-03	4.7E-03	4.6E-03
W	1.1E-02	1.1E-02	1.0E-02	9.9E-03	8.0E-03	7.7E-03	7.4E-03
WSW	3.5E-02	3.3E-02	3.2E-02	3.1E-02	2.6E-02	2.5E-02	2.4E-02
SW	4.7E-02	4.5E-02	4.4E-02	4.2E-02	3.5E-02	3.4E-02	3.2E-02
SSW	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.3E-02	1.3E-02	1.2E-02
S	9.0E-03	8.8E-03	8.5E-03	8.2E-03	7.0E-03	6.8E-03	6.6E-03
SSE	5.7E-03	5.6E-03	5.4E-03	5.2E-03	4.5E-03	4.3E-03	4.2E-03
SE	8.0E-03	7.8E-03	7.6E-03	7.4E-03	6.5E-03	6.3E-03	6.1E-03
ESE	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.1E-02	1.0E-02	1.0E-02
E	3.4E-02	3.3E-02	3.2E-02	3.1E-02	2.7E-02	2.6E-02	2.5E-02
ENE	4.4E-02	4.2E-02	4.1E-02	4.0E-02	3.4E-02	3.2E-02	3.1E-02
NE	3.8E-02	3.7E-02	3.5E-02	3.4E-02	2.8E-02	2.7E-02	2.6E-02
NNE	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.0E-02	9.9E-03	9.6E-03

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

Direction	Distance (m) 3300	4700	5800	7500	11700	13800
N	4.9E-03	3.6E-03	3.1E-03	2.5E-03	1.6E-03	1.4E-03
NNW	3.1E-03	2.3E-03	2.0E-03	1.6E-03	1.1E-03	9.1E-04
NW	4.6E-03	3.4E-03	2.7E-03	2.2E-03	1.4E-03	1.2E-03
WNW	4.4E-03	3.1E-03	2.5E-03	2.0E-03	1.3E-03	1.1E-03
W	7.2E-03	5.1E-03	4.2E-03	3.4E-03	2.2E-03	1.9E-03
WSW	2.4E-02	1.7E-02	1.3E-02	1.0E-02	6.4E-03	5.3E-03
SW	3.1E-02	2.2E-02	1.7E-02	1.3E-02	7.8E-03	6.5E-03
SSW	1.2E-02	8.5E-03	6.9E-03	5.3E-03	3.3E-03	2.7E-03
S	6.4E-03	4.6E-03	3.8E-03	3.0E-03	1.9E-03	1.6E-03
SSE	4.1E-03	3.0E-03	2.5E-03	2.0E-03	1.3E-03	1.1E-03
SE	6.0E-03	4.5E-03	3.7E-03	3.0E-03	1.9E-03	1.6E-03
ESE	9.7E-03	7.1E-03	5.8E-03	4.5E-03	2.8E-03	2.4E-03
E	2.5E-02	1.8E-02	1.4E-02	1.1E-02	6.7E-03	5.5E-03
ENE	3.0E-02	2.1E-02	1.7E-02	1.3E-02	7.8E-03	6.5E-03
NE	2.5E-02	1.7E-02	1.4E-02	1.0E-02	6.3E-03	5.2E-03
NNE	9.3E-03	6.7E-03	5.5E-03	4.3E-03	2.7E-03	2.3E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

Direction	Distance (m) 1400	1500	1600	1700	1800	1900	2000
N	5.3E-09	5.0E-09	4.7E-09	4.5E-09	4.3E-09	4.1E-09	4.0E-09
NNW	3.7E-09	3.5E-09	3.3E-09	3.2E-09	3.0E-09	2.9E-09	2.7E-09
NW	5.2E-09	4.9E-09	4.7E-09	4.5E-09	4.3E-09	4.2E-09	4.0E-09
WNW	5.6E-09	5.3E-09	5.0E-09	4.8E-09	4.5E-09	4.3E-09	4.1E-09
W	9.6E-09	9.0E-09	8.5E-09	8.0E-09	7.6E-09	7.2E-09	6.8E-09
WSW	2.8E-08	2.7E-08	2.5E-08	2.4E-08	2.3E-08	2.2E-08	2.1E-08
SW	3.8E-08	3.6E-08	3.4E-08	3.2E-08	3.1E-08	2.9E-08	2.8E-08
SSW	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	1.0E-08	9.8E-09
S	6.5E-09	6.3E-09	6.1E-09	5.9E-09	5.7E-09	5.5E-09	5.4E-09
SSE	4.3E-09	4.1E-09	3.9E-09	3.8E-09	3.7E-09	3.5E-09	3.4E-09
SE	5.8E-09	5.6E-09	5.4E-09	5.2E-09	5.0E-09	4.9E-09	4.7E-09
ESE	9.5E-09	9.1E-09	8.8E-09	8.5E-09	8.2E-09	7.9E-09	7.7E-09
E	2.5E-08	2.4E-08	2.3E-08	2.2E-08	2.1E-08	2.1E-08	2.0E-08
ENE	3.3E-08	3.2E-08	3.0E-08	2.9E-08	2.8E-08	2.7E-08	2.6E-08
NE	3.1E-08	2.9E-08	2.8E-08	2.6E-08	2.5E-08	2.4E-08	2.3E-08
NNE	1.1E-08	9.9E-09	9.4E-09	8.9E-09	8.5E-09	8.1E-09	7.8E-09

Direction	Distance (m) 2100	2200	2300	2400	3000	3100	3200
N	3.8E-09	3.7E-09	3.6E-09	3.5E-09	3.1E-09	3.0E-09	2.9E-09
NNW	2.6E-09	2.5E-09	2.4E-09	2.4E-09	2.0E-09	1.9E-09	1.9E-09
NW	3.9E-09	3.7E-09	3.6E-09	3.5E-09	3.0E-09	2.9E-09	2.8E-09
WNW	4.0E-09	3.8E-09	3.6E-09	3.5E-09	2.9E-09	2.8E-09	2.7E-09
W	6.5E-09	6.2E-09	5.9E-09	5.7E-09	4.6E-09	4.5E-09	4.3E-09
WSW	2.0E-08	1.9E-08	1.9E-08	1.8E-08	1.5E-08	1.5E-08	1.4E-08
SW	2.7E-08	2.6E-08	2.5E-08	2.4E-08	2.0E-08	1.9E-08	1.9E-08
SSW	9.6E-09	9.3E-09	9.0E-09	8.8E-09	7.6E-09	7.3E-09	7.1E-09
S	5.2E-09	5.0E-09	4.9E-09	4.8E-09	4.1E-09	4.0E-09	3.9E-09
SSE	3.3E-09	3.2E-09	3.1E-09	3.0E-09	2.6E-09	2.5E-09	2.5E-09
SE	4.6E-09	4.5E-09	4.3E-09	4.2E-09	3.8E-09	3.6E-09	3.6E-09
ESE	7.5E-09	7.3E-09	7.1E-09	7.0E-09	6.1E-09	5.9E-09	5.8E-09
E	2.0E-08	1.9E-08	1.9E-08	1.8E-08	1.6E-08	1.5E-08	1.5E-08
ENE	2.5E-08	2.4E-08	2.4E-08	2.3E-08	1.9E-08	1.9E-08	1.8E-08
NE	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.6E-08	1.6E-08	1.5E-08
NNE	7.5E-09	7.3E-09	7.1E-09	6.9E-09	5.9E-09	5.7E-09	5.6E-09

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	2.8E-09	2.2E-09	1.8E-09	1.5E-09	1.0E-09	8.6E-10
NNW	1.8E-09	1.4E-09	1.2E-09	9.8E-10	6.7E-10	5.7E-10
NW	2.7E-09	2.0E-09	1.7E-09	1.3E-09	8.6E-10	7.3E-10
WNW	2.6E-09	1.9E-09	1.5E-09	1.2E-09	8.1E-10	6.8E-10
W	4.2E-09	3.0E-09	2.5E-09	2.0E-09	1.4E-09	1.2E-09
WSW	1.4E-08	9.8E-09	8.0E-09	6.2E-09	3.9E-09	3.3E-09
SW	1.8E-08	1.3E-08	1.0E-08	7.9E-09	4.8E-09	4.0E-09
SSW	6.9E-09	5.0E-09	4.1E-09	3.2E-09	2.0E-09	1.7E-09
S	3.8E-09	2.8E-09	2.3E-09	1.8E-09	1.2E-09	9.9E-10
SSE	2.4E-09	1.8E-09	1.5E-09	1.2E-09	8.2E-10	6.9E-10
SE	3.5E-09	2.6E-09	2.2E-09	1.8E-09	1.2E-09	1.0E-09
ESE	5.6E-09	4.2E-09	3.5E-09	2.7E-09	1.7E-09	1.5E-09
E	1.4E-08	1.0E-08	8.5E-09	6.6E-09	4.1E-09	3.4E-09
ENE	1.8E-08	1.3E-08	1.0E-08	7.8E-09	4.8E-09	4.0E-09
NE	1.5E-08	1.0E-08	8.1E-09	6.2E-09	3.8E-09	3.2E-09
NNE	5.4E-09	4.0E-09	3.3E-09	2.6E-09	1.7E-09	1.4E-09

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              Clean Air Act Assessment Package - 1988


                   S Y N O P S I S   R E P O R T

                  Non-Radon Individual Assessment
                       Mar  12, 2014  06:40 am


  Facility:  Radioactive Waste Processing Facility
   Address:  Benchmark Study
      City:  Oak Ridge
     State:  TN           Zip:    37831


  Source Category:  2 Stacks
      Source Type:  Stack
    Emission Year:  2005


  Comments:  Benchmark Study 2005
             2 Stacks, complete nuclides


              Effective Dose Equivalent
                     (mrem/year)
              _________________________

                      1.83E-01
              _________________________


 At This Location:   1400 Meters Southwest

     Dataset Name:  CAP88 Test2005
     Dataset Date:  3/12/2014 6:39:00 AM
        Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


             MAXIMALLY EXPOSED INDIVIDUAL


 Location Of The Individual:   1400 Meters Southwest
 Lifetime Fatal Cancer Risk:          8.81E-08
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2005

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	5.0E-06	0.0E+00	5.0E-06
Co-57	S	1	7.7E-06	1.7E-05	2.5E-05
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	1.6E-06	2.4E-07	1.9E-06
Cr-51	S	1	0.0E+00	5.4E-05	5.4E-05
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	5.6E-06	3.0E-06	8.6E-06
I-125	F	1	1.3E-02	0.0E+00	1.3E-02
I-129	F	1	0.0E+00	0.0E+00	0.0E+00
I-131	F	1	8.1E-06	1.2E-07	8.3E-06
K-40	F	1	4.4E-06	1.8E-05	2.2E-05
Nb-94	S	1	0.0E+00	3.1E-07	3.1E-07
Nb-95	S	1	0.0E+00	2.9E-06	2.9E-06
Ru-103	S	1	1.9E-07	1.2E-06	1.4E-06
Ru-106	S	1	5.0E-05	0.0E+00	5.0E-05
Mn-54	M	1	2.4E-07	0.0E+00	2.4E-07
Se-75	M	1	2.3E-04	0.0E+00	2.3E-04
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	8.0E-05	0.0E+00	8.0E-05
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	4.2E+01	4.8E-01	4.2E+01
C-14	G	0	9.8E+00	2.3E-02	9.8E+00
Pu-238	M	1	3.8E-08	8.6E-09	4.7E-08
Pu-239	M	1	7.8E-08	2.5E-08	1.0E-07
Pu-240	M	1	7.8E-08	2.5E-08	1.0E-07
U-233	S	1	2.0E-07	3.6E-07	5.6E-07
U-234	S	1	2.0E-07	3.6E-07	5.6E-07
U-235	S	1	1.6E-08	3.5E-08	5.1E-08
U-236	S	1	1.6E-08	3.5E-08	5.1E-08
U-238	S	1	1.7E-07	3.3E-07	5.0E-07
Pu-241	M	1	0.0E+00	1.9E-07	1.9E-07
Sr-89	S	1	6.6E-09	2.3E-08	3.0E-08
Sr-90	S	1	2.5E-08	0.0E+00	2.5E-08
Fe-55	F	1	2.8E-06	1.3E-06	4.1E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	1.0E-06	9.6E-07	2.0E-06
Tc-99	M	1	4.6E-06	3.3E-06	7.9E-06
Zn-65	S	1	2.6E-07	0.0E+00	2.6E-07
Zr-95	F	1	0.0E+00	7.4E-05	7.4E-05

SITE INFORMATION

Temperature:	15 degrees C
Precipitation:	126 cm/y
Humidity:	10 g/cu m
Mixing Height:	663 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 06:40 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2005

Comments: Benchmark Study 2005
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2005
Dataset Date: 3/12/2014 6:39:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.82E-01
INHALATION	9.62E-04
AIR IMMERSION	1.13E-07
GROUND SURFACE	1.26E-04
INTERNAL	1.83E-01
EXTERNAL	1.26E-04
TOTAL	1.83E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	4.77E-07
Pr-144m	3.09E-14
Pr-144	1.68E-13
Co-57	3.83E-07
Co-58	0.00E+00
Co-60	6.30E-07
Cr-51	5.05E-08
Cs-134	0.00E+00
Cs-137	9.40E-06
Ba-137m	3.60E-07
I-125	4.92E-02
I-129	0.00E+00
I-131	5.11E-06
Xe-131m	0.00E+00
K-40	7.16E-06
Nb-94	1.15E-08
Nb-95	5.71E-08
Ru-103	2.06E-08
Rh-103m	1.92E-11
Ru-106	6.81E-06
Rh-106	1.10E-06
Mn-54	2.93E-10
Se-75	4.91E-05
Sb-124	0.00E+00
Sb-125	3.73E-06
Te-125m	2.15E-08
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	9.33E-03
C-14	1.25E-01
Pu-238	1.57E-06
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	3.73E-06
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	3.73E-06
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	3.97E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	3.89E-06
U-235	3.19E-07
U-236	3.29E-07
U-238	2.94E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	1.31E-07
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.74E-10
Sr-90	2.80E-09
Y-90	0.00E+00
Fe-55	5.59E-08
Fe-59	0.00E+00
Ni-63	2.84E-09
Tc-99	3.53E-07
Zn-65	4.01E-10
Zr-95	2.45E-06
Nb-95m	3.21E-10
Nb-95	0.00E+00
TOTAL	1.83E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	1.62E-09
Stomach	6.88E-09
Colon	1.59E-08
Liver	2.28E-09
LUNG	1.40E-08
Bone	1.39E-10
Skin	1.49E-10
Breast	6.60E-09
Ovary	1.84E-09
Bladder	3.66E-09
Kidneys	7.88E-10
Thyroid	3.40E-09
Leukemia	8.35E-09
Residual	2.25E-08
Total	8.81E-08
TOTAL	1.76E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	8.75E-08
INHALATION	5.22E-10
AIR IMMERSION	2.87E-14
GROUND SURFACE	5.00E-11
INTERNAL	8.80E-08
EXTERNAL	5.00E-11
TOTAL	8.81E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	5.79E-13
Pr-144m	1.41E-20
Pr-144	7.64E-20
Co-57	3.36E-13
Co-58	0.00E+00
Co-60	5.35E-13
Cr-51	3.93E-14
Cs-134	0.00E+00
Cs-137	4.77E-12
Ba-137m	1.94E-13
I-125	3.12E-09
I-129	0.00E+00
I-131	4.92E-13
Xe-131m	0.00E+00
K-40	6.66E-12
Nb-94	7.53E-15
Nb-95	3.69E-14
Ru-103	1.71E-14
Rh-103m	6.28E-18
Ru-106	7.91E-12
Rh-106	4.02E-13
Mn-54	2.29E-16
Se-75	3.74E-11
Sb-124	0.00E+00
Sb-125	2.50E-12
Te-125m	8.34E-15
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	5.79E-09
C-14	7.91E-08
Pu-238	2.73E-13
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	5.91E-13
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	5.92E-13
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	3.01E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	2.95E-12
U-235	2.42E-13
U-236	2.50E-13
U-238	2.22E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	1.12E-14
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.58E-16
Sr-90	1.92E-15
Y-90	0.00E+00
Fe-55	3.97E-14
Fe-59	0.00E+00
Ni-63	1.58E-15
Tc-99	3.37E-13
Zn-65	3.26E-16
Zr-95	1.65E-12
Nb-95m	1.72E-16
Nb-95	0.00E+00
TOTAL	8.81E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	2.6E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02
NNW	1.8E-02	1.7E-02	1.6E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02
NW	2.5E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02
WNW	2.7E-02	2.6E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02	2.0E-02
W	4.7E-02	4.4E-02	4.1E-02	3.8E-02	3.6E-02	3.4E-02	3.2E-02
WSW	1.4E-01	1.3E-01	1.2E-01	1.1E-01	1.1E-01	1.0E-01	9.9E-02
SW	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01	1.4E-01	1.3E-01
SSW	5.8E-02	5.6E-02	5.4E-02	5.2E-02	5.0E-02	4.8E-02	4.7E-02
S	3.2E-02	3.1E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02	2.5E-02
SSE	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.8E-02	1.7E-02	1.6E-02
SE	2.8E-02	2.7E-02	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
ESE	4.6E-02	4.4E-02	4.3E-02	4.1E-02	3.9E-02	3.8E-02	3.7E-02
E	1.2E-01	1.2E-01	1.1E-01	1.1E-01	1.0E-01	1.0E-01	9.7E-02
ENE	1.6E-01	1.5E-01	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01
NE	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01	1.1E-01	1.1E-01
NNE	5.1E-02	4.8E-02	4.5E-02	4.3E-02	4.1E-02	3.9E-02	3.7E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	1.8E-02	1.8E-02	1.7E-02	1.7E-02	1.4E-02	1.4E-02	1.3E-02
NNW	1.2E-02	1.2E-02	1.1E-02	1.1E-02	9.2E-03	8.9E-03	8.6E-03
NW	1.8E-02	1.8E-02	1.7E-02	1.6E-02	1.4E-02	1.3E-02	1.3E-02
WNW	1.9E-02	1.8E-02	1.7E-02	1.6E-02	1.3E-02	1.3E-02	1.2E-02
W	3.1E-02	2.9E-02	2.8E-02	2.7E-02	2.1E-02	2.0E-02	2.0E-02
WSW	9.4E-02	9.1E-02	8.7E-02	8.4E-02	7.0E-02	6.7E-02	6.5E-02
SW	1.3E-01	1.2E-01	1.2E-01	1.1E-01	9.4E-02	9.0E-02	8.7E-02
SSW	4.5E-02	4.4E-02	4.2E-02	4.1E-02	3.5E-02	3.3E-02	3.2E-02
S	2.5E-02	2.4E-02	2.3E-02	2.2E-02	1.9E-02	1.8E-02	1.8E-02
SSE	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.2E-02	1.2E-02	1.1E-02
SE	2.2E-02	2.1E-02	2.1E-02	2.0E-02	1.7E-02	1.7E-02	1.6E-02
ESE	3.6E-02	3.5E-02	3.4E-02	3.3E-02	2.9E-02	2.8E-02	2.7E-02
E	9.4E-02	9.1E-02	8.8E-02	8.6E-02	7.3E-02	7.1E-02	6.8E-02
ENE	1.2E-01	1.2E-01	1.1E-01	1.1E-01	9.1E-02	8.7E-02	8.4E-02
NE	1.0E-01	1.0E-01	9.7E-02	9.3E-02	7.6E-02	7.3E-02	7.0E-02
NNE	3.6E-02	3.5E-02	3.3E-02	3.2E-02	2.8E-02	2.7E-02	2.6E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.3E-02	9.5E-03	8.0E-03	6.3E-03	4.0E-03	3.3E-03
NNW	8.4E-03	6.1E-03	5.1E-03	4.1E-03	2.6E-03	2.2E-03
NW	1.2E-02	8.7E-03	7.1E-03	5.5E-03	3.4E-03	2.8E-03
WNW	1.2E-02	8.1E-03	6.6E-03	5.1E-03	3.2E-03	2.6E-03
W	1.9E-02	1.3E-02	1.1E-02	8.7E-03	5.5E-03	4.6E-03
WSW	6.3E-02	4.4E-02	3.5E-02	2.6E-02	1.5E-02	1.3E-02
SW	8.5E-02	5.7E-02	4.5E-02	3.3E-02	1.9E-02	1.6E-02
SSW	3.2E-02	2.2E-02	1.8E-02	1.3E-02	7.8E-03	6.4E-03
S	1.7E-02	1.2E-02	9.7E-03	7.4E-03	4.5E-03	3.8E-03
SSE	1.1E-02	7.9E-03	6.5E-03	5.1E-03	3.2E-03	2.6E-03
SE	1.6E-02	1.2E-02	9.6E-03	7.4E-03	4.6E-03	3.8E-03
ESE	2.6E-02	1.9E-02	1.5E-02	1.1E-02	6.8E-03	5.6E-03
E	6.6E-02	4.6E-02	3.7E-02	2.7E-02	1.6E-02	1.3E-02
ENE	8.2E-02	5.6E-02	4.4E-02	3.3E-02	1.9E-02	1.6E-02
NE	6.8E-02	4.6E-02	3.6E-02	2.7E-02	1.5E-02	1.3E-02
NNE	2.5E-02	1.8E-02	1.4E-02	1.1E-02	6.6E-03	5.5E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.7E-09	9.3E-09
NNW	8.7E-09	8.2E-09	7.7E-09	7.4E-09	7.0E-09	6.7E-09	6.4E-09
NW	1.2E-08	1.1E-08	1.1E-08	1.1E-08	1.0E-08	9.7E-09	9.4E-09
WNW	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.6E-09
W	2.2E-08	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.7E-08	1.6E-08
WSW	6.6E-08	6.2E-08	5.9E-08	5.6E-08	5.3E-08	5.0E-08	4.8E-08
SW	8.8E-08	8.3E-08	7.9E-08	7.5E-08	7.1E-08	6.8E-08	6.5E-08
SSW	2.8E-08	2.7E-08	2.6E-08	2.5E-08	2.4E-08	2.4E-08	2.3E-08
S	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.3E-08
SSE	1.0E-08	9.6E-09	9.2E-09	8.9E-09	8.5E-09	8.2E-09	7.9E-09
SE	1.4E-08	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08
ESE	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.9E-08	1.8E-08	1.8E-08
E	5.8E-08	5.6E-08	5.4E-08	5.2E-08	5.0E-08	4.8E-08	4.7E-08
ENE	7.8E-08	7.4E-08	7.1E-08	6.8E-08	6.5E-08	6.3E-08	6.1E-08
NE	7.3E-08	6.8E-08	6.5E-08	6.1E-08	5.8E-08	5.5E-08	5.3E-08
NNE	2.5E-08	2.3E-08	2.2E-08	2.1E-08	2.0E-08	1.9E-08	1.8E-08

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	9.0E-09	8.7E-09	8.4E-09	8.2E-09	7.2E-09	7.0E-09	6.8E-09
NNW	6.1E-09	5.9E-09	5.7E-09	5.5E-09	4.7E-09	4.5E-09	4.4E-09
NW	9.0E-09	8.7E-09	8.4E-09	8.2E-09	6.9E-09	6.7E-09	6.5E-09
WNW	9.2E-09	8.8E-09	8.5E-09	8.2E-09	6.7E-09	6.4E-09	6.2E-09
W	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.1E-08	1.0E-08	1.0E-08
WSW	4.6E-08	4.5E-08	4.3E-08	4.2E-08	3.5E-08	3.4E-08	3.3E-08
SW	6.3E-08	6.1E-08	5.8E-08	5.6E-08	4.7E-08	4.5E-08	4.4E-08
SSW	2.2E-08	2.2E-08	2.1E-08	2.0E-08	1.8E-08	1.7E-08	1.7E-08
S	1.2E-08	1.2E-08	1.1E-08	1.1E-08	9.5E-09	9.2E-09	9.0E-09
SSE	7.7E-09	7.4E-09	7.2E-09	7.0E-09	6.1E-09	5.9E-09	5.7E-09
SE	1.1E-08	1.0E-08	1.0E-08	9.9E-09	8.8E-09	8.5E-09	8.3E-09
ESE	1.7E-08	1.7E-08	1.7E-08	1.6E-08	1.4E-08	1.4E-08	1.3E-08
E	4.6E-08	4.4E-08	4.3E-08	4.2E-08	3.6E-08	3.5E-08	3.4E-08
ENE	5.9E-08	5.7E-08	5.5E-08	5.3E-08	4.5E-08	4.3E-08	4.2E-08
NE	5.1E-08	4.9E-08	4.7E-08	4.6E-08	3.8E-08	3.6E-08	3.5E-08
NNE	1.8E-08	1.7E-08	1.6E-08	1.6E-08	1.4E-08	1.3E-08	1.3E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	6.6E-09	5.0E-09	4.3E-09	3.5E-09	2.4E-09	2.0E-09
NNW	4.3E-09	3.2E-09	2.8E-09	2.3E-09	1.6E-09	1.3E-09
NW	6.4E-09	4.7E-09	3.9E-09	3.1E-09	2.0E-09	1.7E-09
WNW	6.1E-09	4.3E-09	3.6E-09	2.9E-09	1.9E-09	1.6E-09
W	9.8E-09	7.0E-09	5.9E-09	4.8E-09	3.2E-09	2.7E-09
WSW	3.2E-08	2.3E-08	1.9E-08	1.5E-08	9.1E-09	7.6E-09
SW	4.2E-08	3.0E-08	2.4E-08	1.8E-08	1.1E-08	9.2E-09
SSW	1.6E-08	1.2E-08	9.6E-09	7.4E-09	4.7E-09	3.9E-09
S	8.7E-09	6.4E-09	5.3E-09	4.2E-09	2.7E-09	2.3E-09
SSE	5.6E-09	4.2E-09	3.5E-09	2.8E-09	1.9E-09	1.6E-09
SE	8.1E-09	6.1E-09	5.2E-09	4.2E-09	2.7E-09	2.3E-09
ESE	1.3E-08	9.7E-09	8.0E-09	6.3E-09	4.0E-09	3.4E-09
E	3.3E-08	2.4E-08	2.0E-08	1.5E-08	9.4E-09	7.9E-09
ENE	4.1E-08	2.9E-08	2.4E-08	1.8E-08	1.1E-08	9.3E-09
NE	3.4E-08	2.4E-08	1.9E-08	1.4E-08	8.9E-09	7.4E-09
NNE	1.3E-08	9.2E-09	7.7E-09	6.1E-09	3.9E-09	3.3E-09

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             Clean Air Act Assessment Package - 1988


                    S Y N O P S I S   R E P O R T

                 Non-Radon Individual Assessment
                      Mar  12, 2014  06:50 am


 Facility:  Radioactive Waste Processing Facility
  Address:  Benchmark Study
     City:  Oak Ridge
    State:  TN          Zip:    37831


 Source Category:  2 Stacks
     Source Type:  Stack
   Emission Year:  2006


 Comments:  Benchmark Study 2006
            2 Stacks, complete nuclides


                Effective Dose Equivalent
                       (mrem/year)
                -------------------------

                         1.81E-01
                -------------------------


At This Location:   1400 Meters Southwest

    Dataset Name:  CAP88 Test2006
    Dataset Date:  3/12/2014 6:49:00 AM
       Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


              MAXIMALLY EXPOSED INDIVIDUAL


Location Of The Individual:   1400 Meters Southwest
Lifetime Fatal Cancer Risk:          8.53E-08
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2006

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	3.0E-07	0.0E+00	3.0E-07
Ce-144	S	1	1.3E-05	0.0E+00	1.3E-05
Co-57	S	1	8.3E-06	0.0E+00	8.3E-06
Co-58	S	1	2.6E-07	3.0E-07	5.6E-07
Co-60	S	1	1.7E-06	2.7E-06	4.4E-06
Cr-51	S	1	0.0E+00	9.6E-07	9.6E-07
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	2.2E-05	8.0E-06	3.0E-05
I-125	F	1	1.4E-02	0.0E+00	1.4E-02
I-129	F	1	2.0E-06	0.0E+00	2.0E-06
I-131	F	1	8.0E-06	3.3E-07	8.4E-06
K-40	F	1	6.0E-05	0.0E+00	6.0E-05
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-106	S	1	0.0E+00	0.0E+00	0.0E+00
Mn-54	M	1	4.3E-07	1.0E-07	5.3E-07
Se-75	M	1	5.0E-04	0.0E+00	5.0E-04
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	1.6E-04	0.0E+00	1.6E-04
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	1.0E+02	2.7E-01	1.0E+02
C-14	G	0	8.4E+00	2.4E-02	8.4E+00
Pu-238	M	1	1.5E-08	2.3E-09	1.7E-08
Pu-239	M	1	2.6E-08	5.2E-09	3.1E-08
Pu-240	M	1	2.6E-08	5.2E-09	3.1E-08
U-233	S	1	2.2E-07	2.4E-07	4.6E-07
U-234	S	1	2.2E-07	2.4E-07	4.6E-07
U-235	S	1	1.1E-08	1.1E-08	2.2E-08
U-236	S	1	1.1E-08	1.1E-08	2.2E-08
U-238	S	1	2.1E-07	2.1E-07	4.2E-07
Pu-241	M	1	1.0E-07	3.3E-08	1.4E-07
Sr-89	S	1	1.5E-08	6.7E-09	2.2E-08
Sr-90	S	1	3.0E-08	6.7E-09	3.7E-08
Fe-55	F	1	8.0E-05	3.2E-05	1.1E-04
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	2.7E-06	1.1E-06	3.8E-06
Tc-99	M	1	6.7E-06	3.0E-07	7.0E-06
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature: 15 degrees C
Precipitation: 129 cm/y
Humidity: 10 g/cu m
Mixing Height: 565 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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                           Version 3.0

              Clean Air Act Assessment Package - 1988


    D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

                  Non-Radon Individual Assessment
                      Mar  12, 2014  06:50 am


      Facility:  Radioactive Waste Processing Facility
       Address:  Benchmark Study
          City:  Oak Ridge
         State:  TN           Zip:    37831


      Source Category:  2 Stacks
          Source Type:  Stack
        Emission Year:  2006


      Comments:  Benchmark Study 2006
                 2 Stacks, complete nuclides


         Dataset Name:  CAP88 Test2006
         Dataset Date:  3/12/2014 6:49:00 AM
            Wind File:  .   C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-
PC30\WindLib\ST04W60.WND
```

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.79E-01
INHALATION	2.17E-03
AIR IMMERSION	1.13E-07
GROUND SURFACE	1.35E-04
INTERNAL	1.81E-01
EXTERNAL	1.36E-04
TOTAL	1.81E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	2.74E-09
Ag-110	2.74E-14
Ce-144	1.25E-06
Pr-144m	8.04E-14
Pr-144	4.36E-13
Co-57	1.29E-07
Co-58	9.36E-10
Co-60	1.58E-06
Cr-51	7.38E-10
Cs-134	0.00E+00
Cs-137	3.36E-05
Ba-137m	1.29E-06
I-125	5.07E-02
I-129	1.19E-04
I-131	5.18E-06
Xe-131m	0.00E+00
K-40	1.95E-05
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	1.65E-08
Se-75	1.08E-04
Sb-124	0.00E+00
Sb-125	7.54E-06
Te-125m	4.35E-08
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	2.28E-02
C-14	1.07E-01
Pu-238	5.73E-07
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.12E-06
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.12E-06
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	3.26E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	3.20E-06
U-235	1.37E-07
U-236	1.42E-07
U-238	2.48E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	8.97E-08
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.26E-10
Sr-90	4.19E-09
Y-90	0.00E+00
Fe-55	1.55E-06
Fe-59	0.00E+00
Ni-63	5.48E-09
Tc-99	3.16E-07
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.81E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	1.56E-09
Stomach	6.79E-09
Colon	1.55E-08
Liver	2.20E-09
LUNG	1.35E-08
Bone	1.34E-10
Skin	1.43E-10
Breast	6.35E-09
Ovary	1.77E-09
Bladder	3.52E-09
Kidneys	7.60E-10
Thyroid	3.48E-09
Leukemia	8.05E-09
Residual	2.16E-08
Total	8.53E-08
TOTAL	1.71E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	8.41E-08
INHALATION	1.21E-09
AIR IMMERSION	3.33E-14
GROUND SURFACE	5.47E-11
INTERNAL	8.53E-08
EXTERNAL	5.48E-11
TOTAL	8.53E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	2.26E-15
Ag-110	1.09E-20
Ce-144	1.52E-12
Pr-144m	3.67E-20
Pr-144	1.99E-19
Co-57	1.13E-13
Co-58	7.79E-16
Co-60	1.31E-12
Cr-51	6.13E-16
Cs-134	0.00E+00
Cs-137	1.70E-11
Ba-137m	6.95E-13
I-125	3.22E-09
I-129	5.99E-12
I-131	4.98E-13
Xe-131m	0.00E+00
K-40	1.81E-11
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	1.03E-14
Se-75	8.22E-11
Sb-124	0.00E+00
Sb-125	5.04E-12
Te-125m	1.69E-14
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	1.42E-08
C-14	6.78E-08
Pu-238	9.97E-14
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.77E-13
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.78E-13
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	2.47E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	2.43E-12
U-235	1.04E-13
U-236	1.07E-13
U-238	1.87E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	7.64E-15
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.15E-16
Sr-90	2.89E-15
Y-90	0.00E+00
Fe-55	1.10E-12
Fe-59	0.00E+00
Ni-63	3.05E-15
Tc-99	3.02E-13
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	8.53E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	2.6E-02	2.4E-02	2.3E-02	2.1E-02	2.0E-02	2.0E-02	1.9E-02
NNW	1.8E-02	1.7E-02	1.6E-02	1.5E-02	1.4E-02	1.3E-02	1.3E-02
NW	2.5E-02	2.3E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.9E-02
WNW	2.7E-02	2.5E-02	2.4E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02
W	4.6E-02	4.3E-02	4.0E-02	3.8E-02	3.6E-02	3.4E-02	3.2E-02
WSW	1.4E-01	1.3E-01	1.2E-01	1.1E-01	1.1E-01	1.0E-01	9.7E-02
SW	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01
SSW	5.7E-02	5.5E-02	5.3E-02	5.1E-02	4.9E-02	4.8E-02	4.6E-02
S	3.1E-02	3.0E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02	2.5E-02
SSE	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.7E-02	1.6E-02
SE	2.8E-02	2.7E-02	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
ESE	4.6E-02	4.4E-02	4.2E-02	4.0E-02	3.9E-02	3.8E-02	3.6E-02
E	1.2E-01	1.1E-01	1.1E-01	1.1E-01	1.0E-01	9.8E-02	9.5E-02
ENE	1.6E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01
NE	1.5E-01	1.4E-01	1.3E-01	1.2E-01	1.2E-01	1.1E-01	1.1E-01
NNE	5.0E-02	4.7E-02	4.4E-02	4.2E-02	4.0E-02	3.8E-02	3.7E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	1.8E-02	1.7E-02	1.7E-02	1.6E-02	1.4E-02	1.4E-02	1.3E-02
NNW	1.2E-02	1.2E-02	1.1E-02	1.1E-02	9.1E-03	8.8E-03	8.5E-03
NW	1.8E-02	1.7E-02	1.7E-02	1.6E-02	1.3E-02	1.3E-02	1.3E-02
WNW	1.8E-02	1.7E-02	1.7E-02	1.6E-02	1.3E-02	1.2E-02	1.2E-02
W	3.0E-02	2.9E-02	2.7E-02	2.6E-02	2.1E-02	2.0E-02	2.0E-02
WSW	9.3E-02	8.9E-02	8.6E-02	8.3E-02	6.9E-02	6.6E-02	6.4E-02
SW	1.3E-01	1.2E-01	1.2E-01	1.1E-01	9.3E-02	8.9E-02	8.6E-02
SSW	4.4E-02	4.3E-02	4.2E-02	4.0E-02	3.4E-02	3.3E-02	3.2E-02
S	2.4E-02	2.3E-02	2.3E-02	2.2E-02	1.8E-02	1.8E-02	1.7E-02
SSE	1.5E-02	1.5E-02	1.4E-02	1.4E-02	1.2E-02	1.1E-02	1.1E-02
SE	2.1E-02	2.1E-02	2.0E-02	2.0E-02	1.7E-02	1.7E-02	1.6E-02
ESE	3.5E-02	3.4E-02	3.3E-02	3.3E-02	2.8E-02	2.7E-02	2.6E-02
E	9.2E-02	9.0E-02	8.7E-02	8.5E-02	7.2E-02	6.9E-02	6.7E-02
ENE	1.2E-01	1.1E-01	1.1E-01	1.1E-01	8.9E-02	8.6E-02	8.3E-02
NE	1.0E-01	9.9E-02	9.5E-02	9.2E-02	7.5E-02	7.2E-02	7.0E-02
NNE	3.5E-02	3.4E-02	3.3E-02	3.2E-02	2.7E-02	2.6E-02	2.5E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.3E-02	9.6E-03	8.0E-03	6.3E-03	3.9E-03	3.3E-03
NNW	8.3E-03	6.1E-03	5.1E-03	4.1E-03	2.6E-03	2.2E-03
NW	1.2E-02	8.7E-03	7.1E-03	5.4E-03	3.3E-03	2.8E-03
WNW	1.2E-02	8.2E-03	6.6E-03	5.1E-03	3.2E-03	2.6E-03
W	1.9E-02	1.3E-02	1.1E-02	8.6E-03	5.5E-03	4.5E-03
WSW	6.2E-02	4.3E-02	3.5E-02	2.6E-02	1.5E-02	1.3E-02
SW	8.3E-02	5.7E-02	4.4E-02	3.3E-02	1.9E-02	1.5E-02
SSW	3.1E-02	2.2E-02	1.7E-02	1.3E-02	7.6E-03	6.3E-03
S	1.7E-02	1.2E-02	9.6E-03	7.3E-03	4.4E-03	3.7E-03
SSE	1.1E-02	7.8E-03	6.4E-03	5.0E-03	3.1E-03	2.6E-03
SE	1.6E-02	1.2E-02	9.5E-03	7.3E-03	4.5E-03	3.7E-03
ESE	2.6E-02	1.8E-02	1.5E-02	1.1E-02	6.6E-03	5.5E-03
E	6.5E-02	4.6E-02	3.6E-02	2.7E-02	1.6E-02	1.3E-02
ENE	8.1E-02	5.6E-02	4.4E-02	3.2E-02	1.9E-02	1.6E-02
NE	6.7E-02	4.6E-02	3.6E-02	2.6E-02	1.5E-02	1.3E-02
NNE	2.5E-02	1.8E-02	1.4E-02	1.1E-02	6.5E-03	5.4E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.8E-09	9.4E-09	9.0E-09
NNW	8.4E-09	7.9E-09	7.5E-09	7.1E-09	6.8E-09	6.5E-09	6.2E-09
NW	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.8E-09	9.4E-09	9.1E-09
WNW	1.3E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.8E-09	9.3E-09
W	2.2E-08	2.0E-08	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.5E-08
WSW	6.4E-08	6.0E-08	5.7E-08	5.4E-08	5.1E-08	4.9E-08	4.7E-08
SW	8.5E-08	8.0E-08	7.6E-08	7.2E-08	6.9E-08	6.6E-08	6.3E-08
SSW	2.7E-08	2.6E-08	2.5E-08	2.4E-08	2.4E-08	2.3E-08	2.2E-08
S	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.3E-08	1.2E-08
SSE	9.7E-09	9.3E-09	8.9E-09	8.6E-09	8.3E-09	8.0E-09	7.7E-09
SE	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.1E-08
ESE	2.1E-08	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.8E-08	1.7E-08
E	5.6E-08	5.4E-08	5.2E-08	5.0E-08	4.8E-08	4.7E-08	4.5E-08
ENE	7.5E-08	7.2E-08	6.9E-08	6.6E-08	6.3E-08	6.1E-08	5.9E-08
NE	7.1E-08	6.6E-08	6.2E-08	5.9E-08	5.6E-08	5.4E-08	5.1E-08
NNE	2.4E-08	2.2E-08	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.8E-08

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	8.7E-09	8.4E-09	8.2E-09	7.9E-09	7.0E-09	6.8E-09	6.6E-09
NNW	6.0E-09	5.7E-09	5.5E-09	5.3E-09	4.6E-09	4.4E-09	4.3E-09
NW	8.7E-09	8.4E-09	8.2E-09	7.9E-09	6.8E-09	6.6E-09	6.4E-09
WNW	8.9E-09	8.6E-09	8.2E-09	7.9E-09	6.5E-09	6.3E-09	6.1E-09
W	1.5E-08	1.4E-08	1.3E-08	1.3E-08	1.1E-08	1.0E-08	9.8E-09
WSW	4.5E-08	4.3E-08	4.2E-08	4.0E-08	3.4E-08	3.3E-08	3.2E-08
SW	6.1E-08	5.9E-08	5.7E-08	5.5E-08	4.5E-08	4.4E-08	4.2E-08
SSW	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.7E-08	1.7E-08	1.6E-08
S	1.2E-08	1.1E-08	1.1E-08	1.1E-08	9.3E-09	9.0E-09	8.7E-09
SSE	7.4E-09	7.2E-09	7.0E-09	6.8E-09	5.9E-09	5.7E-09	5.5E-09
SE	1.0E-08	1.0E-08	9.8E-09	9.6E-09	8.5E-09	8.2E-09	8.0E-09
ESE	1.7E-08	1.7E-08	1.6E-08	1.6E-08	1.4E-08	1.3E-08	1.3E-08
E	4.4E-08	4.3E-08	4.2E-08	4.1E-08	3.5E-08	3.4E-08	3.3E-08
ENE	5.7E-08	5.5E-08	5.3E-08	5.2E-08	4.4E-08	4.2E-08	4.1E-08
NE	4.9E-08	4.7E-08	4.6E-08	4.4E-08	3.7E-08	3.5E-08	3.4E-08
NNE	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.3E-08	1.3E-08	1.3E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	6.5E-09	5.0E-09	4.3E-09	3.5E-09	2.3E-09	2.0E-09
NNW	4.2E-09	3.2E-09	2.7E-09	2.3E-09	1.5E-09	1.3E-09
NW	6.2E-09	4.6E-09	3.8E-09	3.1E-09	2.0E-09	1.7E-09
WNW	5.9E-09	4.3E-09	3.6E-09	2.9E-09	1.9E-09	1.6E-09
W	9.5E-09	6.9E-09	5.8E-09	4.7E-09	3.2E-09	2.7E-09
WSW	3.1E-08	2.2E-08	1.8E-08	1.4E-08	8.9E-09	7.4E-09
SW	4.1E-08	2.9E-08	2.3E-08	1.8E-08	1.1E-08	8.9E-09
SSW	1.6E-08	1.1E-08	9.3E-09	7.2E-09	4.5E-09	3.8E-09
S	8.5E-09	6.3E-09	5.2E-09	4.1E-09	2.6E-09	2.2E-09
SSE	5.4E-09	4.1E-09	3.4E-09	2.8E-09	1.8E-09	1.6E-09
SE	7.8E-09	6.0E-09	5.0E-09	4.0E-09	2.7E-09	2.2E-09
ESE	1.3E-08	9.4E-09	7.8E-09	6.1E-09	3.9E-09	3.3E-09
E	3.2E-08	2.3E-08	1.9E-08	1.5E-08	9.2E-09	7.6E-09
ENE	4.0E-08	2.8E-08	2.3E-08	1.8E-08	1.1E-08	9.0E-09
NE	3.3E-08	2.3E-08	1.9E-08	1.4E-08	8.7E-09	7.3E-09
NNE	1.2E-08	9.1E-09	7.6E-09	6.0E-09	3.8E-09	3.2E-09

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Version 3.0

Clean Air Act Assessment Package - 1988

S Y N O P S I S   R E P O R T

Non-Radon Individual Assessment
Mar 12, 2014 06:57 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2007

Comments: Benchmark Study 2007
2 Stacks, complete nuclides

Effective Dose Equivalent
(mrem/year)

2.17E-01

At This Location: 1400 Meters Southwest

Dataset Name: CAP88 Test2007
Dataset Date: 3/12/2014 6:56:00 AM
Wind File: C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 1400 Meters Southwest
Lifetime Fatal Cancer Risk: 1.28E-07

RADIONUCLIDE EMISSIONS DURING THE YEAR 2007

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	7.3E-04	6.8E-05	8.0E-04
Cr-51	S	1	0.0E+00	4.4E-07	4.4E-07
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	1.0E-06	1.5E-06	2.6E-06
I-125	F	1	4.4E-03	0.0E+00	4.4E-03
I-129	F	1	1.6E-06	9.0E-07	2.5E-06
I-131	F	1	2.1E-04	7.1E-08	2.1E-04
K-40	F	1	2.2E-04	0.0E+00	2.2E-04
Nb-94	S	1	2.0E-07	0.0E+00	2.0E-07
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	3.8E-07	9.7E-08	4.8E-07
Ru-106	S	1	0.0E+00	0.0E+00	0.0E+00
Mn-54	M	1	0.0E+00	0.0E+00	0.0E+00
Se-75	M	1	7.7E-06	0.0E+00	7.7E-06
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	5.0E-05	0.0E+00	5.0E-05
Sn-113	M	1	3.5E-07	0.0E+00	3.5E-07
H-3	V	0	1.0E+02	9.3E+01	2.0E+02
C-14	G	0	1.2E+01	3.3E-01	1.2E+01
Pu-238	M	1	8.6E-09	0.0E+00	8.6E-09
Pu-239	M	1	1.4E-08	3.9E-10	1.4E-08
Pu-240	M	1	1.4E-08	3.9E-10	1.4E-08
U-233	S	1	3.8E-07	1.0E-07	4.8E-07
U-234	S	1	3.8E-07	1.0E-07	4.8E-07
U-235	S	1	3.2E-08	5.9E-09	3.8E-08
U-236	S	1	3.2E-08	5.9E-09	3.8E-08
U-238	S	1	3.5E-07	7.8E-08	4.3E-07
Pu-241	M	1	1.2E-07	6.0E-08	1.8E-07
Sr-89	S	1	1.9E-08	1.5E-08	3.4E-08
Sr-90	S	1	4.1E-08	1.9E-08	6.0E-08
Fe-55	F	1	6.8E-07	1.7E-07	8.5E-07
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	9.2E-07	8.3E-07	1.8E-06
Tc-99	M	1	5.9E-06	0.0E+00	5.9E-06
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	16 degrees C
Precipitation:	97 cm/y
Humidity:	10 g/cu m
Mixing Height:	590 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Version 3.0

Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 06:57 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN   Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2007

Comments: Benchmark Study 2007
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2007
Dataset Date: 3/12/2014 6:56:00 AM
Wind File: .   C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	2.12E-01
INHALATION	4.09E-03
AIR IMMERSION	3.82E-07
GROUND SURFACE	1.65E-04
INTERNAL	2.16E-01
EXTERNAL	1.65E-04
TOTAL	2.17E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	2.51E-04
Cr-51	2.02E-10
Cs-134	0.00E+00
Cs-137	2.48E-06
Ba-137m	9.52E-08
I-125	1.60E-02
I-129	1.51E-04
I-131	1.29E-04
Xe-131m	0.00E+00
K-40	6.12E-05
Nb-94	7.02E-09
Nb-95	0.00E+00
Ru-103	3.54E-09
Rh-103m	3.54E-13
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	1.44E-06
Sb-124	0.00E+00
Sb-125	2.09E-06
Te-125m	1.19E-08
Sn-113	6.84E-10
In-113m	9.23E-13

H-3	4.40E-02
C-14	1.56E-01
Pu-238	2.87E-07
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	4.89E-07
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	4.89E-07
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	3.66E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	3.59E-06
U-235	2.34E-07
U-236	2.42E-07
U-238	2.51E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	1.21E-07
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.99E-10
Sr-90	6.89E-09
Y-90	0.00E+00
Fe-55	1.03E-08
Fe-59	0.00E+00
Ni-63	2.55E-09
Tc-99	2.31E-07
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	2.17E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	2.39E-09
Stomach	1.05E-08
Colon	2.39E-08
Liver	3.38E-09
LUNG	2.07E-08
Bone	2.05E-10
Skin	2.19E-10
Breast	9.75E-09
Ovary	2.73E-09
Bladder	5.40E-09
Kidneys	1.16E-09
Thyroid	1.65E-09
Leukemia	1.24E-08
Residual	3.32E-08
Total	1.28E-07
TOTAL	2.55E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	1.25E-07
INHALATION	2.32E-09
AIR IMMERSION	1.71E-13
GROUND SURFACE	8.44E-11
INTERNAL	1.27E-07
EXTERNAL	8.46E-11
TOTAL	1.28E-07

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	2.08E-10
Cr-51	1.95E-16
Cs-134	0.00E+00
Cs-137	1.26E-12
Ba-137m	5.14E-14
I-125	1.02E-09
I-129	7.58E-12
I-131	1.26E-11
Xe-131m	0.00E+00
K-40	5.69E-11
Nb-94	4.60E-15
Nb-95	0.00E+00
Ru-103	3.71E-15
Rh-103m	1.56E-19
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	1.10E-12
Sb-124	0.00E+00
Sb-125	1.40E-12
Te-125m	4.62E-15
Sn-113	6.05E-16
In-113m	5.07E-19
H-3	2.73E-08
C-14	9.89E-08
Pu-238	5.00E-14
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	7.74E-14
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	7.75E-14
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	2.66E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	2.61E-12
U-235	1.78E-13
U-236	1.83E-13
U-238	1.90E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	1.03E-14
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.81E-16
Sr-90	4.74E-15
Y-90	0.00E+00
Fe-55	7.31E-15
Fe-59	0.00E+00
Ni-63	1.42E-15
Tc-99	2.21E-13
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.28E-07

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	3.0E-02	2.8E-02	2.7E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
NNW	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.6E-02	1.5E-02
NW	2.9E-02	2.8E-02	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
WNW	3.1E-02	3.0E-02	2.8E-02	2.7E-02	2.5E-02	2.4E-02	2.3E-02
W	5.4E-02	5.1E-02	4.8E-02	4.5E-02	4.3E-02	4.0E-02	3.8E-02
WSW	1.6E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01	1.2E-01	1.2E-01
SW	2.2E-01	2.0E-01	1.9E-01	1.8E-01	1.7E-01	1.7E-01	1.6E-01
SSW	6.8E-02	6.6E-02	6.3E-02	6.1E-02	5.9E-02	5.7E-02	5.5E-02
S	3.7E-02	3.6E-02	3.4E-02	3.3E-02	3.2E-02	3.1E-02	3.0E-02
SSE	2.4E-02	2.3E-02	2.2E-02	2.1E-02	2.1E-02	2.0E-02	1.9E-02
SE	3.3E-02	3.2E-02	3.1E-02	2.9E-02	2.8E-02	2.7E-02	2.7E-02
ESE	5.4E-02	5.2E-02	5.0E-02	4.8E-02	4.6E-02	4.5E-02	4.4E-02
E	1.4E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01	1.2E-01	1.1E-01
ENE	1.9E-01	1.8E-01	1.7E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01
NE	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01
NNE	6.0E-02	5.6E-02	5.3E-02	5.0E-02	4.8E-02	4.6E-02	4.4E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	2.2E-02	2.1E-02	2.0E-02	2.0E-02	1.7E-02	1.7E-02	1.6E-02
NNW	1.5E-02	1.4E-02	1.4E-02	1.3E-02	1.1E-02	1.1E-02	1.0E-02
NW	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.7E-02	1.6E-02	1.6E-02
WNW	2.2E-02	2.1E-02	2.0E-02	2.0E-02	1.6E-02	1.5E-02	1.5E-02
W	3.6E-02	3.5E-02	3.3E-02	3.2E-02	2.6E-02	2.5E-02	2.4E-02
WSW	1.1E-01	1.1E-01	1.0E-01	1.0E-01	8.5E-02	8.2E-02	7.9E-02
SW	1.5E-01	1.5E-01	1.4E-01	1.4E-01	1.1E-01	1.1E-01	1.1E-01
SSW	5.4E-02	5.2E-02	5.1E-02	4.9E-02	4.2E-02	4.1E-02	4.0E-02
S	2.9E-02	2.8E-02	2.7E-02	2.7E-02	2.3E-02	2.2E-02	2.1E-02
SSE	1.9E-02	1.8E-02	1.7E-02	1.7E-02	1.5E-02	1.4E-02	1.4E-02
SE	2.6E-02	2.5E-02	2.4E-02	2.4E-02	2.1E-02	2.0E-02	2.0E-02
ESE	4.2E-02	4.1E-02	4.0E-02	3.9E-02	3.4E-02	3.3E-02	3.2E-02
E	1.1E-01	1.1E-01	1.1E-01	1.0E-01	8.9E-02	8.6E-02	8.3E-02
ENE	1.4E-01	1.4E-01	1.3E-01	1.3E-01	1.1E-01	1.1E-01	1.0E-01
NE	1.2E-01	1.2E-01	1.2E-01	1.1E-01	9.2E-02	8.9E-02	8.6E-02
NNE	4.3E-02	4.1E-02	4.0E-02	3.9E-02	3.3E-02	3.2E-02	3.1E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

Direction	Distance (m) 3300	4700	5800	7500	11700	13800
N	1.6E-02	1.2E-02	1.0E-02	8.4E-03	5.6E-03	4.7E-03
NNW	1.0E-02	7.5E-03	6.6E-03	5.4E-03	3.7E-03	3.1E-03
NW	1.5E-02	1.1E-02	9.3E-03	7.3E-03	4.7E-03	4.0E-03
WNW	1.5E-02	1.0E-02	8.7E-03	6.9E-03	4.5E-03	3.7E-03
W	2.3E-02	1.7E-02	1.4E-02	1.1E-02	7.6E-03	6.4E-03
WSW	7.7E-02	5.5E-02	4.5E-02	3.5E-02	2.2E-02	1.8E-02
SW	1.0E-01	7.2E-02	5.8E-02	4.4E-02	2.6E-02	2.2E-02
SSW	3.9E-02	2.8E-02	2.3E-02	1.8E-02	1.1E-02	9.2E-03
S	2.1E-02	1.5E-02	1.3E-02	9.9E-03	6.4E-03	5.3E-03
SSE	1.3E-02	9.9E-03	8.4E-03	6.7E-03	4.4E-03	3.7E-03
SE	1.9E-02	1.5E-02	1.2E-02	9.8E-03	6.4E-03	5.4E-03
ESE	3.2E-02	2.3E-02	1.9E-02	1.5E-02	9.5E-03	8.0E-03
E	8.1E-02	5.8E-02	4.8E-02	3.6E-02	2.2E-02	1.9E-02
ENE	1.0E-01	7.0E-02	5.7E-02	4.3E-02	2.7E-02	2.2E-02
NE	8.3E-02	5.7E-02	4.6E-02	3.5E-02	2.1E-02	1.8E-02
NNE	3.1E-02	2.2E-02	1.9E-02	1.5E-02	9.3E-03	7.8E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

Direction	Distance (m) 1400	1500	1600	1700	1800	1900	2000
N	1.8E-08	1.7E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08
NNW	1.2E-08	1.2E-08	1.1E-08	1.0E-08	9.9E-09	9.5E-09	9.1E-09
NW	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08
WNW	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08
W	3.2E-08	3.0E-08	2.8E-08	2.7E-08	2.5E-08	2.4E-08	2.3E-08
WSW	9.6E-08	9.0E-08	8.4E-08	8.0E-08	7.6E-08	7.3E-08	7.0E-08
SW	1.3E-07	1.2E-07	1.1E-07	1.1E-07	1.0E-07	9.9E-08	9.5E-08
SSW	4.0E-08	3.9E-08	3.7E-08	3.6E-08	3.5E-08	3.4E-08	3.3E-08
S	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.9E-08	1.8E-08	1.8E-08
SSE	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08
SE	1.9E-08	1.9E-08	1.8E-08	1.7E-08	1.7E-08	1.6E-08	1.6E-08
ESE	3.2E-08	3.1E-08	2.9E-08	2.8E-08	2.7E-08	2.7E-08	2.6E-08
E	8.4E-08	8.0E-08	7.7E-08	7.4E-08	7.2E-08	7.0E-08	6.8E-08
ENE	1.1E-07	1.1E-07	1.0E-07	9.8E-08	9.4E-08	9.1E-08	8.8E-08
NE	1.1E-07	9.9E-08	9.3E-08	8.9E-08	8.4E-08	8.0E-08	7.7E-08
NNE	3.5E-08	3.3E-08	3.1E-08	3.0E-08	2.8E-08	2.7E-08	2.6E-08

Mar 12, 2014 06:57 am SUMMARY

Direction	2100	2200	2300	2400	3000	3100	3200
	Distance (m)						
N	1.3E-08	1.2E-08	1.2E-08	1.2E-08	1.0E-08	1.0E-08	9.7E-09
NNW	8.7E-09	8.4E-09	8.1E-09	7.8E-09	6.7E-09	6.4E-09	6.3E-09
NW	1.3E-08	1.2E-08	1.2E-08	1.2E-08	9.9E-09	9.6E-09	9.4E-09
WNW	1.3E-08	1.3E-08	1.2E-08	1.2E-08	9.6E-09	9.3E-09	9.0E-09
W	2.2E-08	2.1E-08	2.0E-08	1.9E-08	1.5E-08	1.5E-08	1.4E-08
WSW	6.7E-08	6.4E-08	6.2E-08	6.0E-08	5.1E-08	4.9E-08	4.7E-08
SW	9.1E-08	8.7E-08	8.4E-08	8.2E-08	6.8E-08	6.5E-08	6.3E-08
SSW	3.2E-08	3.1E-08	3.0E-08	2.9E-08	2.5E-08	2.4E-08	2.4E-08
S	1.7E-08	1.7E-08	1.6E-08	1.6E-08	1.4E-08	1.3E-08	1.3E-08
SSE	1.1E-08	1.1E-08	1.0E-08	1.0E-08	8.7E-09	8.4E-09	8.2E-09
SE	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.2E-08	1.2E-08
ESE	2.5E-08	2.4E-08	2.4E-08	2.3E-08	2.0E-08	2.0E-08	1.9E-08
E	6.6E-08	6.4E-08	6.2E-08	6.1E-08	5.3E-08	5.1E-08	5.0E-08
ENE	8.5E-08	8.2E-08	8.0E-08	7.7E-08	6.5E-08	6.3E-08	6.1E-08
NE	7.4E-08	7.1E-08	6.8E-08	6.6E-08	5.5E-08	5.3E-08	5.1E-08
NNE	2.5E-08	2.4E-08	2.4E-08	2.3E-08	2.0E-08	1.9E-08	1.9E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

Direction	3300	4700	5800	7500	11700	13800
	Distance (m)					
N	9.5E-09	7.2E-09	6.3E-09	5.1E-09	3.5E-09	2.9E-09
NNW	6.1E-09	4.6E-09	4.0E-09	3.3E-09	2.3E-09	1.9E-09
NW	9.1E-09	6.7E-09	5.7E-09	4.5E-09	2.9E-09	2.5E-09
WNW	8.7E-09	6.2E-09	5.3E-09	4.2E-09	2.8E-09	2.3E-09
W	1.4E-08	1.0E-08	8.6E-09	7.0E-09	4.7E-09	4.0E-09
WSW	4.6E-08	3.3E-08	2.7E-08	2.1E-08	1.3E-08	1.1E-08
SW	6.1E-08	4.3E-08	3.5E-08	2.7E-08	1.6E-08	1.4E-08
SSW	2.3E-08	1.7E-08	1.4E-08	1.1E-08	6.8E-09	5.7E-09
S	1.3E-08	9.2E-09	7.7E-09	6.1E-09	4.0E-09	3.3E-09
SSE	8.0E-09	6.0E-09	5.1E-09	4.1E-09	2.7E-09	2.3E-09
SE	1.2E-08	8.8E-09	7.5E-09	6.0E-09	4.0E-09	3.4E-09
ESE	1.9E-08	1.4E-08	1.2E-08	9.2E-09	5.9E-09	5.0E-09
E	4.8E-08	3.5E-08	2.9E-08	2.2E-08	1.4E-08	1.2E-08
ENE	6.0E-08	4.2E-08	3.5E-08	2.7E-08	1.6E-08	1.4E-08
NE	4.9E-08	3.4E-08	2.8E-08	2.1E-08	1.3E-08	1.1E-08
NNE	1.8E-08	1.3E-08	1.1E-08	8.9E-09	5.8E-09	4.9E-09

C A P 8 8 - P C

Version 3.0

Clean Air Act Assessment Package - 1988

S Y N O P S I S   R E P O R T

Non-Radon Individual Assessment
Mar 12, 2014 07:06 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN   Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2008

Comments: Benchmark Study 2008
2 Stacks, complete nuclides

Effective Dose Equivalent
(mrem/year)

2.45E-01

At This Location: 1400 Meters Southwest

Dataset Name: CAP88 Test2008
Dataset Date: 3/12/2014 7:05:00 AM
Wind File: C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 1400 Meters Southwest
Lifetime Fatal Cancer Risk: 1.36E-07

RADIONUCLIDE EMISSIONS DURING THE YEAR 2008

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	5.7E-07	1.8E-06	2.3E-06
Cr-51	S	1	6.0E-07	0.0E+00	6.0E-07
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	2.1E-06	8.5E-06	1.1E-05
I-125	F	1	9.0E-03	0.0E+00	9.0E-03
I-129	F	1	0.0E+00	0.0E+00	0.0E+00
I-131	F	1	1.3E-04	0.0E+00	1.3E-04
K-40	F	1	8.2E-05	6.7E-05	1.5E-04
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	1.7E-06	0.0E+00	1.7E-06
Ru-106	S	1	1.1E-06	0.0E+00	1.1E-06
Mn-54	M	1	0.0E+00	0.0E+00	0.0E+00
Se-75	M	1	3.5E-05	0.0E+00	3.5E-05
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	2.1E-05	0.0E+00	2.1E-05
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	1.1E+02	1.3E+00	1.1E+02
C-14	G	0	1.5E+01	9.9E-02	1.5E+01
Pu-238	M	1	1.6E-08	1.0E-09	1.8E-08
Pu-239	M	1	1.5E-08	0.0E+00	1.5E-08
Pu-240	M	1	1.5E-08	0.0E+00	1.5E-08
U-233	S	1	3.0E-07	1.5E-07	4.6E-07
U-234	S	1	3.0E-07	1.5E-07	4.6E-07
U-235	S	1	2.3E-08	1.1E-08	3.5E-08
U-236	S	1	2.3E-08	1.1E-08	3.5E-08
U-238	S	1	2.3E-07	1.7E-07	4.0E-07
Pu-241	M	1	1.7E-07	1.5E-07	3.3E-07
Sr-89	S	1	0.0E+00	1.3E-07	1.3E-07
Sr-90	S	1	3.9E-08	8.0E-08	1.2E-07
Fe-55	F	1	1.9E-06	7.2E-07	2.7E-06
Fe-59	F	1	9.9E-05	0.0E+00	9.9E-05
Ni-63	V	0	5.2E-06	9.3E-07	6.1E-06
Tc-99	M	1	2.6E-04	4.0E-06	2.7E-04
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	15 degrees C
Precipitation:	134 cm/y
Humidity:	10 g/cu m
Mixing Height:	588 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

C A P 8 8 - P C

Version 3.0

Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 07:06 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN   Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2008

Comments: Benchmark Study 2008
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2008
Dataset Date: 3/12/2014 7:05:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	2.42E-01
INHALATION	2.27E-03
AIR IMMERSION	1.47E-07
GROUND SURFACE	8.72E-05
INTERNAL	2.44E-01
EXTERNAL	8.74E-05
TOTAL	2.45E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	8.67E-07
Cr-51	3.89E-10
Cs-134	0.00E+00
Cs-137	1.21E-05
Ba-137m	4.63E-07
I-125	3.31E-02
I-129	0.00E+00
I-131	8.27E-05
Xe-131m	0.00E+00
K-40	4.96E-05
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	2.85E-08
Rh-103m	3.01E-11
Ru-106	1.49E-07
Rh-106	2.43E-08
Mn-54	0.00E+00
Se-75	7.73E-06
Sb-124	0.00E+00
Sb-125	1.01E-06
Te-125m	5.80E-09
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	2.37E-02
C-14	1.88E-01
Pu-238	5.85E-07
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	5.46E-07
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	5.46E-07
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	3.20E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	3.14E-06
U-235	2.13E-07
U-236	2.20E-07
U-238	2.37E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	2.14E-07
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	8.00E-10
Sr-90	1.37E-08
Y-90	0.00E+00
Fe-55	3.76E-08
Fe-59	5.68E-06
Ni-63	8.78E-09
Tc-99	1.22E-05
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	2.45E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	2.54E-09
Stomach	1.09E-08
Colon	2.51E-08
Liver	3.58E-09
LUNG	2.20E-08
Bone	2.18E-10
Skin	2.33E-10
Breast	1.04E-08
Ovary	2.89E-09
Bladder	5.73E-09
Kidneys	1.24E-09
Thyroid	2.70E-09
Leukemia	1.31E-08
Residual	3.53E-08
Total	1.36E-07
TOTAL	2.72E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	1.34E-07
INHALATION	1.27E-09
AIR IMMERSION	3.30E-14
GROUND SURFACE	3.49E-11
INTERNAL	1.36E-07
EXTERNAL	3.49E-11
TOTAL	1.36E-07

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	7.20E-13
Cr-51	3.45E-16
Cs-134	0.00E+00
Cs-137	6.12E-12
Ba-137m	2.50E-13
I-125	2.10E-09
I-129	0.00E+00
I-131	8.02E-12
Xe-131m	0.00E+00
K-40	4.61E-11
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	2.27E-14
Rh-103m	9.81E-18
Ru-106	1.73E-13
Rh-106	8.87E-15
Mn-54	0.00E+00
Se-75	5.90E-12
Sb-124	0.00E+00
Sb-125	6.74E-13
Te-125m	2.25E-15
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	1.47E-08
C-14	1.19E-07
Pu-238	1.02E-13
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	8.65E-14
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	8.66E-14
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	2.43E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	2.38E-12
U-235	1.61E-13
U-236	1.67E-13
U-238	1.79E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	1.83E-14
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	7.27E-16
Sr-90	9.46E-15
Y-90	0.00E+00
Fe-55	2.67E-14
Fe-59	4.55E-12
Ni-63	4.88E-15
Tc-99	1.17E-11
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.36E-07

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	3.4E-02	3.2E-02	3.1E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02
NNW	2.4E-02	2.3E-02	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.8E-02
NW	3.3E-02	3.2E-02	3.0E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02
WNW	3.6E-02	3.4E-02	3.2E-02	3.1E-02	2.9E-02	2.8E-02	2.6E-02
W	6.2E-02	5.8E-02	5.5E-02	5.1E-02	4.9E-02	4.6E-02	4.4E-02
WSW	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01	1.4E-01	1.3E-01
SW	2.4E-01	2.3E-01	2.2E-01	2.1E-01	2.0E-01	1.9E-01	1.8E-01
SSW	7.8E-02	7.5E-02	7.2E-02	7.0E-02	6.7E-02	6.5E-02	6.3E-02
S	4.2E-02	4.1E-02	3.9E-02	3.8E-02	3.7E-02	3.6E-02	3.4E-02
SSE	2.8E-02	2.7E-02	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
SE	3.8E-02	3.6E-02	3.5E-02	3.4E-02	3.2E-02	3.1E-02	3.0E-02
ESE	6.2E-02	5.9E-02	5.7E-02	5.5E-02	5.3E-02	5.1E-02	5.0E-02
E	1.6E-01	1.5E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01	1.3E-01
ENE	2.2E-01	2.1E-01	2.0E-01	1.9E-01	1.8E-01	1.7E-01	1.7E-01
NE	2.0E-01	1.9E-01	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01
NNE	6.8E-02	6.4E-02	6.0E-02	5.7E-02	5.4E-02	5.2E-02	5.0E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	2.5E-02	2.4E-02	2.3E-02	2.2E-02	2.0E-02	1.9E-02	1.9E-02
NNW	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.3E-02	1.2E-02	1.2E-02
NW	2.5E-02	2.4E-02	2.3E-02	2.2E-02	1.9E-02	1.8E-02	1.8E-02
WNW	2.5E-02	2.4E-02	2.3E-02	2.2E-02	1.8E-02	1.8E-02	1.7E-02
W	4.2E-02	4.0E-02	3.8E-02	3.6E-02	2.9E-02	2.8E-02	2.7E-02
WSW	1.3E-01	1.2E-01	1.2E-01	1.1E-01	9.6E-02	9.2E-02	8.9E-02
SW	1.7E-01	1.7E-01	1.6E-01	1.6E-01	1.3E-01	1.2E-01	1.2E-01
SSW	6.1E-02	5.9E-02	5.8E-02	5.6E-02	4.8E-02	4.6E-02	4.5E-02
S	3.3E-02	3.2E-02	3.1E-02	3.0E-02	2.6E-02	2.5E-02	2.4E-02
SSE	2.1E-02	2.0E-02	2.0E-02	1.9E-02	1.7E-02	1.6E-02	1.6E-02
SE	2.9E-02	2.9E-02	2.8E-02	2.7E-02	2.4E-02	2.3E-02	2.3E-02
ESE	4.8E-02	4.7E-02	4.6E-02	4.5E-02	3.9E-02	3.8E-02	3.7E-02
E	1.3E-01	1.2E-01	1.2E-01	1.2E-01	1.0E-01	9.6E-02	9.3E-02
ENE	1.6E-01	1.6E-01	1.5E-01	1.5E-01	1.2E-01	1.2E-01	1.2E-01
NE	1.4E-01	1.4E-01	1.3E-01	1.3E-01	1.0E-01	9.9E-02	9.6E-02
NNE	4.8E-02	4.7E-02	4.5E-02	4.4E-02	3.8E-02	3.6E-02	3.5E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.8E-02	1.3E-02	1.2E-02	9.3E-03	6.1E-03	5.1E-03
NNW	1.2E-02	8.6E-03	7.4E-03	6.1E-03	4.0E-03	3.4E-03
NW	1.7E-02	1.2E-02	1.0E-02	8.1E-03	5.2E-03	4.3E-03
WNW	1.6E-02	1.2E-02	9.7E-03	7.6E-03	4.9E-03	4.1E-03
W	2.6E-02	1.9E-02	1.6E-02	1.3E-02	8.4E-03	7.0E-03
WSW	8.7E-02	6.1E-02	5.0E-02	3.8E-02	2.3E-02	2.0E-02
SW	1.2E-01	8.0E-02	6.4E-02	4.8E-02	2.9E-02	2.4E-02
SSW	4.4E-02	3.1E-02	2.5E-02	1.9E-02	1.2E-02	9.9E-03
S	2.4E-02	1.7E-02	1.4E-02	1.1E-02	6.9E-03	5.8E-03
SSE	1.5E-02	1.1E-02	9.4E-03	7.5E-03	4.8E-03	4.1E-03
SE	2.2E-02	1.6E-02	1.4E-02	1.1E-02	7.0E-03	5.9E-03
ESE	3.6E-02	2.6E-02	2.1E-02	1.7E-02	1.0E-02	8.6E-03
E	9.1E-02	6.5E-02	5.2E-02	4.0E-02	2.4E-02	2.0E-02
ENE	1.1E-01	7.8E-02	6.3E-02	4.8E-02	2.9E-02	2.4E-02
NE	9.3E-02	6.4E-02	5.1E-02	3.9E-02	2.3E-02	1.9E-02
NNE	3.4E-02	2.5E-02	2.1E-02	1.6E-02	1.0E-02	8.4E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.4E-08
NNW	1.3E-08	1.3E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.9E-09
NW	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.4E-08
WNW	2.0E-08	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.6E-08	1.5E-08
W	3.5E-08	3.2E-08	3.1E-08	2.9E-08	2.7E-08	2.6E-08	2.5E-08
WSW	1.0E-07	9.6E-08	9.1E-08	8.6E-08	8.2E-08	7.8E-08	7.5E-08
SW	1.4E-07	1.3E-07	1.2E-07	1.2E-07	1.1E-07	1.1E-07	1.0E-07
SSW	4.3E-08	4.2E-08	4.0E-08	3.9E-08	3.8E-08	3.7E-08	3.5E-08
S	2.3E-08	2.3E-08	2.2E-08	2.1E-08	2.1E-08	2.0E-08	1.9E-08
SSE	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.2E-08
SE	2.1E-08	2.0E-08	1.9E-08	1.9E-08	1.8E-08	1.7E-08	1.7E-08
ESE	3.4E-08	3.3E-08	3.2E-08	3.0E-08	2.9E-08	2.9E-08	2.8E-08
E	9.0E-08	8.6E-08	8.3E-08	8.0E-08	7.7E-08	7.5E-08	7.2E-08
ENE	1.2E-07	1.1E-07	1.1E-07	1.0E-07	1.0E-07	9.7E-08	9.3E-08
NE	1.1E-07	1.1E-07	9.9E-08	9.4E-08	9.0E-08	8.6E-08	8.2E-08
NNE	3.8E-08	3.6E-08	3.4E-08	3.2E-08	3.0E-08	2.9E-08	2.8E-08

Direction	2100	2200	2300	2400	3000	3100	3200
	Distance (m)						
N	1.4E-08	1.3E-08	1.3E-08	1.3E-08	1.1E-08	1.1E-08	1.1E-08
NNW	9.5E-09	9.1E-09	8.8E-09	8.5E-09	7.3E-09	7.0E-09	6.8E-09
NW	1.4E-08	1.3E-08	1.3E-08	1.3E-08	1.1E-08	1.0E-08	1.0E-08
WNW	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.0E-08	1.0E-08	9.8E-09
W	2.3E-08	2.2E-08	2.1E-08	2.1E-08	1.7E-08	1.6E-08	1.6E-08
WSW	7.2E-08	6.9E-08	6.7E-08	6.4E-08	5.4E-08	5.2E-08	5.1E-08
SW	9.7E-08	9.3E-08	9.0E-08	8.7E-08	7.2E-08	7.0E-08	6.8E-08
SSW	3.4E-08	3.3E-08	3.3E-08	3.2E-08	2.7E-08	2.6E-08	2.6E-08
S	1.9E-08	1.8E-08	1.8E-08	1.7E-08	1.5E-08	1.4E-08	1.4E-08
SSE	1.2E-08	1.1E-08	1.1E-08	1.1E-08	9.4E-09	9.1E-09	8.9E-09
SE	1.6E-08	1.6E-08	1.6E-08	1.5E-08	1.4E-08	1.3E-08	1.3E-08
ESE	2.7E-08	2.6E-08	2.6E-08	2.5E-08	2.2E-08	2.1E-08	2.1E-08
E	7.0E-08	6.9E-08	6.7E-08	6.5E-08	5.6E-08	5.4E-08	5.3E-08
ENE	9.0E-08	8.8E-08	8.5E-08	8.2E-08	7.0E-08	6.7E-08	6.5E-08
NE	7.9E-08	7.6E-08	7.3E-08	7.0E-08	5.8E-08	5.6E-08	5.4E-08
NNE	2.7E-08	2.6E-08	2.5E-08	2.5E-08	2.1E-08	2.1E-08	2.0E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

Direction	3300	4700	5800	7500	11700	13800
	Distance (m)					
N	1.0E-08	7.8E-09	6.8E-09	5.6E-09	3.7E-09	3.2E-09
NNW	6.7E-09	5.0E-09	4.4E-09	3.6E-09	2.5E-09	2.1E-09
NW	9.9E-09	7.3E-09	6.2E-09	4.9E-09	3.2E-09	2.7E-09
WNW	9.5E-09	6.7E-09	5.7E-09	4.6E-09	3.0E-09	2.5E-09
W	1.5E-08	1.1E-08	9.3E-09	7.6E-09	5.1E-09	4.3E-09
WSW	4.9E-08	3.5E-08	2.9E-08	2.3E-08	1.4E-08	1.2E-08
SW	6.6E-08	4.6E-08	3.7E-08	2.8E-08	1.7E-08	1.4E-08
SSW	2.5E-08	1.8E-08	1.5E-08	1.2E-08	7.3E-09	6.1E-09
S	1.4E-08	1.0E-08	8.4E-09	6.6E-09	4.3E-09	3.6E-09
SSE	8.6E-09	6.5E-09	5.5E-09	4.5E-09	3.0E-09	2.5E-09
SE	1.3E-08	9.5E-09	8.1E-09	6.5E-09	4.3E-09	3.6E-09
ESE	2.0E-08	1.5E-08	1.3E-08	9.9E-09	6.3E-09	5.3E-09
E	5.2E-08	3.7E-08	3.1E-08	2.4E-08	1.5E-08	1.2E-08
ENE	6.4E-08	4.5E-08	3.7E-08	2.8E-08	1.7E-08	1.5E-08
NE	5.3E-08	3.7E-08	3.0E-08	2.3E-08	1.4E-08	1.2E-08
NNE	2.0E-08	1.4E-08	1.2E-08	9.6E-09	6.2E-09	5.2E-09

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                         C A P 8 8 - P C

                          Version 3.0

             Clean Air Act Assessment Package - 1988


                   S Y N O P S I S   R E P O R T

                Non-Radon Individual Assessment
                     Mar  12, 2014  07:11 am


     Facility:  Radioactive Waste Processing Facility
      Address:  Benchmark Study
         City:  Oak Ridge
        State:  TN           Zip:    37831


     Source Category:  2 Stacks
         Source Type:  Stack
       Emission Year:  2009


     Comments:  Benchmark Study 2009
                2 Stacks, complete nuclides


                 Effective Dose Equivalent
                        (mrem/year)
                 _________________________

                          1.25E-01
                 _________________________


    At This Location:   1400 Meters Southwest

        Dataset Name:  CAP88 Test2009
        Dataset Date:  3/12/2014 7:11:00 AM
           Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


               MAXIMALLY EXPOSED INDIVIDUAL


    Location Of The Individual:   1400 Meters Southwest
    Lifetime Fatal Cancer Risk:          6.43E-08
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2009

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	4.9E-07	0.0E+00	4.9E-07
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	2.5E-07	2.5E-07
Co-60	S	1	2.4E-06	1.5E-05	1.7E-05
Cr-51	S	1	0.0E+00	0.0E+00	0.0E+00
Cs-134	F	1	7.1E-07	0.0E+00	7.1E-07
Cs-137	F	1	2.3E-05	4.5E-06	2.7E-05
I-125	F	1	6.9E-03	0.0E+00	6.9E-03
I-129	F	1	0.0E+00	0.0E+00	0.0E+00
I-131	F	1	1.3E-05	0.0E+00	1.3E-05
K-40	F	1	6.5E-05	7.4E-05	1.4E-04
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	8.9E-07	0.0E+00	8.9E-07
Ru-106	S	1	8.8E-07	0.0E+00	8.8E-07
Mn-54	M	1	0.0E+00	5.0E-07	5.0E-07
Se-75	M	1	3.0E-05	0.0E+00	3.0E-05
Sb-124	M	1	0.0E+00	0.0E+00	0.0E+00
Sb-125	M	1	2.3E-05	0.0E+00	2.3E-05
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	8.1E+01	4.4E-01	8.1E+01
C-14	G	0	6.3E+00	7.8E-02	6.4E+00
Pu-238	M	1	4.2E-09	2.2E-09	6.4E-09
Pu-239	M	1	2.2E-09	4.8E-09	7.0E-09
Pu-240	M	1	2.2E-09	4.8E-09	7.0E-09
U-233	S	1	1.4E-07	1.3E-07	2.7E-07
U-234	S	1	1.4E-07	1.3E-07	2.7E-07
U-235	S	1	4.1E-09	6.2E-09	1.0E-08
U-236	S	1	4.1E-09	6.2E-09	1.0E-08
U-238	S	1	1.6E-07	1.3E-07	2.9E-07
Pu-241	M	1	1.2E-08	5.3E-08	6.4E-08
Sr-89	S	1	4.3E-08	7.3E-09	5.0E-08
Sr-90	S	1	1.8E-08	2.8E-08	4.6E-08
Fe-55	F	1	5.3E-07	2.2E-06	2.7E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	8.4E-06	1.4E-06	9.8E-06
Tc-99	M	1	3.6E-05	0.0E+00	3.6E-05
Zn-65	S	1	3.6E-07	0.0E+00	3.6E-07
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	14 degrees C
Precipitation:	157 cm/y
Humidity:	10 g/cu m
Mixing Height:	569 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 07:11 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN   Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2009

Comments: Benchmark Study 2009
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2009
Dataset Date: 3/12/2014 7:11:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.23E-01
INHALATION	1.69E-03
AIR IMMERSION	6.85E-08
GROUND SURFACE	6.86E-05
INTERNAL	1.25E-01
EXTERNAL	6.87E-05
TOTAL	1.25E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	8.73E-08
Ag-110	4.52E-14
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	4.23E-10
Co-60	6.87E-06
Cr-51	0.00E+00
Cs-134	1.23E-06
Cs-137	3.35E-05
Ba-137m	1.29E-06
I-125	2.55E-02
I-129	0.00E+00
I-131	8.09E-06
Xe-131m	0.00E+00
K-40	5.08E-05
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	1.42E-08
Rh-103m	1.34E-11
Ru-106	1.29E-07
Rh-106	2.17E-08
Mn-54	2.78E-08
Se-75	7.14E-06
Sb-124	0.00E+00
Sb-125	1.22E-06
Te-125m	7.06E-09
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	1.79E-02
C-14	8.11E-02
Pu-238	2.14E-07
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	2.59E-07
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	2.59E-07
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.92E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.88E-06
U-235	6.44E-08
U-236	6.64E-08
U-238	1.70E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	4.28E-08
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	2.89E-10
Sr-90	5.28E-09
Y-90	0.00E+00
Fe-55	4.22E-08
Fe-59	0.00E+00
Ni-63	1.41E-08
Tc-99	1.78E-06
Zn-65	5.47E-10
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.25E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	1.19E-09
Stomach	5.19E-09
Colon	1.18E-08
Liver	1.68E-09
LUNG	1.03E-08
Bone	1.02E-10
Skin	1.09E-10
Breast	4.84E-09
Ovary	1.35E-09
Bladder	2.69E-09
Kidneys	5.78E-10
Thyroid	1.86E-09
Leukemia	6.14E-09
Residual	1.65E-08
Total	6.43E-08
TOTAL	1.29E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	6.33E-08
INHALATION	9.48E-10
AIR IMMERSION	1.64E-14
GROUND SURFACE	2.76E-11
INTERNAL	6.42E-08
EXTERNAL	2.76E-11
TOTAL	6.43E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	5.73E-14
Ag-110	1.80E-20
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	3.52E-16
Co-60	5.71E-12
Cr-51	0.00E+00
Cs-134	6.14E-13
Cs-137	1.70E-11
Ba-137m	6.94E-13
I-125	1.62E-09
I-129	0.00E+00
I-131	7.82E-13
Xe-131m	0.00E+00
K-40	4.72E-11
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	1.18E-14
Rh-103m	4.38E-18
Ru-106	1.52E-13
Rh-106	7.94E-15
Mn-54	1.65E-14
Se-75	5.45E-12
Sb-124	0.00E+00
Sb-125	8.13E-13
Te-125m	2.74E-15
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	1.11E-08
C-14	5.14E-08
Pu-238	3.73E-14
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	4.10E-14
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	4.10E-14
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.45E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.43E-12
U-235	4.88E-14
U-236	5.04E-14
U-238	1.28E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	3.64E-15
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	2.62E-16
Sr-90	3.64E-15
Y-90	0.00E+00
Fe-55	3.00E-14
Fe-59	0.00E+00
Ni-63	7.85E-15
Tc-99	1.70E-12
Zn-65	4.44E-16
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	6.43E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.8E-02	1.7E-02	1.6E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02
NNW	1.2E-02	1.2E-02	1.1E-02	1.0E-02	9.8E-03	9.4E-03	8.9E-03
NW	1.7E-02	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02
WNW	1.8E-02	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.4E-02	1.3E-02
W	3.2E-02	3.0E-02	2.8E-02	2.6E-02	2.5E-02	2.3E-02	2.2E-02
WSW	9.4E-02	8.8E-02	8.2E-02	7.8E-02	7.4E-02	7.0E-02	6.7E-02
SW	1.2E-01	1.2E-01	1.1E-01	1.1E-01	1.0E-01	9.6E-02	9.2E-02
SSW	4.0E-02	3.8E-02	3.7E-02	3.5E-02	3.4E-02	3.3E-02	3.2E-02
S	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.9E-02	1.8E-02	1.7E-02
SSE	1.4E-02	1.4E-02	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.1E-02
SE	1.9E-02	1.9E-02	1.8E-02	1.7E-02	1.6E-02	1.6E-02	1.5E-02
ESE	3.1E-02	3.0E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02	2.5E-02
E	8.2E-02	7.9E-02	7.6E-02	7.3E-02	7.0E-02	6.8E-02	6.6E-02
ENE	1.1E-01	1.0E-01	1.0E-01	9.5E-02	9.2E-02	8.8E-02	8.5E-02
NE	1.0E-01	9.7E-02	9.1E-02	8.6E-02	8.2E-02	7.8E-02	7.5E-02
NNE	3.5E-02	3.3E-02	3.1E-02	2.9E-02	2.8E-02	2.6E-02	2.5E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	1.3E-02	1.2E-02	1.2E-02	1.1E-02	9.9E-03	9.6E-03	9.3E-03
NNW	8.5E-03	8.2E-03	7.9E-03	7.6E-03	6.4E-03	6.2E-03	6.0E-03
NW	1.2E-02	1.2E-02	1.2E-02	1.1E-02	9.5E-03	9.2E-03	8.9E-03
WNW	1.3E-02	1.2E-02	1.2E-02	1.1E-02	9.1E-03	8.8E-03	8.5E-03
W	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.5E-02	1.4E-02	1.4E-02
WSW	6.5E-02	6.2E-02	6.0E-02	5.8E-02	4.8E-02	4.6E-02	4.5E-02
SW	8.8E-02	8.5E-02	8.1E-02	7.8E-02	6.5E-02	6.2E-02	6.0E-02
SSW	3.1E-02	3.0E-02	2.9E-02	2.8E-02	2.4E-02	2.3E-02	2.2E-02
S	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.3E-02	1.3E-02	1.2E-02
SSE	1.1E-02	1.0E-02	1.0E-02	9.7E-03	8.3E-03	8.0E-03	7.8E-03
SE	1.5E-02	1.4E-02	1.4E-02	1.4E-02	1.2E-02	1.2E-02	1.1E-02
ESE	2.4E-02	2.4E-02	2.3E-02	2.3E-02	2.0E-02	1.9E-02	1.8E-02
E	6.4E-02	6.2E-02	6.0E-02	5.9E-02	5.0E-02	4.8E-02	4.7E-02
ENE	8.2E-02	7.9E-02	7.7E-02	7.4E-02	6.2E-02	6.0E-02	5.8E-02
NE	7.2E-02	6.9E-02	6.6E-02	6.4E-02	5.2E-02	5.0E-02	4.8E-02
NNE	2.4E-02	2.4E-02	2.3E-02	2.2E-02	1.9E-02	1.8E-02	1.8E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	9.1E-03	6.8E-03	5.7E-03	4.6E-03	2.9E-03	2.4E-03
NNW	5.8E-03	4.3E-03	3.7E-03	3.0E-03	1.9E-03	1.6E-03
NW	8.6E-03	6.2E-03	5.1E-03	4.0E-03	2.5E-03	2.1E-03
WNW	8.2E-03	5.8E-03	4.8E-03	3.7E-03	2.4E-03	2.0E-03
W	1.3E-02	9.5E-03	7.9E-03	6.2E-03	4.0E-03	3.4E-03
WSW	4.4E-02	3.1E-02	2.5E-02	1.9E-02	1.1E-02	9.3E-03
SW	5.8E-02	4.0E-02	3.2E-02	2.3E-02	1.4E-02	1.1E-02
SSW	2.2E-02	1.5E-02	1.2E-02	9.4E-03	5.7E-03	4.7E-03
S	1.2E-02	8.5E-03	6.9E-03	5.3E-03	3.3E-03	2.8E-03
SSE	7.6E-03	5.6E-03	4.6E-03	3.6E-03	2.3E-03	1.9E-03
SE	1.1E-02	8.2E-03	6.8E-03	5.3E-03	3.3E-03	2.8E-03
ESE	1.8E-02	1.3E-02	1.1E-02	8.1E-03	4.9E-03	4.1E-03
E	4.6E-02	3.2E-02	2.6E-02	1.9E-02	1.2E-02	9.7E-03
ENE	5.6E-02	3.9E-02	3.1E-02	2.3E-02	1.4E-02	1.1E-02
NE	4.7E-02	3.2E-02	2.6E-02	1.9E-02	1.1E-02	9.3E-03
NNE	1.7E-02	1.3E-02	1.0E-02	7.8E-03	4.8E-03	4.0E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	9.1E-09	8.5E-09	8.1E-09	7.7E-09	7.3E-09	7.0E-09	6.8E-09
NNW	6.3E-09	6.0E-09	5.6E-09	5.4E-09	5.1E-09	4.9E-09	4.7E-09
NW	8.8E-09	8.4E-09	8.0E-09	7.7E-09	7.4E-09	7.1E-09	6.8E-09
WNW	9.5E-09	9.0E-09	8.6E-09	8.1E-09	7.7E-09	7.4E-09	7.0E-09
W	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.2E-08	1.2E-08
WSW	4.8E-08	4.5E-08	4.3E-08	4.1E-08	3.9E-08	3.7E-08	3.5E-08
SW	6.4E-08	6.1E-08	5.7E-08	5.5E-08	5.2E-08	5.0E-08	4.8E-08
SSW	2.0E-08	2.0E-08	1.9E-08	1.8E-08	1.8E-08	1.7E-08	1.7E-08
S	1.1E-08	1.1E-08	1.0E-08	1.0E-08	9.7E-09	9.4E-09	9.1E-09
SSE	7.3E-09	7.0E-09	6.7E-09	6.5E-09	6.2E-09	6.0E-09	5.8E-09
SE	9.9E-09	9.5E-09	9.2E-09	8.8E-09	8.5E-09	8.3E-09	8.0E-09
ESE	1.6E-08	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08
E	4.2E-08	4.1E-08	3.9E-08	3.8E-08	3.6E-08	3.5E-08	3.4E-08
ENE	5.7E-08	5.4E-08	5.2E-08	4.9E-08	4.8E-08	4.6E-08	4.4E-08
NE	5.3E-08	5.0E-08	4.7E-08	4.5E-08	4.2E-08	4.0E-08	3.9E-08
NNE	1.8E-08	1.7E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08

Mar 12, 2014 07:11 am SUMMARY

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	6.5E-09	6.3E-09	6.2E-09	6.0E-09	5.3E-09	5.1E-09	5.0E-09
NNW	4.5E-09	4.3E-09	4.2E-09	4.0E-09	3.4E-09	3.3E-09	3.2E-09
NW	6.6E-09	6.4E-09	6.2E-09	6.0E-09	5.1E-09	5.0E-09	4.8E-09
WNW	6.7E-09	6.4E-09	6.2E-09	6.0E-09	4.9E-09	4.8E-09	4.6E-09
W	1.1E-08	1.1E-08	1.0E-08	9.7E-09	7.9E-09	7.6E-09	7.4E-09
WSW	3.4E-08	3.3E-08	3.2E-08	3.0E-08	2.6E-08	2.5E-08	2.4E-08
SW	4.6E-08	4.4E-08	4.3E-08	4.1E-08	3.4E-08	3.3E-08	3.2E-08
SSW	1.6E-08	1.6E-08	1.5E-08	1.5E-08	1.3E-08	1.2E-08	1.2E-08
S	8.8E-09	8.6E-09	8.3E-09	8.1E-09	7.0E-09	6.8E-09	6.6E-09
SSE	5.6E-09	5.4E-09	5.3E-09	5.1E-09	4.4E-09	4.3E-09	4.2E-09
SE	7.8E-09	7.6E-09	7.4E-09	7.2E-09	6.4E-09	6.2E-09	6.1E-09
ESE	1.3E-08	1.2E-08	1.2E-08	1.2E-08	1.0E-08	1.0E-08	9.8E-09
E	3.3E-08	3.2E-08	3.2E-08	3.1E-08	2.7E-08	2.6E-08	2.5E-08
ENE	4.3E-08	4.1E-08	4.0E-08	3.9E-08	3.3E-08	3.2E-08	3.1E-08
NE	3.7E-08	3.6E-08	3.4E-08	3.3E-08	2.8E-08	2.7E-08	2.6E-08
NNE	1.3E-08	1.2E-08	1.2E-08	1.2E-08	1.0E-08	9.8E-09	9.5E-09

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	4.9E-09	3.8E-09	3.2E-09	2.6E-09	1.8E-09	1.5E-09
NNW	3.1E-09	2.4E-09	2.1E-09	1.7E-09	1.2E-09	9.9E-10
NW	4.7E-09	3.5E-09	2.9E-09	2.3E-09	1.5E-09	1.3E-09
WNW	4.5E-09	3.3E-09	2.7E-09	2.2E-09	1.4E-09	1.2E-09
W	7.2E-09	5.2E-09	4.4E-09	3.6E-09	2.4E-09	2.0E-09
WSW	2.3E-08	1.7E-08	1.4E-08	1.1E-08	6.8E-09	5.7E-09
SW	3.1E-08	2.2E-08	1.8E-08	1.3E-08	8.2E-09	6.8E-09
SSW	1.2E-08	8.6E-09	7.1E-09	5.5E-09	3.4E-09	2.9E-09
S	6.4E-09	4.7E-09	3.9E-09	3.1E-09	2.0E-09	1.7E-09
SSE	4.1E-09	3.1E-09	2.6E-09	2.1E-09	1.4E-09	1.2E-09
SE	5.9E-09	4.5E-09	3.8E-09	3.1E-09	2.0E-09	1.7E-09
ESE	9.6E-09	7.1E-09	5.9E-09	4.6E-09	3.0E-09	2.5E-09
E	2.4E-08	1.8E-08	1.4E-08	1.1E-08	7.0E-09	5.8E-09
ENE	3.0E-08	2.1E-08	1.7E-08	1.3E-08	8.2E-09	6.9E-09
NE	2.5E-08	1.7E-08	1.4E-08	1.1E-08	6.6E-09	5.5E-09
NNE	9.3E-09	6.9E-09	5.7E-09	4.5E-09	2.9E-09	2.4E-09

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                         C A P 8 8 - P C

                           Version 3.0

               Clean Air Act Assessment Package - 1988


                   S Y N O P S I S   R E P O R T

                  Non-Radon Individual Assessment
                       Mar  12, 2014  07:22 am


   Facility:  Radioactive Waste Processing Facility
    Address:  Benchmark Study
       City:  Oak Ridge
      State:  TN           Zip:    37831


   Source Category:  2 Stacks
       Source Type:  Stack
     Emission Year:  2010


   Comments:  Benchmark Study 2010
              2 Stacks, complete nuclides


               Effective Dose Equivalent
                      (mrem/year)
               _________________________

                        2.29E-01
               _________________________


  At This Location:   1400 Meters Southwest

      Dataset Name:  CAP88 Test2010
      Dataset Date:  3/12/2014 7:21:00 AM
         Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


             MAXIMALLY EXPOSED INDIVIDUAL


  Location Of The Individual:   1400 Meters Southwest
  Lifetime Fatal Cancer Risk:          1.39E-07
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2010

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	7.7E-07	4.3E-06	5.1E-06
Cr-51	S	1	0.0E+00	0.0E+00	0.0E+00
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	2.3E-05	6.0E-06	2.9E-05
I-125	F	1	2.5E-03	0.0E+00	2.5E-03
I-129	F	1	1.2E-05	0.0E+00	1.2E-05
I-131	F	1	1.1E-04	0.0E+00	1.1E-04
K-40	F	1	2.5E-05	0.0E+00	2.5E-05
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-106	S	1	0.0E+00	0.0E+00	0.0E+00
Mn-54	M	1	3.2E-07	0.0E+00	3.2E-07
Se-75	M	1	3.5E-05	0.0E+00	3.5E-05
Sb-124	M	1	5.8E-03	0.0E+00	5.8E-03
Sb-125	M	1	1.4E-04	0.0E+00	1.4E-04
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	1.1E+02	1.0E+00	1.1E+02
C-14	G	0	1.5E+01	5.2E-02	1.5E+01
Pu-238	M	1	4.5E-10	2.1E-09	2.5E-09
Pu-239	M	1	2.2E-09	6.5E-10	2.8E-09
Pu-240	M	1	2.2E-09	6.5E-10	2.8E-09
U-233	S	1	1.4E-07	1.4E-07	2.8E-07
U-234	S	1	1.4E-07	1.4E-07	2.8E-07
U-235	S	1	7.9E-09	4.6E-09	1.3E-08
U-236	S	1	7.9E-09	4.6E-09	1.3E-08
U-238	S	1	1.4E-07	1.4E-07	2.7E-07
Pu-241	M	1	2.9E-08	9.2E-08	1.2E-07
Sr-89	S	1	1.4E-08	5.2E-09	1.9E-08
Sr-90	S	1	5.0E-08	1.0E-07	1.5E-07
Fe-55	F	1	5.1E-07	1.0E-06	1.5E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	4.1E-06	9.7E-07	5.0E-06
Tc-99	M	1	2.2E-04	1.5E-07	2.2E-04
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	15 degrees C
Precipitation:	132 cm/y
Humidity:	10 g/cu m
Mixing Height:	592 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Version 3.0

Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 07:22 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2010

Comments: Benchmark Study 2010
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2010
Dataset Date: 3/12/2014 7:21:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	2.27E-01
INHALATION	2.34E-03
AIR IMMERSION	1.55E-06
GROUND SURFACE	3.44E-04
INTERNAL	2.29E-01
EXTERNAL	3.46E-04
TOTAL	2.29E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.88E-06
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	3.21E-05
Ba-137m	1.23E-06
I-125	9.24E-03
I-129	7.00E-04
I-131	6.65E-05
Xe-131m	0.00E+00
K-40	8.30E-06
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	3.94E-10
Se-75	7.56E-06
Sb-124	4.74E-04
Sb-125	6.57E-06
Te-125m	3.79E-08
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	2.43E-02
C-14	1.95E-01
Pu-238	7.13E-08
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	7.92E-08
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	7.92E-08
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.96E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.92E-06
U-235	7.76E-08
U-236	8.00E-08
U-238	1.62E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	8.03E-08
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.09E-10
Sr-90	1.77E-08
Y-90	0.00E+00
Fe-55	2.17E-08
Fe-59	0.00E+00
Ni-63	7.27E-09
Tc-99	9.84E-06
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	2.29E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	2.63E-09
Stomach	1.13E-08
Colon	2.61E-08
Liver	3.72E-09
LUNG	2.28E-08
Bone	2.26E-10
Skin	2.42E-10
Breast	1.07E-08
Ovary	3.00E-09
Bladder	5.94E-09
Kidneys	1.28E-09
Thyroid	1.34E-09
Leukemia	1.36E-08
Residual	3.65E-08
Total	1.39E-07
TOTAL	2.79E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	1.38E-07
INHALATION	1.34E-09
AIR IMMERSION	8.03E-13
GROUND SURFACE	1.83E-10
INTERNAL	1.39E-07
EXTERNAL	1.84E-10
TOTAL	1.39E-07

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.56E-12
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	1.63E-11
Ba-137m	6.65E-13
I-125	5.86E-10
I-129	3.52E-11
I-131	6.45E-12
Xe-131m	0.00E+00
K-40	7.72E-12
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	3.07E-16
Se-75	5.77E-12
Sb-124	3.43E-10
Sb-125	4.40E-12
Te-125m	1.47E-14
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	1.51E-08
C-14	1.23E-07
Pu-238	1.24E-14
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.25E-14
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.26E-14
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.49E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.46E-12
U-235	5.88E-14
U-236	6.07E-14
U-238	1.22E-12
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	6.84E-15
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	9.93E-17
Sr-90	1.22E-14
Y-90	0.00E+00
Fe-55	1.54E-14
Fe-59	0.00E+00
Ni-63	4.04E-15
Tc-99	9.40E-12
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.39E-07

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	3.2E-02	3.1E-02	2.9E-02	2.7E-02	2.6E-02	2.5E-02	2.4E-02
NNW	2.3E-02	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.7E-02
NW	3.1E-02	3.0E-02	2.9E-02	2.7E-02	2.6E-02	2.5E-02	2.4E-02
WNW	3.4E-02	3.2E-02	3.1E-02	2.9E-02	2.8E-02	2.6E-02	2.5E-02
W	5.9E-02	5.5E-02	5.2E-02	4.9E-02	4.6E-02	4.4E-02	4.1E-02
WSW	1.7E-01	1.6E-01	1.5E-01	1.4E-01	1.4E-01	1.3E-01	1.3E-01
SW	2.3E-01	2.2E-01	2.0E-01	1.9E-01	1.9E-01	1.8E-01	1.7E-01
SSW	7.3E-02	7.0E-02	6.8E-02	6.6E-02	6.4E-02	6.2E-02	6.0E-02
S	4.0E-02	3.8E-02	3.7E-02	3.6E-02	3.5E-02	3.4E-02	3.3E-02
SSE	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02	2.1E-02
SE	3.5E-02	3.4E-02	3.3E-02	3.2E-02	3.0E-02	3.0E-02	2.9E-02
ESE	5.8E-02	5.5E-02	5.3E-02	5.1E-02	5.0E-02	4.8E-02	4.7E-02
E	1.5E-01	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.3E-01	1.2E-01
ENE	2.0E-01	1.9E-01	1.8E-01	1.8E-01	1.7E-01	1.6E-01	1.6E-01
NE	1.9E-01	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.4E-01	1.4E-01
NNE	6.4E-02	6.0E-02	5.7E-02	5.4E-02	5.1E-02	4.9E-02	4.7E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	2.3E-02	2.3E-02	2.2E-02	2.1E-02	1.9E-02	1.8E-02	1.8E-02
NNW	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.2E-02	1.2E-02	1.2E-02
NW	2.3E-02	2.3E-02	2.2E-02	2.1E-02	1.8E-02	1.8E-02	1.7E-02
WNW	2.4E-02	2.3E-02	2.2E-02	2.1E-02	1.7E-02	1.7E-02	1.6E-02
W	3.9E-02	3.8E-02	3.6E-02	3.5E-02	2.8E-02	2.7E-02	2.6E-02
WSW	1.2E-01	1.2E-01	1.1E-01	1.1E-01	9.2E-02	8.8E-02	8.6E-02
SW	1.6E-01	1.6E-01	1.5E-01	1.5E-01	1.2E-01	1.2E-01	1.1E-01
SSW	5.8E-02	5.6E-02	5.5E-02	5.3E-02	4.6E-02	4.4E-02	4.3E-02
S	3.2E-02	3.1E-02	3.0E-02	2.9E-02	2.5E-02	2.4E-02	2.3E-02
SSE	2.0E-02	1.9E-02	1.9E-02	1.8E-02	1.6E-02	1.5E-02	1.5E-02
SE	2.8E-02	2.7E-02	2.6E-02	2.6E-02	2.3E-02	2.2E-02	2.2E-02
ESE	4.6E-02	4.4E-02	4.3E-02	4.2E-02	3.7E-02	3.6E-02	3.5E-02
E	1.2E-01	1.2E-01	1.1E-01	1.1E-01	9.5E-02	9.2E-02	8.9E-02
ENE	1.5E-01	1.5E-01	1.4E-01	1.4E-01	1.2E-01	1.1E-01	1.1E-01
NE	1.3E-01	1.3E-01	1.2E-01	1.2E-01	9.8E-02	9.4E-02	9.1E-02
NNE	4.6E-02	4.4E-02	4.3E-02	4.2E-02	3.6E-02	3.5E-02	3.4E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.7E-02	1.3E-02	1.1E-02	9.3E-03	6.2E-03	5.2E-03
NNW	1.1E-02	8.3E-03	7.3E-03	6.0E-03	4.1E-03	3.5E-03
NW	1.7E-02	1.2E-02	1.0E-02	8.1E-03	5.3E-03	4.4E-03
WNW	1.6E-02	1.1E-02	9.6E-03	7.6E-03	5.0E-03	4.2E-03
W	2.6E-02	1.8E-02	1.6E-02	1.3E-02	8.4E-03	7.1E-03
WSW	8.3E-02	5.9E-02	4.9E-02	3.8E-02	2.4E-02	2.0E-02
SW	1.1E-01	7.7E-02	6.2E-02	4.7E-02	2.9E-02	2.4E-02
SSW	4.2E-02	3.0E-02	2.5E-02	1.9E-02	1.2E-02	1.0E-02
S	2.3E-02	1.7E-02	1.4E-02	1.1E-02	7.0E-03	5.9E-03
SSE	1.5E-02	1.1E-02	9.2E-03	7.4E-03	4.9E-03	4.1E-03
SE	2.1E-02	1.6E-02	1.3E-02	1.1E-02	7.1E-03	6.0E-03
ESE	3.4E-02	2.5E-02	2.1E-02	1.6E-02	1.0E-02	8.8E-03
E	8.7E-02	6.3E-02	5.1E-02	3.9E-02	2.4E-02	2.0E-02
ENE	1.1E-01	7.6E-02	6.2E-02	4.7E-02	2.9E-02	2.4E-02
NE	8.9E-02	6.1E-02	5.0E-02	3.8E-02	2.3E-02	1.9E-02
NNE	3.3E-02	2.4E-02	2.0E-02	1.6E-02	1.0E-02	8.6E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	2.0E-08	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.5E-08	1.5E-08
NNW	1.4E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08
NW	1.9E-08	1.8E-08	1.7E-08	1.7E-08	1.6E-08	1.5E-08	1.5E-08
WNW	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.7E-08	1.6E-08	1.5E-08
W	3.6E-08	3.3E-08	3.1E-08	3.0E-08	2.8E-08	2.7E-08	2.5E-08
WSW	1.1E-07	9.9E-08	9.3E-08	8.8E-08	8.4E-08	8.0E-08	7.7E-08
SW	1.4E-07	1.3E-07	1.2E-07	1.2E-07	1.1E-07	1.1E-07	1.0E-07
SSW	4.4E-08	4.3E-08	4.1E-08	4.0E-08	3.9E-08	3.8E-08	3.6E-08
S	2.4E-08	2.3E-08	2.3E-08	2.2E-08	2.1E-08	2.1E-08	2.0E-08
SSE	1.6E-08	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08
SE	2.1E-08	2.1E-08	2.0E-08	1.9E-08	1.9E-08	1.8E-08	1.7E-08
ESE	3.5E-08	3.4E-08	3.2E-08	3.1E-08	3.0E-08	2.9E-08	2.9E-08
E	9.2E-08	8.8E-08	8.5E-08	8.2E-08	7.9E-08	7.7E-08	7.4E-08
ENE	1.2E-07	1.2E-07	1.1E-07	1.1E-07	1.0E-07	9.9E-08	9.6E-08
NE	1.2E-07	1.1E-07	1.0E-07	9.7E-08	9.2E-08	8.8E-08	8.4E-08
NNE	3.9E-08	3.7E-08	3.5E-08	3.3E-08	3.1E-08	3.0E-08	2.9E-08

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.2E-08	1.1E-08	1.1E-08
NNW	9.8E-09	9.4E-09	9.1E-09	8.8E-09	7.5E-09	7.3E-09	7.1E-09
NW	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.1E-08	1.1E-08	1.1E-08
WNW	1.5E-08	1.4E-08	1.3E-08	1.3E-08	1.1E-08	1.0E-08	1.0E-08
W	2.4E-08	2.3E-08	2.2E-08	2.1E-08	1.7E-08	1.7E-08	1.6E-08
WSW	7.4E-08	7.1E-08	6.9E-08	6.6E-08	5.6E-08	5.4E-08	5.2E-08
SW	1.0E-07	9.6E-08	9.3E-08	9.0E-08	7.4E-08	7.2E-08	7.0E-08
SSW	3.5E-08	3.4E-08	3.3E-08	3.3E-08	2.8E-08	2.7E-08	2.6E-08
S	1.9E-08	1.9E-08	1.8E-08	1.8E-08	1.5E-08	1.5E-08	1.4E-08
SSE	1.2E-08	1.2E-08	1.1E-08	1.1E-08	9.7E-09	9.4E-09	9.1E-09
SE	1.7E-08	1.7E-08	1.6E-08	1.6E-08	1.4E-08	1.4E-08	1.3E-08
ESE	2.8E-08	2.7E-08	2.6E-08	2.6E-08	2.3E-08	2.2E-08	2.1E-08
E	7.2E-08	7.0E-08	6.9E-08	6.7E-08	5.8E-08	5.6E-08	5.5E-08
ENE	9.3E-08	9.0E-08	8.7E-08	8.5E-08	7.2E-08	6.9E-08	6.7E-08
NE	8.1E-08	7.8E-08	7.5E-08	7.2E-08	6.0E-08	5.8E-08	5.6E-08
NNE	2.8E-08	2.7E-08	2.6E-08	2.5E-08	2.2E-08	2.1E-08	2.1E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.1E-08	8.1E-09	7.1E-09	5.8E-09	3.9E-09	3.3E-09
NNW	6.9E-09	5.1E-09	4.5E-09	3.8E-09	2.6E-09	2.2E-09
NW	1.0E-08	7.5E-09	6.4E-09	5.1E-09	3.3E-09	2.8E-09
WNW	9.8E-09	7.0E-09	5.9E-09	4.7E-09	3.1E-09	2.6E-09
W	1.6E-08	1.1E-08	9.6E-09	7.8E-09	5.3E-09	4.5E-09
WSW	5.1E-08	3.6E-08	3.0E-08	2.4E-08	1.5E-08	1.2E-08
SW	6.8E-08	4.7E-08	3.8E-08	2.9E-08	1.8E-08	1.5E-08
SSW	2.6E-08	1.9E-08	1.5E-08	1.2E-08	7.6E-09	6.4E-09
S	1.4E-08	1.0E-08	8.6E-09	6.8E-09	4.4E-09	3.7E-09
SSE	8.9E-09	6.7E-09	5.7E-09	4.6E-09	3.1E-09	2.6E-09
SE	1.3E-08	9.8E-09	8.4E-09	6.7E-09	4.4E-09	3.8E-09
ESE	2.1E-08	1.5E-08	1.3E-08	1.0E-08	6.5E-09	5.5E-09
E	5.3E-08	3.9E-08	3.2E-08	2.5E-08	1.5E-08	1.3E-08
ENE	6.5E-08	4.6E-08	3.8E-08	2.9E-08	1.8E-08	1.5E-08
NE	5.4E-08	3.8E-08	3.1E-08	2.3E-08	1.4E-08	1.2E-08
NNE	2.0E-08	1.5E-08	1.3E-08	9.9E-09	6.4E-09	5.4E-09

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                          C A P 8 8 - P C

                           Version 3.0

              Clean Air Act Assessment Package - 1988


                    S Y N O P S I S   R E P O R T

                 Non-Radon Individual Assessment
                      Mar  12, 2014  07:28 am


    Facility:  Radioactive Waste Processing Facility
     Address:  Benchmark Study
        City:  Oak Ridge
       State:  TN           Zip:    37831


    Source Category:  2 Stacks
        Source Type:  Stack
      Emission Year:  2011


    Comments:  Benchmark Study 2011
               2 Stacks, complete nuclides


                Effective Dose Equivalent
                       (mrem/year)
                _________________________

                         1.57E-01
                _________________________


   At This Location:   1400 Meters Southwest

       Dataset Name:  CAP88 Test2011
       Dataset Date:  3/12/2014 7:27:00 AM
          Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


              MAXIMALLY EXPOSED INDIVIDUAL


   Location Of The Individual:   1400 Meters Southwest
   Lifetime Fatal Cancer Risk:          9.32E-08
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2011

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	0.0E+00	4.1E-07	4.1E-07
Cr-51	S	1	0.0E+00	0.0E+00	0.0E+00
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	4.8E-06	9.0E-06	1.4E-05
I-125	F	1	2.9E-03	0.0E+00	2.9E-03
I-129	F	1	0.0E+00	0.0E+00	0.0E+00
I-131	F	1	5.9E-05	2.4E-07	5.9E-05
K-40	F	1	7.3E-06	8.6E-07	8.2E-06
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	1.5E-07	0.0E+00	1.5E-07
Ru-103	S	1	0.0E+00	9.6E-08	9.6E-08
Ru-106	S	1	0.0E+00	0.0E+00	0.0E+00
Mn-54	M	1	0.0E+00	0.0E+00	0.0E+00
Se-75	M	1	1.7E-05	0.0E+00	1.7E-05
Sb-124	M	1	5.5E-04	0.0E+00	5.5E-04
Sb-125	M	1	6.6E-05	0.0E+00	6.6E-05
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	1.0E+02	7.0E+00	1.1E+02
C-14	G	0	9.5E+00	3.8E-02	9.6E+00
Pu-238	M	1	5.9E-10	4.2E-10	1.0E-09
Pu-239	M	1	3.9E-09	2.6E-10	4.2E-09
Pu-240	M	1	3.9E-09	2.6E-10	4.2E-09
U-233	S	1	1.8E-07	3.8E-08	2.2E-07
U-234	S	1	1.8E-07	3.8E-08	2.2E-07
U-235	S	1	9.6E-09	1.8E-09	1.1E-08
U-236	S	1	9.6E-09	1.8E-09	1.1E-08
U-238	S	1	1.8E-07	4.5E-08	2.2E-07
Pu-241	M	1	6.3E-08	6.1E-08	1.2E-07
Sr-89	S	1	8.3E-08	1.3E-07	2.1E-07
Sr-90	S	1	3.3E-07	3.8E-08	3.7E-07
Fe-55	F	1	2.6E-06	1.5E-06	4.1E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	7.0E-06	2.7E-07	7.3E-06
Tc-99	M	1	3.1E-05	1.3E-09	3.1E-05
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	16 degrees C
Precipitation:	128 cm/y
Humidity:	10 g/cu m
Mixing Height:	661 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Version 3.0

Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 07:28 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN   Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2011

Comments: Benchmark Study 2011
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2011
Dataset Date: 3/12/2014 7:27:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.55E-01
INHALATION	2.26E-03
AIR IMMERSION	2.17E-07
GROUND SURFACE	5.80E-05
INTERNAL	1.57E-01
EXTERNAL	5.82E-05
TOTAL	1.57E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.49E-07
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	1.53E-05
Ba-137m	5.87E-07
I-125	1.05E-02
I-129	0.00E+00
I-131	3.68E-05
Xe-131m	0.00E+00
K-40	2.65E-06
Nb-94	0.00E+00
Nb-95	2.08E-10
Ru-103	2.16E-10
Rh-103m	1.78E-14
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	3.72E-06
Sb-124	4.45E-05
Sb-125	3.11E-06
Te-125m	1.79E-08
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	2.42E-02
C-14	1.22E-01
Pu-238	0.00E+00
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.42E-07
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.42E-07
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.55E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.52E-06
U-235	6.99E-08
U-236	7.21E-08
U-238	1.30E-06
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	8.16E-08
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.24E-09
Sr-90	4.15E-08
Y-90	0.00E+00
Fe-55	5.75E-08
Fe-59	0.00E+00
Ni-63	1.04E-08
Tc-99	1.39E-06
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.57E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	1.75E-09
Stomach	7.62E-09
Colon	1.74E-08
Liver	2.47E-09
LUNG	1.52E-08
Bone	1.50E-10
Skin	1.61E-10
Breast	7.14E-09
Ovary	2.00E-09
Bladder	3.96E-09
Kidneys	8.53E-10
Thyroid	1.13E-09
Leukemia	9.06E-09
Residual	2.43E-08
Total	9.32E-08
TOTAL	1.86E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	9.19E-08
INHALATION	1.28E-09
AIR IMMERSION	8.86E-14
GROUND SURFACE	2.76E-11
INTERNAL	9.31E-08
EXTERNAL	2.77E-11
TOTAL	9.32E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.24E-13
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	7.76E-12
Ba-137m	3.17E-13
I-125	6.64E-10
I-129	0.00E+00
I-131	3.57E-12
Xe-131m	0.00E+00
K-40	2.46E-12
Nb-94	0.00E+00
Nb-95	1.74E-16
Ru-103	1.88E-16
Rh-103m	1.43E-20
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	2.84E-12
Sb-124	3.22E-11
Sb-125	2.08E-12
Te-125m	6.95E-15
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	1.50E-08
C-14	7.74E-08
Pu-238	0.00E+00
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	2.25E-14
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	2.25E-14
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.17E-12
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.15E-12
U-235	5.30E-14
U-236	5.47E-14
U-238	9.79E-13
Th-234	0.00E+00
Pa-234m	0.00E+00
Pa-234	0.00E+00
Pu-241	6.95E-15
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	1.12E-15
Sr-90	2.86E-14
Y-90	0.00E+00
Fe-55	4.08E-14
Fe-59	0.00E+00
Ni-63	5.80E-15
Tc-99	1.33E-12
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	9.32E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

Direction	Distance (m) 1400	1500	1600	1700	1800	1900	2000
N	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.6E-02
NNW	1.5E-02	1.5E-02	1.4E-02	1.3E-02	1.2E-02	1.2E-02	1.1E-02
NW	2.1E-02	2.0E-02	1.9E-02	1.9E-02	1.8E-02	1.7E-02	1.7E-02
WNW	2.3E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02
W	4.0E-02	3.7E-02	3.5E-02	3.3E-02	3.1E-02	3.0E-02	2.8E-02
WSW	1.2E-01	1.1E-01	1.0E-01	9.9E-02	9.4E-02	9.0E-02	8.6E-02
SW	1.6E-01	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01	1.2E-01
SSW	5.0E-02	4.8E-02	4.6E-02	4.5E-02	4.3E-02	4.2E-02	4.1E-02
S	2.7E-02	2.6E-02	2.5E-02	2.4E-02	2.4E-02	2.3E-02	2.2E-02
SSE	1.8E-02	1.7E-02	1.6E-02	1.6E-02	1.5E-02	1.5E-02	1.4E-02
SE	2.4E-02	2.3E-02	2.2E-02	2.2E-02	2.1E-02	2.0E-02	2.0E-02
ESE	3.9E-02	3.8E-02	3.6E-02	3.5E-02	3.4E-02	3.3E-02	3.2E-02
E	1.0E-01	9.9E-02	9.5E-02	9.2E-02	8.9E-02	8.6E-02	8.3E-02
ENE	1.4E-01	1.3E-01	1.3E-01	1.2E-01	1.2E-01	1.1E-01	1.1E-01
NE	1.3E-01	1.2E-01	1.1E-01	1.1E-01	1.0E-01	9.9E-02	9.4E-02
NNE	4.4E-02	4.1E-02	3.9E-02	3.7E-02	3.5E-02	3.4E-02	3.2E-02

Direction	Distance (m) 2100	2200	2300	2400	3000	3100	3200
N	1.6E-02	1.5E-02	1.5E-02	1.5E-02	1.3E-02	1.2E-02	1.2E-02
NNW	1.1E-02	1.0E-02	1.0E-02	9.7E-03	8.3E-03	8.0E-03	7.7E-03
NW	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.2E-02	1.2E-02	1.1E-02
WNW	1.6E-02	1.6E-02	1.5E-02	1.4E-02	1.2E-02	1.1E-02	1.1E-02
W	2.7E-02	2.6E-02	2.5E-02	2.4E-02	1.9E-02	1.8E-02	1.8E-02
WSW	8.2E-02	7.9E-02	7.7E-02	7.4E-02	6.2E-02	6.0E-02	5.8E-02
SW	1.1E-01	1.1E-01	1.0E-01	1.0E-01	8.3E-02	8.0E-02	7.7E-02
SSW	3.9E-02	3.8E-02	3.7E-02	3.6E-02	3.1E-02	3.0E-02	2.9E-02
S	2.1E-02	2.1E-02	2.0E-02	2.0E-02	1.7E-02	1.6E-02	1.6E-02
SSE	1.4E-02	1.3E-02	1.3E-02	1.2E-02	1.1E-02	1.0E-02	1.0E-02
SE	1.9E-02	1.8E-02	1.8E-02	1.8E-02	1.5E-02	1.5E-02	1.5E-02
ESE	3.1E-02	3.0E-02	2.9E-02	2.9E-02	2.5E-02	2.4E-02	2.4E-02
E	8.1E-02	7.9E-02	7.7E-02	7.5E-02	6.5E-02	6.2E-02	6.1E-02
ENE	1.0E-01	1.0E-01	9.8E-02	9.5E-02	8.0E-02	7.7E-02	7.5E-02
NE	9.1E-02	8.7E-02	8.4E-02	8.1E-02	6.7E-02	6.4E-02	6.2E-02
NNE	3.1E-02	3.0E-02	2.9E-02	2.8E-02	2.4E-02	2.4E-02	2.3E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.2E-02	8.8E-03	7.6E-03	6.2E-03	4.1E-03	3.5E-03
NNW	7.6E-03	5.6E-03	4.9E-03	4.0E-03	2.7E-03	2.3E-03
NW	1.1E-02	8.2E-03	6.8E-03	5.4E-03	3.5E-03	2.9E-03
WNW	1.1E-02	7.6E-03	6.3E-03	5.0E-03	3.3E-03	2.8E-03
W	1.7E-02	1.2E-02	1.0E-02	8.4E-03	5.6E-03	4.7E-03
WSW	5.6E-02	4.0E-02	3.3E-02	2.5E-02	1.6E-02	1.3E-02
SW	7.5E-02	5.2E-02	4.2E-02	3.2E-02	1.9E-02	1.6E-02
SSW	2.8E-02	2.1E-02	1.7E-02	1.3E-02	8.1E-03	6.7E-03
S	1.5E-02	1.1E-02	9.3E-03	7.3E-03	4.7E-03	3.9E-03
SSE	9.8E-03	7.3E-03	6.2E-03	5.0E-03	3.3E-03	2.8E-03
SE	1.4E-02	1.1E-02	9.1E-03	7.3E-03	4.7E-03	4.0E-03
ESE	2.3E-02	1.7E-02	1.4E-02	1.1E-02	7.0E-03	5.8E-03
E	5.9E-02	4.2E-02	3.5E-02	2.7E-02	1.6E-02	1.4E-02
ENE	7.3E-02	5.1E-02	4.1E-02	3.2E-02	1.9E-02	1.6E-02
NE	6.0E-02	4.2E-02	3.4E-02	2.5E-02	1.5E-02	1.3E-02
NNE	2.2E-02	1.6E-02	1.4E-02	1.1E-02	6.7E-03	5.7E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.8E-09
NNW	9.1E-09	8.6E-09	8.2E-09	7.8E-09	7.4E-09	7.1E-09	6.8E-09
NW	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.9E-09
WNW	1.4E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08	1.0E-08
W	2.4E-08	2.2E-08	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.7E-08
WSW	7.0E-08	6.6E-08	6.2E-08	5.9E-08	5.6E-08	5.3E-08	5.1E-08
SW	9.3E-08	8.8E-08	8.3E-08	7.9E-08	7.6E-08	7.2E-08	6.9E-08
SSW	3.0E-08	2.9E-08	2.8E-08	2.7E-08	2.6E-08	2.5E-08	2.4E-08
S	1.6E-08	1.6E-08	1.5E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08
SSE	1.1E-08	1.0E-08	9.7E-09	9.4E-09	9.0E-09	8.7E-09	8.4E-09
SE	1.4E-08	1.4E-08	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.2E-08
ESE	2.3E-08	2.2E-08	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.9E-08
E	6.1E-08	5.9E-08	5.7E-08	5.5E-08	5.3E-08	5.1E-08	5.0E-08
ENE	8.2E-08	7.8E-08	7.5E-08	7.2E-08	6.9E-08	6.6E-08	6.4E-08
NE	7.7E-08	7.2E-08	6.8E-08	6.5E-08	6.2E-08	5.9E-08	5.6E-08
NNE	2.6E-08	2.4E-08	2.3E-08	2.2E-08	2.1E-08	2.0E-08	1.9E-08

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	9.5E-09	9.2E-09	8.9E-09	8.7E-09	7.6E-09	7.4E-09	7.2E-09
NNW	6.5E-09	6.3E-09	6.0E-09	5.8E-09	5.0E-09	4.8E-09	4.7E-09
NW	9.6E-09	9.2E-09	8.9E-09	8.7E-09	7.4E-09	7.1E-09	6.9E-09
WNW	9.8E-09	9.4E-09	9.0E-09	8.7E-09	7.1E-09	6.8E-09	6.6E-09
W	1.6E-08	1.5E-08	1.5E-08	1.4E-08	1.1E-08	1.1E-08	1.1E-08
WSW	4.9E-08	4.7E-08	4.6E-08	4.4E-08	3.7E-08	3.6E-08	3.5E-08
SW	6.7E-08	6.4E-08	6.2E-08	6.0E-08	5.0E-08	4.8E-08	4.6E-08
SSW	2.4E-08	2.3E-08	2.2E-08	2.2E-08	1.9E-08	1.8E-08	1.8E-08
S	1.3E-08	1.2E-08	1.2E-08	1.2E-08	1.0E-08	9.8E-09	9.5E-09
SSE	8.1E-09	7.9E-09	7.6E-09	7.4E-09	6.4E-09	6.2E-09	6.1E-09
SE	1.1E-08	1.1E-08	1.1E-08	1.0E-08	9.3E-09	9.0E-09	8.8E-09
ESE	1.9E-08	1.8E-08	1.8E-08	1.7E-08	1.5E-08	1.5E-08	1.4E-08
E	4.8E-08	4.7E-08	4.6E-08	4.5E-08	3.9E-08	3.7E-08	3.6E-08
ENE	6.2E-08	6.0E-08	5.8E-08	5.7E-08	4.8E-08	4.6E-08	4.5E-08
NE	5.4E-08	5.2E-08	5.0E-08	4.8E-08	4.0E-08	3.8E-08	3.7E-08
NNE	1.9E-08	1.8E-08	1.7E-08	1.7E-08	1.5E-08	1.4E-08	1.4E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	7.1E-09	5.4E-09	4.6E-09	3.8E-09	2.5E-09	2.2E-09
NNW	4.6E-09	3.4E-09	3.0E-09	2.5E-09	1.7E-09	1.4E-09
NW	6.8E-09	5.0E-09	4.2E-09	3.3E-09	2.2E-09	1.8E-09
WNW	6.5E-09	4.6E-09	3.9E-09	3.1E-09	2.0E-09	1.7E-09
W	1.0E-08	7.4E-09	6.3E-09	5.1E-09	3.5E-09	2.9E-09
WSW	3.4E-08	2.4E-08	2.0E-08	1.6E-08	9.8E-09	8.2E-09
SW	4.5E-08	3.2E-08	2.6E-08	2.0E-08	1.2E-08	9.9E-09
SSW	1.7E-08	1.2E-08	1.0E-08	8.0E-09	5.0E-09	4.2E-09
S	9.3E-09	6.8E-09	5.7E-09	4.5E-09	2.9E-09	2.5E-09
SSE	5.9E-09	4.4E-09	3.8E-09	3.1E-09	2.0E-09	1.7E-09
SE	8.6E-09	6.5E-09	5.5E-09	4.5E-09	2.9E-09	2.5E-09
ESE	1.4E-08	1.0E-08	8.6E-09	6.8E-09	4.3E-09	3.7E-09
E	3.5E-08	2.6E-08	2.1E-08	1.6E-08	1.0E-08	8.5E-09
ENE	4.4E-08	3.1E-08	2.5E-08	1.9E-08	1.2E-08	1.0E-08
NE	3.6E-08	2.5E-08	2.0E-08	1.6E-08	9.6E-09	8.0E-09
NNE	1.3E-08	9.8E-09	8.3E-09	6.5E-09	4.2E-09	3.5E-09

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                         C A P 8 8 - P C

                          Version 3.0

              Clean Air Act Assessment Package - 1988


                   S Y N O P S I S   R E P O R T

                 Non-Radon Individual Assessment
                      Mar  12, 2014  07:36 am


   Facility:  Radioactive Waste Processing Facility
    Address:  Benchmark Study
       City:  Oak Ridge
      State:  TN          Zip:    37831


   Source Category:  2 Stacks
       Source Type:  Stack
     Emission Year:  2012


   Comments:  Benchmark Study 2012
              2 Stacks, complete nuclides


               Effective Dose Equivalent
                      (mrem/year)
               _________________________

                       2.02E-01
               _________________________


  At This Location:   1400 Meters Southwest

      Dataset Name:  CAP88 Test2012
      Dataset Date:  3/12/2014 7:36:00 AM
         Wind File:  C:\CAP88-PC\CAP88PCV3_020913\DISK1\program f


             MAXIMALLY EXPOSED INDIVIDUAL


  Location Of The Individual:   1400 Meters Southwest
  Lifetime Fatal Cancer Risk:          1.20E-07
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RADIONUCLIDE EMISSIONS DURING THE YEAR 2012

Nuclide	Type	Size	Source #1 Ci/y	Source #2 Ci/y	TOTAL Ci/y
Ag-110m	S	1	0.0E+00	0.0E+00	0.0E+00
Ce-144	S	1	0.0E+00	0.0E+00	0.0E+00
Co-57	S	1	0.0E+00	0.0E+00	0.0E+00
Co-58	S	1	0.0E+00	0.0E+00	0.0E+00
Co-60	S	1	5.6E-06	0.0E+00	5.6E-06
Cr-51	S	1	0.0E+00	0.0E+00	0.0E+00
Cs-134	F	1	0.0E+00	0.0E+00	0.0E+00
Cs-137	F	1	3.2E-06	3.2E-04	3.3E-04
I-125	F	1	2.9E-03	2.0E-05	2.9E-03
I-129	F	1	2.2E-05	0.0E+00	2.2E-05
I-131	F	1	1.4E-07	0.0E+00	1.4E-07
K-40	F	1	4.3E-05	3.3E-05	7.6E-05
Nb-94	S	1	0.0E+00	0.0E+00	0.0E+00
Nb-95	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-103	S	1	0.0E+00	0.0E+00	0.0E+00
Ru-106	S	1	0.0E+00	0.0E+00	0.0E+00
Mn-54	M	1	0.0E+00	0.0E+00	0.0E+00
Se-75	M	1	7.2E-06	0.0E+00	7.2E-06
Sb-124	M	1	1.0E-03	0.0E+00	1.0E-03
Sb-125	M	1	1.0E-04	0.0E+00	1.0E-04
Sn-113	M	1	0.0E+00	0.0E+00	0.0E+00
H-3	V	0	3.1E+02	2.6E+00	3.2E+02
C-14	G	0	9.0E+00	3.3E-01	9.4E+00
Pu-238	M	1	2.8E-10	7.5E-09	7.7E-09
Pu-239	M	1	2.1E-09	1.8E-08	2.0E-08
Pu-240	M	1	2.1E-09	1.8E-08	2.0E-08
U-233	S	1	1.3E-07	3.7E-08	1.7E-07
U-234	S	1	1.3E-07	3.7E-08	1.7E-07
U-235	S	1	7.5E-09	8.5E-09	1.6E-08
U-236	S	1	7.5E-09	8.5E-09	1.6E-08
U-238	S	1	1.2E-05	2.7E-08	1.2E-05
Pu-241	M	1	1.7E-07	8.3E-08	2.5E-07
Sr-89	S	1	0.0E+00	6.2E-07	6.2E-07
Sr-90	S	1	3.5E-08	1.4E-06	1.4E-06
Fe-55	F	1	6.9E-07	1.4E-06	2.1E-06
Fe-59	F	1	0.0E+00	0.0E+00	0.0E+00
Ni-63	V	0	2.2E-06	1.5E-06	3.7E-06
Tc-99	M	1	6.3E-06	0.0E+00	6.3E-06
Zn-65	S	1	0.0E+00	0.0E+00	0.0E+00
Zr-95	F	1	0.0E+00	0.0E+00	0.0E+00

SITE INFORMATION

Temperature:	16 degrees C
Precipitation:	128 cm/y
Humidity:	10 g/cu m
Mixing Height:	661 m

SOURCE INFORMATION

Source Number:	1	2
Stack Height (m):	30.00	22.00
Diameter (m):	2.69	2.74
Plume Rise Momentum (m/s): (Exit Velocity)	10.54	15.97

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES (M) USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1400	1500	1600	1700	1800	1900	2000
2100	2200	2300	2400	3000	3100	3200
3300	4700	5800	7500	11700	13800	

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Clean Air Act Assessment Package - 1988

D O S E   A N D   R I S K   E Q U I V A L E N T   S U M M A R I E S

Non-Radon Individual Assessment
Mar 12, 2014 07:36 am

Facility: Radioactive Waste Processing Facility
Address: Benchmark Study
City: Oak Ridge
State: TN Zip: 37831

Source Category: 2 Stacks
Source Type: Stack
Emission Year: 2012

Comments: Benchmark Study 2012
2 Stacks, complete nuclides

Dataset Name: CAP88 Test2012
Dataset Date: 3/12/2014 7:36:00 AM
Wind File: . C:\CAP88-PC\CAP88PCV3_020913\DISK1\program files\CAP88-PC30\WindLib\ST04W60.WND

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.95E-01
INHALATION	6.50E-03
AIR IMMERSION	3.58E-07
GROUND SURFACE	9.97E-05
INTERNAL	2.01E-01
EXTERNAL	1.00E-04
TOTAL	2.02E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.99E-06
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	3.63E-04
Ba-137m	1.39E-05
I-125	1.05E-02
I-129	1.36E-03
I-131	6.99E-10
Xe-131m	0.00E+00
K-40	2.48E-05
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	1.54E-06
Sb-124	8.36E-05
Sb-125	4.79E-06
Te-125m	2.76E-08
Sn-113	0.00E+00
In-113m	0.00E+00

H-3	6.94E-02
C-14	1.20E-01
Pu-238	2.57E-07
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	7.36E-07
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	7.36E-07
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00
Ac-228	0.00E+00
Th-228	0.00E+00
U-233	1.17E-06
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	1.14E-06
U-235	9.95E-08
U-236	1.03E-07
U-238	7.65E-05
Th-234	5.67E-09
Pa-234m	8.08E-08
Pa-234	0.00E+00
Pu-241	1.64E-07
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	2.40E-08
Sr-90	1.36E-06
Y-90	1.15E-08
Fe-55	2.87E-08
Fe-59	0.00E+00
Ni-63	5.36E-09
Tc-99	2.83E-07
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	2.02E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
Esophagu	2.25E-09
Stomach	1.02E-08
Colon	2.26E-08
Liver	3.17E-09
LUNG	1.95E-08
Bone	1.93E-10
Skin	2.06E-10
Breast	9.13E-09
Ovary	2.56E-09
Bladder	5.08E-09
Kidneys	1.09E-09
Thyroid	1.33E-09
Leukemia	1.16E-08
Residual	3.11E-08
Total	1.20E-07
TOTAL	2.40E-07

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	1.16E-07
INHALATION	3.69E-09
AIR IMMERSION	1.66E-13
GROUND SURFACE	4.99E-11
INTERNAL	1.20E-07
EXTERNAL	5.01E-11
TOTAL	1.20E-07

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
Ag-110m	0.00E+00
Ag-110	0.00E+00
Ce-144	0.00E+00
Pr-144m	0.00E+00
Pr-144	0.00E+00
Co-57	0.00E+00
Co-58	0.00E+00
Co-60	1.65E-12
Cr-51	0.00E+00
Cs-134	0.00E+00
Cs-137	1.84E-10
Ba-137m	7.51E-12
I-125	6.69E-10
I-129	6.85E-11
I-131	5.54E-17
Xe-131m	0.00E+00
K-40	2.31E-11
Nb-94	0.00E+00
Nb-95	0.00E+00
Ru-103	0.00E+00
Rh-103m	0.00E+00
Ru-106	0.00E+00
Rh-106	0.00E+00
Mn-54	0.00E+00
Se-75	1.18E-12
Sb-124	6.05E-11
Sb-125	3.20E-12
Te-125m	1.07E-14
Sn-113	0.00E+00
In-113m	0.00E+00
H-3	4.31E-08
C-14	7.58E-08
Pu-238	4.47E-14
U-234	0.00E+00
Th-230	0.00E+00
Ra-226	0.00E+00
Rn-222	0.00E+00
Po-218	0.00E+00
Pu-239	1.17E-13
U-235	0.00E+00
Th-231	0.00E+00
Pa-231	0.00E+00
Ac-227	0.00E+00
Th-227	0.00E+00
Fr-223	0.00E+00
Pu-240	1.17E-13
U-236	0.00E+00
Th-232	0.00E+00
Ra-228	0.00E+00

Ac-228	0.00E+00
Th-228	0.00E+00
U-233	8.83E-13
Th-229	0.00E+00
Ra-225	0.00E+00
U-234	8.68E-13
U-235	7.54E-14
U-236	7.79E-14
U-238	5.50E-11
Th-234	2.96E-15
Pa-234m	1.29E-14
Pa-234	0.00E+00
Pu-241	1.40E-14
Am-241	0.00E+00
Np-237	0.00E+00
U-237	0.00E+00
Sr-89	2.63E-14
Sr-90	8.11E-13
Y-90	1.38E-15
Fe-55	2.04E-14
Fe-59	0.00E+00
Ni-63	2.98E-15
Tc-99	2.70E-13
Zn-65	0.00E+00
Zr-95	0.00E+00
Nb-95m	0.00E+00
Nb-95	0.00E+00
TOTAL	1.20E-07

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	2.8E-02	2.7E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02
NNW	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.6E-02	1.5E-02	1.5E-02
NW	2.7E-02	2.6E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02	2.1E-02
WNW	3.0E-02	2.8E-02	2.7E-02	2.5E-02	2.4E-02	2.3E-02	2.2E-02
W	5.1E-02	4.8E-02	4.5E-02	4.3E-02	4.0E-02	3.8E-02	3.6E-02
WSW	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01	1.2E-01	1.1E-01
SW	2.0E-01	1.9E-01	1.8E-01	1.7E-01	1.6E-01	1.6E-01	1.5E-01
SSW	6.4E-02	6.2E-02	6.0E-02	5.8E-02	5.6E-02	5.4E-02	5.2E-02
S	3.5E-02	3.4E-02	3.3E-02	3.1E-02	3.0E-02	2.9E-02	2.8E-02
SSE	2.3E-02	2.2E-02	2.1E-02	2.0E-02	1.9E-02	1.9E-02	1.8E-02
SE	3.1E-02	3.0E-02	2.9E-02	2.8E-02	2.7E-02	2.6E-02	2.5E-02
ESE	5.1E-02	4.9E-02	4.7E-02	4.5E-02	4.4E-02	4.2E-02	4.1E-02
E	1.3E-01	1.3E-01	1.2E-01	1.2E-01	1.1E-01	1.1E-01	1.1E-01
ENE	1.8E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01	1.4E-01	1.4E-01
NE	1.7E-01	1.6E-01	1.5E-01	1.4E-01	1.3E-01	1.3E-01	1.2E-01
NNE	5.6E-02	5.3E-02	5.0E-02	4.7E-02	4.5E-02	4.3E-02	4.1E-02

	Distance (m)						
Direction	2100	2200	2300	2400	3000	3100	3200
N	2.0E-02	2.0E-02	1.9E-02	1.9E-02	1.6E-02	1.6E-02	1.5E-02
NNW	1.4E-02	1.3E-02	1.3E-02	1.3E-02	1.1E-02	1.0E-02	9.9E-03
NW	2.0E-02	2.0E-02	1.9E-02	1.9E-02	1.6E-02	1.5E-02	1.5E-02
WNW	2.1E-02	2.0E-02	1.9E-02	1.9E-02	1.5E-02	1.5E-02	1.4E-02
W	3.4E-02	3.3E-02	3.1E-02	3.0E-02	2.4E-02	2.4E-02	2.3E-02
WSW	1.1E-01	1.0E-01	9.8E-02	9.5E-02	8.0E-02	7.7E-02	7.5E-02
SW	1.4E-01	1.4E-01	1.3E-01	1.3E-01	1.1E-01	1.0E-01	9.9E-02
SSW	5.1E-02	4.9E-02	4.8E-02	4.7E-02	4.0E-02	3.9E-02	3.8E-02
S	2.8E-02	2.7E-02	2.6E-02	2.5E-02	2.2E-02	2.1E-02	2.0E-02
SSE	1.7E-02	1.7E-02	1.6E-02	1.6E-02	1.4E-02	1.3E-02	1.3E-02
SE	2.4E-02	2.4E-02	2.3E-02	2.3E-02	2.0E-02	1.9E-02	1.9E-02
ESE	4.0E-02	3.9E-02	3.8E-02	3.7E-02	3.2E-02	3.1E-02	3.1E-02
E	1.0E-01	1.0E-01	9.9E-02	9.6E-02	8.3E-02	8.0E-02	7.8E-02
ENE	1.3E-01	1.3E-01	1.3E-01	1.2E-01	1.0E-01	9.9E-02	9.6E-02
NE	1.2E-01	1.1E-01	1.1E-01	1.0E-01	8.6E-02	8.2E-02	8.0E-02
NNE	4.0E-02	3.9E-02	3.8E-02	3.6E-02	3.1E-02	3.0E-02	2.9E-02

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)					
Direction	3300	4700	5800	7500	11700	13800
N	1.5E-02	1.1E-02	9.7E-03	7.9E-03	5.3E-03	4.5E-03
NNW	9.7E-03	7.2E-03	6.2E-03	5.1E-03	3.5E-03	2.9E-03
NW	1.4E-02	1.0E-02	8.8E-03	7.0E-03	4.5E-03	3.8E-03
WNW	1.4E-02	9.7E-03	8.2E-03	6.5E-03	4.2E-03	3.6E-03
W	2.2E-02	1.6E-02	1.3E-02	1.1E-02	7.2E-03	6.1E-03
WSW	7.3E-02	5.1E-02	4.2E-02	3.3E-02	2.0E-02	1.7E-02
SW	9.7E-02	6.7E-02	5.4E-02	4.1E-02	2.5E-02	2.1E-02
SSW	3.7E-02	2.6E-02	2.2E-02	1.7E-02	1.0E-02	8.7E-03
S	2.0E-02	1.4E-02	1.2E-02	9.4E-03	6.0E-03	5.1E-03
SSE	1.3E-02	9.4E-03	8.0E-03	6.4E-03	4.2E-03	3.6E-03
SE	1.8E-02	1.4E-02	1.2E-02	9.3E-03	6.1E-03	5.1E-03
ESE	3.0E-02	2.2E-02	1.8E-02	1.4E-02	9.0E-03	7.5E-03
E	7.6E-02	5.5E-02	4.5E-02	3.4E-02	2.1E-02	1.8E-02
ENE	9.3E-02	6.6E-02	5.3E-02	4.1E-02	2.5E-02	2.1E-02
NE	7.7E-02	5.4E-02	4.3E-02	3.3E-02	2.0E-02	1.7E-02
NNE	2.9E-02	2.1E-02	1.7E-02	1.4E-02	8.7E-03	7.3E-03

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	1400	1500	1600	1700	1800	1900	2000
N	1.7E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08
NNW	1.2E-08	1.1E-08	1.1E-08	1.0E-08	9.5E-09	9.1E-09	8.7E-09
NW	1.6E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.3E-08
WNW	1.8E-08	1.7E-08	1.6E-08	1.5E-08	1.4E-08	1.4E-08	1.3E-08
W	3.1E-08	2.9E-08	2.7E-08	2.5E-08	2.4E-08	2.3E-08	2.2E-08
WSW	9.1E-08	8.5E-08	8.0E-08	7.6E-08	7.2E-08	6.9E-08	6.6E-08
SW	1.2E-07	1.1E-07	1.1E-07	1.0E-07	9.7E-08	9.3E-08	8.9E-08
SSW	3.8E-08	3.7E-08	3.6E-08	3.4E-08	3.3E-08	3.2E-08	3.1E-08
S	2.1E-08	2.0E-08	1.9E-08	1.9E-08	1.8E-08	1.8E-08	1.7E-08
SSE	1.4E-08	1.3E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08	1.1E-08
SE	1.8E-08	1.8E-08	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.5E-08
ESE	3.0E-08	2.9E-08	2.8E-08	2.7E-08	2.6E-08	2.5E-08	2.4E-08
E	7.9E-08	7.6E-08	7.3E-08	7.0E-08	6.8E-08	6.6E-08	6.4E-08
ENE	1.1E-07	1.0E-07	9.6E-08	9.2E-08	8.9E-08	8.6E-08	8.3E-08
NE	9.9E-08	9.3E-08	8.8E-08	8.3E-08	7.9E-08	7.6E-08	7.2E-08
NNE	3.4E-08	3.1E-08	3.0E-08	2.8E-08	2.7E-08	2.6E-08	2.5E-08

Direction	Distance (m) 2100	2200	2300	2400	3000	3100	3200
N	1.2E-08	1.2E-08	1.1E-08	1.1E-08	9.8E-09	9.5E-09	9.2E-09
NNW	8.4E-09	8.0E-09	7.8E-09	7.5E-09	6.4E-09	6.2E-09	6.0E-09
NW	1.2E-08	1.2E-08	1.1E-08	1.1E-08	9.5E-09	9.2E-09	8.9E-09
WNW	1.3E-08	1.2E-08	1.2E-08	1.1E-08	9.1E-09	8.8E-09	8.5E-09
W	2.1E-08	2.0E-08	1.9E-08	1.8E-08	1.5E-08	1.4E-08	1.4E-08
WSW	6.3E-08	6.1E-08	5.9E-08	5.7E-08	4.8E-08	4.6E-08	4.5E-08
SW	8.6E-08	8.3E-08	8.0E-08	7.7E-08	6.4E-08	6.2E-08	6.0E-08
SSW	3.0E-08	2.9E-08	2.9E-08	2.8E-08	2.4E-08	2.3E-08	2.3E-08
S	1.7E-08	1.6E-08	1.6E-08	1.5E-08	1.3E-08	1.3E-08	1.2E-08
SSE	1.0E-08	1.0E-08	9.8E-09	9.6E-09	8.3E-09	8.0E-09	7.8E-09
SE	1.5E-08	1.4E-08	1.4E-08	1.3E-08	1.2E-08	1.2E-08	1.1E-08
ESE	2.4E-08	2.3E-08	2.3E-08	2.2E-08	1.9E-08	1.9E-08	1.8E-08
E	6.2E-08	6.1E-08	5.9E-08	5.8E-08	5.0E-08	4.8E-08	4.7E-08
ENE	8.0E-08	7.7E-08	7.5E-08	7.3E-08	6.2E-08	5.9E-08	5.8E-08
NE	7.0E-08	6.7E-08	6.4E-08	6.2E-08	5.1E-08	4.9E-08	4.8E-08
NNE	2.4E-08	2.3E-08	2.2E-08	2.2E-08	1.9E-08	1.8E-08	1.8E-08

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

Direction	Distance (m) 3300	4700	5800	7500	11700	13800
N	9.1E-09	6.9E-09	6.0E-09	4.9E-09	3.3E-09	2.8E-09
NNW	5.9E-09	4.4E-09	3.8E-09	3.2E-09	2.2E-09	1.8E-09
NW	8.7E-09	6.4E-09	5.4E-09	4.3E-09	2.8E-09	2.4E-09
WNW	8.3E-09	5.9E-09	5.0E-09	4.0E-09	2.6E-09	2.2E-09
W	1.3E-08	9.6E-09	8.1E-09	6.6E-09	4.5E-09	3.8E-09
WSW	4.4E-08	3.1E-08	2.6E-08	2.0E-08	1.3E-08	1.1E-08
SW	5.8E-08	4.1E-08	3.3E-08	2.5E-08	1.5E-08	1.3E-08
SSW	2.2E-08	1.6E-08	1.3E-08	1.0E-08	6.5E-09	5.4E-09
S	1.2E-08	8.8E-09	7.4E-09	5.8E-09	3.8E-09	3.2E-09
SSE	7.6E-09	5.7E-09	4.9E-09	3.9E-09	2.6E-09	2.2E-09
SE	1.1E-08	8.4E-09	7.1E-09	5.7E-09	3.8E-09	3.2E-09
ESE	1.8E-08	1.3E-08	1.1E-08	8.7E-09	5.6E-09	4.7E-09
E	4.6E-08	3.3E-08	2.7E-08	2.1E-08	1.3E-08	1.1E-08
ENE	5.6E-08	4.0E-08	3.2E-08	2.5E-08	1.5E-08	1.3E-08
NE	4.6E-08	3.2E-08	2.6E-08	2.0E-08	1.2E-08	1.0E-08
NNE	1.7E-08	1.3E-08	1.1E-08	8.4E-09	5.4E-09	4.6E-09

VITA

Debra A. (Tingley) McCroskey was born in Des Moines, Iowa to James David & Virginia Ann Tingley. She was raised in Merritt Island, Florida in the shadow of the Kennedy Space Center. Following graduation from the University of Florida, she worked as a Radiation Protection Technician at commercial nuclear power plants during refueling and maintenance outages. This experience gave her the inspiration to complete a Master's Degree in Nuclear Environmental Systems Engineering at Clemson University. After working as Radiological Engineer for 15 years, she enrolled at the University of Tennessee in the Nuclear Engineering graduate program. This thesis, which reflects her years of nuclear environmental compliance research and job performance, completes her requirements for graduation with a Master's Degree in Nuclear Engineering.