

**Risk Assessment Revision for
40 CFR Part 61 Subpart W –
Radon Emissions from Operating Mill Tailings**

Task 3 – Risk Assessment Model

Prepared by:

S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

under

Contract Number EP-D-10-042
Work Assignment No. 1-06, Task 5

Prepared for:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

Brian Littleton
Work Assignment Manager

August 31, 2010

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Executive Summary	iii
1.0 Introduction and Background	1
2.0 Risk Assessment Models	2
2.1 AIRDOS, AIRDOS-II, and AIRDOS-EPA	2
2.2 CAP88.....	3
2.3 GENII with FRAMES.....	5
2.4 RESRAD-OFFSITE.....	7
2.5 MILDOS-AREA	9
2.6 MEPAS with FRAMES	12
2.7 AERMOD	12
2.8 GASPAR-II.....	13
2.9 GENII-NESHAPS.....	14
3.0 Detailed Model Evaluations.....	15
3.1 Evaluation Criteria.....	15
3.2 CAP88.....	16
3.3 GENII with FRAMES.....	20
3.4 RESRAD-OFFSITE.....	24
3.5 MILDOS-AREA	27
3.6 MEPAS with FRAMES	30
4.0 Results and Recommendations	34
5.0 References.....	36

LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 1. Evaluation Criteria.....	16
Table 2. Summary of Suitability Review for Five Codes Under Evaluation.....	35

EXECUTIVE SUMMARY

The Office of Radiation and Indoor Air (ORIA) promulgated National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for radon emissions from operating uranium mill tailings impoundments (Subpart W) on December 15, 1989. In support of Subpart W, as well as other portions of radionuclide NESHAP, ORIA published a Final Environmental Impact Statement (FEIS) and a three volume Background Information Document (BID), that provided 1) a detailed description of the Agency's procedures and methods for estimating radiation dose and risk due to radionuclide emissions to the air, 2) detailed risk estimates for each source of emissions, and 3) detailed economic assessments for each source of emissions.

The purpose of this Work Assignment is to revise the risk assessment for the NESHAP for Radionuclides from uranium mill tailing facilities. The information developed in this Work Assignment will be used by the Agency in the determination of whether the existing standards for Subpart W need revising, and, if so, what may represent reasonable revisions to the standard.

As documented in the BID, the FEIS used AIRDOS to calculate dose and risk to the public. This report reviews the appropriateness of using AIRDOS to calculate individual and population dose and risk. Currently available computer models have been reviewed to determine whether models other than AIRDOS exist for calculating dose and risk from the management of uranium byproduct materials from the processing of uranium ores. The atmospheric release risk assessment models reviewed for this Work Assignment were:

- **AIRDOS:** The AIRDOS computer code was developed at Oak Ridge National Laboratory (ORNL) to estimate individual (rem/year) and population (man-rem/year) doses resulting from the atmospheric release of radionuclides from a nuclear facility. Atmospheric dispersion and surface deposition of released radionuclides are estimated as a function of direction and distance from a nuclear power plant or fuel-cycle facility, and doses to man through inhalation, air immersion, exposure to contaminated ground, food ingestion, and water immersion are estimated in the surrounding area. Radionuclide concentrations in food products are estimated from the output of the atmospheric transport model using the terrestrial transport model described in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109. Annual doses are estimated for total body, GI tract, bone, thyroid, lungs, muscle, kidneys, liver, spleen, testes, and ovaries.
- **CAP88:** The CAP88 (which stands for Clean Air Act Assessment Package - 1988) computer model is a set of computer programs, databases and associated utility programs for estimation of dose and risk from radionuclide emissions to air. CAP88 is composed of modified versions of AIRDOS-EPA and DARTAB. CAP88-PC Version 3 incorporates dose and risk factors from Federal Guidance Report 13. CAP88-PC is a U.S. Environmental Protection Agency (EPA) approved system for demonstrating compliance with 40 CFR 61 Subpart H, the Clean Air Act standard which applies to U.S. Department of Energy (DOE) facilities that emit radionuclides to air. EPA will provide the latest version of CAP88 to SC&A for evaluation, otherwise, SC&A will evaluate Revision 3, currently available from the EPA website: <http://www.epa.gov/radiation/assessment/CAP88/>.

- **GENII:** The GENII system, developed by the Pacific Northwest National Laboratory (PNNL), includes the capabilities for calculating radiation doses following chronic and acute releases. Radionuclide transport via air, water, or biological activity may be considered. Air transport options include both puff and plume models. Building wake effects can be included in acute atmospheric release scenarios. The code provides risk estimates for health effects to individuals or populations; these can be obtained using the code by applying appropriate risk factors to the effective dose equivalent or organ dose. In addition, GENII Version 2 uses cancer risk factors from Federal Guidance Report 13 to estimate risk to specific organs or tissues.
- **RESRAD:** RESRAD is a computer model developed by Argonne National Laboratory to estimate radiation doses and risks from RESidual RADioactive materials. Since 1989, RESRAD has been used widely by DOE, its operations and area offices, and its contractors for deriving limits for radionuclides in soil. RESRAD has also been used by EPA, U.S. Army Corps of Engineers, NRC, industrial firms, universities, and foreign government agencies and institutions.
- **MILDOS-AREA:** The Argonne National Laboratory also developed MILDOS-AREA, a computer code that calculates the radiological dose commitments received by individuals and the general population within an 80-km radius of an operating uranium recovery facility. The transport of radiological emissions from point and different area sources is predicted with a sector-averaged Gaussian plume dispersion model. Mechanisms such as radioactive decay, plume depletion by deposition, in-growth of decay products, and resuspension of deposited radionuclides are included in the transport model. Alterations in operation throughout the facility's lifetime can be accounted for in the input stream. The exposure pathways considered are: inhalation; external exposure from groundshine and cloud immersion; and ingestion of vegetables, meat, and milk. Dose commitments are calculated primarily on the basis of the recommendations of the International Commission on Radiological Protection (ICRP). Only airborne releases of radioactive materials are considered in MILDOS-AREA; releases to surface water and to groundwater are not addressed in MILDOS-AREA. MILDOS-AREA is a multi-purpose code that can be used to evaluate population doses for NEPA assessments, maximum individual doses for predictive 40 CFR 190 compliance evaluations, or maximum offsite air concentrations for predictive evaluations of 10 CFR 20 compliance.
- **MEPAS:** Multimedia Environmental Pollutant Assessment System (MEPAS), developed by the Pacific Northwest Laboratory (PNL), is a suite of integrated impact assessment software comprising physics-based fate and environmental transport models of air, soil, and water media. MEPAS simulates the release of contaminants from a source; transport through the air, groundwater, surface water, and/or overland pathways; and transfer through food chains and exposure pathways to the exposed individual or population. For human health impacts, risks are computed for carcinogens and hazard quotients for noncarcinogens.
- **AERMOD:** AERMOD was developed by the AERMIC (American Meteorological Society (AMS)/U.S. Environmental Protection Agency (EPA) Regulatory Model Improvement Committee) as a state-of-the-practice Gaussian plume dispersion model whose formulation is based on planetary boundary layer principles. The AERMOD model utilizes a probability density function and the superposition of several Gaussian

plumes to characterize the distinctly non-Gaussian nature of the vertical pollutant distribution for elevated plumes during convective conditions; otherwise the distribution is Gaussian. Also, nighttime urban boundary layers (and plumes within them) have the turbulence enhanced by AERMOD to simulate the influence of the urban heat island. The AERMOD model is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including point, area and volume sources).

Each of the above computer models was described and discussed in detail, including the results of any benchmarks that were performed between the models. During this phase of the review, four of the models (AIRDOS, GASPAR, GENII-NESHAPS, and AERMOD) were eliminated from further evaluation. Next, a detailed evaluation of the remaining five atmospheric release risk assessment models was performed. The criteria used in the detailed evaluation are shown in Table ES-1. To account for the fact that not all of the criteria were considered to be of equal importance, weight factors were assigned to each of the criteria, as shown in Table ES-1.

Table ES-1. Evaluation Criteria

Evaluation Criteria	Weight Factor
Exposure Pathways Modeled	2
Population Dose/Risk Capability	2
Dose Factors Used	1.75
Risk Factors Used	1.75
Meteorological Data Processing	1.5
Source Term Calculations	1.5
Verification and Validation	1.25
Ease of Use/User Friendly	1.25
Documentation	1
Sensitivity Analysis Capability	1
Probabilistic Analysis Capability	1

The results of the detailed evaluation are shown in Table ES-2.

Table ES-2. Evaluation Results

Evaluation Criteria	Score
RESRAD-OFFSITE	66.25
CAP88	65.5
GENII	61.75
MEPAS	57
MILDOS-AREA	48

As Table ES-2 shows, RESRAD-OFFSITE was the highest scoring of the five codes, narrowly edging out CAP88. However, it is recommended that CAP88, and not RESRAD-OFFSITE, be used to perform the dose and risk calculations required for this Work Assignment. The reasons for this recommendation include:

- RESRAD-OFFSITE does not include the ability to perform population dose and risk estimates, which means that the RESRAD-OFFSITE results would need to be supplemented with population dose and risk estimates from another source. CAP88, on the other hand, is specifically designed to assess radiological emissions to the public.
- The major area where CAP88 is lacking is sensitivity and probability analyses. For this Work Assignment, it is not anticipated that sensitivity or probability analysis will play a major role.
- RESRAD-OFFSITE incorporates CAP88 air dispersion modeling, which means that there are no significant technical differences between the two codes for the purpose of this Work Assignment.
- CAP88 was developed as a predecessor to AIRDOS which was the original code used in the evaluation of mill tailing impoundments during the development of the NESHAPs for radon emissions in 1989.

1.0 INTRODUCTION AND BACKGROUND

The Office of Radiation and Indoor Air (ORIA) promulgated National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for radon emissions from operating uranium mill tailings impoundments (Subpart W) on December 15, 1989. In support of Subpart W, as well as other portions of radionuclide NESHAPs, ORIA published a Final Environmental Impact Statement (FEIS) and a three volume Background Information Document (BID) that provided 1) a detailed description of the Agency's procedures and methods for estimating radiation dose and risk due to radionuclide emissions to the air, 2) detailed risk estimates for each source of emissions, and 3) detailed economic assessments for each source of emissions.

The purpose of this Work Assignment is to revise the risk assessment for the NESHAPs for radionuclides from uranium mill tailing facilities. The information developed in this Work Assignment will be used by the Agency in the determination of whether the existing standards for Subpart W need revising, and, if so, what may represent reasonable revisions to the standard.

As documented in the BID, the FEIS used AIRDOS to calculate dose and risk to the public. This report reviews the appropriateness of using AIRDOS to calculate individual and population dose and risk. Currently available computer models have been reviewed to determine whether models other than AIRDOS exist for calculating dose and risk from the management of uranium byproduct materials from the processing of uranium ores. The report examines the applicability of available models to evaluate radon emissions from operating mill tailings impoundments. By evaluating the various modeling codes against a set of predetermined criteria (outlined in Section 3), it will be determined which code is most suitable for the purposes of determining current dose and risk conditions at these operating sites. The modeling codes will be considered based on their applicability to the problem, whether current analytical methods are employed (such as dose and risk factors), the ability to process population and meteorological data, to what extent the code is documented/validated, and finally, how user friendly and intuitive the code is.

The report is organized into three main sections (Sections 2-4): Section 2 provides a description of the computer models that were evaluated, Section 3 presents the evaluation criteria and results of the evaluation for the main codes selected, and the final section summarizes the results of the evaluation and recommends which code should be used for the individual and population dose and risk analysis, which will be performed as part of Task 4 of this Work Assignment.

2.0 RISK ASSESSMENT MODELS

2.1 AIRDOS, AIRDOS-II, and AIRDOS-EPA

The AIRDOS computer code was developed at Oak Ridge National Laboratory (ORNL) to estimate individual (rem/year) and population (man-rem/year) doses resulting from the atmospheric release of radionuclides from a nuclear facility. Atmospheric dispersion and surface deposition of released radionuclides are estimated as a function of direction and distance from a nuclear power plant or fuel-cycle facility, and doses to man through inhalation, air immersion, exposure to contaminated ground, food ingestion, and water immersion are estimated in the surrounding area. Radionuclide concentrations in food products are estimated from the output of the atmospheric transport model using the terrestrial transport model described in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109. Annual doses are estimated for total body, GI tract, bone, thyroid, lungs, muscle, kidneys, liver, spleen, testes, and ovaries. For additional information regarding the development of AIRDOS, refer to Moore 1975, Moore 1977, and Moore, et al. 1979.

Of particular interest to this Work Assignment, in 1978, the NRC used AIRDOS-II to perform a detailed analysis of the radiological impact of the Irigaray project of solution mining (in situ leaching) operations involving uranium ore deposits in Johnson County, Wyoming. The results of the NRC's AIRDOS-II analysis are presented in the Final Environmental Statement for the Irigaray project (NUREG-0481).

For the NESHAPs for Radionuclides, EIS risk assessment (EPA/520/1-89-005), EPA used AIRDOS-EPA to calculate environmental concentrations resulting from radionuclide emissions into air. The results of the AIRDOS-EPA analysis were estimates of air and ground surface radionuclide concentrations; intake rates via inhalation of air; and ingestion of radioactivity via meat, milk, and fresh vegetables. The AIRDOS-EPA calculated concentration and intake rates, as well as other parameters (such as particle size, respiratory clearance class, and gastrointestinal absorption factor), were passed on to the DARTAB computer program for dose and risk assessments. The DARTAB computer program provides an estimate of the impact of radionuclide emissions by combining information on the amounts of radionuclides inhaled and/or ingested with dosimetric and health effect data for a given quantity of each radionuclide. In addition to the AIRDOS-EPA provided data, the DARTAB NESHAPs for Radionuclides, EIS assessment utilized dosimetric and health effect data that were calculated by RADRISK. The RADRISK program calculates the dose rate to organs resulting from the inhalation or ingestion of a given quantity of a radionuclide. The organ dose rates are then processed by RESRAD to calculate the risk of fatal cancer to a cohort of people. For approximately 500 radionuclides, the calculated risks (i.e., the probability of premature death for a member of the cohort due to inhalation or ingestion of a given quantity of each radionuclide) are written to a data file by RADRISK so that they can be accessed by other computer programs (e.g., DARTAB).

On October 31, 1989, under 40 CFR Part 61, NESHAPs, the EPA issued the final rules for radionuclide emissions to air. AIRDOS-EPA, DARTAB, and the RADRISK dose and risk factors were combined into the Clean Air Act Assessment Package-1988 (CAP88) and used to

generate risk estimates for the risk assessment supporting this rule. With the issuance of CAP88, AIRDOS-EPA, DARTAB, and RADRISK ceased to exist as standalone computer programs. CAP88 is discussed below.

2.2 CAP88

As stated above in the AIRDOS discussion, the CAP88 was developed in 1988 from the AIRDOS, RADRISK, and DARTAB computer programs. The initial version of CAP88 ran on large mainframe computers at ORNL, however, in the late 1980s, the EPA and the U.S. Department of Energy (DOE) began a cooperative project to produce a personal computer version of CAP88 — CAP88-PC, which was released in March 1992. CAP88 implements the NRC's Regulatory Guide 1.109 methodology for calculating doses from the terrestrial food pathways.

Among the modifications and enhancements made to CAP88 during its conversion to CAP88-PC include the fact that CAPP88-PC estimates risk as well as dose. CAP88-PC was modified to perform either "Radon-only" or "Non-Radon" runs, to conform to the format of the 1988 Clean Air Act NESHAPs Rulemaking. "Radon-only" assessments, which only have Rn-222 in the source term, automatically include working level calculations; all other source terms ignore working levels. Also, the organs and weighting factors are modified to follow the ICRP 26/30 Effective Dose Equivalent calculations, which eliminates flexibility on specifying organs and weighting factors. In February 1992, CAP88-PC, Version 2.0 was approved for demonstrating compliance with 40 CFR Part 61 "Subpart H – National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities".

In March 2000, Version 2 of CAP88-PC was issued. CAP88-PC, Version 2 provided a framework for developing inputs to perform full-featured dose and risk assessments in a Windows environment, as well as some minor changes to the DOS version. Like Version 1.0, Version 2.0 of CAP88-PC was approved for demonstrating compliance with 40 CFR Part 61 in October 1999.

In May 2002, CAP88-PC, Version 2.1 was issued. Version 2.1 included changes in installation and operating environment (e.g., improvements in the Windows code error handling), as well as changes to increase the programs flexibility (e.g., site-specific humidity, site-specific distance and sector, and higher radionuclide limit).

In August 2002, CAP88-PC, Version 3.0 was issued. Version 3.0 is a significant update to Version 2.1. Some of the Version 3 enhancements include:

- Incorporated the dose and risk factors from Federal Guidance Report (FGR) 13, in place of the RADRISK data that was used in previous versions
- Expansion of the nuclide database to 825 nuclides which include all the FGR 13-based decay chains
- Eliminated calculation of genetic effects
- Dose factors are now a function of chemical form where specified in FGR 13

- Organ dose equivalent is calculated for 23 internal organs, mortality risk is calculated for 15 cancer sites
- Internal absorption class terminology updated to F (fast), M (medium), and S (slow)
- All particulates are assumed to be 1.0 micron in accordance with the FGR 13 model, with the exception of gases and vapor which are '0'
- Radionuclide transfer factors have been updated to reflect NCRP Report #123
- Version 3 has added (though not fully implemented) age dependent dose factors, cancer morbidity risk factors, additional pathways such as drinking water ingestion and external exposure from multiple depths of soil

In 1994 Maheras, et al. performed a benchmarking of CAP88 to the GENII computer program. The following is a summary of their results:

The results of the benchmark tests were within the 95% acceptance region specified in the test protocol. CAP-88 was found to over-predict effective dose equivalent relative to GENII for elevated releases, largely because CAP-88 calculates a larger atmospheric dispersion factor (χ/Q) than does GENII using the same meteorological data. However, CAP-88 consistently under-predicted effective dose equivalent relative to GENII for ground-level releases. This was because CAP-88 accounts for the processes of plume depletion by dry and wet deposition while GENII does not account for these processes. The effect of depletion was tested and found to be most important for a ground-level release of a highly depositing species such as radioiodine which implies that acceptable benchmark results would be difficult to obtain for a highly depositing species.

ANL/ES-161 presents the results from benchmarking CAP88 against MILDOS-AREA. The ANL/ES-161 results are summarized below in the MILDOS-AREA discussion (Section 2.5).

CAP88-PC was benchmarked against RESRAD-OFFSITE and the results are presented in ANL/EVS/TM/06-3, Section 3. Four areas were tested:

- Simple dispersion model – For the simple dispersion model, ANL/EVS/TM/06-3 reported that the agreement between CAP88-PC and RESRAD-OFFSITE was good, and that the differences for all distances were approximately 6% or less, except at 100 meters where a 13% difference was found. ANL/EVS/TM/06-3 concluded that these differences can be attributed to variations in the vertical dispersion coefficient and the actual area source methodology.
- Dry deposition – For dry deposition, good agreement between the codes was obtained for receptor distances of less than 10,000 meters. After 10,000 meters, the RESRAD-OFFSITE air concentration is about 3 times larger than that from CAP88-PC.
- Wet deposition – Aside from the 100-meter location, RESRAD-OFFSITE and CAP88-PC results remain within 10% of each other out to a distance of approximately 3,000 meters. Thereafter, the CAP88-PC results become increasingly larger than the RESRAD-OFFSITE results up to 80,000 meters.

- Plume rise – The RESRAD-OFFSITE and CAP88-PC plume rise results agree to within about 15% or less for receptor distances of less than 500 meters. After 500 meters, plume rise has negligible differences between the two programs.

In DOE/ORO-2033, MEPAS was benchmarked against RESRAD-OFFSITE. Because CAP88 is linked to RESRAD to perform atmospheric dispersion calculations, DOE/ORO-2033 was in effect a benchmarking of CAP88 against MEPAS. Two comparisons were performed:

- Air concentration – A constant emission of thorium-228 was assumed. The air concentration comparisons show that nearly identical results are obtained with the models for the direct air release scenario.
- Deposition – The soil concentrations at 1 km resulting from deposition from the thorium-228 plume over the 10 years. The deposition comparisons show the models give approximately the same results. At the 1.0-km distance, the magnitude of the predicted deposition rates reflects mainly the predicted air concentrations and the deposition velocities.

Finally, Lehto, et al. (2000) state that the milk cow and meat cattle densities are entered into CAP88 in units of “per square kilometer, but this is erroneous according to [B. Parks].” If CAP88 is to be used, then the correct units for entering milk cow and meat cattle densities will need to be used.

2.3 GENII with FRAMES

The Hanford Environmental Dosimetry Upgrade Project was undertaken to incorporate the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) into updated versions of the environmental pathway analysis models used at Hanford. The resulting second generation of Hanford environmental dosimetry computer codes was compiled in the Hanford Environmental Dosimetry System (Generation II, or GENII). The purpose of this coupled system of computer codes was to analyze environmental contamination resulting from acute or chronic releases to, or initial contamination of, air, water, or soil. This was accomplished by calculating radiation doses to individuals or populations. The GENII system was designed to provide a state-of-the-art, technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment.

GENII was designed to include the capabilities: 1) for calculating radiation doses for acute releases, with options for annual dose, committed dose, and accumulated dose; 2) for calculating the same types of doses from chronic releases; and 3) for evaluating exposure pathways including direct exposure via water (swimming, boating, and fishing), soil (surface and buried sources), air (semi-infinite cloud and finite cloud geometries), inhalation pathways, and ingestion pathways.

The GENII release scenarios include acute releases to air from ground level or elevated sources, or to water; chronic releases to air from ground level or elevated sources, or to water; and initial contamination of soil or surfaces. GENII accounts for source term variations, including decay of radionuclides to the start of the exposure scenario, input of total radioactivity or specified

fractions, and input of measured concentrations in specified environmental media. Air transport options include both puff and plume models. Building wake effects can be included in acute atmospheric release scenarios. Interfaces were provided for external calculations of atmospheric dispersion, geohydrology, biotic transport, and surface water transport. The model used by GENII to estimate radionuclide concentration in edible plant portions considers uptake from two pathways: direct deposition and absorption through roots from soil. The model is a variant of that prepared for the NRC for use in Regulatory Guide 1.109. Target populations were identified by distance and direction for individuals, populations, and for intruders into contained sources. The code provides risk estimates for health effects to individuals or populations; these can be obtained using the code by applying appropriate risk factors to the effective dose equivalent or organ dose. In addition, GENII, Version 2 implements these models plus those of ICRP Publications 56 through 72 and the related risk factors published in Federal Guidance Report 13.

The original version of GENII, released in 1988, was composed of seven interrelated computer codes and their associated data libraries. The connection between the codes is through data transfer files, i.e., the output of one code is stored in a file that can be read by the next code in the system. The environmental transport calculations were performed in ENV, while the individual and population doses were calculate in DOSE. The code DITTY was used to calculate long-term (>10,000 years) exposures. External and internal dose factors were calculated by the EXTDF and INTDF codes. Finally, two data preparation codes were provided: APPRENTICE and ENVIN. The experienced GENII user could stop the process at any point and edit the intermediate data transfer files to obtain specific information on the processes occurring or on intermediate results.

For maximum flexibility, the most current version of GENII, Version 2.10, has been divided into several interrelated, but separate, exposure and dose calculations consisting of four independent atmospheric models, one surface water model, three independent environmental accumulation models, one exposure module, and one dose/risk module, each with a specific user interface. GENII, Version 2.10 operates within the Framework for Risk Analysis in Multimedia Environmental System (FRAMES). FRAMES allows the addition of other computer modules to the GENII system. For example, GENII does not explicitly include modules for performing groundwater transport calculations, however, with FRAMES, groundwater transport models can be incorporated into the GENII model. Additional information on FRAMES is provided in Section 2.3.1.

In 1994, Maheras, et al. performed a benchmarking of CAP88 to the GENII computer program. The results of this benchmark are presented above in Section 2.2.

ANL/EAD/TM-24 benchmarked GENII against RESRAD. Unfortunately, the ANL/EAD/TM-24 benchmarking was mostly interested in comparing the two codes' ability to analyze ground contamination scenarios, rather than air release scenarios, so the ANL/EAD/TM-24 results are of little value to this Work Assignment.

2.3.1 FRAMES

Over the past 35 years, medium specific models have been and will continue to be developed in an effort to understand and predict environmental phenomena, including fluid-flow patterns (e.g., groundwater, surface water, and air), contaminant migration and fate, human or wildlife exposures, impacts from specific toxicants to specific species and their organs, cost-benefit analyses, impacts from remediation alternatives, etc. The DOE Office of Environmental Management (DOE-EM), the EPA Office of Research and Development (EPA-ORD), and the EPA Office of Radiation and Indoor Air (EPA-ORIA) have realized the need for a common platform to access and link these medium-specific models. The objective is to 1) combine existing models and approaches that assess hazardous and radioactive releases in and their impacts on the environment into a single framework and 2) structure the framework into a flexible and versatile, user-friendly tool that meets the needs of both organizations. FRAMES has been developed by Pacific Northwest National Laboratory (PNNL) to meet this need.

FRAMES is a software platform for selecting and implementing environmental software models for risk assessment and management problems. Currently, MEPAS and GENII are available in FRAMES, while other codes are scheduled to be included in the future. The FRAMES User Interface (FUI) allows users to link, select, and interact with environmental codes for environmental and human health analyses. The FUI is used to: create, access, save, and exit Global Input Data (GID) files; select module types and connections; run the scenario models in sequence; and perform several other functions. In this manner, FRAMES can be used to select the most desirable features of specific models and link them together into a superior single integrated model. For example, the output from a source term generation code (e.g., GALE) could be linked with a sophisticated atmospheric transport code (e.g., AERMOD) which is linked to an exposure pathways evaluation model (e.g., CAP88).

Unfortunately, as stated above, at this time only MEPAS and GENII are available in FRAMES, and since these two programs perform similar calculations, it's not clear that there is any advantage to the current FRAMES. Also, in order to take advantage of future FRAMES capabilities, the process necessary to setup and run a single model (i.e., GENII or MEPAS) within FRAMES is more complicated than to setup and run the same model outside of FRAMES (at least to the authors of this report). For these reasons, a wait-and-see attitude has been taken with regard to FRAMES, which will also influence the selection of GENII and MEPAS for use in this Work Assignment, since they are only available within FRAMES.

2.4 RESRAD-OFFSITE

RESRAD is a computer model developed by Argonne National Laboratory to estimate radiation doses and risks from RESidual RADioactive materials. Since its first release in 1989, RESRAD has been used widely by DOE, its operations and area offices, and its contractors for deriving limits for radionuclides in soil. RESRAD has also been used by the EPA, U.S. Army Corps of Engineers, NRC, industrial firms, universities, and foreign government agencies and institutions. RESRAD evaluates the radiological dose and excess cancer risk to an individual who is exposed while residing and/or working in an area where the soil is contaminated with radionuclides.

RESRAD-OFFSITE code is an extension of the original RESRAD code. The most current version is RESRAD-OFFSITE Version 2.6, which was released July 7, 2010.

RESRAD-OFFSITE considers initial radiological contamination in soil in settings ranging from a clean cover layer on top of it to up to five partially saturated layers below it. The code has a capability to model the radiation exposure of an individual who spends time directly above the primary contamination (onsite) and in the vicinity of the primary contamination (offsite).

Nine exposure pathways are considered in RESRAD-OFFSITE: direct exposure from contamination in soil, inhalation of particulates and radon, ingestion of plant foods, ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and incidental ingestion of soil. By selecting different pathways, RESRAD-OFFSITE can be used to simulate various exposure scenarios, including Rural Resident Farmer, Urban Resident, Worker, and Recreationist.

The RESRAD Users Manual and the RESRAD-OFFSITE website (<http://web.ead.anl.gov/resrad/home2/offsite.cfm>) state that RESRAD-OFFSITE “links with the CAP88 computer code for performing air dispersion calculations”.

Regarding radon, the RESRAD-OFFSITE Users Manual indicates that it uses the same model as RESRAD for onsite exposures, and the RESRAD Users Manual describes the radon model as:

The primary environmental parameters that can influence the dispersion of radon in outdoor air are meteorological conditions, such as wind speed and stability class. The calculation of outdoor radon concentrations by using all these parameters requires a comprehensive atmospheric dispersion code such as the MILDOS-AREA code (...). These extensive computations are not practical for the purposes of the RESRAD code, because the average radon concentration outdoors on top of a radium-contaminated area would be dependent on the size of the contaminated area and the average wind speed, and it would not be very sensitive to other meteorological parameters.

In addition, RESRAD-OFFSITE includes radon transport to an offsite location. Radon offsite “concentrations are computed [by RESRAD-OFFSITE] from the flux of radon released from the primary contamination and the in-growth and decay-adjusted Chi/Q factors for radon and its short-lived progeny, computed from the atmospheric transport model.” It is not clear from this if RESRAD-OFFSITE uses the CAP88 equilibrium fraction method for estimating the short-lived radon progeny concentrations (see Section 2.5), or if the progeny concentrations are calculated directly from the Bateman equation.

RESRAD-OFFSITE was benchmarked against CAP88-PC and the results are presented in ANL/EVS/TM/06-3, Section 3, and summarized above in Section 2.2.

ANL/EAD/TM-24 benchmarked RESRAD against GENII. Unfortunately, the ANL/EAD/TM-24 benchmarking was mostly interested in comparing the two codes’ ability to analyze ground contamination scenarios, rather than air release scenarios, so the ANL/EAD/TM-24 results are of little value to this Work Assignment.

In 2008, as part of their verification of MILDOS-AREA, Argonne National Laboratory (ANL) compared the MILDOS-AREA air dispersion component with that of the RESRAD-OFFSITE code. The results of that comparison are summarized below in Section 2.5.

In DOE/ORO-2033, RESRAD-OFFSITE was benchmarked against MEPAS. Because CAP88 is linked to RESRAD to perform atmospheric dispersion calculations, DOE/ORO-2033 was, in effect, a benchmarking of CAP88 against MEPAS. The DOE/ORO-2033 results are summarized above in Section 2.2.

2.5 MILDOS-AREA

MILDOS estimates impacts from radioactive emissions from uranium milling facilities. These impacts are presented as dose commitments to individuals and the regional population within an 80-km radius of the facility. Only airborne releases of radioactive materials are considered: releases to surface water and to groundwater are not addressed in MILDOS, i.e., liquid exposure pathways are not treated by MILDOS. Exposure pathways of concern are assumed to be inhalation of airborne radioactive material, ingestion of vegetables, meat, and milk contaminated via deposition, and external exposure to radiation emitted by airborne activity and activity deposited on ground surfaces. MILDOS can be used to evaluate population doses for NEPA assessments, maximum individual doses for predictive 40 CFR 190 compliance evaluations, or maximum offsite air concentrations for predictive 10 CFR 20 compliance evaluations.

In the mid-1970s, UDAD (Uranium Dispersion And Dosimetry) was developed by ANL for the NRC to provide comprehensive estimates of the potential radiation dose rate and dose to the standard man and the standard population in the vicinity of a uranium processing facility, such as a uranium mill or mine. UDAD was applied, initially in 1976, for the assessment of the radiological impact of the Bear Creek uranium mining and milling project and was later expanded for generic evaluation of uranium milling in the United States. UDAD is documented in NUREG/CR-0553.

In 1981, MILDOS (NUREG/CR-2011) was developed by Pacific Northwest Laboratory (PNL) from UDAD. The models and assumptions on which the MILDOS program was based are described in the NRC Regulatory Guide 3.51 and NUREG/CR-0553. Models were included in MILDOS to consider both point sources (stacks, vents) and area sources (ore pads, tailing areas). Particulate release is limited to radionuclides of the uranium-238 decay series (i.e., U-238, Th-230, Ra-226, and Pb-210). Other radionuclides within the U-238 series are implicitly accounted for under the secular equilibrium assumption. Gaseous release was limited to consideration of Rn-222, plus ingrowth of daughters. The dose to exposed individuals is calculated for comparison with requirements of both 40 CFR 190 and 10 CFR Part 20. Ingestion dose factors were based on ICRP Publication 2 and 10A, inhalation dose factors were calculated in accordance with the ICRP's Task Group on Lung Dynamics' lung model (TGLM) (ICRP 1966 and 1972), and external dose factors were directly taken from Hones and Soldat (1977).

In 1989, Argonne National Laboratory developed the MILDOS-AREA code (ANL/ES-161) to provide enhanced capability to compute doses from large-area sources and to incorporate changes in methods for dosimetry calculations (ICRP 1979). The revised program was designed

for use on IBM or IBM-compatible personal computers. MILDOS-AREA considers the same radionuclides as MILDOS. A validation study of MILDOS-AREA was conducted using measured Rn-222 concentration and flux data from the Monticello, Utah uranium mill tailings impoundment. The results of this study demonstrated that use of MILDOS-AREA can result in generally good agreement between model-generated and measured Rn-222 concentrations.

In 1997, MILDOS-AREA computer code was further updated by ANL to incorporate dose conversion factors derived by the ICRP recommendations of 1978, and to make it compatible with the January 1, 1994, revision of 10 CFR Part 20. The 1997 update also created an example problem for applying MILDOS-AREA to in-situ leach facilities.

In 1998, MILDOS-AREA was provided with the user-friendly software interface. This graphical user interface (GUI) is simple and easy to use and allows MILDOS-AREA to run under the Windows operating system.

ANL/ES-161, Appendix B presents a comparison between MILDOS-AREA and CAP88¹. Calculated Rn-222 concentrations and working levels calculated by the two codes at 12 distances and four directions were compared. The Rn-222 concentrations calculated by the two codes are in very good agreement for distances greater than about 1 km for the release point, and, at closer distances, the CAP88 calculated Rn-222 concentrations are as much as 50% higher than the MILDOS-AREA concentrations.

However, for the working level calculations, the results are much different. Near the source (e.g., <1 km), the CAP88 calculated working levels are much greater (sometimes greater than an order of magnitude) than the MILDOS-AREA calculated working levels. At larger distances (e.g., 5 to 10 km), the working levels calculated by the two codes are about the same, and at even larger distances (e.g., 70 km), the MILDOS-AREA calculated working levels are greater (by up to about 50%) than the CAP88 calculated working levels. The reason for this is the different approaches used by the two codes to calculate radon decay product concentrations. CAP88 uses a fixed linear interpolation of the decay product equilibrium fraction beginning at 0.267 at 150 meters and reaching a final equilibrium fraction of 0.698 at 19,551 meters. MILDOS-AREA, on the other hand, directly calculates the radon daughter concentrations based on the Rn-222 concentration and plume travel time. The ANL/ES-161, Appendix B results indicate that radon daughter equilibrium factors are significantly less than 27% at small distances and greater than 70% at very large distances from the source.

In 2008, ANL prepared a limited-scope verification and benchmarking of MILDOS-AREA by comparing spreadsheet calculation results with MILDOS-AREA-generated reports. The differences between the simple spreadsheet calculations and the MILDOS-AREA-generated reports were less than 5%, and in most cases the results were within 3%. The MILDOS-AREA air dispersion component was also compared with that of the RESRAD-OFFSITE code. The major differences between the two codes that were identified by ANL are presented below:

¹ ANL/ES-161 actually compared MILDOS-AREA to AIRDOS-EPA. However, since CAP88 uses the same methodology for calculating Rn-222 air concentrations and working levels as AIRDOS-EPA, the results of the ANL/ES-161 comparison are valid for CAP88.

- Dose Outputs: Population doses and organ doses are not included in the RESRAD-OFFSITE code.
- Different Default Values:
 - The codes use different default dose conversion factors and consumption rates.
 - MILDOS-AREA assumes U-234 is in equilibrium with U-238.
- Differences in Release, Dispersion, and Deposition Models:
 - In RESRAD-OFFSITE, both dry deposition and wet deposition are considered, whereas only dry deposition is considered in MILDOS-AREA.
 - RESRAD-OFFSITE uses the average mass loading, deposition velocity, average concentration, and source area to calculate the source term (release rate), whereas MILDOS-AREA uses windblown particle emission to calculate the source term.
 - The RESRAD-OFFSITE code does not include resuspension from ground surface deposition in air concentration calculations.
 - In RESRAD-OFFSITE, accumulation in offsite surface soil includes accumulation due both to irrigation with contaminated water and to deposition of contaminated dust, whereas only deposition of contaminated dust is included in MILDOS-AREA.
 - In RESRAD-OFFSITE, the soil concentration is affected by mixing in the surface layer, erosion, and leaching, whereas in MILDOS-AREA, it is affected by the constant deposition and environmental loss.
 - RESRAD-OFFSITE calculates the average air and soil concentrations from deposition for different selected areas, whereas MILDOS-AREA calculates air concentration and ground deposition at a specified receptor location (no area associated).
- Differences in Exposure Pathways:
 - The RESRAD-OFFSITE code does not include air submersion pathway dose.
 - External pathway dose in MILDOS-AREA is calculated by assuming infinite surface source, whereas RESRAD-OFFSITE calculates it by assuming a finite volume source with uniform concentration within the mixing layer.
 - In calculating radionuclide concentration in the edible part of the plant, RESRAD-OFFSITE includes root uptake from contaminated soil, foliar uptake from overhead irrigation, and foliar uptake of dust; MILDOS-AREA does not include uptake from irrigation.
 - There are five categories of plants in MILDOS-AREA: edible above-ground vegetables, potatoes, other edible below-ground vegetables, pasture grass, and

hay. The edible above-ground vegetables, potatoes, and below-ground vegetables are for human consumption, and pasture grass and hay are for animal consumption. There are four categories of plants in RESRAD-OFFSITE: fruit, grain, nonleafy vegetables; leafy vegetables; pasture and silage; and hay. The fruit, grain, nonleafy vegetables and leafy vegetables are for human consumption, and pasture, silage and hay are for animal consumption.

- In RESRAD-OFFSITE, it is assumed that ingestion of contaminated plants, soil, and water all contribute to meat and milk contamination. In MILDOS-AREA, contaminated soil and water ingestion is not included.

2.6 MEPAS with FRAMES

The Multimedia Environmental Pollutant Assessment System (MEPAS) is an integrated software implementation of physics-based fate and transport models for health and environmental risk assessments of both radioactive and hazardous pollutants. MEPAS is a “multimedia” model in that pollutant transport is modeled within, through, and between multiple media (air, soil, groundwater, and surface water). The estimated concentrations in the various media are used to compute exposures and impacts to the environment, to maximum individuals, and to populations. Of most import to this Work Assignment, the MEPAS atmospheric component for the air media includes models for emission from a source to the air, initial plume rise and dispersion, airborne pollutant transport and dispersion, and deposition to soils and crops.

MEPAS, developed by PNL, is a suite of integrated impact assessment software comprising physics-based fate and environmental transport models of air, soil, and water media. MEPAS simulates the release of contaminants from a source; transport through the air, groundwater, surface water, and/or overland pathways; and transfer through food chains and exposure pathways to the exposed individual or population. For human health impacts, risks are computed for carcinogens and hazard quotients for noncarcinogens.

In DOE/ORO-2033, MEPAS was benchmarked against RESRAD-OFFSITE. Because CAP88 is linked to RESRAD to perform atmospheric dispersion calculations, DOE/ORO-2033 was, in effect, a benchmarking of CAP88 against MEPAS. The DOE/ORO-2033 results are summarized above in Section 2.2.

The most current version of MEPAS operates within FRAMES. FRAMES allows the addition of other computer modules to MEPAS. Additional information on FRAMES is provided in Section 2.3.1.

2.7 AERMOD

The American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) was formed to introduce state-of-the-art modeling concepts into the EPA’s air quality models. Through AERMIC, a modeling system, AERMOD, was developed as a state-of-the-practice Gaussian plume dispersion model whose formulation is based on planetary boundary layer principles. The AERMOD model utilizes a probability

density function and the superposition of several Gaussian plumes to characterize the distinctly non-Gaussian nature of the vertical pollutant distribution for elevated plumes during convective conditions; otherwise the distribution is Gaussian. Also, nighttime urban boundary layers (and plumes within them) have the turbulence enhanced by AERMOD to simulate the influence of the urban heat island. The AERMOD model is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including point, area and volume sources).

The development of AERMOD began in 1991 and underwent seven steps: initial model formulation, developmental evaluation, internal peer review/beta testing, revised model formulation, performance evaluation and sensitivity testing, external peer review, and submission to the EPA for consideration as a regulatory model. On November 9, 2005, EPA issued the final rule to replace the widely used Industrial Source Complex (ISC) air dispersion model with the state-of-practice air dispersion model AERMOD in many air quality impact assessments.

Because AERMOD only calculates atmospheric dispersion and deposition, but not dose to individual and the population through the exposure pathways, it would be necessary to link AERMOD to either an existing or custom designed and developed program in order to evaluate dose and risk. Although it may be a worthwhile effort to upgrade the atmospheric dispersion capabilities of a dose evaluation program (such as CAP88) to include the AERMOD dispersion models, it is beyond the scope of this Work Assignment, and AERMOD will not be evaluated further.

2.8 GASPAR-II

The GASPAR code was written in 1977 by Oak Ridge National Laboratory for the NRC. GASPAR is an air release dose code that models the release of noble gases in a semi-infinite plume, radioiodine and particulate emissions using the release model described in NRC Regulatory Guide 1.109 (NRC 1977). The code was developed mainly to analyze effluent releases from nuclear power operations. GASPAR considers such pathways as inhalation, plume-immersion, ground-shine, and ingestion of various contaminated media (meat, milk, vegetation, etc.). Dose calculations can be applied to a defined population or an individual who are evaluated for four age groups: infants (0-1 years), children (1-11 years), teens (12-18 years), and adults (over 18 years). Each calculation considers seven organs (bone, G.I. tract, kidney, liver, lung, skin, and thyroid) as well as the whole body dose.

In 1987, GASPAR-II was developed by PNL, however, while changes were made to the values of some parameters and dose factors used in the code, no changes were made to the mathematical models used by GASPAR.

GASPAR was eliminated from further consideration in this Work Assignment for the following reasons:

- Dose factors – GASPAR-II utilizes the inhalation and ingestion dose factors from ICRP Publication 2, as modified slightly in later ICRP documents. Since ICRP Publication 2

was published in 1959, the ICRP has issued two major updates of its dosimetric guidance. The details of these ICRP updates have been provided in SC&A 2009. Thus, the dosimetry used by GASPAR-II is out-of-date and cannot be readily updated.

- Atmospheric dispersion – GASPAR-II does not calculate atmospheric dispersion, therefore it would be necessary to utilize a separate program (such as XOQDOQ) to process the raw meteorological data and generate atmospheric dispersion and deposition factors for input into GASPAR-II.
- Risk factors – GASPAR-II only calculates radiological dose, and does not calculate risk. Although it is possible to convert the doses reported by GASPAR-II into risk by designing and using a post-processor, it is believed that such an approach would not be practicable for various reasons, including the fact that the GASPAR-II doses are based on ICRP Publication 2.

2.9 GENII-NESHAPS

GENII-NESHAPS is a modified version of the more general GENII code which was designed to help site managers plan and improve compliance with 40 CFR 61, Subparts H and I. The code implements the same methods as the original GENII code, except it hardwires certain parameters so that they cannot be changed by the user. This was done so that the code would automatically incorporate certain elements necessary to the NESHAPS regulation.

The following statement is currently being displayed on the EPA website (<http://www.epa.gov/rpdweb00/neshaps/models.html>):

EPA does not presently support GENII-NESHAPS, and there is no intention to do so.

Because of this and the fact that GENII is being evaluated for use, GENII-NESHAPS was eliminated from further consideration in this Work Assignment.

3.0 DETAILED MODEL EVALUATIONS

3.1 Evaluation Criteria

The evaluation criteria used were:

- **Exposure Pathways Modeled (2):** Are all of the exposure pathways that are essential to this analysis included in the code? Additionally, does the code allow for exposures to different age groups (i.e., adults, teens, children, infants) and/or sexes to be calculated?
- **Population Based Dose/Risk Capability (2):** Does the code allow for the calculation of a population dose/risk based on a site-specific unique population distribution or does the code only allow the calculation of dose/risk based on a single defined receptor location?
- **Dose Factors Used (1.75):** Does the code utilize dose conversion factors based on the most recent International Commission on Radiological Protection (ICRP) recommendations?
- **Risk Factors Used (1.75):** Does the code utilize the most recent risk factors?
- **Processing of Meteorological Data (1.5):** Can the code process “raw” meteorological data, or does the meteorological data need to be pre-processed prior to being entered into the code? For example, does the code accept “raw” meteorological tower data (e.g., from <http://www.epa.gov/scram001/surfacemetdata.htm>), or does it accept joint frequency data, or does it only accept dispersion and deposition factors? If a code does not include the capability to process “raw” meteorological data, than a separate code (e.g., STAR from http://www.epa.gov/scram001/metobsdata_procaccprogs.htm) would need to be run to generate the input necessary for the risk assessment model.
- **Source Term Calculation (1.5):** Can the code calculate radon releases, or must the releases be pre-calculated and entered into the code? If a code does not include the capability to calculate the radon release, than an additional calculation would be needed to estimate the source term so that it can be entered into the risk assessment model. Alternatively, a code that contains an internal source term calculation would be difficult to modify should the source term model change.
- **Verification and Validation (1.25):** Is there a readily available V&V package that supports the code? Is the V&V package complete? Has there been independent (i.e., by someone other than the code’s developer) V&V performed?
- **Ease of Use/User Friendly (1.25):** Is the code provided with a user interface that is intuitive and easy to understand and use? Alternatively, does the code require the user to manipulate structured input data files? Additionally, does the code have features not required for this analysis, but that might complicate its use?
- **Documentation (1):** Is the code well documented? Are there User’s Manuals readily available? In addition to providing instructions as to how to use the code, are the mathematical models used by the code well documented? It is expected that all of the codes selected for evaluation would have high scores for this criteria.

- **Input Parameter Sensitivity Analysis (1):** Does the code have the capability to perform sensitivity analyses on the input data, or must parameter sensitivity be determined by multiple runs, each run varying a single parameter? EPA 1989, Section 7 describes uncertainty analyses that were performed. Although this Work Assignment does not specify them, EPA may want to perform similar uncertainty analyses for this revision in the future.
- **Probabilistic Analysis Capability (1):** Is there a probabilistic analysis version of the code available? Although the calculations being performed for WA 1-04 are being done deterministically, at some point the EPA may desire to perform a probabilistic analysis, and it would be desirable to use the same code for both analyses.
- **SC&A Familiarity (tie breaker):** If two or more models have identical (or nearly identical [i.e., within 10%]) scores based on the above criteria, then the SC&A recommendation will be based on how familiar SC&A is with the operation of each code.

The above list of evaluation criteria is preliminary, and SC&A will work with the Work Assignment Manager (WAM) to finalize the code evaluation criteria. As can be seen from the above list, some criteria are of greater importance than other criteria. To account for this, each criterion will be given a weighting factor ranging from 1 to 2; preliminary weighting factors are shown in parenthesis on the above list of evaluation criteria. SC&A will work with the WAM to develop the final weighting factors for each criterion. The final score of the evaluation will be the sum of each criterion's score times its weighting factor.

Table 1. Evaluation Criteria

Evaluation Criteria	Weight Factor
Exposure Pathways Modeled	2
Population Dose/Risk Capability	2
Dose Factors Used	1.75
Risk Factors Used	1.75
Meteorological Data Processing	1.5
Source Term Calculations	1.5
Verification and Validation	1.25
Ease of Use/User Friendly	1.25
Documentation	1
Sensitivity Analysis Capability	1
Probabilistic Analysis Capability	1
SC&A Familiarity	N/A

3.2 CAP88

3.2.1 Exposure Pathways Modeled (2)

Criteria: Are all of the exposure pathways that are essential to this analysis included in the code? Additionally, does the code allow for exposures to different age groups (i.e., adults, teens, children, infants) and/or sexes to be calculated?

Fields, D.E.; Miller, C.W.; Cotter, S.J. *Validation of the AIRDOS-EPA Computer Codes by Simulating Intermediate Range Transport of Kr-85 from the Savannah River Plant*. Atmos. Environ. 18:2029-2036; 1984.

Score: 5 **Weighted Score:** 6.25

3.2.8 Ease of Use/User Friendly (1.25)

Criteria: Is the code provided with a user interface that is intuitive and easy to understand and use? Alternatively, does the code require the user to manipulate structured input data files? Additionally, does the code have features not required for this analysis, but that might complicate its use?

Evaluation: Code contains very intuitive menus which prompt the user in a linear fashion to enter all pertinent model data. Of the five main codes analyzed in detail, CAP88 is the easiest to implement and most user friendly.

Score: 5 **Weighted Score:** 6.25

3.2.9 Documentation (1)

Criteria: Is the code well documented? Are there User's Manuals readily available? In addition to providing instructions as to how to use the code, are the mathematical models used by the code well documented?

Evaluation: The mathematical models and equations used by the code are presented in Chapter 12 of the user's guide.

"Mathematical Models in CAP88-PC" (Parks, DOE, 1997) provides additional documentation beyond the User's Manual.

Score: 5 **Weighted Score:** 5

3.2.10 Sensitivity Analysis Capability (1)

Criteria: Does the code have the capability to perform sensitivity analyses on the input data, or must parameter sensitivity be determined by multiple runs, each run varying a single parameter?

Evaluation: Sensitivity analyses can only be carried out using individual runs.

Score: 0 **Weighted Score:** 0

3.2.11 Probabilistic Analysis Capability (1)

Criteria: Is there a probabilistic analysis version of the code available?

Evaluation: Probabilistic analysis is not available for this code.

Score: 0 **Weighted Score:** 0

3.2.12 SC&A Familiarity (N/A)

Criteria: To be used as a tiebreaker when the top two codes have a final score within 10% of each other.

Evaluation: SC&A has very good overall familiarity with the CAP88 code, as SC&A helped assist EPA in the development of the mainframe version of the code, as well as assisted in writing the User's Manual. Since that time, SC&A has continued to use CAP88 in our consulting work for various clients.

3.3 GENII with FRAMES

3.3.1 Exposure Pathways Modeled (2)

Criteria: Are all of the exposure pathways that are essential to this analysis included in the code? Additionally, does the code allow for exposures to different age groups (i.e., adults, teens, children, infants) and/or sexes to be calculated?

Evaluation: Exposure pathways include: external (air immersion, ground-shine, recreational swimming/boating/shoreline exposure), ingestion (food crops, animal products, aquatic food, inadvertent soil, drinking water), and inhalation (air, resuspended soil, inhalation of waterborne contaminants).

Radon is considered a special radionuclide model for GENII along with tritium and carbon-14.

Score: 5 **Weighted Score:** 10

3.3.2 Dose Factors Used (1.75)

Criteria: Does the code utilize dose conversion factors based on the most recent International Commission on Radiological Protection (ICRP) recommendations?

Evaluation: "The GENII computer code was developed for the Environmental Protection Agency (EPA) at Pacific Northwest National Laboratory (PNNL) to incorporate the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) and radiological risk estimating procedures of Federal Guidance Report 13 into updated versions of existing environmental pathway analysis models."– GENII Users' Guide, October 2004

ICRP documents are noted as publications 56-72.

Score: 4 **Weighted Score:** 7

3.4.4 Population Based Dose/Risk Capability (2):

Criteria: Does the code allow for the calculation of a population dose/risk based on a site-specific unique population distribution or does the code only allow the calculation of dose/risk based on a single defined receptor location?

Evaluation: RESRAD can only calculate dose to an individual receptor as defined by the user. Population-based dose and risk calculations are not available with RESRAD- OFFSITE.

Score: 0 **Weighted Score:** 0

3.4.5 Meteorological Data Processing (1.5)

Criteria: Can the code process “raw” meteorological data, or does the meteorological data need to be pre-processed prior to being entered into the code? For example, does the code accept “raw” meteorological tower data, or does it accept joint frequency data, or does it only accept dispersion and deposition factors?

Evaluation: Joint frequency data can be input manually into the code or can also be read from a ‘STAR’ file. A single stability class/wind speed can also be used in place of the joint frequency data.

Meteorological data (in the STAR format) for 267 U.S. sites are provided with the code package.

Score: 5 **Weighted Score:** 7.5

3.4.6 Source Term Calculation (1.5)

Criteria: Can the code calculate radon releases, or must the releases be pre-calculated and entered into the code?

Evaluation: The code requires input of diffusion coefficients (from soil/cover, floor of a building, etc.) and other properties of radon, such as an emanation coefficient which will define the radon release value.

Score: 4 **Weighted Score:** 6

3.4.7 Verification and Validation (1.25)

Criteria: Is there a readily available V&V package that supports the code? Is the V&V package complete? Has there been independent (i.e., by someone other than the code’s developer) V&V performed?

Evaluation: The V&V package is contained in the document:

Yu, C.; Gnanapragasam, E.; Cheng, J.J.; Biwer, B. Benchmarking of RESRAD-OFFSITE: Transition from RESRAD (onsite) to RESRAD-OFFSITE and Comparison of the RESRAD-OFFSITE Predictions with Peer Codes. Environmental Science Division of Argonne National Laboratory.

The document compares the code against CAP88 and ISCLT3 for atmospheric transport calculations and also against the base RESRAD code for onsite calculations, which itself was benchmarked against GENII-S, DECOM, PRESTO-EPA-CPG, and the NUREG/CR-5512 methodology.

Score: 5 **Weighted Score:** 6.25

3.4.8 Ease of Use/User Friendly (1.25)

Criteria: Is the code provided with a user interface that is intuitive and easy to understand and use? Alternatively, does the code require the user to manipulate structured input data files? Additionally, does the code have features not required for this analysis, but that might complicate its use?

Evaluation: The code brings the user in a linear fashion through each of the input screens and provides a default value which will fit most situations. If the user tries to input a value that is outside the theoretical range for a given parameter, the code notifies the user and blocks them from entering the given value.

Score: 4 **Weighted Score:** 2.5

3.4.9 Documentation (1)

Criteria: Is the code well documented? Are there User's Manuals readily available? In addition to providing instructions as to how to use the code, are the mathematical models used by the code well documented?

Evaluation: The main User Manual is available on the main code's website which includes both a User's Guide (Appendix A of the document) and the methods and equations used by the code (main body of the User Manual).

Score: 5 **Weighted Score:** 5

3.4.10 Sensitivity Analysis Capability (1)

Criteria: Does the code have the capability to perform sensitivity analyses on the input data, or must parameter sensitivity be determined by multiple runs, each run varying a single parameter?

data and must be constructed in ASCII format by the user. Also like GENII, there do not appear to be any preloaded population files present with the software.

Score: 3 **Weighted Score:** 6

3.6.3 Dose Factors Used (1.75)

Criteria: Does the code utilize dose conversion factors based on the most recent International Commission on Radiological Protection (ICRP) recommendations?

Evaluation: Per the MEPAS website: “Health impacts from exposure to radiation are estimated using health effects conversion factors or USEPA slope factors... values are based on recommendation given in the BEIR V report (NAS 1990) and International Commission on Radiological Protection (ICRP) Publication 60 (ICRP 1990).”

Score: 4 **Weighted Score:** 7

3.6.4 Risk Factors Used (1.75)

Criteria: Does the code utilize the most recent risk factors?

Evaluation: Per the MEPAS website: “Two methods are available to estimate the risk of cancer fatalities: use of health- effects conversion factors and use of USEPA slope factors.” Slope factors are based on USEPA (U.S. Environmental Protection Agency). 1994. Health Effects Assessment Summary Tables FY 1994 - Supplement Number 2. EPA/540/R-94/114. Office of Emergency and Remedial Response, Washington, D.C.

Score: 5 **Weighted Score:** 8.75

3.6.5 Meteorological Data Processing (1.5)

Criteria: Can the code process “raw” meteorological data, or does the meteorological data need to be pre-processed prior to being entered into the code? For example, does the code accept “raw” meteorological tower data, or does it accept joint frequency data, or does it only accept dispersion and deposition factors?

Evaluation: MEPAS accepts joint frequency data as a user input. It has not been established whether modules exist in the MEPAS suite of tools to convert and analyze meteorological data in other formats, as GENII contains.

Score: 4 **Weighted Score:** 6

3.6.6 Source Term Calculation (1.5)

Criteria: Can the code calculate radon releases, or must the releases be pre-calculated and entered into the code?

4.0 RESULTS AND RECOMMENDATIONS

Table 2 summarizes the results of the code evaluation as presented in Section 3. As shown, RESRAD-OFFSITE was the highest scoring of the five codes, narrowly edging out CAP88. However, it is recommended that CAP88, and not RESRAD-OFFSITE, be used to perform the dose and risk calculations required for this Work Assignment. The reasons for this recommendation include:

- RESRAD-OFFSITE does not include the ability to perform population dose and risk estimates, which means that the RESRAD-OFFSITE results would need to be supplemented with population dose and risk estimates from another source. CAP88, on the other hand, is specifically designed to assess radiological emissions to the public.
- The major area where CAP88 is lacking is sensitivity and probability analyses. For this Work Assignment, it is not anticipated that sensitivity or probability analysis will play a major role.
- RESRAD-OFFSITE incorporates CAP88 air dispersion modeling, which means that there are no significant technical differences between the two codes for the purpose of this Work Assignment.
- CAP88 was developed as a predecessor to AIRDOS, which was the original code used in the evaluation of mill tailing impoundments during the development of NESHAPs for radon emissions in 1989.

GENII also finished high in the detailed evaluation; however, the main concern with GENII is that it currently is only available within FRAMES. As stated in Section 2.3.1, it was found that the process necessary to setup and run GENII within FRAMES was complicated relative to setting up and running pre-FRAMES GENII, and the present FRAMES GENII combination does not provide any technical advantage over the pre-FRAMES GENII. There are similar concerns regarding using MEPAS within FRAMES. The concern with FRAMES resulted in both GENII and MEPAS receiving low Ease of Use/User Friendly scores, which resulted in neither of them being selected for use.

MILDOS-AREA received the lowest ranking in the detailed evaluation, primarily due to its inability to perform risk calculations, which is a major component of this Work Assignment. Although it does not impact this Work Assignment, MILDOS-AREA is limited to evaluating only the isotopes of the U-238 decay series, which means that another code would be required if other nuclear fuel cycle facilities were to be evaluated, such as was done in the 1989 analysis.

Table 2. Summary of Suitability Review for Five Codes Under Evaluation

Evaluation Criteria	CAP88	GENII via FRAMES	RESRAD-OFFSITE	MILDOS-AREA	MEPAS via FRAMES
Exposure Pathways Modeled	10	10	10	10	10
Population Dose/ Risk Capability	10	6	0	8	6
Dose Factors Used	8.75	7	8.75	3.5	7
Risk Factors Used	8.75	8.75	8.75	0	8.75
Meteorological Data Processing	7.5	7.5	7.5	6	6
Source Term Calculations	3	3	6	3	3
Verification and Validation	6.25	6.25	6.25	6.25	5
Ease of Use/ User Friendly	6.25	1.25	5	6.25	1.25
Documentation	5	5	5	5	3
Sensitivity Analysis Capability	0	4	5	0	4
Probabilistic Analysis Capability	0	3	4	0	3
Totals	65.5	61.75	66.25	48	57

5.0 REFERENCES

Argonne National Laboratory (ANL), 1998, *MILDOS-AREA User's Guide (Draft)*, Environmental Assessment Division, September.

Beres, D.A., 1990, *The Clean Air Act Assessment Package-1988 (CAP-88) A Dose and Risk Assessment Methodology for Radionuclide Emissions to the Air*, S. Cohen and Associates. Prepared for U.S. Environmental Protection Agency, October.

Eckerman, K.F and Ryman, J.C, 1993, *External Exposure to Radionuclides in Air, Water, and Soil – Federal Guidance Report No. 12*, U.S. Environmental Protection Agency, EPA-402-R-93-081, September.

Fields, D.E.; Miller, C.W.; Cotter, S.J, 1984, *Validation of the AIRDOS-EPA Computer Codes by Simulating Intermediate Range Transport of Kr-85 from the Savannah River Plant*. Atmos. Environ, 18:2029-2036.

International Commission on Radiological Protection (ICRP), 1996. *1996 Age Dependent Doses from Intakes of Radionuclides*, In Annals of the ICRP, Vol. 26, ICRP Publication 72, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP), 1990. *1990 Recommendations of the International Commission on Radiological Protection*, In Annals of the ICRP, Vol. 21, ICRP Publication 60, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP), 1977, *1977 Recommendations of the International Commission on Radiological Protection*, In Annals of the ICRP, Vol. 1, ICRP Publication 26, Pergamon Press, New York.

Lehto, M.A., J.C. Courtney, N. Charter, and T. Egan, 2000, "Comparisons of CAP88PC Version 2.0 Default Parameters to Site Specific Inputs," Argonne National Laboratory, Waste Management '00, Session 21, Abstract #397, February 27 to March 2.

Maheras, S.J., P.D. Ritter, P.R. Leonard, and R. Moore, 1994, "Benchmarking of the CAP-88 and GENII Computer Codes using 1990 and 1991 Monitored Atmospheric Releases from the Idaho National Engineering Laboratory," Health Physics, 67, pp. 509-517, November.

Moore, R.E., et al., 1979, "AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides," Oak Ridge National Laboratory, Prepared for U.S. Environmental Protection Agency, ORNL-5532, EPA-520/1-79-009, June.

Moore, R.E., 1977, "AIRDOS-II Computer Code for Estimating Radiation Dose to Man From Airborne Radionuclides in Areas Surrounding Nuclear Facilities," Oak Ridge National Laboratory, ORNL-5245, April.

Moore, R.E., 1975, "AIRDOS: A Computer Code for Estimating Population and Individual Doses Resulting From Atmospheric Releases of Radionuclides From Nuclear Facilities," Oak Ridge National Laboratory, ORNL/TM-4687, January.

Napier, B.A.; Strenge, D.L.; Ramsdell Jr., J.V.; Eslinger, P.W.; Fosmire, C. 2004, *GENII Version 2 Software Design Document*, Pacific Northwest National Laboratory, Prepared for U.S. Environmental Protection Agency, November.

Napier, B.A.; 2004, *GENII Version 2 User's Guide*, Pacific Northwest National Laboratory. Prepared for U.S. Environmental Protection Agency, PNNL-14583, October.

National Academy of Sciences (NAS), 1990, *Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V*, Committee on the Biological Effects of Ionizing Radiations, Board on Radiation Effects Research, Commission on Life Sciences, National Research Council, National Academy Press, Washington, D.C.

Pacific Northwest National Laboratory (PNNL), 2010, *GENII Version 2: User's Guide*. Prepared for U.S. Environmental Protection Agency, PNNL-14583, Rev. 3a, June.

Trinity Engineering Associates Inc., 2007, *CAP88-PC Version 3.0 User Guide*. Prepared for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, December.

U.S. Department of Energy (DOE), 1997, Parks, B; *Mathematical Models in CAP88-PC*, June.

U.S. Environmental Protection Agency (EPA), 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides – Federal Guidance Report No. 13*, EPA 402-4-99-001, September.

U.S. Environmental Protection Agency (EPA), 1994, *Health Effects Assessment Summary Tables FY 1994 - Supplement Number 2*, Office of Emergency and Remedial Response, EPA/540/R-94/114, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1989, *Risk Assessment Methodology – Environmental Impact Statement for NESHAPS Radionuclides – Volume I: Background Information Document*, EPA 520/1-89-005, September.

U.S. Environmental Protection Agency (EPA), 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion – Federal Guidance Report No. 11*, EPA-520/1-88-020, September.

U.S. Nuclear Regulatory Commission (NRC), 2003, *Standard Review Plan for In Situ Leach Uranium Extraction License Applications – Final Report*, NUREG-1569, June.

U.S. Nuclear Regulatory Commission (NRC), 1978, “Final Environmental Statement, Related to the Wyoming Mineral Corporation, Irigaray Uranium Solution Mining Project,” NUREG-0481, September.

U.S. Nuclear Regulatory Commission (NRC), 1977, *Regulatory Guide 1.109 – Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I – Revision 1*, Office of Standards Development, October.

Yu, C.; Gnanapragasam, E.; Cheng, J.J.; Biwer, B., 2006, *Benchmarking of RESRAD-OFFSITE: Transition from RESRAD (onsite) to RESRAD-OFFSITE and Comparison of the RESRAD-OFFSITE Predictions with Peer Codes*, Argonne National Laboratory, Environmental Science Division, ANL/EVS/TM/06-3, DOE/EH-0708, May.