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Eden Radioisotopes

Considerations for design of atmospheric effluent system

December 2022

BG Fritz

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Acronyms and Abbreviations

CAP-88 PC	Clean Air Act Assessment Package – 1988 Personal Computer version
EPA	U.S. Environmental Protection Agency
JFD	joint frequency distribution
PNNL	Pacific Northwest National Laboratory

Radionuclides

^{98}Mo	molybdenum-98
^{99}Mo	molybdenum-99
^{100}Mo	molybdenum-100
^{99}Tcm	technetium-99m

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1.0 Introduction

Technetium-99m (^{99m}Tc) is the most widely used radioisotope for medical procedures. It is used to diagnose and stage serious medical conditions such as heart disease, cancer, infection, and inflammation. Technetium-99m is used in more than 40,000 imaging procedures daily in the United States and at least an equal number of procedures throughout the rest of the world. Molybdenum-99 (^{99}Mo) is the parent isotope of ^{99m}Tc. For more than 25 years, the U.S. supply of ^{99}Mo has been solely reliant on aging nuclear reactors located outside the United States, resulting in supply interruptions that disrupt the provision of healthcare for patients.

Eden Radioisotopes, LLC, is attempting to design and build a less than 2-MW nuclear reactor for the sole purpose of providing ^{99}Mo. This reactor would be a small, dedicated reactor for medical isotope production. While the small size and single mission result in relatively low atmospheric emissions, it is still important to optimize design of the atmospheric effluent system to minimize dose to member of the public.

Here, the EPA-approved atmospheric model CAP-88 PC is used to compare some various effluent design considerations and the resulting dose from atmospheric emissions. In this report, the difference in estimated dose to a maximally exposed individual, as well as the location of the potential receptor, are estimated for various stack heights, velocities, and exhaust rates. Additionally, another EPA-approved model, COMPLY, is tested to evaluate the similarity in the estimated doses between the two models.

2.0 Methods

For this evaluation, several inputs to CAP-88 PC were varied in order to evaluate the impact to potential dose. The model and inputs are described below. Additionally, the EPA model COMPLY was run for comparison against CAP-88 PC.

2.1 CAP-88 PC

CAP-88 PC is a free model developed by the U.S. EPA for estimating dose from atmospheric release of radionuclides. The model uses joint frequency distribution wind data to determine the relative dose around an emission source.

2.1.1 CAP-88 inputs

A large library of default meteorological data is provided with CAP-88 PC[1]. For this evaluation, wind speed and direction data from Midland, TX was used. Midland, TX is approximately 75 miles from the proposed Eden facility and should provide an acceptable surrogate location for meteorological input. In addition to the wind speed and direction data, other inputs are necessary for CAP-88 PC to run. For this exercise, all input parameters were estimated for the area and either kept constant or varied within the range described below (Table 2-1). The stack exit velocity was calculated as a function of the stack diameter. An exhaust rate of 5,000 cubic feet per second was assumed, so the exit velocities for a 0.5-, 1- and 1.5-meter diameter stack are 12, 3 and 1.3 m/s, respectively.

Table 2-1. CAP-88 input parameters used.

Parameter	Value Used
Annual rainfall	46 cm
Annual average air temperature	17 deg C
Lid height	1,000 m
Annual average absolute humidity	9 g/m^3
Number of stacks	1
Stack height	10, 15, 20 m
Stack diameter	0.5, 1, 1.5 m
Plume type	Momentum
Stack exit velocity	12, 3, 1.3 m/s
Food Source	Rural
State	New Mexico

2.1.2 Radiological effluent

The radiological effluent from the future Eden facility is currently unknown. For this evaluation the radiological effluent was kept constant for all modeling runs as a unit dose for each nuclide. This provides a comparison of the impact other input parameters have on the expected dose at a downwind location. While a fixed emission rate will be used, it is necessary to model isotopes

[1] File 23023 Midland/Regional air Te

expected to be present in the exhaust. For modeling purposes, an annual total of 10 Ci will be used (Table 2-2).

Table 2-2. Modeled atmospheric effluent (per year). Not representative of actual expected effluent.

Isotope	Emission from each stack (Ci/yr)
H-3	1
Ar-41	1
Kr-85	1
Kr-87	1
Kr-88	1
I-131	1
I-133	1
Xe-133	1
I-135	1
Xe-135	1
Total	**10**

2.1.3 Receptors

For modeling purposes, a grid of receptors in the vicinity of the Eden facility was considered. These receptors were at distances of 100, 150, 175, 200, 225, 250, 275, 300, 350, 400, 450,500 and 1000 meters. The concentration, and corresponding dose, is calculated at each distance in each of the 16 ordinal directions. The location at 500 meters represents, nominally, the concentration at the facility fence line.

2.2 COMPLY

To the extent possible, the model inputs for COMPLY were set equal to the CAP-88 PC inputs. Only a 15-m tall stack was modeled. Wind rose data for Hobbs, NM, and Midland-Odessa, TX, were used as the meteorological inputs. The building dimensions were chosen as 10-m high, 10-m wide and 50-m long. The receptor farm location distance was chosen to be 10,000-m. This distance (6.2 miles) was considered reasonable, yet still conservative as the area immediately surrounding the Eden facility is industrial and/or scrub brush. Receptors were modeled at both 500 and 1000 meters for comparison with the receptors modeled with CAP-88 PC.

3.0 Results

Results for both CAP-88 PC and COMPLY model runs are included in this section. Comparison of the two models is captured in the Discussion.

3.1 CAP-88 PC

A summary of the results for the CAP-88 PC runs are summarized below. This includes the MEI dose and location (Table 3-1) as well as the dose at two receptor locations (Table 3-2) and breakdown of the relative contribution to dose from each isotope for one modeled scenario (Table 3-3). Note that these modeled doses are for a purely hypothetical release and do not represent the expected doses in the vicinity of the Eden facility.

Table 3-1. Modeled MEI dose (mrem) for the various stack configurations tested (location in parentheses).

Stack Diameter	**Stack height**		
	10 m	15 m	20 m
0.5 m	0.274 (150 m N)	0.123 (225 m N)	0.0680 (300 m N)
1 m	0.316 (150 m N)	0.137 (200 m N)	0.0743 (300 m N)
1.5 m	0.333 (150 m N)	0.143 (200 m N)	0.0766 (300 m N)

Table 3-2. Modeled dose (mrem) at 500 and 1000 meters North of the stacks.

Stack Diameter	**Stack height**		
	10 m	15 m	20 m
0.5 m	0.11 & 0.054	0.079 & 0.042	0.057 & 0.033
1 m	0.13 & 0.058	0.086 & 0.046	0.061 & 0.036
1.5 m	0.14 & 0.062	0.090 & 0.048	0.062 & 0.037

Table 3-3. Modeled contribution to dose (mrem) for each isotope and pathway at the MEI location (200 m N) for a 15-m stack with a 1-m stack diameter.

Isotope	Modeled Annual Dose (mrem)		Isotope	Modeled Annual Dose (mrem)
Kr-88	3.07×10^{-3}		Cs-135	1.35×10^{-12}
Rb-88	3.24×10^{-5}		I-133	1.73×10^{-2}
Xe-133	4.35×10^{-5}		Xe-133m	3.49×10^{-4}
I-131	1.05×10^{-1}		Ar-41	1.94×10^{-3}
Xe-131m	3.72×10^{-12}		H-3	5.72×10^{-4}
I-135	7.03×10^{-3}		Kr-85	7.65×10^{-6}
Xe-135m	3.04×10^{-6}		Kr-87	1.25×10^{-3}
Xe-135	3.49×10^{-4}		Rb-87	4.00×10^{-17}
TOTAL	1.37×10^{-1}			

Table 3-4. Modeled contribution to dose (mrem) for each pathway at the MEI location (200 m N) for a 15-m stack with a 1-m stack diameter

Pathway	Modeled Annual Dose (mrem)
Ingestion	4.75×10^{-4}
Inhalation	1.26×10^{-1}
Air Immersion	1.05×10^{-2}
Ground Surface	1.14×10^{-6}
TOTAL	1.37×10^{-1}
Internal	1.27×10^{-1}
External	1.05×10^{-2}
TOTAL	1.37×10^{-1}

3.2 COMPLY

Only a few scenarios were evaluated with the COMPLY program. The COMPLY model is relatively labor intensive (for a simple dispersion model), with each run requiring several minutes to input the necessary operational parameters. Since COMPLY does not consider plume rise, a comparison scenario was run using CAP-88 PC with a 15-m stack but no exit velocity.

Table 3-5. Model results for COMPLY.

Meteorology Source	MEI dose at 500 m N	MEI dose at 1000 m N
Midland-Odessa, TX	0.2 mrem/yr	0.086 mrem/yr
Hobbs, NM	0.2 mrem/yr	0.06 mrem/yr
CAP-88 PC*	0.097 mrem/yr	0.051 mrem/yr
*Meteorology from Midland-Odessa, TX. Stack exit velocity = 0		

4.0 Discussion

As expected, the stack height and exit velocity of the effluent have an impact on the modeled doses. A taller stack with a higher exit velocity results in the plume being higher off the ground initially and taking longer for the plume centerline to reach the surface, allowing more time for dispersion of the contaminant. For example, a nearly 5x reduction in the MEI dose is predicted when the stack height is doubled from 10 to 20 meters and the stack diameter is reduced from 1.5 to 0.5 meters. Because the modeled MEI dose is inside of the 500-m fence line distance, the modeled dose at the fence line is less sensitive to changes in stack height and diameter. At the 500-m distance, going from a short and wide stack to a tall narrow stack only reduces the modeled dose by a factor of 2 (nominally).

For the expected nuclides in the atmospheric effluent, radio iodine is the primary contributor to the modeled dose (Table 3-3), contributing 99% of the estimated dose to an MEI. This is primarily driven by thyroid uptake of iodine through ingestion of food products. While consumption of food products may not be a particularly common scenario in the vicinity of the Eden facility, it is still notable that radioiodine (^{131}I and ^{135}I) is driving the estimated dose. Reduction of iodine species in the exhaust stream could provide a significant reduction in the modeled dose to a hypothetical receptor.

The cases chosen for comparison of COMPLY and CAP-88 PC were for a 15-m high exhaust stack. The two models have some inherent differences; for example, CAP-88 PC does not address building generated turbulence. Additionally, COMPLY does not account for differences in dispersion under various atmospheric stabilities. Despite these differences, the two models agreed within a factor of 2 for the expected dose at both 500-m and 1000-m from the release point. Additionally, COMPLY identified radioiodine as the largest contributor to dose. Because COMPLY allows the user to select the distance between farms and the source for a potential receptor, the modeled dose is sensitive to the selection of the farm location. The meteorological data source had a slight impact in the modeled dose; use of data from Hobbs, NM resulted in a slightly lower dose at 1000-m relative to when the Midland-Odessa, TX data was used.

5.0 Conclusion

In general, when designing atmospheric effluent systems, it is desirable to get the release plume as high as possible to facilitate dispersion of the contaminant before it reaches ground level (and potential receptors). Here, we evaluated the relative impact that changes in stack height and diameter could have on the modeled dose to hypothetical receptors. This is relevant to the Eden facility as they move towards a final design; changes in the effluent system can be easier to implement now rather than later on in the design process. One design change that could potentially provide a large reduction on dose to members of the public would be mitigation of radio iodine releases. As the facility moves towards securing an operating permit, assessment of the potential dose to members of the public will be one requirement. The computer model COMPLY may be the program required to demonstrate compliance. For the Eden facility, COMPLY appears to provide results similar to CAP-88 PC, another regulatory model commonly used to demonstrate compliance with applicable dose requirements. It may be advisable to get the regulatory agency to accept CAP-88 PC results instead of COMPLY; CAP-88 PC provides a quicker set-up and, more importantly, provides a much more thorough output. Results from CAP-88 PC include the estimated doses at all user entered locations and provides an assessment the relative contribution to dose for each isotope and pathway.

6.0 References

EPA (U.S. Environmental Protection Agency). 2019. *CAP-88 PC Version 4.1 Users Guide*. Available online at: https://www.epa.gov/sites/production/files/2019-11/documents/cap88-pc_4.1_user_guide.pdf.

Fritz, B.G., K.A. Wagner, J.C. Hayes. 2020. *NorthStar Environmental Monitoring Plan: Preliminary Pathway Assessment*. PNNL-30337, Pacific Northwest National Laboratory, Richland, WA.

Fritz, B.G., K.A. Wagner, J.C. Hayes. 2021, *NorthStar Environmental Monitoring Plan: Implementation Assistance*. PNNL-29980, Pacific Northwest National Laboratory, Richland, WA.

Mitchell, E.A. Jr. 1982. A comparison of short-term dispersion estimates resulting from various atmospheric stability classification methods. *Atmospheric Environment* 16(4);765-773

ORAU (Oak Ridge Associated Universities). 2015. *Technical Basis Document for Revisions to NRC Regulatory Guide 3.63*, Section C.1, Fourth Paragraph (Final). (RFTA 14-011), DCN 5244-TR-01-1, Oak Ridge, TN. Available online at: https://www.nrc.gov/docs/ML1631/ML16313A580.pdf

Woodward, J.L. 1998. *Estimating the Flammable Mass of a Vapor Cloud*. Appendix A. American Institute of Chemical Engineers, New York, NY.

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