NEUP CINR R&D 23-29622
Development of the Technical Bases to Support Flexible Siting of Microreactors based on Right-Sized Emergency Planning Zones (EPZ)

PI: Saya Lee

DOE-NE Technical point of contact: Efe Kurt

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Project Objectives

- The objective of the proposed project is to provide the technical basis to support the application of a right-sized Emergency Planning Zone (EPZ), to aid in the deployment of a microreactor research, development, and deployment (RD&D) platform at the Penn State University Park campus as proposed by the Post-Industrial Midwest and Appalachia (PIMA) Nuclear Alliance (NA).
- The proposed study will serve as a template to provide flexible siting in support of future microreactor deployments that may be placed closer to demand centers and industrial facilities, thereby making them more economically competitive.
- This study will support the Level III PRA assessments by developing methods and models to improve the characterization of post-accident near-field atmospheric dispersion of radionuclide particles for a generic microreactor. The risk-informed approach in this case includes describing the risk profile of the microreactor, which includes characterizing the reactor-specific risks, which are related to the Level I and II Probabilistic Risk Assessments (PRA), and the more generic and site-specific items related to the Level III PRA.
- Furthermore, by describing the site-specific risks, PIMA-NA can adopt a more rapid licensing approach, which allows the site license application to proceed separately from the design certification application of the microreactor.

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Project Team and Contributors

- PSU
  - **PI: Saya Lee (NUCE)**
  - **Co-PI: Gretta Kellogg (AIMI)** & Two contributors for VR/XR and One contributor for Economic Impact
  - Four Contributors from the Office of Physical Plant (**OPP**): Two Licensing and Two Site Selection
  - Two Contributors from the Office of Government and Community Relations (**OGCR**)

- Pitt-Tech
  - **Co-PI: Sola Talabi – EPZ, Licensing, and QA**

- Westinghouse (**WEC**)
  - Michael Valore & Seven contributors
  - Two for Radionuclides Inventory and Mechanical Source Terms
  - Three for Licensing
  - One for Business Model / Community Outreach
  - One for Communication

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Milestones / Deliverables

1. **Recommended Guidelines for Microreactor Nearfield Atmospheric Dispersion Assessments:** This report will provide recommendations on model improvements and enhancements to characterize near-field aerosol dispersion for microreactors. This includes the finalization of fidelity and data requirements, the recommendations for the development of a specialized/tailored CFD model for studying aerosol dispersion, recommendations for NRC code enhancements and applicability to ongoing DOE programs, and empirical data requirements for model enhancements.

2. **Penn State University Site-Specific Atmospheric Dispersion Assessment**: This will include an estimate of the post-accident scenario atmospheric dispersion of radionuclide particles in the unlikely event of an accident at the Penn State University Campus. This analysis will include an estimate of the dose at distance based on a bounding dose release from the reactor, which would be determined by input from the microreactor vendor.

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Tasks & Schedule

Task 1: Stakeholder Engagement

Task 2: Literature Review

Task 3: Preliminary Analysis

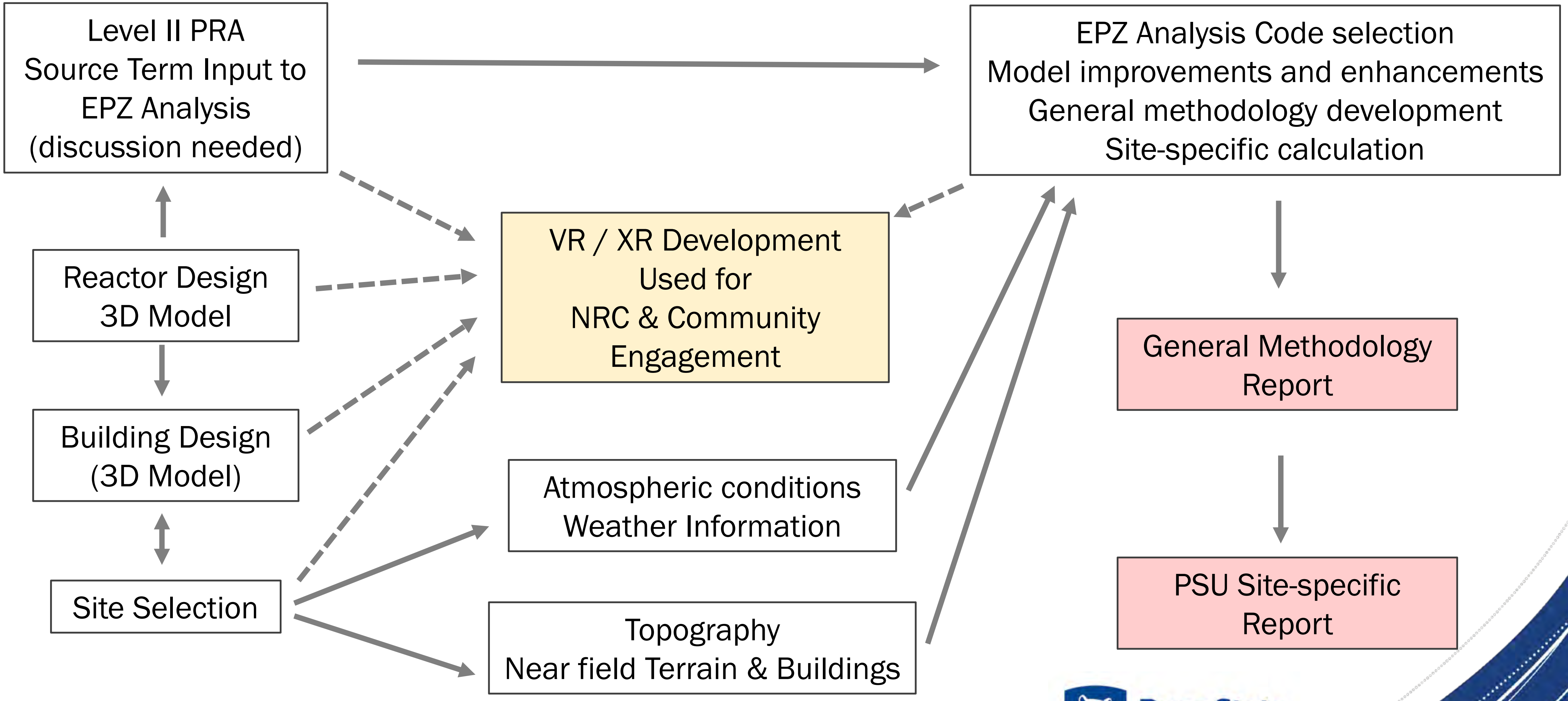
Task 4: Model Development and Methodology

Task 5: Site-Specific Risk Assessment

Task 6: Regulatory Approval Pathway Application

Tasks	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Stakeholder Engagement & Societal Acceptance Research								
Stakeholder Engagement								
Societal Acceptance Research								
Task 2: Literature Review								
EPZ Review: Microreactors & Research Reactors, SMRs, LLWRs								
Acquiring Codes								
Societal Acceptance Review								
Task 3: Preliminary Analysis								
Identification of dispersion mechanisms applicable to microreactors								
Microreactor source terms (Westinghouse Level II)								
Gap assessment								
Site selection methodology								
Identification of atmospheric conditions & topography								
Identification of the best site candidates on the PSU campus								
Identification of site-specific atmospheric conditions & topography								
Task 4: Model Development and Methodology								
Development of Methodology to Implement Dynamic Modeling								
Development of Methodology to Include Credit from Additional Dispersion and Deposition Phenomena								
Building 3D model								
eVinci 3D model								
Develop site-specific models								
PSU-specific buildings and Co-locations								
Develop XR Immersion Modeling Tools								
Documentation of results								
Year 1 Report								
Task 5: Site-Specific Risk Assessment								
Idealized site determination								
Co-location risks								
Transportation risks								
Task 6: Regulatory Approval Pathway Application								
Generating Guideline or Plan								
Feasibility study to identify critical parameters for fission product deposition within microreactor containments – Collaboration with WEC								
Community engagement plan, and the use of outcomes of community elicitation exercises to inform the regulatory framework								
Technical exercises to establish a robust justification of the proposed approach, which will include experimental quantification of microreactor Decontamination Factors								
Characterization of site-specific risks including near- and far-field aerosol dispersion with respect to the microreactor								
Reconciliation with the Section 104 licensing approach.								
Task 7: Final Report								

Workflow



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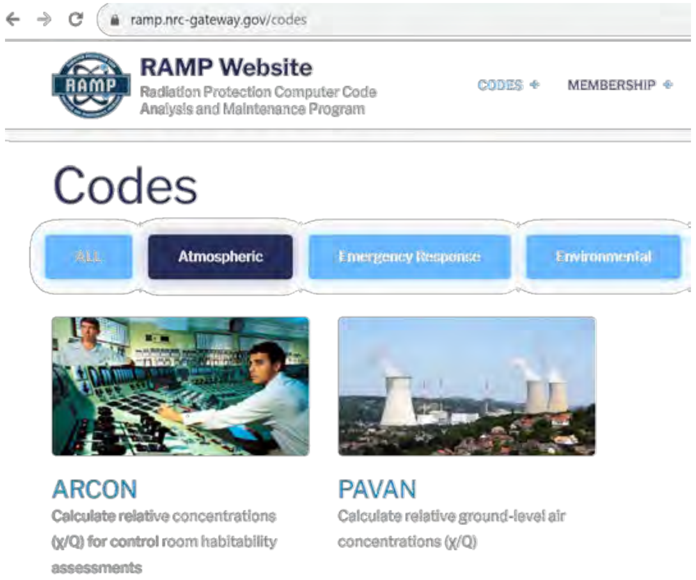
Atmospheric Dispersion Code Review

- **ARCON -** Code System to Calculate Atmospheric Relative Concentrations in Building Wakes. (https://ramp.nrc-gateway.gov/codes/arcon)
- **Pavan** - Calculate relative ground-level air concentrations (χ/Q) (https://ramp.nrc-gateway.gov/codes/pavan)
- **RASCAL** - Radiological Assessment System for Consequence Analysis for radiological emergencies (https://ramp.nrc-gateway.gov/codes/rascal)
- **Visual Sample Plan** - Develop a defensible sampling plan based on statistical sampling theory (https://ramp.nrc-gateway.gov/codes/vsp)
- **MELCOR/MACCS -** MACCS simulates the impact of severe accidents at nuclear power plants (NPPs) and other nuclear facilities on the surrounding environment. As the only code used by the NRC to support Level-3 a probabilistic risk assessments (PRAs), MACCS can use a site's weather data to determine hypothetical land contamination levels, doses to individuals, health effects and risks on populations based on protective action recommendations, and economic losses resulting from a NPP accident. A list of references can be located on the left-hand side of this webpage. (https://www.nrc.gov/about-nrc/regulatory/research/obtainingcodes.html#4)
- **Hotspot** - Provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety analyses of facilities handling nuclear material. Lawrence Livermore National Laboratory Health Physics Code
- **AERMOD** - AERMOD is the state-of-the-science, steady-state Gaussian air dispersion model that is EPA-approved for most refined modeling scenarios.
- **CAP88** - CAP88-PC EPA (Clean Air Act Assessment Package - 1988) is a computer code for estimating the dose and risk from emissions of radioactive material to the air. CAP88-PC is a regulatory compliance tool under the National Emissions Standard for Hazardous Air Pollutants (NESHAPs).



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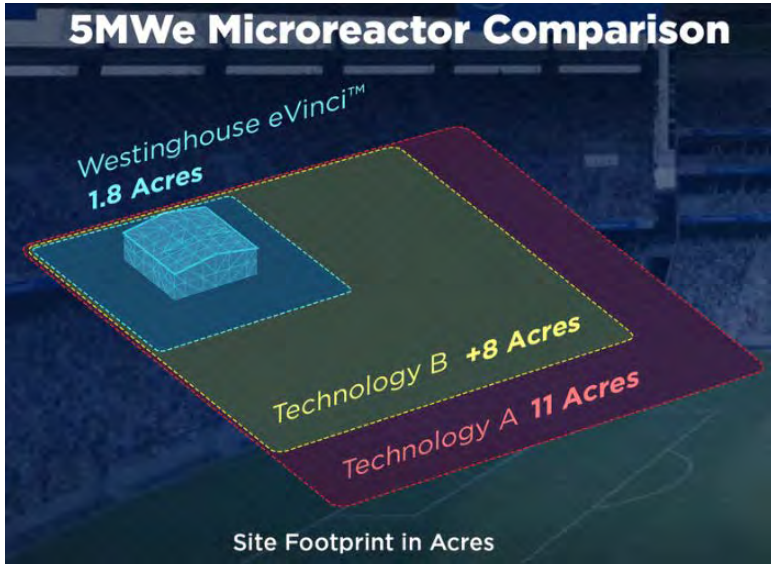
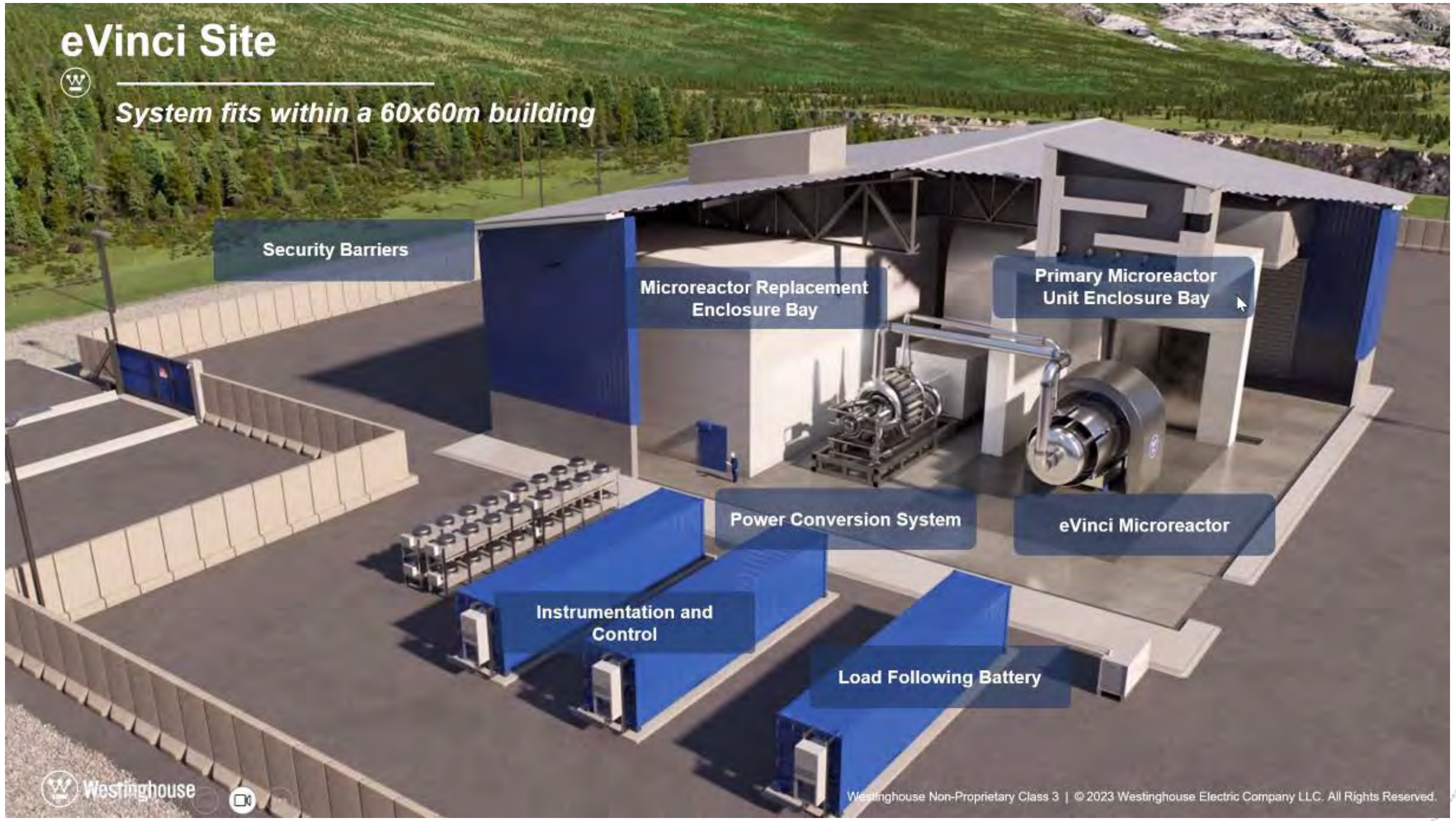
Code Inputs - Building

- To be added



https://www.westinghousenuclear.com/energy-systems/evinci-microreactor/



Source Terms

2019 - Westinghouse eVinciTM Micro-Reactor Licensing Modernization Project Demonstration

	Gap Fraction	Heat-Up and Cooldown Release Fractions including the Gap Fraction								
		Peak Temp = 750°C			Peak Temp = 850°C			Peak Temp = 950°C		
		Min	Nom	Max	Min	Nom	Max	Min	Nom	Max
Species	Duration	2.3 hrs	2.8 hrs	3.5 hrs	4.3 hrs	5.3 hrs	6.4 hrs	6.2 hrs	7.6 hrs	9.3 hrs
Nobles	1.7E-04	5.0E-04	5.7E-04	6.6E-04	3.1E-03	3.6E-03	4.5E-03	1.8E-02	2.1E-02	2.7E-02
I	1.4E-04	4.0E-04	4.5E-04	5.3E-04	2.4E-03	2.9E-03	3.6E-03	1.4E-02	1.7E-02	2.1E-02
Cs	1.4E-04	4.6E-04	5.3E-04	6.2E-04	3.0E-03	3.5E-03	4.4E-03	1.8E-02	2.1E-02	2.6E-02
Sr	1.7E-06	5.0E-06	5.7E-06	6.6E-06	3.1E-05	3.6E-05	4.5E-05	1.8E-04	2.2E-04	2.7E-04
Mo	4.4E-05	1.3E-04	1.4E-04	1.7E-04	7.6E-04	9.1E-04	1.1E-03	4.5E-03	5.4E-03	6.7E-03
Ba	3.5E-06	1.0E-05	1.1E-05	1.3E-05	6.1E-05	7.3E-05	8.9E-05	3.6E-04	4.3E-04	5.4E-04
La	3.5E-08	1.0E-07	1.1E-07	1.3E-07	6.1E-07	7.3E-07	9.0E-07	3.6E-06	4.3E-06	5.4E-06
Ce	3.5E-08	1.0E-07	1.1E-07	1.3E-07	6.1E-07	7.3E-07	9.0E-07	3.6E-06	4.3E-06	5.4E-06
Sb	8.7E-05	2.5E-04	2.8E-04	3.3E-04	1.5E-03	1.8E-03	2.2E-03	9.0E-03	1.1E-02	1.3E-02
Te	1.4E-04	4.0E-04	4.5E-04	5.3E-04	2.4E-03	2.9E-03	3.6E-03	1.4E-02	1.7E-02	2.1E-02
Ru	8.7E-06	2.5E-05	2.8E-05	3.3E-05	1.5E-04	1.8E-04	2.2E-04	9.1E-04	1.1E-03	1.4E-03

TABLE I. Radionuclide inventory for HTGR Accident (adapted from [10])

Isotope	Activity [Bq]
Cs-134	1.211E+14
Cs-137	3.465E+14
I-131	3.891E+15

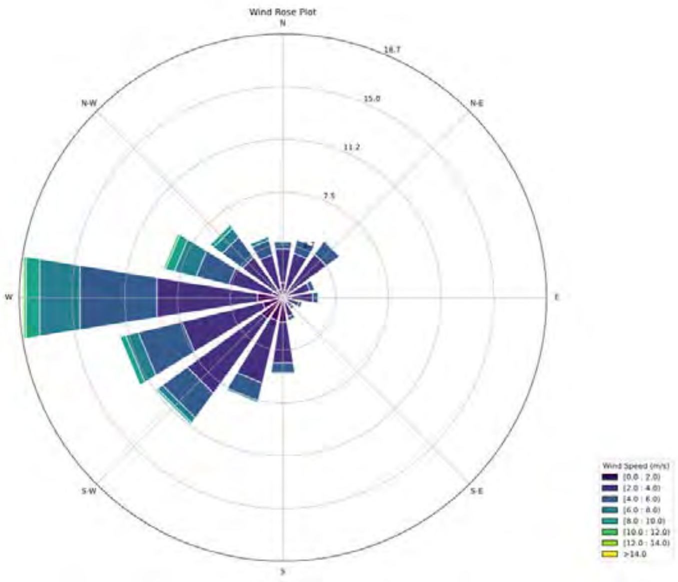
Description	Value (units)	Notes
Nuclide Information		
Core Nuclide Inventories	See notes	Inventories at Shutdown were generated for a 1 MWt nominal core. These are increased by a factor of 14 for the 14 MWt design.
Nuclide Chemical Forms	See notes	All nuclides were assumed to be particulate, except noble gases. Iodine volatilizes from aqueous solutions in the presence of low pH (excess hydrogen) and excess oxygen. The eVinci Micro-Reactor has no water, so iodine oxidation and subsequent volatilization is judged to not be a concern.
Dose Conversion Factors		Dose conversion factors are taken from US Environmental Protection Agency (EPA) Federal Guidance Reports 11[14] and 12[15] consistent with analysis that follows RG 1.183.[16]
Atmospheric Assumptions		
Atmospheric Dispersion Factor (X/Q)	1 sec/m^3	The assumed value of 1 sec/m^3 is a physical maximum, representing no dispersion. This is representative of <1 meter of distance between the source and the dose receptor.
Breathing Rate	3.5E-04 m^3/s	Standard NRC Dose Analysis Assumption
Geometry Assumptions		
Monolith Volume	1 ft^3	Arbitrary value as the leak rate is 1%/day.
Maximum Monolith Leak Rate	0.001 wt%/day	It is anticipated that the Canister is maintained at a positive pressure relative to the Monolith, even during accident conditions. Thus, any leakage out of the Monolith is a non-physical conservative assumption.
Monolith Activity Removal Rate	N/A	No removal was assumed in the monolith.
Canister Volume	1 ft^3	Arbitrary value as the leak rate is 1%/day.
Maximum Canister Leak Rate	0.001 wt%/day	The standard value for a large dry containment at a 60 psig design pressure is 0.1 weight-%/day. This is expected to be conservative with respect to the leak rate from the Canister.
Maximum Canister Activity Removal Rate	N/A	No removal was assumed in the Canister.
SVS Volume	1 ft^3	Arbitrary value as the leak rate is 1%/day.
Maximum SVS Leak Rate	0.001 wt%/day	The standard value for a large dry containment at a 60 psig design pressure is 0.1 wt%/day. This is expected to be conservative with respect to the leak rate from the SVS.
Maximum SVS Activity Removal Rate	N/A	No removal was assumed in the SVS.
Fuel Damage Assumptions – Scenario 1		
Activity Release Fractions	See notes.	Fission product release fractions were calculated for postulated monolith isothermal heat up using the ORNL-Booth model for releases from uranium dioxide fuel. Peak temperatures were assumed at 750°C, 850°C, and 950°C, along with minimum, nominal, and maximum heat up and cooldown rates.
Number of Fuel Channels	378 (1 MWt), 4219 (14 MWt)	The number of fuel channels does not scale linearly with power.

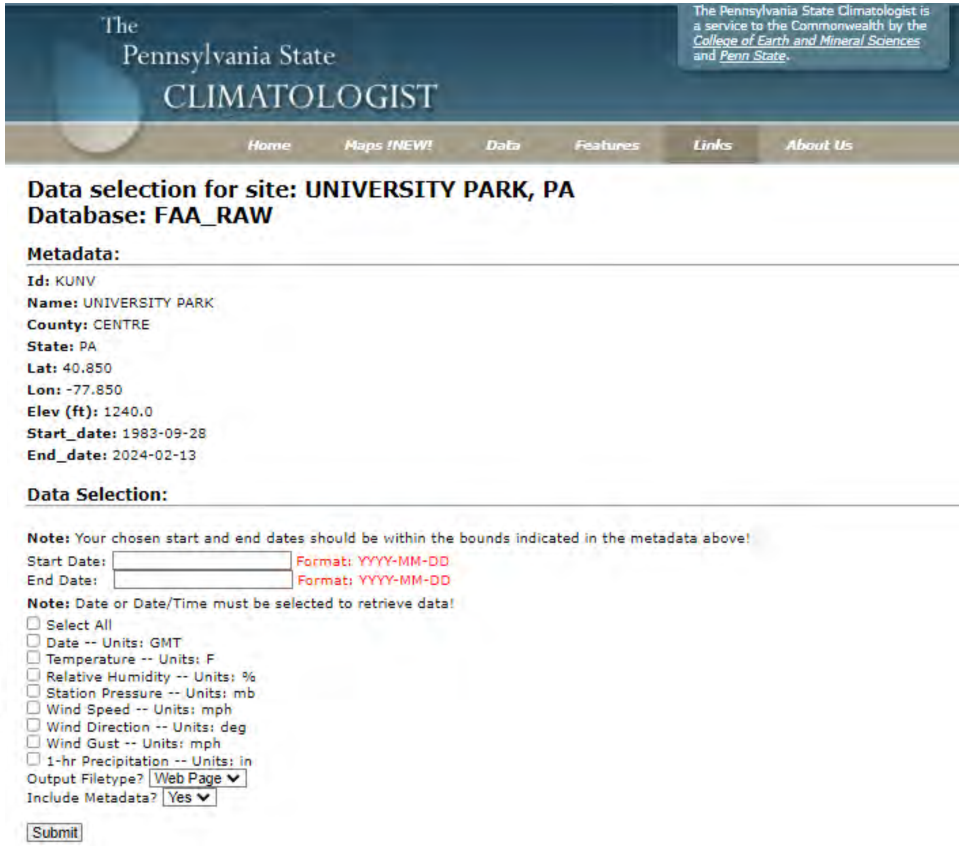
Code Inputs - Meteorological Data

- Meteorological data for 5 years is ideal, 3 years minimum
  - 15-minute intervals, 64 direction weather data input
  - http://climate.met.psu.edu/data/ida/index.php?t=3&x=faa_raw&id=KUNV

- Calculations done for each year
  - Year with most conservative results should be chosen

Date (GMT)	Time	Wind Speed (mph)		Wind Direction (deg)
24/01/2023	00:00	00:53:00	11.5	290
24/01/2023	00:00	01:53:00	10.4	270
24/01/2023	00:00	02:53:00	11.5	280
24/01/2023	00:00	03:15:00	13.8	280
24/01/2023	00:00	03:35:00	12.7	260
24/01/2023	00:00	03:55:00	15	270
24/01/2023	00:00	04:15:00	17.3	270
24/01/2023	00:00	04:35:00	17.3	270
24/01/2023	00:00	04:55:00	18.4	260
24/01/2023	00:00	05:15:00	21.9	260
24/01/2023	00:00	05:35:00	12.7	270
24/01/2023	00:00	05:55:00	18.4	260
24/01/2023	00:00	06:15:00	16.1	260
24/01/2023	00:00	06:35:00	16.1	260
24/01/2023	00:00	06:55:00	16.1	250
24/01/2023	00:00	07:15:00	15	260
24/01/2023	00:00	07:35:00	17.3	260
24/01/2023	00:00	07:55:00	20.7	260
24/01/2023	00:00	08:15:00	13.8	260
24/01/2023	00:00	08:35:00	16.1	250
24/01/2023	00:00	08:55:00	16.1	260
24/01/2023	00:00	09:15:00	20.7	250
24/01/2023	00:00	09:35:00	21.9	260
24/01/2023	00:00	09:55:00	18.4	250
24/01/2023	00:00	10:15:00	15	260
24/01/2023	00:00	10:35:00	13.8	260
24/01/2023	00:00	10:53:00	16.1	270
24/01/2023	00:00	11:53:00	17.3	280
24/01/2023	00:00	12:53:00	13.8	260





Atmospheric Dispersion

Time integrated Gaussian Plume Equation

$$C(x,y,z,H)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}\exp\left[-\frac{\lambda x}{u}\right]DF(x)$$

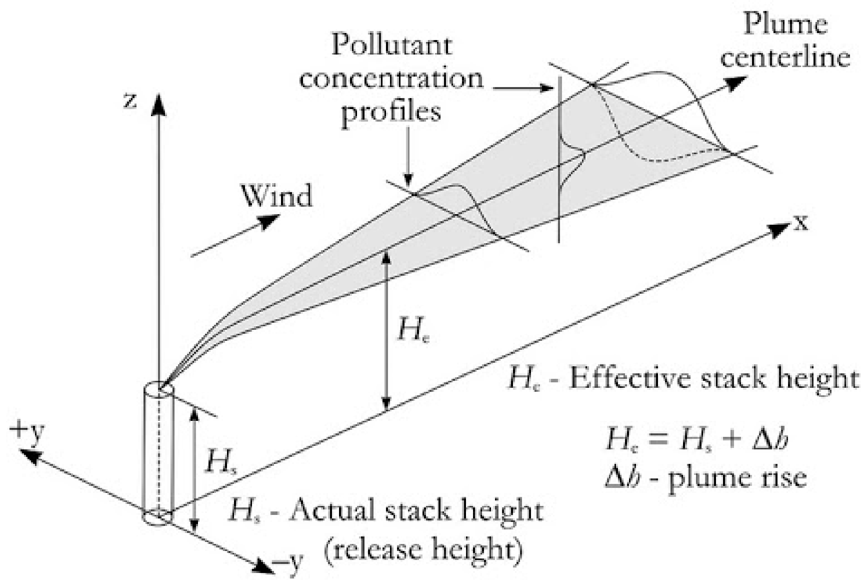
Concentration of Radionuclide $(Ci.s.m^{-3})$

Total amount of pollutant released (Ci)

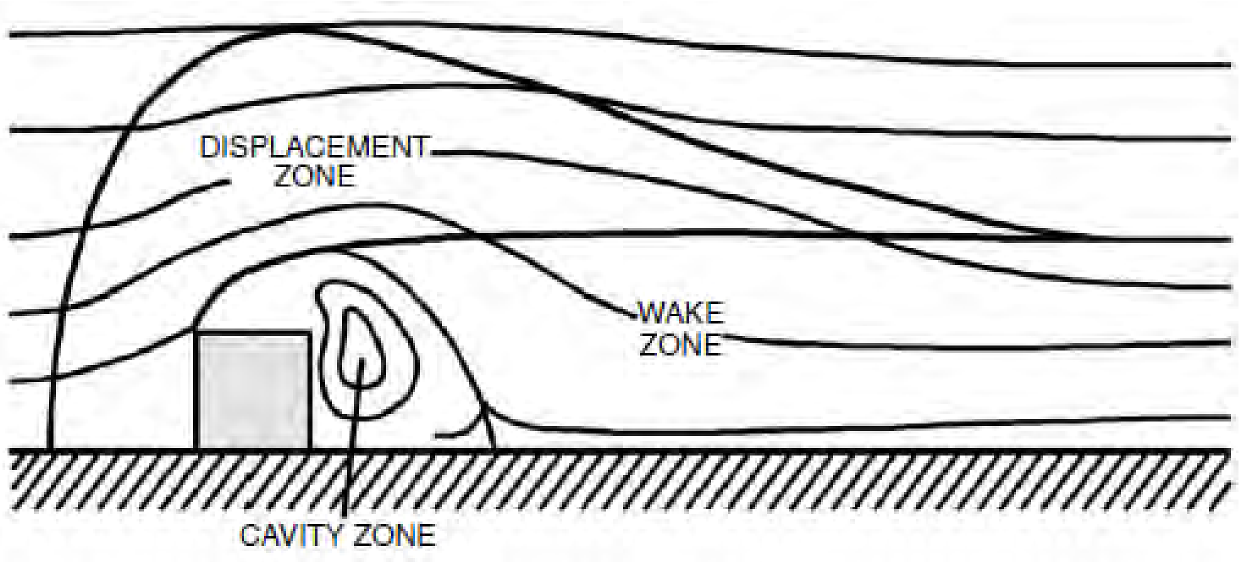
$$\frac{C}{Q}\equiv\left[\frac{s}{m^3}\right]$$

Treats vertical (σ_z) and crosswind (σ_y) dispersion as a Gaussian distribution.

Gaussian Plume model



Building Wake Effect



- Tall buildings and other structures will disturb the flow of air. Creating three main zones of flow:
  - Displacement Zone
  - Wake Zone
  - Cavity Zone
- If the release point is at least 2.5 times the height of the building, the plume will penetrate into the displacement zone and may be considered as coming from an elevated source.

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Code Inputs – Topography of Penn State Campus

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Outcomes

- 2024 ANS Annual Meeting Paper submitted
  - Erik Hisahara, Christopher Balbier, and Saya Lee, “Preliminary Parametric Study of Microreactor EPZ”
- 2024 14th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Operation, and Safety (NUTHOS), Aug 25-28, Vancouver, Canada.
  - Abstract accepted & Draft under preparation.
  - Erik Hisahara, Christopher Balbier, and Saya Lee, “
- 2024 Pacific Basin Nuclear Conference (PBNC), Oct 7-10, Idaho Falls.
  - Abstract submitted.
  - Aditi Verma, Gretta D. Kellogg, and Nonna Sorokina, “Community Engagement through AI-enabled Extended Reality to Support Micro-reactors Deployment” Under “Fostering Energy Justice: Engaging Communities for a Sustainable Nuclear Future” session.

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Next Steps

- Y1/Q2
  - EPZ Literature review internal report
  - SAR Literature review internal report
  - Code review internal report – Task 2

- Y1/Q3
  - Risk-informed EPZ inputs development
  - On-going SAR and Licensing pathway
  - Identification of dispersion mechanisms applicable to microreactors
  - Identification of atmospheric conditions & topography

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Thank You!

Questions?