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)

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Co-PIs: Gretta Kellogg (Penn State), Sola Talabi (Pitt-Tech)

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- Project Overview
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- Community and Regulatory Engagement Plan
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Project Overview - 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.
- Furthermore, by describing the site-specific risks, PIMA-NA FRONTIER can adopt a more rapid licensing approach, which allows the site license application to proceed separately from the design certification application of the microreactor.

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
  - Two Contributors from AIMI and Business supporting Community Engagement
  - 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, Stakeholders Engagement, and Licensing**

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

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PIMA NA: Post Industrial Midwest and Appalachia Nuclear Alliance

- **Objective:** Accelerate the development and deployment of advanced nuclear reactors and their applications in various industries to support economic development and American energy leadership
- **Approach:** Establish a nuclear reactor RD&D platform at Penn State University
- Support end-users and nuclear reactor developers
  - Test-bed for nuclear reactor applications RD&D
  - Investigate enabling technologies (digital twin, advanced manufacturing)
  - Establish an effective pathway to regulatory approval and Community Engagement
- Identify funding opportunities with strategic partners

The Westinghouse and Penn State University relationship

There is long history of partnership between Penn State and Westinghouse.

In May 2022, Penn State and Westinghouse announced that they will partner on research and development efforts focused on exploring and applying nuclear engineering and science innovations to societal needs. Discussions are ongoing about siting the eVinci at Penn State.

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FRONTIER: FRONTIER – Forging a Renaissance of Nuclear Through Innovation Entrepreneurship and Research.

- Aim for first deployment of a microreactor on a university campus.
- Located at the Penn State University Park campus.
- 15MW Westinghouse eVinci microreactor will be used for an expected period of 8-12 years before refueling. Potential lifecycle of 64+ years.
- PSU Scope: Site and Facility Design, R&D Program, Acquisition, Construction, Ownership, Operations & Maintenance.
- **Active Community engagement**
- Website: (https://frontier.psu.edu/)
- **NRC docket will open in Q1 in CY2025**

eVinci microreactor

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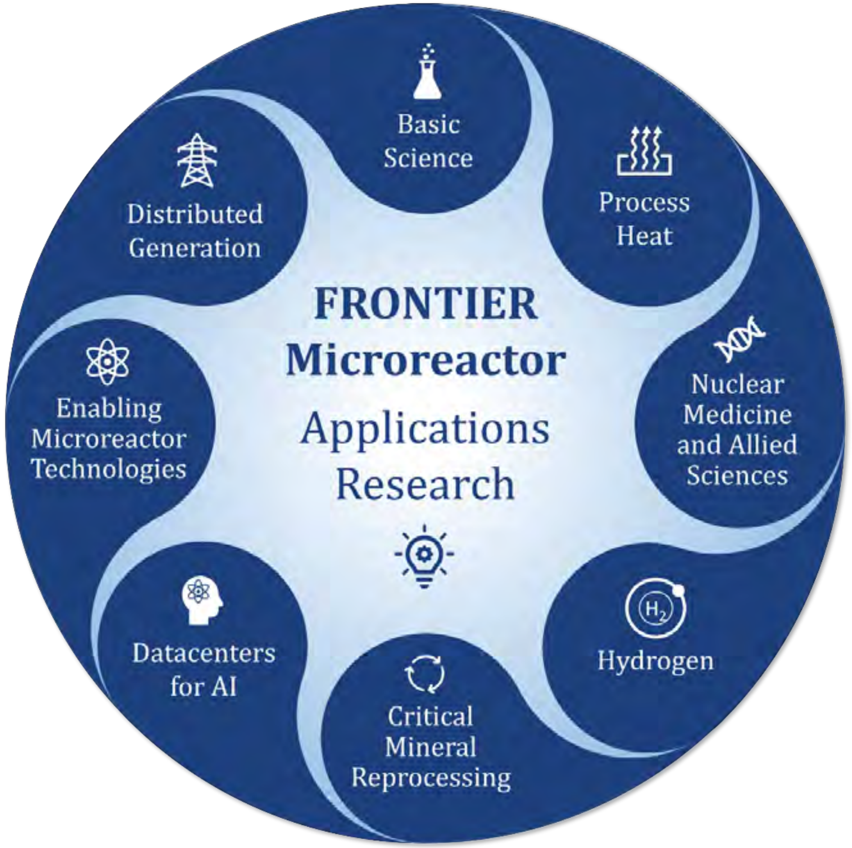
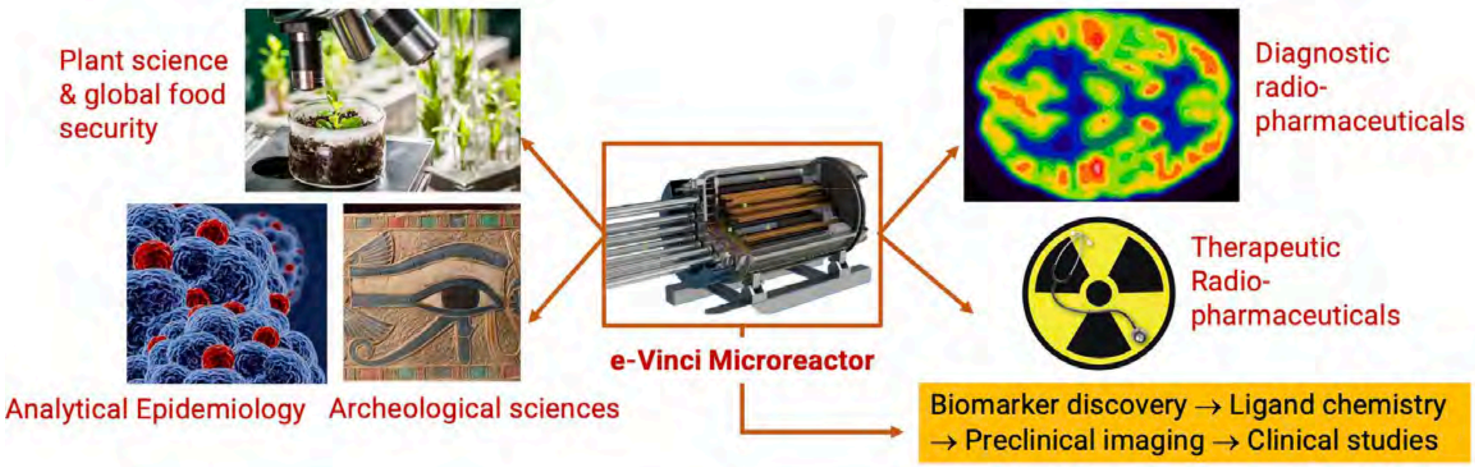
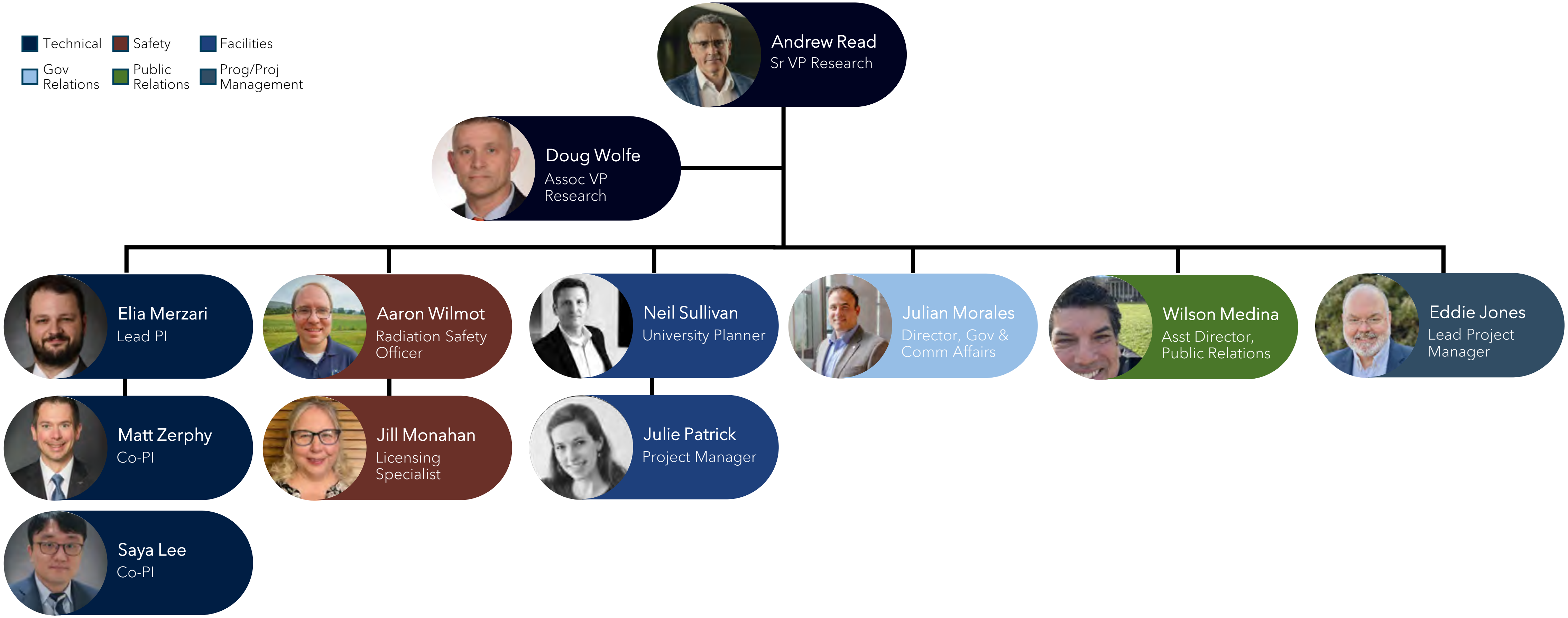
FRONTIER is a Research Platform to Advance Microreactor Applications



- Complementary research, education, & outreach focus to RSEC
- Focus is on demonstration Microreactor applications and developing enabling technologies and workforce development



PENN STATE FRONTIER DEPLOYMENT CORE TEAM

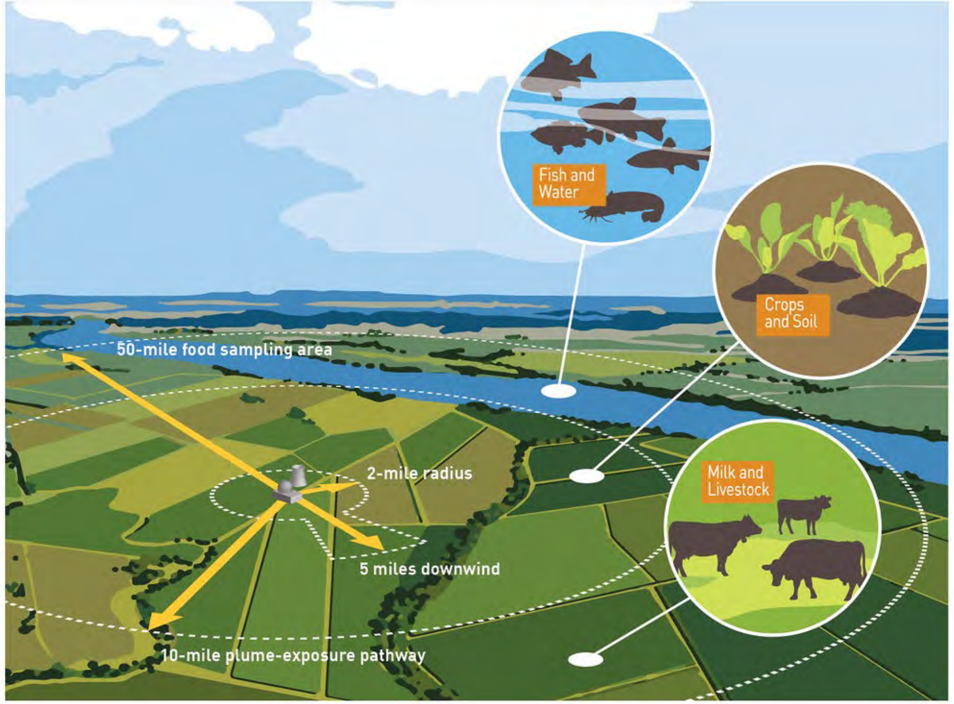


EPZ

- Emergency planning zones (EPZs) are essential safety factors for nuclear facilities, where protective action plans, such as evacuation and sheltering

- NRC separates EPZ into Plume (PEPZ) and Ingestion (IEPZ)

- NUREG-0396 established the technical basis for the 10-mile (~16 km) PEPZ and 50-mile (~80km) IEPZ



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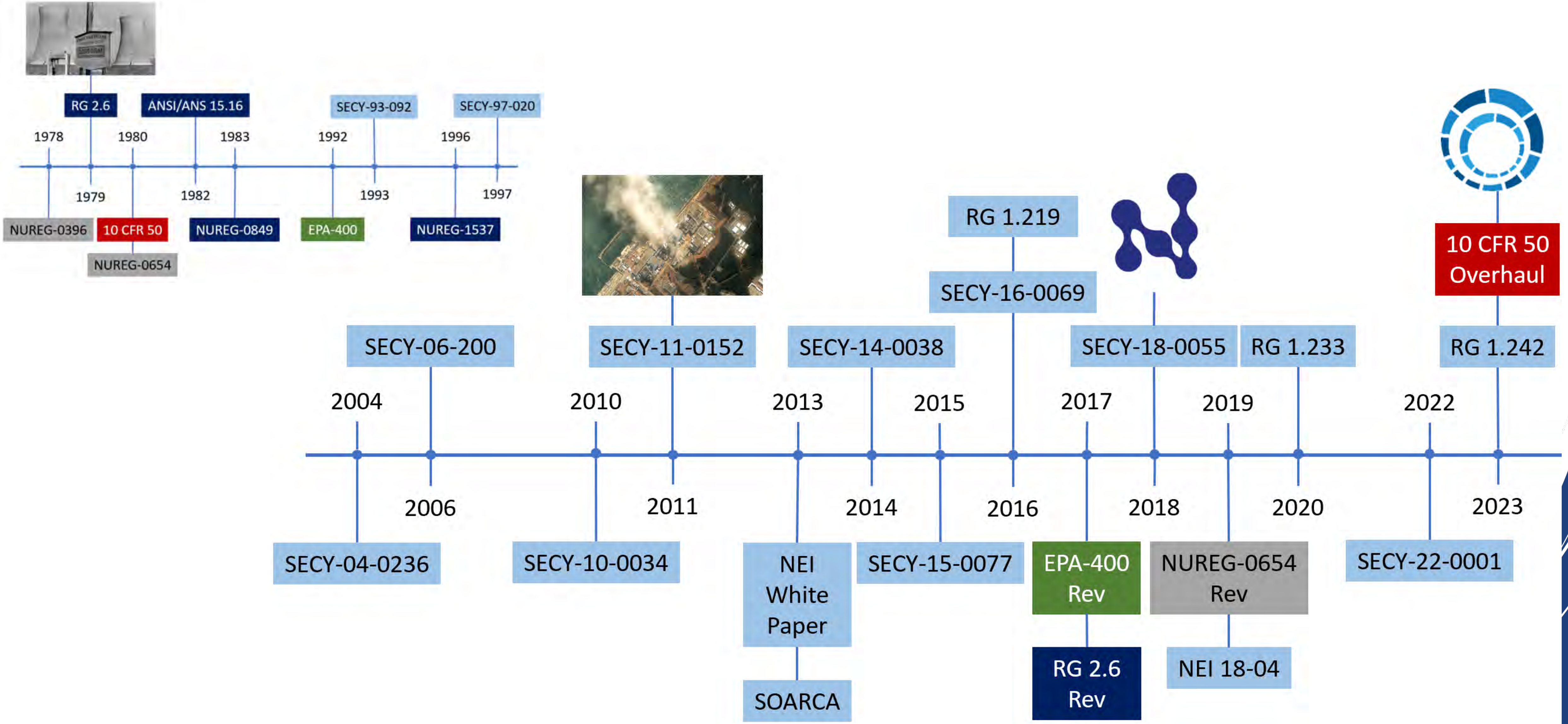
Emergency Planning Regulatory Activity



EPZ sizing based on reactor thermal power level

A class 104 license for Research Reactors [ANSI/ANS 15.16]

Authorized power level	Acceptable EPZ size
≤2 MW	Operations boundary
>2 MW and ≤ 10 MW	100 m
>10 MW and ≤ 20 MW	400 m
>20 MW and ≤ 50 MW	800 m
>50 MW	Will be determined on a case-by-case basis

Emergency zones (plume exposure pathway)	Whole body dose criteria	Dose evaluation period
U.S.	10-50 mSv	4 days
IAEA	100 mSv	7 days
Korea	10 mSv	2 days
Sweden	20 mSv	7 days

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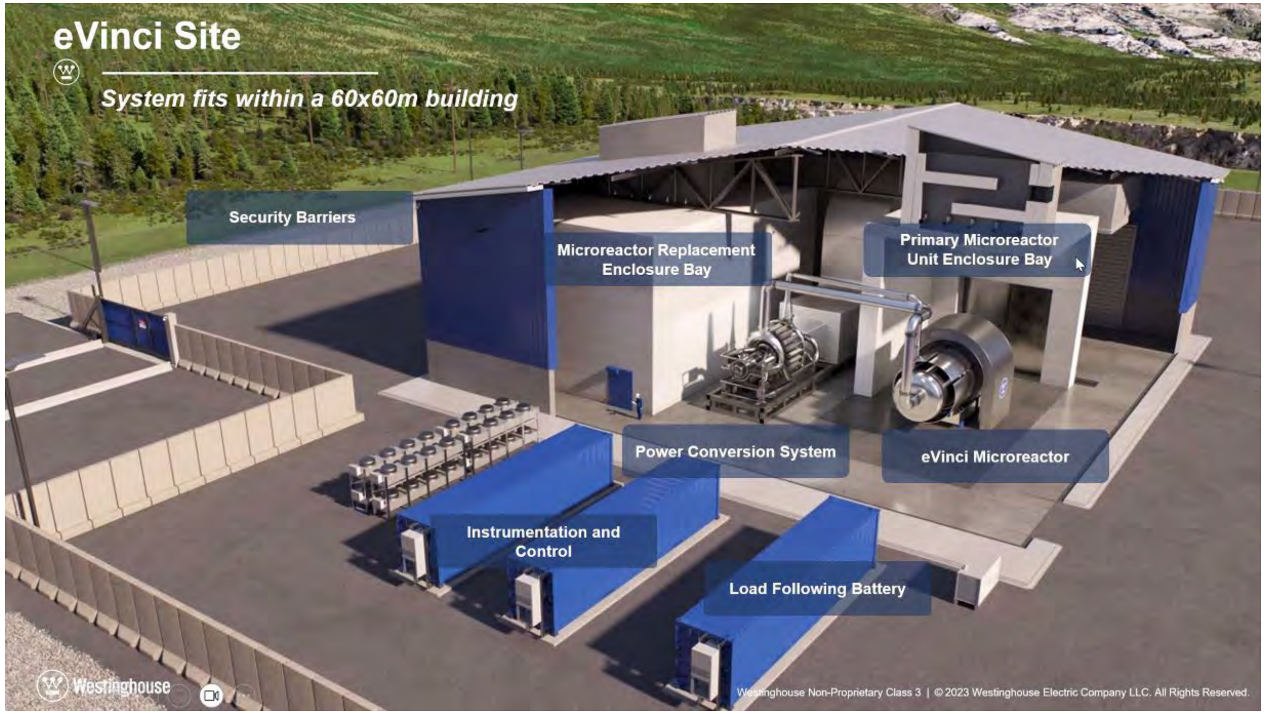
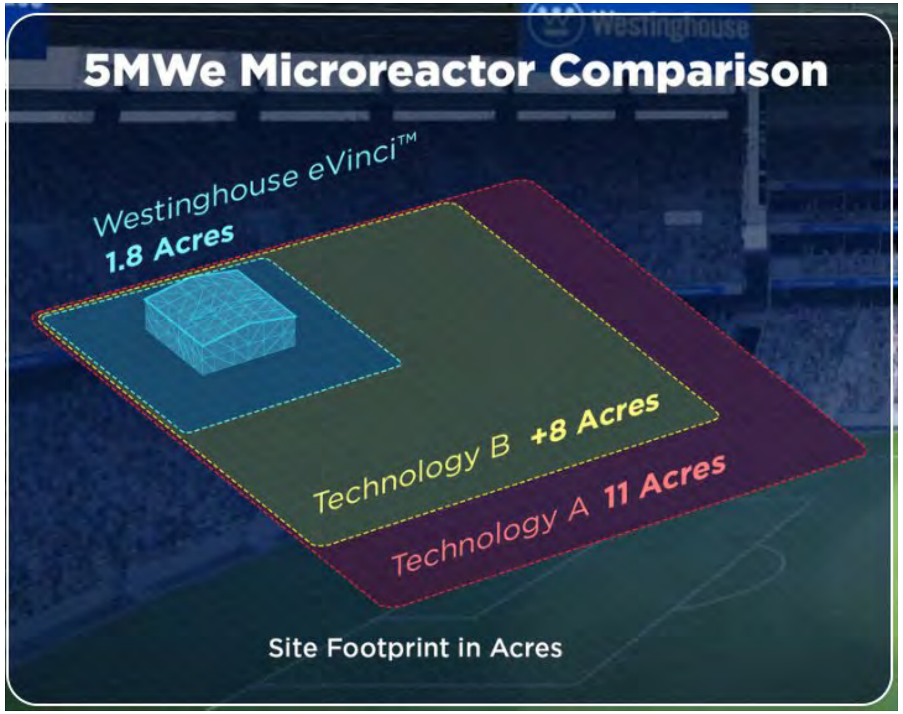
Microreactor Siting





Near-Field Atmospheric Dispersion

- Near-Filed Atmospheric Transport and Dispersion (ATD)
  - Field measurements,
  - Wind tunnel measurements,
  - Particle tracking based on computational fluid dynamics (CFD), and
  - Empirical models such as Gaussian Plume Models

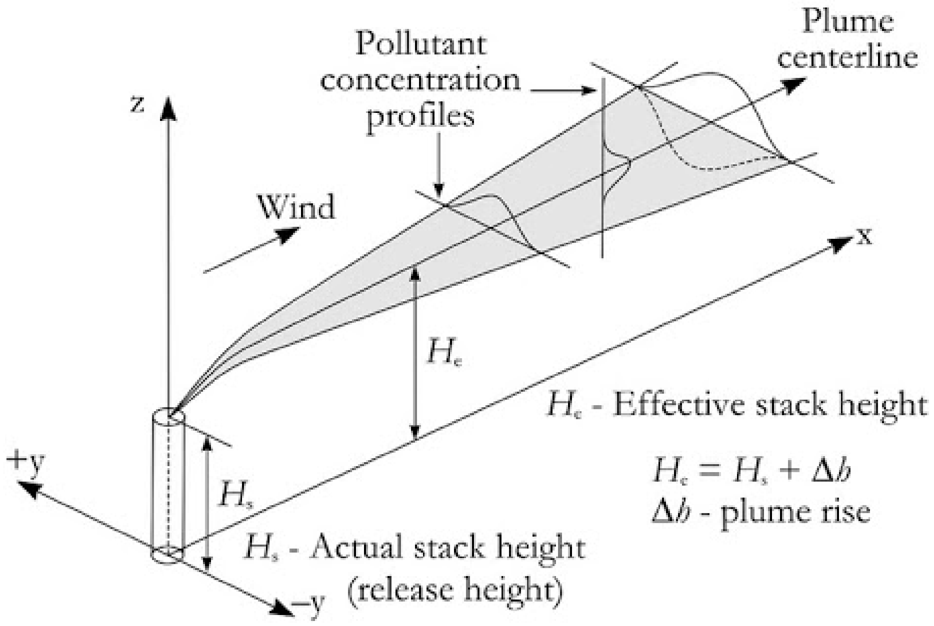
Gaussian Plume Model

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

Treats **crosswind** ($\boldsymbol{\sigma_y}$) and **vertical** ($\boldsymbol{\sigma_z}$) dispersion as a Gaussian distribution based on weather stability classes

Stability class	Open/Rural sites		Urban/Industrial sites	
	$\sigma_y(m)$	$\sigma_z(m)$	$\sigma_y(m)$	$\sigma_z(m)$
A	$\frac{0.22x}{\sqrt{1+0.0001x}}$	$0.20x$	$\frac{0.32x}{\sqrt{1+0.0004x}}$	$0.24x\sqrt{1+0.001x}$
B	$\frac{0.16x}{\sqrt{1+0.0001x}}$	$0.12x$		
C	$\frac{0.11x}{\sqrt{1+0.0001x}}$	$\frac{0.08x}{\sqrt{1+0.0002x}}$	$\frac{0.22x}{\sqrt{1+0.0004x}}$	$0.20x$
D	$\frac{0.08x}{\sqrt{1+0.0001x}}$	$\frac{0.06x}{\sqrt{1+0.0015x}}$	$\frac{0.16x}{\sqrt{1+0.0004x}}$	$\frac{0.14x}{\sqrt{1+0.0003x}}$
E	$\frac{0.06x}{\sqrt{1+0.0001x}}$	$\frac{0.03x}{1+0.0003x}$	$\frac{0.11x}{\sqrt{1+0.0004x}}$	$\frac{0.08x}{\sqrt{1+0.0015x}}$
F	$\frac{0.04x}{\sqrt{1+0.0001x}}$	$\frac{0.016x}{1+0.0003x}$		

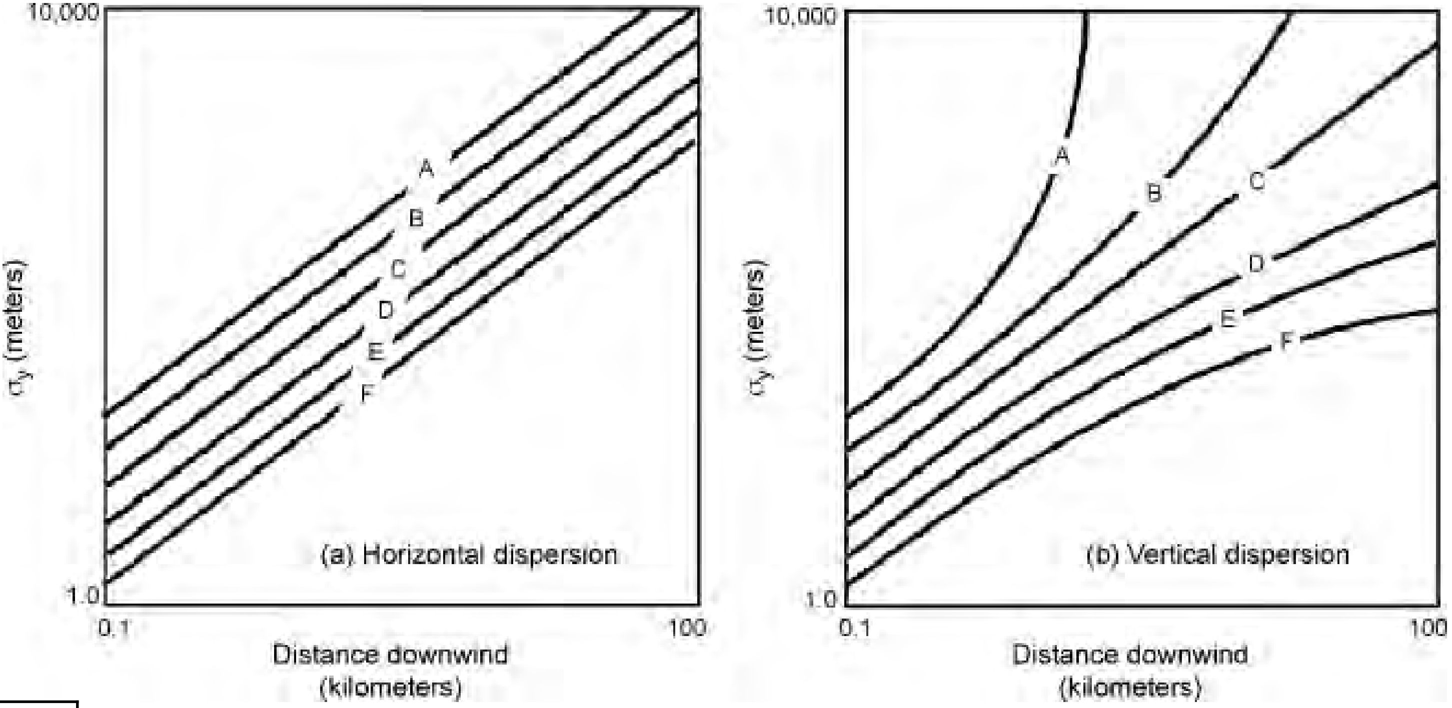
Gaussian Plume model



Dispersion Coefficient – Model Review

Formulations were established using results from experimental campaigns and are specific to the conditions under which is determined.

Briggs model	σ_y or $\sigma_z = ax(1+bx)^c$
Doury model	σ_y or $\sigma_z = A(t)^k$
Hanna et al.	σ_y or $\sigma_z = ax^b + c$



Gaussian Plume Limitations

Theoretically, the model is only valid when certain basic assumptions are completely met:

- Stationary and steady state conditions; Uniform wind speed; Constant atmospheric stability
- Gaussian distribution concentration; Neglection of buoyancy effects; Constant emission height

In practical terms, the Gaussian plume model should not be applied under conditions of:

1) Low wind speeds
2) Complex terrain
3) Spatial and temporal changes

However, adjustments to the basic Gaussian plume formulation allow it to be applied in many situations in which it theoretically should no be applied.

After investigation, modifications to the dispersion coefficients σ_y and σ_z can be applied to improve the model for a specific application.

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Modified Dispersion Coefficient – Model Review

Empirically based adjustments to the Gaussian plume formulation allow it to be applied in many situations. Nevertheless, any system based extensively on empirical adjustments has a severely limited capability to produce generalizations. Some models tried to apply building wake effects to modified dispersion coefficients Σ_y and Σ_z.

- Huber (1984):
  Suggested that Σ_y and Σ_z are functions of the building **height**, **width** and receptor **distance**

$$\Sigma_y = 0.7\frac{w_b}{2} + 0.067\,(x - 3h_b)$$

$$\Sigma_z = 0.7h_b + 0.067\,(x - 3h_b)$$

- Fuquay (Gifford, 1968) :
  Used to be the model recommended by RG 1.145

$$\Sigma_y\Sigma_z = [\sigma_y^2 + cA/\pi]^{1/2}[\sigma_z^2 + cA/\pi]^{1/2}$$

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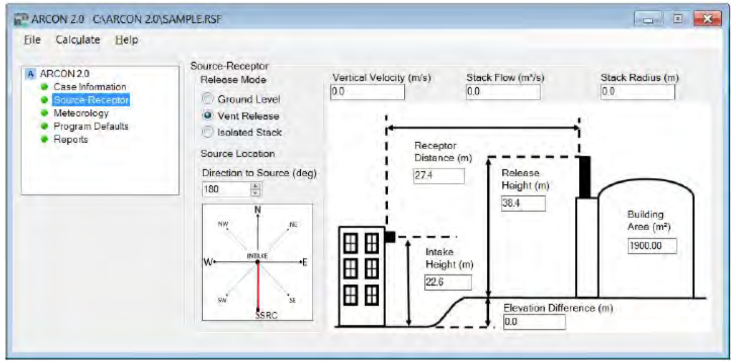
EPZ – Atmospheric Dispersion Code

- ARCON



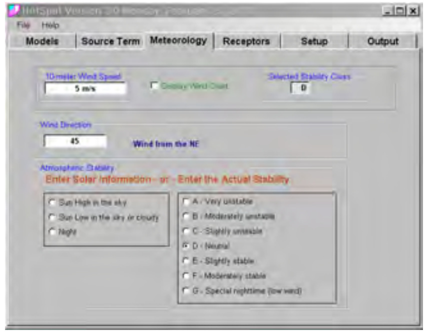
Atmospheric Relative CONcentration in Building Wakes

Code developed for the NRC, used to calculate χ/Q in support to habitability assessment

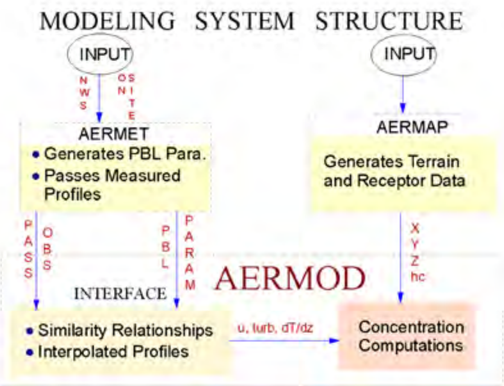
Valid for near-field distances (>10 m) range

Incorporates building wake effects

- HotSpot Heath Physic



- AERMOD



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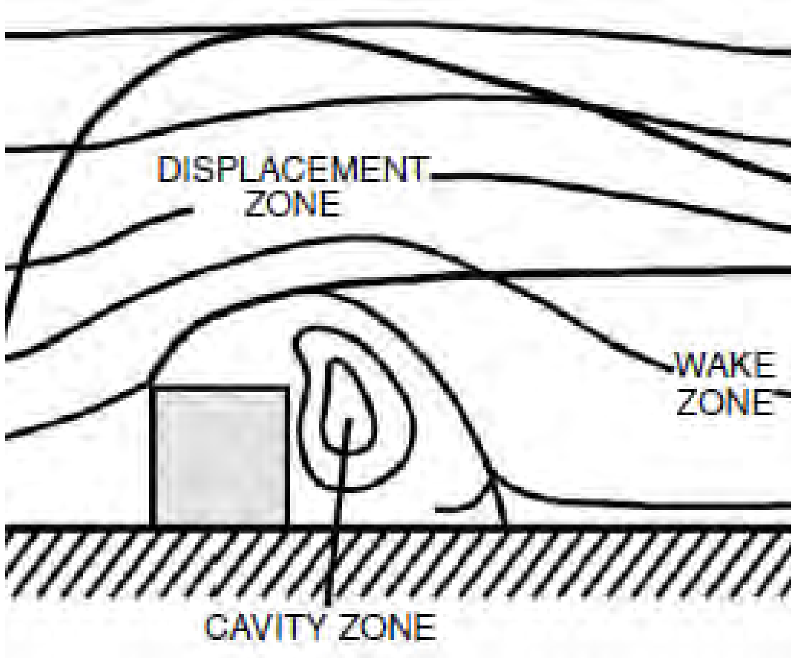
Building Wake & Meandering

Tall buildings and other structures will disturb the flow of air, creating three main zones of flow:

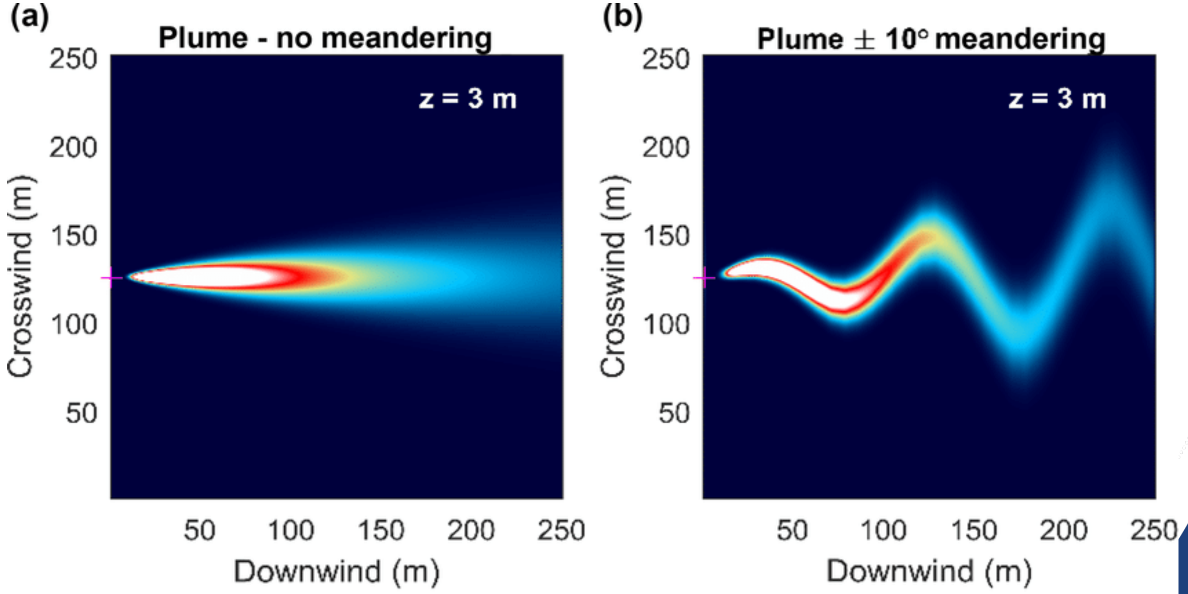
- Displacement Zone
- Wake Zone
- Cavity Zone



Plume meander should be consider when:

Low wind speeds ≤ 6 m/s

For distances ≤ 800 m and stability classes D, E, F, and G (NRC, 1983)



(Caulton, Dana R. et al., 2018)

ARCON Gaussian Plume model

$$\frac{\chi}{Q} = \frac{1}{\pi \sigma_y \sigma_z U} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-0.5\left(\frac{h_e - h_i}{\sigma_z}\right)^2\right]$$

$$\Sigma_y = \left(\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2\right)^{1/2}$$

$$\Sigma_z = (\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2)^{1/2}$$

Sub-script 1: Low wind speed (or wind meandering)

Sub-script 2: Building wake

$$\Delta\sigma_{y1}^2 = 9.13\text{x}10^5\left[1 - \left(1 + \frac{\text{x}}{1000\text{U}}\right)\exp\left(-\frac{\text{x}}{1000\text{U}}\right)\right]$$

$$\Delta\sigma_{z1}^2 = 6.67\text{x}10^2\left[1 - \left(1 + \frac{\text{x}}{100\text{U}}\right)\exp\left(-\frac{\text{x}}{100\text{U}}\right)\right]$$

$$\Delta\sigma_{y2}^2 = 5.24\text{x}10^{-2}U^2A\left[1 - \left(1 + \frac{\text{x}}{10\sqrt{A}}\right)\exp\left(-\frac{\text{x}}{10\sqrt{A}}\right)\right]$$

$$\Delta\sigma_{z2}^2 = 1.17\text{x}10^{-2}U^2A\left[1 - \left(1 + \frac{\text{x}}{10\sqrt{A}}\right)\exp\left(-\frac{\text{x}}{10\sqrt{A}}\right)\right]$$

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Meteorological Data – Penn State

- Data is treated as the requirements of RG 1.145
- Hourly Weather data (wind speed/direction/stability)
- RG 1.23 requires at least 1 to 3 years of onsite meteorological data

The Pennsylvania State CLIMATOLOGIST

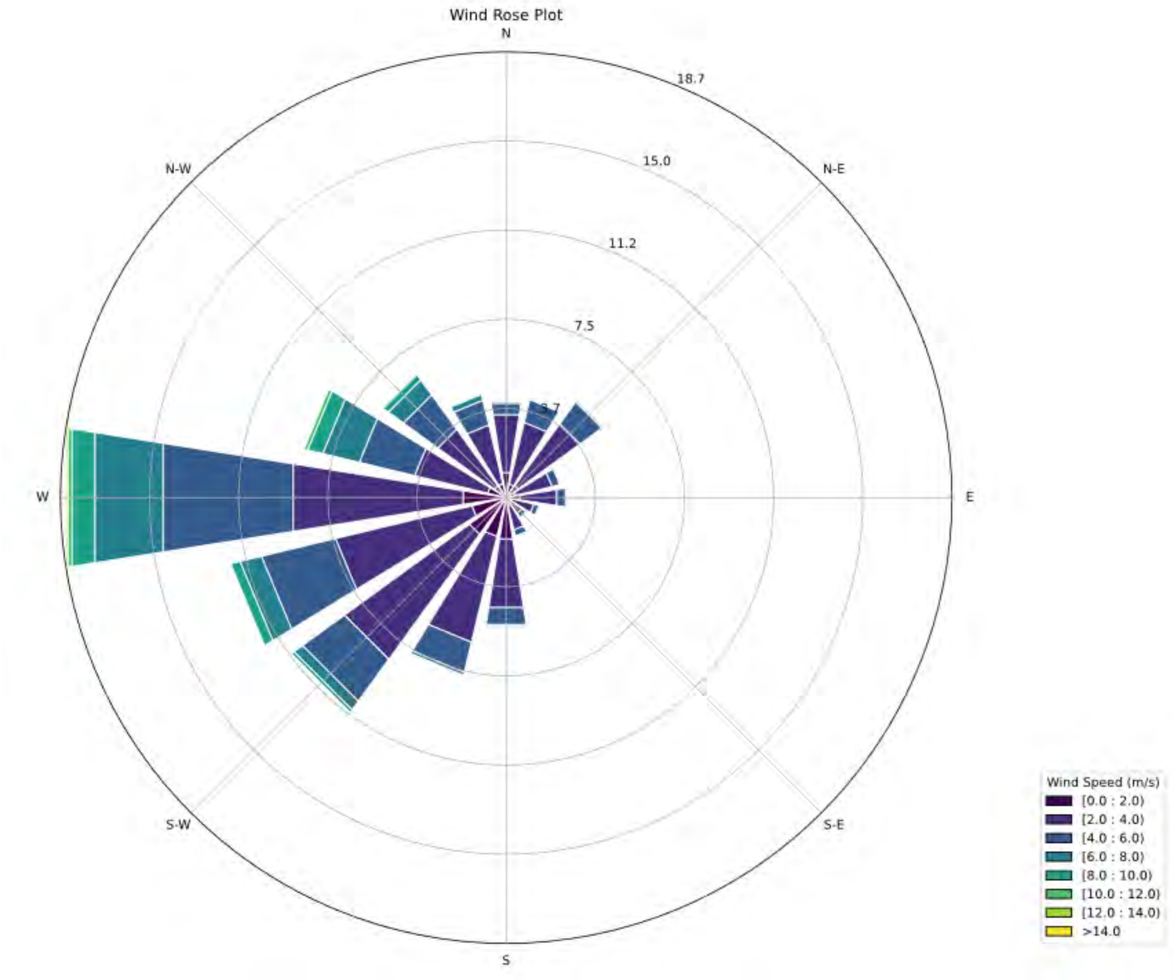
The Pennsylvania State Climatologist is a service to the Commonwealth by the College of Earth and Mineral Sciences and Penn State.

Home | Maps !NEW! | Data | Features | Links | About Us

Data selection for site: UNIVERSITY PARK, PA
Database: FAA_RAW

Metadata:

Id: KUNV
Name: UNIVERSITY PARK
County: CENTRE
State: PA
Lat: 40.850
Lon: -77.850
Elev (ft): 1240.0
Start_date: 1983-09-28
End_date: 2024-02-13



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

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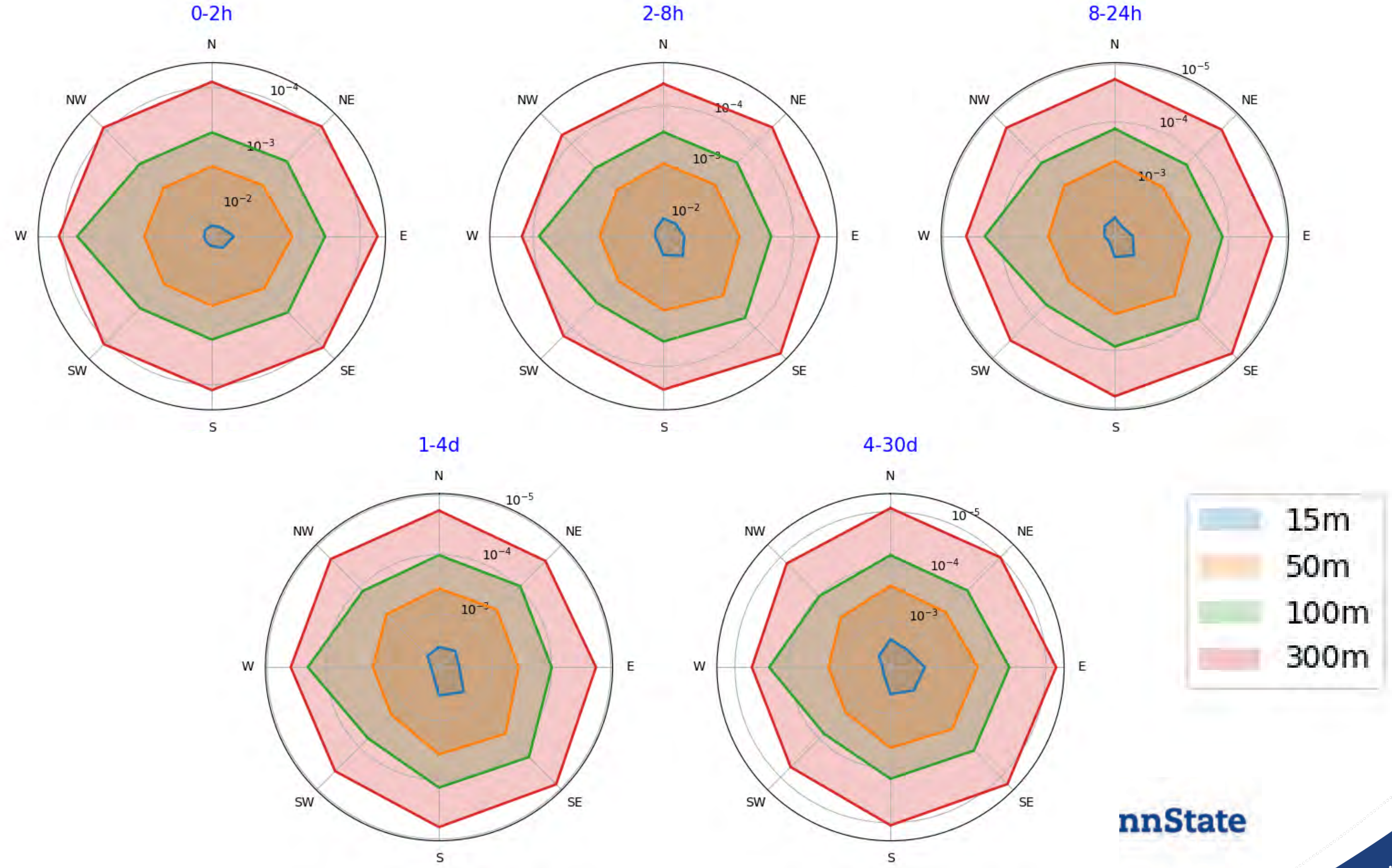
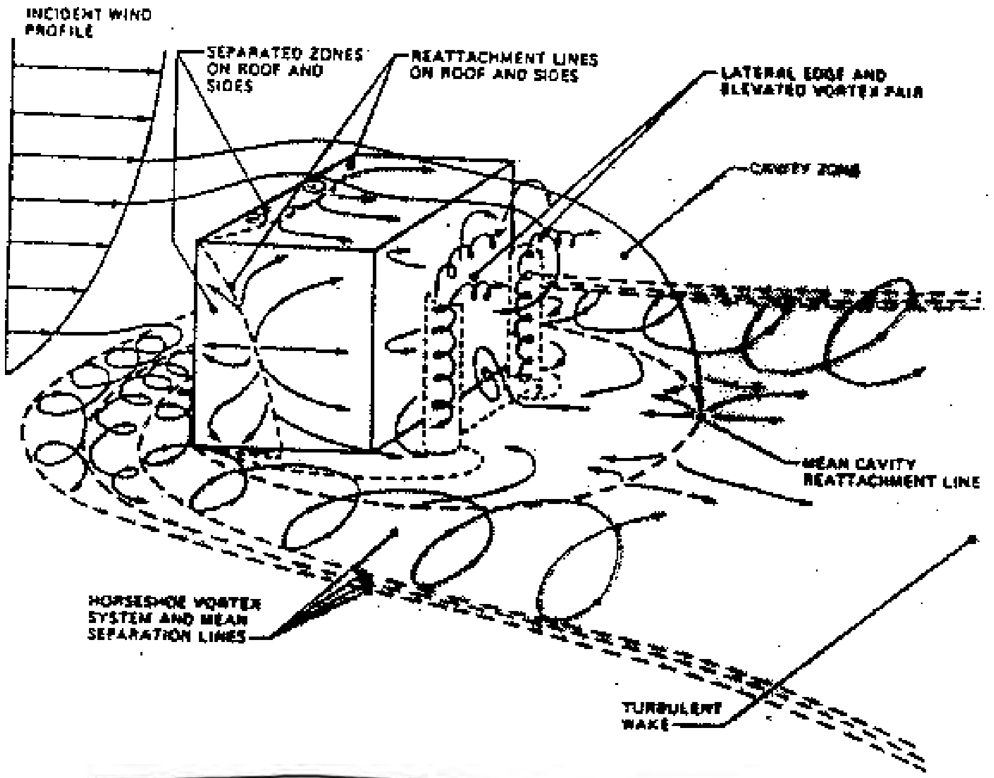
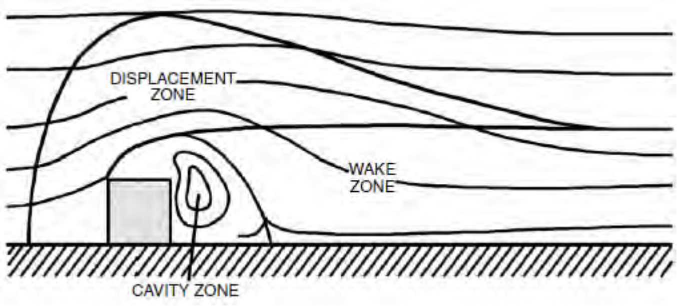
95th percentile χ/Q



Cavity and Wake Zones for the Near-Field Analysis





- 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.

$$\frac{\chi}{Q} = \frac{1}{\pi \sigma_y \sigma_z U} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-0.5\left(\frac{h_e - h_i}{\sigma_z}\right)^2\right]$$

$$\Sigma_y = \left(\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2\right)^{1/2}$$

$$\Sigma_z = \left(\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2\right)^{1/2}$$

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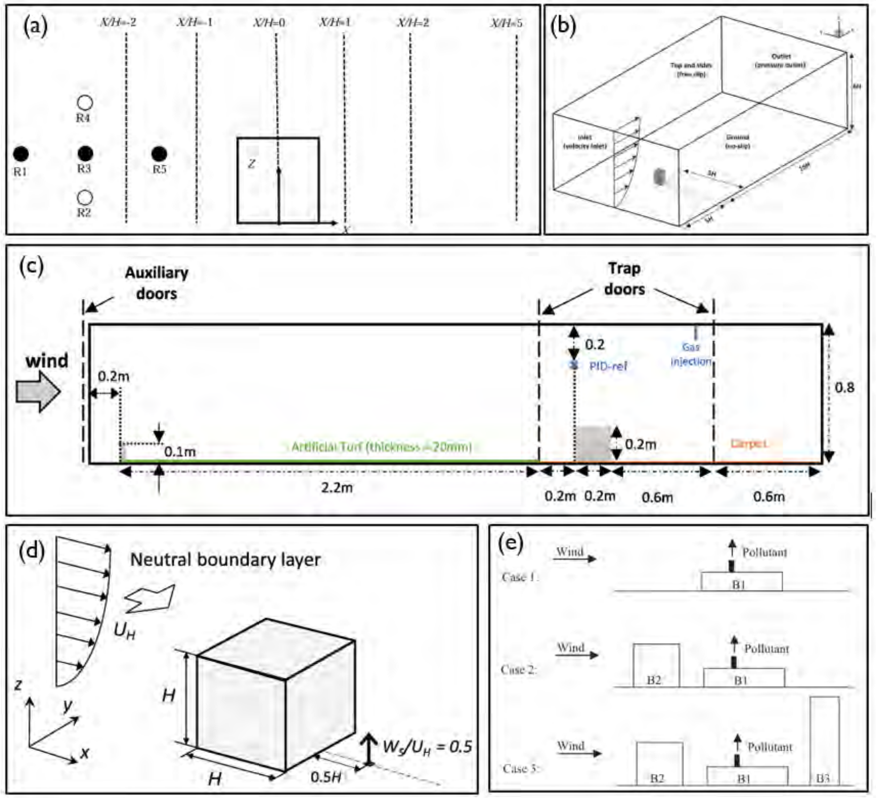
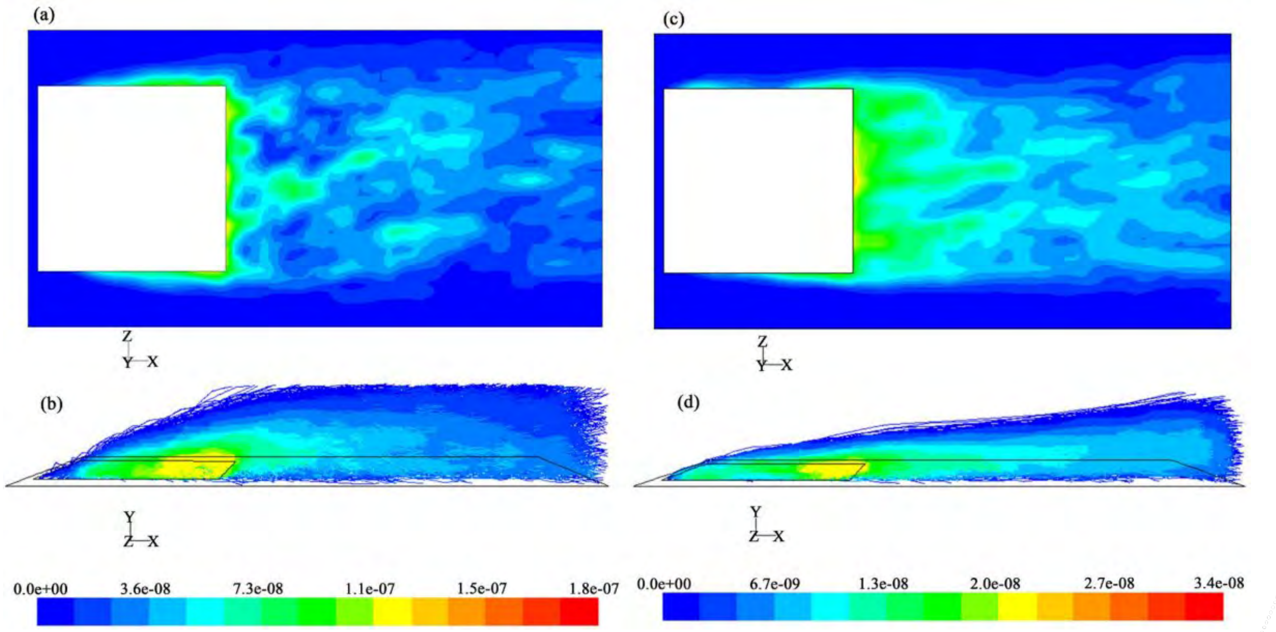
Existing CFD/Experiment Benchmark



Works to be compared to Gaussian ATD models: Woodward et al. [71] (a); Keshavarzian et al. (2021) [70] (b); Keshavarzian et al. (2022) [66] (c); Chavez et al. [72] (d); and Tominaga and Stathopoulos (2018) [74] (e).



Top and side views of particle concentration found using RLZ k-e by Nimmatoori et al. for high (right) and low (left) wind speeds [78].

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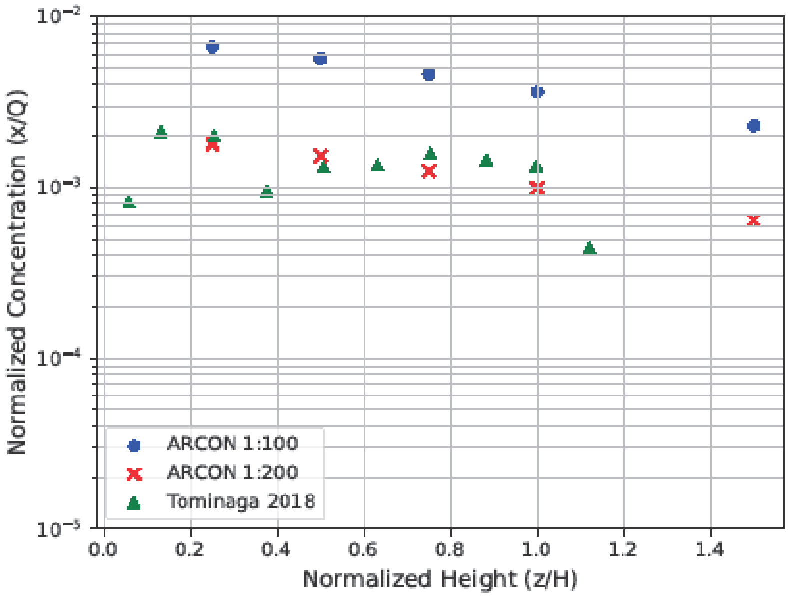
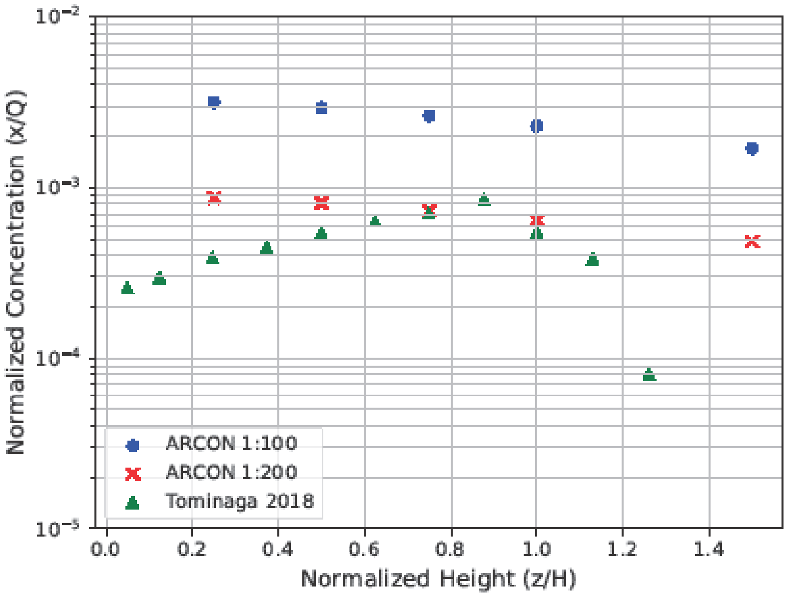
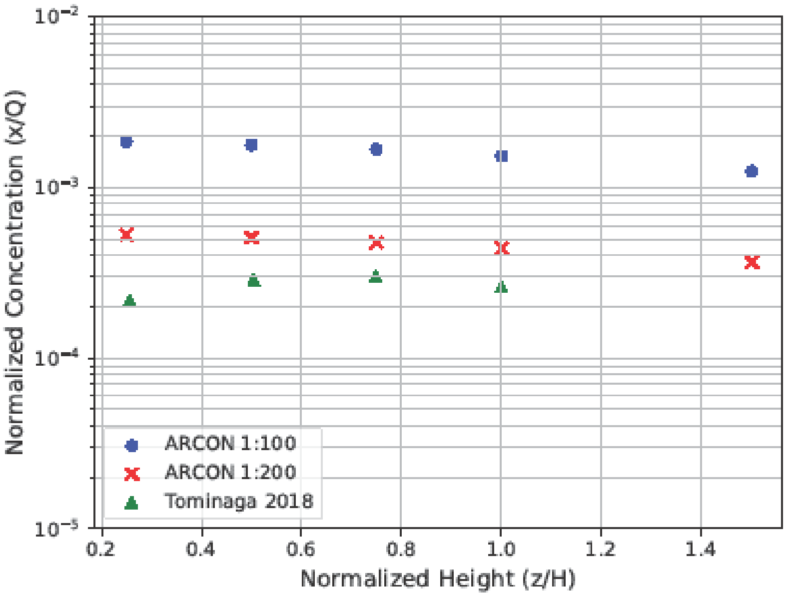
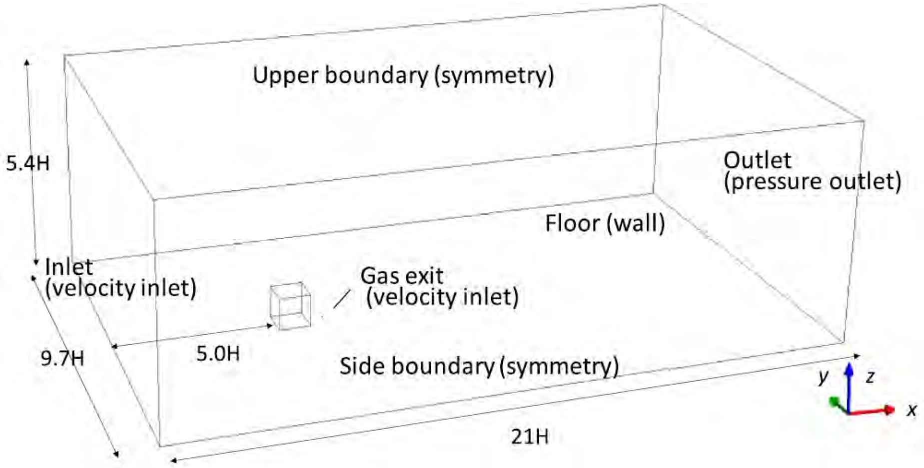
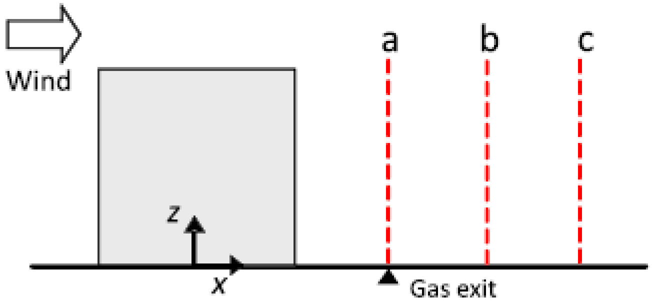
ARCON Code Comparison with Tominaga 2018











	Horizontal	Vertical
1:100 range ->	20 ~ 40 m	5 ~ 30 m
2:200 range ->	40 ~ 80 m	10 ~ 60 m

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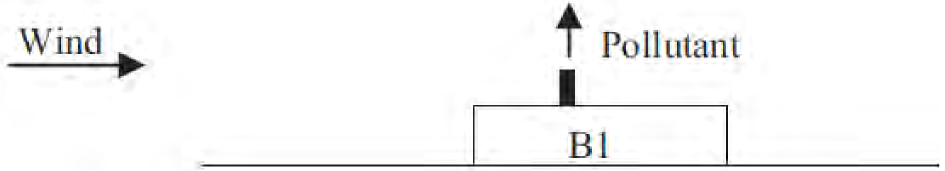
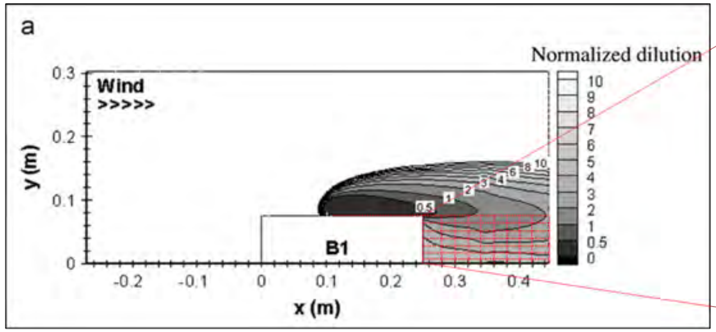
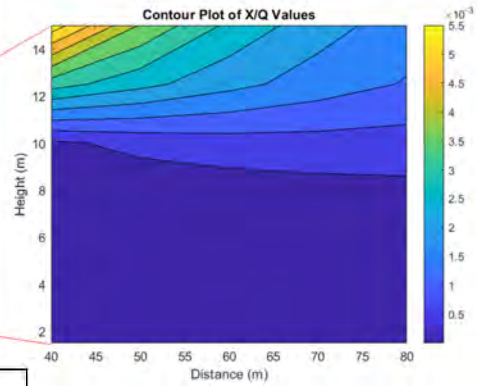
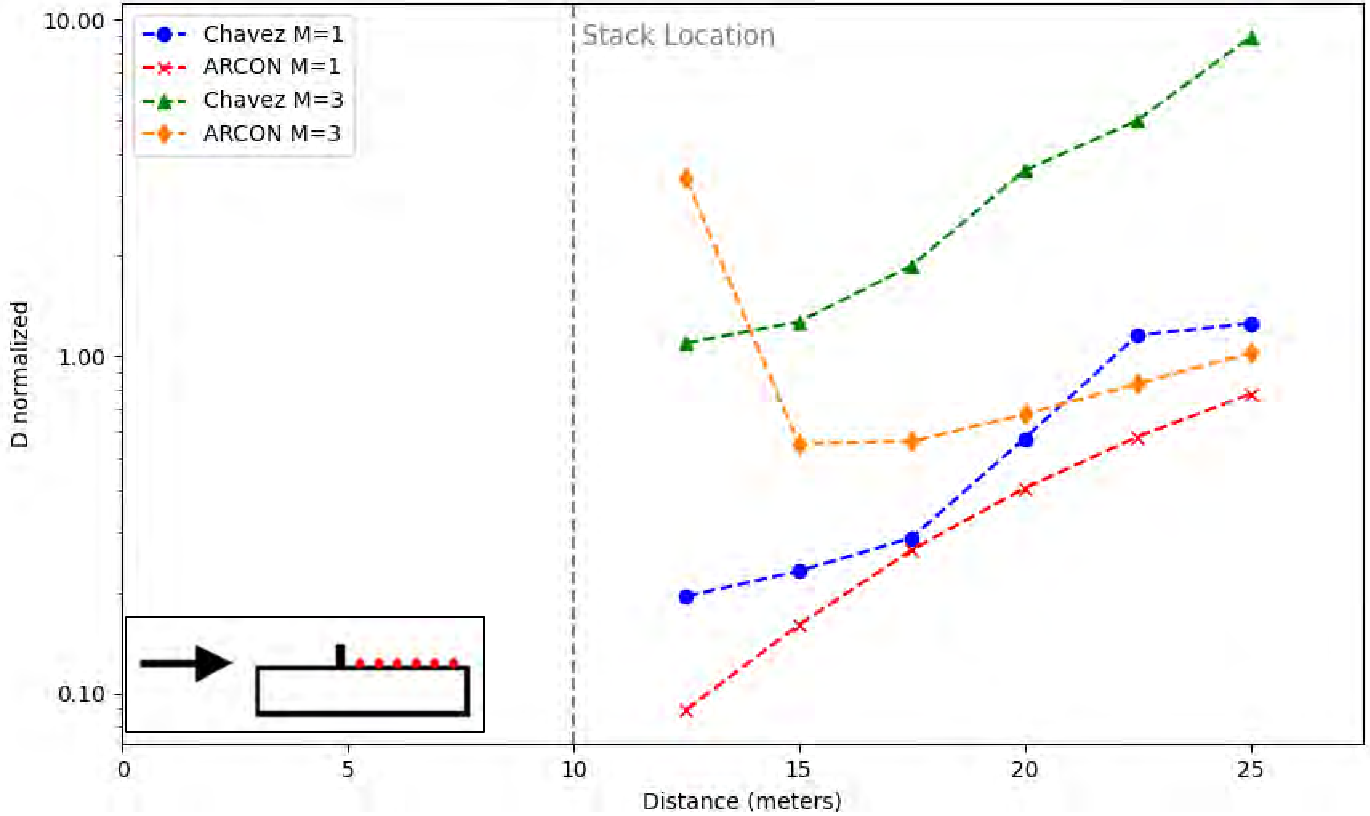
ARCON Code Comparison with Chavez et al. 2011



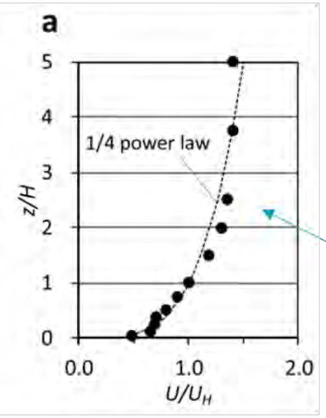






Simulation Setup to Reproduce Tominaga 2018

$$\frac{U(z)}{U_{ref}} = \left(\frac{z}{z_{ref}}\right)^{1/4}$$



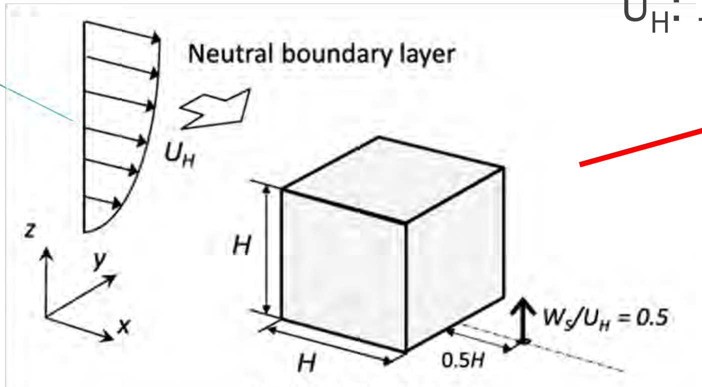
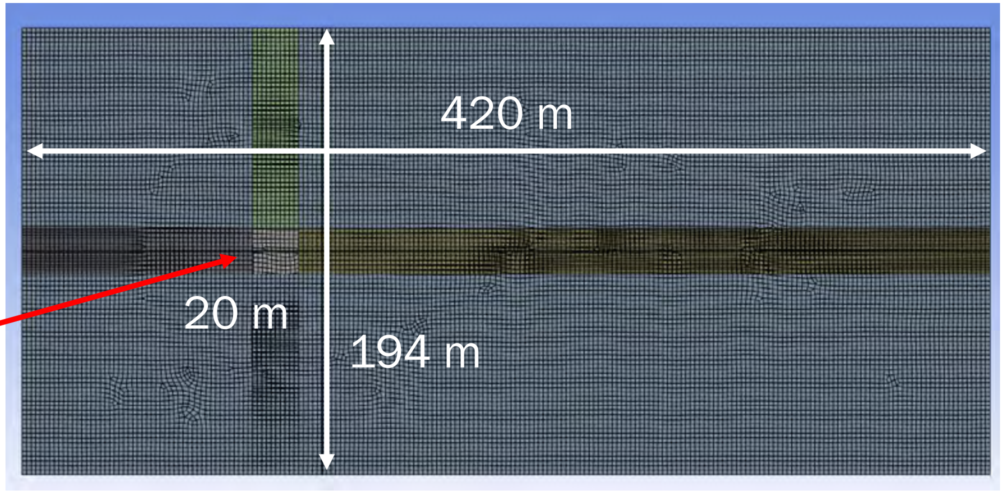
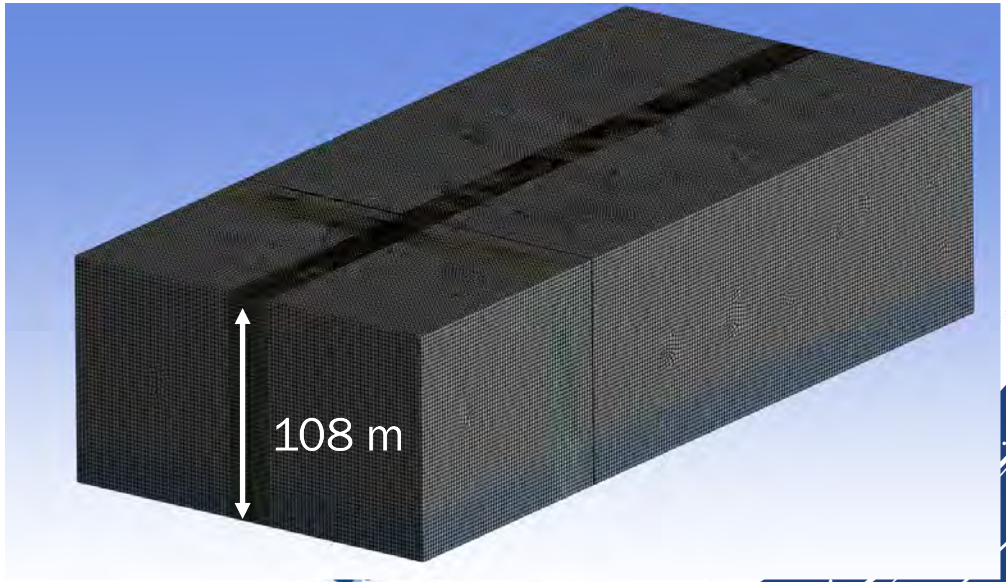


Fig. 1. Model flow field.

U_H: 1.26 m/s

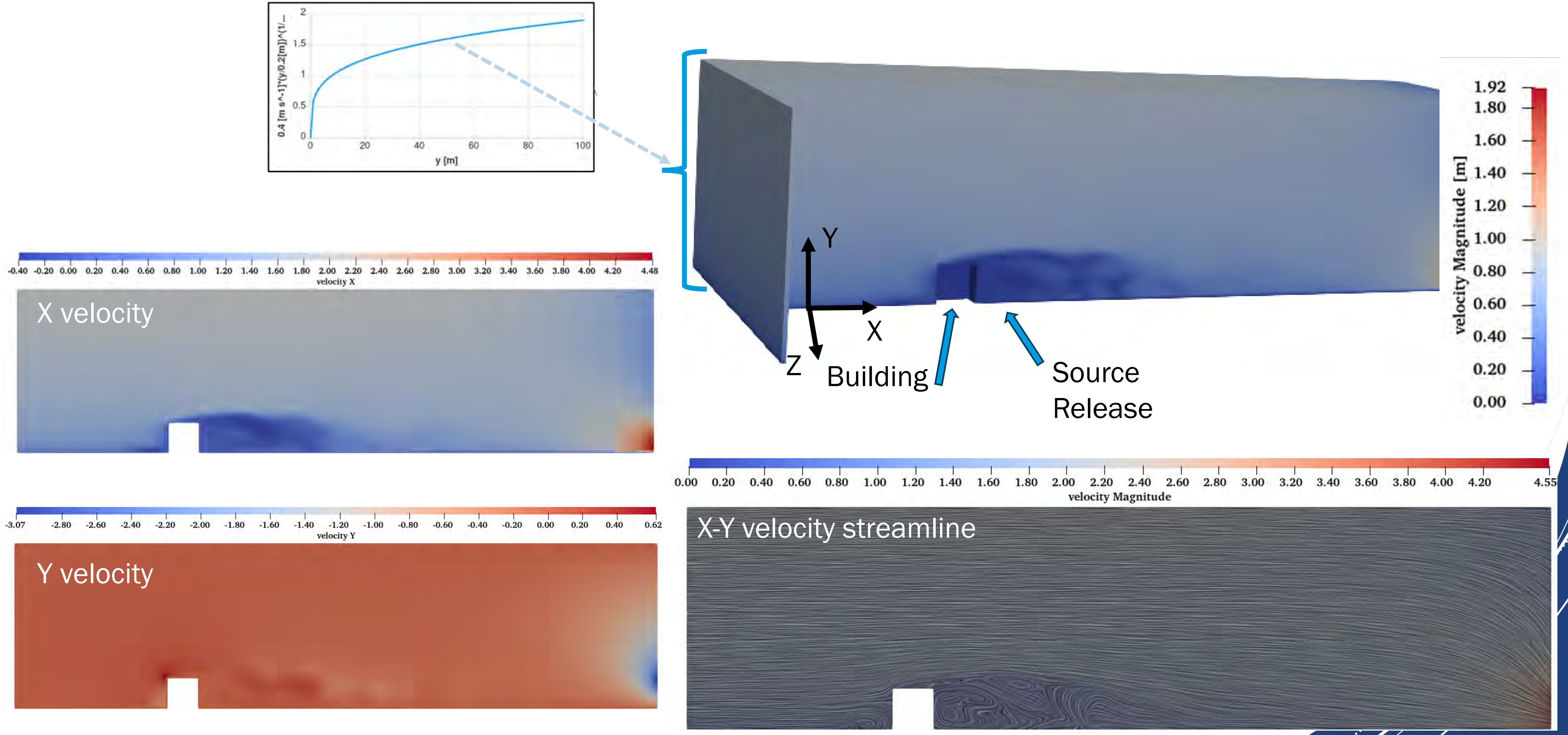




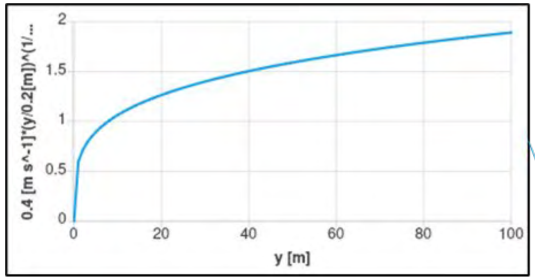
- Geometric parameters are linearly scaled
- Non-geometric parameters are scaled based on ¼ power law
- C_0 is maintained (312.5 ppm)

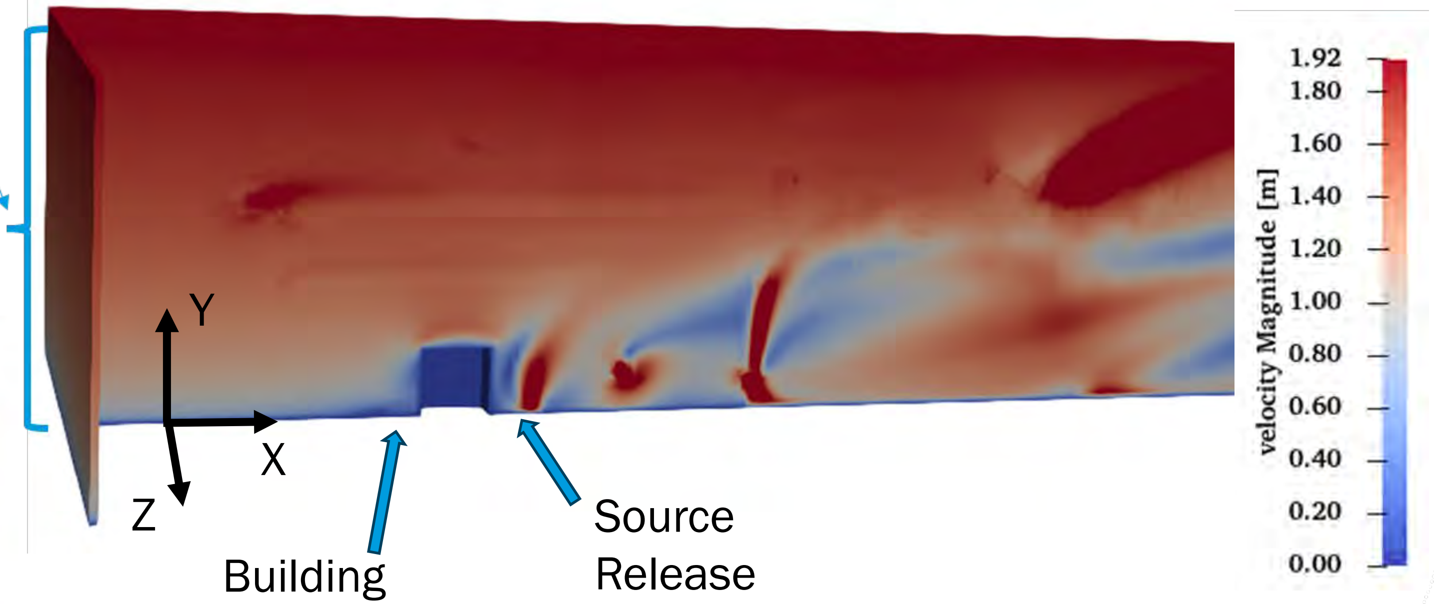
Parameter	Experiment	1:100
H [m]	0.2	20
U_H [m/s]	0.4	1.26
W_s [m/s]	0.2	0.63
C_0 [ppm]	312.5	312.5

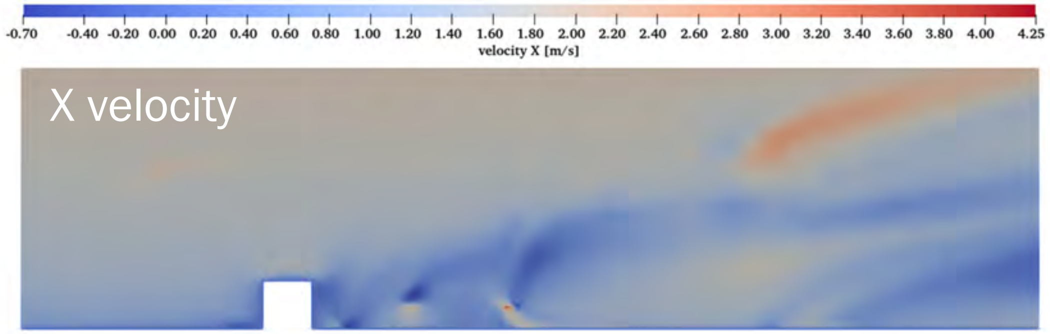
Preliminary Results - Near-Field Velocity Distribution

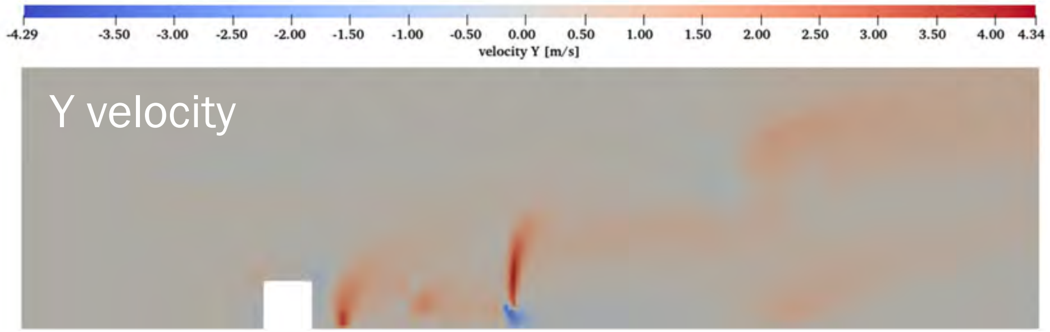


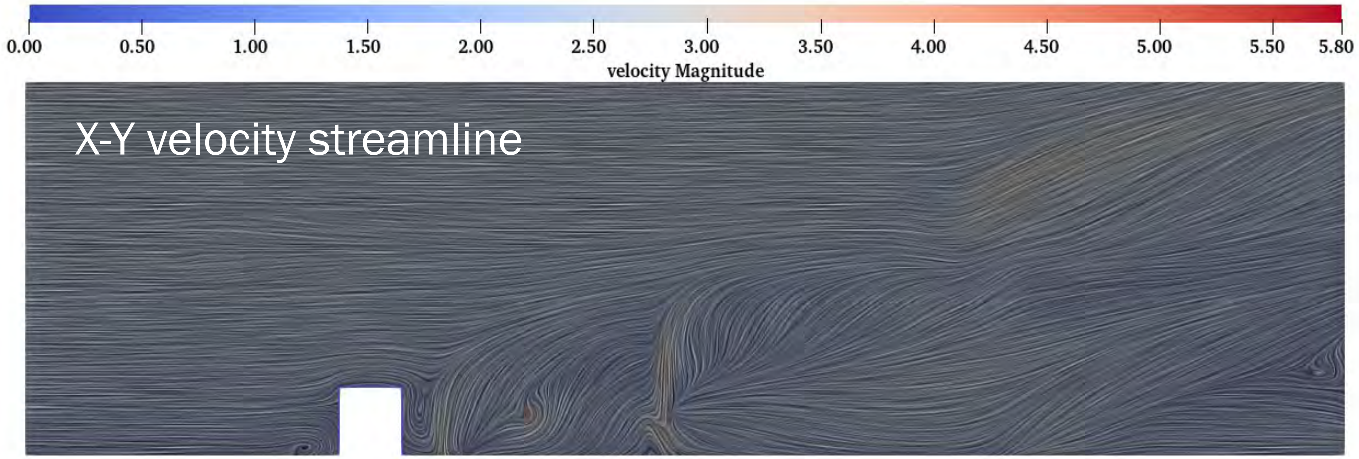
Preliminary Results - Near-Field Velocity Distribution



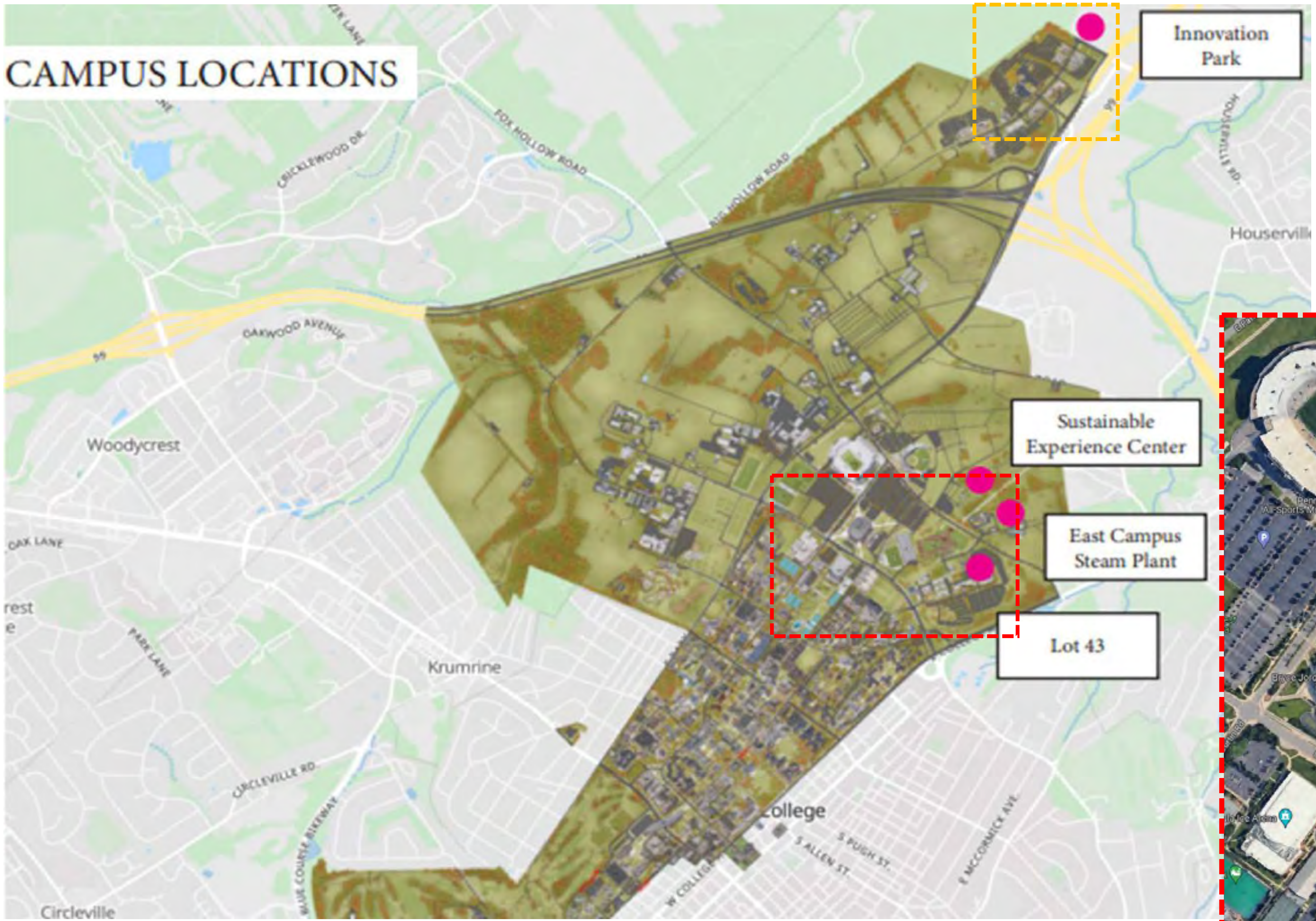


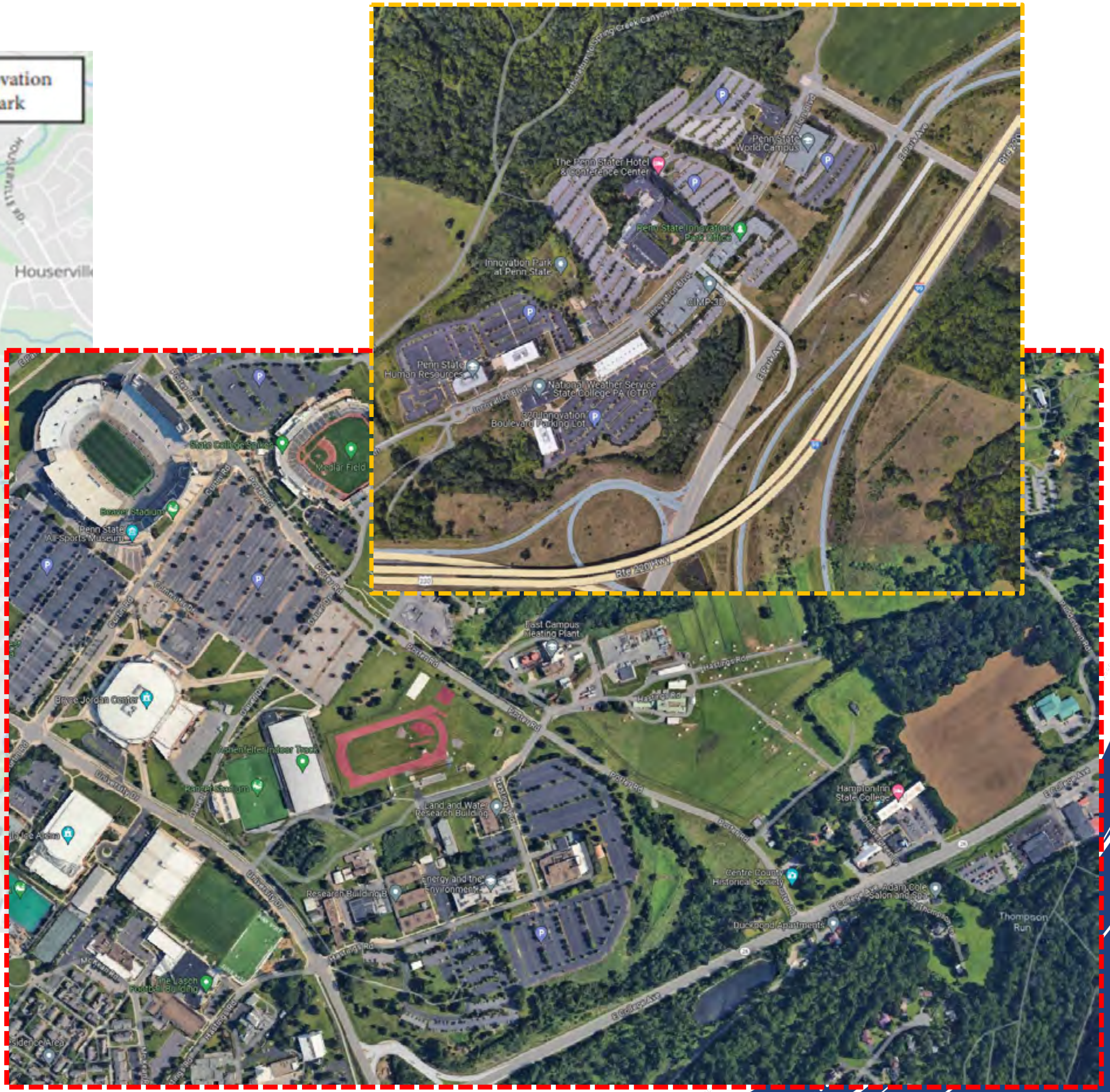




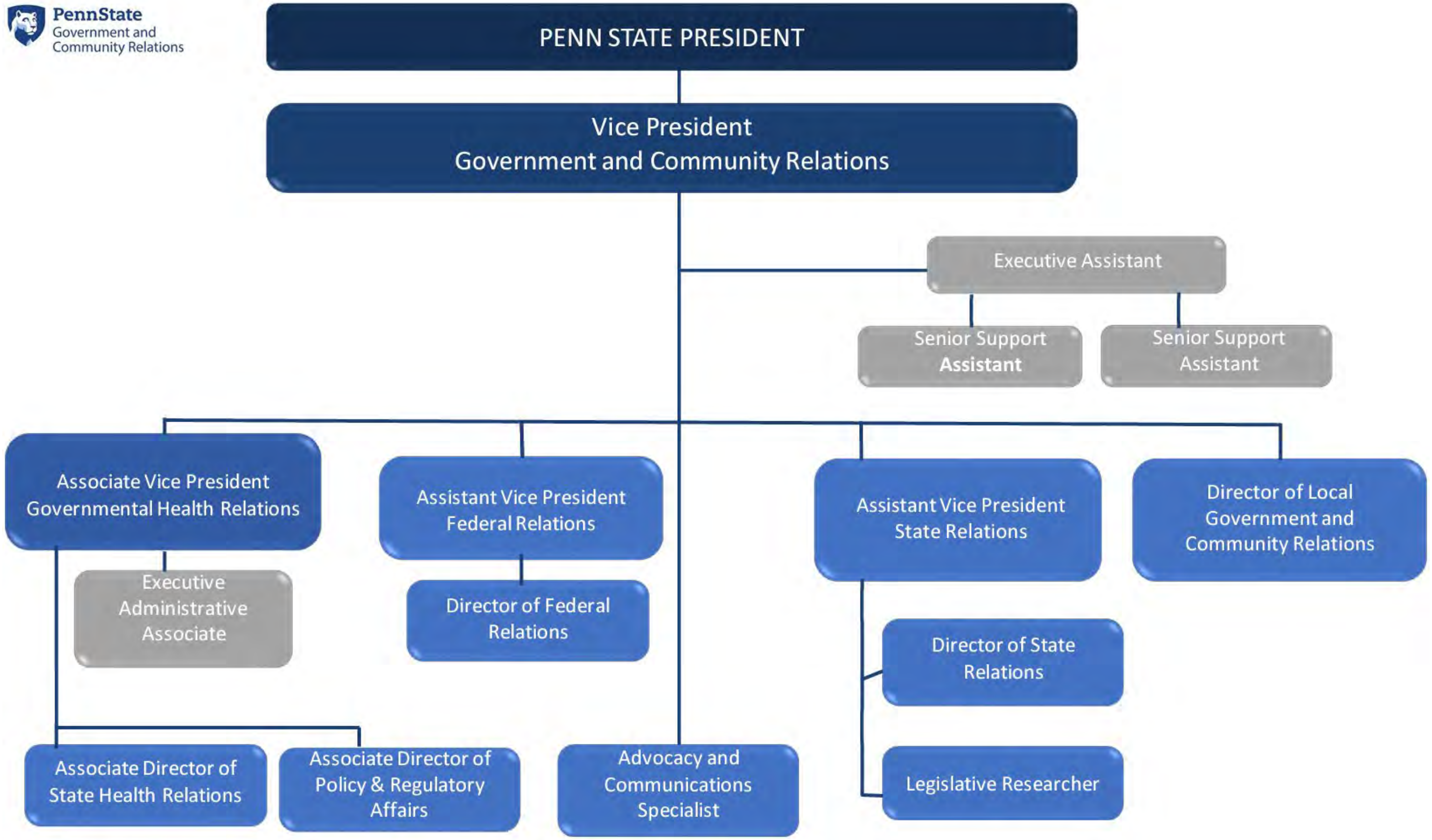


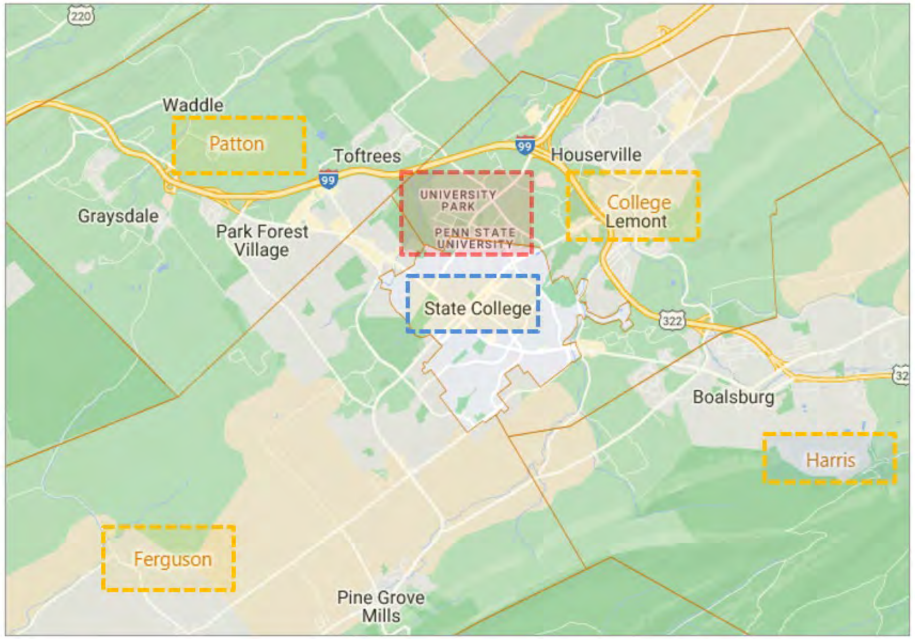
Penn State Site-Specific Study Candidates





Community Engagement Plan





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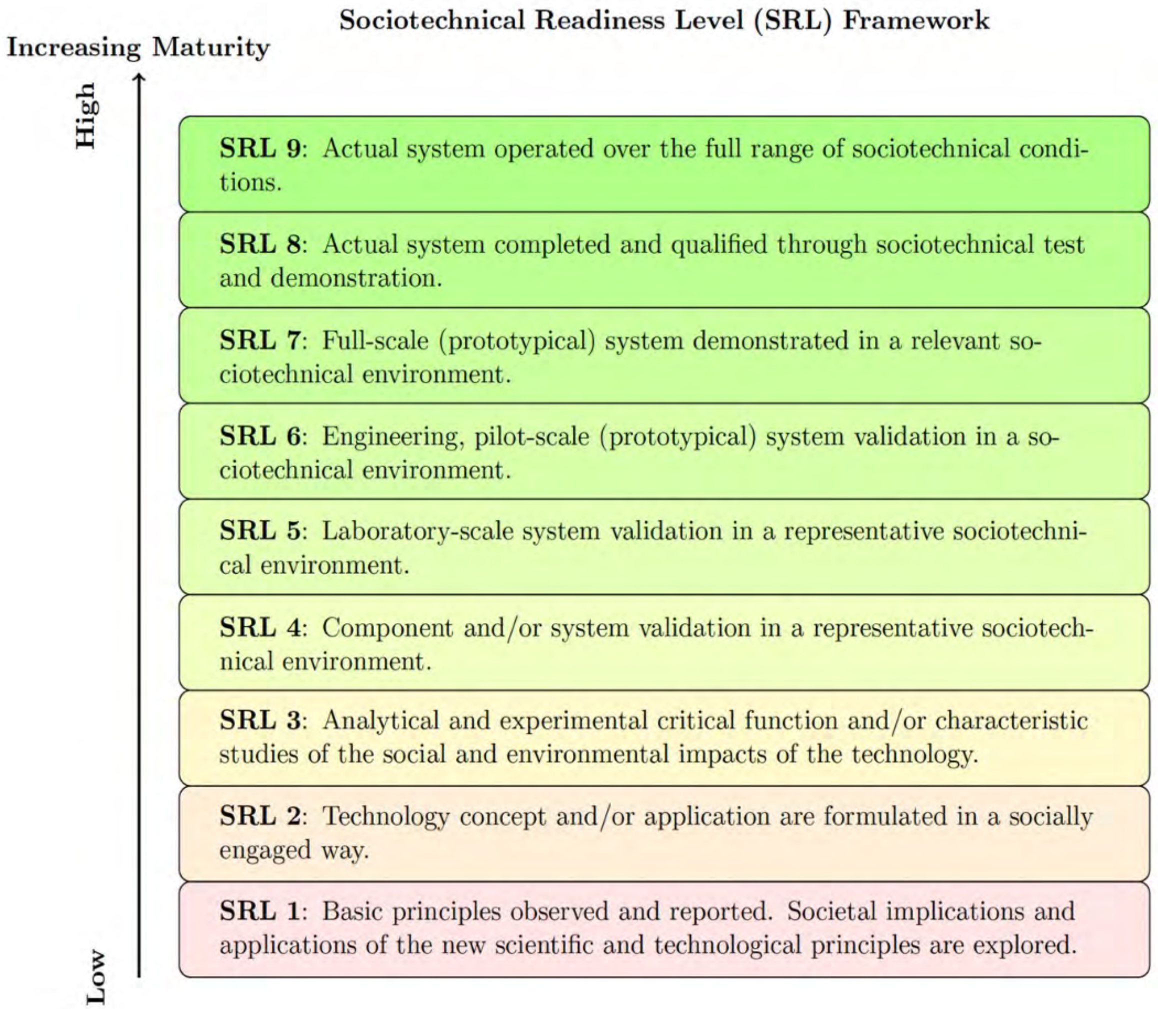
Sociotechnical Readiness Level (SRL)



Verma and Allen (2024) proposes the SRL framework
The current team implemented and tested SRL.

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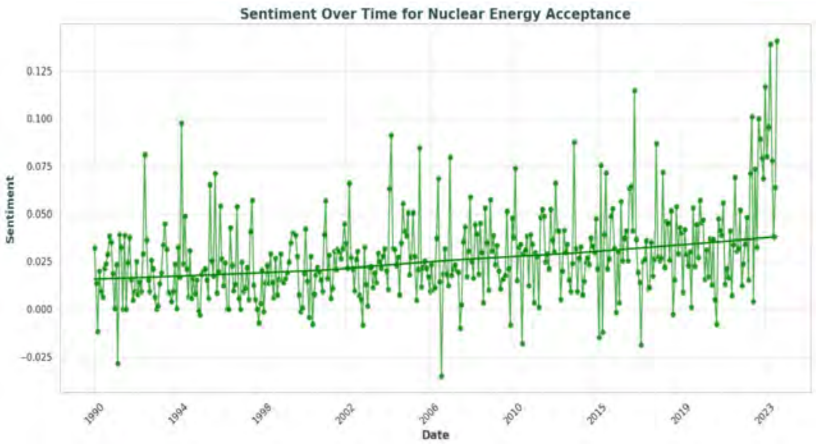
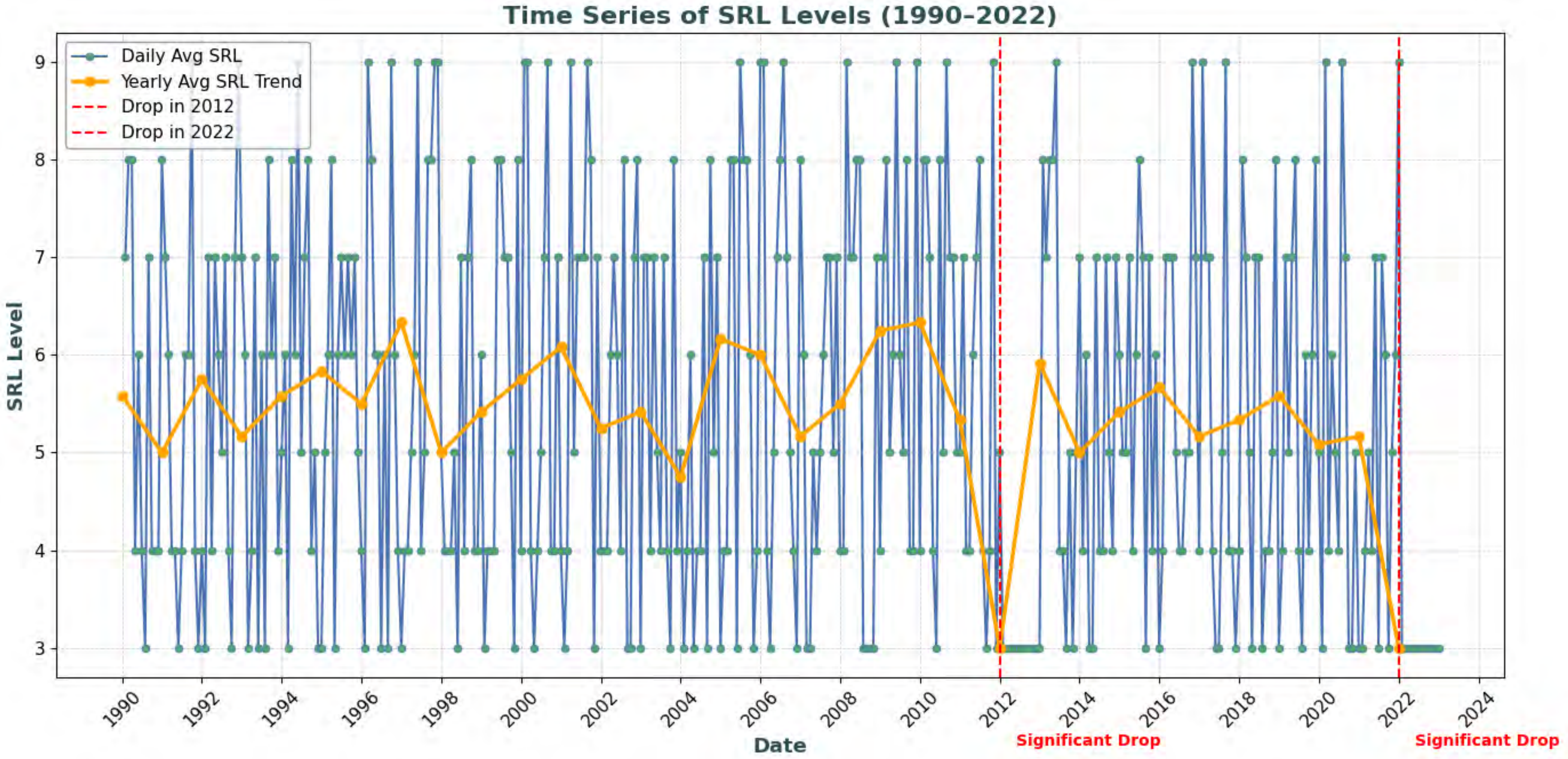
SRL Time Trends



Sentiment Score	Mapped SRL
< -0.75	3–4 (Low SRL) – Strong societal resistance
-0.75 to -0.25	4–5 – Some skepticism
-0.25 to 0.25	5–6 (Neutral) – Balanced opinions
0.25 to 0.75	7 – Positive perception
> 0.75	8–9 (High SRL) – Strong societal acceptance



- Scraped news releases (1990–2024) from multiple news agencies.
- Extracted articles containing keywords: “nuclear energy,” “nuclear reactor” "nuclear power".
- Significant sentiment drops in **2012 (Fukushima aftermath)** and **2022 (Russia Ukraine war).**
- Positive sentiment recovery post-2015 aligns with increasing clean energy investments.

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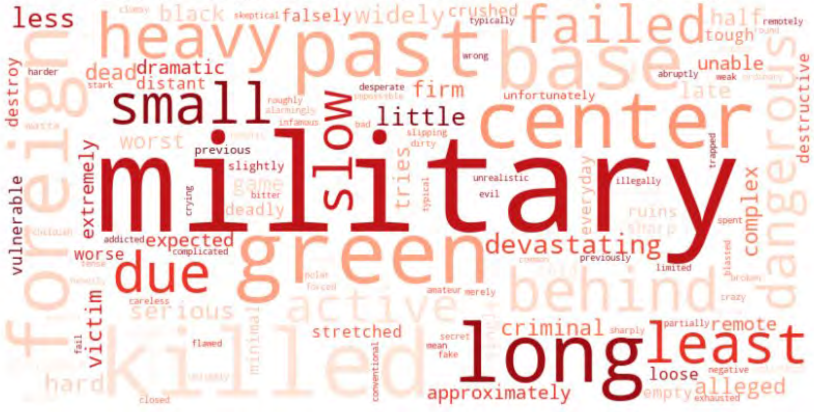
Word Cloud Analysis

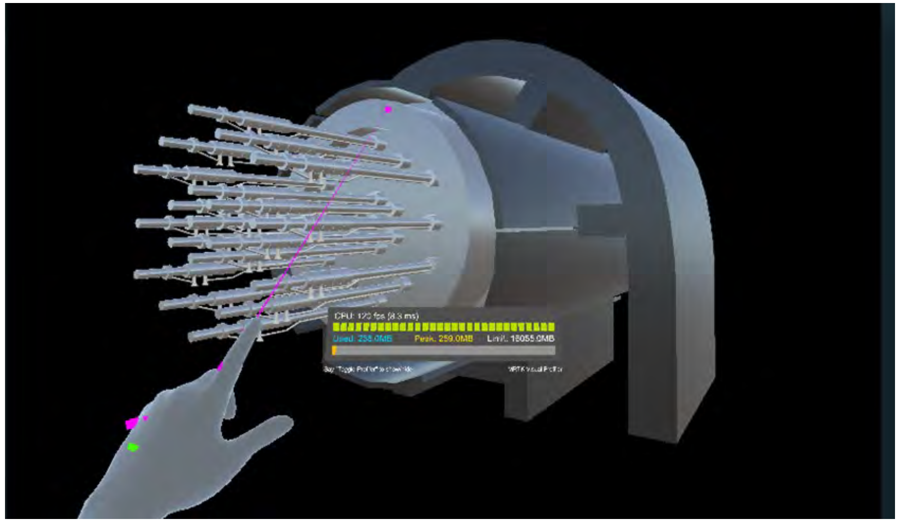
Positive Keywords Associated with High SRL (SRL > 7)

Negative Keywords Associated with Low SRL (SRL < 4)



- Word cloud analysis highlights positive and negative sentiment words associated with high (SRL > 7) and low (SRL < 4) societal readiness levels.
- **Positive SRL (green):** "new," "clean," "economic," "important" → Reflects progress and acceptance.
- **Negative SRL (red):** "military," "past," "failed," "devastating" → Suggests fear and resistance.

Immersive Experience (XR) Development for Community Engagement



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Regulatory Engagement Plan

Westinghouse Regulatory
Engagement Plan
Submitted to NRC in 2021

Penn State FRONTIER
10 CFR Part 50
Two-part Licensing Approach

RSAR and ER (under 10 CFR Part 51)
Required for the
Construction Permit Application.

FRONTIER designated as a Research Reactor
The Construction Permit Application under
10 CFR Part 50.23

NEI 18-04 for Licensing Basis Event
Identification

The EPZ Size in this NEUP Project

To Evaluate the EPZ Size Down
from the 400-meter Radius
to the Site Boundary

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Types and Frequency of the Communications between the FRONTIER team and the NRC staff

Routine Project Management Discussions

To ensure timely communication of issues and consistent understanding of the status of issue resolution. These interactions may also take the form of simple phone calls and email communications.

Drop-In Meetings

For the General Exchange of Information on Non-Technical Topics such as Planning for Future Interactions and Scheduling Discussions
Not directly Related to Regulatory Action or Decisions.

Technical Discussions

To provide the opportunity for direct engagement with NRC staff reviewers in specific subject areas and To include reviewers and management.

An initial Drop-In meeting held in late 2024

The FRONTIER team officially engaged the NRC by opening a docket for the project in February 2025

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Conclusions

- Recommendations on Atmospheric Dispersion model
  - Atmospheric Dispersion code vs Existing CFD simulations performed
  - Extended CFD simulation is being performed
  - Model Improvement
  - Penn State Site-Specific Study will be performed this year

- Community Engagement Plan
  - SRL study
  - Immersive Experience
  - FAQs and Website being developed

- Regulatory Engagement Plan
  - Regulatory Engagement has been initiated
  - This project will support the Regulatory Engagement Plan and summarize the effort to generate a guideline for other microreactor developers

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Outcomes

- **Conference Papers**

1. Erik Hisahara, Christopher Balbier, Saya Lee, Rohan Biwalkar, Sola Talabi, Preliminary Parametric Study of Microreactor EPZ, American Nuclear Society Transactions, Vol. 130, No. 1, 2024, 857-860
2. Erik Hisahara, Christopher Balbier, Saya Lee, Rohan Biwalkar, Sola Talabi, Preliminary Study of Microreactor Emergency Planning Zone.14th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Operation and Safety (NUTHOS-14), August 24 – 29, 2024, Vancouver, Canada.

- **Talks**

1. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, Research Seminar at Penn State Scranton, March 19, 2025, The Pennsylvania State University, State College, PA
2. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, Seminar at the Department of Finance, Smeal College of Business, February 26, 2025, The Pennsylvania State University, State College, PA
3. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, 2025 Annual Meeting of Southwestern Finance Association, February 12-14, 2025, San Antonio, Texas.
4. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, BSB Colloquium, February 11, 2025, The Pennsylvania State University. ***Online Workshop.***
5. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, 2025 Data Summit, Office of Planning, Assessment and Institutional Research, February 12, 2025, The Pennsylvania State University. ***Online Workshop.***
6. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, 2025 3rd Contemporary Issues in Financial Markets and Banking, January 13-14, 2025, Nottingham-Trent University, Nottingham United Kingdom. Online Conference.
7. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness, 2024 Massey Sustainable Finance Conference (MSFC2024), December 2-3, 2024, Auckland, New Zealand.
8. Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, "Sustainable Energy Marketplace and Societal Readiness", ***Seminar*** at the Ken and Mary Lindquist Department of Nuclear Engineering, The Pennsylvania State University, October 31, 2024, State College, PA.

- **Posters**

1. Jainil Kakka, Hyungjin Kim, Saya Lee, Nonna Sorokina, Darshana Sunoj, Praneeth Sunkavalli "Sustainable Energy Marketplace and Societal Readiness", 2024 ICDS Symposium, The Pennsylvania State University, October 23, 2024, State College, PA.

Thank You!

Questions?