Atmospheric ^{41}Ar Plume Tracking and Model Development of the UF Training Reactor Using a Large-Volume NaI Detector

Gabriel A. Sandler*, Hannah E. Gardiner, James Baciak
University of Florida
PI: James Baciak, gaj91@ufl.edu
Consortium for Verification Technology (CVT)

Introduction

- Tracking and monitoring gaseous radioactive materials is essential in the event of unexpected radioactive release.
- An updated mobile system for tracking radioactive releases would help to alleviate current issues in plume tracking as well as gain the ability to track a radioactive release in real-time.
- We are investigating the feasibility of mobile tracking through study and measurement of the ^{41}Ar plume released from the University of Florida Training Reactor (UFTR) research reactor. One unique feature of the UFTR is the large volume of air that passes through the core, producing and releasing significant quantities of radioactive ^{41}Ar gas via neutron activation of argon present in air.
- A large-volume NaI(Tl) detector took experimental data from the ^{41}Ar plume to verify and validate the results of an in-house Gaussian atmospheric dispersion plume model coupled with MCNP6.
- The university could benefit from the design of this coupled code to replace UF's currently utilized code COMPLY.
- The coupled model would provide a more accurate source term for the UFTR.

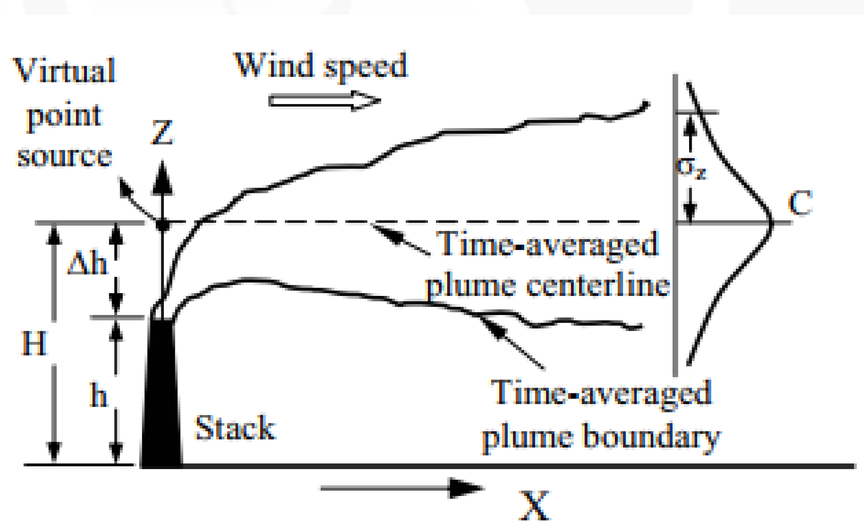
Atmospheric Dispersion Theory

- Atmospheric dispersion models are utilized to predict the concentration of pollutants as they diffuse throughout the atmosphere.
- Atmospheric stability is defined as the degree in which the atmosphere promotes or reduces vertical mixing and requires knowledge on adiabatic lapse rate.
- If the adiabatic lapse rate of dry air (9.77 °C km^{-1}) is smaller than the actual lapse rate, air moves upwards, promoting radionuclide diffusion. If the actual lapse rate is smaller than the adiabatic lapse rate, air has a tendency to move back to its original elevation, thus reducing upward motion. [1]
- In order to analyze the spread of radionuclides, the Gaussian Dispersion Model can be utilized.
- To arrive at the Gaussian model, the following assumptions are made: [2]
  - Continuous emission from a point source
  - Constant wind speed and direction
  - No downwind diffusion
  - No inversion layer
  - Flat terrain
  - Upward reflection from the ground is included
  - Dispersion is a function of downwind distance
- With these assumptions, the turbulent diffusion equation can be solved analytically in order to produce the Gaussian dispersion equation:

$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z}\left[exp - \left(\frac{y^2}{\sigma_y^2}\right)\right]\left\{exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\} \quad [3]$$

C is the concentration of the radionuclide at point (x, y, z), Q is the emission rate of the radionuclide, U is the wind speed, H is the effective stack height, σ_y is the horizontal dispersion coefficient, and σ_z is the vertical dispersion coefficient.

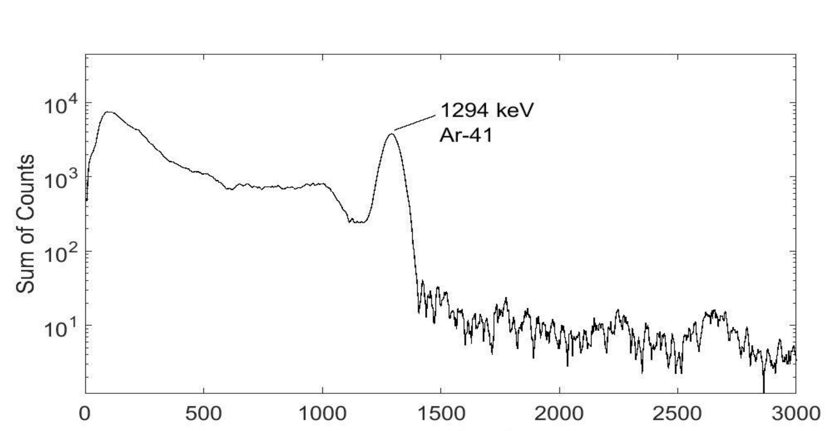
- As the radionuclides flow downwind, the vertical and horizontal dispersion is modelled through the use of the normal distribution. This spread moves outward from the centerline of the plume and is dependent on source distance and atmospheric conditions.



Example of atmospheric dispersion and the Gaussian plume model [2]

Experimental Trial

- A large volume (4 x 4 x 16 in) mobile NaI detector was coupled to a Hamamatsu PMT in a carbon-fiber package.
- A survey was taken on June 10th, 2016 to observe the UFTR's plume spectrum.
- The detector placed on the roof of the building adjacent to the stack exhaust.
- The measurement with the reactor at full power took 26 minutes and began at 4 p.m., thirty minutes after the UFTR startup.
- The measured background-subtracted count rate of ^{41}Ar was 70.78 ± 1.19 CPS.



Reactor emissions spectrum after background subtraction

Model and Simulations

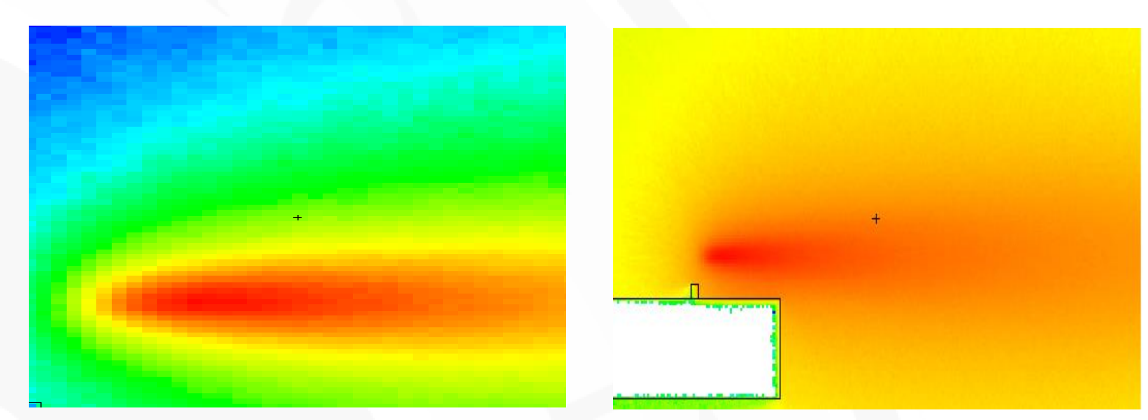
- A Gaussian atmospheric dispersion code was built in MATLAB to create 3-dimensional plume model.
- The ^{41}Ar concentrations solved in the dispersion code are utilized to create a plume source file which is coupled directly into a MCNP6 input file.

Constant Variables in Gaussian Dispersion Model

Variable	Value
Q	1.3587E-04 Ci s^{-1}
H	9.1 m
V_s	10.896 m s^{-1}
D	0.876 m
X (Plume Length)	60 m
Y (Plume Width)	18 m
Z (Plume Height)	24 m

- The F8 tally was utilized on the simulated NaI detector. By multiplying the MCNP and MATLAB results, the coupled Gaussian plume model can predict the counts recorded per second by the NaI detector:

$$Simulated\ Ar-41\ CPS = Total\ Plume\ Activity * F8\ Tally$$



FMESH Tally of Plume in downwind direction (left) far view (right) close up

Simulation Results from 12 to 5 p.m.

Time	V	Direction	Class	Simulated Count Rate (SCR)	Experimental Count Rate (ECR)	$\frac{abs(SCR-ECR)}{ECR}$
12 p.m.	4.6 mph	ESE	C	264.60 ± 8.33 cps	70.78 ± 1.19 cps	273.83%
1 p.m.	5.8 mph	E	B	394.11 ± 17.62 cps	70.78 ± 1.19 cps	456.81%
3 p.m.	12.7 mph	ESE	C	63.22 ± 2.76 cps	70.78 ± 1.19 cps	10.68%
4 p.m.	5.8 mph	SE	B	200.46 ± 7.20 cps	70.78 ± 1.19 cps	183.21%
5 p.m.	12.7 mph	E	C	60.67 ± 4.32 cps	70.78 ± 1.19 cps	14.28%

Sensitivity Analysis on Wind Speed for 3 p.m. Plume Model

% Change	Velocity	Simulated Count Rate (SCR)	Experimental Count Rate (ECR)	$\frac{abs(SCR-ECR)}{ECR}$
-20%	10.16 mph	102.41 ± 3.93 cps	70.78 ± 1.19 cps	44.69%
-10%	11.43 mph	75.51 ± 3.19 cps	70.78 ± 1.19 cps	6.68%
-5%	12.065 mph	64.19 ± 2.86 cps	70.78 ± 1.19 cps	9.31%
Base Value	12.7 mph	63.22 ± 2.76 cps	70.78 ± 1.19 cps	10.68%
+5%	13.335 mph	53.37 ± 2.48 cps	70.78 ± 1.19 cps	24.59%
+10%	13.97 mph	49.02 ± 2.32 cps	70.78 ± 1.19 cps	30.74%
+20%	15.24 mph	44.98 ± 2.13 cps	70.78 ± 1.19 cps	36.46%

Summary & Future Work

- A Gaussian dispersion model was developed in MATLAB and coupled with MCNP6 in order to accurately estimate the spread of ^{41}Ar from the UFTR.
- A precise UFTR ^{41}Ar source model can be integrated into the UFTR safety basis.
- When comparing the experimental data to the simulated data, the plume model was able to predict the CPS with a 10.68% difference in value.
- For future experiments, we will utilize a portable weather station to accurately predict atmospheric conditions while also observing the effect of time on the plume.
- For the model, we will study building downwash algorithms as well as investigating non-Gaussian dispersions models such as Lagrangian and Eulerian models.
- The experimental and simulation data will be utilized to support the development of an updated mobile system for tracking radioactive releases in real-time.

References

1. Bolch, W. Atmospheric Dispersion of Radionuclides. [PowerPoint Slides].
2. A A. Abdel-Rahman, "On the atmospheric dispersion and gaussian plume model". 2nd International Conference on Waste Management, Water Pollution, Air Pollution, Indoor Climate (WWAI'08) Corfu, Greece, October 26-28, 2008.
3. I. Lagzi, R. Mészáros, G. Gelybó, A. Leelőssy (2013). Atmospheric Chemistry. Retrieved from http://ttktamop.elte.hu/sites/ttktamop.elte.hu/files/tananyagok/athmospheric_chemistry.pdf

This work was funded in-part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534

National Nuclear Security Administration