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 (9.7°F °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:

$$C(x,y,z) = \frac{1}{4\pi \sigma_x \sigma_y \sigma_z} \exp \left( -\frac{x^2}{\sigma_x^2} - \frac{y^2}{\sigma_y^2} - \frac{z^2}{\sigma_z^2} \right) \left[ \exp \left( -\frac{x^2}{\sigma_x^2} \right) + \exp \left( -\frac{x^2}{2\sigma_x^2} \right) \right]$$

$C$ 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, $\sigma_x$ is the horizontal dispersion coefficient, and $\sigma_y$ 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.

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.

<table>
<thead>
<tr>
<th>Simulation Results from 12 to 5 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>12 p.m.</td>
</tr>
<tr>
<td>1 p.m.</td>
</tr>
<tr>
<td>2 p.m.</td>
</tr>
<tr>
<td>4 p.m.</td>
</tr>
<tr>
<td>9 p.m.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>% Change</th>
<th>Velocity (mph)</th>
<th>Simulated Count Rate (SCR)</th>
<th>Experimental Count Rate (ECR)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30%</td>
<td>10.16 mph</td>
<td>100.41 ± 1.30 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>46.4%</td>
</tr>
<tr>
<td>-10%</td>
<td>11.43 mph</td>
<td>75.51 ± 1.19 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>6.5%</td>
</tr>
<tr>
<td>0%</td>
<td>12.05 mph</td>
<td>64.19 ± 1.32 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>9.1%</td>
</tr>
<tr>
<td>+10%</td>
<td>13.07 mph</td>
<td>50.37 ± 1.24 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>25.6%</td>
</tr>
<tr>
<td>+50%</td>
<td>13.37 mph</td>
<td>26.03 ± 1.32 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>35.7%</td>
</tr>
<tr>
<td>+100%</td>
<td>13.49 mph</td>
<td>44.06 ± 1.23 cps</td>
<td>70.78 ± 1.19 cps</td>
<td>36.4%</td>
</tr>
</tbody>
</table>

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 10.6% 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


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