Project Title: **Real Time Radioactive Plume Visualization**

Team Name: **Radioactive Plume**

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Project Synopsis

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Introduction

The United States Federal Emergency Management Agency (FEMA) and other emergency response agencies would presently benefit from a modern approach for calculating and displaying the airborne concentration of radioactive materials located in plumes. These plumes can originate from the intentional or accidental release of radioactive materials from a nuclear reactor. Nuclear power is a sustainable alternative as it produces less carbon emissions than fossil-fuel generators. However, these plants pose the threat of radiological accidents or disasters. The Three Mile Island core meltdown in 1979, the Chernobyl disaster of 1986 due to overheated fuel rods, and the unexpected earthquake-induced disaster at Fukushima, are just some of the cases that demonstrate the risks of nuclear reactors. In the event that a reactor accidentally releases radioactive plumes, experts in the field, such as Dr. Keith Holbert, believe that it is imperative that officials be provided with proper estimates of the downwind dose such that they can take protective actions and advise the public as well as emergency workers. Existing plume modelling software are not as effective as they could be thus, team *Radioactive Plume* has been working on a project that aims to remedy the issues of current software, by providing a more accurate tool for radiological plume modeling. The team's main customers are Dr. Keith Holbert and other state emergency response agencies, including FEMA. The team's budget rests at one hundred dollars and the expected completion date is November 26th, 2021.

This report begins with a discussion of the project scope where the problem is identified followed by the team's solution and the list of target specifications. Changes to the scope are also addressed in this section. Subsequently, a brief overview of all completed and in-progress tasks is presented along with a discussion of any delays. A summary of the team's completion plan follows, which explores the team's plan of action in order to complete the project on-time and within budget. A discussion of the team's plan for both online and in-person demo day is then presented along with a vision of the final project. Finally, the report ends with an analysis of how the project adheres to three ABET criterion 4 considerations.

Project Scope

Radionuclides in the atmosphere present an invisible vector of harm that is often only noticed long after exposure. Thus, time is of the essence if predictions and decisions are to be made by state agencies. However, current software applications designed to model downwind plumes for radiological materials are complex, time-consuming, and not easily accessible. The team's mission is to create a visual tool that remedies these issues by providing a user-friendly, fast-responding, and easily accessible radiological plume modeling visual tool that can generate dosage estimates within minutes. The goal is to assist officials in reducing the negative health effects associated with radiation in the event of a radiological emergency. The project will estimate the airborne concentration of radioactive materials in a downwind plume and its consequential radiation dose during various atmospheric conditions. This will be done by building on a preexisting Geographic Information System (GIS) framework to develop a novel approach to visualizing radiation and quantifying the effective dose. The team has outlined a set of target specifications (project controls) in order to execute the project. These include:

1. A predefined list of inputs which will be used for dosage calculations and plume estimations:
    1. Nuclear power plant/reactor selection
    2. Downwind distance
    3. Downwind direction
    4. Off-centerline distance
    5. Atmospheric stability class selection
    6. Wind speed, wind direction
    7. Release height
    8. Atmospheric mixing lid height
    9. Reactor hold-up time
    10. Release duration
    11. Source release rates for: noble gases, iodines, particulates (cesiums)
2. Stationary-based and time-based equations relating to diffusion, fallout, normalized concentrations, and radiation doses to people.
3. A GIS framework, identified as ArcGIS, to add layers of nuclear reactors, important buildings, streets, etc.
4. A JavaScript framework to calculate and display the airborne concentration of radioactive materials in a downwind plume, both visually and numerically.
5. Outputs: visually mapped plume concentrations, numerical estimates of dosages, pop-up messages for users.
6. A website which hosts the entire plume visualization tool with all inputs and outputs.

Thus, the team's final project design is a website which accepts inputs, layers the estimated plume concentrations using ArcGIS, then calculates the airborne concentration of radioactive materials in a downwind plume using JavaScript, thus predicting the trend of the particles spreading with time through map layering and mathematical calculations. Since the spring semester, no significant **changes** have been made to the project execution, however a few changes were made within the individual target specifications. These changes are listed below:

- The inputs will now include the option to choose between SI or English (imperial) units.
- As opposed to solely relying on importing atmospheric data from current weather conditions, users will now have the option to manually enter this information, in the event that other data repositories are unavailable.
- Instead of mapping the plume doses in three colors only (red, orange, yellow), a fourth color will be added to signify a "safe" zone.

Completed Tasks

During the spring semester, the team accomplished many important milestones. First the team modeled a stationary-based diffusion equation in MATLAB that will be used to compute the expected total equivalent dose (TED), and the adult thyroid and child thyroid radiation doses. The team explored and selected a GIS framework that can be embedded in a website and coded with the desired functions. The team selected ArcGIS as the mapping framework due to its compatibility with various coding languages and because Arizona State University (ASU) has a licensing agreement with the developer, Esri. Additionally, the team selected Python and JavaScript as the coding languages of choice, based on their functionality with ArcGIS. The team also selected a domain and web hosting service. The domain name “radplume.com” was purchased from GoDaddy and the hosting plan will be purchased in the fall semester.

During the summer, team members worked individually to learn the necessary skills required for completion of the project. Three of the team members learned Python, studied the basics of HTML/CSS, and learned JavaScript to prepare for the coding needed during the fall semester. Team members also began converting the diffusion equations from MATLAB to Python. In addition, team members utilized various training resources in order to become familiar with ArcGIS capabilities and requirements for integration with the selected coding languages. Finally, the team researched and identified the radiation dose areas that will be represented visually in the project.

In-Progress Tasks

For the fall semester, the team has identified major tasks which will ensure completion of the project. One of these, which has already been completed, was identifying the project dose area layers. In reference to these layers, the team has decided to incorporate layers for TED, thyroid, and emergency worker doses. Currently, the team is in-progress with authoring the underlying code that will be needed for the project. This includes authoring the input and output code blocks, the diffusion equation, and the dose area parameter layers. The team is aiming to have the necessary code completed by the end of September. While the code is being written, testing and debugging will be done routinely to ensure that no major errors are found later in the semester, and to confirm accuracy in results. The next two major tasks will be to integrate the Python code with ArcGIS, and then embed both into the JavaScript website. The final task will involve developing the user interface and adding scenarios that can be selected by the users. Currently, the team has not experienced nor anticipates any obstacles that would cause a **delay** in the completion of project tasks. However, the team is always in contact with one another and often shares resources and progress on tasks such that they will be prepared to adapt should any obstacles arise.

Completion Plan

To complete the project on time and within budget, the team has created a weekly task list, shown in Table 1. The team has decided to work on each project control, listed earlier, one at a time thus, the sections are split into coding blocks which will be combined later. First, team members will use Python to author the code for the inputs and the outputs. Then, they will personalize an ArcGIS map with desired layers of nuclear power reactors, streets, schools, etc. They will then modify the dose equations required for mapping the plume dosages such that it produces time-dependent estimates. These equations will be converted into another code block. Once each section is completed, the team will test the code to ensure that any bugs or issues are identified and resolved. The team will also test the results from the code against benchmarks outlined by the Environmental Protection Agency (EPA) to ensure accuracy. By comparing estimates made by EPA, the team will be able to gauge how well the project is working. Next, the team will configure the code blocks with ArcGIS online. This ensures that the desired visual effects and inputs and outputs are performing as intended. Afterwards, the team will embed the entire map (and Python code) into the website using JavaScript. Final testing, debugging, and finishing touches will be added as the team works on their demo day presentation. A detailed view of these tasks is found in Table 1 below.

Table 1: Weekly Task List

Week	Task
8/19 – 8/25	• Refamiliarize with project requirements and goals
8/25 – 9/1	• Select expected doses for project areas (red, orange, yellow, white) • Develop weekly schedule for semester • Begin building landing page for website
9/1 – 9/8	• Author code for **input/output coding blocks** • Write code for **expected dose layers** (TED, thyroid, emergency workers) • Team continues to work on diffusion equations for plume models
9/8 – 9/15	• **Plume diffusion equations** are reviewed, made to be time-dependent. • Ensure functionality of diffusion equation transferred from MATLAB to Python • Assemble individual coding blocks (input/output, dose layers, etc) • **First written report** is submitted (Sept 10th)
9/15 – 9/22	• Team tests developed Python code against identified benchmarks (EPA data) to ensure accuracy • Re-do equations and/or code if necessary • Continue to work on the website: landing page, navigation bar, etc.
9/22 – 9/29	• Team **embeds Python code into ArcGIS Online** • Troubleshoot/fix issues with ArcGIS integration • Review code blocks if necessary to ensure accurate outputs
9/29 – 10/6	• Team **embeds** code and ArcGIS project **into website** (radplume.com) • Troubleshoot/fix issues with the website integration • Finish up navigation bar and landing page
10/6 – 10/13	• Team builds **user interface** and links with appropriate input/outputs • Work on the **front-end** aspect of the website (login page, populate “about us” page with project/team information).
10/13 – 10/20	• **Troubleshooting**/fixing issues with user interface development
10/20 – 10/27	• Test website, continue to troubleshoot/ identify bugs/issues and resolve
10/27 – 11/3	• Work on **aesthetics** of the project (fonts, color, images, etc.) • Final touches on each webpage
11/3 – 11/10	• Team incorporates **pre-loaded scenarios** into project (pre-recorded videos of how the website will function, simulate example scenarios to demonstrate the functionality of project)
11/10 – 11/17	• Team finishes plume project. **Website is published**! • Incorporate videos and screen-captures of project into video presentation • Work on final written report
11/17 – 11/24	• Team works on demo day **showcase plan**: online and in-person plan needed • Submit final written report
11/24 – 12/3	• Final touches on presentations for **demo day**.

Final Demo Day Vision

The following two paragraphs outline the team's vision for the final demo day, where the project will be on display and presented to the public.

In-person:

The team plans to have a table set up with a large display board and two laptops. The display board will present the project background information, the problem that the project is trying to solve, key equations used to develop the software, as well as the contour and surface plots developed in MATLAB which were used in the initial stages of the project. One laptop will have the project website open and available for interaction while the other will be an on-going Zoom meeting where online team members can interact with guests and be present with the sole on-campus team member.

Online:

The team plans to prepare a video introduction of the project which will be placed next to the team's project description and Zoom link on demo day. This video will provide a brief overview of the project background, scope, and a pre-recorded simulation of the final product, demonstrating its functionality. The Zoom link will be available for guests to enter the team's "room" if they have any questions or comments. Within the Zoom room, there will be an image summarizing the key points of the project and the website will be opened in the background in the event that the team needs to showcase a specific function of the project.

ABET Considerations:

The ABET Engineering Criteria (EC2000) handbook outlines a set of accreditation standards required for all post-secondary programs. Criterion 4 states that any major design experience should adhere to engineering standards and realistic constraints. The following paragraphs provide a brief analysis of how the project incorporates three major engineering considerations.

Environmental:

While nuclear energy is beneficial, there are valid concerns of its negative impact on the environment. Accidental radiological releases can expose living organisms to harmful levels of radiation. In addition to aiding emergency response agencies in protecting the general public, the Radioactive Plume project will visually depict the initial extent of doses which will assist in the recovery and decontamination efforts of the **environment** following a radiological release.

Health and Safety:

In line with these environmental concerns, the project also aims to protect the health and safety of the public. The radioactive particles released from a plume can elicit a large variation of responses including, but not limited to skin rashes, radiation sickness, cancer, and death. Although there are many safeguards and protocols in place to prevent a radiological accident, the probability that one will occur is not negligible. The Radioactive Plume project will help protect the **health and safety** of the public by equipping emergency response agencies with a visual tool to determine unsafe radiological dose areas such that they can best advise people in the affected areas on how to minimize their exposure to potentially harmful levels of ionizing radiation.

<u>Social</u>:

This project also encompasses **social** implications by demonstrating to the public that there are tools and resources available to aid and assist their well-being in the event of a radiological release. In previous disasters throughout history, response efforts lacked quick response tools and cutting-edge technology to appropriately respond. This project showcases a response tool which should help mitigate the social fear of an ill-prepared response to a radiological incident. Unlike other plume modelling tools, the team intends to allow public access such that every citizen will be able to explore its features both for leisure and in the event of an emergency.

Conclusion

Nuclear power reactors provide many benefits in terms of electricity production but it is also important to consider its potential risk of releasing harmful radioactive particles. In the event of such a release, it is imperative that local authorities be equipped with tools that can provide them with quick, accurate estimates of how much potential damage can be done to individuals. Although there exists some software which can model radioactive plumes, they were found to be somewhat limited in their predictions. As a result, team *Radioactive Plume* has been working on a project which will serve as an accurate visual plume-modelling tool that can predict the trend of the particles spreading with time. The project will be created through map layering and mathematical calculations using a combination of GIS frameworks and coding languages such that the final design will be a website capable of accepting inputs and displaying estimated plume dosages. The team has set a budget of one hundred dollars and an expected completion date of November 26th, 2021. The team has not made any significant changes to the scope since the spring semester. However, a few minor adjustments were made to the individual target specifications in order to create a more interactive and user-friendly design. The team has utilized great time management skills and as such, has not experienced any delays. If all continues to go as planned, the project will be completed on time and within budget with no difficulties for demo day.