PNNL-37385

# Sensor Placement Optimization Study for the Built Environment: Next Steps Report

March 2025

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# Summary

Systems of fixed-position radiation sensors can provide information that assists emergency responders following nuclear incidents. First responder organizations that implement systems of fixed-position sensors face numerous decisions regarding sensor selection, quantity, and placement. Researchers at Pacific Northwest National Laboratory (PNNL) have evaluated the performance of several hypothetical sensor systems during a simulated activation of a radiological dispersal device. Due to technical limitations, PNNL's analysis was limited to a single location and number of scenarios. This document describes additional research and analysis that would result in improved guidance to first responder organizations considering installation of radiation monitoring systems.

# Acknowledgments

The authors would like to thank the Department of Homeland Security National Urban Security Technology Laboratory for sponsoring this work and invaluable feedback and guidance.

# Acronyms and Abbreviations

| | |
|---|---|
| PNNL | Pacific Northwest National Laboratory |
| QUIC | Quick Urban and Industrial Complex |
| RDD | Radiological Dispersion Device |
| WRF | Weather Resource and Forecasting |

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# 1.0 Introduction

Per an interagency agreement between the Department of Homeland Security Science and Technology Directorate National Urban Security Technology Laboratory and the Department of Energy Pacific Northwest National Laboratory (PNNL), researchers at PNNL have evaluated the performance of a hypothetical system of radiation sensors during a simulated release of radioactive material in an urban environment. The results of this analysis are available in the report *Sensor Placement Optimization Study for the Built Environment: Operational Use Cases* (PNNL 2025).

The 2025 study evaluated the performance of a small number of systems of fixed-position radiation sensors during a simulated activation of a radiological dispersal device (RDD) in lower Manhattan. Our simulations successfully demonstrated how a system of radiation sensors might perform as a radiological plume traverses an urban environment, and we expect our analysis will be useful to first responder organizations considering whether to construct a radiation detection system. However, we experienced technical challenges that limited the number and scope of simulations we were able to run for the study. This prevented us from developing firm guidelines for sensor selection and placement. This document suggests follow-on research and analysis that would allow us to develop additional guidance that covers a wider range of environments and scenarios.

# 2.0 Recommendations

Our recommendations for follow-on research are grouped into four categories: 1) improving the modeling framework, 2) simulating additional scenarios, 3) improving analysis techniques, and 4) developing knowledge products for first responder organizations.

## 2.1 Modeling Framework

### 2.1.1 Weather Forecasting

We used the Weather Resource and Forecasting (WRF) model to generate localized weather information that could be used by the Quick Urban and Industrial Complex (QUIC) model to simulate plume movement. QUIC modeled the wind as a uniform wind field, which could have reduced simulation accuracy. We recommend conducting additional research in using QUIC with WRF generated data to determine how to model non-uniform wind fields.

### 2.1.2 Simulating Built Environments

We encountered two limitations on the number of buildings that could be modeled. The QUIC model removes buildings from the simulation to reduce computational workload, and the Monte Carlo N-Particles model has a limit on the size of the building definition file. We do not expect these limitations to affect scenarios set in rural or suburban environments. These limitations did affect our ability to accurately simulate built environments in dense urban neighborhoods.

Figure 1 is a map of an area in lower Manhattan where we simulated a radioactive plume from an RDD. The gray rectangles are the buildings modeled in QUIC. The map indicates a significant fraction of the buildings were not modeled.

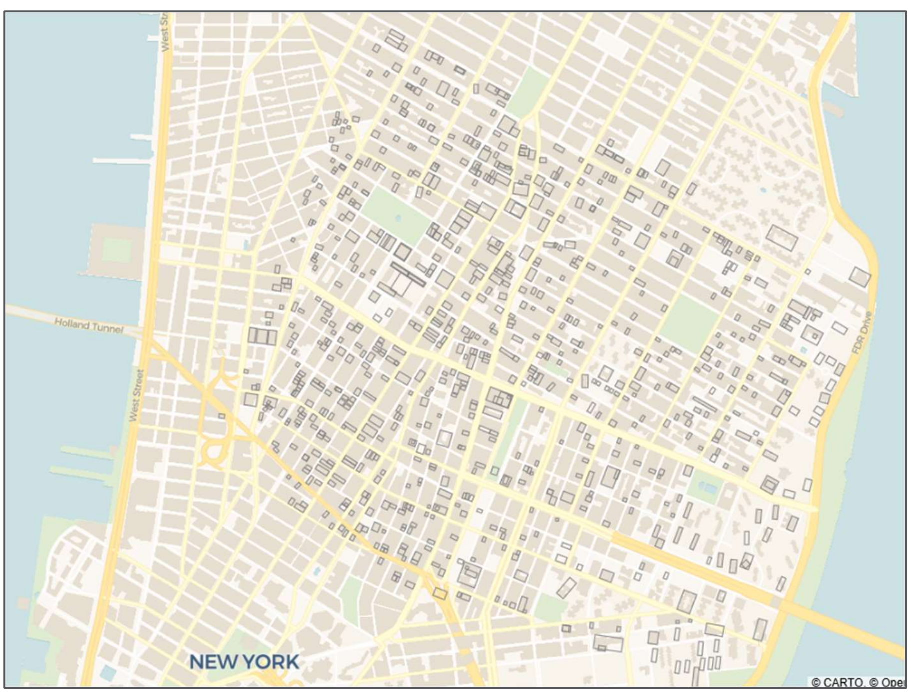


Figure 1. Template map used to model a radiological release lower Manhattan

For dense urban environments, we recommend aggregating the buildings on a single block into a single building. Aggregation would remove features like narrow alleys and backyards from the dataset, and building heights would be averaged for the entire block. However, we suspect aggregation would improve overall accuracy of the simulation. Simplifying the building geometry could also potentially decrease computational workload and increase the size of the area that can be simulated.

### 2.1.3 Aeolus Urban Dispersion Model

We recommend evaluating the Aeolus model for simulating particle dispersion in place of QUIC. The Aeolus model is a three-dimensional fluid dynamics model for predicting dispersion of contaminants in an urban area (Gowardhan et al. 2017) developed at the Lawrence Livermore National Laboratory. For our purposes, the Aeolus model may have fewer limitations than the QUIC model.

## 2.2 Scenarios

### 2.2.1 Locations and Weather Conditions

We recommend simulating releases of radioactive material at additional locations. The simulated locations would include rural, suburban, low-density urban, and high-density urban areas. We would simulate several different locations for each density type to account for unique geographic features.

To account for the impact of weather and wind direction, we also recommend simulating several different types of weather at a single location.

### 2.2.2 Isotopes

Our analysis has been limited to Cs-137. We recommend running simulations with other isotopes that would provide a wider energy spectrum. Simulating additional isotopes will help us determine whether our instrument selection and placement guidelines are suitable for a wider range of scenarios.

Simulations could use isotopes such as Co-60, Am-241, or a combination of Am-241 and Be-9. Co-60 is a gamma and beta emitter with a half-life of 5.3 years. It has several industrial and medical applications. Am-241 emits alpha particles and a low-energy gamma rays. It has a half-life of 432 years and is commonly used in smoke detectors. Am-241 can be combined with Be-9 (which is not radioactive) to create a neutron source.

Future work could also consider sensor placement studies for detecting isotopes that primarily emit alpha or beta particles (e.g., Po-210 and Sr-90, respectively) and generally require close-up measurements or detection with air samplers. These isotopes can be detected at standoff via air radioluminescence and commercial ultraviolet sensors or cameras. Minimum detectable concentration studies for isotopes of interest could be executed with existing modeling frameworks and supported with UV cameras available at PNNL.

### 2.2.3 Activity Levels

We recommend simulating a wider range of activity levels. Our prior analysis was limited to releases of 1,000 Ci of Cs-137. Simulating both smaller and higher activity levels, perhaps ranging from 100 to 10,000 Ci, would help us understand the relationship between activity level and optimal detector spacing. We would also be able to observe how dose rates and deposited activity levels vary with the initial activity level.

## 2.3 Analysis

### 2.3.1 Deposition and Local Contamination Levels

Our analysis did not distinguish between activity deposited on the ground and buildings and airborne activity. An estimate of the amount of deposited material is necessary to estimate the long-term dose rates in that area, i.e., the dose rates present after the airborne material has passed through. We recommend that future research calculates the amount of deposited activity. Such information could help us identify methods for using fixed sensors to estimate local contamination levels and estimate long-term dose.

### 2.3.2 Types of Radiation Sensors

Our analysis assumed that the simulated radiation monitoring instruments could provide count rate and dose rate information, but did not make specific assumptions regarding the type of detector used, and we did not account for varying sensitivities between different types of detectors. Addressing different types of detectors and instruments in future research is required to develop guidelines for first responder organizations that address the tradeoff between instrument cost and sensitivity and other features. For instance, a larger overall sampling area could be established with lower cost instruments compared with a smaller set of higher cost instruments.

Our analysis assumed the sensor system was only capable of producing gamma and x-ray count rates, which can be converted to dose rates if we know the energies of the gamma and x-rays, or which nuclides are present. We recommend future research consider how instruments that provide energy spectra could be used in the early phases of incident response. Instruments that provide energy spectra would help emergency responders identify the nuclides involved and potentially aid in detecting release with lower initial activity levels.

### 2.3.3 Quantitative Trend Analysis

Our recent analysis identified some possible trends related to detector placement and interpretation of sensor output. However, the trend analysis was qualitative. We did not conduct enough scenarios for quantitative analysis of simulation outputs. Assuming future research runs more scenarios and generates larger datasets, we recommend conducting regression analysis for key parameters. For example, a linear regression model with distance as the independent variable and altitude at which max dose rate occurred as the dependent variable could help us determine whether the suspected relationship between distance and dose rates is statistically significant and whether it applies to other locations, activity levels, and weather conditions.

### 2.3.4 Incorporation of Varying Height to Sensor Layout

The project staff identified height as a key variable in plume detection. A plume may rise over the sensor such that it would provide little to no information until gravitational settling becomes the primary force on the emitted particles and pulls them back down to the level of the sensors. More analysis could determine whether a 3D layout, rather than just a planar layout of detectors at uniform height above ground, affects detection ability.

### 2.3.5 Uncertainty Quantification

Uncertainty in the modeling framework is driven by many factors, likely chief among them being weather conditions. This was initially explored in the past project. Future work should conduct further sensitivity studies to understand the impact of different parameters on spatiotemporal dose rates and how these may translate to overall guidance for sensor placement. Similar studies could be performed for both QUIC and AEOLUS to understand if there are significant differences between those frameworks. It may also be possible to compare simulation results with measured data for some recent experiments, if needed.

## 2.4 Knowledge Products

We recommend providing knowledge products to first responder organizations based on the results of the research described in the previous sections. The knowledge products would help first responders select radiation monitoring instruments that are suitable for their needs and place the instruments in optimal locations. The knowledge products would also help first responder organizations understand the capability of their system and interpret the information the system provides following a nuclear incident.

# 3.0 References

Gowardhan, Akshay, et al. 2017. *Fast Running Urban Dispersion Model for Radiological Dispersal Device (RDD) Releases: Model Description and Validation*. Lawrence Livermore National Laboratory. https://doi.org/10.2172/1409992

Multi-Agency. 2023. *Interagency Agreement (IA) Between DHS Science & Technology Directorate and the DOE Pacific Northwest National Laboratory 70RSAT23KPM000034 Statement of Work (SOW).*

PNNL. 2025. *Sensor Placement Optimization Study for the Built Environment: Operational Use Cases*. Pacific Northwest National Laboratory.

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