Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Title: Far Field Modeling Methods for Characterizing Surface Detonations

Savannah River National Laboratory (SRNL) analyzed particle samples collected during experiments that were designed to replicate tests of nuclear weapons components that involve detonation of high explosives (HE). SRNL collected the particle samples in the HE debris cloud using innovative rocket propelled samplers. SRNL used scanning electronic microscopy to determine the elemental constituents of the particles and their size distributions. Depleted uranium composed about 7% of the particle contents. SRNL used the particle size distributions and elemental composition to perform transport calculations that indicate in many terrains and atmospheric conditions the uranium bearing particles will be transported long distances downwind. This research established that HE tests specific to nuclear proliferation should be detectable at long downwind distances by sampling airborne particles created by the test detonations.

Figure 1: *HE test with SRNL rocket entering cloud.*

Awards and Recognition

None.

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publically published in its current form.

SRNL Legal Signature

Signature **Date**

LDRD-2014-00073
LDRD Report

Title: Far Field Modeling Methods for Characterizing Surface Detonations

Project Team: Alfred Garrett (Primary), ***Eliel Villa-Aleman, Michael Summer, Steve Chiswell***
Subcontractor: None

Thrust Area: ST3

Project Type: Strategic

Project Start Date: October 1, 2013
Project End Date: September 30, 2015

Savannah River National Laboratory (SRNL) analyzed particle samples collected during experiments that were designed to replicate tests of nuclear weapons components that involve detonation of high explosives (HE). SRNL collected the particle samples in the HE debris cloud using innovative rocket propelled samplers. SRNL used scanning electronic microscopy to determine the elemental constituents of the particles and their size distributions. Depleted uranium composed about 7% of the particle contents. SRNL used the particle size distributions and elemental composition to perform transport calculations that indicate in many terrains and atmospheric conditions the uranium bearing particles will be transported long distances downwind. This research established that HE tests specific to nuclear proliferation should be detectable at long downwind distances by sampling airborne particles created by the test detonations.

FY2015 Objectives

- Measure particle size distributions as a function of elemental composition.
- Perform particle transport and deposition calculations to determine if large percentages of uranium-bearing particles would remain airborne at distances of 25 km or more downwind.

Introduction

There are relatively few signatures of nuclear proliferation near the end of the production process when weapon components are being fabricated, tested and assembled. One signature that can be potentially be detected far from the test location is particulate debris from high explosives (HE) detonations. The HE tests verify that the non-nuclear initiator of a nuclear weapon explosion works. The debris cloud created by the HE test contains particles composed of the initiator components, which include depleted uranium. The uranium-bearing particles will range in size from sub-micron diameters that may be transported long distances downwind to millimeter or larger pieces that will fall to the ground quickly. If no other airborne sources of uranium are in the area, the uranium-bearing particles would be a strong indicator of a HE test relating to nuclear weapons. In order to gain knowledge about signatures created by HE nuclear weapons components tests. The Department of Energy (DOE) conducted a series of experiments that simulated actual HE component tests. SRNL successfully used an innovative method to collect particles in the debris cloud in which the particle collectors were mounted on a rocket that was fired into the debris cloud immediately after the detonation. This created a unique data set for analysis of the particles created by nuclear weapons related HE detonation. The first objective of this project was to analyze the particle samples to determine their elemental constituents and size distributions. The second objective was to use this information to perform transport and deposition calculations to determine how far downwind the signature of a nuclear weapon related HE test could be detected by collecting uranium-bearing particles created by the HE detonation.

Approach

The approach to analyzing the particle samples was a two-step process. First, the elemental constituents of the particle samples had to be determined, and the size distributions for the different types of particles had to be computed. Commercially available software for automated particle counting was used as well as a particle counting code developed by SRNL. Both codes produced similar size distributions, but the SRNL code was able to isolate and count smaller particles than the commercially available code.

After the particle size distributions by element were derived from the particle data, SRNL ran transport and deposition codes to determine how far downwind a significant part of the uranium-bearing particles would remain airborne. If the transport calculations showed that a large percentage of the uranium-bearing particles remained in the atmosphere far downwind from the detonation site, then this would verify that the uranium particles are a viable signature of nuclear weapons initiators or “triggers”.

Explain the approach used to conduct the research.

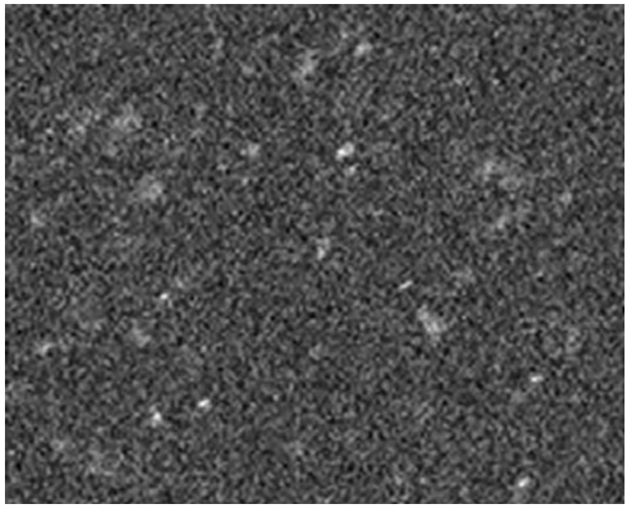

Figure 2: ***Uranium brightness map derived from particle collection media.***

Results/Discussion

SRNL extracted particle elemental composition from their characteristic x-ray spectrum by using Oxfords Energy Dispersive Spectrometer (EDS) detector. The primary elemental constituents found were carbon (C), copper (Cu), iron (Fe), oxygen (O), sulfur (S), aluminum (Al) and uranium (U). Percent composition of the particles on an element-by-element basis is shown in Figure 3. Results are shown for a lower resolution full image of particles deposited on collection media and a higher resolution subsection of the same image. The totals in both cases add up to more than 90%, indicating that the 7 elements listed above account for most of the material in the particles.

.

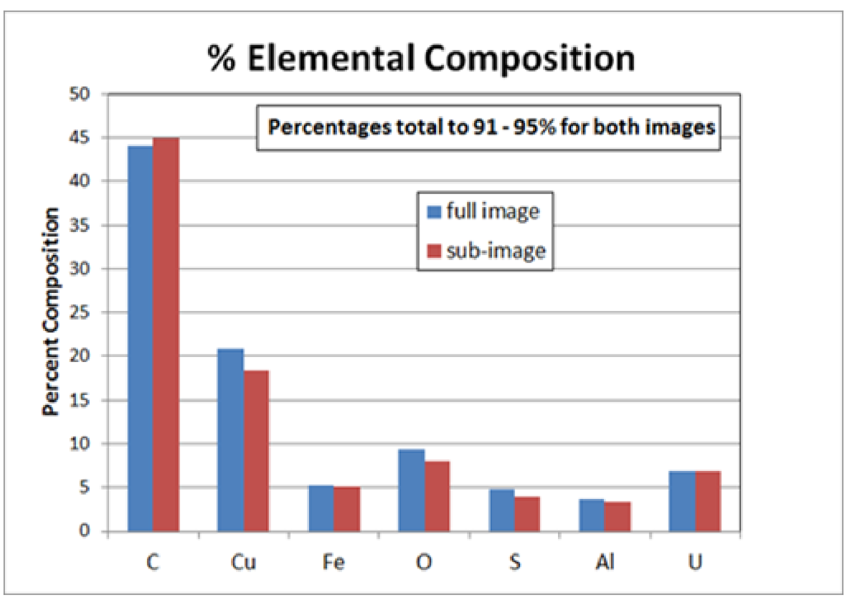

Figure 3: *Particle size distributions on an element by element basis.*

Commercially available software and a code written by SRNL were both used to count the particles in the images of the particles deposited on the collection media. Both codes produced particle size distributions similar to the one shown in Figure 4. The size distributions have sharp peaks at about 100 nanometers (nm) for uranium and carbon, and the other elements as well. This is a key result of this research, because all particles with diameters of about 100 nm have negligible gravitational settling velocities and because these particles also are not removed from the atmosphere efficiently by either Brownian motion (< 100 nm) or impaction (>100 nm)[1]. As a result, the particles created by HE tests of nuclear triggers appear to be largely in a size range that will travel far downwind before they are deposited.

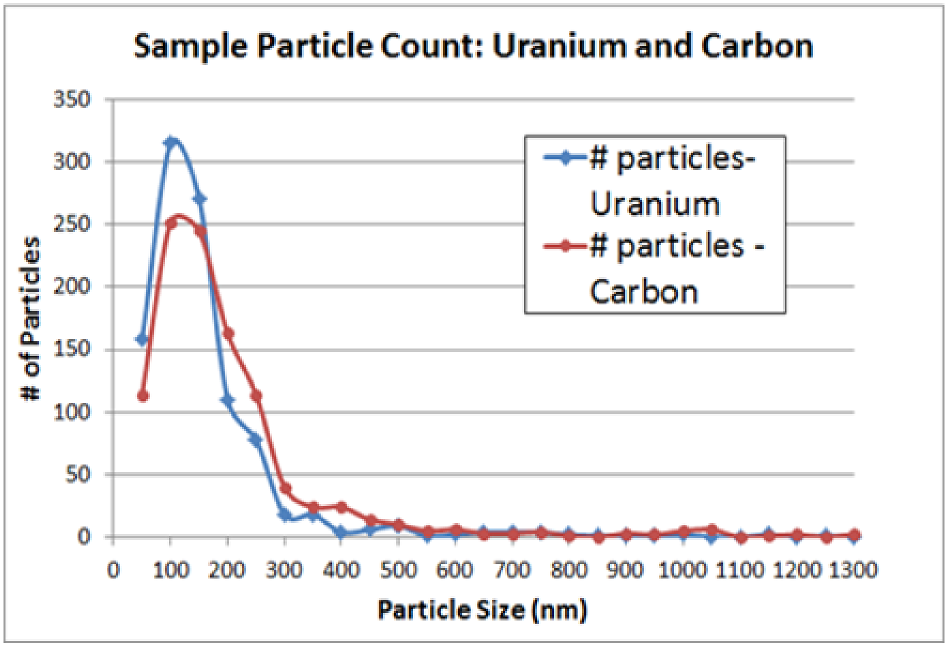

Figure 4: Size distributions of particles largely composed of uranium and carbon.

FY2015 Accomplishments

Particle size distributions as a function of elemental composition were derived from particle samples:

- Distributions were sharply peaked at about 100 nanometer diameters
- 100 nanometer uranium particles have negligible fall velocities and can potentially be transported long distances downwind from source.

Transport and deposition calculations verified that large percentages of 100 nm particles would remain airborne at distances of 25 km or more downwind:

- Slowest particle cloud depletion at night in stable conditions.
- Forested areas remove particle from atmosphere more rapidly than bare surfaces.

Figure 5 shows results of transport and deposition calculations for 100 nm uranium particles for 6 different atmospheric stability classes, ranging from most unstable (A) when strong solar heating is producing rapid turbulent mixing to most stable (F) characteristic of clear nights with minimal turbulence. In all cases, more than 40% of the particles were still airborne 25 km downwind from the source location. The deposition velocity used in the computations shown in

Figure 5 was 0.02 cm/sec, which is appropriate for a minimally vegetated surface, such as a desert[1, 2]. If the debris cloud is being transported over a forest, the deposition velocity will be higher, approximately 0.5 cm/sec (Ref. 2).

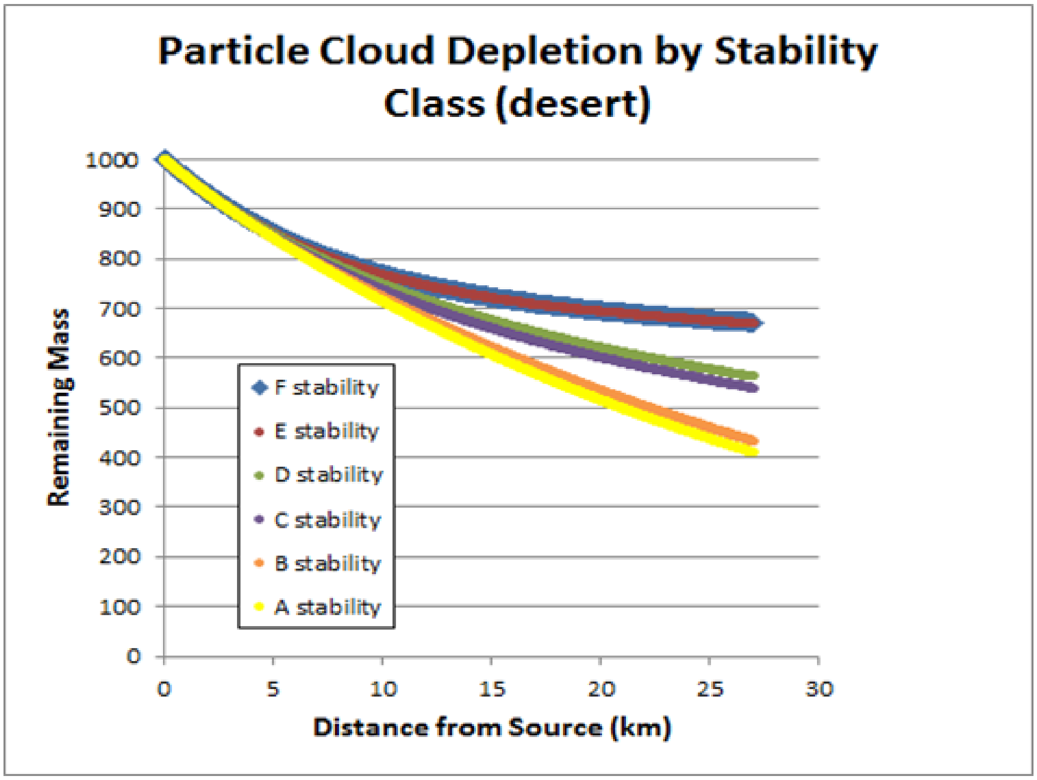

Figure 5: Computed removal rate of 100 nm uranium particles over desert (bare) surface.

Figure 6 shows the predicted deposition as a function of downwind distance for a debris cloud passing over a forest (deposition velocity = 0.5 cm/sec). The removal rates are much higher, because the probability of a particle impacting and sticking to the surface of a leaf or branch is much greater than the probability of impacting and sticking to bare ground. Figure 6 indicates that most particles would be scavenged from a debris cloud passing over a forest in unstable atmospheric conditions, but significant numbers of particles would remain airborne in more stable conditions.

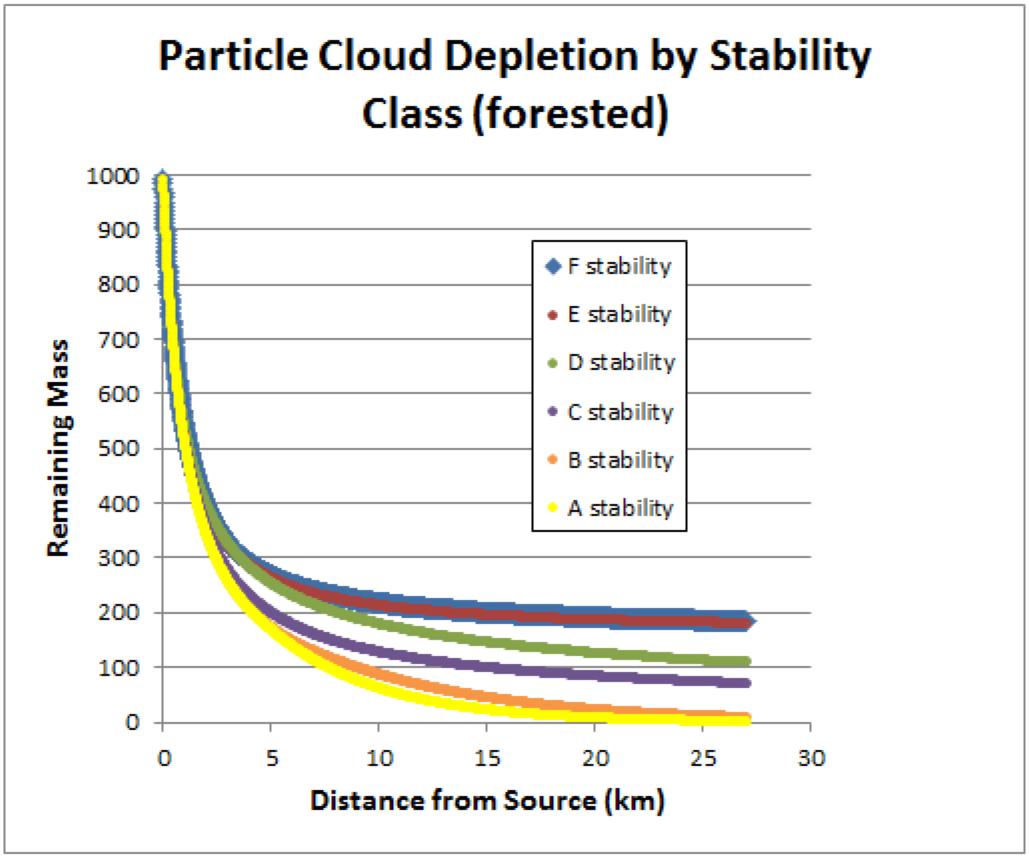

Figure 6: Computed removal rate of 100 nm uranium particles from debris cloud passing over forest.

Future Directions

- Challenge/Barrier 1: gain entry into DOE's HE test program
  - Currently only weapons labs
  - Use SRNL data collection technologies (debris cloud sampling with rockets; ACE particle collector)
- Challenge/Barrier 2: develop airborne systems with on-board real-time particle sample analysis
  - Better detection of small, irregular debris clouds that travel long distances before being depleted
- Challenge/Barrier 3: develop multi-element signature for HE weapons test debris particles

FY 2015 Publications/Presentations

1. SRNL anticipates presenting these results to DOE-HQ (NA-22) late in calendar 2015 or early in 2016.

References

1. Giorgi, F., 1988: "Dry deposition velocities of atmospheric aerosols as inferred by applying a particle dry deposition parameterization to a general circulation model", *Tellus*, 40B, 23-41.
2. Ould-Dada, Z., 2002: "Dry deposition profile of small particles within a model spruce canopy", *Science of the Total Environment*, 286, 83-96.

Acronyms
None.

Intellectual Property
None.

Total Number of Post-Doctoral Researchers
None.