Estimation of Ground-Level Radioisotope Distributions for Underground Nuclear Test Leakage

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Overview

During an On-Site Inspection (OSI), an Inspection Team will utilize a number of methods to narrow the search region for more detailed sample collection and analysis. An understanding of the type, amount, and dispersion of the possible radiological signatures on the surface of the site is important to guide development of and use of radiological search tools.

In this work, we review the available data on U.S. underground nuclear tests in order to develop a model for the ground-level radionuclide distribution that may be encountered during OSI.

DOE/NV-317 [1]

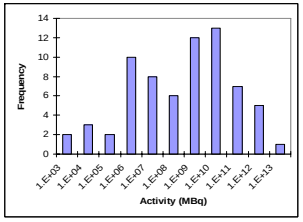
This report provides information on releases of radioactivity of U.S. tests from 1961-1992. Approximately 80 test releases (with isotopic information) that were non-operational or accidental were used in this study. Although DOE/NV-317 is a good starting point, measurement limitations at the time may not have provided a complete description, and therefore additional efforts to understand the radiological conditions on the ground may be required.

Top 15 aerosol radionuclides ranked by frequency of detection. Most frequently detected isotopes are fairly short lived, and the high specific activity may be a factor in the detection frequency. Highlighted radionuclides have life-times greater than 1 week and provide an initial radionuclide set for consideration.

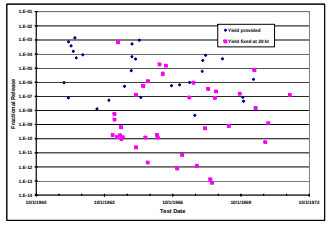
	Isotope	Frequency	T 1/2
1	I-133	63	20.3 hours
2	I-131	62	8.04 days
3	I-135	62	6.61 hours
4	Cs-138	27	32.2 minutes
5	Ba-140	19	12.8 days
6	Rb-88	15	17.8 minutes
7	Ru-103	14	39.4 days
8	Te-132	13	77.9 hours
9	I-132	11	143 minutes
10	Sr-91	8	9.7 hours
11	I-134	8	52.6 minutes
12	Zr-95	6	64.4 days
13	Ru-106	5	368 days
14	Ba-139	5	84.9 minutes
15	Ce-141	5	32.4 days

Released Activity in U.S. Underground Tests

DOE/NV-317 provides the activity data for each test in which an accidental or non-operational radioactivity release was observed. Of the tests in which leakage was observed, the total released activities were > 1GBq (normalized to 12 hours post-detonation) as shown below. Also, the fraction of total activity that was released varied by over 8 orders of magnitude, but was generally below 0.001%. Note that these fractions are for total fission products released; the fraction of volatile isotopes would be higher than indicated here. After the early 1970s, there were no non-operational releases, indicating maturation of containment design.



Estimated total activity at 12 hours post detonation for ~80 releases. Wide range due to variability in yield, burial depth, soil composition, and release time.

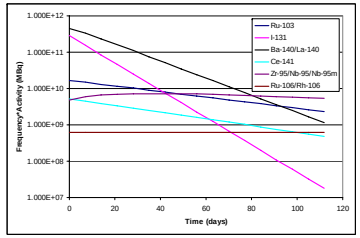


Fractional release assuming 10^{20} Bq per kiloton yield. Yields documented as '<20 kt' were fixed at 20 kt.

Likely OSI Radionuclide Signatures

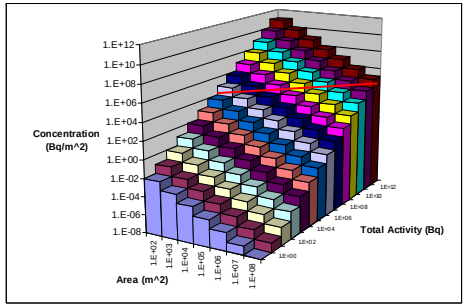
Of the top-15 list of detected radionuclides from DOE/NV-317, only six of these isotopes have a half-life sufficiently long to be relevant to OSI. Each of these decays at a different rate, resulting in a time-dependent make-up of the radionuclide signatures. In the figure below, we plot the product of activity (starting with a gram) of the six isotopes including daughter products and the fraction of releases in which each isotope was detected as a function of the number of days since the nuclear test occurred. Two daughters are ignored, ^{131m}Xe (since it is a gas) and ^{103m}Rh (due to the low-energy gamma-ray emissions).

This plotted metric provides an overall estimate of the likelihood of observing each nuclide as a function of time. For times less than 60 days, ^{131}I and ^{140}Ba will be prominent, with other isotopes becoming more optimal at later times.



Ground Concentrations

The total area of deposition will vary considerably depending on the local terrain and weather conditions; however, a range from 100 m^2 to 100 km^2 is a reasonable starting range for OSI applicability. Using the range of released activities tabulated in DOE/NV-317, we calculate possible concentration levels as in the figure below.



Concentration calculation assumptions: deposition ranges from 0.1% to 100% depending on local environment and weather conditions. Area of deposition assumed to range from 100 m^2 to 10^8 m^2 (100 km^2) for reasonable On-Site Inspection areas of interest.

Ground level concentration estimation as a function of the deposition area and total ground source activity. Red line signifies estimate of equivalent average soil activity. About 30% of the phase space in this estimation above the redline.

Assuming a standard soil emission of ~2 gamma rays per square centimeter per second, a rough estimate of the background would be 2×10^4 Bq/m^2, which corresponds to the level of the red line in the figure. Although detection can occur below the background level (especially with spectral analysis methods), the background level of activity provides a baseline that can be useful for comparing different detection capabilities. The background level of activity is achieved at the smallest area of 100 m^2 when there is a ground activity of 10^6 Bq, which can equal the actual release if the deposition is 100%, or would require a release of 10^9 Bq if the deposition is 0.1%.

[1] C.R. Schoengold, M.E. DeMarre, E.M. Kirkwood, "Radiological Effluents Released from US Continental Tests 1962 Through 1992," DOE/NV-317, (1996).

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