Technical Capability Standard for Aerial Mounted Radiation Detection Systems

Domestic Nuclear Detection Office

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Homeland Security

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1 Overview

1.1 Introduction

A Technical Capability Standard (TCS) is a government-unique standard that establishes targeted performance requirements for radiation detection and non-intrusive imaging systems. The purpose of the TCS is to establish, where practical, requirements and applicable test methods that are based on threat-informed unclassified source materials and test configurations that are not addressed in consensus standards. Threat-informed source materials and configurations are based on a realistic threat interpretation as agreed to by the Technical Capability Standard Working Group (TCSWG). In support of this effort, unclassified detection capability benchmarks were established that do not compromise nuclear weapon design information. TCSs are developed by an inter-agency TCSWG. Membership of the TCSWG includes representatives from the Department of Homeland Security Domestic Nuclear Detection Office (DNDO), National Institute of Standards and Technology (NIST), Customs and Border Protection (CBP), the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), the Federal Bureau of Investigation (FBI), the Office of the Assistant Secretary of Defense for Homeland Defense and Americas' Security Affairs (ASD/HD&ASA), the Defense Threat Reduction Agency (DTRA), and several national laboratories (Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Savannah River National Laboratory (SRNL), Sandia National Laboratories (SNL), and Pacific Northwest National Laboratory (PNNL)).

It is anticipated that after a TCS is developed, DNDO will work within the consensus standards arena to ensure that future American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) N42 series consensus standards reflect the capabilities described by the TCS benchmarks, where applicable.

1.2 Background of Aerial Detection

Aerial radiological detection plays an important role in the Preventative Radiological Nuclear Detection (PRND) mission. As an initial response, aerial search is a rapid method for surveying large areas to locate possible radiological sources prior to deployment of ground-based assets. Aerial radiological surveys have been conducted since the 1960's, when they were originally used to monitor nuclear testing activities. Since then, they have been expanded to include planned surveys such as over nuclear power plants, area monitoring, national security support for radiological baseline mapping for special events, and national security emergency response activities [1, 2].

1.3 Scope of Aerial TCS

This TCS (Document#: 500-DNDO-119430v0.00) addresses the mandate in the Security and Accountability For Every (SAFE) Port Act (H.R. 4954-16, Subtitle C – Port Operations, Section 121 (f) Standards) [3] that states: "The Secretary, acting through the Director for Domestic

Nuclear Detection and in collaboration with the National Institute of Standards and Technology, shall publish technical capability standards and recommended standard operating procedures for the use of nonintrusive imaging and radiation detection equipment in the United States. Such standards and procedures:

1. Should take into account relevant standards and procedures utilized by other federal departments or agencies as well as those developed by international bodies; and

2. Shall not be designed so as to endorse specific companies or create sovereignty conflicts with participating countries."

The Aerial TCS standard involves testing of aerial detection and identification capabilities for gamma-emitting radioactive material against the PRND mission. This TCS does not address the detection of neutrons. Other aerial detection applications and missions such as radiological mapping (mapping of an area of radiological contamination) or routine monitoring surveys of nuclear power plants, are not included as a requirement. However, it should be noted that radiological mapping may augment a search response and aid in more accurately identifying the location of a detected radiological hotspot. A discussion of mapping best practices is included in Appendix B. For flight test requirements, the Aerial TCS assumes a helicopter platform. A tiered approach is used, with lowest tier requirements based on a system of typical size and detection capability, assumed here to be a NaI(Tl)-based system with four 4×4×16 inch detectors. Additional detection and identification tests are included for higher tier responses, which may be met by larger detector systems. As an alternate to radiological flight testing, a ground-based method for testing to these requirements is also outlined in the TCS.

1.4 Purpose

The purpose of this TCS is to establish Radiological/Nuclear detection performance requirements for aerial systems for threat-informed sources as outlined in the DNDO threat traceability memo [7]. The TCS does not address Federal Aviation Administration (FAA) requirements which are necessary for a detector system to be flown in or on a helicopter platform. However, this TCS does include select environmental and mechanical requirements which may affect the performance of the radiation detector systems while flying; including radio frequency interference (RFI), vibration, and temperature. As a secondary result, measurements may provide the level of data quality needed to produce high quality validated models to predict the performance of an aerial system.

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3 Definitions and Abbreviations

3.1 Definitions

Aerial detector system: Detection system that is mounted in or on an aircraft and is FAA-certified to operate while the aircraft is in flight.

Alarm: An audible, visual, or other signal activated when the instrument reading or response exceeds a preset value or falls outside a preset range.

Coverage factor: Numerical factor (*k*) used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

Exposure Rate: A measure of ionization produced in air by X- or gamma-ray radiation. The special unit of exposure rate is the Roentgen per hour, abbreviated in this standard as R/h.

False negative: A lack of indication by the instrument of a radioactive source that is present or a radionuclide identification not reported by the instrument when a radioactive source is present.

False positive: An indication by the instrument that a radioactive source is present when the source is not present, or a radionuclide identification reported by the instrument when the identified source is not present.

Field of View: The approximately circular area underneath the airborne (gamma) radiation detector system corresponding to which a given percent of detected source gammas originate. Typically, this is taken to be a circular area with radius equal to the altitude above ground level (AGL), corresponding to approximately 70% of detected gammas.

Fluence: The *fluence*, Φ, is the quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da. The unit of fluence is m^{-2}. (ICRU Report 60 [4])

Fluence rate: The *fluence rate*, $\dot{\Phi}$, is the quotient of dΦ by dt, where dΦ is the increment of the fluence in the time interval dt, thus $\dot{\Phi} = \frac{d\Phi}{dt}$. The unit of fluence rate is $m^{-2}s^{-1}$. (ICRU Report 60 [4])

GPS: Global Positioning System; the space-based satellite system which provides position and time information.

Instrument: A complete system consisting of one or more assemblies designed to measure and/or quantify one or more characteristics of ionizing radiation or radioactive material.

Radioactive source: Man-made radioactive material, or radioactive material other than that of the natural environment.

Radiation background: Radiation produced by natural sources, cosmic or terrestrial. Here, the radiation background refers to the gamma background, primarily from the natural Uranium (U), Thorium (Th) and Potassium (K) terrestrial decay chains.

Special nuclear material (SNM): The term "special nuclear material" means plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, but does not include uranium, thorium, or any other material that is determined by the Nuclear Regulatory

Commission (NRC) pursuant to the provisions of Section 61 of the Atomic Energy Act of 1954, as amended, to be source material.

Standard test conditions: The range of values of a set of influence quantities under which a calibration or a measurement of response is carried out.

3.2 Abbreviations and Acronyms

AGL	Above Ground Level
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CBP	Customs and Border Protection
DHS	Department of Homeland Security
DNDO	Domestic Nuclear Detection Office
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
FBI	Federal Bureau of Investigation
GM	Geiger Müller
HEU	Highly Enriched Uranium
HPGe	High Purity Germanium
ICRU	International Commission on Radiation Units and Measurement
IEEE	Institute of Electrical and Electronics Engineers
LANL	Los Alamos National Laboratory
MCNP	Monte Carlo N-Particle
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Material
NRC	Nuclear Regulatory Commission
NUSTL	National Urban Security Technology Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PRND	Preventative Radiological Nuclear Detection
SI	International System of Units
SNL	Sandia National Laboratories
SNM	Special Nuclear Material

SRNL	Savannah River National Laboratory
TCS	Technical Capability Standard
TCSWG	Technical Capability Standard Working Group
WGPu	Weapons Grade Plutonium

4 General Considerations

4.1 Test Conditions

The tests in this standard shall be carried out in a location with average ground level ambient gamma radiation levels of ≤ 20 μR/h and ambient neutron radiation levels of ≤ 600 n/s/m^2. The meteorological conditions including ambient temperature, relative humidity and atmospheric pressure will be recorded during testing.

4.2 Uncertainties and Units

4.2.1 Uncertainties

The uncertainties for radiation field measurements shall be documented. The uncertainties in detector readings (e.g., exposure rate detector) should not exceed 10%.

4.2.2 Units

This standard uses the International System of Units (SI). Multiples and submultiples of SI units will be used, when practical, according to the SI system.

This standard also uses the following non-SI units:

- Energy: kilo-electron-volt (symbol: keV), 1 keV = 1.602 $\times 10^{-16}$ J, and mega-electron-volt (symbol: MeV), 1 MeV = 1.602 $\times 10^{-13}$ J.
- Exposure: Roentgen (symbol: R), 1 R = 2.58$\times 10^{-4}$ Coulomb per kilogram (symbol: C/kg).
- Exposure rate: Roentgen per hour (symbol: R/h), 1 R/h = 2.58$\times 10^{-4}$ C/kg/h.
- Dose rate: milli-Roentgen equivalent man (symbol: mrem), 1 mrem = 10 μSv.
- Distance: feet (symbol: ft), 1 ft = 0.3048 m.

4.2.3 Special Word Usage

The following word usage applies:

- The word "shall" signifies a mandatory requirement (where appropriate a qualifying statement is included to indicate that there may be an allowable exception).
- The word "should" signifies a recommended specification or method.

- The word “may” signifies an acceptable method or an example of good practice.

5 General Characteristics

5.1 General

In this TCS, aerial detector systems are required to:

- detect gamma sources as defined in this TCS,
- record relevant data including but not limited to gamma spectral data, gamma total count rates, real and live time, and global positioning system (GPS) location data and altitude data for each sample point,
- have a method to determine altitude above ground level,
- provide an identification of the test sources for detector systems with radionuclide identification capabilities, and
- alert the user (audibly and visually) when a radiation level is measured that is greater than a defined set point.

It should be noted that altitude determination using a radar altimeter is preferred to GPS Height Above Ellipsoid (HAE) altitude which must be corrected for to provide the height above ground level. Accurate real-time altitude determination is important especially in urban areas or locations where the altitude is constantly changing.

Aerial detector systems may have mapping capabilities to provide the user with a map of radiation measurement results. Some aerial detector systems may also have neutron detection capability. However, verification tests of the mapping capability and tests of neutron detection are not addressed in this TCS.

5.2 Detector System Test Requirements

The detector system shall use settings supplied by the manufacturer. All system parameters and settings shall be the same during both laboratory and flight tests, and for the duration of the testing. The manufacturer-supplied settings and parameters shall include the background mode for each alarm type, whether static or dynamic, and alarm threshold determination.

5.3 Scoring and Measurement Requirements

5.3.1 Test Replication

All tests shall consist of 20 trials, unless otherwise specified. For flight testing, each trial will consist of flying a straight line, centered over the source. The length of the flight line will be determined by the source strength and resulting field of view of the detector. Section 5.8 lists the acceptable ranges for the test parameters of speed, altitude and offset from the source.

5.3.2 Compliance with the Requirement

Test results are in compliance with a requirement when a detection or correct identification of the sources and configurations listed in Table 1 occurs in 18 out of 20 trials in the radiological detection and identification tests outlined in Section 6, unless otherwise specified.

5.3.3 Test Scoring

For detection tests, the response is considered correct when the system alarms above a manufacturer-specified threshold within a two second window from closest approach of the aircraft to the source.

For identification tests, the results are characterized based on the DNDO scoring criteria [5]; appropriate system response depends on the type of target source measured. The response is correct when the instrument identifies the target source. The reporting of additional radionuclides and background radionuclides by the system is sometimes allowed. Radionuclide identification tests shall be scored using Categories C3 and C4 from the DNDO technical scoring criteria (see Appendix A).

5.4 Test Reporting

All alarms and radionuclides identified by the system shall be recorded. All spectra from dwell measurements acquired from a test shall be saved and associated with the system response displayed for that test. The detector time-stamped spectral data for each sample, with GPS (and altimeter data if available) will be recorded.

5.5 Test Location Considerations

5.5.1 Required Infrastructure for Flight Testing

The test location should have the ability to conduct flight operations on site. The test location should also have availability of one or more helicopter aircraft suitable for mounting detector systems. Detectors may be mounted inside the aircraft or outside in pods attached to the aircraft. Mounting the detectors outside the aircraft will eliminate the variable attenuation effects of fuel which may be a factor inside the aircraft, and reduce attenuation due to the aircraft body. The location should have the necessary infrastructure for the flight or alternate ground-based testing, and have adequate personnel support for the testing.

The location, geographic area, and logistics should also allow for easy movement of the test assets to the test location.

5.5.2 Physical Requirements

The test location should include adequate open spaces for the flight tests, on the order of miles. The location should have an area (preferably square) of sufficient length to allow detection system levels to start at and return to those of ambient background, for flight tests defined in Section 6 over the test source objects defined in Table 1. The flight test area within the field of view should be free of any interfering radiological sources other than natural background radiation. The location should also include sufficient area for a pre-flight background flight line described in Section 6.2.3. An ideal location should also include an area of level terrain without any known anomalies in background radiation due to contamination or natural variation in the substrate.

To ensure that the test area meets requirements, and to map the radiological background, a pre-flight survey should be conducted. It should be noted that background conditions can vary greatly over the course of a flight. For example a simple rain, which would not impede aircraft operations, will significantly affect the background levels and spectral features. As a result, additional background measurements may be needed prior to testing and after testing without the source being present.

5.5.3 Radiological Support

The test location should have access to the required radiological sources for testing defined in Section 5.7. The test location should allow adequate storage facilities to secure radiological and SNM sources after testing, and have adequate radiological support on site. The location should also include the necessary detection equipment as specified in Section 5.6.

5.6 Test Equipment

Instrumentation shall be available to monitor the environmental conditions as well as the ambient gamma and neutron background levels. For gamma measurements, a High Purity Germanium (HPGe) detector calibrated for efficiency and energy shall be available for ground-based spectral measurements. When tests are performed, the gamma-ray background intensity shall be measured using a pressurized ion chamber or similar environmental radiation measurement device that is calibrated to provide gamma-ray exposure rate. Although neutron detection is not addressed in this TCS, the ground-based background neutron count rate should be monitored with a neutron detector to ensure that no neutron sources are present during the test period. The calibration of all monitoring instrumentation, including those devices used to monitor meteorological conditions, shall be traceable to NIST or another similarly recognized organization. The calibration data from the HPGe and background gamma detector shall be saved with the test data.

The HPGe detector shall be used to obtain the ground truth spectrum for each test source. For the industrial sources, the HPGe spectra will be recorded with the sources in a shielded configuration only. Additionally, the HPGe will measure and characterize the radiation background at the test location. The HPGe detector should be calibrated according to ANSI/IEEE N42.14 [6]. Sources used to calibrate the HPGe detector shall be traceable to NIST or other recognized organization and cover an energy range of 40 keV to 2.6 MeV.

The gamma detector (an ionization chamber or energy-compensated Geiger-Müller (GM) detector) shall be used to record a measurement of the ambient exposure rate at the location where the sources will be placed to monitor for changes in radiation level while tests are being performed. The energy response of the gamma detector from 20 keV to 3 MeV shall be known and shall display photon energies up to 4 MeV. The gamma detector will also be used to measure and record the exposure rate of shielded industrial sources at 1 meter.

The neutron detector shall be used during test setup (i.e., at the start of the test) to measure and record the neutron background at the location where the gamma sources will be placed. The detector shall have the ability to integrate over an operator-selectable time interval to obtain a more reasonable measurement of the neutron background fluence rate.

5.7 Aerial TCS Test Source Configurations

All radioactive test source configurations for flight tests and tests performed for each source category are shown in Table 1. For alternate ground-based tests described in Section 7, scaled source strengths based on scaled distances are given in Table 4.

Table 1. Source Test Configurations for Flight Radiological Tests

Source	Dose Rate at 1 meter (mrem/hr)	Fluence Rate at 1 meter (Photons/s/cm^2)	Detection (Bare)	Detection (Shielded Shipping Container)	Identification (Bare)	Identification (Shielded Shipping Container)
^{137}Cs	1	1.08×10^3		X		X
^{60}Co	1	6.78×10^2		X		X
^{192}Ir	1	1.14×10^3		X		X
^{90}Sr	1	6.99×10^2		X		N/A
WGPu	N/A	2.09×10^2	X		X	
HEU	N/A	3.19×10^2	X		X	

Notes: Measured at 1 m from shipping container surface to the reference point of the detector.

5.7.1 Industrial Sources

The industrial sources used for the test here shall be tested in the shipping containers (shielded containers designed for shipping the sources). The shipping containers shall meet the dose rate limit requirements corresponding to the boundary between Yellow II and Yellow III Department of Transportation (DOT) shipping limits, or 1 mrem/hr at 1m from the surface of the shipping container, with an acceptable range of 0.8 mrem/hr to 1 mrem/hr. Shipping limits are shown below in Table 2. The shipping containers shall be appropriate for the test sources with strengths shown below in Table 3 using the activity ranges corresponding to the Aerial TCS Threat Traceability Memo [7]. These ranges were selected based on International Atomic Energy Agency (IAEA) Safety Guide Categories 2 and 3 [8]. A single activity shall be chosen in this range based on source availability. If necessary, additional shielding configurations may be used to produce a dose rate of 1 mrem/hr at 1 m from the center of the shield. If used, the type and amount of shielding used should be recorded. Photon fluence rates are also shown in Table 1 and assume a lead shield for simplicity; they are calculated for the dose rate of 1 mrem/hr using Monte-Carlo N-Particle (MCNP) simulations and a 40 keV low energy cut-off. The fluence rate for ^{90}Sr assumes equilibrium with ^{90}Y and uses beta spectra obtained from the NRC's Radiological Toolbox [10]. Fluence rate values do not include background.

Note: Due to possible spatial variations in the radiation field from a shielded industrial source, all dose or exposure rate measurements will be taken at 1 meter from the center of the source can. The industrial source will be also be placed in the same orientation with respect to the detector for flight and ground testing. The source can will be oriented vertically for ground testing and horizontally for flight testing respectively, with the center of the source can aligned with the center of the broad area of the detector facing the source.

Table 2. Shipping Labels for Radioactive Materials

Label	Maximum radiation level at any point on the external surface (MRL)		Radiation Level at 1 m or Transportation Index (TI)
White I	MRL ≤ 0.005 mSv/h (0.5 mrem/h)		0 mSv/h (0 mrem/h)
Yellow II	0.005 mSv/h (0.5 mrem/h) < MRL ≤ 0.5 mSv/h (50 mrem/h)	AND	0mSv/h (0 mrem/h) < TI < 0.01 mSv/h (1 mrem/h)
Yellow III	0.5 mSv/h (50 mrem/h) < MRL ≤ 2 mSv/h (200 mrem/h)	OR	0.01 mSv/h (1 mrem/h) < TI < 0.1 mSv/h (10 mrem/h)
Yellow III (Must be shipped under exclusive use provisions; see 49 CFR part 173.441(b))	2 mSv/h (200 mrem/h) < MRL ≤ 10 mSv/h (1,000 mrem/h)	OR	< 0.1 mSv/h (10 mrem/h)

Table 3. Shielded Industrial Sources

Radionuclide	Activity range*	Relevant Gamma-ray Line(s)
^{60}Co	0.8 – 8 Ci	1173 keV, 1332 keV
^{137}Cs	3 – 30 Ci	662 keV
^{192}Ir	2 – 20 Ci	612 keV, 885 keV
^{90}Sr	30 – 300 Ci	Beta emitter

* These values were provided by the NRC

5.7.2 SNM Sources

The SNM sources to be tested are equivalent to 400 g of weapons grade plutonium (WGPu) and 25 kg of highly enriched uranium (HEU), as detailed in the Threat Traceability Memo [7]. Detection requirements are for the WGPu source only. Sources with different masses, shapes, and forms may be used for testing; however the emitted source fluence will depend on the geometry used due to differences in self-attenuation. The SNM sources will be tested in a bare configuration; there are no masking requirements for SNM for the Aerial TCS, as explained in the Aerial Threat Traceability Memo.

The amount of ^{241}Am present varies widely for different WGPu sources. There is a need to limit the amount of low-energy gamma-ray emissions from ^{241}Am to ensure that test results are comparable when tests are performed using different WGPu sources. Copper (Cu), as listed in the American Society for Testing and Materials (ASTM) B152 [15] with more than 99.9 % Cu content, may be used as a shielding material to reduce these low-energy emissions. In order to provide comparable results, the net count rate of the 60 keV line from ^{241}Am shall be no more than 10 times greater than that of the net count rate of the 375 keV line for ^{239}Pu (e.g., if the count rate for the 375 keV line for ^{239}Pu is 100 cps, then the count rate for the 60 keV line for ^{241}Am shall not exceed 1,000 cps). Scaling of the total fluence as well as the ^{241}Am 60 keV energy line and key WGPu lines such as the 414 keV line will be considered in the use of a shield.

The fluence rates are calculated using the total energy spectrum from 40 keV to 3 MeV. It is recommended to use the dose rate value for the industrial sources.

5.8 Aerial TCS Flight Test Parameters

The following parameters pertain to the flight test; as mentioned, an alternate ground-based testing is also possible (see Section 7). The altitude for testing against the SNM sources and industrial sources shall be at 100 feet above ground level (AGL) ± 20% at a nominal minimum test speed of 70 knots ± 10%, and with zero offset ± 25 feet for each pass over the source.

NOTE – Only one specific altitude, speed, and offset were chosen based on the goal to test performance of the detector systems rather than characterize their response to gamma radiation as a function of altitude, offset (lateral distance of the source from the detector), and source energy.

Some test parameters, such as altitude AGL, may not be recorded real time or may be manually recorded. A radar altimeter or GPS unit onboard the aircraft is suggested for the tests to provide an accurate real-time measurement and recording of position information. If possible, the altimeter should be integrated with the detector system for flight tests.

6 Aerial TCS Radiological Tests

Testing (radiological detection and identification) may be performed using flights or on the ground through the use of a moving source as described in Section 7. All tests will be conducted with manufacturer-provided recommended settings. If flight testing is used, the flight test shall be conducted using a helicopter aircraft platform with flight parameters given in Section 5.8. If multiple sources are flown on one path, they will be separated by no less than one-half of a mile (2280 feet). In either case, the overload and state-of-health tests as well as environmental tests shall be ground-based. In addition, the Background Effects test (Section 6.8) may be performed as a ground-based test if a natural background step, as described in that section, is not available in the flight area.

6.1 Testing Order

The first test to be conducted (for flight or ground based test methods) shall be the false alarm measurement. Prior to the flight tests, a pre-flight background survey should be conducted to characterize the background of the flight test area. At the start and end of each day of flight testing calibration checks shall be performed and a background line will be flown to allow the setting of alarm levels; these daily checks and procedures are outlined in the remainder of this section.

The following shows the order of TCS tests for flight tests:

- Pre-Flight Background Survey
- Stability/False Alarm Test (ground-based, laboratory)
- Overload Test (ground-based, laboratory)
- Environmental Tests (ground-based, performed prior to radiological flight tests)
- Radiological Tests (flight-based, detection and identification)
- Background Step Test (flight-based if location allows)

6.2 Aerial TCS Test Procedures

6.2.1 Ground Truth Measurements

At the start and end of each day of flight testing, measurements of the ambient ground-based background and of the radiological sources will be made with the ground truth equipment. The background exposure rate (mean and standard deviation) will be measured with the gamma detector for 5 minutes at the location where the sources will be placed. A 5-minute background spectrum will additionally be measured, at the same locations where the exposure rates are measured, with the HPGe detector to verify that test or other sources are not detected or identified by the detector systems.

Ground measurements of exposure rate and spectra using the gamma and HPGe detectors will also be made of the shielded industrial sources and SNM sources to be used for testing. These measurements will be made for 1 minute, at a distance of 1 meter from the center of the shield. This is done as a quality check, to verify source spectra and strengths, and to verify quoted manufacturer exposure rates for industrial sources outside the shield.

The ambient meteorological conditions (temperature, relative humidity, and atmospheric pressure) will also be recorded. The meteorological conditions will be recorded at the beginning and end of each testing cycle and also at a point of time in between when the condition, such as temperature, would be at its peak (or minimum). If possible, the flight crew or operators will record the ambient temperature at altitude.

6.2.2 Detector Operational checks

At the start and end of each flight, or upon take-off and landing, the detector energy calibration will be checked, and background and source measurements will be made. These checks will be performed on the ground, with the detector system mounted in or on the helicopter as it will be flown for the flight test. The calibration and source checks will be made for approximately 1 minute, to verify that the respective count rates for background and the source indicate that the system is functioning properly. Source measurements will be made with check source/sources available at the test location. Measurements will be made with the same check source/sources at a set distance from the detector. The sources should also be at the same orientation with respect to the detector, centered at a perpendicular distance from the broad area of the detector.

6.2.3 Background Flight

At the start and end of each flight test, a flight will be performed over a designated background run at the test altitude. This background flight will allow detection systems to record background and set alarm levels, if needed, prior to the start of the flight test. This background flight also allows a measure of daily relative changes in background, such as from radon levels. It is assumed that the background flight path will be in close proximity to the test flight path, so that it may be flown directly before the test. Also, it will be of a length to allow approximately 5 minutes of flight background at the nominal test flight speed.

6.2.4 Data Recording

Data will be downloaded from each detector system at the end of each flight.

6.2.5 Go/No Go Criteria

Flight testing will not be conducted if weather or aircraft conditions are deemed unsafe for flight. The aviation personnel have ultimate authority for flight go/no go decisions.

6.3 Pre-flight Survey

A single pre-flight background survey of the flight area should be conducted prior to the start of the flight tests. This survey characterizes the flight test background and ensures that there are no interfering sources of radiation. The survey should be conducted at the altitude of flight tests given in Section 5.8 (100 feet). The survey should be conducted with an aerial detection system that is representative of a typical or average aerial detection system such as a NaI (Tl)-based system with four 4×4×16 inch detectors. The survey should include as a minimum an area of the required size for flight tests as described in Section 5.5.2. The flight pattern should be parallel lines of a maximum of 100 ft spacing, covering the desired flight test area as shown in Figure 1.

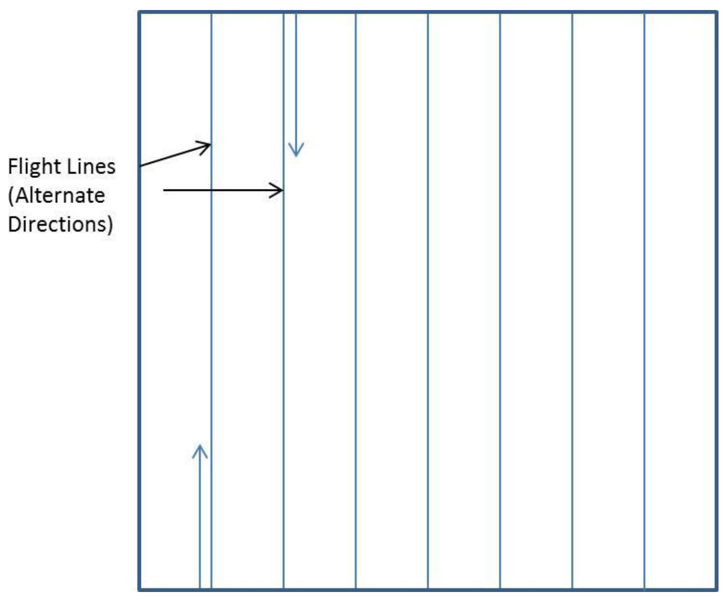

Figure 1. Schematic of flight background survey

6.4 Stability/False Alarm Test

6.4.1 Requirement

The purpose of this test is to ensure that the detector system is functional prior to radiological and environmental tests. When tested in an area with a stable background (only natural statistical fluctuations) at the levels stated in Section 4.1, the alarm rate for gamma detection and radionuclide identification when applicable, shall be no more than 1 alarm over a period of 1 hr.

6.4.2 Test method

Observe the detector system over a period of 10 hr in an area that has a controlled background (i.e., no radioactive sources present in the testing area during the duration of the test). Record the number of gamma alarms, and identifications (if radionuclide identification capabilities are available) observed over the 10-hr test period. The results are acceptable if there are no more than 10 alarms or identifications over the test interval. If an alarm is accompanied by an ID of NORM (naturally occurring radioactive material), the alarm is not counted as a false alarm.

NOTE: This test method corresponds to a false alarm rate of 1.7 alarms/hr at a 95% one-sided upper confidence bound.

6.5 Overload test

6.5.1 Requirement

An over-range indication (e.g., "over-range," "high counts") shall be activated when the detector system is exposed to a radiation field that is greater than the manufacturer-stated maximum exposure rate. If the alarm is reset or acknowledged by the user without the radiation field being reduced, a visual indication shall be provided indicating that the radiation field is still present and that the detector is not fully operational.

The time required to return to non-alarm condition after the radiation field is returned to background levels without any user interaction (other than acknowledging an audible alarm) levels shall not be greater than 1 minute. If the maximum rate is not provided, testing is not possible.

6.5.2 Test method

1. Set up the detector system per manufacturer settings for flight operation.
2. When the detector is operational, move a ^{137}Cs source adjacent to the detection assembly at a distance needed to produce a radiation field that is 50% greater than the manufacturer's stated value at the surface of the detection assembly and hold the position

for a period of 1 minute. The system shall alarm and remain in alarm until the exposure rate is reduced to the pre-test level.

3. Before reducing the radiation field back to background, acknowledge or reset the audible alarm to verify that the visual indication remains activated.
4. Remove the radiation source and measure the time required for the detector to indicate the pre-test radiation level.
5. Repeat steps 2 through 4 two additional times for a total of three trials.

The results are considered acceptable when the detector alarms as required during exposure to the over-range ^{137}Cs source and recovers within 1 min after the source is removed in each of the three successive trials.

6.6 Single Radionuclide (Gamma) Detection

6.6.1 Requirement

Detection systems will be tested against all source configurations given in Table 1 for the flight parameters given in Section 5.8. Results for HEU will be analyzed for characterization only and not count as a requirement. This test will be a single radionuclide test; no other combinations of sources such as masking configurations are considered at this time. An acceptable response is detection in 18 out of 20 trials. Record the time that it takes the system to alarm from the point of closest approach from the aircraft to the source. Accurate evaluation of this time window will require synchronizing the detector data and time-stamp with the time stamp from position data, from the radar altimeter data, or GPS system.

Note that times larger than 2 seconds will decrease the confidence level of the alarm, assuming a 1 second integration time.

6.6.2 Test Method

1. Fly over background/calibration line at the start of the day to set thresholds.
2. Fly in a straight line over each source for a total of 20 trials or passes over the source, within flight parameters (see Figure 2). Real-time monitoring and recording of the aircraft altitude and position for each pass above the source will be conducted as practical during the flight by flight crew.
3. Record real-time alarms and identifications.
4. Repeat steps 2 and 3 for a total of 20 trials. Repeat runs if needed (steps 2 and 3) to ensure 20 passes within flight parameters as feasible based on real-time monitoring.
5. Record time-stamped detector spectral data with embedded GPS and altimeter if available for each pass.

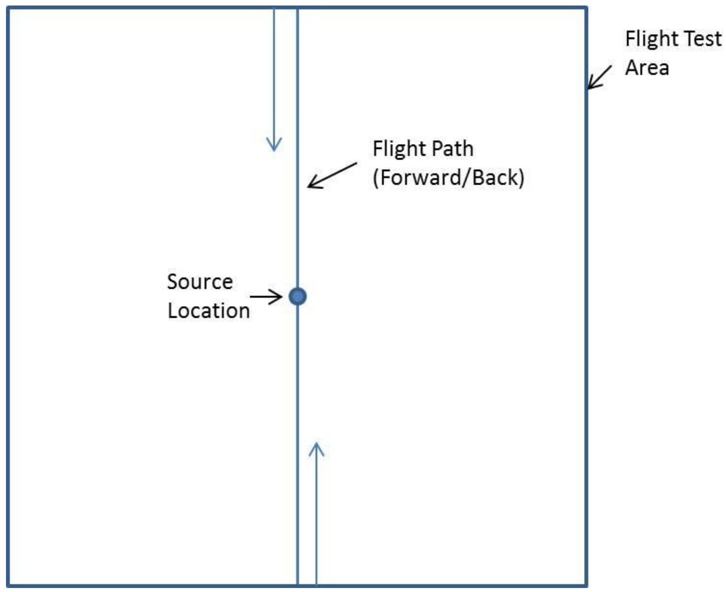

Figure 2. Schematic of flight paths as a straight line centered over the source for detection and identification flight tests

6.7 Single Radionuclide (Gamma) Identification

6.7.1 Requirement

Only systems with identification capability will be tested. Analysis of test results will be conducted using the DNDO scoring criteria given in the DNDO Scoring Guide [5] and used for characterization purposes only, as discussed in Section 5.3.3. The scoring criteria C3 and C4 are listed in Appendix A.

6.7.2 Test Method

1. Fly over background/calibration line at the start of the day to set thresholds.
2. Fly in a straight line over each source for a total of 20 trials or passes over the source, within flight parameters. Real-time monitoring and recording of the aircraft altitude and position for each pass above the source will be conducted as practical during the flight by flight crew.
3. Record real-time alarms and identifications.
4. Repeat steps 2 and 3 for a total of 20 trials. Repeat runs if needed (steps 2 and 3) to ensure 20 passes within flight parameters as feasible based on real-time monitoring.
5. Record time-stamped detector spectral data with embedded GPS and altimeter if available for each pass.

6.8 Background Effects

Aerial detection involves a challenge of gradually to rapidly changing background levels due to changes in land composition, altitude changes, or naturally occurring radioactive material (NORM) sources. While sharp background steps may induce alarms, it is expected that the aerial detector system shall function normally when exposed to changing background situations that may be encountered during normal use. As a test of this, the system will perform normally when exposed to a gradual step change in background radiation level similar to the test included the ANSI 42.43 Mobile Standard [9]. Figure 3 and Figure 4, taken from this standard, provide a graphic representation of the ideal test process. The test will include exposure to an artificially induced or real step change in background, both with and without a source present. The test will involve either a flight test with the test parameters specified in Section 5.8, or a ground-based test with speed and distance scaled as $\frac{v1}{d1} = \frac{v2}{d2}$ (Eq.1).

6.8.1 Requirement

The system will respond normally to a flight over an artificially induced or real step change in background radiation level with no source present. The test will involve a step decrease in background and a step increase back to ambient background levels along a straight line flight path, (i.e., the detector system moving from the area of increased background to normal background, and from the normal background to the increased background). A successful response will be no alarms out of three trials in both directions. The system will also detect the ^{137}Cs source listed in Table 1 in three out of three trials for each step change, when the source is placed at the center of the background step as shown in Figure 3 and Figure 4.

6.8.2 Test Method

The response of the aerial detector system will be tested against a step change in the background level of a factor of 3 from the average ambient background at the test location. The test will be conducted for both a step increase and a step decrease as described above. The background rise (or fall) time should be 15 seconds from normal to elevated (or elevated to normal). For the test, the source will be placed in the center of the detection zone. The detection zone corresponds to the distances the detection system travels in the 15-second background rise time interval at the nominal test speed of 70 knots, or the corresponding distance traversed in 15 seconds if ground-based testing is conducted.

Ideally this test will be conducted as a flight test if a naturally occurring background step, such as from a land-water interface, is present at the flight test location. Achieving the required background elevation using an artificially induced background step from NORM sources such as ^{226}Ra, ^{232}Th, or granite blocks is not feasible for a flight test due to the large distances of increased background required (at a speed of 70 knots, the distance travelled in one second is approximately 118 feet). Therefore, the flight test shall utilize a naturally occurring background step, to be identified in the pre-test survey, with an elevation level, duration, and rise time approximating the ideal test conditions described above.

1. For each flight direction, the aircraft shall be over the area of elevated background and over the area of normal background for a minimum of one minute each at the test flight altitude. This may be accomplished by flying at a lower speed or hovering of the aircraft if the aircraft operation allows for this.
2. The detection system will be flown over the area of increased background in both directions (ambient to elevated and elevated to ambient), at the flight altitude, with no source present for 3 trials in each direction. The number of alarms will be recorded for each direction.
3. Next, the system will be flown over the background step with the shielded ^{137}Cs source from Table 3 in the center of the detection zone
4. The system will be flown over the shielded ^{137}Cs source after the 1 minute stabilization period at elevated background.
5. Repeat steps 3 and 4 for a total of 3 trials in both directions (ambient to elevated and elevated to ambient) with the number of alarms recorded for each direction.

If there is no naturally-occurring background step at the flight location the test may be performed as a ground-based test to be designed at a future time in accordance with Section 7.

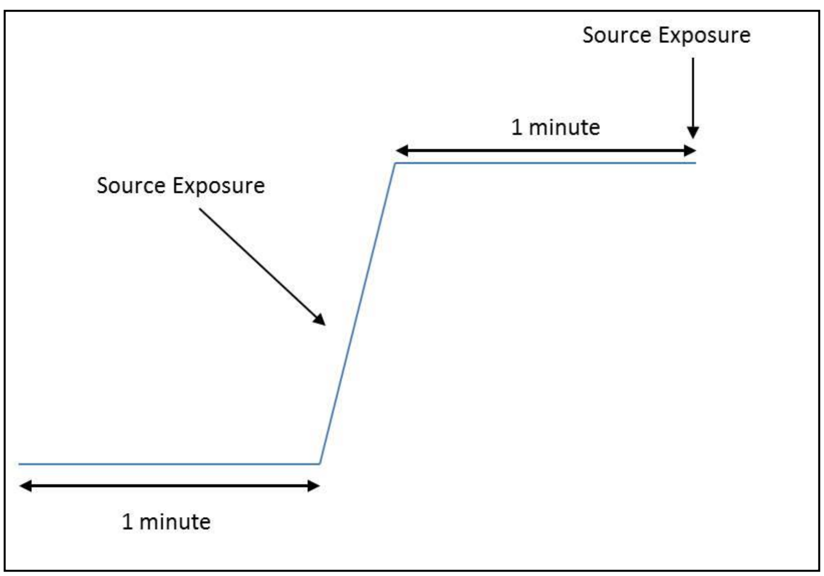

Figure 3. Increasing background with source

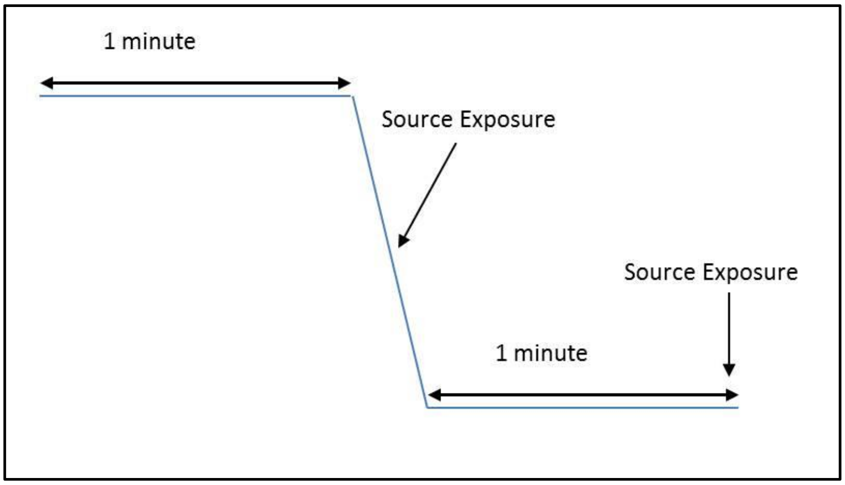

Figure 4. Decreasing background with source

7 Alternate Ground-Based Test Method

Based on an assessment of ground-based methods, modeling comparisons of detector response for ground-based geometries to those of flight described in Appendix C, and recent ground validation test results summarized in Appendix D, the following ground-based method was designed as an alternate for flight testing for the radionuclide detection and identification tests. The method may use either a source or detector in motion via a "rabbit" or vehicle-based system, with the source and detector elevated to three meters above the ground. Appendix D validation test results are for a vehicle-based detector mounting system with stationary source and moving detector. The detector system will be positioned with the broad detector area facing the source and centered vertically with respect to the source as shown in Figure 5. For two-pod detector systems, the two detector arrays will be tested in a flight configuration (separated by the given distance for pod mounting).

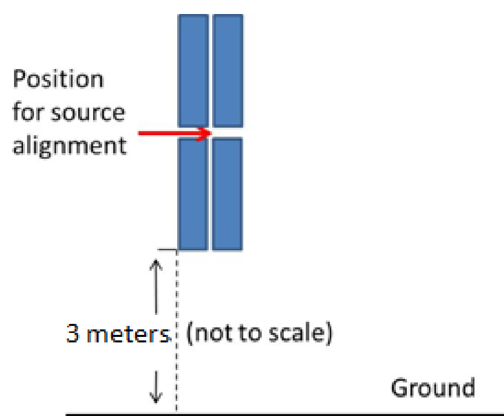

Figure 5. Orientation of detector system and source shown for a four detector system (Detector package not shown)

It is assumed that scaling of the source distances and speeds from the flight parameters of 100 feet and 70 knots (80 mph) will be required. Scaling of velocity and distance will be conducted using the relation $\frac{v1}{d1} = \frac{v2}{d2}$ as described in Appendix B, to maintain the same field of view for the detector system with scaling. The recommended scaled test parameters based on validation test results and feasibility are 20 mph (9 m/s) and 25 ft (7.6 m). Scaled source strengths for these parameters are given in Table 4 below and are scaled from the flight source strengths in Table 1 to yield equivalent detector responses. Measured scaling factors are used, and are specified in Table 11 in Appendix D for four sets of test parameters.

The detector system will be centered along the source path with adequate path length to allow the detector system to start and return to background (before and after passing the source). For industrial sources, it is assumed that industrial sources will be rented and tested in manufacturer-supplied shielding (shipping container), and that reduced strengths may require a different geometry and shielding, therefore scaling will be conducted using scaling factors from Table 11 in Appendix D for fluence rates and/or dose rates with a tolerance of ±20%.

Table 4. Scaled Source Strengths for Ground Measurements at 25 feet Source to Detector Distance

Source	Fluence Rate at 1 meter (Photons/s/cm^2)	Dose Rate at 1 meter (mrem/hr)
^{137}Cs	72	0.0664
^{60}Co	45	0.0664
^{192}Ir	76	0.0664
^{90}Sr	46	0.0664*
WGPu	14	NA
HEU	21	NA

*Primary beta emitter, scaled strength given as dose rate due to Bremsstrahlung

7.1 Requirement

A total of 20 trials will be performed for each test configuration. The system will detect the required sources (from Table 1) with scaled strengths from Table 4 in 18 out of 20 trials. A response is considered positive if it occurs within a two second window of closest approach, to be determined from the time of the alarm. As with flight-based radiological tests, the identification responses and detection of HEU will be analyzed for characterization purposes and results will be reported.

7.2 Test Method

1. Prior to measurements, record the background response at the detector location with a 15-minute dwell measurement.
2. Move the source past the detector system at the distances and speeds given in Table 11, with source strengths scaled from Table 1 according to the measured scaling factor.
3. Repeat step 2 for a total of 20 trials for each source test configuration. Record all detection and identification alarms and times.

8 Environmental and Mechanical Requirements

8.1 Radio frequency susceptibility

8.1.1 Requirement

The detector system should not be affected by radio frequency (RF) fields over the frequency range of 30 MHz to 4 GHz at an intensity of 50 volts per meter (V/m).

8.1.2 Test Method

Without radiation test sources, expose the detector to a RF field at the required intensities and over the required frequency ranges. The test should be performed using an automated sweep at a frequency change rate not greater 1% of the fundamental (previous) frequency. Dwell time should be chosen based on the detector's response time, but should not be less than three seconds. The results are acceptable if no alarms, spurious indications, or reproducible changes in response occur that exceed ±15% of the initial indicated value.

8.2 Ambient temperature

8.2.1 Requirement

The detector system shall be operational at temperatures from -40 ºC to +60 ºC (-40 ºF to +140 ºF).

The detector system shall be able to survive unpowered, uncontrolled storage temperatures of -40 ºC to +71 ºC (-40 ºF to +160 ºF).

8.2.2 Test Method - Operation

With the detector system powered from an external power source, switch the detector on and place the detector in an environmental chamber. Allow the chamber and detector to stabilize at 22 °C. During the last 30 minutes of the stabilization period, perform the functionality test by collecting spectral results and 10 count rate readings from ^{57}Co and ^{60}Co placed in a location that provides an exposure rate of approximately 50 µR/hr (from each source) at the surface of the detector.

Remove the sources from the chamber and increase the temperature in the chamber at a rate of 10 °C /hr to +60 °C. At each 10 °C (30, 40, and 50 °C) increment, stabilize the temperature for a period of 1.5 hours. During the last 30 minutes of the stabilization period, collect spectral results and 10 count rate readings from ^{57}Co and ^{60}Co placed in a location that provides an exposure rate of approximately 50 µR/hr (from each source) at the surface of the detector and verify that the system responds to an unmoderated ^{252}Cf neutron source (when provided). The sources shall be removed during each temperature ramp cycle.

At the high temperature limit of +60 °C, the detector system shall be exposed for a period of two hours with the functionality test as described previously performed during the last 30 minutes of the two-hour period. This same process shall be performed for temperatures that are less than the reference temperature of 22 °C. The 10 °C intervals are 10, 0, -10, -20, and -30 °C, and the lower temperature limit is -40 °C. The test at -40 °C shall be the same as that performed at +60 °C. The test is considered acceptable when the mean count rate readings remain with ±15 % of the mean readings obtained at 22 °C. Peak shifts obtained from the spectral data shall be reported.

8.3 Vibration

8.3.1 Requirement

The mounted detector shall withstand exposure to vibrations associated with the operation of helicopter equipment. The physical condition and functionality of the detector shall not be affected by exposure (e.g., solder joints shall hold, nuts and bolts shall not come loose).

8.3.2 Test Method

Conduct an external examination (visual inspection) and ensure that the detector is functioning properly. Prior to the test, perform the functionality test by collecting spectral results and 10 count rate readings from ^{57}Co and ^{60}Co sources of strength and at a location that provides an exposure rate of approximately 50 µR/hr (from each source) at the surface of the detector.

Using a rigid mount that is attached to the vibration source, mount the detection system as it would be mounted to the helicopter platform using the manufacturer-provided mounting components (vibration isolators, brackets, hardware, etc.).

The detector shall then be subjected to random vibration for a period of four hours in the mounted configuration while exposed to the radiation sources. The random vibration shall be based on the break point frequencies shown in Figure 6 and Table 5. All values are based on the test method found in Section 514.6, Category 18 (Aircraft Stores – Assembled/Material, Helicopter) [16]. The response of the system shall be monitored for changes during the vibration exposure. The readings shall stay within ±15% of the mean readings obtained prior to the test. After the four hour vibration interval, re-expose the detector to the same exposure rates used prior to the test and determine the mean reading from 10 independent readings for each source type. Each mean reading obtained shall be within ±15% of the mean reading obtained prior to the test. After the test, inspect the detector system for mechanical damage and loose components.

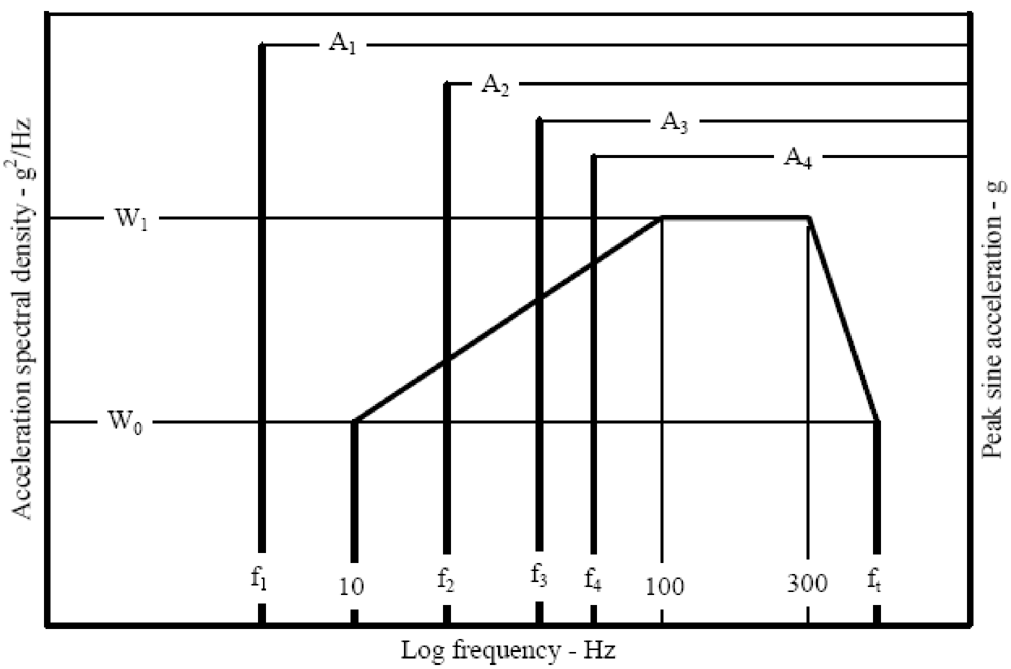

Figure 6. Helicopter Vibration Exposure

Table 5. Vibration Break Points

Break Point	Frequency, Hz	g^2/Hz
1	10	0.0020
2	100	0.020
3	300	0.020
4 (f_t)	500	0.0020

Appendix A. DNDO Scoring Criteria

A1. Most Abundant Radionuclide (MAR)

If the radiation source is a single object, the MAR or MARs is (are) the radioisotope(s) that is (are) present with an atomic abundance of at least 10%. If the radiation source consists of two or more distinct objects in a detector's field of view, the atomic abundance used to define a MAR is taken to be the gamma-ray flux (at the detector) weighted average of the atomic abundances of the individual objects. For example, if two single isotope button sources such as ^{137}Cs and ^{60}Co are placed so that the gamma flux at the detector is the same for each, they would both be considered to have 50% abundance. If the sources are sufficiently separated in space, they are considered independently with respect to scoring.

A2. Category C

The category of correct (C) means the instrument correctly identified at least one MAR present as the isotope identified with the most confidence, or with confidence less than only a radionuclide expected to be present (either a decay chain or background radionuclide). However, in the case of background, it means it identified either nothing or only a background radionuclide. C3 and C4 are specific (C) categories listed below.

A3. Category C3

With a target source present, the system:

- Identified all MARs
- Did not identify at least one MAR also present.
- Reported only radionuclides that were MARs, in the decay chain, or background radionuclides

A4. Category C4

With a target source present, the system:

- Identified all MARs
- Identified only radionuclides that were MARs, in the decay chain or background radionuclides

Appendix B. Mapping Best Practices (Informative)

B1. Survey Method

The practice of aerial gamma radiological surveys to detect and characterize ground-based gamma radiation levels has been practiced since the 1960's, when it was used to monitor nuclear testing [1,2]. Gamma radiation mapping has also been used to characterize natural ground-based radiation levels, such as mapping the natural uranium of the earth's crust [11, 12]. Since then, aerial radiological surveys have been used for both routine surveys such as of nuclear power plants, and surveys of areas of radiological contamination, such as at Fukushima as well as mapping locations of lost radioactive sources [11, 13]. An aerial radiological survey may be performed with a helicopter or fixed wing system. Ideally, a large geometry NaI (Tl)-based detector array is used, for example a 16-liter system is recommended for mapping of background radiation deposition [11]. The system should have the capability for processing both gross count and spectral information.

The survey method depends on the area of survey, time constraints and required altitude. For example, for lower altitudes and smaller survey areas, a helicopter-based platform may be used, with a survey grid pattern of equally spaced parallel lines [1, 14] (Figure 7). The spacing of the survey lines is dependent on the survey area, time and desired accuracy of the survey. For large or highly contaminated areas to be surveyed with time constraints, a serpentine pattern may be used (Figure 8). This survey may be typically conducted with a fixed wing platform, and allows an overview of a large area quickly or may serve as an initial survey, to be followed by more detailed surveys using grid patterns.

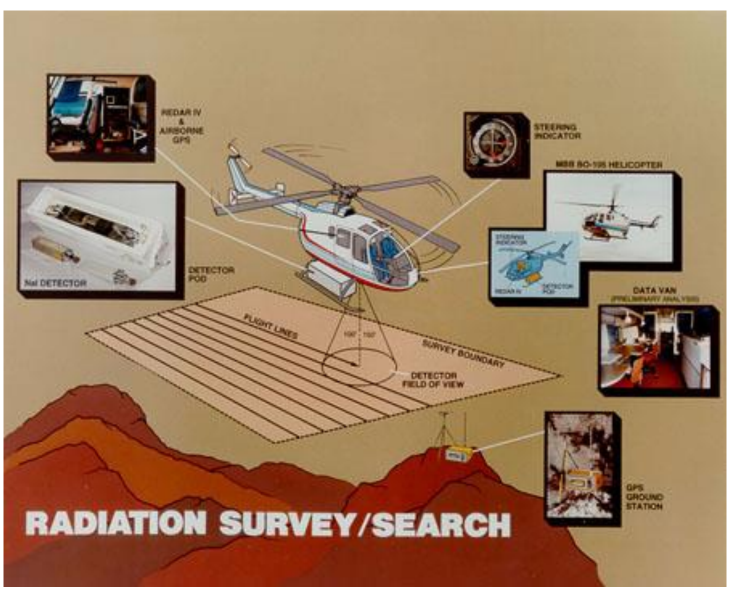

Figure 7. Illustration of typical grid-based survey pattern and mapping [1, 2]

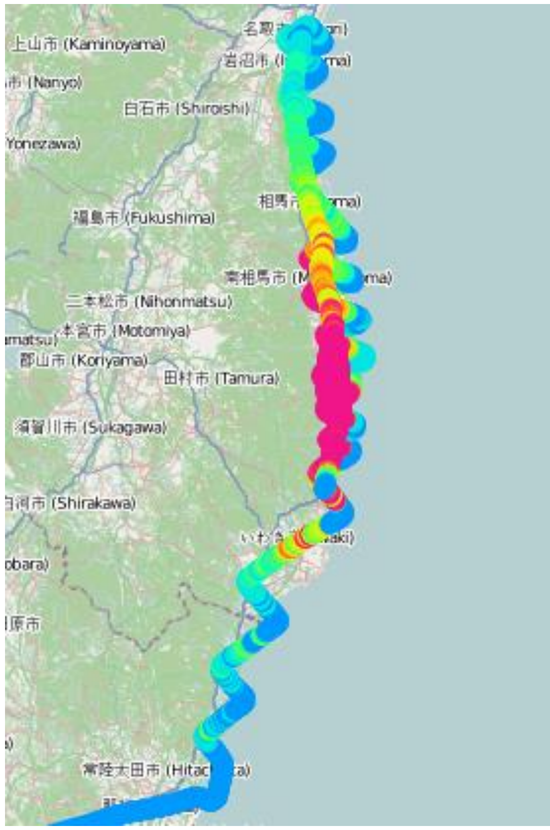

Figure 8. Example of a serpentine survey pattern: NNSA AMS Fukushima C-12 Fixed Wing Data [11, 13]

B2. Flight Parameters and Line Spacing

The typical altitude for a grid-based mapping survey is between 100-300 feet AGL. The field of view typically defined for a mapping scenario is the circular area in which 60%-70% of the source counts originate. Although this will vary with the flight altitude and energy of the source, as a general rule of thumb, it is taken to be a circle with a diameter of twice the altitude AGL.

B3. Data Acquired

The detector processing system should have the ability to record single and summed detector spectral data with a second-by-second time interval or smaller. Detector energy ranges should be 20 keV to 4,000 keV, to include man-made and cosmic radiation sources [1]. As well, the detector system should have automatic gain stabilization as well as the ability for the gain stabilization to be turned off if desired (for example, due to effects of particular source peaks on the stabilization routine). The data recorded should also include radar altimeter or GPS position data, which is integrated or time-synchronized with the detector system.

B4. Mapping Products

The detection system should have the ability to display in real or near-real time a map of summed detector count-rates at the position of each detector acquisition. The associated detector software should enable near-real time calculations of other mapping quantities, such as ground-based exposure rate maps, mapping of a man-made ratio [1, 11], or isotopic maps. Mapping analysis software may include interpolation and data smoothing methods such as triangulation-based interpolation and inverse distance weighting of data points.

Appendix C. Assessment of Ground-based Testing Methods as Alternative for Flight Tests (Informative)

The use of ground-based radiological testing has been proposed in the past as an alternate method for aerial radiological flight tests, as it is in general less expensive to conduct and does not require the infrastructure and flight certifications needed for aerial tests. The differences in detection and identification of the possible ground-based methods as compared to source flight tests are assessed here, including effects from differences in the field of view, motion of the detector system, and background magnitude and variability. There are several methods for ground-based tests which have been performed or considered in previous test campaigns. Stationary crane testing, and stationary stand-off testing and moving source stand-off testing are considered. The following presents an overview of the thought process for planning a ground-based test.

C1. Stationary Crane Testing

Crane testing was previously performed for the DNDO aerial mounted radiation detection systems Gryphon tests as a supplement to flight tests. Here, the detector is suspended by a crane above the source; for these purposes the source would be directly under the detector system. This method does not include the sometimes detrimental effects of the aircraft motion, which results in an increased sensitivity to the source for crane testing as compared to flight testing. The relative effect of motion on sensitivity depends on the altitude, as well as settings for the detector system, such as integration time. For relatively low altitudes, such as 50 feet, the effect of motion is most severe, as much as a factor of two decrease in sensitivity for a moving system. For more typical flying altitudes such as 100 or 150 feet, this effect is less, and is estimated to be an approximately 25% decrease at 100 feet, and closer to 20% at 150 feet, assuming a one-second integration time. (At higher altitudes, this effect is further reduced, assuming that the integration time is increased to provide maximum detection sensitivity.) Further, crane detection provides a static background, and does not include the significant and rapid changes in flight background due to aerial detector motion, altitude, and topography changes, which will affect the false alarm rate and alarm threshold. The magnitude of the background, however, is the same as that of the flight background at the given elevation.

Crane testing also has a comparable field of view (neglecting motion) of scattered source photons that the detector sees relative to the flight measurements. However, crane testing may be difficult to conduct due to the high elevations, large cranes and associated infrastructure and regulations required. Table 6 shows sensitivity estimates for ^{137}Cs simulations based on gross count detection, in numbers of sigma above background, for aerial and ground-based methods. The average backgrounds with altitude used in the calculations are based on those measured for a commercial four-detector NaI-based system during the Gryphon tests. These numbers are therefore guidelines, with the sensitivity varying with average background at other locations.

C2. Stationary Stand-Off Measurements

Rather than elevate the detector system with a crane, stationary ground-based stand-off measurements may be conducted. As with crane testing, this method does not include effects of motion, which as noted results in an approximately 20% to 25% increase in sensitivity to the source for stationary measurements, and does not include effects of rapidly changing background due to altitude/topography changes. Conversely, the higher background magnitude at ground level contributes to a reduction in sensitivity for ground-based measurements as compared to flight measurements.

Ground-based stand-off testing shows a different (reduced) field of view of the source than aerial detection which additionally contributes to reduce the sensitivity of ground-based measurements as compared to flight measurements. Figure 9 shows a comparison of simulated net ^{137}Cs spectra for stationary ground-based and aerial detection at a source-detector distance of 100 feet, for a "typical" 4-log NaI (Tl) system of 4×4×16 inch crystals and point source geometry, with modeling results in Table 6. For the aerial simulation, the source is directly under the helicopter, centered with respect to the four detectors. For the ground-based simulations, the source is also centered with respect to the four detectors, and the detector system is elevated approximately one foot above ground. In both, the largest detector area (4×16 inch side) is perpendicular to the source. The difference in the scattered components of the spectra is assumed to arise from a reduction in scattered gammas reaching the detector for the ground-based orientation.

While the difference in the scattered component may have a negligible effect on photo-peak based detection and identification, gross count detection sensitivity would be reduced for a point source. The combined reduction due to spectral shape differences (reduction in scattered component) and increased background magnitude is predicted to be close to 40%, comparing stationary ground to crane measurements. However, the reduction in gross count sensitivity is closer to 20% compared to flight measurements, due to the added effect of the increase in sensitivity due to lack of motion for the stationary ground-based measurements. It is also possible that ground-based measurements may be performed at closer distances, such as 50 feet, with approximate $1/r^2$ scaling used to provide detection at 100 feet. While this would neglect differences in air attenuation or scattering, these are expected to be a second order correction for scaling from 50 to 100 feet. Figure 10 shows that the overall shape of the spectra at 50 feet is close to that at 100 feet, and the total count rate scales approximately as $1/r^2$.

C3. Moving Source Ground-Based Measurements

Additionally, moving source or detector ground-based measurements may be performed by scaling the distance and velocity as $\frac{v1}{d1} = \frac{v2}{d2}$. If the source is moved relative to the detector, which may be more feasible given the large detector sizes, these also do not include changes in detector background due to detector movement. The larger ground background and reduced field of view are predicted to further decrease total count sensitivity by up to 40% for a point source as compared to aerial flyovers. However, simulations indicate that elevation of the source above the ground increases the scattered contribution to the detector for ground-based testing (Table 7, Figure 11). Modeling indicates that elevation of the point source to three meters may reduce the difference in scattered count rate by approximately 80%. The ground-based method would also require scaling of velocity and distance (and source strength), as the typical flying speed of 70 knots or 80 mph and required length is difficult to achieve in moving source "rabbit" systems. Scaling to distances of less than 12.5 feet (3.8 meters) with corresponding speed of 10 mph (4.5 meters per second) is not recommended due to increasing effects of source and detector geometry (the source does not appear as a point source).

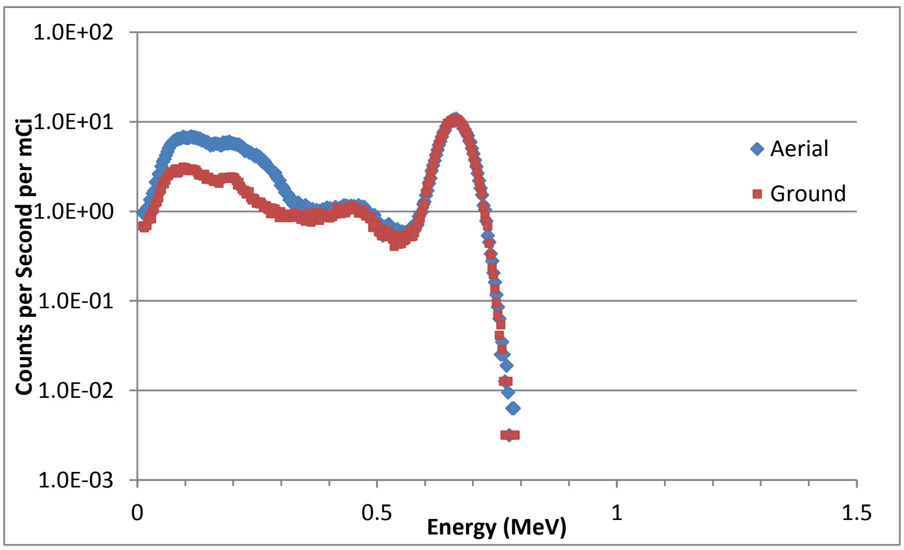

Figure 9. Comparison of simulated net ^{137}Cs spectra for static aerial and ground-based measurements, with 100 feet perpendicular source to detector distance, for a typical detector system

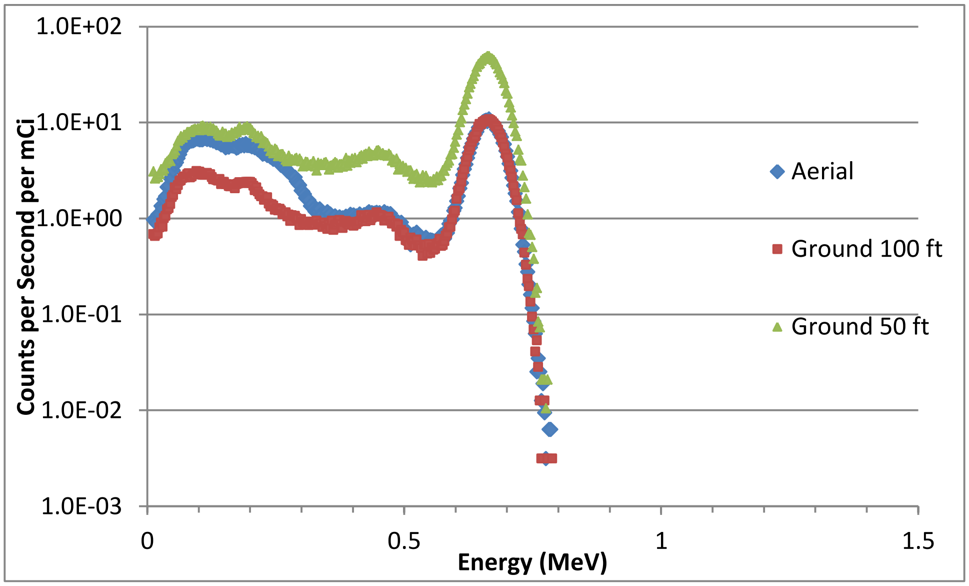

Figure 10. Comparison of simulated net ^{137}Cs spectra for static ground-based measurements, at 50 feet and 100 feet perpendicular source to detector distance, for a typical detector system

Table 6. Comparison of sensitivity of ground-based and flight measurements.

		Source (cps/mCi)	BKG (Gryphon)	Sigma	% Diff	Photopeak (cps/mCi)
Aerial	Stationary	833	8262	9.16	0.26	2.44E+02
	Moving	614	8262	6.76	0.00	
Ground	Stationary	553	10120	5.50	-0.40*	2.44E+02
	Moving	393	10120	3.91	-0.42**	

* Compared to static aerial

** Compared to flight

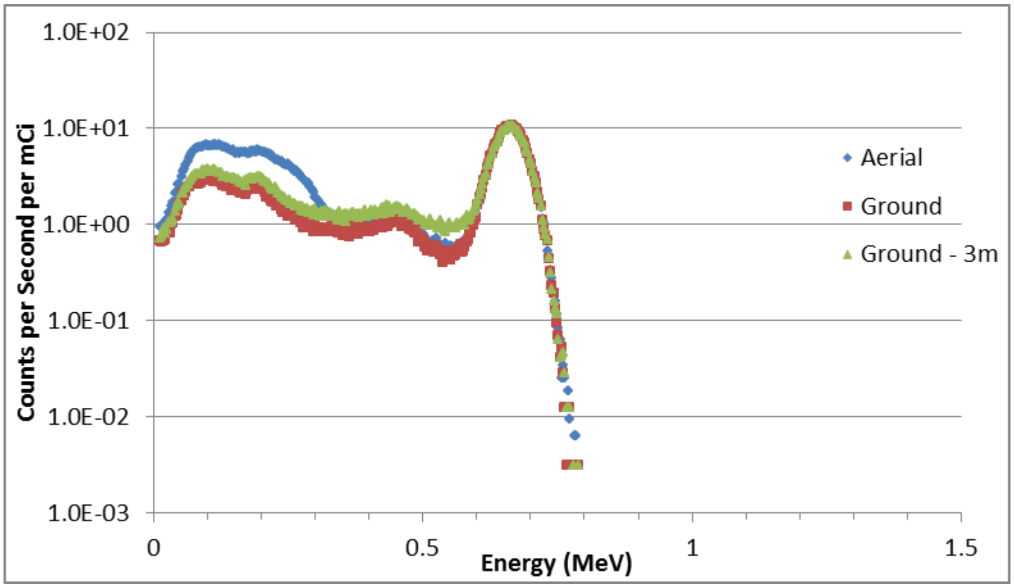

Figure 11. Comparison of simulated (net) source spectra for static aerial and ground based detection including source on ground and elevated.

Table 7. Detection Responses for Ground-Based Testing for Elevated Source

Source AGL (meters)	Ratio to Flight Gross Counts	Ratio to Flight Photopeak
0	0.664	1.0
1	0.705	1.0
3	0.783	1.0
5	0.812	1.0
7	0.819	1.0
10	0.804	1.0

C4. Conclusions

In summary, ground-based testing methods do show some key spectral differences as compared to aerial flight testing. For one, the scattered gammas and resulting gross count rates are reduced for stand-off ground measurements as compared to flight measurements resulting in a lowered gross count rate based detection sensitivity; as well the spectral shape (peak to Compton) is different which may affect some detection or identification algorithms. Elevation of the source for ground-based stand-off detection does improve the agreement in scattered gammas detected. It should be noted that the photopeak sensitivities are comparable, indicating that identification performance (using algorithms based on photopeak counts) may be comparable for both methods. Some detection algorithms based on photopeak ID may also be comparable. Crane testing does provide a comparable field of view to that of flight measurements, with a similar scattered gamma component and spectral shape, but may be less feasible due to cost than use of a rabbit system.

For sources that are not close to the minimum detectable activity (MDA), ground-based methods may be feasible as an alternate for flight testing. These methods lack the large variation of detector background seen in aerial flights; therefore a threshold should be used for testing with these methods corresponding to that which would be used for aerial detection (to be set by the manufacturer).

Appendix D. Ground-based Validation Test Results (Informative)

D1. Stationary Measurements

Stationary measurements were made with a four-crystal NaI (Tl) system and ^{137}Cs shielded industrial source to validate detector response and parameters for moving ground-based tests. Dwell measurements were made with the source at 50 ft., and the detector above ground at 1 m, 3 m, 5 m elevations, with results shown in Table 8. Minimal difference was seen from 1 to 3 m (2-3% difference), and a drop at 5 m (7-9% drop in total counts). The 3 m elevation was chosen due to slight increase in peak counts and model predictions for a point source. Table 9 shows dwell measurement results made at this altitude as a function of distance, showing close to a $1/r^2$ scaling with distance.

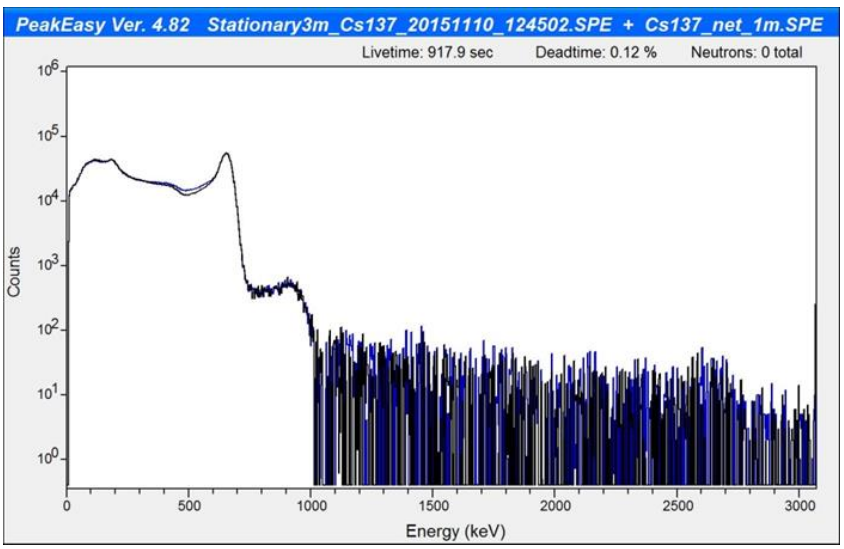

Figure 12. Spectra from dwell measurements at 1 m and 3 m showing minimal difference

Table 8. ^{137}Cs Elevation Dwell Measurements

Elevation (m)	Net Pk (cps)	Net Src (cps)	Ratio	Ratio Net cts
1	1048	6649	1.00	1.00
3	1081	6506	1.03	0.98
5	1054	6047	1.01	0.91

Table 9. Stationary ^{137}Cs Stand-Off Measurements and Source Scaling

Distance (ft)	Net Pk (cps)	Net Src (cps)	Ratio Pk	Ratio Net cts	Scaling Factor
12.5	20245	101023	4.23	3.95	0.0165
25	4781	25573	4.42	3.93	0.0652
50	1081	6506	4.79	3.90	0.256
100	226	1668	1.00	1.00	1.0

D2. Moving Ground Tests

Table 10 below shows results for a direct comparison of flight and ground results for the ^{137}Cs shielded industrial source of dose rate 0.9 mrem/hr. Scaled average and maximum sigma values compare well within standard deviations. Scaling is based on the number of detectors (four for ground, three for flight) and the square of average backgrounds (a factor of 1.7). The higher standard deviation of flight measurements is assumed to be due to larger deviations in flight parameters as compared to ground-based tests.

Table 10. Comparison of High Speed Rail and Flight Tests for ^{137}Cs

		Net Src (cps) Measured	Net Src (cps) Scaled	Sigma above Bkg Measured	Sigma above Bkg Scaled	Standard Deviation
Average	Flight	994.0	1325.3	23.1	**26.7**	5.3
	Ground	1439.5	1439.5	17.1	**28.8**	2.1
Maximum	Flight	1238.0	1650.7	28.8	**33.3**	
	Ground	1555.0	1555.0	18.6	**31.4**	

Results from moving ground tests with ^{137}Cs sources of strengths scaled based on distance are shown in Table 10. Scaling factors were based on model results shown in Table 11. A background scaling factor of 1.414 was also applied to scaled point source strengths at 12.5 ft, 25 ft, and 50 ft, taken from the square root average flight to ground background ratio (2) from the previous flight validation flight tests to provide equivalence to flight testing. The industrial source was near the shipping limit at 0.9 mrem/hr and could not be scaled. Scaled sigma values are adjusted for actual source strengths and have the background factor removed to allow comparison with the high speed run. As well, scaled values are adjusted for the differences in background at the two test locations. The measured ratios shown are of scaled sigma values from a given distance to the previous (higher) distance, and show values close to one for scaling from point sources, but a jump from the industrial to point source. Ratios using calculated fluence values from HPGe ground truth spectra show a value close to 1, indicating that this difference is due to the source configuration, and that scaling factors yield equivalent detector responses when scaling by fluence. Measured scaling factors are shown, assuming the ratio of fluence values for the industrial source to point source at 50 ft. The measured moving scaling factors are close to the stationary factors and model results.

The source is well within detection limits without the background factor and adjusting for the 20% increase due to point source configuration, at 20 sigma above background in a background of 7 - 9 µR/hr. Based on results, scaled source strengths are estimated to be above a typical detection threshold for allowed ambient background ranges given in Section 4.1; therefore the background factor is not included in the TCS requirements.

Table 11. Source Scaling

(ft)	(mph)	Model Factor Ground	Model Factor Air	Actual Factor	Measured Sigma Ave	Measured Sigma Scaled	Ratio	Measured Factor	Config
12.5	10	0.020	0.0179	0.0195	37.4	26.4	1.05	0.0187	Point
25	20	0.070	0.0694	0.0663	35.7	25.3	1.00	0.0664	Point
50	40	0.255	0.267	0.2770	35.8	25.3	1.22*	0.227/0.254 **	Point
100	80	1.0	1.0	1.0	17.1	20.7			Industrial

* Adjustment for estimated fluence rates yields 1.0 ± 10%

** Based on ratio of fluence rates

In Table 12 the deviations in measured (unscaled) sigma values and test parameters of speed, source-detector distance and source offset (for flight only) are shown, indicating that ground-based testing allows for tighter control of parameters. All results for scaled distances are for ground measurements; flight measurements are also made for the 100 ft and 80 mph parameters. Flight results are for runs which fall within the tolerances of ±20 ft for altitude and offset only.

Table 12. Deviations in Ground and Flight Measured Test Parameters

Distance (ft)	Speed (mph)	Ave Sigma	SD (%)	Ave. Speed (mph)	SD (%)	Ave. Distance (ft)	SD (%)	Offset (ft)
12.5	10	37.4	9.7	11	8.3	12.8	5.1	
25	20	35.7	5.6	20.9	3.2	26.2	1.9	
50	40	35.8	9.7	40.8	1.3	50.6	0.7	
Ground 100	80	17.1	7.4	79.5	1.1	100.7	0.7	
Flight 100	80	23	20	75.1	10	95 – 100	10	9 - 11