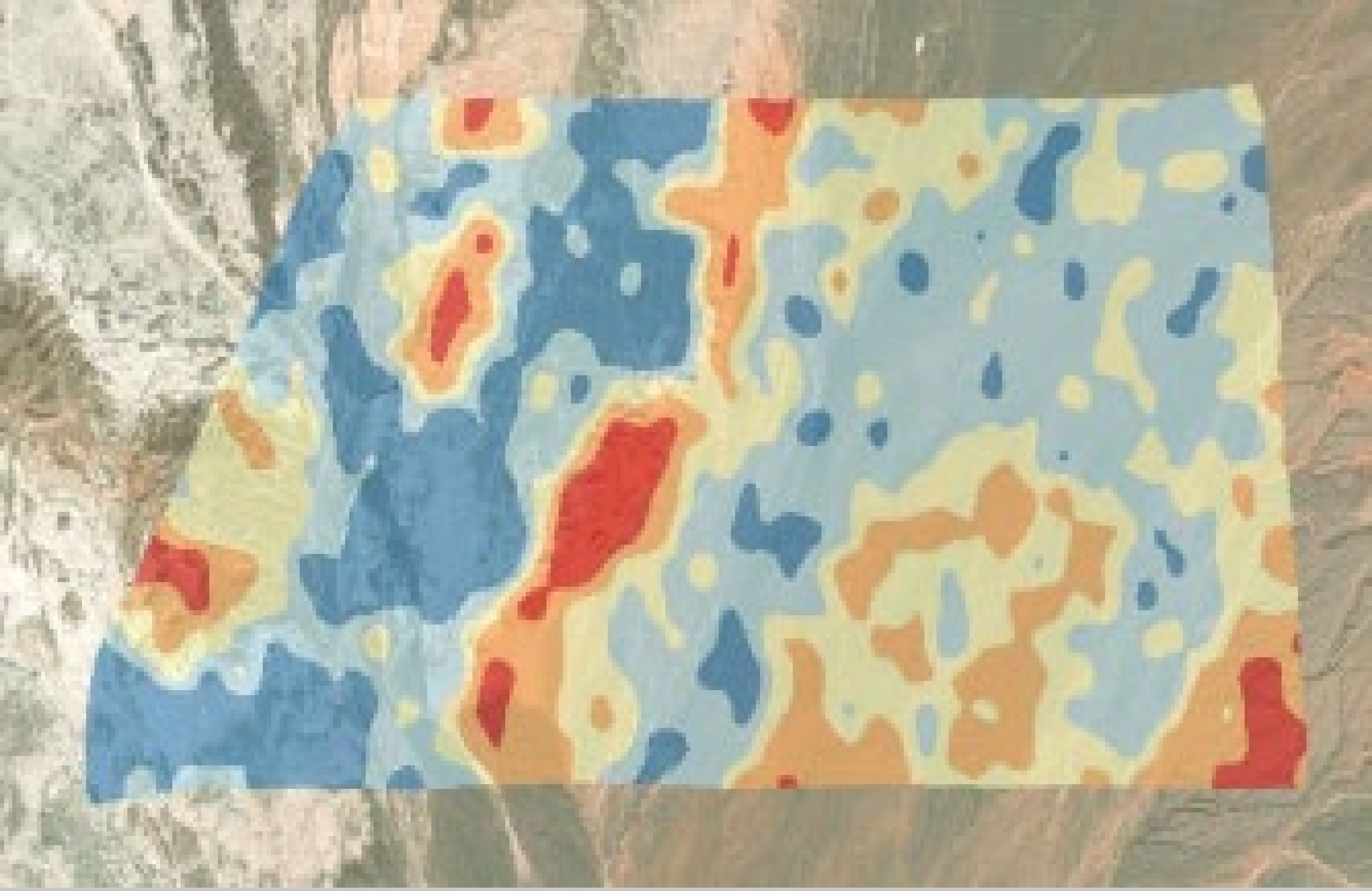

Background Radiation Characterization Surveys

Technical Guidance and Concept of Operations

March 2025

Science and Technology

NUSTL
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

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FOREWORD

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NUSTL provides independent technology evaluations and assessments for first responders, thereby enabling informed acquisition and deployment decisions, and helping to ensure that responders have the best technology available to use in homeland security missions.

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EXECUTIVE SUMMARY

The "Background Radiation Characterization Surveys" document includes processes and procedures intended to make it easier for federal, state, local, tribal, and territorial (FSLTT) partners to plan, perform and record background radiation surveys. Enabling jurisdictions with varying resources and skill sets to conduct surveys and show the end results will help FSLTT partners to gain a better understanding of their background radiation environment and quantify spatial and temporal variations.

The document is separated into two parts: Part One is Technical Guidance and Part Two, Concept of Operations (CONOPS). Part One contains science-driven recommendations for how to plan, conduct, and document background radiation surveys. It explains how to develop a radiation survey plan, including tips on how to collect the best data possible in a manner that will maximize the survey information's usefulness. Part Two outlines the major steps involved in designing and performing a background radiation characterization survey and provides examples for three different types of surveys: quick and simple surveys, moderate surveys, and advanced surveys. The CONOPS is designed to be scalable so that those designing and executing the survey may choose an option that best matches the available and/or desired level of technical knowledge, equipment, and survey duration and complexity. Part Two assumes jurisdictions will use instruments that are already available as a part of their existing preventative radiological nuclear detection (PRND) or consequence management capabilities (i.e., response and recovery after an uncontrolled release of radioactive material.) While the CONOPS provides guidance for a range of survey approaches of varying complexity, it does not provide all the technical details and instruction needed for the more advanced survey options.

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INTRODUCTION

An ideal background survey will provide first responders, emergency managers, and public health officials with a better understanding of the typical levels of radiation in their jurisdiction. Having this data collected, validated, and mapped will provide an environmental baseline that is useful to both preventative radiological nuclear detection (PRND) (e.g., search and interdiction of radioactive material) and consequence management (CM) operations.[1]

This guidance presents steps for designing, conducting, and documenting a comprehensive, geographically mapped background radiation characterization survey (hereafter, a "background survey"). Its audience includes, but is not limited to, the following who may assist with radiological or nuclear emergency preparedness and response:

- State, local, tribal, and territorial (SLTT) environmental protection and radiation safety/health personnel
- Law enforcement, firefighters, emergency management, and other first responders
- Hospital or nuclear medicine staff
- College/university staff
- Private company radiation safety staff/staff of environmental health and safety programs

This document provides technical guidance and key considerations for:

- Identifying the survey area boundaries
- Determining locations, spacing, and coverage of measurements
- Selecting the appropriate radiation detection equipment
- Surveying/sampling techniques and priorities
- Recording, storing, collecting, and visualizing survey data
- Reviewing and evaluating data

The technical guidance is part one of two. Accompanying it as the second part is a concept of operations (CONOPS) for designing a background radiation characterization survey, which outlines the major steps involved in designing and performing a background survey and provides examples for three different types of surveys: quick and simple surveys, moderate surveys, and advanced surveys.

[1] "Consequence management" refers to activities undertaken to mitigate the consequences of a radiological or nuclear incident. These activities include actions taken while responding to such an incident (e.g., saving lives, establishing public safety boundaries) and when recovering from an incident (e.g., mapping the extent of radioactive contamination, monitoring the progress of cleanup efforts).

BACKGROUND RADIATION CHARACTERIZATION SURVEYS

PART 1: TECHNICAL GUIDANCE

1.0 BENEFITS OF CONDUCTING A BACKGROUND RADIATION SURVEY

Quantifying background radiation prior to a threat or emergency can help with execution of both PRND and CM operations. Specific use cases are described below.

1.1 CHARACTERIZE AN ENVIRONMENT FOR PRND OPERATIONS

PRND missions focus on localizing, identifying, and adjudicating a radionuclide as a threat or non-threat. Background surveys can support planning for PRND operations (for example, securing special events) by providing a baseline for comparison to future measurements. Using the results of a background survey, responders can identify areas of potential interest, such as pre-existing hot spots that may merit special radiological/nuclear security considerations during detection operations. Background surveys that are conducted for this purpose should be updated periodically and maintained by local and state law enforcement authorities and provided to intelligence fusion centers to support field operations and people who assist with detection alarm/alert resolution.

1.2 ASSIST WITH ADJUDICATING ALARMING PRND EQUIPMENT DURING ROUTINE PATROL

Some first responders carry radiation detection equipment with them when patrolling or responding to non-radiological emergencies. A background survey can be used to document an area or facility where there are elevated radiation levels, perhaps enough to cause PRND equipment to alarm. For example, PRND equipment may alarm if a responder patrols past an industrial radiation source, a medical center or patient treated with radioisotopes, a machine that uses radiation, or a building constructed with materials that naturally contain higher amounts of radioactive materials like granite. Documenting these areas may provide additional context for responders who must assist with detection alarm/alert resolution.

1.3 ALLOW FOR DISCOVERY OF ENVIRONMENTAL RADIOACTIVE ANOMALIES, CONTAMINATION, OR HAZARDS

A background survey may also inadvertently discover radioactive contamination or elevated radiation levels that may pose a risk to the environment and/or public. If this occurs, it should be reported to appropriate SLTT and federal authorities (e.g., local public health agencies, state radiation control programs, and the U.S. Environmental Protection Agency (EPA) or U.S. Nuclear Regulatory Commission (NRC)). Common examples of undocumented radioactive contamination or exposure include:

- Historical industrial sites, such as factories, hospitals and other former medical sites, and mines
- Improperly disposed radioactive waste, such as at landfills
- Orphaned (i.e., lost or abandoned) radioactive material
- Improperly operated or stored industrial equipment, radiography cameras, and nuclear density gauges such as Troxler gauges

- Inadequately shielded medical or industrial radiation generating machines (e.g., x-ray or radiation therapy machines while in use)
- Radiological sources that may exist in museums, antique stores, or personally owned license exempt materials

In some, but very rare cases, the accidental discovery of radioactive material may require a response with public screening and decontamination, environmental cleanup, and recovery operations. A famous example of this is an orphaned source discovery that occurred in Goâiania, Brazil [1]. Radioactive contamination was also discovered in 2005 in Great Kills Park, now part of the Gateway National Recreational Area in New York City, during a routine aerial radiation survey.

1.4 FACILITATE CHARACTERIZATION OF AREAS WITH LOW-LEVEL RADIOACTIVE CONTAMINATION

Conducting and documenting a background survey before an incident establishes a preexisting baseline that may assist responders with identifying and characterizing contamination after an incident. Having this data-set ready and mapped in advance may positively affect the timeliness of consequence management operations, especially when the detectable levels of radioactive contamination are relatively low or only slightly above background.

After a release of radioactive material, emergency responders will need to establish answers to several critical questions, such as the following:

- What specific areas are contaminated and what is the range of radioactivity detected?
- What is the size of the area(s) with low levels of radioactive contamination (e.g., 2-5 times background)?
- How and where has radioactive contamination spread by natural transport (i.e., wind and rain) or human activity (e.g., driving)?
- What areas require long-term protective actions due to radioactive contamination?

While high levels of radioactive contamination may easily be attributed to the incident, first responders and public health officials may find it more challenging to distinguish lower levels of contamination from pre-existing background radiation. This is because background radiation may vary from area to area or building to building; some areas will have higher background radiation than others.

1.5 ASSIST WITH THE LATE PHASE OF A RESPONSE

After an incident that releases significant radioactive material into the environment such as a nuclear power plant release, nuclear weapon accident or detonation, or radiological dispersal device, the radiological emergency response flows through three incident phases: early, intermediate, and late. The late phase is the period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed. This phase may extend from months to years [2].

The act of reducing levels of radioactive contamination is called remediation. The goal of remediation is to reduce contamination to a level at which radiation exposure risk to people is low enough to reopen and release an area for re-occupancy. Remediation planning requires engagement with stakeholders among government, the public, property owners/managers, special interest groups, and businesses before, during, and after cleanup. The remediation planning process involves distinguishing pre-existing background from low levels of contamination to determine the amount of clean-up possible given the remediation goals, allotted funding, and time constraints. Having access to background survey measurements collected before the contaminating incident is essential to help remediation planners with making cleanup level decisions and communicating them to key stakeholders.

1.6 ENABLE MORE EFFECTIVE COMMUNICATION WITH THE PUBLIC AFTER AN INCIDENT

Data from a previous background survey can be used to communicate with the public about the presence of natural radioactivity in building materials and the environment, as well as man-made sources of radiation. In the event of a release of radioactivity, the public will demand answers and SLTT officials will need to communicate risk in a timely and accurate way.

In unaffected areas or areas with very low levels of contamination, data from a pre-existing background survey may be used to demonstrate that the post-incident radiation levels are the same as, or very close to, the levels that were measured before the release, which should help to assure residents in the affected area(s). Meanwhile, in areas with significant contamination, officials can use the background survey to show the extent of contamination and highlight the importance of adhering to protective actions.

Without a background survey, it will be harder to convince the public not only that radiation is a naturally-occurring phenomenon, but that they can continue to live safely – even comparably to how they lived before the radiation emergency – in areas where they may be exposed to very low levels of radiation. Residents will need this reassurance, made more believable if supported with pre-incident data, since many may assume they have been (or expect to be) residing only in areas with “zero” radiation, which is never possible. While a background survey will not prevent fear of radiation, it may help to establish trust and confidence with the public during the response and recovery.

2.0 OVERVIEW OF BACKGROUND RADIATION

Background radiation refers to the radiation to which a member of the population is exposed from natural and man-made sources. Background radiation varies spatially throughout a geographic area, as well as temporally on time scales from hours and days to months and years. The spatial variability is due to the variability of the radionuclide content of different materials; for example, granite can contain more radioactivity than other materials, so radiation levels may be higher when driving past a granite building, flying over a cemetery with granite headstones, or walking past a granite rock outcrop. Radiation dose rates can also vary hourly due to temperature and precipitation variations or seasonally due to soil moisture content or snow cover. For example, rainfall can cause the background radiation exposure rate to double due to the washout of airborne decay products of radon gas that can be released from soil. Conversely, several inches of snow covering the ground may reduce the measured radiation exposure rate by about 15 percent [3]. Natural background radiation is due to terrestrial sources, such as naturally occurring radioactive materials (NORM) in soil (e.g., Uranium-238, Thorium-232, and Potassium-40), cosmic radiation originating from the Sun and sources elsewhere in the galaxy (e.g., galactic cosmic rays) [4]. Radon is a gaseous decay product of radium and as such it can be released from soil into the air. The presence of man-made radioactive sources (e.g., radiopharmaceuticals, industrial gauges), radiation-generating equipment such as x-ray machines, or nuclear medicine patients can cause measured background radiation levels to be as much as four times higher than natural background levels at that location [5].

Humans are continuously exposed to background radiation going about their daily lives. The expected average annual radiation dose from background sources in the United States is about 620 mrem; Figure 2-1 depicts the proportion of average annual radiation exposure from natural background, industry, consumer, and medical procedures [6]. It is important to note that, of the sources shown in Figure 2-1, survey instruments will not pick up radon, an alpha emitting gas produced in the soil and found in air. Survey instruments will detect radiation from medical devices (e.g., x-ray machines), from radiopharmaceuticals used in medical treatments and during transportation to hospitals and nuclear pharmacies, and in patients who have received treatment with radiopharmaceuticals. Nuclear medicine patients may also contaminate objects (e.g., trash) that come in contact with bodily fluids, such as tissues or adult diapers [7]. Being aware of these sources of background radiation exposure can be helpful when planning, executing, and reviewing the results.

The next few sections will provide an overview of typical background radiation sources and how they can contribute to the measured radiation levels during background surveys.

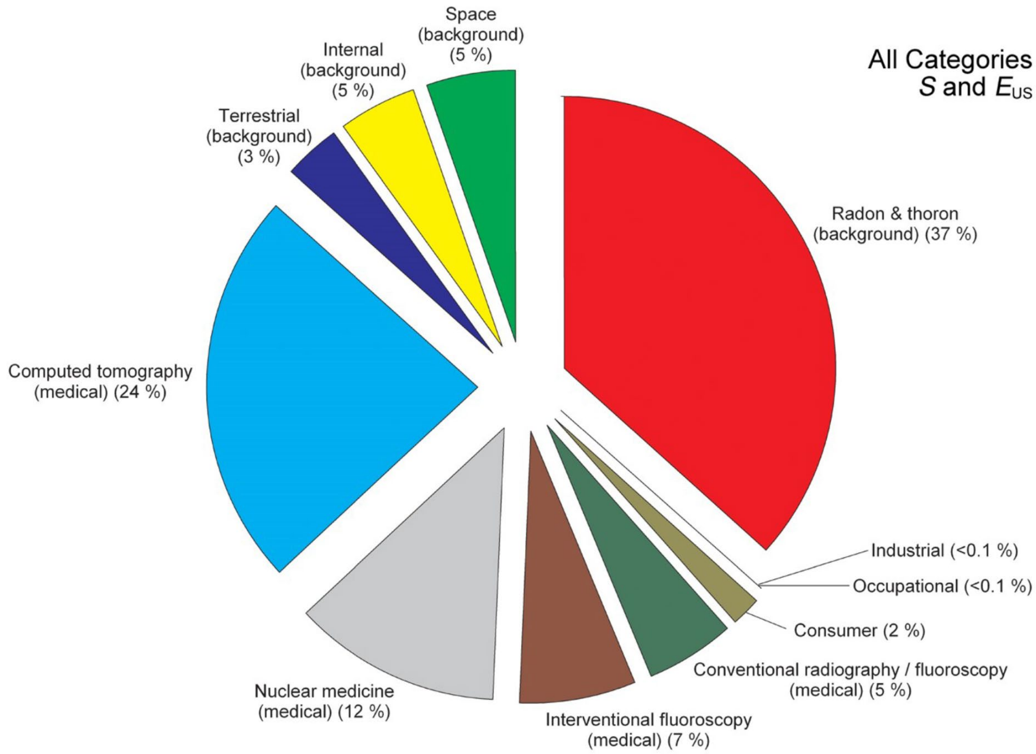

Figure 2-1 US Background Radiation

The figure shows effective dose to U.S. population in 2006 from all categories.
S = person-Sievert; EUS = effective dose per individual in United States.

Image Credit: National Council on Radiation Protection and Measurements [6].

2.1 VARIATION OF BACKGROUND RADIATION

Background radiation varies based on location – both outdoors and indoors – depending mainly on the mineral content in the ground/building materials and the cosmic ray intensity [8]. In fact, the background dose rate in one corner of a room can be different from the dose rate in any other corner of the room, which may be due to the composition of building materials, objects in the room, and shielding of radiation by dense objects. For larger areas, such as whole cities, the background variations can be much more significant, as can be seen later in Figure 2-2.

Some of the largest factors that contribute to background variation are building materials and the geological makeup in the environment being surveyed. Generally, wood is the least radioactive, followed by brick and concrete [9]. A house that is made from granite, whether it is sheets of granite or granite rocks, is more likely to have higher levels of radioactivity than a wood frame house. Some materials, like sandstone, marble, and limestone, tend to have lower levels of radioactivity.

Some examples of materials and their background count rates can be seen in Table 2-1, which is from NUREG 1507, and demonstrates how various detector types yield different results for varying surface materials [10]. The values are not absolute for these materials as bricks, ceramics, concrete, and drywall values can vary depending on where the raw materials originate.

Table 2-1 Background Radiation Counts in Various Materials

(Source: US Nuclear Regulatory Commission [10])

Surface Material	Background Count Rate (cpm)[a]					
	Gas Proportional			GM	ZnS	NaI
	α Only	β Only	α + β			
Ambient[b]	1.00 ± 0.45[c]	349 ± 12	331.6 ± 6.0	47.6 ± 2.6	1.00 ± 0.32	4,703 ± 16
Brick	6.00 ± 0.84	567.2 ± 7.0	573.2 ± 6.4	81.8 ± 2.3	1.80 ± 0.73	5,167 ± 23
Ceramic block	15.0 ± 1.1	792 ± 11	770.2 ± 6.4	107.6 ± 3.8	8.0 ± 1.1	5,657 ± 38
Ceramic tile	12.6 ± 0.24	647 ± 14	658 ± 16	100.8 ± 2.7	7.20 ± 0.66	4,649 ± 37
Concrete block	2.60 ± 0.81	344.0 ± 6.2	325.0 ± 6.0	52.0 ± 2.5	1.80 ± 0.49	4,733 ± 27
Drywall	2.60 ± 0.75	325.2 ± 8.0	301.8 ± 7.0	40.4 ± 3.0	2.40 ± 0.24	4,436 ± 38
Floor tile	4.00 ± 0.71	308.4 ± 6.2	296.6 ± 6.4	43.2 ± 3.6	2.20 ± 0.58	4,710 ± 13
Linoleum	2.60 ± 0.98	346.0 ± 8.3	335.4 ± 7.5	51.2 ± 2.8	1.00 ± 0.45	4,751 ± 27
Carbon steel	2.40 ± 0.68	322.6 + 8.7	303.4 ± 3.4	47.2 ± 3.3	1.00 ± 0.54	4,248 ± 38
Treated wood	0.80 ± 0.37	319.4 ± 8.7	295.2 ± 7.9	37.6 ± 1.7	1.20 ± 0.20	4,714 ± 40
Untreated wood	1.20 ± 0.37	338.6 ± 9.4	279.0 ± 5.7	44.6 ± 2.9	1.40 ± 0.51	4,623 ± 34

[a] Background count rates determined from the mean of five 1-minute counts.

[b] Ambient background determined at the same location as for all measurements, but without the surface material present.

[c] Uncertainties represent the standard error in the mean count rate, based only on counting statistics.

The other significant reason for background radiation fluctuation is due to intensity of cosmic radiation. Since cosmic radiation comes from highly energetic particles from the sun and stars, some of the radiation reaches the ground while other radiation interacts with the Earth's atmosphere, is absorbed, and creates different types of radiation. Hence some areas at higher altitudes experience higher background radiation since cosmic radiation travels through less atmosphere. In fact, gamma background measurements taken on an airplane at 30,000 feet will be significantly higher than if taken with the same equipment in the same location, but at ground level [11].

Background radiation can also fluctuate with weather. Rain, wind, and snow can all impact radiation levels and cause natural background radiation levels to change, either increasing or decreasing depending on the exact conditions. For this reason, it is best to avoid performing background surveys during or for a day following moderate to heavy rain, sleet, or snow [12]. Other fluctuations can be a result of past and present land use. Former industrial or medical facilities, for example, might contain contamination or lost or forgotten radioactive materials, which can produce elevated radiation readings.

2.2 IMPACT OF VARIABILITY ON RADIATION SURVEY OPERATIONS

When performing surveys with detectors that acquire second by second radiation flux rates, such as mobile radiation detection systems or backpack radiation detectors, it is noticeable that background radiation varies throughout the survey area. For example, imagine a street that is full of houses made from wood except for one that is made of concrete. As the surveyor passes the concrete house, the measured background rate increases. If the surveyor does not know or cannot tell that the difference is due to building materials, either the survey team or a reach-back team will have to analyze the data to see what caused the increase. A slight increase in counts could be due to natural causes such as statistical fluctuations in the background, electronic noise in the equipment, or in rare instances, it could be due to something less innocuous (e.g., nuclear reactor accident, large contamination incident, misplaced radioactive material). Passing through tunnels, under bridges/overpasses, and other structures may also result in noticeable fluctuations in background levels compared to the environment on either side.

Figure 2-2 shows a survey of the National Mall in Downtown Washington, DC prior to the 2009 Presidential Inauguration carried out by a National Nuclear Security Administration Nevada Field Office (NNSA/NFO) helicopter [13]. From the symbology on the map, one can visualize how the background fluctuates within the survey area and where the maximum background radiation is located. The shaded red area represents the location with the greatest gross counts recorded, which are still relatively low and corresponds to a granite monument that contains naturally occurring radioisotopes. Blue areas represent the least gross counts recorded and are often, but not always, associated with bodies of water [14]. This survey can be compared to Figure 2-3 and Figure 2-4, which depict surveys conducted by the United States Geological Survey (USGS) with flight line data to characterize potassium, uranium, and thorium levels throughout the United States beginning in the 1970s [15]. The USGS also estimated the cosmic ray exposure and terrestrial contribution to background dose rate throughout the United States and Canada (Figure 2-4).

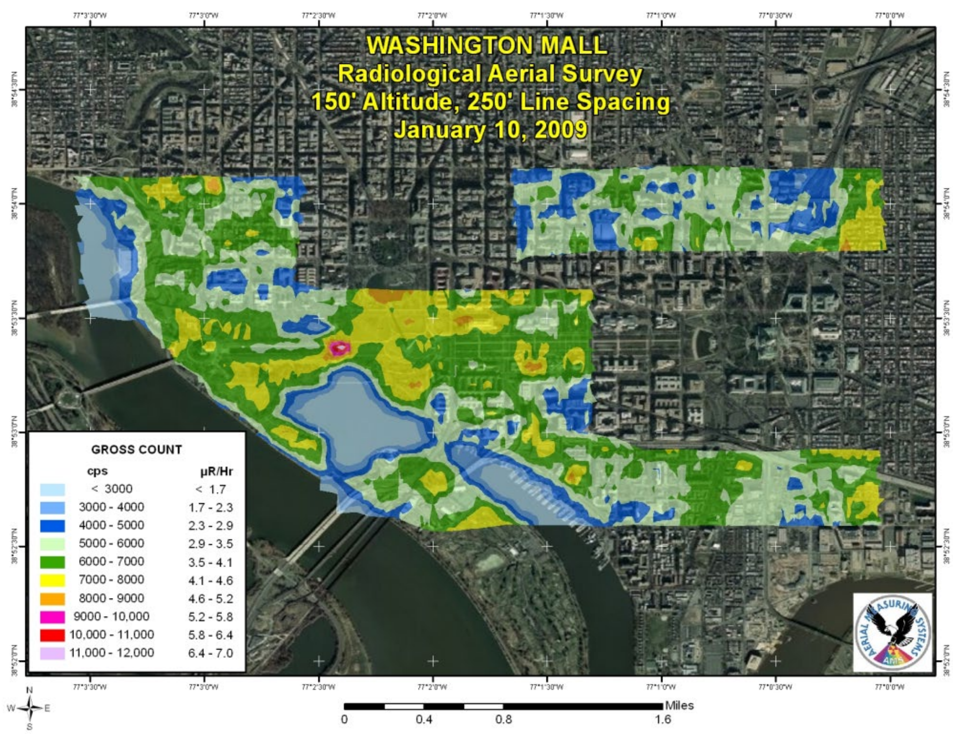

Figure 2-2 NNSA/NFO Radiological Survey of Downtown Washington, DC

Image Credit: NNSA/NFO [13]

Since the maps in Figure 2-3 and Figure 2-4 are broad and span the entire country, they do not contain enough detail to make decisions within local jurisdictions and should not be used to inform emergency operations. However, a map like Figure 2-3 contains enough resolution and detail of local-level fluctuations in background to educate responders about the range of background readings in their area.

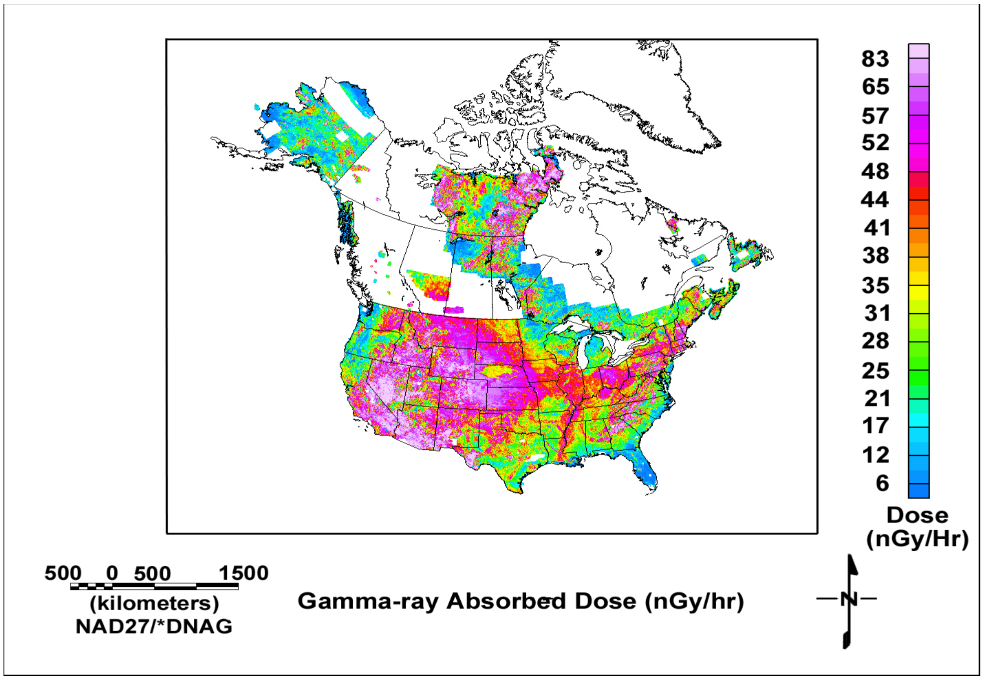

Figure 2-3 USGS Gamma-Ray Terrestrial Dose

Source: US Geological Survey [11]

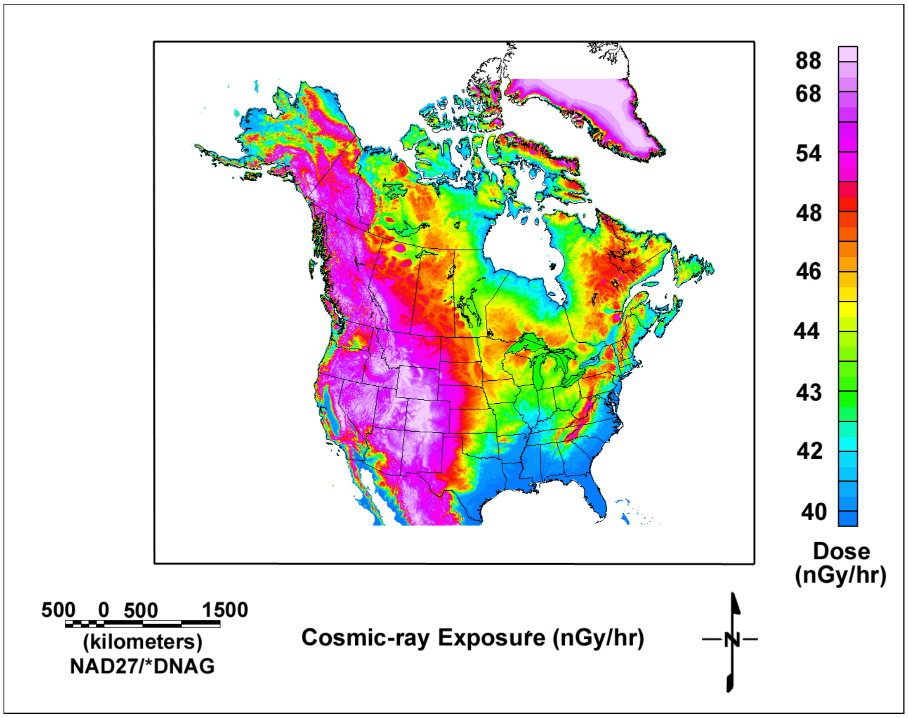

Figure 2-4 USGS Cosmic Ray Exposure

Image Credit: US Geological Survey [11]

3.0 ANOMALY DETECTION

While performing background radiation surveys, there is a chance of discovering areas that have elevated readings. The higher readings could be due to things like natural geologic formations, fertilizer, or construction materials and equipment, including devices using licensed radioactive materials, such as industrial soil density gauges. Before executing a background survey, SLTT jurisdictions should anticipate encountering elevated readings and develop appropriate procedures to allow for adjudication of anomalies in a way that does not disrupt the overall survey or unnecessarily burden emergency response resources (See Step 7 of the CONOPS for additional information). These plans for handling elevated or otherwise unusual readings should cover topics such as:

- Adjudication guidance for alarming equipment and anomalies, including identifying thresholds for when an anomaly requires notification or reach back to technical experts for further evaluation or emergency response
- Collection and recording of additional measurements to:
    - Verify elevated radiation measurement(s) with additional measurements (preferably collected using a second instrument)
    - Attempt to identify the source of the elevated readings (e.g., rock outcrop, building materials)
    - Identify location(s) with the highest readings
    - Identify the nuclide(s) present if a RIID is available
- Notification protocols and call trees
- Chain of command in effect
- Emergency response teams and operations, should there be a potential life-safety or security concern resulting from the adjudicated anomaly

4.0 SELECTING A SURVEY AREA

A background survey is a documentation of the radiological characteristics of an area before any radiological release happens. The first step to designing a background survey is to select a survey area. For the purposes of this document, a survey area refers to the geographical area where the background survey is performed.

A geographical area should be chosen with respect to the purpose of the background survey. If the purpose of a background survey is to inform PRND operations ahead of an event at a football stadium, the background survey area would most likely encompass the stadium, the parking lots, and any nearby neighborhoods. On the other hand, if the purpose of the background survey was to prepare for the consequences of a nuclear reactor release, the background survey area would most likely encompass a wide area surrounding the nuclear reactor. Similarly, if the purpose is to prepare for the consequences of an intentional act – such as the detonation of a radiological dispersal device – it might make sense to select city, county, neighborhood, or critical infrastructure boundaries to delineate a survey area. Those familiar with the Multi-agency Radiation Survey and Site Investigation Manual (MARSSIM) should be aware that there are differences between selecting a survey area for purposes of MARSSIM and selecting a survey area for a background survey [16].

- The MARSSIM begins with the assumption that a site or facility is contaminated, and the aim of the survey is to determine how much contamination is present and whether it has been adequately characterized and (later) cleaned up.
- A background survey, on the other hand, begins with the assumption that the area(s) being surveyed are not contaminated and the aim of the survey is simply to determine what levels of radiation are present.

Because of this, although the MARSSIM discusses at length how to select an appropriate background reference area to ensure that the “background” measured does not include contamination, this is not applicable when planning the surveys described here.

5.0 SURVEY AND SAMPLE METHODS

There are a variety of measurement methods that can be used to determine typical background radiation levels for a particular area.[2] They range from direct field measurements of the radiation exposure rate in units of micro-Roentgen per hour (μR/hr), to obtaining samples of soil, vegetation, or other materials sent to a laboratory for analysis to determine the isotopic make-up of the material in units of Becquerels per gram (Bq/g). When designing a background survey, planners should consider the mission for which they intend to use the data, since this will influence the type of measurement: exposure rate, radionuclide identification, or radioactivity.

For consequence management operations it is necessary to differentiate between those that occur immediately following an incident (i.e., response operations) and those taking place weeks, months, or years afterwards (i.e., recovery operations). While both types of operations require comparing data collected before and after the incident, responding to the incident calls for a different set of goals and actions than recovering from the incident. In general, background surveys intended for response operations benefit from exposure rate measurements, while recovery operations benefit from environmental samples that cover measurements for alpha, beta, and gamma radiation to inform remediation decisions.

Background surveys that will be used to inform response activities can be performed routinely using PRND instruments issued to and carried by personnel likely to be involved in a response. Background surveys that are intended to produce data that will inform PRND operations (see sections 1.1 and 1.2) typically have a greater focus on collection of direct gamma measurements to identify elevated hotspots. If a hotspot is identified, additional gamma-ray spectra may be collected using a RIID, or other spectroscopy-capable equipment, to identify the nuclide that is responsible for the hotspot(s) [17].

Surveying for Alpha Radioactivity:

Surveying for alpha radioactivity is time-consuming because it requires surveying at distances of about 0.25 inch at a very slow survey speed. In addition, there are very few places that have naturally elevated levels of alpha radioactivity, and most alpha-emitting radionuclides also emit weak gamma or x-ray radiation that can be detected with gamma detectors. Thus, performing background surveys for alpha activity is less important than for other forms of radiation unless the local geology is rich in alpha-emitting radionuclides (evidenced, for example, by very high radon concentrations).

[2] For the purposes of this document, "background survey" refers to the overall effort to characterize background radiation in an area by performing direct radiation measurements and by collecting samples for later laboratory analysis of radioactivity.

5.1 SELECTING SURVEY TECHNIQUES AND METHODS

In general, the techniques and methods used to collect data during a background survey should match those that would be used by responders conducting consequence management operations. This includes using the same instrumentation, configurations, measurement times, heights, etc., when possible. This also includes verifying the operability of the instruments prior to use by performing response or operability checks. The background survey should duplicate, as much as possible, the techniques and methods used during a response, which will benefit data quality assessment and improve the utility of the data when compared to measurements taken during an incident response.

With the exception of ionization chambers and energy-compensated Geiger-Muller (GM) detectors, most radiation instruments do not give accurate dose rate measurements for any nuclide other than the one with which they were calibrated. If the survey requires an accurate dose rate, consider performing the survey with an ionization chamber or energy-compensated GM detector. However, if relative readings (e.g., “hot spots” and “cold spots”) are sufficient, then most instruments will provide useful results, provided the same instrument is used for the entire survey.

Section 5.2 provides a summary of the types of equipment and surveys that are common during SLTT PRND and consequence management operations. Section 5.3 describes how some of these categories of equipment can be used to conduct a background survey, since the selection of equipment will impact the survey techniques and design.

Different radiation detectors and instruments will give different readings, even when they are held side by side. Part of the reason is that instruments are allowed to differ from the actual radiation level by 10% (the difference can be as high as 20% if a correction factor is provided). In addition, some instruments read out in count rates (cps or cpm) while others read out in dose rates (mR/hr or mSv/hr). The reason for these differences and some methods that can be used to correlate readings between different instruments are discussed in greater detail in section 8.3.1.

Maintaining Properly Functioning Equipment:

It is important to maintain properly functioning radiation detection instruments to ensure information obtained from the instruments is reliable. Since the background surveys will be performed in absence of an emergency, ideally the instruments will be calibrated according to the manufacturer recommendations and checked monthly or quarterly and prior to using.

1. Calibration requirements: Most calibrations will be performed by the manufacturer or other approved vendor. Calibration frequency is specified in the Owner's Manual for the instrument. If a jurisdiction anticipates using the results of a background survey for important decisions later (e.g., setting remediation goals, informing radiation injury compensation claims) then having a calibrated instrument may be preferred. (Note: Per NCRP Statement 14, annual calibration is not required for instruments that pass their monthly or quarterly response checks and that are not being used for regulatory compliance purposes [41].)
2. Battery Check: Before using an instrument, a battery test must be performed to ensure that there is enough power for the instrument to function properly. This will vary depending on the type of instrument.
3. Background Check: Background determination should be performed under conditions that replicate actual sample measurement conditions to the extent possible (i.e., similar sample containers or measurement geometry).
4. Check Source: Depending on the type of radiation that an instrument is calibrated for, a different check source may be required to check the consistency of measurements.

5.2 TYPES OF EQUIPMENT USED FOR PERFORMING RADIOLOGICAL SURVEYS

When planning to conduct a background survey, planners should review the types of equipment that would be available to them and, to the extent possible, design a background survey that matches the type of survey that would be done for a real-world emergency response operation. An added benefit to this approach is that it gives responders an opportunity to practice their emergency response techniques and procedures, all while collecting useful background characterization data. Several specific examples of the types of equipment used to perform surveys are explained below.

PRND operations typically involve equipment, such as personal radiation detectors (PRDs), which display results in count rates and sometimes also display exposure rate. If an elevated measurement is detected, spectroscopic/radioisotope identifying (RIID) equipment may be used to determine the radioisotope(s) responsible. The following list explains some common equipment types for PRND missions and provides a short explanation of when they are used [18] [19].

- **Handheld radiation instruments** can be used for exposure rate or contamination surveys but typically lack geospatial information to produce the continuous mapping that a backpack detector or mobile system and its software can offer.

- PRDs can be used like handheld meters to identify hazard zones and elevated dose rates, though handheld meters generally provide a more accurate response than PRDs at background radiation levels. Additionally, some PRDs automatically subtract background, which means the accuracy of the instrument reading depends on the success of the background subtraction algorithm. For this reason, PRDs are not generally used for conducting a background survey if there are other (better) instruments available.

- **Backpack radiation detectors** are best suited for areas within a facility/venue or for areas that are not easily accessible by vehicle. Most backpack systems are capable of radionuclide identification and may report dose rate or exposure rate in addition to count rate.
- **Mobile and aerial radiation systems** are great options for wider areas surrounding the point of interest and can be used to provide dense data sets of gross gamma counts. Most mobile systems have spectroscopic capability for radionuclide identification and also measure dose rate or exposure rate. They tend to be more sensitive than their handheld counterparts because of their greater volume. However, the greater sensitivity in aerial systems is somewhat offset if flown at higher altitudes. For example, the strength of the "signal" from a radioactive source measured at an altitude of 300 feet is 25 times stronger than the same source measured at an altitude of 1500 feet. In addition, large scintillation detectors such as those used in aerial systems do not always give accurate ground level dose rates unless they have been properly calibrated (for example, by using an altitude spiral). If data is recorded in counts per second by the mobile system, it will not be very useful during consequence management operations unless it is converted to exposure rates.
- **Gamma-ray spectroscopic instruments** can be used to identify the isotopes that are present in hotspots or general areas with radioactive contamination that produces a dose rate greater than two times the background. RIIDs using sodium iodide detectors are frequently used for routine radionuclide identification, while high purity germanium (HPGe) detectors can be used to collect high-resolution spectra of a found source that may be difficult to identify with other instruments. If conducting a background survey intended to inform consequence management missions, a HPGe detector will give the best energy resolution and has the best ability to identify individual radionuclides, while instruments with large sodium iodide (NaI) detectors, such as the 2-liter crystals used for many mobile, maritime, and aerial gamma spectroscopy systems, will give adequate energy resolution and much greater sensitivity to low levels of radiation compared to HPGe devices.

Compared to typical PRND operations, consequence management operations (i.e., response and recovery) will likely employ a broader range of survey types and equipment: first responders will conduct activities including identifying high exposure areas, such as the hot zone or dangerous radiation zone (measured in R/hr), tracking and monitoring responder radiation dose (measured in rem), and surveying for surface contamination (typically measured in gross-alpha or gross-beta readings in dpm/100cm^2). Additionally, physical samples taken from surfaces or the environment where radioactive material deposited, may be collected and sent to a lab for analysis.[3] More advanced equipment may also be deployed by the federal government or SLTT jurisdictions, such as a sensitive, high-resolution mobile detection device that measures nuclide activity or activity concentration (e.g., aerial measurement systems and gamma spectroscopy instruments).

The following are some common types of equipment used to support consequence management operations:

- **Handheld radiation instruments** can be used for a variety of purposes, such as determining dose rates, presence of contamination, and radionuclide identification. Surveys performed with handheld ion chambers, GM meters, or gamma-ray spectrometers can be used to correlate and correct aerial and mobile surveys and can be used for both indoor and outdoor surveys.
- **Backpack radiation detectors** can be used to survey for contamination deposition and hazard zones in areas that are hard to drive through or fly over. Backpack surveys are more practical for tight areas as they have GPS and can accurately and continuously record the dose rate and location for the duration of the survey.
- **Mobile and aerial radiation systems** can provide the largest coverage and can easily produce color-coded maps of the area. Having such surveys is important for determining the post-incident deposition footprint, and for quickly distinguishing hazard zones.
- **Radionuclide identifiers and spectroscopic detectors** can be used to identify radionuclides. Additionally, higher end HPGe detectors calibrated for gamma spectroscopy produce higher resolution spectra that can be used to identify radionuclides and quantify the radioactivity concentration in Bq per volume or mass of soil.

Lower Limit of Detection:

- The minimum detectable activity (MDA) or lower limit of detection (LLD) describes the lowest reading that can be considered reliable.
- Ensure the chosen instrument is capable of reliably detecting the desired level of radiation and that the MDA and LLD are lower than the amount of radiation that needs to be measured. This information should be readily available in the instrument's specification sheet.
- There are various ways to calculate LLD. Examples of LLD calculations can be found in Counting Statistics For Laboratory and Portable Instruments [42].

[3] Additional information on the types of surveys typically conducted during consequence management may be found in the Federal Radiological Monitoring and Assessment Center (FRMAC) Monitoring and Sampling Manual. [27] [28]

5.3 BACKGROUND SURVEY EQUIPMENT

This section provides an overview of how certain categories of equipment might be utilized for conducting a background survey. Each piece of equipment has pros and cons. For example, prices of the equipment can vary from relatively inexpensive thermoluminescent dosimeters (TLDs) or optically stimulated luminescent dosimeter (OSL) badges to aerial measuring systems aboard airplanes and helicopters that can cost tens or hundreds of thousands of dollars. Additionally, some equipment is better suited for covering large outdoor areas while other equipment is better suited for indoor areas. Table 5-1 provides a consolidated description of these types of equipment, as well as some considerations for their use.

PRND missions focus on localizing, identifying, and adjudicating the radionuclide as a threat or non-threat. If conducting a background survey intended to inform PRND operations, background spectroscopy measurements should be taken at the same location(s) where a suspected source may be found. The distance between the measurement and the source will vary, depending on the expected strength of the source and the sensitivity of the detector. For common spectroscopy-capable handheld PRND equipment (e.g., RIIDs and SPRDs), the distance would likely be fairly close to the source.

When consequence management missions use spectroscopic detectors, they focus on identification and quantification of gamma-emitting radionuclides. Note that in this context “handheld” refers to instruments that are too large to wear on one’s belt (like a PRD) but are small and light enough for a single person to easily hand-carry while collecting measurements. For example, a high-purity germanium (HPGe) gamma detector can be carried from place to place, but the instruments tend to be too large and too heavy to do so easily for extended periods of time.

Table 5-1 Pros and Cons of Instrument Types

Equipment Type	Pros	Cons	Price
Dosimeters (e.g., TLDs, OSLs)	Portable. Easy to use. Ability to place dosimeters in locations for long periods of time. Averages temporal variations.	A long passive survey time is required. High number of dosimeters are needed for the same spatial resolution as a mobile/aerial survey. As these can sit in locations for weeks at a time, a theft and tampering risk is present.	Low
Ion chambers (handheld)	Portable. Easy to use. Produce results that are useful to inform consequence management.	Most handhelds require manual data entry, but new versions of this equipment may allow for Bluetooth or other wireless connectivity to CBRNResponder or proprietary software.	Low
GM detectors (handheld)	Portable. Easy to use. Produce results that are useful to inform consequence management. Energy-compensated GM detectors provide accurate dose rate across a wide range of energies. “Pancake” GM detectors that give measurements in counts per minute (CPM) or counts per second (CPS) are useful for measuring contamination levels.	Most handhelds require manual data entry, but new versions of this equipment may allow for Bluetooth or other wireless connectivity to CBRNResponder or proprietary software. Results are gross counts (includes alpha, beta, and gamma radiation) with no distinction. Some GM detectors provide dose rates; however, they may not be very accurate at background levels.	Low
Scintillation detectors (handheld)	Portable. Easy to use. Produce results that are useful to inform consequence management. Ability to distinguish between alpha and beta radiation.	Not all SLTT agencies will have probes that can distinguish alpha and beta radiation. Determining the amount of beta may require additional work, which is described in NCRP 161 [20]. Most handhelds require manual data entry.	Medium
PRDs	Portable. Simple to use. Available to most responding organizations.	Some PRDs do not report in units of exposure, which is an important unit for consequence management operations. Generally, these instruments are less sensitive than the others in this table.	Low
Backpacks	Portable. Ability to move through crowds and tight spaces. Second by second data, often including GPS location.	May require more technical knowledge to analyze large data sets. Can be heavy and uncomfortable to wear for extended periods of time.	Medium

Equipment Type	Pros	Cons	Price
RIIDs (handheld) (low resolution)	Portable. Ability to identify radionuclide. Simple to use.	Energy resolution not as good as HPGe; may misidentify isotope(s).	Low
HPGe's (high resolution)	Ability to identify radionuclide with better resolution than RIID.	Heavier than the low resolution RIID. Must be kept cold internally (requires to be powered on continuously). Requires some technical knowledge to calibrate, maintain, and analyze data.	High
Mobile systems (ground)	Produce dense data sets that are geolocated. Sensitivity allows the ability to determine where background radiation changes.	Most systems have results in count rate. May require more technical knowledge to analyze large data sets.	High
Mobile systems (aerial; manned)	Produce dense data sets that are geolocated. Unhindered by terrain or other obstacles on the ground. Ability to determine the extent of dispersion.	Costly. Most SLTTs cannot fund their own system and dedicated aerial asset. Requires more technical knowledge to collect and analyze data.	High

5.3.1 Surveys with Dosimeters

Dosimeters, such as TLDs, present an inexpensive and relatively easy way to conduct a background survey over a long period of time (months to years), although there are some limitations. TLDs are an example of a passive type of dosimeter[4]: they do not display or indicate on the device itself if radiation is being detected but the dosimeters are instead sent to a laboratory for analysis. This significantly adds to the data processing time. Nonetheless, results from TLDs placed, collected, and read prior to an incident can be used to inform dose estimates and changes in low levels of exposure if TLDs are also used during the response for comparison.

TLDs are relatively inexpensive and can be obtained and analyzed through dosimetry companies, hospitals, or universities. TLDs require less technical knowledge to deploy than other survey equipment, and anyone can place them if the GPS coordinates of the location are accurately recorded. TLDs can be set up across an area, hung both indoors and outdoors, and left alone until they are ready to be collected and read. They can be placed at weather stations [21], traffic lights, government buildings, public transit hubs, or other areas of interest. If TLDs are used for background surveys, they should be placed in locations where they will not be disturbed or removed. Past studies that utilized TLDs typically placed them at a height of 1 meter above the ground, although rooftop locations were used for a few studies [22] [23]. One advantage of using TLDs is that they are capable of being used to monitor background radiation through all seasons; however, they require a robust container to protect them from environmental conditions like rain, humidity, dirt, etc.

When designing a survey that uses TLDs, there are a few limitations and challenges to consider. While TLDs can easily provide measurements in total dose, they do not have spectroscopic capabilities and cannot identify isotopes. In some past studies where TLDs were used to collect background measurements, not all dosimeters were successfully retrieved, as some were lost or stolen [24]. Results can also potentially be skewed by things like nuclear medicine patients sitting by the dosimeters for extended periods of time, radiography sources being used on construction sites nearby, or the seasonal fluctuation of background radiation. For these reasons TLDs may need to be occasionally checked for loss or damage and be exchanged every one to three months. For additional quality assurance, handheld meters should also be used at several of the TLD locations to compare results.

5.3.2 Surveys with Handheld Meters

Handheld meters have some advantages such as being easy to use, relatively inexpensive, and can be used both indoors and outdoors. Handheld meters are common among federal and SLTT response agencies, and surveyors may be able to borrow meters from places like law enforcement departments, fire departments, universities, and the state radiation control departments.

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[4] Radiation dosimeters can be generalized into two categories: active and passive. [45] Active dosimeters display real-time results. Passive dosimeters can detect radiation, but require another means to read the results, such as TLDs, which can only be read using a TLD reader. Both types of dosimeters could be used for background surveys.

The type of radiation that is detectable by a handheld meter will depend on the configuration, but detection of alpha, beta, and gamma, and even collection of spectroscopic data is possible. Standard PRND handheld instruments do not provide the most accurate dose results at background levels and are often limited to detection of gamma radiation. A pressurized ion chamber would give the most accurate background dose rates.

Though handheld meters are relatively simple to use, other drawbacks to consider are that most handhelds do not have GPS capabilities, so radiation data and GPS coordinates must be tracked either electronically (see section 7.3) or on paper for each survey location. However, more modern handheld devices can be paired with phone applications, such as CBRNResponder or proprietary software, that allow for datalogging, including GPS locations. If handhelds are used for a background survey, a survey grid should be formed (see section 6.3). Handhelds can also be used in conjunction with other survey methods to either calibrate mobile systems or to corroborate results from high-purity germanium (HPGe) spectra (see section 8.3).

5.3.3 Surveys with Backpack Detectors

Backpack detectors are relatively simple to use and are ideal for surveys in hard-to-reach areas such as inside of buildings and stadiums however, the results require more technical knowledge to analyze and process. Backpack operators can walk at a casual pace of approximately 0.5–1.0 m/s and some backpack detectors have a built in GPS and can record and map data in real time. Data can also be viewed in real time with a phone connected via Bluetooth to the backpack as well as be monitored remotely. Images of a facility's floorplan can be uploaded to proprietary software or CBRNResponder (see section 7.0) and users can easily map their surveys to specific rooms and areas to produce similar color-coded maps that aerial and mobile systems produce. For outdoor areas, backpacks can produce color-coded maps using the same software as mobile surveys. Most backpack detectors have gamma spectroscopy capabilities and can help identify the isotopes in any hotspots that are encountered.

5.3.4 Surveys with Mobile and Manned Aircraft Systems

For purposes of this guidance, the term "mobile" is used to refer to survey techniques using vehicles, boats, and other forms of ground transportation. While mobile and aerial (manned aircraft) systems are the most expensive, they are the most efficient option for background surveys as they can cover a large geographic area in a relatively short amount of time. Many mobile systems use NaI detectors and can map and record data in real-time, color-code measurements based on pre-defined thresholds, and place measurements on a map at the GPS coordinates where they were collected.

Mobile systems can provide near-real-time results in the field for dose rate and radionuclide identification. Newer models of gamma spectrometers can perform analysis for the user and do not require a working knowledge of gamma spectroscopy. Mobile surveys require at a minimum one gamma detector as well as a GPS system that allows for real time monitoring. Vehicles can be equipped with two sets of detectors, one on each side of the trunk, if interested in surveying both sides of the street. Mobile systems can be set up on ambulances [25] or other local vehicles like police cars and fire trucks. Detectors can be turned on while the vehicle is on shift and data can be pulled from the detector at the end of the shift. Detectors can also be mounted on the roof of a vehicle as seen in Figure 5-1. Figure 5-2 shows how detectors are normally stacked inside of a vehicle such as a van or truck. Mobile equipment can also be used for stationary measurements (e.g., to identify a radionuclide present in low levels), where the vehicle carrying the mobile system can be parked during the data collection.

Figure 5-1 RSI Gamma Detectors on Roof Rack

Image Credit: Radiation Solutions Inc. (RSI) [37]

Figure 5-2 RSI Common Truck Configuration

Image Credit: Radiation Solutions Inc. [37]

Aerial (manned aircraft) survey equipment can have many different configurations. Generally, manned aircraft setups use the same gamma detectors as ground-based mobile systems, however the aerial cases can typically hold more gamma detectors. An example of an aerial gamma case can be seen in Figure 5-3. A single gamma detector can be used for an aerial survey, but more are ideal. For aerial surveys, the gamma detector can either be mounted inside the plane/helicopter or outside the helicopter on the skids.

Figure 5-2 RSI Aerial Gamma Detector Case

Image Credit: Radiation Solutions Inc. [37]

Aerial surveys typically use a low-flying helicopter or airplane. A minimal survey team can consist of a pilot, who can turn the instrument on at the start of a flight and turn it off after the survey is completed, and a scientist or technician to whom the data is then sent to for later analysis and mapping; alternatively, data could be transmitted for analysis during the flight. If resources permit, a more efficient flight crew could consist of a pilot, copilot, and a scientist and/or technician to operate the instrument and interpret the data during the flight. The scientist/technician could help develop the mission plan/flight path for the team to fly and attend to equipment setup and troubleshooting. The scientist/technician can analyze and process the data, or this can also be carried out remotely by a "home" team on the ground.

Table 5-2 Typical Aerial Measuring System (AMS) Heights and Coverage

Method and Height	Area per Hour	Sensitivity (relative to 150')
Bell 412 150' (helicopter) above ground level (AGL)	10 km^2/hr	1
Bell 412 (helicopter) 300' AGL	20 km^2/hr	0.25 (1/4)
King Air 350 (fixed wing) 1000' AGL	100 km^2/hr	0.023 (1/44)

Table 5-2 shows the typical altitude and the average area per hour that U.S. Department of Energy (DOE) aircraft fly as well as the relative sensitivity of the instruments at each altitude. For example, doubling the altitude from 150 to 300 feet reduces the sensitivity to 25%. While the helicopter is typically flown at 150 or 300 feet above ground level (AGL), it can also be flown at a higher or lower altitude if desired. Helicopters flying at 150 feet AGL provide higher sensitivity and better area resolution than flying at higher altitudes. However, increasing resolution and sensitivity also increases the time needed to complete the survey. Aerial background surveys will usually try to fly patterns of closely spaced parallel lines and tighter line spacing provides more data and greater coverage. The area covered depends on the pilot's turn time: a slower turn can decrease the area per hour that can be covered.

It is important for aerial surveys to also use ground-based measurements to calibrate results for the greatest accuracy. To validate aerial measurements, high purity germanium detectors are used to identify isotopes (usually natural radionuclides like K-40, U-238, and Th-232) and their respective concentrations. To convert from a count rate (cpm) to exposure rate (μR/hr), a pressurized ion chamber (PIC) that is NIST traceable can be used to determine the exposure rate at 1 meter above ground, which can be compared to the aerial count rates at the same location. The PIC will detect contributions from cosmic and radon sources, whereas the aerial measurements could strip out these components [26].

5.4 BACKGROUND SAMPLE TYPES AND TECHNIQUES

Environmental sampling will be an important part of consequence management operations, specifically during late-phase recovery if there was widespread contamination. It may also be desirable to develop a background sampling plan in conjunction with the field measurements, to establish a baseline to compare future samples. Additionally, it may be helpful to have a sampling plan ready to investigate anomalous readings that are detected during the survey.

A well-executed and thorough sampling plan may involve taking a variety of environmental samples, such as soil and water samples. Some SLTTs may have predefined processes and procedures for collecting samples and not all samples will be processed and analyzed in the same manner. The FRMAC Monitoring and Sampling Manual [27] [28] provides the standard sampling techniques that FRMAC uses during recovery.[5] FRMAC techniques can be combined with already existing SLTT practices or fully adopted and used for collecting background samples. Like with survey techniques, it is best to use the same sampling process for characterizing background as would be used during a real emergency response.

Sample analysis will depend on the availability of suitable labs. State radiation control, public health departments, or local universities may be able to analyze the collected samples if they have the appropriate radiation analysis labs and expertise. If these resources are not available, samples could be sent to commercial or federal labs. The same people who are responsible for consequence management sampling operations should be engaged in the development of a background sampling plan.

5.4.1 AIR SAMPLES

Airborne radioactive material refers to any radioactive material dispersed in the air and can be in the form of dusts, fumes, particulates, mists, vapors, or gases. High- and low-volume air samples can be useful for providing the background airborne radiation and radon concentrations. The desired detection sensitivities will influence the selection of air sampling equipment. Low-volume air samplers are considered to have a flow rate less than 10 cubic feet per minute and contain filter paper or filter paper and a cartridge. High-volume air samplers have a flow rate greater than 10 cubic feet per minute and use filter paper or impactors. It is crucial to record the start and stop time of the air sample, the flow rate (or total volume of air collected), and the location.

When interpreting the results, both those collecting the sample and those assessing the data should be aware of when the air sample will be analyzed. Radon concentration in the air sample is greatest immediately after sample collection, then decays. After a period of 72 hours, virtually all the radon and thoron progeny will have decayed, so what remains in the air filter sample could be assumed to be long-lived isotopes of interest. [29]

[5] For additional FRMAC documents and manuals, visit their "Documents and Manuals" page.

Not all jurisdictions have air sampling equipment, and it is not necessary to plan and conduct a robust background survey. Incorporating air samples into a background survey, for those jurisdictions that have the equipment, will provide an opportunity for teams to get hands on practice, but the primary focus remains collection of gamma readings.

5.4.2 Soil Samples

Soil samples can be divided into three categories: ground deposition samples, soil samples, and core samples.

- Ground deposition samples are taken during the early phase of the radiological emergency, with the assumption that the contamination resides primarily on the ground surface and has had no or very minimal weathering or leaching into the soil. This type of sample includes soil, any vegetation, rocks, sticks, and other vegetative debris located directly above the soil.
- Soil samples are typically free of debris and vegetation and are used to determine the radioactive concentration of the soil. Soil samples are usually analyzed in laboratories. Generally, labs prefer to have the soil samples as uniform as possible.
- Core soil samples are soil samples taken at various depths to create a contamination depth profile. The depth of sampling will be dependent on the elapsed time since deposition, the porosity of the soil, and any potential interaction with precipitation or runoff.

It’s important to note that, in core samples, agencies reviewing sampling results may see some evidence of fallout from atmospheric nuclear weapons testing in the 1950s–1970s. Knowing the existing levels of certain radiological concentrations (Cs-137 or uranium isotopes) in background soil sampling in advance would be useful as a comparison to samples taken during an emergency (e.g., radiological dispersal device made with Cs-137).

5.4.3 Water Samples

Water samples can be collected from well water, surface water, rainwater, snow, and water treatment plants; however, the priority should be potable drinking water. Water treatment plants are responsible for purifying water to acceptable drinking water standards. Sampling at the intake and the outlet is sufficient. Intake samples will represent the quality of water before being treated while the outlet samples will represent the quality of water that is being dispersed for public use. These samples can be collected by water treatment plant personnel and mimic the standard regulatory samples they already collect on a routine basis to verify standards are being met. Municipalities test for combined Ra-226/228 plus gross alpha and beta concentrations regularly.

6.0 COVERAGE AND SPACING

The design of any radiation survey depends on the objective and what the survey is intended to accomplish. In this section two types of surveys will be discussed, each calling for a different survey design. One type of survey aims to determine the degree of variability in radiation dose rates across a survey area. This type of survey is most effective if the survey points are selected randomly, without a pattern. A higher level of variability requires a greater number of survey points to have confidence in how radioactivity is distributed across the survey area (both natural and manmade). A second type of survey aims to describe the radiation levels across a survey area, that is, to map radiation levels in that area. This sort of survey is most effective if performed methodically, using a grid of survey locations or by following a series of survey lines. (Note: even when using a grid survey approach, survey locations can be chosen randomly within the grid, or a random location can be selected to start with and then the grid can be established around the starting point).

6.1 DETERMINING THE NUMBER OF MEASUREMENTS

If there is some doubt as to whether the survey area has enough measurement locations to be representative of the area, some resources exist to help determine the answer. MARSSIM is an interagency document that provides guidance on appropriate reference areas and methods to adequately cover a survey area [16]. While MARSSIM was developed to characterize and track the remediation status of sites already suspected of being contaminated, some of its guidance can be adapted for a background survey. The DOE's Pacific Northwest National Laboratory (PNNL) developed a software tool called Visual Sample Plan (VSP) to assist in implementing the MARSSIM process where adequate survey and sample coverage is a requirement. VSP can be used to help determine sample and measurement locations within the survey area. It can also be used post-survey to determine data variability and whether more measurements should be collected within the survey area.

One could also determine the number of measurement locations by evaluating the equations directly, without the use of software. By solving for the number of measurements , one could determine the number of surveys and samples necessary to meet a desired percent confidence level [30] [31]. (See Appendix A for more detailed information.)

6.2 COVERAGE

Coverage refers to how many measurements are completed in the survey area. Coverage can vary considerably, depending on the intended objective of the survey. Survey areas may range in size from entire countries to individual buildings and facilities, while spacing and sampling locations are usually chosen at random, or at random locations within a targeted area.

Background radiation levels can vary from place to place, even if there is no contamination present. Greater variability in radiation levels calls for more locations to be measured to adequately characterize the survey area and increase coverage. (Note: See Step 7 in the CONOPS for guidance on how to determine if the survey area has enough measurement locations to provide adequate coverage using a statistical approach). Typically, a survey area that is homogenous and not highly statistically variable would require static measurements at approximately five to 15 random locations to provide useful statistics. The size of the survey area is not as important as the amount of variability in the data and the number of data points in the survey area. The number of survey locations might be the same for different-sized survey areas, provided the statistical variability of the survey results in the survey area is low. Five to 15 measurements may seem sparse; however, if the measurements are high-quality measurements (e.g., averaged over several minutes rather than a few seconds), they will be valuable for consequence management operations. Ideally, the five to 15 survey points will be in units that can be easily compared to protective action guidance as exposure/dose rate surveys are the most valuable to obtain. Those planning and conducting the survey should also consider performing contamination surveys for alpha, beta, and gamma radiation in areas with elevated exposure/dose rate readings.

Other types of surveys, such as mobile surveys, usually record data every second. When mapped, this data looks thorough due to the large number of data points and the high degree of coverage, although no single data point would qualify as a high-quality measurement. This data may also be more beneficial for informing PRND operations or identifying hotspots, as it may depict fluctuations over a very short geographic distance. However, if the counts per second of the mobile systems are not converted into useful radiation units (e.g., exposure rate), then the map will not be very useful for data assessors during consequence management operations.

Typically, most mobile systems will be accompanied by handheld exposure/dose rate surveys at random spots along the path to provide a calibration coefficient from counts per second to an exposure rate in μR/hr. When mobile systems are used, it is recommended that five to 15 random, static measurements still be collected to correlate the data and provide useful statistics. Coverage for the background survey area using mobile systems will vary depending on the mission and the time available to those performing the survey. Deciding to cover each side of the road, all major roads, or all minor roads in the survey area are just some of the decisions that would need to be made when using ground-based mobile systems. Another decision would be whether to cover every row at a football stadium or every five rows when using backpack systems. If using aerial systems, coverage of the survey area could be done rather quickly but will depend on the desired line spacing and altitude, which would need to be figured out in advance with the aerial crew.

6.3 SPACING

Spacing refers to the distance between surveys and samples within a survey area. There are several established techniques available for determining the spacing of measurements for surveys. MARSSIM suggests to randomly select a starting point within the survey area and then establish a systematic pattern. This systematic sampling grid may be either triangular or square. The triangular grid is generally more efficient. There are other ways to choose survey locations within the survey area, such as using completely random locations, or using random locations within a subdivided survey area where each subdivided area has one random location.

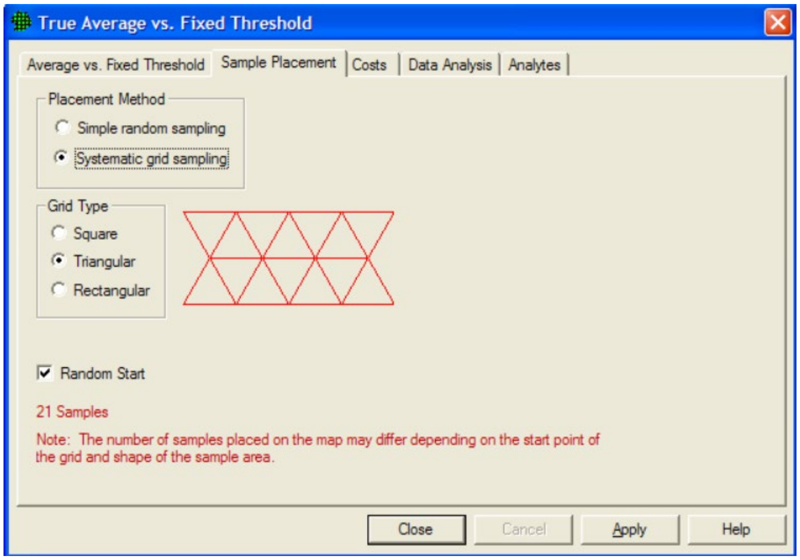

Figure 6-1 VSP Screenshot of Sampling Pattern

VSP is a tool that can assist in implementing sampling strategies and grid patterns, as seen in Figure 6-1. The user needs to create a survey area and then select the type of sample placement method (random or systematic) and the type of grid (square, triangular, or rectangular). The user can also select a random location within the survey area to start the grid pattern. Selecting a random starting location will assist in producing unbiased sample locations within the survey area.

Figures 6-2, 6-3, and 6-4 are examples of varying coverage and spacing within a survey area. The survey area in this case is the whole area encompassed in the screenshot. The blue dots represent sampling locations. Each example has 15 sampling locations. Figure 6-2 is an example of a survey area with good coverage, meaning that the majority of the survey area could be represented by a sampling location. However, the sampling locations appear to be random, as there is not a systematic grid pattern. Because the sampling locations are not in a systematic grid pattern, there could be large areas within the survey area that are not represented by a sampling location.

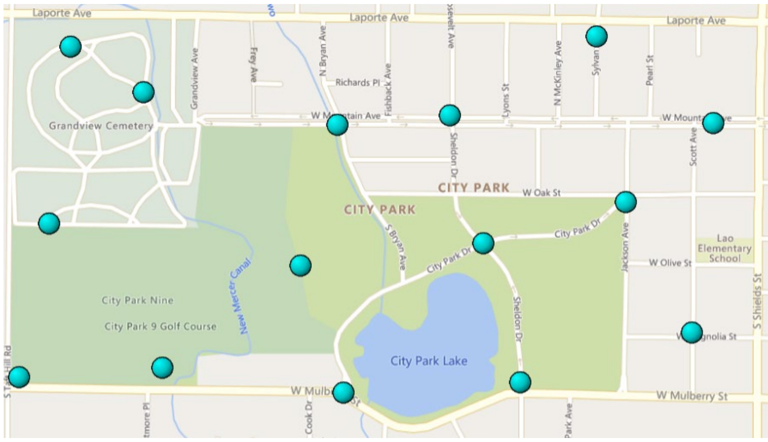

Figure 6-2 Example of Good Coverage and Random Spacing

Figure 6-3 is an example of a survey area with poor coverage, meaning that the majority of the survey area is not represented by a sampling location. However, the sampling locations appear to follow a systematic triangular grid pattern. The systematic triangular pattern is one of the best grid patterns to follow.

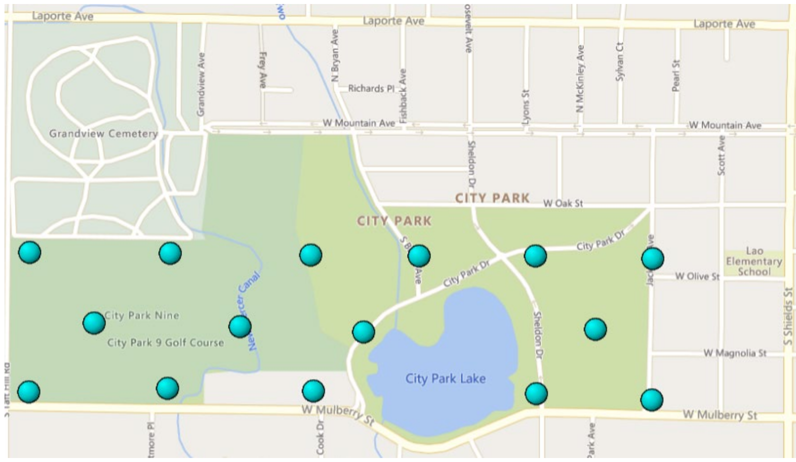

Figure 6-3 Example of Limited Coverage and Triangular Spacing

Figure 6-4 is an example of a survey area with good coverage, meaning that the majority of the survey area is represented by a sampling location. Also, the sampling locations appear to follow a systematic square grid pattern. This example is the best example out of the three presented.

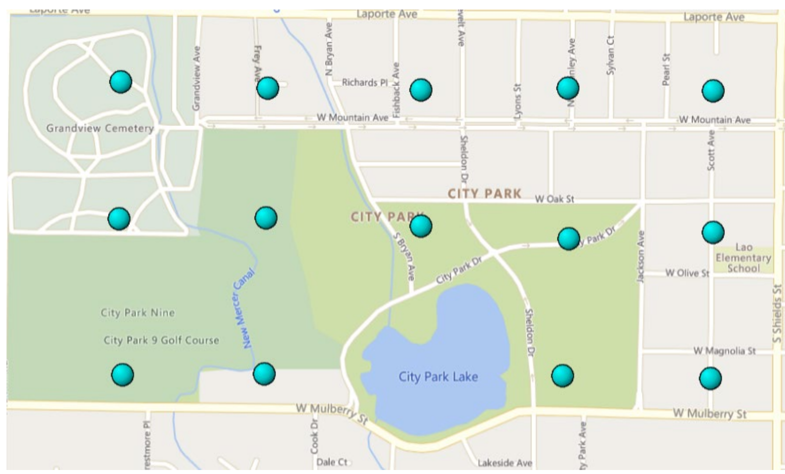

Figure 6-4 Example of Good Coverage and Square Spacing

For background surveys to inform PRND operations, spacing is usually based on accessibility to perform surveys and detection limits. For instance, if surveying neighborhoods, mobile systems are limited to surveying the streets where they have access to drive. Choosing to survey every five rows at a football stadium would be an example of spacing by detection limits. One could survey every row because they are accessible, but it could have been determined that the backpack system could detect anomalies up to five rows away. This is similar to aerial systems as they fly parallel lines within the survey area, where line spacing is determined by altitude and the field of view of the detectors. For instance, if a helicopter is flying at 150 feet AGL, the line spacing may be 300 feet to cover the field of view for the detector without missing any part of the survey area. Achieving a lower detection limit requires closer spacing of survey points or survey lines; conversely, a wider spacing results in a higher detection limit. Depending on the goals of the background survey, spacing of survey and sample locations may be specific, random, or selected to meet a statistical goal.

6.4 OUTDOOR CONSIDERATIONS

Performing surveys outdoors and recording the corresponding data may be easier than indoors because the GPS of the location is unobstructed. Agencies performing surveys should ensure that the locations are easily accessible to the teams collecting data (e.g., not located on private property or at a location with difficult terrain). If GPS does not function in urban areas, teams should ensure that they record location by other means. If no spacing was recommended, performing five–15 surveys spaced out as equally as possible within the area of interest is a good practice.

6.5 INDOOR CONSIDERATIONS

Indoor areas could have the most variability due to construction materials and radon levels. Surveyors should perform surveys on different construction materials and note the materials during data collection. As stated before, it is possible to record an indoor location and measurement data with CBRNResponder. Surveys should focus on the floors and walls in high traffic areas and be in locations that are easily accessible to the teams collecting data.

6.6 COVERAGE AND SPACING EXAMPLE FOR MOBILE SURVEYS

As mentioned above, aerial systems fly parallel lines within the survey area, where line spacing is determined by altitude and the field of view of the detectors. For instance, if a helicopter is flying at 150 feet AGL, the line spacing may be double the helicopter's altitude, approximately 300 feet, to cover the field of view for the detector without missing any part of the survey area. Achieving a lower detection limit requires closer spacing of survey points or survey lines; conversely, a wider spacing results in a higher detection limit.

To demonstrate coverage and spacing for a background survey using ground or aerial mobile systems, a 35-square-mile area covering a portion of Southern Las Vegas will be discussed as an example area.[6] (See Figure 6-5). This area includes residential and commercial areas as well as highways, parks, and some large open desert lots. Using GIS software, it is estimated that this area has approximately 750 miles of roads.

Figure 6-5 Example 35-Square-Mile Area in Las Vegas for a Mobile and Aerial Survey

Assuming that one mobile ground team is used, a total survey time would be approximately 25 hours, or 3 days of 8-hour shifts. This includes survey time as well as prep time, breaks, refueling, and other miscellaneous time. This total survey time also assumes that the average speed is 30 miles per hour or more and the team only drives one direction per street, i.e., east *or* west not east *and* west. Depending on the granularity of the desired survey, time and

[6] This is only a small portion of Las Vegas and the surrounding metropolitan area.

coverage could be reduced by limiting the surveys to main city streets. For background surveys intended to inform PRND operations before a major event, however, it is likely that all the neighborhood streets near the point of interest would be included in the survey. For this example, Table 6-1 shows the time for surveying this 35-square-mile sample area with a helicopter and plane. The plane flying at 1000 feet AGL can cover the area in the least amount of time, while the helicopter flying at an altitude of 150 feet AGL covers the area in nearly the same amount of time as a single ground mobile team, when considering total time. It is worth noting that, while flying at a higher altitude reduces survey time, it also reduces the sensitivity of the survey (as was shown in Table 5-2), failing to detect increases in local exposure rate that a lower-altitude survey would have noted.

It's also worth noting that calculating total aerial survey time must – like the ground team estimate above – take into account practical limitations; this is why a survey by helicopter could take the same total survey time as the ground team despite the flight-speed advantage of the helicopter. Based on helicopter speed and survey area alone, the survey time at 150 feet AGL would be approximately 9 hours. The helicopter however, will have to make fuel stops and pilots can only fly for a limited number of hours per day, considerations that add to the survey time. Adding in time for calibration over water, pre-, post-, and in-transit flight time, the total time is approximately 3 days. As part of the preparation for aerial surveys, time for calibration over water needs to be factored in so that the team can fly over a body of water and determine non-terrestrial gamma count rate for background corrections to survey area data. The 3-day estimate also accounts for pre- and post-flight checks, ramp time, climbing, descending, and transit time to and from the area of interest.

Table 6-1 Overview of AMS Survey Time

Method and Height	Survey Time (hours)	Total Time, including survey time, pre-, post-, calibration, and transit flight time (hours)
Bell 412 (helicopter), 150' AGL	9	20 (assume 3 days)
Bell 412 (helicopter), 300' AGL	4.48	10 (assume 2 days)
King Air 350 (fixed wing), 1,000' AGL	1.07	5

Figure 6-6 shows the line spacing for a King Air (plane) at 1000 ft. AGL and a speed of 270 fps. The accompanying table illustrates the flight details needed to calculate the aerial rate. Despite the line spacing, the aerial rate is the highest of all three options due to the speed on the plane.

Angle	1° from Cartesian X axis
Line Spacing	556 m (1820 ft)
Offset	
Area	88.8 km²
Line Count	14
Total Distance	157.7 km
Time	0d 1h 4m 26s
Turn Time	150 s
Speed	270 fps
Altitude	1000 ft AGL
Aerial Rate	**80 km²/hr**

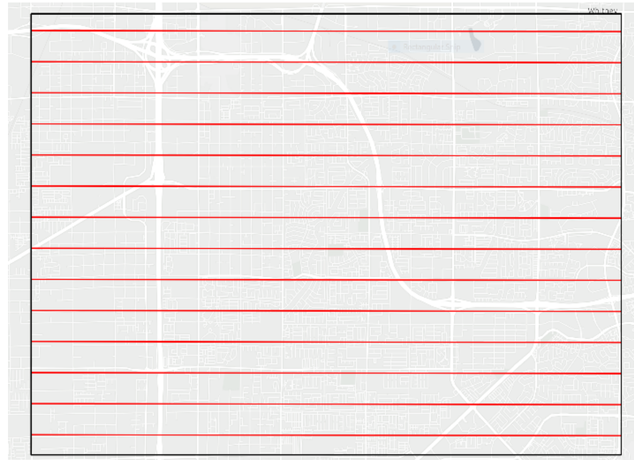

Figure 6-6: King Air Line Spacing and Coverage at 1,000'

Figure 6-7 shows the line spacing for a Bell 412 (helicopter) at 300 ft. AGL and a speed of 120 fps. The lines are spaced closer together than for the plane's survey and the speed and altitude are lower.

Angle	1° from Cartesian X axis
Line Spacing	182.9 m (600 ft)
Offset	.7
Area	88.8 km²
Line Count	43
Total Distance	484.3 km
Time	0d 4h 29m 42s
Turn Time	70 s
Speed	120 fps
Altitude	300 ft AGL
Aerial Rate	**20 km²/hr**

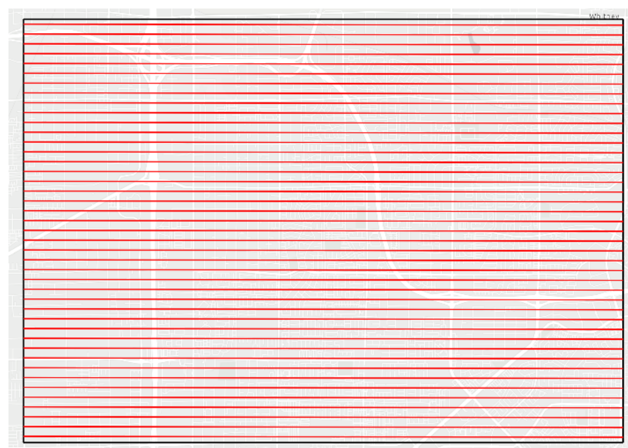

Figure 6-7 Bell 412 Line Spacing and Coverage at 300'

Figure 6-8 shows the line spacing for a Bell 412 at 150 ft. AGL and a speed of 120 fps. The speed and turn time stayed the same as the previous example; however, the altitude and line spacing was decreased by half, so the lines are even closer together.

Angle	1° from Cartesian X axis
Line Spacing	91.44 m (300 ft)
Offset	.8
Area	88.8 km^2
Line Count	86
Total Distance	968.7 km
Time	0d 9h 0m 34s
Turn Time	70 s
Speed	120 fps
Altitude	150 ft AGL
Aerial Rate	**10 m^2/hr**

Figure 6-8 Bell 412 Line Spacing and Coverage at 150'

7.0 DATA STORAGE AND VISUALIZATION

7.1 DATA VISUALIZATION

Multiple tools are available to assist in visualizing and interpreting background radiation data; the below is not an all-encompassing list. The tools included in this section consist of free software options, as well as those that charge for subscriptions. Depending on the desired results, not all the software options have equal capabilities. Different levels of training may be required based on the tool being used and the techniques being applied. Most have similar in visualization outputs. Statistical and data analysis packages provided by the software, however, are where the biggest discrepancies exist. For instance, if one would like to interpolate between data points, this capability exists in ArcGIS and Visual Sample Plan (VSP), but does not currently exist in CBRNResponder or Google Earth Pro.

7.1.1 CBRNRESPONDER

Mentioned previously in the data management section, CBRNResponder is a free software tool for emergency response organizations in the United States. Developed by FEMA, DOE/NNSA, and EPA, and enables FSLTT response organizations to rapidly, securely and collaboratively record, share, and aggregate large quantities of data. Many FSLTT agencies are already familiar with and/or use this software, which can be accessed the web as well as on smartphones and tablets (iOS, Android, Windows), making it seamlessly and rapidly employable at all levels of government during a radiological or nuclear emergency response. Besides the ability to store data, the user can also view the data on a map and set symbology based on user-inputted thresholds shown in Figure 7- 1. There are no statistical tools available in CBRNResponder; however, data can easily be exported to Excel for statistical analysis.

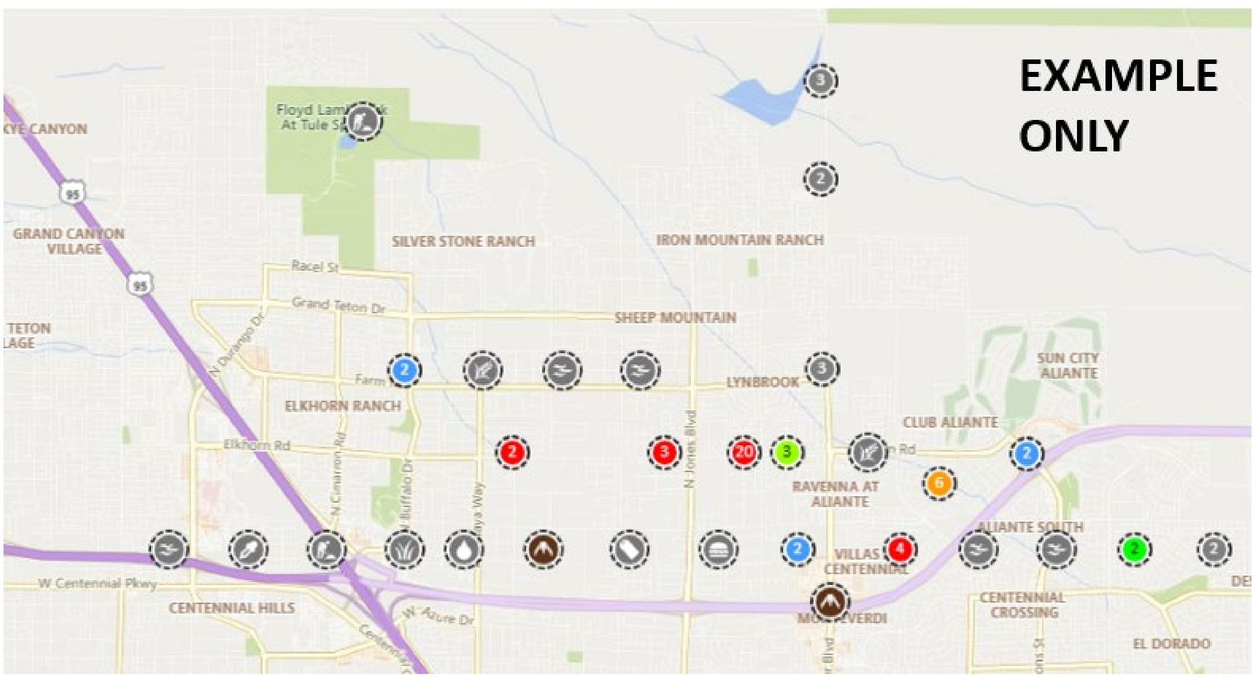

Figure 7-1 CBRNResponder: Example Data Visualization

Other functions available in CBRNResponder include:

- Data filtering
- Displaying different data layers
- Uploading and displaying GIS files (kml or shapefiles)
- Creating and sharing drawings

7.1.2 Other GIS Software

GIS software allows data scientists to create custom maps and perform geospatial analyses to help make smarter decisions. It is a constantly evolving blend of data, technology, analytical tools, and expertise. GIS can be used in a multitude of ways to examine patterns across geography and time. There are several desktop GIS software options that can be used to visualize, manipulate, and analyze geospatial data. These include:

- ArcGIS: from Environmental Systems Research Institute (ESRI), ArcGIS platforms – the traditional ArcGIS Desktop and the more recent ArcGIS Pro – run on Windows and offer a robust set of tools to perform advanced geospatial analysis. This tool is widely accepted and used in government settings around the world. ESRI charges a fee for a software license.
- QGIS: an open-source GIS software that is available for Windows, Mac, and Linux. It is a true desktop GIS that can perform advanced geospatial analysis and has an extensive library of plugins.
- Google Earth Pro: a free tool for users with advanced visualization and assessment needs, yet can be learned fairly quickly. This tool can be used to complement other GIS software, import and export GIS data, and create maps with advanced tools. Google Earth Pro can be used to visualize, assess, create/upload, or overlay geospatial data.[7]
- R: a free software environment for statistical computing and graphics that can also be used to create graphs and maps.

[7] A useful list of tutorials for Google Earth Pro has been compiled by the University of Ottawa and can be accessed at uottawa.libguides.com/GIS/GoogleEarthPro. [43]

7.1.3 Visual Sample Plan

VSP is a free software tool developed by Pacific Northwest National Laboratory (PNNL) [32]. VSP supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of measurements to support confident decision-making. This software is appropriate to use for all types of survey areas (outdoor background surveys, smaller outdoor areas, and indoor survey areas). VSP couples site, building, and measurement location visualization capabilities with optimal sampling design and statistical analysis strategies. VSP provides statistical methods to help determine the number and location of measurements to ensure that a surveyed area is characterized with an acceptable level of confidence. The value of using VSP increases with the quantity of collected data because of VSP's capability of analyzing existing data to drive monitoring and sampling plans to meet specific goals. Using VSP could improve the efficiency of measurement efforts and, as a result, reduce both financial costs and time spent [27].

7.2 DATA COLLECTION AND STORAGE SOFTWARE

A background radiation survey may log between 10's to 10,000's of measurement points, so using some form of software for data collection and storage is highly encouraged. Below are a few software programs to consider.

- CBRNResponder is capable of recording and storing data for both indoor and outdoor radiation surveys and can also track teams, equipment, and measurement data in real time. Survey routes can be assigned through CBRNResponder, and data can be reviewed, corrected, accepted, and rejected. Data and surveys can be stored long-term and can be easily found in the future to use as a reference. Section 7.3.1 provides more information on how to use CBRNResponder for collecting and mapping background survey measurements.
- RadSurv is an electronic survey system for completing and storing radiological surveys. Survey map templates provide an efficient way to configure maps for reusability and the system facilitates entry of dose and contamination measurements.
- Health Physics Assistant is an application developed by On Site Systems to meet the radioactive inventory and training history needs of radiation safety departments, along with dosimetry and procurement requirements of lab personnel who are using radioactive material for research. The platform is designed to help track contamination surveys and could be used for indoor areas [33].
- Visual Survey Data System (VSDS) is a software platform originally created for the nuclear power industry that allows users to record survey and sample data directly onto photographs and maps.

Other software programs include NuCare RAD IQGeoFinder and Bertin DataExpert10. SLTTs may also have their own software or databases that are already in use. The above options are not included to persuade SLTT organizations to abandon their current capabilities if those capabilities meet their needs; however, surveyors should use some form of software to electronically record and store all the survey and sample data for the background survey. The next few sections elaborate on what data this software should be capable of collecting.

7.3 RECORDING DATA FOR SURVEYS

Whether data is collected and tracked on paper or electronically, some key items must be recorded for each measurement, including:

- Date
- Time
- GPS coordinates
- Dose rate, exposure rate, or count rate with appropriate measurement units
- Distance of measurement from ground/object surveyed (if applicable)
- Comments about the survey location
- Instrument model and/or identifying number
- Weather conditions (e.g., snow, rain)

This information is important to track for purposes of future comparison, or in case there are any ambiguities or elevated readings that require further analysis. GPS coordinates are critical during background surveys so that known hot spots can be accurately recorded and anomalies can be adjudicated or further investigated. Depending on the instrument, measurements may be count rates, exposure rates, or dose rates and surveyors should aim to keep units consistent (e.g., mrem/hr, µrem/hr, mR/hr, µR/hr). Notes and comments can help explain anomalies or provide additional information about the survey location (e.g., next to a hospital or cancer clinic, construction). Data can also be saved in N42.42 format and easily shared with other agencies for analysis if necessary[8].

7.3.1 RECORDING SURVEY DATA IN CBRNRESPONDER

CBRNResponder provides the ability to track and enter data via the website or the mobile app and to visualize it in a geographic information system (GIS) environment. Data from mobile, aerial, or backpack surveys can also be uploaded in bulk via a spreadsheet using the CBRNResponder bulk upload feature. For every survey point, CBRNResponder requires surveyors to enter relevant information.

If using CBRNResponder, the background survey should be created as an "event" and the event should have a name, for example, "Jurisdiction Background Survey Month Year." If there are multiple teams being used for the survey, the teams and their respective assigned equipment can also be added to CBRNResponder. The date and time will automatically update to the current date and time, but this can be edited for older data. The app will populate the GPS coordinates of the current location automatically, or locations can be selected on the map or addresses, and GPS coordinates can be entered manually.

[8] The purpose of the N42 data format is to facilitate manufacturer-independent transfer of information from radiation measurement instruments. [44]

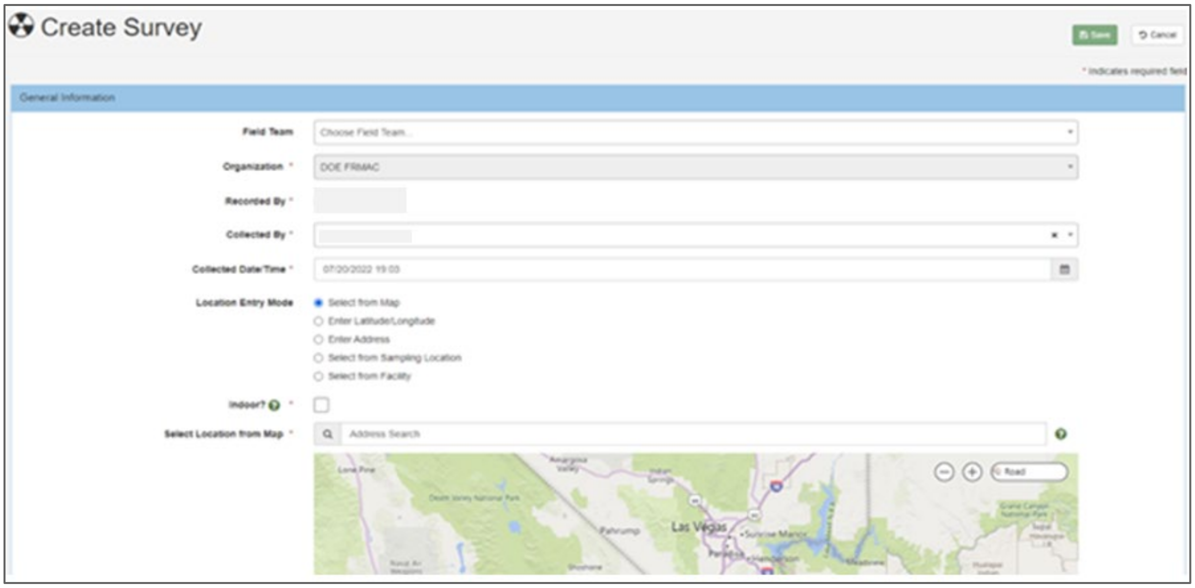

Figure 7-2 CBRNResponder: Creating a Survey Point

Additionally, CBRNResponder asks surveyors/data recorders to choose their meter and probe. If these are prepopulated for the teams, they will appear in the drop-down menu and will not allow a person to select the wrong instrument. The correct radiation type should be chosen for the survey. The value is then entered, and the appropriate units should be chosen for the value. Again, if the equipment is assigned to the teams, they will not be able to choose the incorrect units like cpm for a dose measurement with an ion chamber. Other information like height, distance from the source, and orientation of the meter can be chosen. Comments and any pictures of the location can be added. If spectra were taken at a hotspot, they can also be uploaded to CBRNResponder.

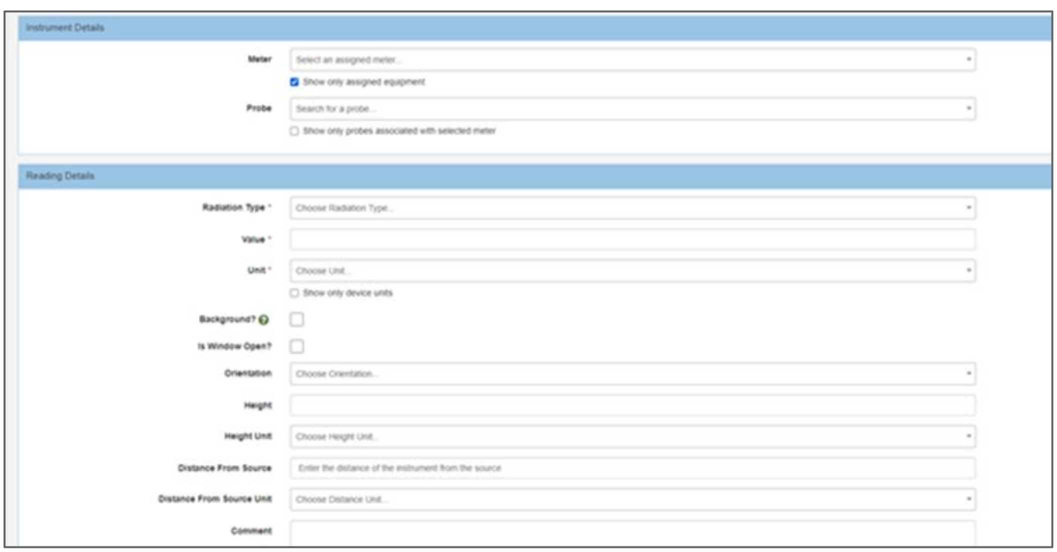

Figure 7-3 CBRNResponder: Entering Survey Details

As mentioned, CBRNResponder is not the only tool available and some SLTTs have their own software and can track and record their own survey data. If software is not available, a simple spreadsheet will be sufficient, with columns for the key items mentioned above. Spreadsheets can be uploaded to the software after they are completed. Hardcopies of the spreadsheets can also be printed and used if laptops, phones, and tablets are not available.

7.4 RECORDING DATA FOR SAMPLES

As with surveys, it is important to ensure accurate units are used for all samples. Depending on the sample type, units may be in metric or standard units. Keeping units uniform for the same types of samples can help prevent extra work in converting units later on. If standard time is used, ensure that a.m. and p.m. are used properly as incorrect times can skew results.

For every sample collected, the following should be adhered to:

- Ensure that a chain of custody form is completed for each sample
- Place a unique number or barcode on each sample
- Use the same sample control form for all sample types
- Record the sample collector's name, the date, time, and exact GPS location
- Record the exposure rate and contamination survey results for each sample
- For air samples:
  - Record the type of filter and/or cartridge that was used
  - Record the start and stop time of the air sample collection and the total volume collected or the start and stop flow rates
- For soil samples: Record the volume and the depth of the sample
- For water samples: Note the source of the water and record the volume

Most samples will have to be sent to radiological laboratories for analysis and it may take many days to weeks to get a sample result back from a laboratory. Reach out to state radiological health programs for assistance in finding a suitable laboratory. Before collecting samples for the background survey, it is advisable to consult the radiological laboratory to ensure that the laboratory can handle the influx of samples and that the sample containers are compliant with their processes. Again, proper labeling and tracking must be used to prevent samples and results from getting mishandled. Lab results will usually be sent in an electronic data package and most sample results are reported as radioactivity concentrations. If necessary, some data analysis will be performed to convert the concentrations into dose rates.

Lab results will have to be added to the electronic data storage for the background survey to allow others to readily access them. Ideally, this electronic data storage will be the same software that contains the rest of the data from the background survey. For more information on how to do this using CBRNResponder, see Step 6 in Part 2: CONOPS.

7.5 DETERMINE SUMMARY STATISTICS

7.5.1 PRE-SURVEY DETECTOR STATISTICS

It is prudent to understand the instrumentation before it is used for the background survey or in a response. Determining basic statistics (e.g., typical radiation exposure rates, count rates, variability of these values over time and across broad areas) for each detector system is advantageous. Some detectors yield results that are noticeably variable while at the same location. It is suggested, at a minimum, to determine the average background reading and the standard deviation of each detector system in a controlled environment.

7.5.2 POST-SURVEY STATISTICS

The average and standard deviation for all the results in the survey area should be determined to help summarize and assess the uniformity of the results. If the survey area is large and encompasses multiple terrain changes and climate differences, it may not be appropriate to determine the average and standard deviation from all the locations. Statistics for a subpart of the survey area would be more appropriate. For example, if the background survey was done for the state of California, which has a large area and encompasses different terrain and climate patterns, it may not be appropriate to combine survey data from coastal areas in the south with survey data collected in the mountainous north. Regional statistics would be more appropriate in that case.

7.6 DATA REVIEW

After data is collected, it should be reviewed. A data review should include checks to verify that the detector systems were working properly, the results are reasonable, and that the data collection records are complete. Some simple quality control or quality assurance checks include:

- Measurement/sample matches the assignment
- Proper meter/probe was used
- Measurement/sample is taken at the proper location
- Measurement/sample date and time are correct
- Measurement/sample raw value is reasonable
- Measurement/sample result is reported in the proper units
- Measurement result unit prefixes are correct (e.g., kilo, milli, micro)
- Uploaded pictures/spectra/files are confirmed to be attached

Data review plays a crucial step in producing a good background survey. For instance, some buildings and bridges can contain higher amounts of NORM than surrounding structures. Once the data is reviewed and it is verified that the dose rates are higher due to the NORM in the structure, this can be documented and referred to in the future. This will save time and resources by avoiding having to repeat the analysis to verify that the hotspots are caused by NORM in the structures, and they are not something that they need to investigate further.

Data review is also crucial because inaccurate and erroneous data can potentially cause confusion if used for comparison during a real-world event. For example, if a city is hosting the Olympics and the background dose rates around the facility have accidentally been reported to be higher than they truly are, Olympic survey teams may ignore or take longer to notice higher readings there. They could attribute it to the false high background readings that were previously recorded there, when in fact the higher dose rates are due to nefarious material. As another example, assume dose rates are incorrectly calculated from the activity concentrations of a soil sample, which causes dose rates to be reported as lower than they really are. If there is an actual release of material from a nuclear reactor, remediation could try to achieve a lower result than possible, and this could keep an area closed permanently or much longer than needed.

Because mobile systems can quickly acquire a significant amount of data, data review is typically not performed on each individual measurement. The data review is usually done through visualization of all collected data and color-coded data based on either pre-defined or statistical based thresholds. This way, it is easier for the data analyst to visualize outliers in the data and focus on data that needs attention. Outliers in the data require a more in-depth data review to understand the underlying cause of variability. Section 8 includes more information on the data assessment process.

8.0 DATA ASSESSMENT

The ultimate goal of any radiation survey is to make use of the data that was collected. This requires assessing the data for accuracy and to confirm it is adequate to answer the intended question(s), such as, are there any localized hot spots in the survey area, or are there a sufficient number of measurements to characterize the area? Data assessment need not be performed by the same person(s) who collected the data; for example, radiation surveys performed by the police department might be assessed by scientists in the state or local health or environmental department. Regardless of who performs it, it is important that a data assessment takes place. Described in this section are several ways to examine the collected data and better understand what it means, including determining the summary statistics, accounting for expected variability over time and over the area surveyed, and correlating readings collected with different types of radiation detectors from the air or from a moving vehicle with the actual radiation dose rate at a fixed location on the ground.

8.1 SPATIAL AND TEMPORAL VARIATIONS

To understand the significance of a “hot spot,” the person reviewing the data must be able to determine what caused radiation dose rates to be higher at that location than elsewhere (e.g., geology, local land use, terrain). Radiation levels can change over time, in ways both expected and unexpected. Because of seasonal differences in soil moisture, snow cover, and radon, for example, background exposure rates will vary throughout the year. Heavy snow cover will act as a shield, reducing the radiation dose rate compared to readings in the summer when the ground is bare; rain, on the other hand, can wash radon decay products out of the air and onto the ground where they will give a short-lived spike in measured radiation levels [12]. In addition to these predictable changes, radiation dose rates might also change due to changes in land use and construction that occur from year to year. Even something as minor as changing fertilizers can cause radiation levels to change from one year to the next as some types of fertilizer are made from raw materials that have different levels of natural radioactivity.

Depending on the detection systems employed, spatial and temporal variances may be statistically insignificant, or they may be readily apparent. Measurements from an integrating dosimeter such as a TLD that are read quarterly may help provide a seasonal average, effectively smoothing out variations in background radiations that occur over periods of hours and days. A stationary ion chamber, however, taking continuous measurements for the same time as the TLD would reveal hourly variations, and by averaging thousands of measurements, would have smaller uncertainties for the quarterly and hourly average than that derived from the TLDs.

8.2 BASIC CORRELATION OF MOBILE TO STATIC MEASUREMENTS

If collecting data using a mobile system, the results may be in units of counts per unit time (e.g., cpm or cps) and will need to be converted to dose rate units (e.g., mR/hr). The process to create a basic calibration curve to convert from count rate to exposure rate is found below. While the process to convert count rate systems to exposure rate with precision is quite involved, this basic technique is simple enough to use during emergencies and can be used for a background survey if the available resources, time, and/or technical expertise are limited.

Calibration Curve Creation Process:

1. Perform a "dwell" measurement in which the mobile system is stationary while collecting data. (i.e., until the reading stabilizes, which typically takes around 15 seconds).
2. Take an exposure rate measurement at about 1 meter above the ground at the dwell location with a different instrument such as a calibrated ion chamber.
3. Record the results and location.
4. Repeat Steps 1–3, at five to 15 additional locations that have varying amounts of radioactivity.
5. Determine the average dwell count rate at each location.
6. Determine the average exposure rate at each location.
7. Determine the ratio of counts per exposure rate at each location.
8. Plot results on graph and determine a regression line (this can be done in Microsoft Excel). The equation to the regression line is the conversion factor for the data set.

The caveat to this method is that it is only valid for the gamma-ray energy of the calibration source if the instrument being used is a Geiger counter or a scintillation detector. (Ion chambers and energy compensated Geiger counters do not have this problem.) Hence, if each dwell location was at a background level with no variation, then the method would only be valid for background levels. This method could be tested if the user has access to radioactive sources to create non-background variability in the measurements.

8.3 CORRELATION OF PERTINENT DATA

If multiple data types are collected at the same location and time, it is possible to correlate the data types. Such correlations are useful to understanding how data collected during an aerial radiation survey can be used to determine the actual radiation dose rate at the surface. Correlation might not be necessary if the data will only be used qualitatively (i.e., only to show "hot" and "cold" spots). Some useful types of data correlation are as follows:

- Aerial surveys to stationary ground-based data
- Aerial surveys to mobile ground-based surveys
- Mobile surveys to static exposure rate meter measurements
- Exposure rate surveys to contamination surveys
- Exposure rate to soil samples
- HPGe in situ measurements to soil samples

There are many combinations that can be correlated, but survey data analysts should choose combinations that would alleviate the burden of data collection. For example, correlating exposure rate surveys with mobile survey data would enable data analysts to determine exposure rates on a second-by-second basis, which may save time for the field teams.

8.3.1 Correlating Mobile and Aerial Data with Static Measurements

Mobile and aerial survey results need to be correlated with static measurements, which will likely require expertise that most SLTT jurisdictions do not possess. For this reason, these correlations are typically performed by federal agencies. SLTT teams, however, may decide to collect the mobile/aerial and static measurements and request assistance from federal partners with correlation, depending on available resources.

When performing vehicle surveys, for example, correlating mobile measurements with static ones requires also taking into account that the car's body acts as shielding for the detectors it carries. The shielding factor can be calculated and applied to the car's detectors once dose rates have been collected both inside and outside the car and those rates have been compared. To collect that data, background measurements can be taken with a handheld meter at the same location as the car. Similarly, dose rates can be measured with handheld ion chambers at different location points along the mobile route outside and inside the car. A radioactive check source can also be placed outside the vehicle and measurements can be compared between both the mobile and handheld detectors.

Aerial surveys require a similar process of collecting additional static measurements before making correlations. Aerial surveys are likely to fly over a body of water first to determine the cosmic radiation dose. In this case, the body of water acts as a shield and shields the terrestrial radiation. Cosmic radiation also changes with altitude so determining cosmic radiation levels at different altitudes is important, especially if the aerial survey is performed at varying altitudes. Cosmic radiation can be determined and subtracted out when recording ground measurements for the survey. Alternatively, ground and aerial dose rates can be measured at the same point. To collect the necessary static measurements, aerial surveys fly a line synchronized with a ground team, usually one equipped with a large handheld pressurized ion chamber (PIC), which is highly sensitive to low background rates. The PIC is placed one meter above the ground on a tripod while it counts and determines the dose rate. Using the additional dose rate measurements, SLLT's could determine and apply a correction factor, similar to the car's shielding factor, to their aerial results, yielding more accurate aerial measurements. Further AMS calibration procedures can be found in "AMS Ground Truth Measurements: Calibration and Test Lines" [26].

Once all needed measurements have been made data is ready to be compared and correlated. SLLT's are encouraged to use geospatial software, such as ArcGIS, to assist with this process. The first step to comparing and correlating data is to ensure that the data is conveyed using the same units; this may require conversion. When comparing count rate from an aerial mobile system with the count rate of a ground-based mobile system, the count rates for the same area will be different because of the altitude differences and detector setup. A conversion factor between an aerial system and mobile system can be determined but may be difficult to calculate because the measurement locations will not necessarily align between ground- and aerial-based surveys. Determining spatial proximity between the ground and aerial data would be time consuming, yet necessary. Determining a location for a test line or a survey area that both aerial- and ground-based units can easily survey multiple times would be helpful to determine correlation factors.

As mentioned previously, calibrating mobile and aerial systems to convert from a count rate to an exposure rate at a meter above the ground is recommended for surveys that are intended to produce quantitative data. When that calibration is complete, mobile data, aerial data, and static measurements can all be compared on the same map in a geospatial software program. Setting the map symbology for values from all three survey types allows for a visual comparison of the measurements to determine if they are similar. This data visualization may be the easiest and quickest way to determine how well the data are correlated. The next step is to determine the correlation coefficient between the mobile, aerial, and static survey data, which can be done with many widely available statistical software packages.

9.0 FEDERAL ASSISTANCE

SLTT agencies can request federal resources to help complete or update a background radiation survey. Having SLTT agencies and federal partners work together to accomplish a survey will have additional benefits, such as fostering collaboration and strengthening relationships. Jurisdictions can request support from the Radiological Assistance Program (RAP), Aerial Measurement System (AMS), Department of Homeland Security Mobile Detection Deployment Program (MDDP), EPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT), or the National Guard Bureau's Weapons of Mass Destruction-Civil Support Team (WMD-CST). Often, these resources are deployed to support drills and/or plume phase or ingestion pathway exercises for states with FEMA-compliant Radiological Emergency Preparedness (REP) programs for nuclear power plants. Leveraging these federal response assets during drills and exercises that have a data collection component may be a more efficient strategy for some SLTTs to help complete or update a background survey.

10.0 CONCLUSION

This technical guidance provides information for SLTT responders and planners designing a background radiation survey. Characterizing background radiation in advance of a particular threat or emergency can assist with execution of both PRND and consequence management goals. While this technical guidance discussed different type of surveys, equipment, data collection and data storage options, it is intended to present options and encourage SLTT planners to make use of the equipment and training currently available to them.

Accompanying this technical guidance is a CONOPS, which walks SLTT planners through the major steps involved in designing a background survey. The CONOPS provides three scales of surveys: quick and simple surveys, moderate surveys, and advanced surveys. Each of the steps in the CONOPS can be completed with limited equipment, personnel, and expertise or scaled up by using more specialized survey equipment and trained personnel.

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BACKGROUND RADIATION CHARACTERIZATION SURVEYS

PART 2: CONCEPT OF OPERATIONS (CONOPS)

1.0 PURPOSE

This document is for first responders or planners working for state, local, tribal, and territorial (SLTT) governmental agencies designing and conducting a background radiation characterization survey (hereafter a "background survey") of a defined area(s). The purpose of such surveys is to characterize background radiation levels, identify hot spots, assist with preventative radiological nuclear detection (PRND) operations, and provide data that can be compared to future consequence management operations.

After a radiological or nuclear emergency many people may be evacuated. Agriculture, grocery stores, public spaces, and more may be affected. It will be necessary to perform radiological surveys to demonstrate that homes are safe to reoccupy, that fields are safe to use for pastures, and that public buildings and spaces can be used for work and recreation once again. To understand exactly how much contamination is present and whether the contamination has been cleaned up effectively, these post-incident radiological surveys can be compared to prior background surveys (such as those discussed in Part 1 of this document). Having a good background radiation survey will help with this comparison by showing the location of pre-existing areas with elevated radiation levels. This CONOPS outlines how to perform one.

The guidance contained within this document is designed to be scalable so that those planning and executing the survey may choose an option that best matches the available and/or desired level of technical knowledge, equipment, and survey complexity. It is not possible to describe in detail how to conduct this type of survey for every model of radiation instrument that could be used. This CONOPS assumes organizations will perform background surveys using instruments that are already available as a part of their existing PRND or consequence management (response and recovery) capabilities.

This CONOPS is also designed to be implemented by responders/planners with a broad range of knowledge, from patrol officers with a basic understanding of how to use a personal radiation detector (PRD), to technical experts with formal training on more advanced detection systems. The CONOPS assumes that the personnel using this document have been instructed on how to properly operate the instruments they will use. While this CONOPS provides direction for a range of survey approaches and complexity, it does not provide all the technical details and instruction needed, especially for the more advanced survey options.

2.0 SCALABILITY

Each of the steps in this CONOPS can be completed with limited equipment, personnel, and knowledge or scaled up by using more specialized survey equipment and better-trained personnel. The intent of this CONOPS is to help design a background survey that will produce helpful background data, regardless of its scale or complexity.

This CONOPS provides three scales of surveys: quick and simple, moderate, and advanced surveys. To demonstrate what might be needed as the complexity of the background survey increases, below is a list, though not an all-inclusive one, of training that may be required at each scale. Additional examples of how each step in the background survey process might vary at each scale of survey are described in section 3: Process.

- **Quick and Simple Surveys:** Any training needed for a quick and simple survey is minimal. The training should include how to turn the instrument on/off and how to read and record the results from the display. An example of a quick and simple survey is one or more police officers with PRDs recording the instrument readings as they walk or drive within the survey area.
- **Moderate Surveys:** Training needed for a moderate survey could include instruction on how to use and operate more specialized equipment and how to read and record the results. An example of a moderate survey is state environmental protection department technicians surveying an event venue (e.g., state fairgrounds) using a combination of handheld ionization chambers and radioisotope identifiers (RIIDs).
- **Advanced Surveys:** Training needed for an advanced survey could include classroom instruction time, training courses or specialized degrees. This will require a more advanced understanding of how to use and apply the detection systems or specially trained individuals, such as pilots using an aerial monitoring system. An example of an advanced survey is trained radiation safety professional(s) operating an aerial radiation system while flying a survey to map surface radiation levels across part or all of a city, then using aerial radiation dose rates to convert their readings to accurate surface radiation exposure rates.

Note that the different scales of surveys can build on each other; meaning that even if an advanced survey is completed first, the data from a quick and simple survey and a moderate survey could still be documented and used and, if appropriate, the data from all survey types can be correlated. (See section 8.3 in the Technical Guidance.)

3.0 PROCESS

This section describes the process – including the question(s), key decisions, and goals – for each step of planning a background survey. The actual survey design may vary due to the availability of the equipment and personnel, the amount of data collected, and evaluation of the results. The eight steps of the survey design process are illustrated below:

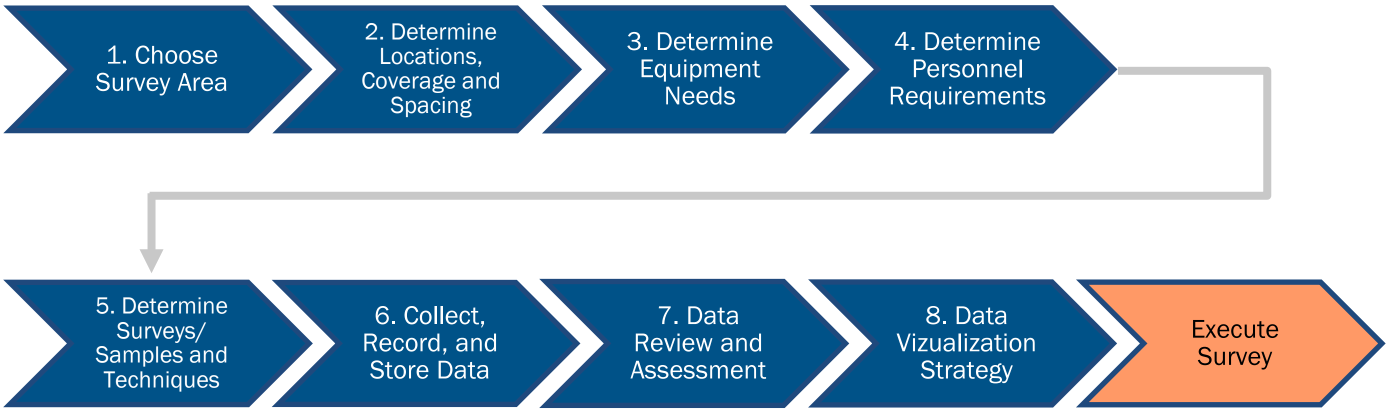

Figure 3-1 Survey planning process flowchart

Each step in the process has a similar layout in this CONOPS document and consists of:

- Topic question(s)
- A brief discussion
- An example survey

The discussion sections mainly focus on completing a quick and simple survey as those with more advanced detection systems can presumably apply these same concepts to their situations. If users of this document need assistance with the detection equipment, they should contact the manufacturer of the equipment for more information on its use and function.

The example survey used to explain the process is based on the following assumptions:

- The background survey is being performed in an urban area
- The organization has the equipment and personnel available to perform the radiation background survey

Note this example is for informational purposes only and may not address a planning scenario that is relevant to all organizations. While this example does not use real data and does not reflect the views or resources of any SLTT agencies mentioned, the concepts and processes it illustrates can be used to plan for and complete all three scales of background surveys.

STEP 1: CHOOSE AN APPLICABLE SURVEY AREA

- **Question:** What are the boundaries for the background survey?
- **Key Decisions:** Determine how large the survey area should be and what areas it should include.
- **Discussion:** The background survey should ideally be in the same general location that might be affected by a radiological release and/or have very similar characteristics as the location where a release could happen. A geographical area should be chosen with respect to the purpose of the background survey. If the purpose of the background survey is to prepare for PRND or consequence management operations following a possible release at a special event, the survey area may be more limited. If it is being done to characterize typical background measurements for a city, town, or jurisdiction, however, the area may be a lot larger. (See section 4 of the Technical Guidance for more information selecting a survey area.)

  When choosing the size and boundaries of the selected area, consider the following:

  - What existing zones (the town boundaries, city limits, county lines, etc.) or natural boundaries (such as rivers, streams, mountains and shores) could be used to define the area?
  - Is there critical infrastructure such as schools, hospitals or agricultural areas that should be included?

Quick and Simple Survey	Moderate Survey	Advanced Survey
• Use the town/city limits as boundaries for the background survey. • Alternatively, create a circle around the point of interest to serve as the boundary for the background survey.	• Use the existing zones and ensure critical infrastructure, such as nearby hospitals and schools, are included in the background survey. • Use each zone as its own smaller survey area to help divide the whole background survey area into smaller sections.	• Ensure the area is large enough for an aerial survey. • Work with other organizations to ensure the survey area is adequate for different survey/sampling methods.

Figure 3-2 Suggestions for choosing survey boundaries at three levels of complexity

Determining survey area boundaries is subjective: there is no “correct” size or method to determine the survey area. Practically speaking, the area shouldn’t be so large that it will be difficult to survey, but it shouldn’t be too small either, otherwise it will not be representative of the entire area.

When choosing boundaries, consider which areas would be impacted and/or surveyed in the event of a release of radioactive material to help determine which general areas need to be included in the survey. In some cases, there may be pre-existing zones, districts, or neighborhoods to use as boundaries, or consider creating boundaries to include critical infrastructure, community reception centers, agricultural areas, and population areas. Once the survey area is determined, the boundary lines around the survey area can be drawn.

Should I conduct one giant survey or multiple smaller surveys?

Next, consider the size of the chosen area. A background survey of a large area could take a considerable amount of time and personnel to complete; however, it does not need to be completed all in one day or at one time. Breaking up a large area can make it easier to complete the survey by tackling it in smaller portions over multiple days or with multiple teams. Results from each smaller survey should be added to any previous background survey results until the entire background survey area is covered.

It is important that the same instruments are used to take all measurements throughout a survey area (i.e., the same instruments should be used in each of the smaller zones). Surveys must also be conducted in similar weather conditions. (Thinking through impacts of weather conditions is discussed further in the example following Step 2: Determine Coverage, Spacing, and Locations.)

Example: In the example, the survey area boundary is already determined. Figure 3-3 shows the outlines of six zones for an urban area survey. The zones were created using city limits, major roadways, waterways, and natural geologic formations. Property types within the zones may include residential, commercial, and recreational properties. Each of the six zones will be treated as a separate survey area, which will be important for deciding survey and sampling locations. This is discussed in more detail in the next section, Step 2: Determine Coverage, Spacing, and Locations.

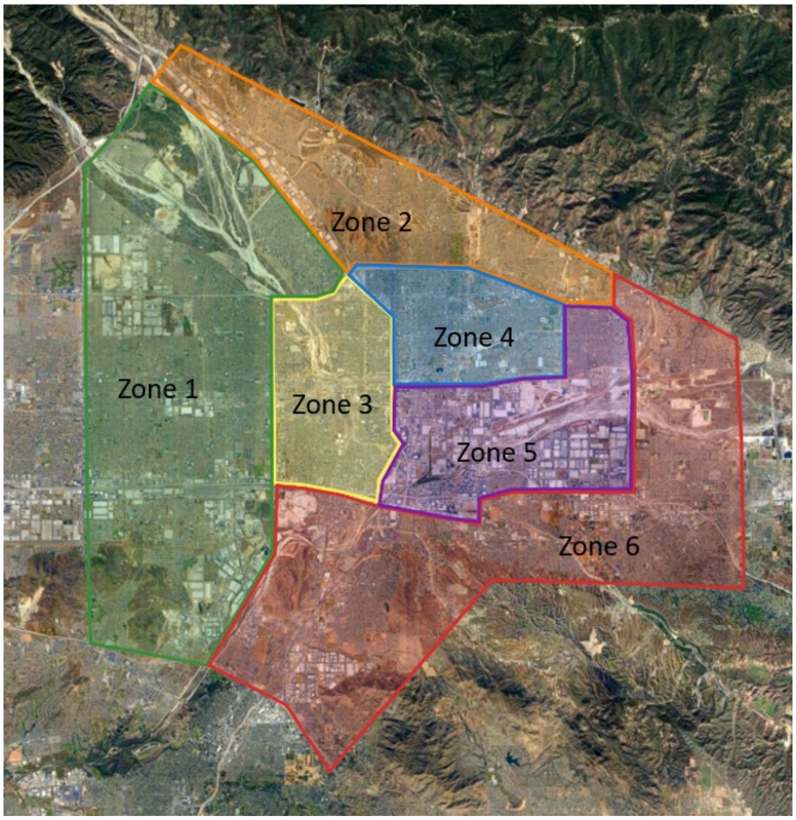

Figure 3-3 Zones for an urban area

STEP 2: DETERMINE LOCATIONS, SPACING AND COVERAGE

- **Question:** Which locations should be surveyed, how far apart should each measurement be taken (spacing), and how can the whole survey area be effectively covered (coverage)?
- **Key Decisions:** Determine how many measurements should be obtained and where each of those measurements should be taken.
- **Discussion:** General measurement locations should be spread out over the entire survey area. Additionally, specific surveys and sample locations should also be considered near or inside of critical infrastructure or other important buildings/areas. Concentrating surveys and samples in a limited portion of the overall area will not provide the necessary coverage. With that in mind, a large survey area does not necessarily require a lot of sample locations.

  In general, for handheld surveys, *five to 15 measurement locations* are usually sufficient, and measurements should be taken *using a systematic pattern*, such as a triangular or square pattern. Depending on the variability and evaluation of the results, more measurements may be needed. This is discussed in more detail in section 6 of the Technical Guidance and in Step 7: Data Review and Assessment of this CONOPS.

  - **Location**: The locations for taking each measurement/sample should be representative of the attributes within the survey area. For instance, including a variety of measurement locations, such as critical infrastructure, community reception center sites, agricultural sites, geologic formations, or populated areas will help generate good background data for the variety contained within the survey area.
  - **Coverage**: There is no defined number of measurements that is required to be taken in a survey area. In general, approximately five to 15 measurements/samples per survey area is enough to provide adequate coverage. More survey locations may be required to produce statistically useful results, depending on the variability within the designated area. See section 6.2 of the Technical Guidance for more detailed information on coverage.
  - **Spacing**: Measurements/samples should be taken at points as evenly spaced as possible throughout each survey area. The spacing of the measurements can be determined by visually spacing them out evenly to cover the entire survey area to collect useful data. Refer to section 7.3 of the Technical Guidance for more information on spacing.

Quick and Simple Survey

- Measurement locations should be evenly spread out throughout the entire survey area.
- Include critical infrastructure and/or key resources by adding or adjusting survey point locations.

Moderate Survey

- The measurement/sample locations should be evenly spread out throughout each smaller survey section within the entire boundary.
- Use specialized software such as VSP to generate measurement/sample locations by using a systematic pattern- based approach from a random starting location.

Advanced Survey

- Specialized systems such as mobile detection systems or aerial monitoring systems can be employed. See section 6 of the Technical Guidance for information on spacing considerations.

Figure 3-4 Suggested measurement considerations for surveys at three levels of complexity

Can I take measurements anywhere?

Ease of access to the location should be considered when deciding the coverage, spacing, and locations of each measurement/sample. Survey and sample locations won't be perfectly evenly spaced 100% of the time. The location may be impacted by limited access to areas such as rough terrain, private property, or bodies of water. The measurement/sample locations should be adjusted accordingly to accommodate ease of access, such as moving the location to a nearby intersection, while trying to maintain coverage and spacing requirements to the extent possible. In addition, the planner may want to start with a visual assessment to identify rock outcroppings, building materials, and changes in surface like roads vs. soil.

Example: In this example, Figure 3-5 shows the measurment spacing for a single zone. It was determined by the survey planner that 15 measurements are to be collected using instrumentation that is readily available. A rectangular grid pattern was chosen and a random start location for the pattern was employed. The random nature of the locations were then modified to make the locations more easily accessible to field teams. Measurement locations were moved off of private property and closer to road intersections, hence the rectangular pattern is slightly modified to assist field teams with collecting data. If a measurement location is changed to a more accessible location, it is important to record detailed information, including uploading pictures to CBRNResponder or the data management software being used, to ensure the location can be easily relocated.

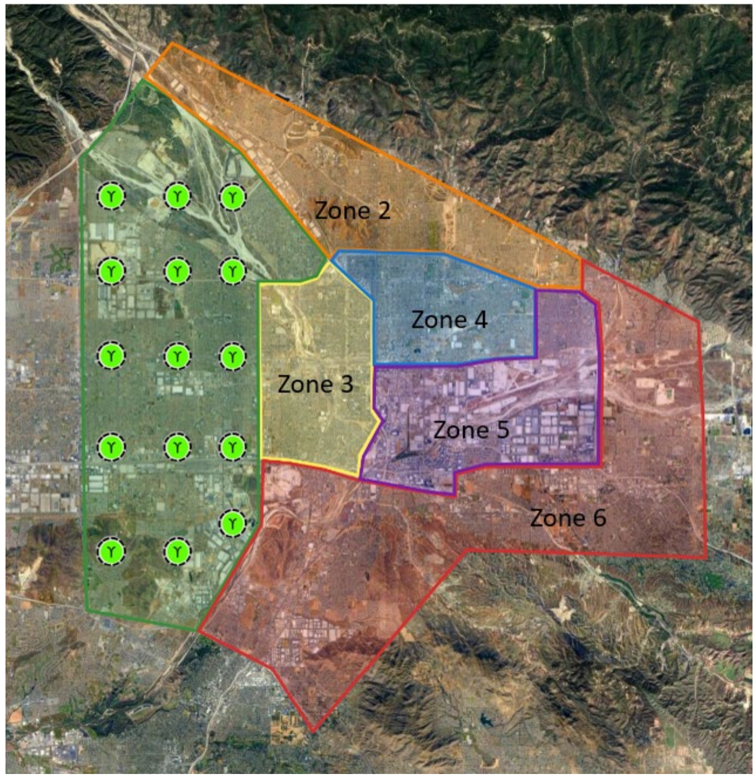

Figure 3-5 The 15 measurement locations that were chosen for Zone 1 shown in a rectangular grid pattern

STEP 3: DETERMINE EQUIPMENT NEEDS

- **Question:** What equipment is available, is it operational, and is it adequate to cover the survey area in the available time (or in a reasonable amount of time)?
- **Key Decisions:** Determine what type of equipment is available, how much equipment is available, and what equipment would be best suited to complete a background survey.
- **Discussion:** Some SLTT organizations may have predefined processes and procedures for making measurements and collecting samples after a radiological or nuclear emergency. Additionally, personnel have likely been exposed to or trained on the use of the instrumentation that is readily available, which would remove or lessen any learning curves and training requirements. The same collection processes and equipment that would be used during an emergency should be used for the background survey to ensure data is easily comparable.

  Performing a background survey should not require purchasing new equipment just for conducting the survey. Examples of equipment and the pros and cons of each type is further described in section 5.3 of the Technical Guidance.

  Maintaining the instrumentation for operation is important. Instrumentation that is not well maintained may provide inaccurate results. See section 5.1 in the Technical Guidance for more information on calibration. Some things to consider before use:

  - Have the batteries been changed recently?
  - Does the instrument appear damaged?
  - Does the instrument give the expected response, or has it been calibrated recently?

Quick and Simple Survey	Moderate Survey	Advanced Survey
• PRDs are readily available and can be used to take exposure rate measurements at each location within the survey area.	• Readily available GM detectors and ion chambers are used to take exposure rate measurements at each survey location. • If equipment is available and people are trained in their operation, other measurements can be taken, such in-situ gamma spectroscopy can be performed.	• Specialized systems such as mobile detection systems or aerial monitoring systems can be employed. • If aerial systems are used, ideally use energy-compensated GM detectors and/or ion chambers for measurement correlation. • Physical sampling equipment to collect samples such as soil samples, agricultural samples, and/or water samples.

Figure 3-6 Suggestions for determining equipment needs for a survey at three levels of complexity

Example: For this example, assume that the SLTT organization possesses a few different types of radiation detectors. The assumption is that the SLTT organization possesses a dose rate meter such as the one shown in Figure 3-7a, a contamination meter shown in Figure 3-7b, and a PRD which displays a count rate and an exposure rate, Figure 3-7c. These are examples of types of instruments that would typically be used by SLTTs when responding to a radiological incident. The equipment is maintained and calibrated on a regular basis and operational checks are performed, such as powering on the system, checking battery levels, and a source check with radioactive material (when available).

(a) (b) (c)

Figure 3-7 Example dose rate meters: a) Ludlum 9P-1, (b) Ludlum 3002 with a 44-93 alpha/beta scintillation probe, and (c) Thermo RadEye

Do I have to use these specific instruments?

No! It is best to use the instruments you have readily available. It is ideal to use the same instrument for each type of survey, meaning using the instrument with same serial number with associated detector probe. This helps with consistency of the recorded results.

The equipment shown above are examples of common, easy to use radiation detection instruments. Instruments that display results in exposure rate or dose rate will work best for a Quick and Simple Survey. The report "Mission Analysis for Using Preventive Radiological/Nuclear Detection Equipment for Consequence Management" provides guidance on different types of PRND equipment and how they can be used during consequence management operations.[9]

[9] Buddemeir, B.R., Wood-Zika, A.R., Haynes, D., et.al. "Mission Analysis for Using Preventive Radiological/Nuclear Detection Equipment for Consequence Management." Office of Science and Technical Information, US Department of Energy. 1 September 2017. Available: https://www.osti.gov/servlets/purl/1404850

STEP 4: DETERMINE PERSONNEL REQUIREMENTS

- **Question:** Can available personnel cover the survey area in a reasonable amount of time, and do they have enough training to perform the survey with the available equipment?
- **Key Decisions:** Determine the number of people needed to complete the survey and decide what type of training, if any, they need.
- **Discussion:** The type and amount of equipment available will determine the number of people needed and any training they might need. Most background surveys can be easily completed with only a couple of people. The more personnel that are available that have instrumentation, the more quickly the survey can be completed.

  Consider using personnel from SLTT response organizations that would respond to a radiological emergency. Trying to use the same personnel can provide an opportunity to practice during a non-emergency state, while also helping to familiarize personnel with the location, equipment, data recording requirements, and data assessment methodologies that would be used during a response to an incident in that location.

  Training may or may not be required depending on the users' familiarity with the equipment. Most likely, radiation detection instrumentation is not used frequently and a quick, just-in-time training on equipment use or techniques might be necessary before the start of the survey. If training needs are greater than expected, plan to do the training a few days or weeks before the survey.

  Ensure that everyone knows what to do prior to starting the surveys. A pre-survey briefing to go over the tasks for the day and address any questions should be conducted with participants.

Quick and Simple Survey	Moderate Survey	Advanced Survey
• Requires one to three minimally trained personnel. • Survey could likely be completed in a few days or less. • Locations are easy to find and easily accessible from a vehicle.	• Requires one- three minimally trained personnel and/or one to three+ moderately trained personnel. The "+" indicates that the more personnel available (with instrumentation) the quicker the survey can be completed. • Each smaller survey area within the entire background survey boundaries can be completed in a few days or less.	• One to three specially trained personnel in addition to the personnel listed for a moderate survey. • Time requirements for the personnel involved can vary. For example, using mobile detection systems to drive the entire area could possibly take days but completing an aerial survey may only take one or two hours.

Figure 3-8 Suggestions for determining personnel, training, and time needs for a survey at three levels of complexity

Example: In this example, each zone is a separate survey area. There are a total of six zones. Assumptions are as follows:

- There are two teams available
- Each zone has approximately 15 survey/sample locations
- It takes approximately five minutes to travel from one location to the next
- It takes around five minutes at each location to take measurements and record the results.

With these assumptions, each zone will take approximately two hours to complete per team. Each team will have three zones to complete, therefore each team will be collecting data for about six hours.

If this time commitment is not possible, remember that the surveys for each zone do not have to be performed all in one day. For example, this collaboration could be scheduled every other month for two–three hours until each zone is complete.

It is important to note that surveys should be conducted in similar weather conditions due to the possibility of weather or other environmental events affecting the background measurements. Background radiation can fluctuate with weather. Rain, wind, snow, and leaf cover can all impact radiation levels. For more information on background radiation see section 2 of the Technical Guidance.

In this example, data was only collected for one zone on the first day, so that the data could be reviewed and assessed to determine if the number of measurement locations needed to be increased or decreased to meet the statistical goals, which are discussed further in Appendix A. After the minimum number of measurement/sample locations was determined for the first zone, that number can be used to inform the number of measurement locations in all the other zones. Additionally, by collecting data in only one zone on the first day, any problems that are noted can be remedied for the next survey day to increase overall efficiency.

STEP 5: DETERMINE SURVEYS/SAMPLES AND TECHNIQUES

- **Question:** What measurement need to be taken or samples need to be collected and what techniques should be used?
- **Key Decisions:** Determine which types of surveys or samples would provide useful information based on the equipment and personnel available.
- **Discussion:** Developing an appropriate survey and sampling plan will require an understanding of the purpose of the survey (e.g., pre-event background survey in a limited area), the location(s) to be surveyed (e.g., a large sports complex and surrounding areas), the survey instruments and sampling equipment available for use, the qualifications of personnel available to do the work, and the nature of the results to be obtained (e.g., exposure rates). In general, any process used to collect data during an emergency response should be the same process used for the background survey. It will be a valuable opportunity for SLTT agencies to practice and communicate during non-emergency conditions. In addition, ensuring that the data collection process aligns with recommended guidance will be helpful to compare the background data with data collected during and after a radiological release.

Quick and Simple Survey	Moderate Survey	Advanced Survey
• Take an exposure rate/dose rate measurement approximately one meter off the ground. Let the instrument stabilize for about a minute before reading the result from the display. • Use instruments that display count rate results in cpm or cps for contamination surveys. Measurement should be taken about ¼–½ inch above the surface to avoid contaminating the detector.	• Use mobile detection systems to walk or drive through survey areas. • Use in situ gamma spectroscopy equipment, such as a High Purity Germanium detector, to characterize the background at one meter above the ground.	• Take physical samples (e.g., soil samples, agricultural samples, and/or water samples). • Use aerial monitoring systems to cover the entire background survey area.

Figure 3-9 Suggestions for survey/sample measurement needs for a survey at three levels of complexity.

Example: Once the available equipment and personnel are known (Step 3: Determine Equipment Needs and Step 4: Determine Personnel Requirements), the survey and sampling techniques can be determined. For this example, the focus is collecting dose or exposure rate measurements and contamination measurements using the equipment available. By using readily available equipment, the same emergency response procedures for collecting surveys can be used for the background survey. Using the same equipment, survey techniques, and recording results in the same measurement units helps to ensure pre-event and post-event surveys are comparable. (Note: All of the survey and sample types listed below do not have to be used but are included here for reference).

Dose Rate Surveys:

- Perform using a Ludlum 9DP-1 ion chamber.
- The survey will be taken at a height of approximately one meter above ground.
- The team will wait for at least one minute for the dose rate to stabilize.

Exposure Rate Surveys:

- Perform using a Thermo RadEye.
- The survey will be taken at a height of approximately one meter above ground.
- The team will wait for at least one minute for the dose rate to stabilize.

Contamination Surveys:

- Perform using a Ludlum 3002 with the 43-93 alpha/beta scintillator.
- The survey will be taken between ¼– ½ inches above the surface (to avoid contaminating the detector) with instruments that display results in count rate (e.g., counts per second).
    - Consider which mode to take contamination measurements in. The Ludlum 3002 can take measurements in rate meter mode which provides results in cpm or in count mode where it can be set to collect a total number of counts for a specified increment of time.
- Both the alpha and beta values will be recorded.

Gamma Spectroscopy: Static in-situ gamma spectroscopy surveys can be taken at 1 meter above ground level with the instrument facing the ground.

Air samples: If air samples are collected, they should be collected at the height of a person's breathing zone, approximately 1.5 meters above ground level.

Soil samples: Consider taking physical samples where elevated measurements are located, make sure to record pertinent information as described in Step 6 and follow the chain of custody requirements.

Refer to section 5 of the Technical Guidance for more information on background survey types and techniques.

STEP 6: COLLECT, RECORD, AND STORE DATA

- **Questions:** Where and how is data being recorded? What information needs to be recorded for each measurement?
- **Key Decisions:** Determine if data will be recorded on paper or electronically (or both) and what type of software will be used.
- **Discussion:** The preferred option for many SLTT agencies may be to record and manage data electronically using CBRNResponder. It is a free web-based platform that standardizes how these organizations store and display radiological data. It can be accessed on a computer or a mobile device. However, jurisdictions should use the software tool they plan to use during a radiological emergency for consistency; this does not have to be CBRNResponder.

  After measurement locations are determined, survey routes can be assigned to individuals or field teams and data can be reviewed and managed within the platform. Data can be stored long-term in CBRNResponder, and the background survey can easily be updated and accessed in the future to use for comparison and decision making. Some other software programs that SLTT agencies may consider for recording, storing and aggregating data include Health Physics Assistant, VSDS, NuCare RAD IQ ™ GeoFinder, and Bertin DataExpert10. See section 7 in the Technical Guidance for additional information.

  This step does not present information for each scale of survey because regardless of whether a quick and simple, moderate, or advanced survey is being performed, the following key information must be recorded for each measurement:

  - Date and time
  - Location and/or GPS coordinates
  - Dose rate and/or count rate with appropriate units
  - Collector’s name and agency affiliation
  - Comments/photos about the survey location
  - Weather conditions (e.g., precipitation, snow cover)
  - Distance from a wall if applicable (e.g., indoors)

  Information about the instrument(s) used to take the measurements can also be recorded and stored in the software’s equipment inventory so that the same instrument can be easily used in the future.

  - Instrument manufacturer, model, and serial number
  - Last calibration date
  - Instrument counting efficiency (contamination surveys only)
  - Detector surface area (contamination surveys only)

Example: For this example, CBRNResponder is used to record data and perform the following actions:

- Create an event named "Background Radiation Survey 2024" and ensure that it is shared with partners.
  - This event in CBRNResponder should have an indefinite end date to allow background measurements to continue to be added to the background survey in the future.
- Add equipment to the CBRNResponder equipment inventory with the appropriate information (e.g., meter and probe, serial numbers, efficiencies, surface areas)
- Create field teams:
- Assign personnel to each team
- Assign equipment to each team
  - Ensure that field teams have the CBRNResponder app installed on their mobile devices
  - Ensure that the correct equipment is assigned to each field team

If field teams collect data through the CBRNResponder mobile app, CBRNResponder requires that certain data fields be completed before data can be submitted and uploaded. There are also non-required fields, such as the free text comments section, which allows field teams to make notes for any measurement or sample.

If permissions in CBRNResponder are setup and partnerships are established, data collected by any field team (whether from Nebraska or Missouri) could be seen in CBRNResponder by both jurisdictions. By using CBRNResponder, the survey teams ensure that essential information is recorded, and data is shared with partner organizations, allowing them to view, assess, and export data.

For additional information about how to create an event, establish partnerships, set up permissions, manage an equipment inventory, and enter and view data, see the CBRNResponder Resources Library which has job aids and videos on these topics.[10]

If the background survey is broken up into several smaller surveys, make sure that the results from each smaller survey are added to the original event created for the background survey in CBRNResponder.

Do I have to use CBRNResponder?

No! CBRNResponder is a common and widely used application for recording, storing, and viewing data for a variety of survey and sample types. Examples for each survey type were not included in this section because all the survey types can use the same software. If SLTT organizations already have their own data management software, they should consider using it depending on what works best for their organization.

[10] CBRNResponder's Resources Library can be found at www.cbrnresponder.net/#resources/documents/index

STEP 7: DATA REVIEW AND ASSESSMENT

- **Questions:** What information should be verified when reviewing the data? Were enough measurements or samples taken to confidently characterize the survey area? Do any measurements require follow up?
- **Key Decisions:** Determine if the data collected is complete and correct. This process involves meeting pre-agreed to data quality criteria. Determine if enough measurements were collected in the survey area to meet the criteria.
- **Discussion:** Data review should include verification that the information for each measurement is complete, all the requested information is recorded, and validate that the quality objectives have been achieved. Use the pre-agreed data quality criteria to review and assess the data, keeping in mind the intended use of the data, the question the data is being used to answer, or the decision it is trying to inform. Inaccurate and bad data can cause confusion and negatively impact decisions and the speed of response in a real-world incident. Data review and assessment helps to ensure enough measurements that meet pre-agreed upon criteria are collected to produce a reliable background survey.

  Data verification and validation should include assessment of the following:

  - Proper meter/probe was used
  - Date and time are correct
  - Measurement/sample is at the requested location
  - GPS location appears accurate
  - Appropriate units were used
  - Raw value is reasonable
  - If using CBRNResponder:
    - Field team and/or surveyor name is correct
    - Data was entered into the correct event
    - Check for any comments about the location or conditions
    - Check for attached pictures, spectra, or attached files

  After a survey is completed for a survey area, a basic statistical summary of the data can be generated. At a minimum, the average and standard deviation for all the results in that survey area should be determined. Note that results for each background measurement may show temporal or spatial variation, which may or may not be statistically significant.

  To confirm whether enough measurements or samples were taken to characterize the survey area, some statistical analysis will need to be performed. Software tools exist to assist with statistical analysis, such as Visual Sample Plan (VSP). Analyzing data within the survey area, VSP can determine the minimum number of samples required to meet statistical goals. For more information about using VSP and determining the appropriate number of samples, see Appendix A.

For purposes of this guidance, a radiation anomaly will be defined as a measured exposure rate exceeding two to three times the average or typical background exposure rate of the rest of the survey area. Some survey areas will have unique anomalies due to a variety of factors (e.g., building materials, rock formations) and these should be identified and shared as appropriate. Radiation anomalies should be further investigated, and each jurisdiction should have their own guidance for how to handle alarming equipment and anomalies in the event an elevated measurement is taken that warrants follow up, notification, or a prompt response. Examples of radiation anomalies that may be detected but are within regulatory compliance and do not require follow-up include properly identified radioactive shipments and patients that have received nuclear medicine treatments. Since different types of detectors may be used for data collection, the specific detection limits used to identify anomalies will be based on the capabilities of the detection equipment and should be established prior to beginning data collection. See section 5 in the Technical Guidance for more information.

To confirm whether enough measurements or samples were taken to characterize the survey area, some statistical analysis will need to be performed. Software tools exist to assist with statistical analysis, such as Visual Sample Plan (VSP). Analyzing data within the survey area, VSP can determine the minimum number of samples required to meet statistical goals. For more information about using VSP and determining the appropriate number of samples, see section 6 and Appendix A.

Quick and Simple Survey	Moderate Survey	Advanced Survey
• Data verification and validation.	• Generate a basic statistical summary of the data and include average and standard deviation, in addition to data verification and validation.	• More advanced statistical analysis and use of software tools such as VSP. See the optional advanced concept discussed below.

Figure 3-10 Suggestions for data review for surveys of three levels of complexity

Example: If data is collected by individuals or field teams using the CBRNResponder app, the data can be reviewed and assessed on the CBRNResponder website remotely by users with the proper data permissions. An established agreed upon criteria checklist is used to verify that each measurement meets the data quality objectives. If the data meets the standard criteria, then it is marked as approved in CBRNResponder. If the data does not meet the standard, CBRNResponder may automatically apply a flag to the data point, for example if the units are suspicious[11]. If the error can be fixed, then the data is edited (preferably with an associated comment) and then approved. If the data does not meet the standard, and an error was noted and could not be remedied, then the data is marked as rejected in the CBRNResponder assessment policy (preferably with a comment).

[11] An example of "suspicious" units would be units of mR/hr recorded for a measurement made with a "pancake" GM detector because these detectors can only measure exposure accurately for the nuclide with which it was calibrated. Such detectors are best used to measure contamination, recorded in counts per minute or counts per second (cpm or cps).

For data assessment, the average and standard deviation for each survey area was calculated using an excel spreadsheet for each instrument. This means that an average and standard deviation were obtained in each survey area for the following:

- Dose rate measurements using the Ludlum 9DP-1
- Exposure rate measurements using the Thermo RadEye
- Alpha contamination measurements using the alpha/beta scintillator probe
- Beta contamination measurements using the alpha/beta scintillator probe

The average and standard deviation for each zone is compared to other zones to determine if there are any noticeable differences in the data. An average and standard deviation is also calculated for the entire background survey area for all the measurements in the combined zones. Note the below basic statistical analysis would likely be done for a moderate survey but could also easily be done for a quick and simple survey.

Exposure Rate (µR/hr)		
Zone	Average	Standard Deviation
1	10.6	1.1
2	10.8	1.3
3	11.0	0.8
4	11.3	1.0
5	10.9	0.8
6	11.0	0.9

Figure 3-11 Average and standard deviation for exposure rates collected in each zone

VSP can be used to confirm whether enough measurements/samples have been taken to characterize the survey area. In this example, only one zone was surveyed and then the data was analyzed in VSP to see if the number of measurements in the survey area was adequate. After determining the minimum number of measurements needed (n = 8), the recommended number of measurements were collected in the other survey areas. Alternatively, all survey areas could have been completed at the same time, then analyzed to see if any more measurements were needed.

STEP 8: DATA VISUALIZATION STRATEGY

- **Question:** What tools are available to assist in visualizing and interpreting the data and how are they used?
- **Key Decisions:** Determine what type of visual aids would be best suited to represent the data.
- **Discussion:** There are several software options that can be used to help visualize and interpret the collected data. Some platforms may be able to support both data analysis and data visualization; however, jurisdictions may choose to use separate systems depending on the capabilities and desired product. Most are similar in visualization capabilities; however, the statistical and data analysis packages provided by the software is where the biggest differences exist. Depending on what the desired result is, some software packages are free to use such as CBRNResponder and Visual Sample Plan (VSP), others, such as ArcGIS Pro, must be purchased.

  A reasonable choice is to use the same software that is used to collect the data, CBRNResponder, which has a mapping function along with the ability to see more information about each measurement by clicking on the measurement icon.

  VSP can also be used to visualize data and to statistically analyze the data. VSP helps users obtain answers to these questions:

  - How many samples are needed?
  - Where should samples be taken?
  - The data supports which decisions?
  - What is the confidence of those decisions?

  Google Earth Pro is a relatively easy visualization software to learn, and data can be imported into this software and displayed in multiple data layers and/or as a time series. ArcGIS is another very common geographic information system (GIS) platform that can also be used to analyze data. Many SLTT agencies already use ArcGIS to visualize information during emergencies. (Section 8 of the Technical Guidance provides more information on the various software options.)

Quick and Simple Survey	Moderate Survey	Advanced Survey
• Use free software such as CBRNResponder to plot measurement data on a map and view details about each measurement/sample location.	• Use any of the available software to plot measurement data to create maps of the background survey area. • These maps could include information from air samples and/or in-situ gamma spectroscopy measurements taken.	• Use software, whether your own or one of the options widely available, to create detailed maps of background survey data. • This would include aerial maps or maps created using data from mobile systems.

Figure 3-12 Suggestions for data visualization for surveys of three levels of complexity

Example: For this example, CBRNResponder is used to visualize data. Figure 3-13 (on the following page) shows the measurement locations in each of the zones. Each zone has 8 measurements, which is the minimum number of measurement locations calculated previously in VSP. Figure 3-13 also shows the measurement locations represented with colored markers that correspond to the exposure rate value. The color ramp covers the range of values and goes from bright green (lowest exposure rate values = 9-10 μR/hr) to orange (highest exposure rate value = 13 μR/hr). The color-coded markers help the viewer to more quickly visualize where the higher and lower exposure rate values are located and that there does not seem to be any pattern indicative of existing widespread contamination. Remember that the colors do not indicate levels of risk; orange simply indicates locations with the highest exposure rates (all of which, in this case, are too low to be harmful).

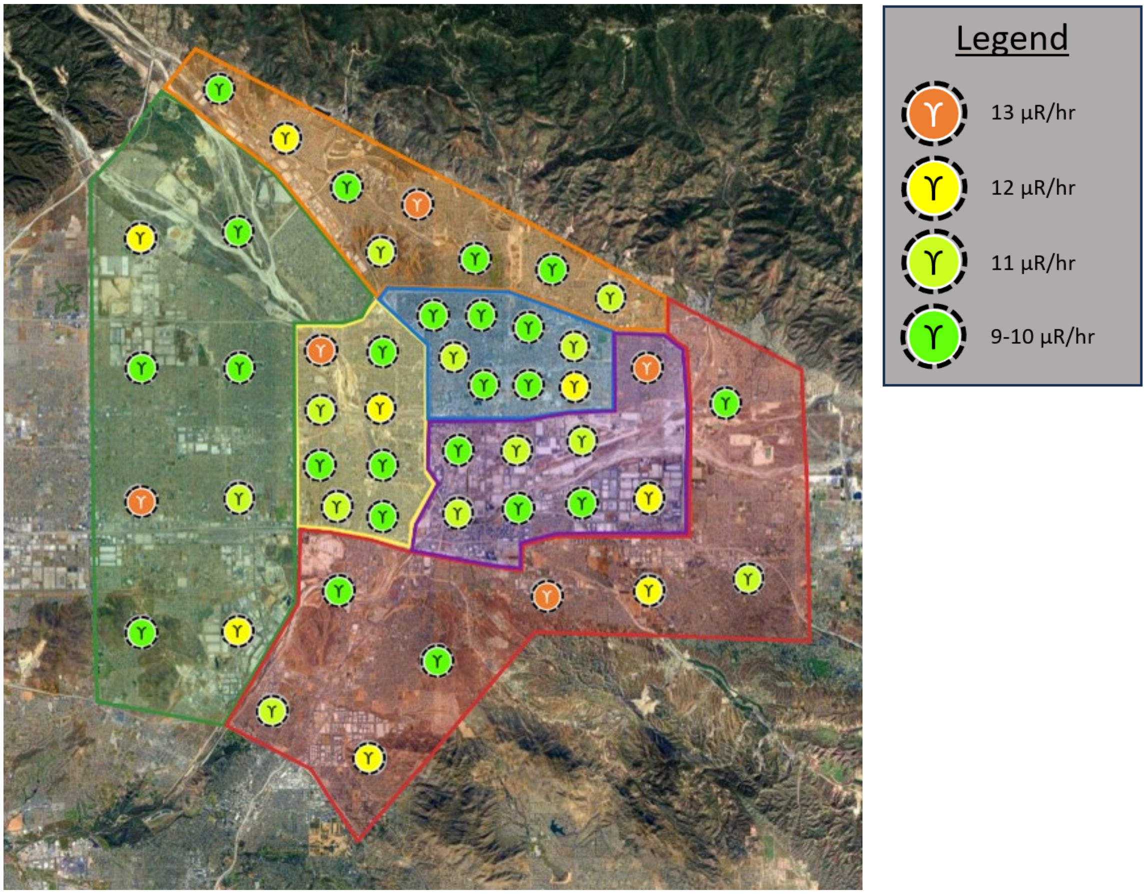

Figure 3-13 Measurement locations in each zone represented by color-coded markers according to exposure rate

Appendix A. HOW MANY MEASUREMENT LOCATIONS ARE NEEDED FOR THE SURVEY AREA?

Figure A-1 shows Zone 1 from the same example used throughout this CONOPS. To show how it was determined that eight sample locations were necessary in each zone an initial five random measurements were collected in this specific zone, and they were not spaced throughout the zone in a grid pattern.

Were enough measurements collected for this zone of the background survey? One way to determine this is to analyze the collected data and use a software code called VSP to assist with a statistically valid answer.

Figure A-2 shows the drop-down menu selections used within VSP. To show the confidence in the background values that were collected, “Construct Confidence Interval on the Mean” was selected to determine if further sampling is needed to meet the statistical sampling goals.

Figure A-1 Map of zone 1 showing the 5 original sample locations

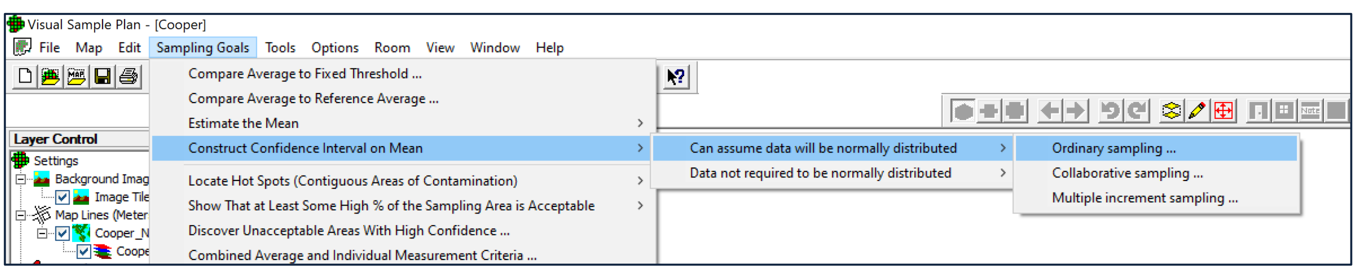

Figure A-2 Navigation of sampling goals menu in VSP to show the confidence in the background values collected

Figure A-3 shows the “Data Analysis” tab in VSP where the mean and standard deviation are calculated. This shows the mean to be 11.8 μR/hr with a standard deviation of 1.9 μR/hr. This information is used to determine how many total measurement locations are needed to meet the statistical tests discussed in the next step.

Enter the results from the five initial measurements in the “Data Entry” tab. Then click on the “Summary Statistics” tab to view the summary statistics which includes the mean and the standard deviation for the data set that is needed for the parameters mentioned in the next step.

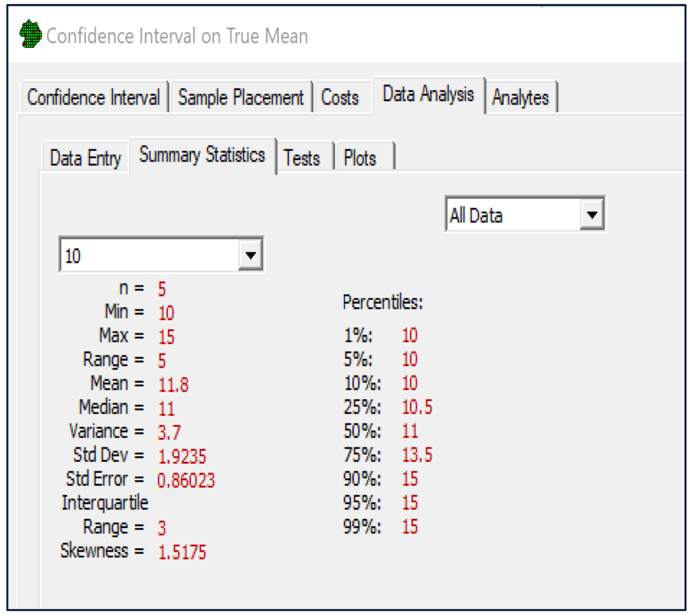

Figure A-3 Summary Statistics tab in VSP after results from the five measurements were entered in the Data

Figure A-4 shows the dialog box that opens in VSP for the user to input information to perform data confidence calculations. The recommended confidence level to aim for is 95%. Users must then select a range for the collected samples to fall within relative to the mean. For the example used throughout this CONOPs, the values from the five collected samples should fall within two units of the true mean, or approximately 20% of the mean (11.8 μR/hr) for the set of data used in this example, because 20% is an acceptable operating range for the detectors used in the examples. That is, users should select a range of units from the true mean that corresponds to the acceptable operating range of detection equipment used while taking the measurements for a respective survey. Based on the information entered in Figure A-4, the VSP determined that six total measurements are needed to meet the statistical requirements.

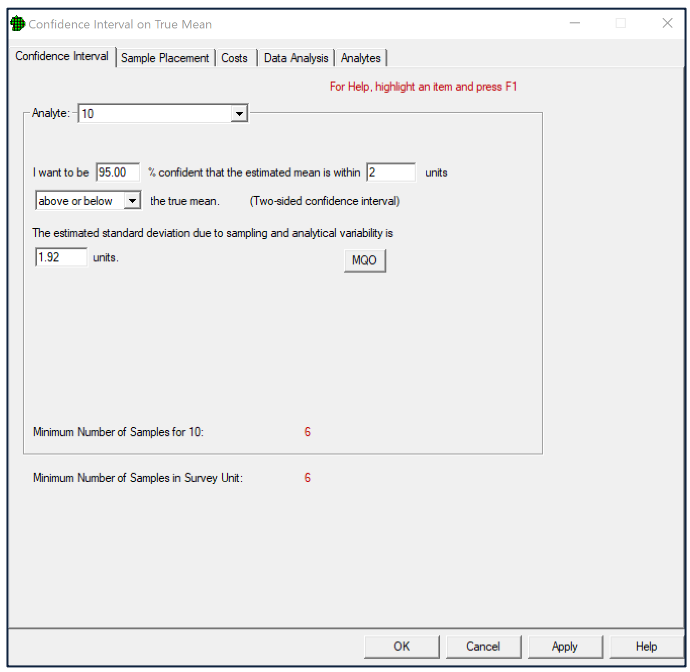

Figure A-4 Information required to be input into the VSP software for the software to perform the calculations

Once the number of total measurements necessary has been determined, VSP can generate grid sample locations in a square, triangular, or rectangular shape. Clicking on the "Sample Placement" tab allows the user to select which type of placement grid they want to use and the grid type. Figure A-5 shows systematic grid sampling with a triangular grid type as the user's selection for the example survey. This means the survey area would have measurement locations that are the same distance apart from each other and arranged in a triangle-based grid. For the example, a note that the option to use a random start location has also been selected; this choice is a best practice that users should select to remove bias from any location within the survey area. Figure A-5 shows the original five measurements collected in the example background survey as black pins. The blue pins represent the six measurement locations generated by VSP in a triangular grid pattern.

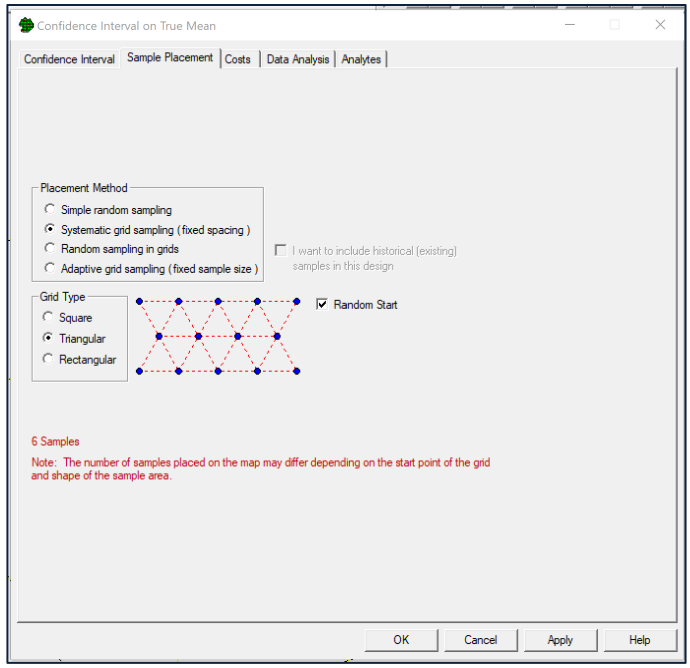

Figure A-5 The sample placement tab in VSP shows users their options for grid type used for measurement locations.

VSP can generate more locations than are minimally required to achieve the desired confidence level. The size and shape of the survey area, selected grid pattern, and the number of locations can be selected at the discretion of the survey design team.

Because five locations were selected to begin the example survey, the survey team could decide to use those same five locations as part of the six total locations needed since the initial five were selected randomly/ not biased. One additional sample or exposure rate measurement, then, would be required to meet the statistical requirements for the example survey area. Figure A-7 illustrates Zone 1 with all but one of the additional measurement locations suggested by VSP removed.

Figure A-6 Shows the five original measurements represented by the black pins and six measurement locations generated by VSP as the blue pins

Which suggested location(s) to use in order to meet statistical requirements is up to the discretion of the survey design person/team. For the example survey, the northeast blue pin from VSP is the additional measurement location simply because it provides for a measurement in that region of the survey area.

Six measurement locations were needed to meet the statistical goals for the Zone 1 area. Assuming nothing is geologically or radiologically different in the other zones of the example survey area, the same number of measurement locations in this area can be applied to the other survey zones.

Still, collecting additional measurements beyond the minimum calculated with the VSP helps ensure the statistical goals—that is, the high confidence in the survey data's reliability and lack of bias--are achieved. When planning, instead of repeating the VSP calculations process for each survey zone, one or two more measurement locations could be added to the minimum of six measurement locations required for each smaller survey area, providing a total of seven to eight total measurement locations for each zone. These seven to eight measurement locations should be placed in a triangular or square grid pattern to evenly space the measurement locations throughout the entire survey area.

Figure A-7 Shows the five original measurement locations that are represented by the black pins and one of the VSP-generated measurement locations represented by the blue pin for a total six measurement locations

Appendix B. RADIATION UNITS, QUANTITIES, AND UNDERSTANDING INSTRUMENT READINGS

Because most people do not work with radiation and have received little, if any training in radiation safety, the quantities that are measured (e.g., dose, exposure, activity) and the units used to describe these quantities are not common knowledge.

Each of the units of measurement described further below use the same system of prefixes:

- M (mega) = 1,000,000 times the basic quantity (e.g., 1 MBq = 1 million Bq)
- k (kilo) = 1000
- m (milli) = 1/1000
- μ (micro) = 1/1,000,000

B.1 Radiation Quantities and Units

Exposure: Radiation exposure is a measure of the amount of ionization produced in air by ionizing x-ray and gamma radiation.

- Units: Exposure is measured in Roentgen (R), milli-Roentgen (mR), and micro-Roentgen (μR).

Dose: Radiation dose is a measure of the amount of energy deposited by ionizing radiation in one gram of an absorber (e.g., air, water, human tissue).

- Units: Dose is measured in units of rad (r) in the US and in Gray (Gy), if using the international system (SI) of units.

Dose Equivalent: Dose equivalent is a measure of the biological impact of the radiation dose (i.e., absorbed energy) that was deposited. Different types of radiation cause different levels of genetic damage for the same amount of energy deposition, a phenomenon called relative biological effect (RBE). Alpha radiation, for example, causes about 20 times as much damage as does gamma radiation for the same amount of energy deposited in tissue.

Dose equivalent is calculated by multiplying the absorbed dose by the RBE of the radiation to which a person was exposed.

- Units: Dose equivalent is measured in rem in the US and Sievert (Sv) in SI units
- Dose equivalent is only appropriate when referring to radiation dose to humans
- Alpha radiation has an RBE of 20, beta and gamma radiation have an RBE of 1, neutron radiation has an RBE of 5-20, depending on the neutron energy

Radioactivity: The amount of radioactivity present is a measure of the number of atoms that are undergoing radioactive decay (with the emission of radiation) every second.

- Units: The Becquerel (Bq) is the SI unit and is the amount of radioactive material that undergoes 1 decay per second.

In the US, radioactivity is measured using the Curie (Ci), which is the amount of radioactive material that undergoes 37 billion ($3.7x10^{10}$) decays every second.

- Different radionuclides decay at different rates and have different amounts of radioactivity per gram. For example:
  - 1 gram of thorium-232 (Th-232) contains about 0.11 μCi (~4.1 kBq) of radioactivity
  - 1 gram of radium-226 (Ra-226) contains about 1 Ci (~37 GBq) of radioactivity
  - 1 gram of cobalt-60 (Co-60) contains about 1100 Ci (~42 TBq) of radioactivity

B.2 Understanding Radiation Detection Instrument Readings

There are two general categories of radiological survey instruments: those designed to measure radiation and those to measure contamination. Some instruments can do both.

The instrument used for a survey must be capable of accurately measuring the exposure and dose rates that survey planners anticipate encountering. In general, the instrument should be capable of measuring exposure rates of a few μR/hr. Be sure to check the instrument's specification sheet to verify the minimum and maximum measurement range capabilities.

- For example, a yellow Civil Defense - V instrument that reads in R/hr is not likely to give accurate readings of environmental radiation that is a million times lower (several μR/hr).
- Similarly, a PRD that overloads at 25 mR/hr cannot be used to measure dose rates of 100 mR/hr.

It is normal for radiation instrument readings to vary from moment to moment, from place to place, and even between calibrated instruments.

- This should not cause concern unless the readings change by a significant amount (e.g., a factor of more than two or three at normal environmental radiation levels).

Instruments that measure the presence of radioactive material in terms of counts per minute (cpm) or counts per second (cps) are not the preferred options for conducting background surveys; they are better used for detecting contamination on personnel and equipment.

- Converting count rate (cpm or cps) readings to radiation exposure or dose rate is outside the scope of this guidance and should only be done by experienced radiation safety professionals.

Geiger Mueller (GM) and sodium iodide scintillation detectors will not give accurate radiation dose rates for nuclides other than cesium-137 (Cs-137), which is what they are calibrated with.

- How inaccurate would the readings be? For example, the actual dose rate from Co-60 will be about twice as high as the meter reading while the actual dose rate from most medical radionuclides will be only about 20–25% of the instrument reading.
- The exception to this is that energy-compensated GM tubes are designed to give an accurate response across a wide range of gamma energies.

Appendix C. HELPFUL ONLINE TOOLS

1. ArcGIS

   www.arcgis.com/index.html

2. Bertin DataExpert10

   www.bertin-technologies.com/product/environmental-radiation-monitoring/dataexpert-10-software

3. CBRNResponder

   www.cbrnresponder.net

4. Google Earth Pro

   www.google.com/earth/versions

5. Health Physics Assistant

   https://www.hpassist.com/radiation-safety-assistant.html

6. NuCare RAD IQ™ GeoFinder

   www.nucaremed.com/products/radiation-measurement/software-platform/rad-iq-geofinder/?ckattempt=1

7. VSDS

   www.environmental-expert.com/software/version-vsds-environmental-monitoring-software-490606

8. VSP Job Aids

   www.pnnl.gov/projects/visual-sample-plan/documentation

9. Radiological Data Assessment Guidance for Emergency Response

   www.cbrnresponder.net/app/index#resources/documents/download/2308