Iowa Army Ammunition Plant (IAAAP) Aerial Radiation Survey Final Work Plan

by
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October 2002

Produced for:
The U.S. Army Operations Support Command

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[a] Argonne National Laboratory is operated by The University of Chicago under contract W-31-109-ENG-38, for the U.S. Department of Energy.

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Contents

Notation

The following is a list of the acronyms and abbreviations (including units of measure) used in this report. Notation used only in certain equations and tables is defined in the respective equations and tables.

Acronyms and Abbreviations

ADC	analog-to-digital converter
AEC	U.S. Atomic Energy Commission
AGL	above ground level
Am	americium
AMS	Aerial Measurement System
ANL	Argonne National Laboratory
APG	Aberdeen Proving Ground
ATSDR	Agency for Toxic Substances and Disease Registry
BAECP	Burlington Atomic Energy Commission Plant
Bi	bismuth
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
COPC	constituent of potential concern
Co	cobalt
Cs	cesium
DERP	Defense Environmental Restoration Program
DGPS	differential global positioning system
DOE	U.S. Department of Energy
DQO	data quality objective
DU	depleted uranium
EBP	East Burn Pads
EDA	Explosives Disposal Area
ER,A	Environmental Restoration Account-Army
ERC	Emergency Response Command Post
EOD	Explosives Ordinance Disposal
EPA	U.S. Environmental Protection Agency
FFA	Federal Facilities Ageement
FS	firing site
FUSRAP	Formerly Utilized Sites Remedial Action Program
GC	gross count
GPS	global positioning system
HRS	Hazard Ranking System
HPGe	high purity germanium
IAAAP	Iowa Army Ammunition Plant

IAG	interagency agreement
IOP	Iowa Ordnance Plant
IRP	Installation Restoration Program
K	potassium
MDA	minimum detectable activity
MMGC	man-made gross count
NaI	sodium iodide
NAWS	Naval Air Weapons Station
NCRP	National Council on Radiation Protection and Measurements
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NRHP	*National Register of Historic Places*
NV	Nevada Operations Office
ORNL	Oak Ridge National Laboratory
Pa	protactinium
Pb	lead
PRG	preliminary remediation goal
QA	quality assurance
Ra	radium
RAB	Restoration Advisory Board
RCRA	Resource Conservation and Recovery Act
RDGPS	real-time differential global positioning system
REDAC	Radiation and Environmental Data Analyzer and Computer
REDAR	Radiation and Environmental Data Acquisition and Recorder
ROD	Record of Decision
RSL	Remote Sensing Laboratory
SECOM	Security Command Center
SOP	Standing operating procedure
Th	thorium
Tl	thallium
U	uranium
USACE	U.S. Army Corps of Engineers

Units of Measure

bbl	barrel(s)	m	meter(s)
Bq	becquerel(s)	m^2	square meter(s)
Ci	curie(s)	m^3	cubic meter(s)
µCi	microcurie(s)	mCi	millicurie(s)
cpm	count(s) per minute	mg	milligram(s)
cps	count(s) per second	mi	mile(s)
d	day(s)	mi^2	square mile(s)
ft	foot (feet)	min	minute(s)
ft^2	square foot (feet)	mL	milliliter(s)
ft^3	cubic foot (feet)	mm	millimeter(s)
gal	gallon(s)	mph	mile(s) per hour
g	gram(s)	pCi	picocurie(s)
Gy	gray(s)	R	roentgen(s)
h	hour(s)	µR	microroentgen(s)
in.	inch(es)	rad	radiation absorbed dose
keV	kiloelectron volt(s)	s	second(s)
kg	kilogram(s)	yd^3	cubic yard(s)
lb	pounds(s)	yr	year(s)

Abstract

The Iowa Army Ammunition Plant (IAAAP) is initiating an investigation to identify areas that might be affected by the release of anthropogenic (man-made) radioisotopes. This evaluation involves a comprehensive assessment of gamma-emitting radioactive materials at the site, both natural and anthropogenic. The assessment will be done by using sodium iodide gamma radiation detectors mounted on a Bell 412 helicopter flown over the survey areas. Using an aerial platform for the survey will allow large areas of IAAAP to be quickly assessed with regard to the magnitude, nature, and extent of gamma-emitting radioisotopes. The main objective of this survey is to identify areas that have been affected by a release of man-made radioactive isotopes and to help determine areas that have not been affected.

The Bell 412 twin-engine helicopter will fly preplanned flight paths over the survey areas at an altitude of 100 feet, safety permitting. If conditions or topography make this an unsafe altitude, the survey may be conducted from a higher elevation.

Before every data-gathering flight, the helicopter will take readings over a designated test/calibration strip to aid in data analysis and as a data quality assurance procedure. In addition, flights and readings will be made to determine the cosmic and atmospheric contribution to the radiation background at IAAAP during the survey period. These data will be used to determine the terrestrial contribution to the exposure measured by the sensors.

No physical samples will be taken during this survey, and the survey equipment will not come into contact with radiologically contaminated soils or materials. No Argonne or Remote Sensing Laboratory personnel will be in contact with radiologically contaminated soils or materials.

The data will be analyzed, and the extent of anthropogenic gamma-emmitting contamination will be determined, as will the nature and extent of the natural gamma-emitting radioisotopes present. A detailed discussion of the sensitivity and resolution of the detector system will be provided in the project report. The results of this survey will be given to the U.S. Army in the form of a written report and processed electronic geographic information system data.

Section 1
Introduction and Purpose

1.1 Background

An aerial radiological survey of the entire IAAAP and selected off-post areas will be conducted to assess, within the limits of the detector system, the nature and extent of gamma-emitting radioisotopes, both anthropogenic (man-made) and natural. The survey objective is to identify areas that have been affected by a release of man-made radioactive isotopes and to help determine areas that have not been affected.

The Remote Sensing Laboratory (RSL), operated by Bechtel Nevada (BN) for the U.S. Department of Energy Nevada Operations Office (DOE/NV), with support from Argonne National Laboratory (ANL), will conduct the aerial survey of IAAAP. Specialized airborne sensors will be used to determine radioactive contamination. RSL will determine background radiation levels at IAAAP and radiation contaminant levels over the entire plant by using the Aerial Measurement System (AMS) in a DOE helicopter. ANL will provide required technical support and perform a quality assurance (QA) role.

RSL and ANL have proven capabilities for detecting radioactive materials by utilizing both aerial and ground-based survey platforms and for analyzing these data within a restoration environment. Recent surveys at the U.S. Army's Aberdeen Proving Ground (APG) and the U.S. Navy's China Lake Naval Air Weapons Station (NAWS) have been successful in defining the relative amounts and spatial extent of surface radioactivity and in contributing to an understanding of the impacts of this contamination.

IAAAP was recently added to the list of locations being addressed by the Formerly Utilized Sites Remedial Action Program (FUSRAP), managed by the U.S. Army Corps of Engineers (USACE) in coordination with DOE. Certain portions of the plant (approximately 1,900 acres) were formerly used by the Atomic Energy Commission (AEC). Actions performed in these areas, and potentially other areas at IAAAP, created the potential for radioactive contamination. Such radiologically contaminated areas are the responsibility of FUSRAP, while remediation of the balance of the site remains part of the responsibility of the Department of Defense's Environmental Restoration Account-Army (ER,A).

This aerial radiological survey is designed to identify areas that may have been affected by the release of anthropogenic radioisotopes and to determine if any areas exist that constitute an immediate danger to human health or the environment. A secondary objective of the survey is to produce data that can be used in conjunction with other site information to guide future restoration efforts.

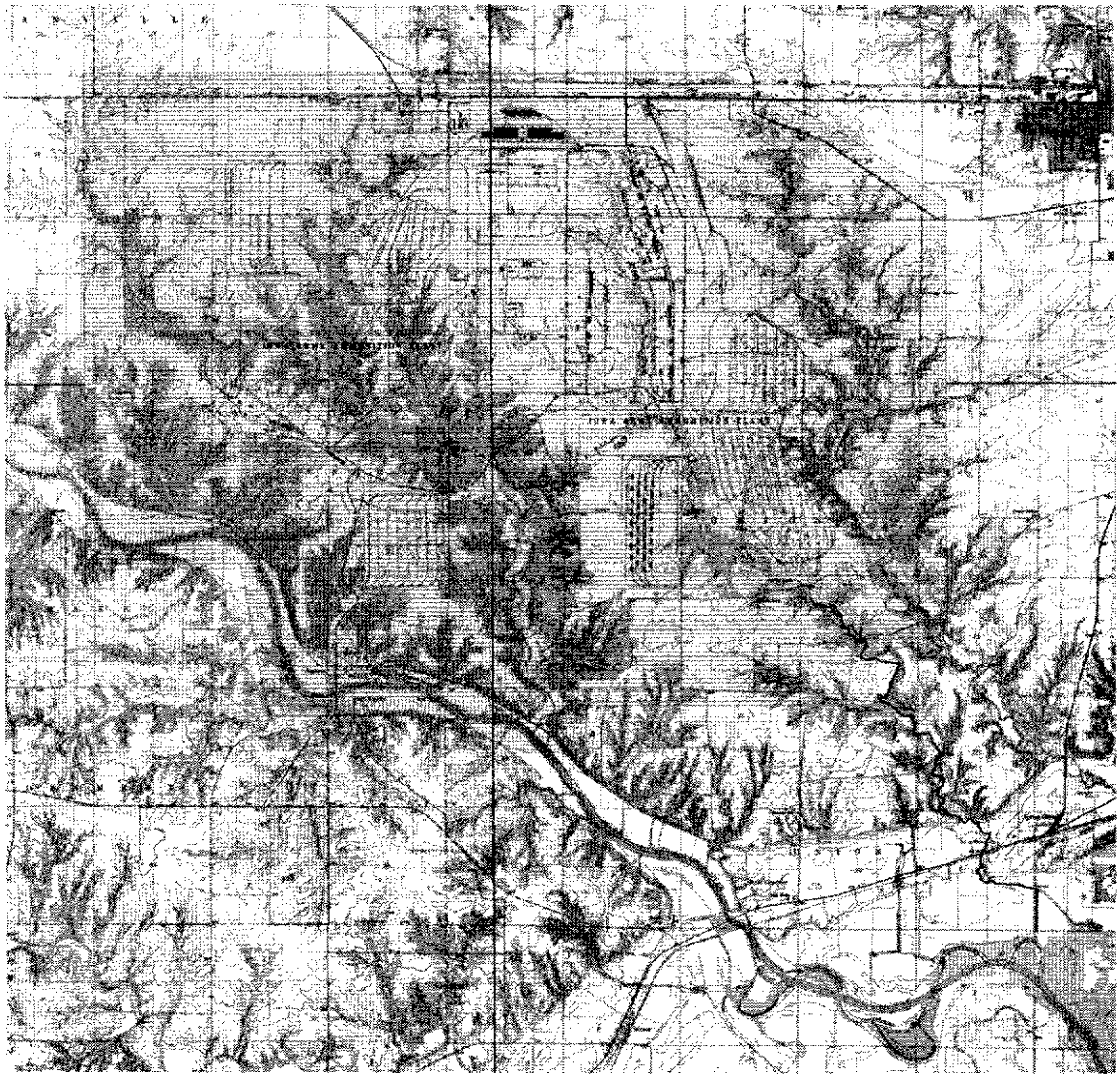

Figure 1 IAAAP Areas to be Surveyed by the AMS showing flight lines

Constituents of potential concern (COPCs) include depleted uranium (DU), radium-226 (Ra-226), Pu-239, and fission products. Cesium-137 (Ce-137) will be used as an indicator of long-lived fission products.

1.2 Scope of Work for the Aerial Radiation Survey

The aerial radiological survey will be composed of three technical components and a project management/QA component (all of which are described in more detail below). The three technical components of this project are to:

- Conduct an aerial radiological survey of the entire site;

- Take corroborative ground-based measurements at five locations to demonstrate the ability of the aerial survey to reproduce ground-based measurements; and

- Determine detectability limits for radiological COPCs, which are necessary to establish a ceiling on the amount of each that could be present yet go undetected. The minimum quantity of DU that is detectable by the aerial survey will be determined empirically by using known sources placed at a test range near the RSL-Nellis facilities. The Cs-137, Pu-239 [Am-241], and Ra-226 detectability limits will be calculated.

1.2.1 Aerial Survey

An aerial radiological survey of the entire 30-mi^2 of IAAAP and some off-post areas will be performed as shown in Figure 1. The survey will acquire georeferenced, time-resolved gamma spectra from a low flying helicopter. Aerial measurements will be taken at a ground speed of 60 knots (69 miles per hour [mph]) at 100 ft above ground level (AGL) with a nominal spacing of 200 ft between flight paths, safety permitting.

Data will be processed to map the total exposure rate, man-made exposure rate (apparent), DU concentration, both excess protactinium-234m (Pa-234m) and excess thorium-234 (Th-234), Cs-137 concentration (excess Cs-137), Pu concentration (derived from Am-241), and Ra-226 concentration (excess bismuth-214 [Bi-214]).

Results for Cs-137, Pu (Am-241), and Ra-226 will be reported in terms of equivalent surface concentration and uniform soil concentration for distributed sources. Results for DU will be reported in terms of surface and soil concentration for distributed sources, plus apparent point-source activity.

1.2.2 Corroborative Ground-Based Measurements

Corroborative measurements will be made at five selected locations (typically at a point of minimal spatial radiological gradient), and then the measurement results will be compared with the aerial results. The measurements at each location will consist of a field gamma spectroscopy measurement done with a high-purity germanium (HPGe) detector and a pressurized ion chamber measurement. These measurements and their comparison with the aerial data will be presented in the report. On the basis of the comparison of the ground and aerial measurements, the report will also estimate the site-wide average concentrations of Cs-137 and Ra-226.

1.2.3 Empirical Determination of DU Detection Limit

Aerial detection limits for DU will be determined for both point and distributed DU sources. Plates of 0.5-in.-thick DU will be used to establish system point source response for 0.5-in. fragments, which are representative of DU fragments found on the site. The resulting conversion factors for surface concentration and uniform soil concentration, plus point source detectability, will be reported. The observed variance at IAAAP will be used to define the corresponding DU detection limits. Pu detection limits will be computed. The report will briefly describe the procedures and present the results for both DU and Pu detection determinations.

1.2.4 Project Management

Project management will consist of those activities necessary to control and support the principal tasks cited above.

1.2.4.1 Project Planning Support

Project planning support will consist of the development of this work plan, which describes the purpose of the aerial radiological survey of the IAAAP and the data quality objectives (DQOs) to support the initial site investigation decisions. The work plan also provides a general description of each of the aerial survey data acquisition and data analysis tasks and specifies project quality assurance (QA) requirements. Deliverables under this task include an interim draft work plan for internal review, a final draft for regulatory review, and a final work plan. Other activities included under this task include attending meetings and/or conference calls with the regulators and stakeholders to resolve questions on the draft plan, as well as participation in coordination and planning meetings, conference calls, and site visits as determined necessary by the IAAAP Restoration Program Manager.

1.2.4.2 Quality Assurance and Data Evaluation Technical Support

This support will involve independent technical assessment of the data acquisition and analysis techniques used by RSL, evaluation of uncertainties associated with these techniques, and interpretation of final survey results, including assessment of the natural background and anthropogenic radioisotope spatial information developed by RSL to identify anomalies that should be highlighted for further investigation.

1.2.4.3 Report Preparation

Report preparation includes the generation of a report that contains site history and background, survey methods, results, and data analysis; production of maps and other graphics products; technical review and editing; and production of the final survey report. It is anticipated that the introductory sections of the report will be developed in coordination with IAAAP personnel, including descriptions of the survey purpose and objectives, site background, physical characteristics and land use, and results of the QA and data analysis process. The report format and outline will be developed in coordination with the IAAAP Restoration Program Manager.

This task will also include preparation of an interim draft report, final draft report, and final report, with associated review and comment resolution cycles. Up to 25 copies of the final report will be published. The IAAAP Restoration Program Manager will receive a CD with a copy of the report in electronic format. This task also includes production of graphics products for public and regulatory meetings and attendance at meetings as requested by the IAAAP Restoration Program Manager.

1.3 Location

IAAAP is a secured, operational facility located on approximately 19,000 acres (approximately 30 mi^2) in Des Moines County, in southeastern Iowa, approximately 6 mi west of Burlington, Iowa. Burlington has a population of approximately 27,208 people. All IAAAP land is currently owned and under the control of the Army. Portions of the facility were previously under control of other tenant organizations including the AEC. Additionally, some areas of the facility have been excessed and are no longer under the control of the Army. These excessed areas include former residential areas that are not expected to have been impacted by AEC activities. Approximately 7,751 acres are currently leased for agricultural use, 7,500 acres are forested land, and the remaining areas are used for administrative and industrial operations.

1.4 Site Description

IAAAP areas impacted by AEC operations consist of approximately 1,900 acres of the 19,000-acre plant. IAAAP is an active facility, currently operating to load, assemble, and pack ammunition items, including projectiles, mortar rounds, warheads, demolition charges, anti-tank mines, anti-personnel mines, DU armor-piercing munitions, and components of these munitions, including primers, detonators, fuses, and boosters. These operations use explosive material and lead-based initiating compounds. Only a few of the production lines are currently in operation.

1.4.1 State of Iowa Licenses for DU Operations

The site contractor, Mason & Hanger–Silas Mason Co., Inc., was issued Nuclear Regulatory Commission (NRC) Source Material License SUC-1381 authorizing possession of DU in solid form. This license was terminated and then reissued as Iowa Department of Public Health License 0290-1-29-SM1, which was issued to American Ordnance, LLC (who replaced Mason & Hangar–Silas Mason Co., Inc.) on April 13, 2000. This license authorizes "assembly and demilitarization of staballoy DU penetrators in munitions assemblies and for research and development as described in the application to the NRC dated October 6, 1993."

1.4.2 Climate

IAAAP has a mean temperature of 51.8 °F. Average annual precipitation is 40.61 in., well distributed throughout the year. The local area in southeast Iowa is wetter and warmer than most of the state of Iowa. Winters are usually mild, with infrequent, heavy snows. Ice storms are common, with one or two destructive storms occurring each year. Spring comes fairly early, with the potential for frost through the middle of April. March is the windiest month, while May and June are the wettest. Thunderstorms are frequent, especially in June and July, with one storm occurring every three days on average. Thunderstorms occur on an average of 55 days each year.

1.4.3 Topography

The topography of the surrounding area is characterized as a natural prairie and is currently used as farmland. The IAAAP area terrain ranges from flat (60%) to hilly and rough (40%).

The Skunk River and its tributaries are located in the southwest portion of the plant. Elevation at IAAAP ranges from 575 to 725 ft above sea level.

1.4.4 Hydrology

Three major streams—Brush Creek, Spring Creek and Long Creek—drain most of IAAAP. A small, unnamed tributary that drains directly into Skunk River drains a small part of the southwestern sector of IAAAP. These streams divide the facility into four drainage basins that trend generally northwest—southeast across the facility. These four watersheds are classified by the State of Iowa Water Quality Standards as Class B(w) waters, indicating that there is warm water suitable for wildlife, fish, and aquatic and semiaquatic life and secondary water uses. Additionally, a small area within the northern portion of IAAAP falls within the Flint Creek watershed.

1.4.5 Ecology

IAAAP has an abundance of fish and wildlife. Management plans for forest, land, and fish and wildlife have been instituted to help maintain the wildlife and plant populations while allowing consumptive and nonconsumptive recreational activities.

1.4.6 Endangered Species

IAAAP does have habitat of the type preferred by the Indiana bat (federally listed endangered species) and the orange-throated darter (State of Iowa threatened species). The Indiana bat has been found at the site. The Indiana bat frequents small streams surrounded by trees, a habitat that is fairly abundant at IAAAP. The orange-throated darter likes streams with consistent flow, gravel beds, and swirling pools for spawning. Long Creek, downstream of the Mathes Lake Spillway, provides such habitat. Other streams at IAAAP may also provide this habitat.

1.4.7 Archeology and Historic Sites

According to the archeological site files at the Office of the State Archeologist in Iowa City, Iowa, there is one recorded prehistoric site at IAAAP. A single broken projectile point was found, and no further work was done to determine whether the point was an isolated find or part of a disturbed site. There are numerous prehistoric sites throughout southeastern Iowa, most of which are not recorded. Some of these may be located within IAAAP. It is not uncommon for arrowheads to be discovered on cropland in southeastern Iowa.

One building on IAAAP may qualify for listing on the *National Register of Historic Places* (NRHP). It is a single-story limestone block structure built in 1872 and named Winnebago No. 2. It was used as a one-room schoolhouse. No known action to place this building on the NRHP is pending.

1.5 General Operational History

The construction of the approximately 19,000-acre IAAAP began in early 1941 and was completed in February of 1942. At this time, the plant was known as the Iowa Ordnance Plant

(IOP). Day and Zimmerman Company, Inc., initially operated the plant. The Army produced the first ordnance items in the fall of 1941. Between the start and end of World War II, plant products included 75- to 155-mm artillery projectiles and 100- to 1,000-lb bombs. Production of ammunition was halted in August of 1945. The plant, which reverted to a government owned and operated facility, was put to use storing and demilitarizing large quantities of ammunition.

In 1947, IOP was selected as the first production facility for manufacturing high explosive components for weapons under the AEC. A portion of Line 1; the Explosive Disposal Area (EDA) sites; Yards C, G, and L; and the Firing Site (FS) areas came under control of the AEC and its contractor, Silas Mason Company (later known as Mason & Hanger–Silas Mason Co., Inc.) The AEC is also thought to have operated at other locations within IAAAP. The areas occupied by the AEC covered approximately 1,900 acres within the IOP and became known as the Burlington Atomic Energy Commission Plant (BAECP).

In the late 1960s, it was determined that AEC operations at BAECP would be phased out and consolidated at the Pantex Plant near Amarillo, Texas. The BAECP closed in July 1975, and control of the areas reverted to the IOP under direction of the Army. Later, the plant name was changed from the IOP to IAAAP, as it is referred to today.

Section 2
Data Collection Methods for the IAAAP Aerial Survey

2.1 Collection Area

Aerial measurement techniques will be used to evaluate the distribution of gamma-emitting radioisotopes at IAAAP and selected surrounding areas. Figure 1 (presented in Section 1) shows areas of IAAAP to be surveyed.

Data will be collected by the AMS mounted on a Bell 412 twin-engine helicopter. The helicopter will fly in preplanned flight paths over the survey areas at an altitude of 100 ft, safety permitting. If conditions or topography makes this an unsafe altitude, the survey may be conducted at a higher elevation. Flight paths are designed to provide complete coverage of the survey areas.

Before every data gathering flight, the helicopter will take readings over a calibration strip (test line) to aid in data analysis. In addition, measurements will be made to determine the cosmic and atmospheric contribution to the radiation background at IAAAP.

Several factors will be considered in selecting the test line for the aerial survey. The primary factor is that the terrestrial gamma radiation over the line (about 1 mile in length) should be relatively constant. A secondary factor is the desire to have visual references for the flight crew to guide them along the test line (such as a power line or a fence row). A third factor is the desire to avoid inhabited areas. Since the test line will be flown at the survey altitude twice on every flight, flying over inhabited areas could cause many complaints.

The test line will be flown and measurements taken at the beginning and end of each flight, and the average net count rate over the test line will be calculated from these measurements. For each flight, this average net count rate will be compared with the average of all prior test line count rates (C_{ave}). If the count rate of the new line differs by less than 200 counts (about 0.2 µR/h) from C_{ave}, the system will be judged to be working correctly. If the count rate is outside of that range, then the system will be inspected and tested on the ground before any more data are collected.

No physical samples will be taken during this survey, and the survey equipment will not come into contact with radiologically contaminated soils or materials. No ANL or RSL personnel will be in contact with radiologically contaminated soils or materials.

2.2 Collection System History

The AMS that will be used for this survey has been used to conduct hundreds of aerial radiological surveys throughout the world. It was initially developed in 1958 and has been continually updated since then. Surveys have been performed over most DOE and commercial nuclear reactor sites, as well as at many environmental cleanup sites in the United States.

The AMS equipment that will be used to perform the surveys at IAAAP consists of a radiation detector and data acquisition computer system mounted on a high-performance helicopter. A mobile data-analysis computer system supported the helicopter survey operations and allowed the spectral data to be reduced and presented as isopleth contour maps of exposure rates and isotopic intensities.

2.3 Instruments

The survey will be conducted with an array of twelve 2 × 4 × 16-in. NaI detectors mounted on a twin-engine Bell 412 helicopter, as shown in Figure 2. The AMS data acquisition system — Radiation and Environmental Data Acquisition and Recorder, Model V (REDAR V) — collects second-by-second spectral information, spanning 0 to 4,000 keV, as illustrated in Figure 3. Gamma emissions from any isotopes that are of concern at IAAAP fall within this energy range. The measured energy spectrum permits the data analyst to distinguish between radiological contamination and simple changes in background radiation. The spectral information also helps identify specific radioactive isotopes.

To provide extra capability to the collection system, the signals from the 12 NaI detectors are routed to four analog-to-digital converters (ADCs). The signals from all 12 detectors are fed into one ADC to produce the maximum sensitivity, The signals from a single detector are fed into a separate ADC to ensure useful data if detected activities become too high. Finally, the signals from the remaining detectors in each pod (5 and 6) are fed into the two remaining ADCs to provide redundancy in the data collection effort and to provide a quality assurance function.

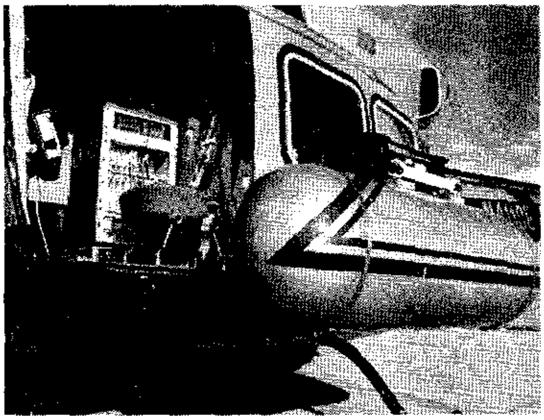

Figure 2 Photo Showing a Pod Containing the Sodium Iodide Detectors beneath a Twin-Engine Bell 412 helicopter

Table 1 shows examples of the strength of both a point source and a distributed surface contamination source that can be detected by the AMS. In the table, the isotopes U-238 and Pa-234m are used as examples. In an actual survey, the full spectrum of detected gamma radiation compiled by the AMS allows the identification of any gamma-emitting radioisotopes present (in detectable amounts) rather than just target contaminants. Each radioisotope decays with a characteristic set of gamma ray emissions. Each of these gamma emissions has a specific energy. By examining the energy spectrum from 38 to 3,026 keV and comparing the various energies of the detected gamma emissions, the analyst can identify the decaying radioisotope. This technique allows a more accurate determination of the amounts of anthropogenic radioisotopes present compared with background levels, even if background levels change spatially over the survey area. As shown in Table 1, this approach has different sensitivities to different radioisotopes because of the number and energy of gamma emissions that characterize each isotope. Appendix A contains a brief primer on radiation, exposure, and dose.

Table 1 Sensitivity of the Measurements at Various Altitudes for both U-238 and Pa-234m

Altitude (ft)	^{238}U	^{234m}Pa
Point source sensitivity (mCi)		
50	4.4	5.9
150	80	62
300	930	310
Distributed surface source (μCi/m²)		
50	6.7	6.8
150	19	9.2
300	74	14

Helicopter flight positions during the surveys will be continuously determined with a radar altimeter and a real-time differential global positioning system (RDGPS). The RDGPS provides latitude and longitude position with an accuracy of better than ±5 m (16 ft). With this RDGPS, GPS data from a network of precisely measured locations surrounding the United States are transmitted to a control center, where range, timing, and ephemeris errors from the 24 GPS satellites are evaluated. Corrections for each satellite are then up-linked to a geo-stationary satellite, broadcast back to earth, and utilized by the helicopter RDGPS. Without these corrections, GPS accuracy would have been ±20 to 30 m (66 to 98 ft). The radar altimeter determined the aircraft's altitude by measuring the round-trip propagation time of a signal reflected off the ground. For altitudes up to 300 m, the accuracy of this system is ±0.6 m, or ±2%, whichever is greater.

In aerial surveys, an aircraft's altitude, flight line spacing, and speed are chosen to optimize the detector sensitivity to radioisotopes and spatial resolution while maintaining a safe and efficient flight configuration. For this survey, the position information will be directed to an aircraft steering indicator and used to guide the aircraft along predetermined, parallel flight lines. The position information from the RDGPS and the radar altimeter data will be simultaneously recorded, along with the spectral information from the NaI(T1) detectors, at 1-second intervals for post-flight analysis.

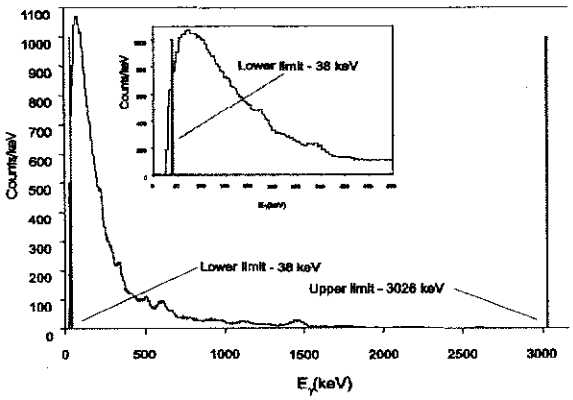

Figure 3 System Sensitivity to Gamma Ray Energy (The figure shows an example spectrum of energy values.)

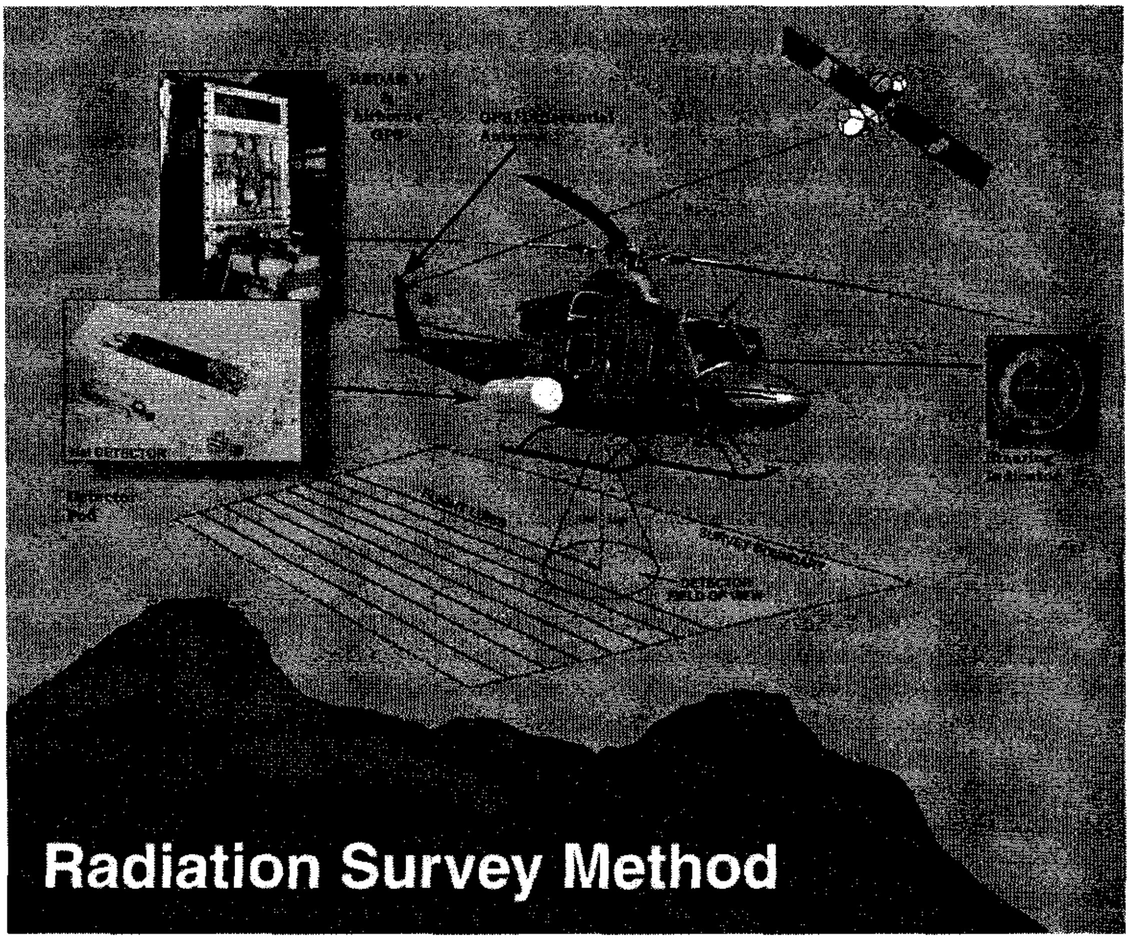

Figure 4 Overview of the Data Collection Activities (Image courtesy of DOE's RSL)

A computer-based system, the Radiation and Environmental Data Analyzer and Computer (REDAC) system, will be used to evaluate the acquired data immediately following each survey flight. The REDAC system consists primarily of a computer, software, and a large-bed plotter.

2.4 Collection Methods

2.4.1 Aerial Collection

Data will be collected by using a Bell 412 helicopter and the AMS equipment described above. The helicopter will be flown at a constant speed of 60 knots and altitude of 100 ft AGL over the survey area in a series of parallel flight lines (Figure 4). This procedure will be continued until all of the desired area is surveyed. The data set for this survey, collected at the rate of one measurement per second during the flight, will consist of positional and altitude data, atmospheric information, and gamma-ray energy spectra. The first flight of the survey will be a reconnaissance flight conducted above 500 ft to verify and update the existing flight hazard maps. The hazard maps will be updated with the locations of towers, power lines, or other high structures that could present a hazard to a helicopter flying at 100 ft AGL.

The survey will consist of parallel flight lines spaced nominally at 200 ft to provide complete coverage. Each data collection flight will include a pass over the test line, passes over the lines in the survey area designated for that flight, and then a repeat of the test line before landing and preparing for the next flight. These procedures are described in detail below.

Flights over the test line will be used to calibrate the detectors and to determine the contribution of cosmic and atmospheric radiation to the measurements. The test line location will be determined at the time of the survey.

2.4.2 Calibration and Data Quality

Fluctuations in atmospheric radon and cosmic radiation will be measured during each flight. These data will be analyzed to determine the contribution to the survey from atmospheric and cosmic sources. In the subsequent calculations, the count rate from radon, equipment, and cosmic radiation will be removed from the aerial data, and appropriate algorithms will be applied.

As described above, a test line will be established for the IAAAP survey. This line will be flown and measured as part of each data gathering flight. Measurements from the test lines will be used to calibrate the instruments, quantify cosmic and atmospheric radon variability, and account for other varying conditions.

An altitude profile (also referred to as an altitude spiral) will be flown in the first days of the survey period. The altitude profile will consist of several traversals of a specific path (usually the test line) conducted at five or six different altitudes. The air attenuation coefficient and an initial background count rate will be determined from these data. These values will be used to adjust the measurements for minor fluctuations in altitude during subsequent flights.

2.4.3 Ground-Truth Measurements

Five corroborative measurements will be made at selected locations (typically these locations will have a minimal spatial radiological gradient) and then compared with the aerial results. The measurements at each location will consist of a field gamma spectroscopy measurement with an HPGe detector and one pressurized ion chamber measurement. These measurements and their comparison with the aerial data will be presented in the report. On the basis of the comparison of ground and aerial measurements, the report will also estimate the sitewide average concentrations of Cs-137 and Ra-226.

2.5 System Sensitivity

The AMS can detect small changes in radiation over the detector footprint. For example, in other surveys of this type, landscape features such as wetlands are clearly detectable because of the shielding effects of water. Heavy vegetative cover can also reduce the amount of radiation reaching the detectors, usually because of the moisture present in the leaves and other plant structures. The highest gamma emissions are detected from bare or recently disturbed soil (in areas without anthropogenic contributions to the gamma emissions) because the natural gamma emissions are not shielded from the detector. Concrete structures and buildings also show up clearly in the survey results because emissions from naturally occurring radioisotopes are present in construction materials and there is no vegetation to shield the emissions from the detectors. This correlation of survey results with identifiable surface features provides an additional quality check on the collected data.

A more detailed discussion of the detection limits for the various COPCs in this survey is provided in Section 6.

2.6 Data Analysis Algorithms

2.6.1 Gross Count Method

To obtain a gross count (GC) contour, the count data that will be collected by the AMS equipment will be first integrated between 38 and 3,026 keV:

$$C_G = \sum_{E=38}^{3026} c(E) \ , \qquad (1)$$

where

C_G = gross count rate (counts per second [cps]),
E = photon energy (keV), and
$c(E)$ = count rate in the energy spectrum at energy E (cps).

The system records gamma rays with energies up to 4,000 keV; however, there are very few gamma rays above 3,000 keV.

Since GC contours are meant only to depict terrestrial radiation levels, counts from cosmic radiation and airborne radon will be subtracted. Furthermore, the terrestrial GC rate will be converted to an exposure rate at 1-m (3.3-ft) height by applying a conversion factor. The calculations for the exposure rate, E_G, are summarized below. All counts will be normalized using detector live time:[1]

$$E_G = \frac{C_G - B}{S_f} e^{\mu(H-100)} \ , \qquad (2)$$

where

---

[1] "Live time" is the amount of time over which the detector integrates readings.

E_G = exposure rate from terrestrial gamma ray emissions (μR/h),
B = background count rate from cosmic radiation, atmospheric radon, and aircraft materials (cps) (this parameter differs from total background radiation in that the latter includes all sources with the exception of anthropogenic contamination),
S_f = conversion factor (cps/μR h^{-1})
H = aircraft's altitude (ft), and
μ = an attenuation coefficient (1/ft).

The background count rate from cosmic radiation, atmospheric radon, and aircraft materials will be determined as discussed above. The contours generated from these data will reflect the exposure rate at a height of 1 m from terrestrial sources (the background exposure rate will be subtracted).

The S_f factor in Equation 2 converts the count rate (cps) to an exposure rate (μR/h). The exponential term in Equation 2 corrects for changes in the attenuation of the gamma radiation in air because of slight variations in the aircraft's altitude. The attenuation coefficient, μ, will be obtained from experimentally measured data collected over the test line during the survey.

The conversion from gross count to an exposure rate is based on the assumption that the source is spread uniformly over the width of the detector footprint, or field of view. Because of this assumption, the exposure rate will be underestimated over sources that are small with respect to the size of the footprint. For example, an intense point source of radiation can produce measured count rates at the detector equivalent to those from a much less intense large-area source. These issues and calculations are further discussed in Section 6.

GC data include contributions from natural sources of radiation. Consequently, these data include variations in terrestrial background radiation levels. Contours resulting from these variations in natural radiation often match specific surface features, such as tree lines, boundaries of cultivated land, and bodies of water, because of the different attenuation characteristics of the different materials. Exposure rate contours offer a sensitive means of identifying anomalous, potentially anthropogenic changes in the radiation environment, in addition to detailing variations in the natural background radiation emissions.

2.6.2 Man-Made Gross Count Method

The man-made gross count (MMGC) method is used to differentiate between anthropogenic radiation and naturally occurring radiation in a survey. The MMGC method, also referred to here as the MMGC filter, relies on the fact that most gamma ray emissions from long-lived, anthropogenic sources of radioactivity occur in the energy region below about 1,400 keV. In areas where only natural sources of gamma radiation are present, the ratio of the counts appearing below 1,400 keV to those appearing above 1,400 keV remains relatively constant. This relationship is true even if natural background radiation levels vary by a factor of 10 across the survey area. If this ratio changes spatially, it is most likely because of a contribution from anthropogenic gamma radiation.

The MMGC algorithm is a means of identifying regions in the survey area where the shape of the energy spectrum deviates significantly from the shape of the background, or reference, spectrum. The MMGC algorithm is very sensitive to small changes in the abundance of anthropogenic isotopes, while being very insensitive to large changes in the abundance of natural isotopes.

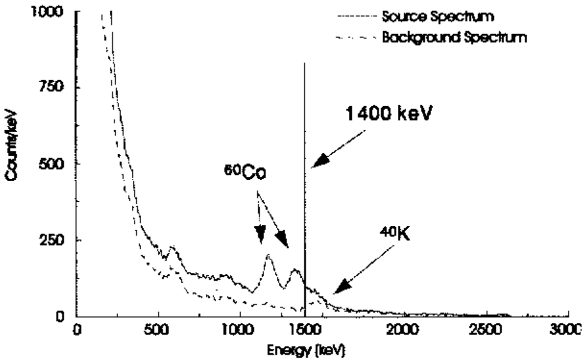

Figure 5 NaI Gamma Ray Spectrum Illustrating MMGC Energy Regions

Figure 5 shows two typical NaI gamma ray spectra. Superimposed on a background spectrum is a spectrum obtained with cobalt-60 (Co-60) present. Counts from an anthropogenic radioisotope such as Co-60 fall almost entirely in the low-energy region below 1,400 keV. This condition is true for most anthropogenic radioisotopes of concern. This causes the ratio of counts in the low-energy range to counts in the high-energy range to change.

The normal ratio of counts in the low-energy region to counts in the high-energy region for a survey area is calculated from data obtained in an area that contains only natural sources of radioactivity. These counts are integrated over each energy region. To match the energy limits of the discrete channels of the acquired spectra, the low-energy region extends from 38 to 1,394 keV. The high-energy limits are then 1,394 to 3,026 keV. This ratio can be computed with Equation 3:

$$K_{MM} = \frac{\sum_{E=38}^{1394} c_{ref}(E) - B_{MML}}{\sum_{E=1394}^{3026} c_{ref}(E) - B_{MMH}}\ , \tag{3}$$

where

K_{MM} = ratio of low-energy counts to high-energy counts in the reference region of the survey,
B_{MML} = average background counts in the MMGC low-energy window (cps), and
B_{MMH} = average background counts in the MMGC high-energy window (cps).

The background count rates are derived from the flights as described in Section 5.6.1. These two background count rates remove the effect of nonterrestrial background from the MMGC extraction in a manner similar to the background removal in the GC algorithm. The subscript "*ref*" denotes that the counts in each channel, *c(E)*, are obtained from a reference area of natural background radiation. This ratio is applied to each second of data from the survey area:

$$C_{MM} = \left[\sum_{E=38}^{1394} c(E) - B_{MML} \right] - K_{MM} \left[\sum_{E=1394}^{3026} c(E) - B_{MMH} \right] , \qquad (4)$$

where

C_{MM} = anthropogenic (man-made) count rate (cps).

The MMGC algorithm allows the data to be analyzed such that variations in the count rate due to changes in natural background levels are filtered out. In regions with only natural background radiation, the MMGC algorithm will yield count rates that fluctuate statistically around zero. Variations in count rate due to anthropogenic or industrially enhanced radioisotopes then appear as isolated contours.

The increase in sensitivity obtained with the MMGC analysis over that of the GC method is significant. However, the MMGC filter is also sensitive to changes in the relative composition of natural background radiation. For example, areas where uranium (a naturally occurring radioisotope) is naturally high relative to the other natural radioisotopes, as measured in the reference area, will appear as anomalies when this algorithm is used.

2.6.3 Isotope Extraction Algorithms

The algorithms employed in the search for particular isotopes are very similar to the MMGC algorithm. The major difference is that instead of using the full gamma-ray energy spectrum, they use only a few small portions of it. Two such algorithms are the Two-window algorithm and the Three-window algorithm.

2.6.3.1 The 2-Window Algorithm

The 2-window algorithm is the simplest of several window algorithms in use. It employs a narrow window centered on the energy of the specific photopeak of the isotope of concern. The algorithm assumes that the background counts in the photopeak window are proportional to the counts recorded in a background window located at higher energies. The background window may abut the photopeak window or may be separated from it in the energy spectrum. Note that the form of the equation for C_2 is identical in form to the equation for MMGC previously defined:

$$C_2 = \left[\sum_{E=E_1}^{E_2} c(E) - B_{2L} \right] - K_2 \left[\sum_{E=E_3}^{E_4} c(E) - B_{2H} \right] , \qquad (5)$$

with

$$K_2 = \frac{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{2L}}{\sum_{E=E_3}^{E_4} c_{ref}(E) - B_{2H}} , \qquad (6)$$

where

C_2 = count rate from the 2-window algorithm (cps),

$c(E)$ = count rate in the gamma-ray energy spectrum at the energy E (cps),

E_n = limiting energies of the windows ($E_1 < E_2 \leq E_3 < E_4$) (keV),

K_2 = ratio of the counts in the photopeak window to the counts in the background window in the reference region of the survey area,

$c_{ref}(E)$ = count rate in the reference gamma-ray energy spectrum at energy E (cps),

B_{2L} = average background counts in the 2-window low-energy window (cps), and

B_{2H} = average background counts in the 2-window high-energy window (cps).

The proportionality factor, K_2, is determined in a region of the survey that does not contain any of the specific isotope of concern so that the photopeak window contains only background counts and, therefore, can be simply related to the number of counts in the background window. If the principal source of background gamma rays in the photopeak window is from scattered gamma rays from photopeaks at higher energies, this is a good assumption. If there are other isotopes with photopeaks in or near the photopeak and background windows, this algorithm fails.

2.6.3.2 The 3-Window Algorithm

If a reference region free of the specific isotope cannot be found or if the compositions of the other isotopes change drastically between the reference region and the rest of the survey area, then a simple multiplicative factor will not relate the counts in the photopeak window to the counts in the background window. To solve this problem, the Three-window algorithm employs a background window on each side of the photopeak window. (The two background windows generally abut the photopeak window in energy.) This algorithm assumes that for any spectrum, the number of background counts in the photopeak window is linearly related to the counts in the two background windows.

$$C_3 = \left[\sum_{E=E_2}^{E_3} c(E) - B_{3P} \right] - K_3 \left[\left(\sum_{E=E_1}^{E_2} c(E) - B_{3L} \right) + \left(\sum_{E=E_3}^{E_4} c(E) - B_{3H} \right) \right], \qquad (7)$$

with

$$K_3 = \frac{\sum_{E=E_2}^{E_3} c_{ref}(E) - B_{3P}}{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{3L} + \sum_{E=E_3}^{E_4} c_{ref}(E) - B_{3H}}, \tag{8}$$

where

C_3 = count rate from the 3-window algorithm
E_n = limiting energies of the windows ($E_1<E_2<E_3<E_4$)
B_{3P} = average background counts in the 3-window photopeak window (cps)
B_{3L} = average background counts in the 3-window low-energy window (cps)
B_{3H} = average background counts in the 3-window high-energy window (cps)
K_3 = ratio of the counts in the primary window to the counts in the two background windows in a reference region of the survey area.

The Three-window algorithm is also very useful in extracting low-energy photopeak counts where the shape of the Compton-scatter contributions from other isotopes is changing significantly.

2.6.4 Gamma Spectral Analysis

The MMGC algorithm is very general and is sensitive to any change in the low-energy portion of the spectrum. It does not exactly identify the causes of the change — whether (1) a true anthropogenic isotope is present in this region, (2) the increased low-energy gamma rays are caused by naturally occurring isotopes whose gamma rays underwent more inelastic scatterings before reaching the detectors (for example, a change from a grassy meadow to a dense wooded area), or (3) the isotopic composition of the spectrum in this region of the survey is significantly different from where K_{MM} was determined (for example, granite versus limestone). Once a region appears in the anthropogenic contours, the energy spectrum is searched for individual isotopes. An analysis of the gamma-ray spectrum is used to identify the isotopes that are present in the spectrum and caused the MMGC deviation.

Generally, the large background field (from the naturally occurring isotopes) is not of interest — only the portion of the spectrum attributable to the anthropogenic isotopes is. Unfortunately, the number of counts at any given energy in a single 1-second measurement is so small as to make the identification of a particular isotope very difficult. To increase the number of counts in the spectrum being analyzed (and thus produce better statistics), the spectra from neighboring measurements are combined to produce a single spectrum showing the radiation measured over some larger area.

To determine net spectra at an identified anomaly, each area of interest is divided into "peak" and "background" regions. The contour levels used to define these regions are usually MMGC levels. The peak and background boundaries may be defined by other means (e.g., GC contour levels). The peak region of the spectrum consists of the spectra contained in the area bounded by the chosen contour level. The background region consists of the spectra contained outside the chosen contour level. This partitioning generally guarantees that the background spectrum is representative of the geology near the anomaly, but there will be some contribution of anthropogenic radioactivity in the background region.

This technique produces a net spectrum that has very little contribution from the naturally occurring radionuclides in the region and makes the identification of the remaining isotopes fairly easy. The technique has one major drawback in that it does not necessarily produce a true indication of the strength of the isotopes seen in the net spectrum. That is, comparing the intensity of an isotope in one net spectrum with the intensity of that same isotope in another spectrum may not be meaningful.

Numerous techniques can be used to scale the background spectra when creating the net gamma-ray spectra. One technique that will be used on the IAAAP data is to compute the ratio of the live times of the peak and background regions and use the results to normalize the data. The technique that will be used on these data creates a net spectrum by subtracting the background spectrum, normalized by the ratio of the peak live time to the background live time, from the peak spectrum:

$$c_{Net}(E)=c_{Peak}(E)-\frac{T_{Peak}}{T_{Bkg}}c_{Bkg}(E) \ , \tag{9}$$

where

$c_{Net}(E)$ = counts in the net energy spectrum at the energy E (cps),

$c_{Peak}(E)$ = counts in the peak energy spectrum at the energy E (cps),

T_{Peak} = total spectrum live time composed of all peak-region spectra (s),

T_{Bkg} = total spectrum live time from all background-region spectra (s), and

$c_{Bkg}(E)$ = counts in the background energy spectrum at energy E (cps).

This method of normalization is relatively straightforward to implement. If there is an excess of naturally occurring radioisotopes, the net spectrum will preserve the high-energy photopeaks of these isotopes.

Spectral Distortions. When the survey has been performed over an area exhibiting large, rapid variations in the elevation of the terrain, the net spectra can suffer from another type of error. In the case where the aircraft is flown at a constant elevation while passing over a canyon or begins to climb early to pass over a mountain, the added air mass distorts the gamma-ray spectrum by removing more of the low-energy gamma rays than the higher-energy gamma rays. If this increased altitude occurs in spectra that will be used to assemble the background spectrum, then the background will be slightly deficient in low-energy gamma rays. Subtracting the background from the peak spectrum will produce a net spectrum that has no discernable photopeaks but only a gently varying excess of low-energy gamma rays.

If the survey contains areas of very high activity, the count rate in the detectors may become high enough to distort the spectra. This distortion results from having insufficient time between the electrical pulses generated by the amplifiers on the photomultiplier tubes. When these pulses reach the data collector, one pulse is superimposed on the tail of another pulse, and the data collector determines a voltage for this combined pulse that is no longer characteristic of the individual pulses. At moderate count rates, this distortion may appear as a broadening of the photopeak widths and possibly as a shift in the photopeak's apparent energy. At very high count rates, these effects become more severe, and it may be nearly impossible to recognize any pattern to the photopeaks present in the spectrum. If the count rate in the 12-detector array is high and produces distorted spectra, then the analysis continues using the spectra collected by the single detector.

2.7 Methods to Estimate Soil Concentrations

The instruments used in this survey measure gamma emissions, which directly correspond to exposure levels. However, many radiation protection regulations are written in terms of soil activity levels rather than exposure levels, because soil activity levels are more commonly measured. Soil activity levels of concern are generally determined on the basis of human or ecological health risks, which, in turn, are directly related to exposures. These exposure estimates are computed from the soil activity level data on the basis of a number of assumptions.

The exposure data gathered during the IAAAP aerial survey will be used to estimate what soil activity levels would result in these measured exposures through a similar, inverted process. By making assumptions about the distribution of the radioisotopes in the soil, soil activity levels that would provide equivalent measured exposures can be computed.

The conversion from a measured count rate to soil activity depends on several factors, including the distance from the source to the detector, the types and thicknesses of materials between the source and detector, the size of the detector, and the distribution of the isotope in the soil. For this aerial survey, all of these factors will be known with the exception of the source distribution in the soil. Table 2 gives typical conversion factors and minimum detectable activities (MDAs) for four possible distributions. (The point source is assumed to be directly below the aircraft flight path. All of the other distributions vary only as a function of the depth in the soil.) This topic is presented in more detail in Section 6.

Table 2 Minimum Detectable Activities (MDAs) for Pa-234m as a Point Source and Three Separate Soil Distributions

	Source Distribution			
Parameter	**Point Source**	**Uniform Depth**	**Exponential Depth[a]**	**Surface**
Conversion factor	0.89 (mCi/cps)	0.80 (pCi/g/cps)	0.70 (pCi/g/cps)	0.13 (µCi/m^2/cps)
MDA	37 (mCi)	34 (pCi/g)	29 (pCi/g)	5.5 (µCi/m^2)

[a] Where the distribution is of the form $A = A_0 e^{(-z/z_0)}$ with z_0 = 3 cm, and where the measured activity is averaged over the top 2.5 cm.

Section 3
Data Quality Objectives

3.1 Introduction

A survey work plan, such as this document, is developed to provide detailed descriptions of all the instruments, methods, procedures, decisions, and plans that will be involved in a field data collection activity. In the data quality objective (DQO) process, this information, along with information about the type of decision to be made, is used to determine if the field data collection activities and subsequent analysis methods produce data of sufficient quality to be used to support the required decision. The DQO process in general and its application for the IAAAP survey is presented in Section 3.2. This introductory section (Section 3.1) summarizes the survey plans and procedures (from Section 2) in terms relevant to the DQO process and makes also analogies to traditional field survey methods.

Because, this survey will use remote sensing equipment to gather data, it is inherently different from traditional field sampling programs. Field data collection efforts are generally described in detailed sampling plans that define and describe the various equipment, procedures, and methods that will be used to collect the samples. In addition, the location, size, and type of sample are described exactly. For this remotely sensed gamma survey, descriptions of the equipment that will be used, how the system will be deployed, how data will be collected, and how the data (computationally processed and analyzed in quantifiable terms) will be presented, take the place of a more traditional sampling plan.

This survey is also different from traditional gamma walk-over surveys, where a site-specific background count rate is established, and readings are compared to this rate to determine if they are significantly above background. In the IAAAP survey, natural isotopic ratios, specific to IAAAP, will be calculated from the measurements over known background regions in the survey area. These ratios will be used to detect changes in a specific isotope's abundance. Because site-specific isotopic ratios form the basis for analysis, the reliance on NIST-traceable sources for instrument verification during the survey is reduced. In fact, once the survey is started, data flights will be verified by measurements taken over a test strip established as part of the survey.

3.1.1 Sample Types

The field data that will be collected by the IAAAP survey are instrument readings rather than material samples. The readings that will be made as part of this survey contain two parts: (1) gamma spectral information spanning 0 to 4,000 keV and, (2) positional information, both horizontal and vertical. These data will be collected once per second, as described in Section 2. Section 2 also contains descriptions of the relative accuracy and precision of these measurements. Section 1.2 gives an overview of how the sensitivity of the system to various COPCs will be established. The description of the types of readings that will be made and the equipment that will be used to make those readings is analogous to describing the samples to be collected in a more traditional sampling plan. These descriptions are provided in Section 2.

3.1.2 Sample Method and Procedures

Describing the detection system (the AMS) and the various flight parameters (speed, height, line spacing, etc.) is analogous to defining standard field sampling procedures (e.g., sample size, sampling methods, etc.). By specifying the altitude and speed of the aircraft, along with a description of the AMS system, the data collection activities are completely specified in quantifiable terms. How these instruments will be controlled is also described in Section 2. For example, systems that provide both horizontal and vertical control for the pilot are presented, and how deviations will be handled are also noted (e.g., Equation 2 will be used to adjust for variations in altitude that occur during a data flight). The role of an on-board technician to oversee and verify data collection is also described.

3.1.3 Sample Locations and Number

Data will be collected over the entire 30 mi^2 of the plant, along with areas immediately adjacent to the boundaries (approximately 500 ft) and along two waterways as described in Section 1. Sample lines will be flown at 60 knots (nominally 100 ft/s) with a spacing of 200 ft. Measurements will be made once per second.

3.1.4 Quality Assurance Procedures

In many field sampling efforts, procedures such as splitting samples and providing trip blanks are used as quality control/quality assurance measures. For the IAAAP survey, a test strip will be flown at the beginning and end of every data-gathering flight. This procedure will provide two sets of quality control/quality assurance samples for every data gathering flight. These data will be used in two ways: (1) if variations between the data flights are minor and, based on the experience of the RSL mission scientist, within acceptable ranges, the data will be used to calibrate each data set or (2) if the variations are significant, the area will be re-flown. This procedure is analogous to providing trip blanks or duplicate samples in a standard sampling environment.

Several factors will be considered in selecting the test line for the aerial survey. The primary factor is that the terrestrial gamma radiation over the line (about 1 mile in length) should be relatively constant. A secondary factor is the desire to have visual references for the flight crew to guide them along the test line (such as a power line or a fence row). A third factor is the desire to avoid inhabited areas. Since the test line will be flown at the survey altitude twice on every flight, flying over inhabited areas could cause many complaints.

The test line will be flown and measurements taken at the beginning and end of each flight, and the average net count rate over the test line will be calculated from these measurements. For each flight, this average net count rate will be compared with the average of all prior test line count rates (C_{ave}). If the count rate of the new line differs by less than 200 counts (about 0.2 μR/h) from C_{ave}, the system will be judged to be working correctly. If the count rate is outside of that range, then the system will be inspected and tested on the ground before any more data are collected.

Using altitude spirals to determine the contribution to the survey from atmospheric and cosmic sources and obtaining confirmatory measurements with ground-based gamma-spectroscopy instruments are analogous to using standards and duplicate sampling methods in a more traditional field sampling program.

In addition to these procedures, once a data flight is complete, the data are immediately evaluated to determine if problems existed during the flight. Within a short time after a flight (typically 40 minutes), a visual examination of the data will be completed in the data center. Preliminary data analysis will also be performed on-site. In addition to providing a quality assurance/quality control function, this rapid on-site data screening will allow sampling procedures to be changed or the area reflown if questionable results are obtained.

3.1.5 Data Analysis

Typical sampling plans require the description of the laboratory (or field) data analysis methods and equipment that will be used. For the data acquired during the IAAAP survey, the data analysis equations presented are analogous to laboratory methods and describe completely how the data will be processed.

Once the data are processed through one of the analysis equations (gross count, man-made gross count, 2-window, 3-window, etc.), the processed data in regions without anthropogenic influences are approximately normally distributed. Using statistical analysis, any values in these distributions that appear anomalous can be classified as "anomalies." In evaluating the data populations that result from these analyses, an appropriate threshold can be established. Typically for aerial surveys with the AMS, any data more than three standard deviations (3σ) from the mean are classified as anomalies. However, spatial patterns also need to be evaluated to determine if the data actually represent potential anomalies in the field, or are part of the normal distribution of background values. Additional processing will be done in areas with potential anomalies as described in Section 2.6.4

The analyses for the IAAAP data will be described in the final report. This work plan describes these general procedures; specifics can not be provided until the data are processed to determine the resulting distributions and any spatial correlations.

3.1.6 Potentially Impacting Factors

Factors that could potentially affect survey results are the detection system, the speed of the aircraft, the altitude of the aircraft, contributions from cosmic sources, and variations in shielding (e.g., vegetation cover or soil moisture). These factors are all discussed in Section 2, and the equations that will be used for analysis presented.

The detection system is described and the redundancies of the ADCs are described. The collection of gamma spectroscopy data, positional data, and altitude data are described, along with relative accuracies of these measurements. Section 2 presents the equations that will be used to account for variation in altitude and other survey parameters and Section 2.6.4 describes how spectral distortions will be analyzed.

Standard walk-over radiological surveys utilize a "typical area background" (TAB) value as the basis for evaluating point-by-point measurements. Counts higher than the TAB are declared as "anomalous" or "above background," while counts lower than the TAB are declared as "no counts above background". Observed counts in nature, even in the absence of anthropogenic isotopes, vary greatly about the TAB. If tolerances are set too low, this natural variability creates erratic (false) positive and negative results. If tolerances are set too high (to avoid false indications) many anthropogenic contributions will be missed. Sophisticated gamma spectral processing of the IAAAP aerial measurements data will greatly improve detectability of anthropogenic contributions by removing the highly variable natural background counts on a point-by-point basis. Examples of beneficial results are as follows: anthropogenic contributions in low background areas will not be ignored, and high natural background areas will not trigger erroneous anthropogenic indications.

As described in Section 5, the RSL mission scientist will have on-site decision making authority during the survey. The mission scientist will consider site environmental conditions, weather, equipment, and other variables before each data flight with regard to how these factors could affect the data quality (the pilot in charge will make safety decisions). Using these site-specific factors and technical expertise, the mission scientist will direct the data gathering flights.

3.1.7 Qualitative and Quantitative Descriptions

This work plan quantitatively defines all the parameters related to the IAAAP survey. Specific values for speed, altitude, and descriptions of the AMS have been set. In addition to these items, the data analysis procedures have been described quantitatively in the form of the equations that will be used, and qualitatively in describing why and how each equation will be used.

Details of how the resulting data will be used are presented in a more quantitative fashion in Section 3.2, in keeping with the preliminary nature of this survey. This qualitative approach is in keeping with EPA DQO guidance. The EPA document, *Data Quality Objectives Process for Hazardous Waste Site Investigations* (EPA 2000a) states:

> *The DQO Process has both qualitative and quantitative aspects. The qualitative parts promote logical, practical planning for environmental data collection operations and complement the more quantitative aspects. The quantitative parts use statistical methods to design the data collection plan that will most efficiently control the probability of making an incorrect decision...Although the statistical aspects of the DQO Process are important, planning teams may not be able to apply statistics to every hazardous waste site investigation problem. For example, in the early stages of site assessment [e.g., RCRA Facility Assessments, Superfund Preliminary Assessments/Site Inspections (PAs/SIs)], statistical data collection designs may not be warranted by program guidelines or site-specific sampling objectives. In some*

cases, investigators may only need to use judgmental sampling or make authoritative measurements to confirm site characteristics.

The IAAAP aerial radiation survey fits this description quite well. It is a preliminary survey in the early stages of a site assessment. It is premature to specify exactly how the data gathered during this process will be used. It is important, however, to specify exactly how the data will be gathered, processed, and analyzed, so future decisions about the appropriateness of the data to a specific decision can be ascertained. This document provides that information. Additional, site- and data-specific information will be provided in the final report.

3.2 DQO Process and Application

The DQO process is a series of planning steps based on the scientific method for establishing data quality criteria and for developing survey designs (EPA 1994, 2000). The DQO process provides a systematic approach for defining the criteria necessary for a successful survey. As described in the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), the DQO process is an important part of the planning phase of the data life cycle for radiological surveys conducted in support of site cleanup. DQOs are developed for each phase of the radiation survey and site investigation process by using a graded approach.

A graded approach to DQO development allows for the collection of different types of data during each phase of the site investigation process on the basis of the specific decisions that are anticipated during each phase. As the site investigation and cleanup process progress, DQOs become more specific and rigorous, usually with statistical limits on decision errors as the process is completed and final status surveys are designed and conducted. Because the IAAAP aerial radiological survey is being conducted in support of the early phases of site investigation, the DQOs outlined in this document focus on supporting initial site investigation decisions. This support covers decisions on whether to further investigate anomalies identified during the survey and decisions on which areas are considered affected or unaffected by radioactive materials. The information gathered and data collected by this survey will only be part of the information considered when making these decisions.

The DQO process consists of the following seven steps:

1. State the problem
2. Identify the decision,
3. Identify the inputs to the decision,
4. Define the study boundaries,
5. Develop the decision rule,
6. Specify tolerable limits on decision errors, and
7. Optimize the design.

The following sections discuss the steps of the DQO process as they relate to the aerial radiological survey for the IAAAP.

3.2.1 State the Problem

Aerial radiological survey data are needed to (1) determine if anomalies associated with man-made gamma emitting radionuclides are present and may warrant further investigation and (2) help determine areas that are considered affected or unaffected by radioactive materials. Anomalies represent total gamma exposure rates, man-made gamma count rates, or calculated average surface soil radionuclide concentrations that differ from local background conditions.

3.2.2 Identify the Decision

The primary decision that the aerial radiological survey will support is determining whether additional investigation is needed for certain areas of the IAAAP (i.e., are there anomalies associated with man-made gamma emitting radionuclides that indicate the need for further investigation?). The survey will identify any areas that pose an immediate threat to human health.

The evaluation of anomalies will include a review of the total radiation exposure rate, man-made gamma count rates, and isotopic-specific data for gamma energies associated with Pu-239, Ra-226, Cs-137, and U-238.

3.2.3 Identify the Inputs to the Decision

The primary inputs to the decision will be the raw data (including ground truth measurements) collected as part of the aerial survey and historical site information, including aerial photographs and GIS layers. The aerial survey data will be evaluated and presented on maps for use in decision making related to follow-up investigations. The following types of figures represent anticipated inputs for decision making:

- Plots of total exposure rate (μR/h),
- Plots of MMGC rates, and
- Plots of calculated average soil concentrations or count rates from gamma energies associated with specific radionuclides including Pu-239, Ra-226, Cs-137, and U-238.

3.2.4 Define the Study Boundaries

For this aerial radiological survey, the study area boundaries are determined by the IAAAP property boundary (approximately 30 mi^2 for the flyover footprint area), and the study area includes two off-post areas: (1) along Brush Creek to the Mississippi River and (2) along Long Creek to Skunk River.

3.2.5 Develop the Decision Rule

If the data indicate that there is evidence of anthropogenic gamma-emitting radionuclides (using procedures discussed in Section 5), the area will be flagged as requiring further investigation.

If the data show no evidence of anthropogenic gamma-emitting radionuclides, additional review of historical evidence will be necessary to support a decision of no further investigation for that area. The finding of no anthropogenic gamma-emitting radionuclides will indicate that there is no immediate danger to human health or the environment.

The technology used for this survey represents the state of the art for rapid survey and detection of gamma-emitting radionuclides from large land areas by using an airborne survey platform. For many radionuclides, this system is capable of detecting radioactivity at levels approximately equal to the naturally occurring average background levels. Because the helicopter must operate at an established safe height and speed and because the field of view of the detector system is relatively wide, the ability to detect small areas ("hot spots") of low-yield gamma emitters is limited.

Specific detection levels are discussed in more detail in Section 6.1.6, but for decision-making purposes, the system is best used for contamination conditions that result in large area sources of gamma emitters (e.g., airborne releases, spills, or fallout). Because of the capability for detecting small discrete "chunks" of DU is limited, and because final cleanup guidelines (with associated size and averaging requirements) have not been established, the aerial measurement data should, in most cases, be supplemented with historical process information prior to determining that an area is unaffected by radioactive materials.

3.2.6 Specify Tolerable Limits on Decision Errors

Areas exhibiting total gamma exposure rates, man-made gamma count rates, or calculated soil concentrations greater than established investigation levels will be flagged for further investigation in future studies. Investigation levels for the total gamma exposure rate and man-made gamma count rate measurements will be based on the background levels for these parameters. The investigation levels for specific radionuclides are based on the uniform soil detection levels (MDAs) for the aerial measurement system shown in Table 3. For Ra-226 and Cs-137, the system MDAs are very close to the background levels of these radionuclides. However, the algorithms discussed in Section 5 provide a method to determine if these levels appear anomalous. For the other potential contaminants of concern (Pu-239 and U-238), the MDAs are low enough to provide useful information concerning the need for follow-up investigation and to assure that concentrations representing immediate human health concerns are not missed by the system. Also for these contaminants the algorithms discussed in Section 5 can provide a means to determine if the concentrations measured by the detectors appear anomalous.

Table 3 also provides example preliminary remediation goals (PRGs) for each of the potential contaminants of concern based on EPA default assumptions for an outdoor worker exposure scenario. These PRGs are shown as an example only and do not represent proposed cleanup guidelines for the IAAAP.

The example investigation levels shown in Table 3 are based on estimated sensitivity values for the aerial measurement system. Detailed calculations using site specific data will be performed following the field measurements, and final investigation levels based on these calculations will be provided in the final survey report.

Table 3 Estimated Aerial Survey Sensitivity[a]

	Point Source MDA[b]				CERCLA Risk Range Concentrations[g]	
Nuclide (+ progeny)	No offset (mCi)	Midway (mCi)	Uniform Soil[c] (pCi/g)	Surface Deposition (µCi/m^2)	10^{-6} (pCi/g)	10^{-4} (pCi/g)
DU[d,f]	20	45	40	6.5	1.8	180
^{137}Cs	0.10	0.2	0.3	0.04	0.11	11
^{226}Ra[e]	0.70	1.8	1.4	0.30	0.026	2.6
^{239}Pu[h]			3.1	0.13	14	1400

[a] Twelve 16 x 4 x 2- inch NaI(Tl) detectors, 100 ft AGL, 200 ft spacing, 60 knots.

[b] Can be total of fragments within detector's field of view, whose radius is approximately the altitude AGL.

[c] Other depth profiles generally have greater sensitivity, but overburden will hamper sensitivity.

[d] No self-attenuation (negligible, if pieces are less than 0.5 cm in diameter).

[e] Assuming concentration of surrogate (Bi-214) in secular equilibrium.

[f] Concentrations of DU less than the specified MDA fall within the CERCLA risk range with daughter products.

[g] PRG for outdoor worker

[h] No progeny in calculations. The surrogate for Pu-239 is Am-241. The ratio of Pu:Am is expected to be less than 10:1.

All of the sensitivities cited above are for concentrations in excess of the natural background. In other words, the soil activity is the sum of the concentration detected in the aerial survey plus the average concentration in the survey area. This sum is calculated for each radionuclide. The average abundance will be estimated from the set of judiciously selected ground-based, corroborative measurements.

3.3 Examples of Concentration Estimations

Since the detectors employed on the aerial system are not shielded, the detector footprint (field of view) has no firm boundary. The main factors that define the footprint are the energy of the gamma rays and the attenuation of the gamma rays by the atmosphere. The detector array is thus capable of detecting gamma rays from large distances, but the atmospheric attenuation acts to shield gamma rays from large distances.

The conversion factors used for converting the measured count rate into activity concentrations are based on calculations that assume the radioactivity is uniformly dispersed over an area on the ground that is "large" compared to the field of view of the detector array.

The field-of-view calculations are based on integrating the number of gamma rays from a small radioactive source element at location r with activity n(r) gamma rays per second. This initial flux is decreased by the fraction intercepted by the detector (the $A(E)/4\pi d^2$ factor) and the attenuation through the soil and atmosphere (the exponential term).

$$c(E) = \int n(\mathbf{r}) \frac{A(E)}{4\pi d^2} e^{\left[-\left(d \left\{ \frac{\mu}{\rho} \right\}_{air} \rho_{air} \right) - \left(z \sec(\theta) \left\{ \frac{\mu}{\rho} \right\}_{soil} \rho_{soil} \right) \right]} dV \,, \tag{10}$$

where:

$c(E)$ = count rate in the photopeak at energy E,

$n(r)$ = activity of the small source element in volume dV,

$A(E)$ = effective area of the detector at energy E,

d = distance between the source element and the detector,

z = distance of the source element below ground level,

θ = angle formed at the detector between the source element and the perpendicular to the ground,

$\left\{ \frac{\mu}{\rho} \right\}_{air}$ = mass attenuation coefficient for air,

ρ_{air} = density of air,

$\left\{ \frac{\mu}{\rho} \right\}_{soil}$ = mass attenuation coefficient for soil, and

ρ_{soil} = density of soil.

First, define the distance between the source element and the detector as two components: (1) a vertical distance, h + z, composed of the height of the detector above the ground and the distance of the source element below ground level and (2) a horizontal distance, r.

For a uniform surface distribution of a radioactive isotope (z = 0), the equation becomes:

$$c(E) = \frac{S_0 A(E)}{4\pi} \int_0^{\infty} \frac{1}{d^2} e^{-\left(d \left[\frac{\mu}{\rho} \right]_{air} \rho_{air} \right)} 2\pi r \, dr \,, \tag{11}$$

where

S_0 = surface activity and

r = horizontal distance of the source element from directly below the detector.

If the source area extends only a finite distance from the origin (instead of the infinite distance shown), equation 11 can produce the count rate if the upper limit of the integral is changed to reflect the radius of the source. Table 4 presents the results of these calculations that compare the effect of changing the size of the contaminated area. A spot size with a radius of 1,000 m approximates the "infinite" area used by the other calculations, and this spot size is given a correction factor of 1.0. The factors in the table multiply the activity value generated by the "large" area calculations. In other words, if the detector count rate in the Am-241 photopeak for 1 second indicates that the large area activity is X pCi/g, then a small spot with a 10-m radius (directly beneath the aircraft's path) and an activity of 13.71*X pCi/g would also produce that count rate.

Table 4 Finite Size Corrections for Am-241, Th-234, Cs-137, Pa-234m, and Bi-214

	Correction Factor[a]				
Source Radius (m)	Am-241 (59.5 keV)	Th-234 (93 keV)	Cs-137 (662 keV)	Pa-234m (1001 keV)	Bi-214 (1764 keV)
1000	1.0	1.0	1.0	1.0	1.0
400	1.00	1.00	1.00	1.01	1.02
100	1.08	1.10	1.25	1.31	1.40
50	1.43	1.49	1.87	1.99	2.18
40	1.70	1.79	2.31	2.47	2.72
30	2.28	2.41	3.19	3.43	3.79
20	4.09	4.37	5.92	6.41	7.13
15	6.54	7.01	9.58	10.39	11.59
10	13.71	14.74	20.32	22.06	24.61
5	45.77	49.58	68.66	74.97	83.45
4	73.86	79.54	110.50	119.07	133.29
3	135.42	146.85	202.06	224.92	246.08
2	325.00	381.80	505.14	539.80	599.81
1	1625.00	1909.00	2357.33	2699.00	3199.00

[a] For a detector system at 31 m (100 ft) AGL and a detector response that is an average of the isotropic and cosine cases. The detector array passes directly over the centers of these finite-size spots.

As can be seen from the table, as the gamma-ray energy increases, the contributions from large distances become more important. This is a result of the higher-energy gamma rays being able to travel farther before they are attenuated.

Section 4
Quality Assurance

This project will be performed under the Argonne QA program. The purpose of the QA program is to establish procedures for performing high-quality work on projects and to ensure that the planned procedures are being followed during the course of the work. QA procedures would be followed with regard to data collection, text revisions, and records retention. The Argonne QA program conforms to the good management practices of DOE Order 5700.6C on QA.

Section 5
Project Management

5.1 Project Institutions

This project will be managed by Joseph Ginanni, DOE National Nuclear Security Agency. The RSL at Nellis will be responsible for the field work associated with this project. Dr. Steven Riedhauser will the the RSL mission scientist. The Environmental Assessment Division at Argonne will be responsible for project management and preparation of the final report. The principal investigator from Argonne will be Dr. Gustavious Williams, who reports directly to Dr. Anthony J. Dvorak, Director of the Environmental Assessment Division.

5.2 Project Time Frame

The survey is currently planned for October 23-30, 2002, with four good flying days required during this period to complete the survey. However, if these dates are not satisfactory, and the team is not already in the field, later dates can be considered. If required, and weather permits, an alternative date to perform the survey is the first or second week of November. After then, the survey will have to be postponed until the spring of 2003 (probably around April).

The current schedule calls for flights to begin on Wednesday, October 23. The first day will include the site reconnaissance survey, a perimeter flight, an altitude spiral, and the start of data collection flights (which include flights over the established test strip). The altitude spiral will also be flown over the established test strip. A typical data gathering flight lasts for 2.5 hours, and is expected to complete 20 to 22 lines of the survey. The lines in the southern portion of the plant will be flown on Wednesday. The northern portion of the survey will be flown on Thursday, to avoid flying over the town of Middletown on the weekend. Data flights will continue Friday and Saturday, with flights over Production Line 1 and Production Line 3 left until the end of the survey to avoid conflicts with workers on the ground. The operations of the production lines will not affect the aerial survey, but the survey noise and the presence of a low-flying helicopter may affect the production lines.

Table 5 is a schedule for a typical day. This includes calibration activities, data analysis, and data flights. Actual schedules may differ because of survey needs, weather, or other factors.

Table 5 Typical daily activities.

Time	Activity
07:00	Electronic Technicians report to work at FBO
07:30	Electronic Technicians start calibration and collect preflight
08:00	Data Technicians runs preflight instrument verification data; Mission Scientist reviews data
08:30	1st flight departs
11:00	1st flight returns Lunch; Refuel and prepare for 2nd flight
12:30	2nd flight departs; Process data from morning flight
15:00	2nd flight returns Process data from afternoon flight; Prepare for next day's flights
17:00	Data Technicians assembles analysis for overnight processing

5.3 Environmental Factors

The mission scientist from RSL will decide whether to fly each day on the basis of site environmental factors that affect data collection. Several environmental parameters could potentially impact the survey and influence the survey data. For example, presence of snow, standing water, or saturated surface soils can affect gamma-ray measurements. These factors all relate to the amount of water present between the radionuclides in the soil and the detectors. The RSL mission scientist will be responsible for collecting data to describe daily weather conditions from appropriate sources.

The amount of water in the soil varies greatly under normal conditions. Regions that are near river beds or are constantly irrigated tend to have naturally high water content. Soil in the desert has a very low level of moisture. The decision on whether to fly will be based on an increase from this "normal" level of soil moisture. If there is more than one-half inch of snow on the ground, one-tenth inch of standing water, or the soil is more than 20% saturated (about the moisture content of clay), the measurements of gamma-ray activity will vary significantly from normal values. Since the "thickness" of this layer of water between the soil and the detectors varies over the footprint of the measurement, there is no consistent method to correct for the excess water. The mission scientist will decide not to fly the regions affected by the water in his judgement. This decision may be made on the basis of weather reports, driving around the survey area, or getting out of the vehicle and inspecting handfuls of soil in several locations.

5.4 Safety Factors

Before (and during) each flight, the pilot in command from RSL will make decisions as to whether flight conditions are safe on the basis of local actual and expected conditions. For example, if winds are more than 30 knots or are gusting by more the 15 knots, this typically represents a safety concern. However, the pilot in command can terminate flights on the basis of any conditions deemed unsafe.

5.5 Early Project Termination

If the survey has experienced a series of delays due to weather, equipment problems, or priority assignments (e.g., national security), the mission scientist from RSL will consult with the IAAAP Restoration Program Manager to determine the appropriate actions.

Section 6
Health and Safety Plan

To be provided as a separate document.

Section 7
Decontamination Activities

The survey instruments and equipment used in this project will not come into contact with any contaminated soils or materials. Decontamination will not be required.

No Argonne or RSL personnel will come into contact with materials contaminated with radioisotopes.

Section 8
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Appendix A: Radioactivity and Radiation

To provide a background for discussions of the aerial radiation survey methods and results, this appendix contains a brief introduction and discussion of radioactivity and radiation. Naturally occurring and anthropogenic radioisotopes, including natural background radiation levels, are discussed. The discussion includes explanations of radiation exposure and radiation dose.

A.1 Radioactivity

Elements consist of atoms that have the same number of protons (i.e., positive nuclear particles). The atoms can differ in the number of neutrons within the nucleus. These different nuclear species are called isotopes (Cember 1988). Most elements have several isotopes. While differing numbers of neutrons do not affect the chemical properties of these elements, their stability can be affected. If the number of neutrons versus protons lies outside a relatively narrow range, the isotope will be unstable and prone to break apart (decay). An isotope that is prone to decay is commonly referred to as a "radioisotope" because it is radioactive (emits radiation as it decays). Radiation is energy traveling in the form of waves or rays (such as photons and gamma rays) or particles (such as alpha or beta particles).

In many cases, radioisotopes undergo a series of transformations until a stable isotope is reached. This series of transformations is called a decay chain or series. The different elements that result from these transformations are called progeny or daughter products. Each isotope in these chains has its own characteristic radiation emissions, releasing radiation of a specific type and energy.

The more abundant types of radiation are gamma rays, beta particles, and alpha particles. An alpha particle is composed of two protons and two neutrons. Alpha particles can be stopped (shielded) by a single sheet of paper. A beta particle is a negatively charged electron emitted from the nucleus. Beta particles are more penetrating than alpha particles but are also quickly attenuated in the environment. For example, beta particles can be stopped by a thin sheet of aluminum or by a few centimeters of water. Unlike alpha and beta particles, gamma radiation has no mass and no charge. Gamma radiation can pass through paper, aluminum, or even several centimeters of lead and is thus more easily detected by remote sensors (sensors that can detect radiation at a large distance from its source) than are alpha and beta particles. This report focuses on gamma radiation.

The characteristic gamma emissions (defined by energy levels) for different isotopes are well known and form the basis for using remote sensing devices to detect the presence of a particular isotope. The detection efficiency of remote detection devices depends on the energy of the gamma ray and the amount and type of matter between the decaying isotope and the detector. For example, soil and water are good shielding materials. Gamma ray emissions can be stopped by several inches of either, preventing human exposure to potentially damaging radiation (but also preventing remote detection). In contrast, air does not attenuate gamma radiation as quickly and allows detection of radioactive materials with remote sensing devices.

For some radioisotopes of concern, such as those in depleted uranium (DU), the energies of the gamma emissions are difficult to detect. However, for many of these isotopes, the decay of one of its progeny generally provides a more easily detected gamma emission. These emissions can then be used to determine the amount of the original isotope present. DU is typically detected by the gamma emissions from the decay of protactinium-234m (^{234m}Pa), a uranium-238 (^{238}U) progeny product with a half-life of slightly more than 1 minute.

A.2 Activity, Exposure, and Dose

Radiation is measured and reported in a number of different ways, depending on the way the measurements were made and their intended use. "Activity" is the rate of isotopic decay. Activity units are used when the concentrations of radioactive materials are needed. Because of the difference in the rates of decay of isotopes, mass measurements (grams) are not useful for quantifying these materials. Instead, the measurement unit needs to be based on the decay rate. It is measured as the number of disintegrations per unit time. A typical activity unit is the curie (Ci). It is equal to the activity of 1 gram of radium-226 (^{226}Ra). The international unit equivalent is the bequerel (Bq), which is defined as 1 disintegration per second. The activities of various isotopes can be measured in the laboratory from field-collected samples of soil, sediment, or water. These isotope-specific activities are then used in risk assessments to derive cancer risk estimates. They can also be used to derive estimates of the amount of radiation energy absorbed by a given mass of tissue, which determines the amount of damage done to that tissue. The amount of energy absorbed by tissue from an exposure is called a "dose." Typical dose units are the rad and the gray (Gy).

When the effects of radiation are being measured in the environment, as opposed to measurements made in the laboratory, exposure is generally measured directly. The detectors used in this survey measured the amount of gamma radiation striking them each second. This value was then converted into an "exposure rate." The typical unit of exposure is the roentgen (R), which is a measure of the amount of radiation absorbed by a given volume of air. Measurements in this report are given in microroentgens (µR). A microroentgen is 1/1,000,000th of a roentgen. While not directly used in cancer risk estimates or dose calculations, exposure measurements provide a means of comparing ambient radiation levels across large areas to determine if further investigation is required. Typically, occupational exposure level calculations use roentgens as a general exposure unit.

A.3 Natural and Anthropogenic Radioisotopes

A.3.1 General

Radiation comes both from natural sources (i.e., cosmic rays or terrestrial materials) and, potentially, from anthropogenic (man-made) radioactive isotopes. As noted previously, most natural elements have a number of isotopes, some of which are radioactive and subject to decay. Naturally occurring radioactive materials are found everywhere in the environment. Anthropogenic isotopes, on the other hand, are in the environment because of their manufacture, use, and disposal by humans.

Many components contributed to forming the total gamma-ray energy spectrum measured by the sensors that will be used in this study. These components are (1) natural terrestrial radionuclides, (2) airborne radon gas and its progeny, (3) cosmic rays, (4) anthropogenic terrestrial radionuclides, and (5) contributions from equipment that will be used in the study.

The first three components are considered to be natural background radiation. The anthropogenic radionuclides (such as cobalt-60 [^{60}Co] and cesium-137 [^{137}Cs]) are the components of the most interest in environmental surveys. In this study, uranium is a radionuclide of interest because of testing activities involving DU at IAAAP. Areas with DU contributions will be identified on the basis of gamma emissions from protactinium-234m (^{234m}Pa). The final item in the above list represents radioisotopes present in the measuring equipment and all sources of "noise" in the final spectrum — including noise in the electronics.

A.3.2 Background Radiation

Levels of background radiation in the environment are variable and depend on many factors. Local geology has a large influence on the amount of background radiation because of the varying amounts of naturally occurring radioisotopes present in different rocks and soils. Because water is a good shielding material, the amount of water in the environment can also affect the amount of background radiation emissions from the ground surface. For example, a wetland area that has a few inches of standing water will have very low levels of surface radiation emissions.

The most prominent natural isotopes usually represented in aerial gamma-ray spectra are potassium-40 (^{40}K) (0.012% of natural potassium); two progeny products in the thorium-232 (^{232}Th) chain — thallium-208 (^{208}Tl) and actinium-228 (^{228}Ac); and two progeny in the uranium-238 (^{238}U) chain — lead-214 (^{214}Pb) and bismuth-214 (^{214}Bi). These naturally occurring isotopes typically contribute 1 to 15 μR/h to the background radiation field (Lindeken et al. 1972).

The contribution of radon and its progeny to the background radiation field depends on such factors as the concentration of uranium and thorium parent isotopes in the soil, the permeability of the soil, and the meteorological conditions at the time of measurement (Nazaroff 1992). Soil releases of radon lead to an average air concentration of 8 becquerels per cubic meter (Bq/m^3) (216 picocuries per cubic meter, pCi/m^3) over the northern hemisphere (NCRP 1991). Typically, the amount of airborne radiation from radon and its progeny contributes 1 to 10% of the natural background radiation level measured in aerial surveys conducted by DOE's Remote Sensing Laboratory.

The contribution of cosmic rays to the background radiation field varies with elevation above mean sea level and, to a lesser extent, with geomagnetic latitude and the 11-year solar sunspot cycle. In the continental United States, values range from 3.3 μR/h at sea level to 12 μR/h at an elevation of 9,800 ft (Klement et al. 1972). Calculations of the cosmic-ray contribution used in the data analysis discussed in this report depend solely on the variation with elevation.

Background radiation exposure rates have been measured at many locations across the United States. A National Council on Radiation Protection and Measurements report (NCRP 1987) gave results from seven different studies that measured exposure rates from background radiation. The smallest study included 6 measurements taken near Boston; the largest study involved 9,026 measurements in 102 different towns located in 24 states (most east of the Mississippi River). The exposure rates reported in these studies ranged from 7.9 to 26 µR/h (NCRP 1987).[2] These measurements include the exposure rate from cosmic radiation.

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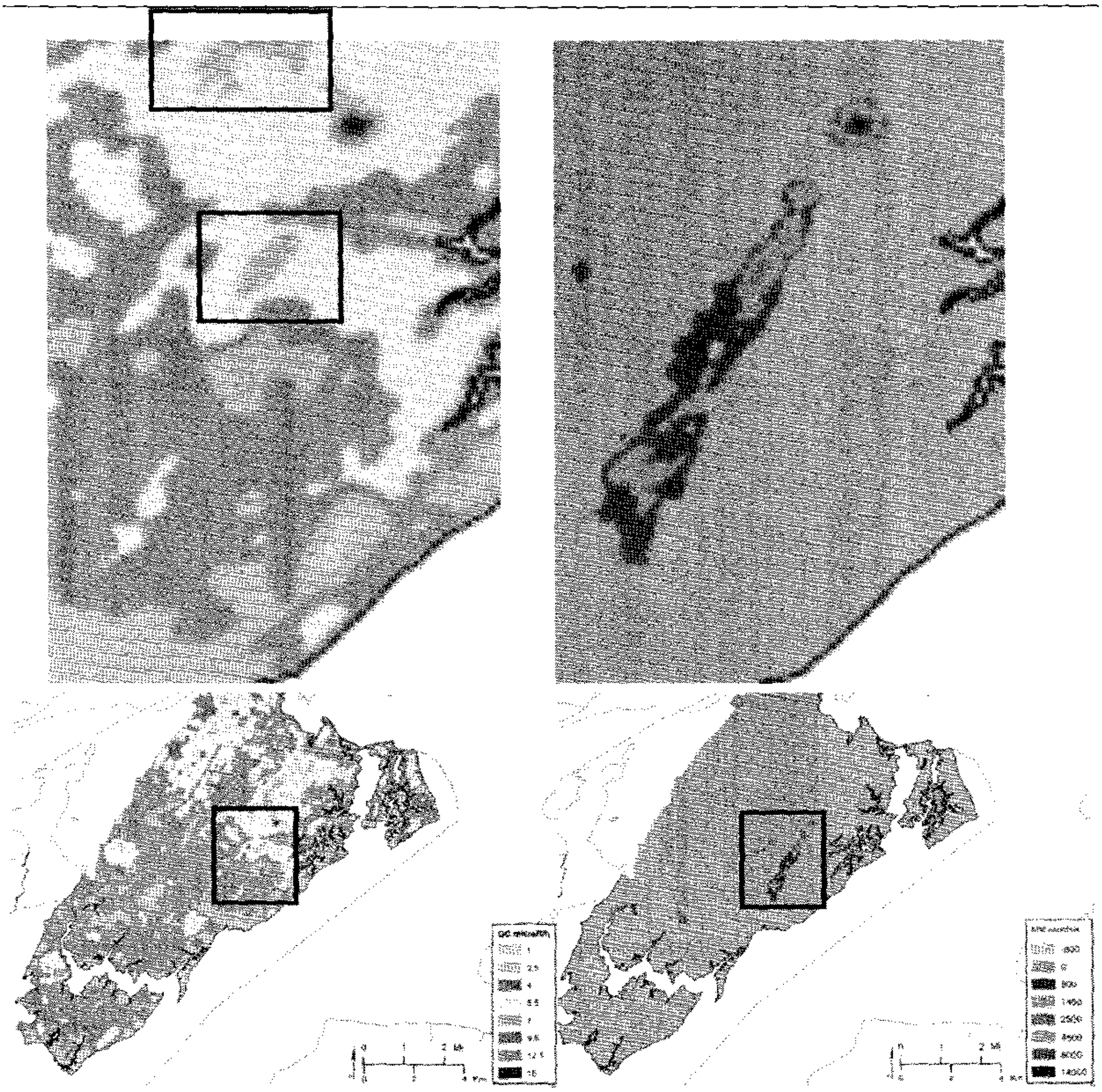
[2] Results were reported in mGy/yr and converted to µR/h based on NCRP (1987) procedures: 76µR/h = 1 mGy/yr.

Appendix B: Examples of DU Aerial Survey Results in Wet Conditions



These images show the effects of soil moisture on total gross-count (left image) and how it has little impact on the efficiency of the extraction algorithms (right image).

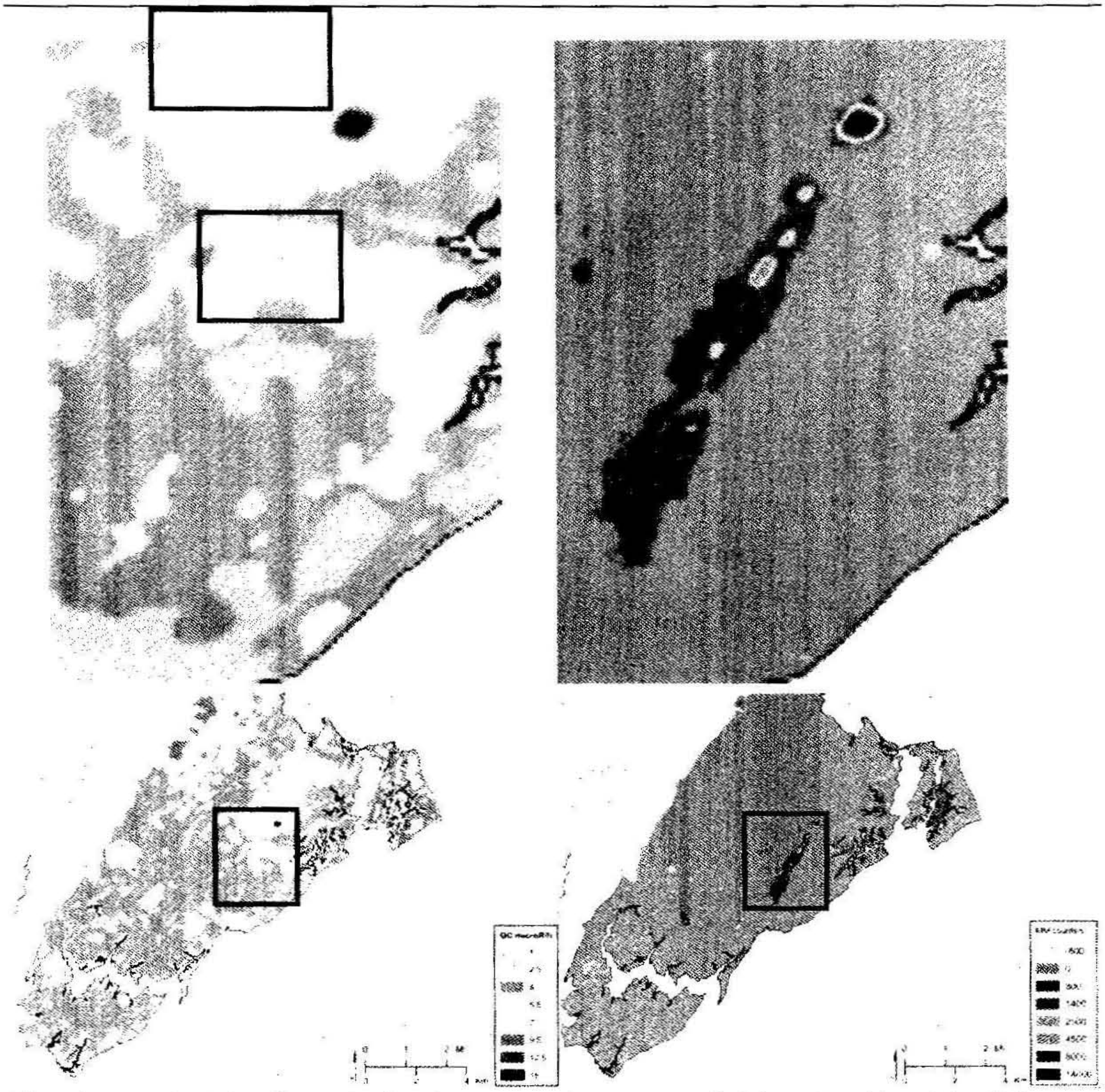
The image on the left shows gross-count readings from the APG survey converted to approximate microR/hr equivalents at 1 meter. These readings range from 1 to 16 micro R/hr, a large range. Geology in this area does not change significantly over the scale of these images (approximately 5 km for the upper images). However, this is a very wet area with marshes and swamps. Inlets from the Chesapeake Bay can be seen on the right side of the figures.

The image on the right shows the man-made gross count (which indicated the presence of anthropogenic isotopes), which was extracted from the gross-count readings. As expected, background areas range from -800 cps to +800 cps and are normally-distributed around 0. Anomalies are plotted when data fall outside of three standard deviations from the mean (3 sigma). This is represented by the light blue color and higher.

The left image shows two boxes, both with readings in the 7 microR/hr range. The upper box has this reading because it is a raised dry area, the second area has an elevated reading because of DU.

The right image clearly shows the DU plume on the high-velocity test range. The extraction algorithms clearly find DU in areas with lower than normal total gross count areas, and differentiate between other areas with higher readings. This is true even thought the DU plume shown goes through areas that range from relatively dry, to very wet.

Appendix B: Examples of DU Aerial Survey Results in Wet Conditions



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