Introduction to Aerial Radiological Measurements

Presented by

U.S. Department of Energy

National Nuclear Security Administration

Aerial Measuring System

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy. DOE/NV/03624--1303

Questions for the Audience

- Are you familiar with Aerial Radiological Measurements (ARM)?

  Yes/**No**

- Does your organization:

  A) operate an ARM system,

  B) plan to operate aerial radiation detection assets, or

  C) just simply want to learn what ARM is.

Course Structure

- **Objective:**
  - Provide participants with **basic** information about aerial radiation detection of:
    - ground contamination
    - radiation anomalies
- **Techniques:**
  - Virtual instructor lead training
- **Prerequisites:**
  - Basic knowledge of radiation detection and radiation protection concepts

Course Outline

What?
What is ARM?

Why?
Reasons for Use of ARM

Who?
Aviation and Science Team

How?
Equipment, Basic Mission Profiles, Data Analysis

Q&A

Your Instructors

- All instructors are emergency responders in the U.S. Department of Energy Aerial Measuring System (AMS) asset, with a minimum of 3 years of relevant experience. They will introduce themselves in the next few minutes.

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Q&A

What constitutes aerial radiation measurements (ARM) asset?

Aircraft

+

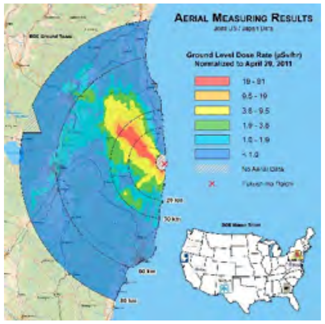
Radiation Detection Equipment

+

Trained Personnel

=

Aerial Radiation Detection Asset



What is ARM?

Interview with the US DOE Team Leader during Fukushima NPP accident response describing AMS mission

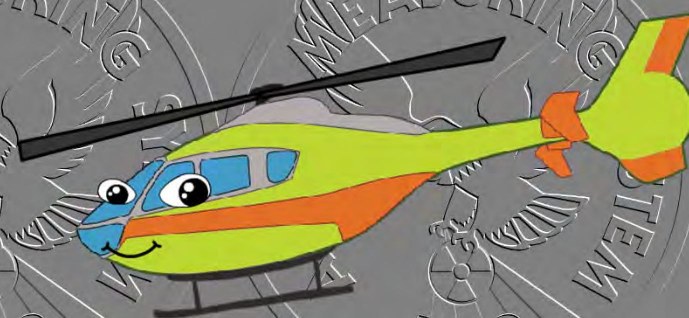
Aircraft

Question for Audience:

- Where can you get a helicopter to support aerial detection mission?

Answers:

- Military
- Law Enforcement – Police
- Search and Rescue Organizations
- Private charter companies
- Purchasing your own



Aircraft

Police helicopter (Eurocopter EC135) used by the Germany BfS team

Civil Defense helicopter (Airbus EC145) used by French CEA Helinuc team

SAR helicopter (Bell UH-60) used by Japanese team during Fukushima response

Military helicopter (Bell UH-1) used by AMS team in Japan during Fukushima response

Chartered helicopter (Aerospatiale AS350) used by French IRSN team

Bell 412 helicopter own by US DOE and dedicated to aerial emergency response mission by AMS asset

DOE AMS Aircraft Fleet

Bell-412

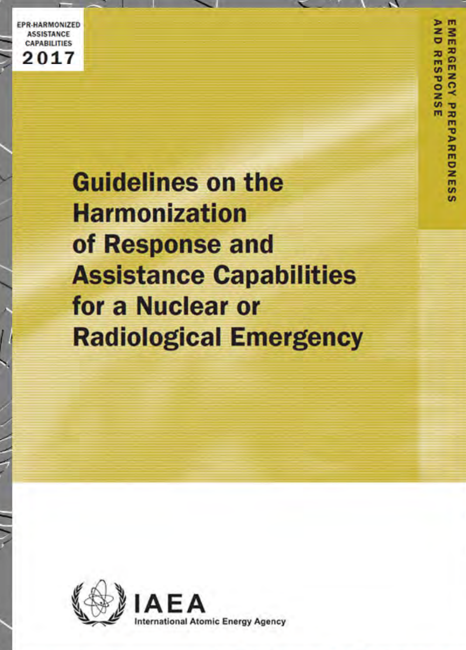
- Twin-Pac turboshaft engine
- IFR (all weather) rated
- 120 knots (140 mph)
- Range 360 nm (410 sm)
- Max Endurance 3 hrs (without refueling)
- Mission Altitudes: 50–500 feet AGL
- Mission Speed: 70 knots (80 mph)

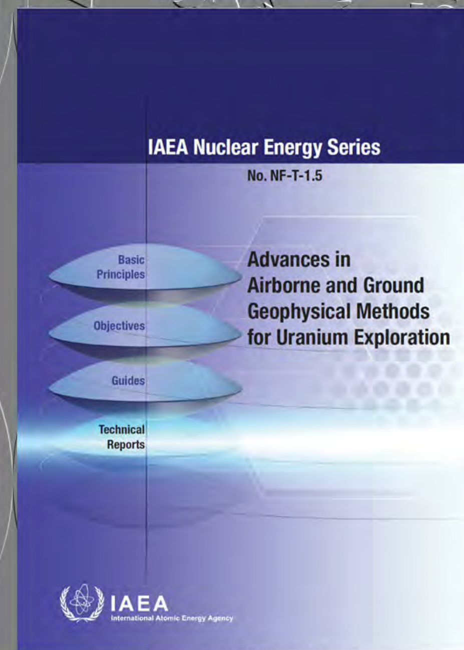
Beech King Air B-350ER

- Twin-engine turbo prop
- IFR (all weather) rated
- 300 knots (345 mph)
- Range 1878 nm (2161 sm)
- Max Endurance 10 hrs. (without refueling)
- Mission Altitudes: 500–2000 feet AGL
- Mission Speed: 160 knots (184 mph)

Radiation Detection Equipment

Aerial System Requirements (Reference Documents)





https://www.dhs.gov/sites/default/files/publications/Technical Capability Standard for Aerial Mounted Radiation Detection Systems.pdf

https://www.iaea.org/publications/11159/guidelines-on-the-harmonization-of-response-and-assistance-capabilities-for-a-nuclear-or-radiological-emergency

https://www.iaea.org/publications/8641/advances-in-airborne-and-ground-geophysical-methods-for-uranium-exploration

Examples of Commercial Systems

- There are several manufactures of the aerial/mobile radiation detection systems on the market.
- Majority of them follow the same philosophy of design and have similar basic components:
  - Detector package
  - Control Unit
  - Acquisition Software

SPIR-Ident Mobile Platform
Airborne and Carborne
Mobile Spectrometry
MIRION Technologies

https://www.mirion.com/products/spir-ident-mobile-advanced-spectroscopy-platform

RADPatrol
NUVIA Dynamics

http://picoenvirotec.com/enviro/siris/

RS-700 / RS-600 Series
Mobile Radiation
Detection System
Radiation Solutions, Inc.

https://www.radiationsolutions.ca/mobile/

Example of In-House Built System

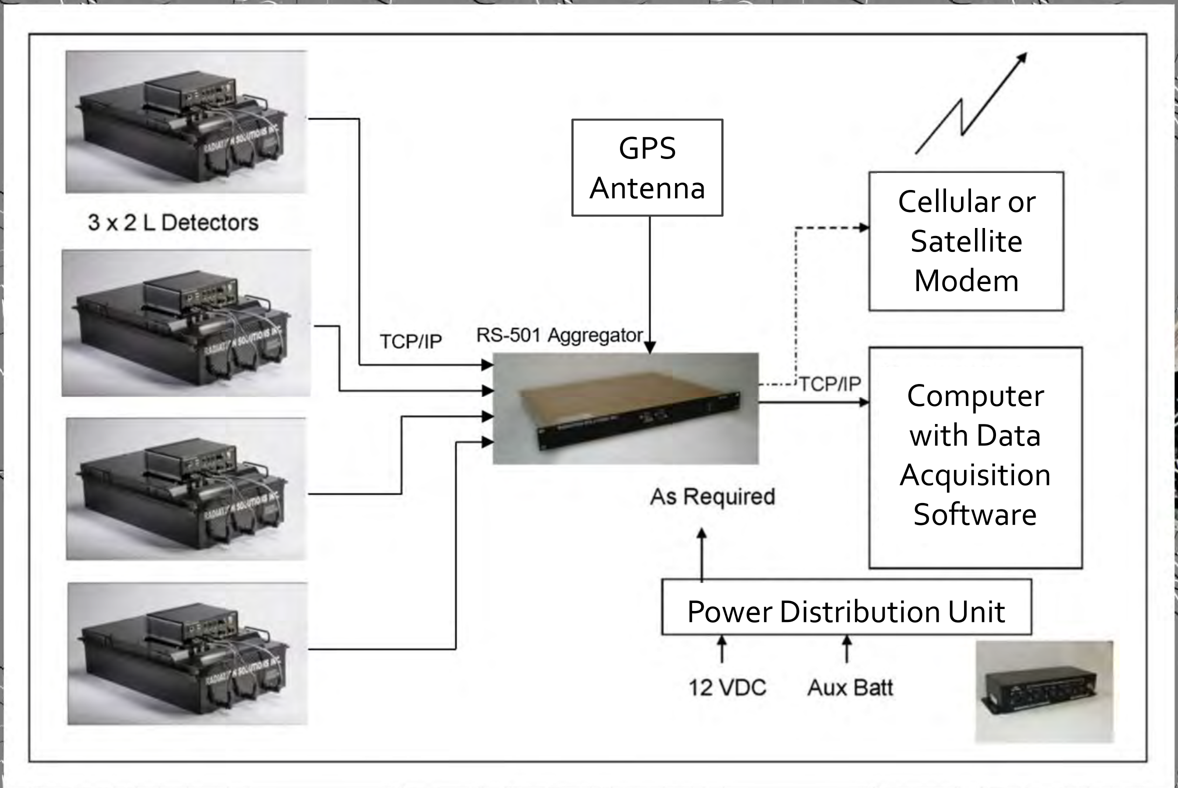
Spectral Advanced Radiological Computer System (**SPARCS)** is a radiological data acquisition and analysis system designed for the nuclear or radiological emergency response mission.

- Modular system that records the gamma radiation levels, spectral data and GPS coordinates
- Operator display with key data and position tracking on a map
- Portable, relatively light, and durable enough that it can be readily mounted in almost any vehicle, boat or aircraft
- Wide array of applications to include search, portal monitoring, pre-event baseline surveys and emergency response
- Easy to install and operate
- Available as long term loan from US DOE NA-81 Office

Detector Pod:

- 4 NaI(Tl) Gamma Detectors:
  - 2"x4"x16" (5 cm x 10 cm x 40 cm)
  - 2"x4"x4" (5 cm x 10 cm x 10 cm)
  - 2"x4"x4" (uplooking)
  - 1"x1" (2.5 cm x 2.5 cm)
- Support Electronics:
  - HV power supplies
  - Pre-amplifiers
  - Multi-channel analyzers
- Size:
  - 30"L x 15"W x 10"H
  - (76 cm x 38 cm x 25 cm)
- Weight:
  - 70 lb (32 kg)

DOE AMS Configuration with 4 x RSX-3 (12 crystals)



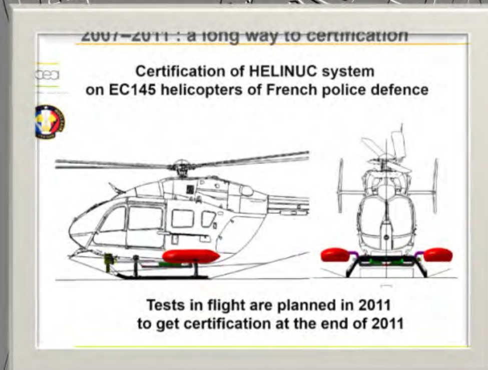
Data Acquisition System Installation

Detectors mounted externally to the aircraft (examples)

RSI detectors mounted on external platform utilized by LA County Sheriffs Department

Mirion detectors in the external basket mounted to the helicopter skids utilized by French IRSN

Commercial mounting solutions



Custom designed, built, and certified detector pods utilized by French CEA

Data Acquisition Systems Installation

Detectors mounted internally to the aircraft (examples)

AMS system (two RSI RSX-3 modules 12 L NaI(Tl) with controller mounted on the floor of US Air Force UH-60 helicopter during response to Fukushima Daichi NPP accident

Instituto Nazionale di Fisica Nucleare AGRS system (in-house developed 16 L NaI(Tl) system) mounted to the French Aerospatiale AS350 during AGC2019 exercise in Orange, France

Question for Audience:

- What would be better – mounting detectors inside a helicopter or outside a helicopter?

Answers:

And the answer is . . . . It depends.

Data Acquisition System Installation

Radiation detectors can be mounted on the helicopter in external pods (External Mounting), or attached to the floor inside a helicopter cabin (Internal Mounting)

External Mounting	Internal Mounting
Difficult	Easy
External mounting requires aviation authority approvals	Mounted to the helicopter floor as cargo, usually approved by crew chief/mechanic
Expensive	No cost/cargo straps
Low attenuation of signal	Higher signal attenuation due helicopter frame
GPS antenna can be mounted in the pod	GPS antenna in the window
Requires specific model helicopter	Any helicopter with sufficient floor space

Questions from the Audience

Introduction to Aerial Radiological Measurements (ARM)

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U.S. Department of Energy

PART 2

Course Outline

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Q&A

Why: Example 1

An earthquake and tsunami has seriously damaged a nuclear power plant.

— — — — — — — — —

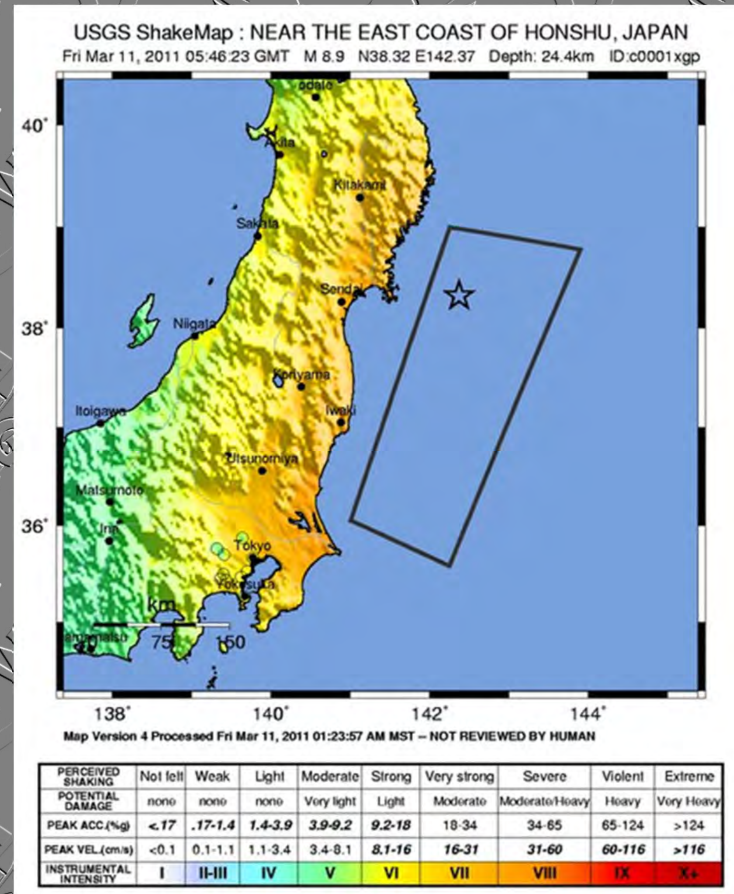
2011 Tōhoku Earthquake and tsunami caused a series of radioactive releases at the Fukushima Daiichi nuclear power plant.

— — — — — — — — —

The extent and magnitude of the contamination needs to be determined.

— — — — — — — — —

This information is needed for evacuation and shelter-in-place decisions.



https://commons.wikimedia.org/wiki/File:2011_Japan_shakemap.jpg

Fukushima Daichi Accident

Video courtesy of Channel 4 News a British public broadcast service and uploaded to YouTube https://youtu.be/QO_w8tCn9gU

Fukushima Daiichi NPP

- March 11, 2011 8.9 earthquake off coast of Honshu Island, Japan
- Generates 14 m tsunami resulting in fatalities, damage, and a serious nuclear incident at Fukushima Daichi NPP with significant radioactive ground contamination of about 800 square km.

Question for the Audience: 

How do we quickly estimate the level and extent of ground contamination?

Question for Audience:

How can WE rapidly obtain radiological information of large (10-100 km) ground contamination after radiological accident, or locate radiation anomalies?

Answers:

- Atmospheric dispersion modeling,
- Sampling,
- Hand-held, direct readout instruments,
- Mobile/carborne radiation detection systems,
- Aerial radiation detection systems.

Why: Example 2

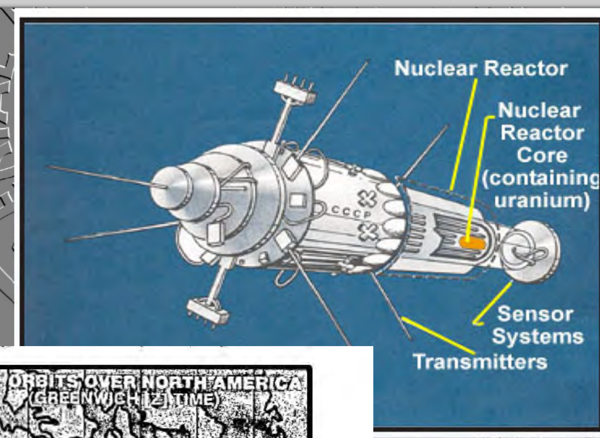
A satellite with a nuclear power plant onboard malfunctions and crashes over land.

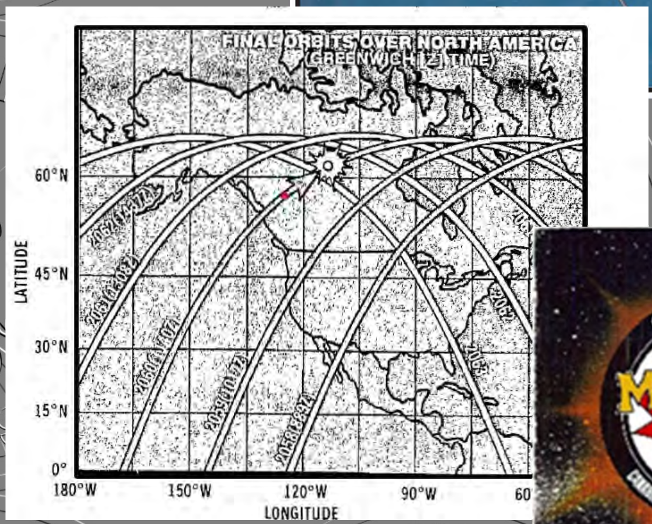
At 11:53 GMT on January 24 1978, Russian reconnaissance satellite Kosmos 954 with nuclear reactor on board (50 kg of U-235), after a malfunction reentered the Earth's atmosphere over western Canada, scattering debris over a 600 km path.

The recovery survey area looking for debris covered over 124000 square kilometers.

Question for the Audience:

How can the area be surveyed quickly?





Operation Morning Light

National Security

A microwave ranging transponder unit is placed under a landmark. The distance limitations of the units meant constant movement was necessary as the search moved along the footprint.

Team members, dressed in specially designed arctic clothing, begin the painstaking process of searching the area with hand-held radiation detectors.

Introduction

In the pre-dawn hours of January 24, 1978, a Canadian Mounted Police corporal located in Hay River, in the Canadian Northwest Territories, reported a meteor sighting. One hundred and twenty-five miles north, in Yellowknife, a night janitor reported mysterious lights streaking across the darkened sky. What these eye-witnesses actually saw was the re-entry of the Soviet satellite Cosmos 954 into Earth's atmosphere.

Background

Cosmos 954 launched into orbit on September 18, 1977. The satellite was designed to cover the world's oceans at a 150-mile high orbit. The cylindrical satellite weighed approximately 4.4 tons and contained a nuclear reactor to generate power. Although it did not pose an explosive danger, the reactor produced radioactive isotopes, including strontium, cesium, and iodine.

The North American Aerospace Defense Command, the organization that tracks all the satellites and debris orbiting in space, first noticed Cosmos 954 slipping in its orbit soon after its launch - a potentially dangerous situation that might result in an impact with Earth. Acting on this information, the U.S. National Security Council directed the U.S. Department of Energy (DOE) to take operational control of emergency response efforts in the U.S. and place its nuclear emergency response capabilities on alert.

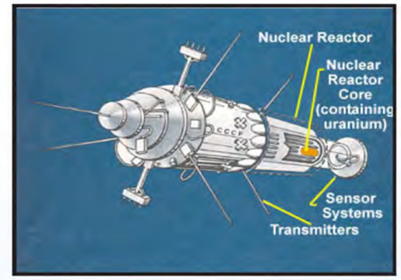
Preparing for impact

Team members from the DOE Nuclear Emergency Support Team (NEST) began preparing to deploy to the point of impact from locations in Las Vegas, Nevada; Fairfield, California; Washington, D.C., and Albuquerque, New Mexico.

DOE nuclear response capabilities include the world's leading scientists, engineers and technicians. NEST is deployed to locate and identify nuclear materials, assess suspected nuclear devices, render safe procedures in recovery of nuclear devices as well as packaging and transport of devices to disposition locations. Team members were prepared to deploy on two hours notice.

National Security

When re-entry occurred over Canada, U.S. President Carter contacted Canadian Prime Minister Trudeau to offer specialized U.S. capabilities in locating and isolating the errant satellite and its radioactive byproducts. The American response team, under the direction of the Nevada DOE manager, arrived in Canada on January 24, 1978 and reported to the Canadian Forces for assistance in recovery efforts code named 'Operation Morning Light.' By January 28, NEST members were in Yellowknife awaiting deployment to satellite debris locations.



Artist rendition of the Soviet Cosmos 954 satellite.

Recovery

Field operations in the Canadian Northwest Territories largely consisted of joint Canadian-American airborne radiation surveys, local area helicopter radiation surveys, ground search and recovery operations, and airborne logistical support during the winter and spring of 1978. A 500-mile long 'footprint' pinpointing the area of fallen debris was identified and field crews began the arduous task of recovering the debris along the vast, frozen area.

Based on computer calculations, two characteristics of satellite debris were identified:

- A number of beryllium cylinders, rods and products separated from the nuclear reactor in the satellite
- The reactor core, which began to disintegrate over a range of 310 miles, would result in small radioactive particulates scattered over a wide area

Actual debris was located in four areas in the Northwest Territories. Plates, disks, rods, and other objects with radiation levels measuring from one to 200 roentgens/hour were recovered. Approximately 100 radiological objects, ranging in size from particles to large pipes, were collected.

Scientists could not collect the microscopic radioactive fission products that resulted from the reactor core disintegration upon re-entry into Earth's atmosphere. A survey conducted in the Great Slave Lake area of the Northwest Territories revealed elevated background radiation caused by the widely dispersed matter from the reactor core. Both Canadian and U.S. experts concluded that any health hazard created by the remaining particulate matter was minimal and would decrease with time. The team recovered more than 90% of the radioactive material in the reactor inventory.

For more information, contact:
U.S. Department of Energy
National Nuclear Security Administration
Nevada Field Office
Office of Public Affairs
P.O. Box 98518
Las Vegas, NV 89193-8518
phone: 702-295-3521
fax: 702-295-0154
email: nevada@nnsa.doe.gov
http://www.nv.energy.gov

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Question for Audience:

How can we rapidly search large (10-100 km) to locate radiation anomalies like radioactive debris?

Answers:

- Walking with radiation detection backpacks
- Mobile/vehicle-mounted systems
- Aerial systems

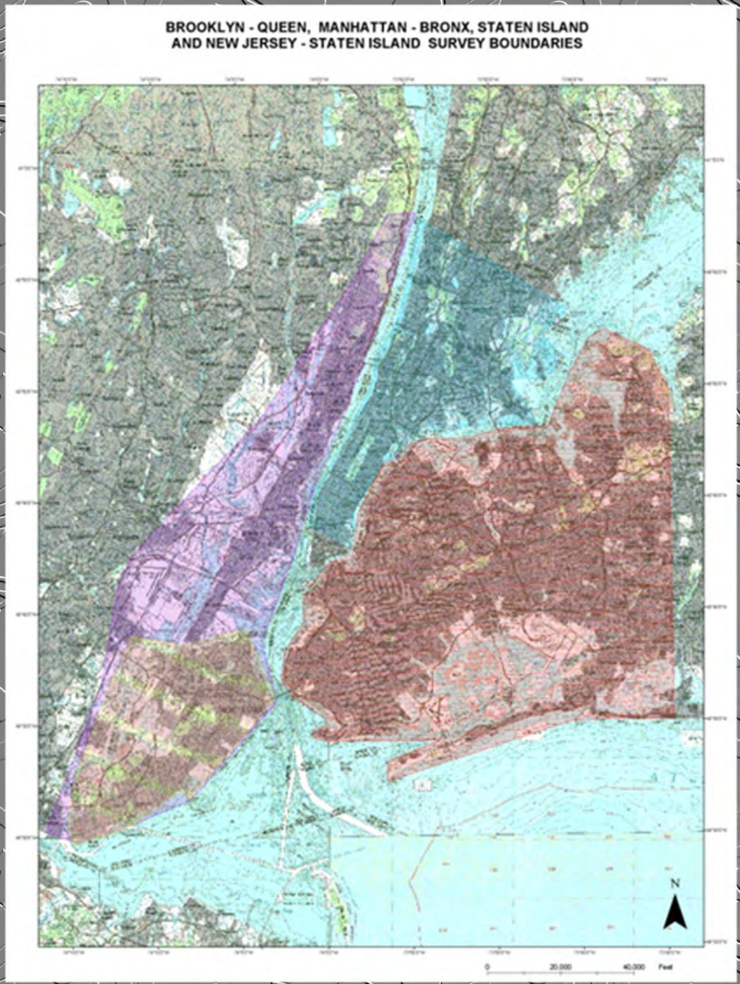
Why: Example 3

A large city wants to know the distribution of normal background radiation.

In 2005 New York City wanted a background radiological survey of all five boroughs (Manhattan, Brooklyn, Queens, the Bronx and Staten Island).

Question for the Audience: 

How can the measurements be taken efficiently and reliably?



Question for Audience: 

How can WE rapidly obtain radiological background information ?

Answers:

- Sampling,
- Hand-held, direct readout instruments,
- Mobile/carborne radiation detection systems,
- Aerial radiation detection systems.

Why Aerial Radiological Measurements?

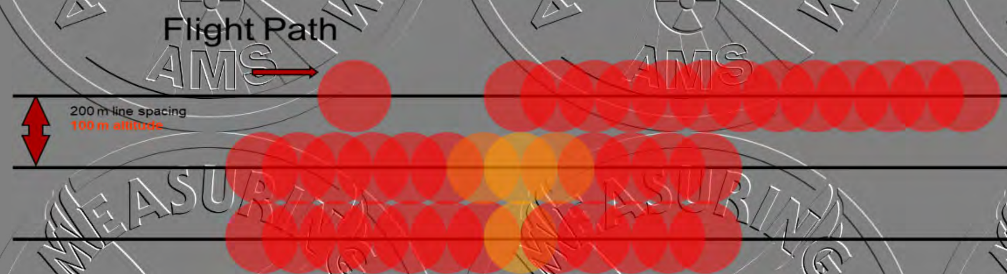
Safety	contamination, terrain
Speed	**flying** versus **driving** versus **walking**
Consistency	same system, same calibration
Cost	common misconception

Safety

Air	Ground
175 m (500 feet) away from contaminated terrain (air attenuation of gamma rays)	Walking on contaminated terrain (direct exposure to gamma radiation)
No inhalation dose risk	Inhalation dose risk due to resuspension
No issue with access due to complex terrain	Potential injury/no access in complex terrain

Speed

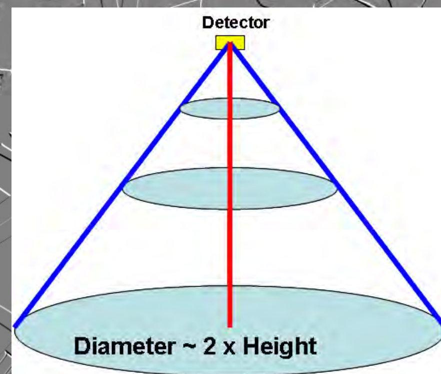
- Large areas can be covered quickly
- Rule of thumb: The diameter of the aerial footprint is equal to 2 x flight altitude
- For absolute coverage the line spacing should be 2 x flight altitude: for example flying at 100 m AGL = line spacing 200 m



Altitude Tradeoffs

Low detector

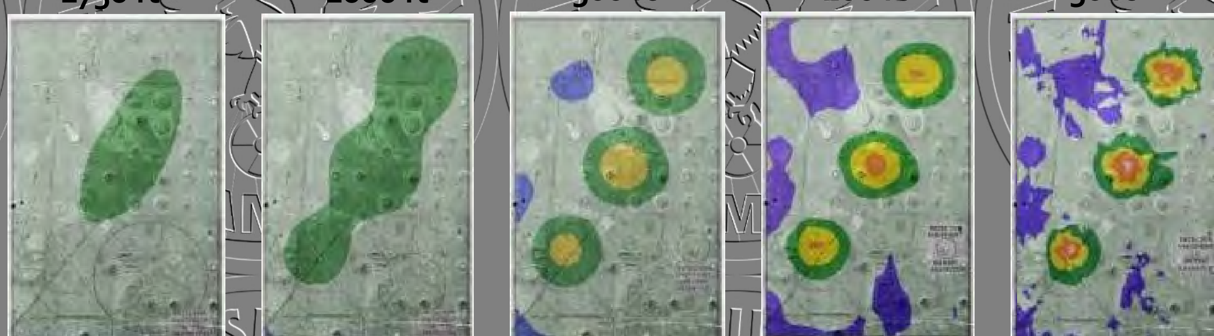
- High Resolution
- Discrete sampling
- Slow coverage
- $1/R^2$ minor loss
- Atmospheric attenuation is small



High detector

- Low resolution
- Area averaging
- Rapid coverage
- $1/R^2$ significant loss
- Atmospheric attenuation is large

1750 ft **1000 ft** **500 ft** **200 ft** **50 ft**

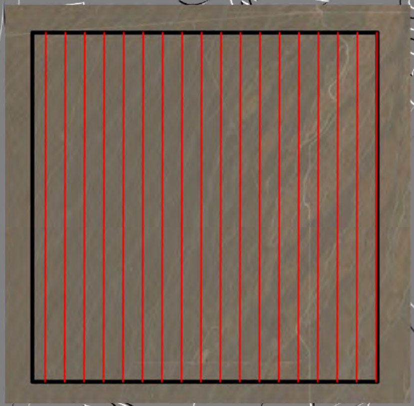


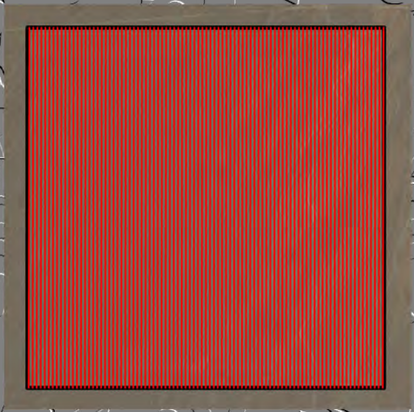
Speed

Information below compares the area covered by an aerial system in contrast to a mobile (ground) system. It assumes there are no obstructions for the aerial system and the ground system has complete access to area to be covered. In this case, a direct correlation can be used without taking into account detectability but focusing on the area to be covered.

The area to be covered is 1 square mile (5280 feet x 5280 feet).

Flat land with no obstructions.





Speed

Helicopter Mission at 150 ft and 300 ft line spacing flying at 70 knots		
Width Distance (1 Mile=5280 feet)	5280.00	feet
Line Spacing (feet)	300.00	feet
Number of Lines (Distance/Line Spacing)	18	lines
Aircraft Speed 70 knots(1 knot = 1.15 mph)	80.5	mph
Speed (1 mph = 5280 ft / 60 min/hr)	7089	ft/min
Minutes per Line	0.75	min/line
Turnaround Time (.5 minutes)	0.50	
Total Minutes per Line	1.25	minutes
Total Time to Cover 1x1 sq-miles	22.5	minutes

Speed

Mobile system with 60 ft detector view and traveling at 30 mph		
Width Distance (1 Mile=5280 feet)	5280.00	feet
Line Spacing (feet)	60.00	feet
Number of Lines (Distance/Line Spacing)	88.00	lines
Vehicle Speed	30.00	mph
Speed (1 mph = 5280 ft / 60 min/hr)	2640.00	ft/min
Minutes per Line	2.00	min/line
Turnaround Time (.5 minutes)	0.50	
Total Minutes per Line	2.50	minutes
Total Time to Cover 1x1 sq-miles	220.00	minutes

Speed

Conclusion: advantage AMS

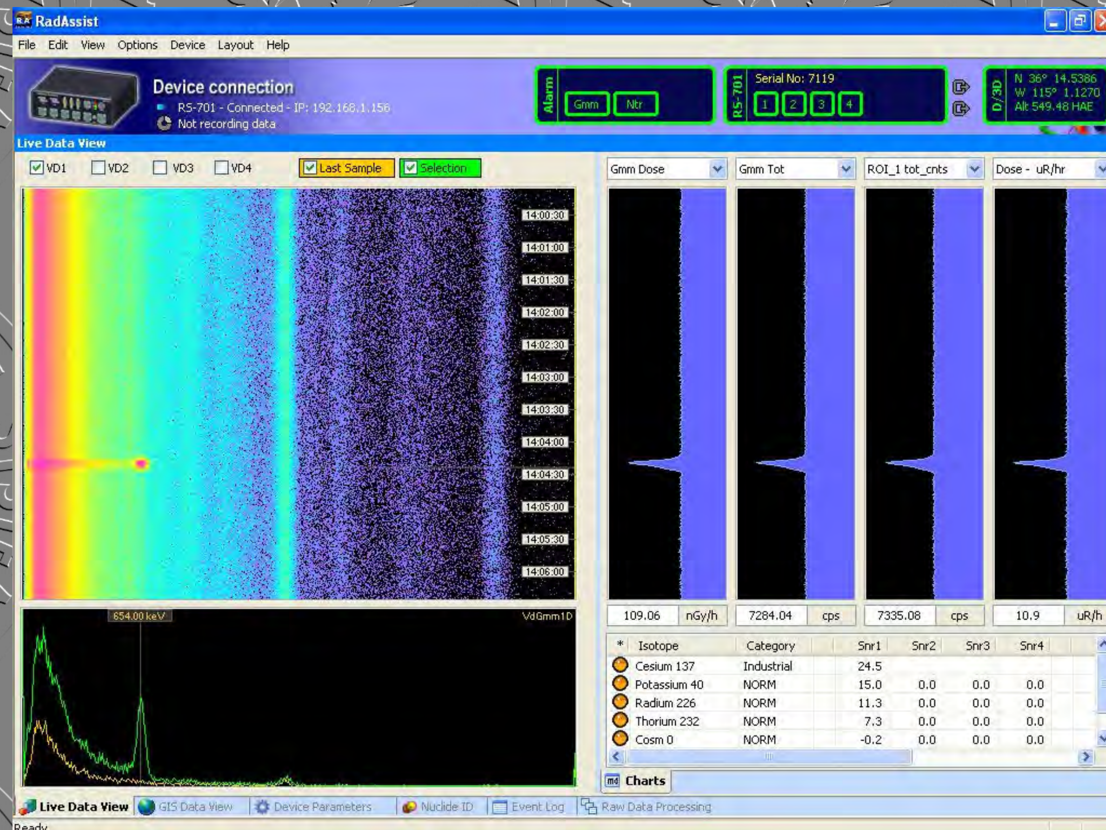
Time Multiplier Difference between Aerial and Mobile	x10
Aircraft can cover the survey area 10 times faster.	

Consistency

Air	Ground
Single calibrated radiation detection system and operator	**Multiple** radiation detection instruments and operators

Consistency

- Data are continuously recorded over survey area.
- Corrections are made for variations in altitude to remove artifacts.



Cost

The largest cost = helicopter

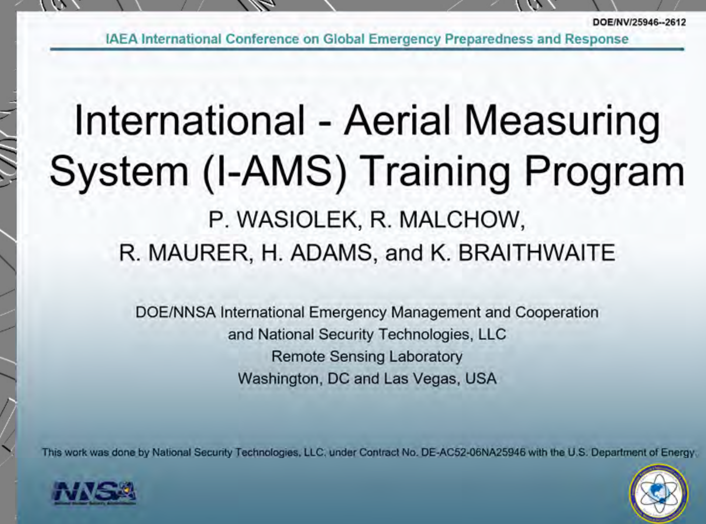
Cost reduction = agreements with other agencies operating helicopters

- military/paramilitary (Switzerland)
- civil defense (France)
- law enforcement (Canada, Germany, USA)
- search and rescue (SAR) (Taiwan)

Second largest cost = training

Cost reduction = utilizing already existing expertise

- geological/geophysical services in many countries have aerial measurements expertise (Canada, Norway, Sweden)
- utilizing international assistance (IAEA-RANET, bilateral agreements)


DOE/NV/25946--2612

IAEA International Conference on Global Emergency Preparedness and Response

International - Aerial Measuring System (I-AMS) Training Program

P. WASIOLEK, R. MALCHOW, R. MAURER, H. ADAMS, and K. BRAITHWAITE

DOE/NNSA International Emergency Management and Cooperation and National Security Technologies, LLC
Remote Sensing Laboratory
Washington, DC and Las Vegas, USA

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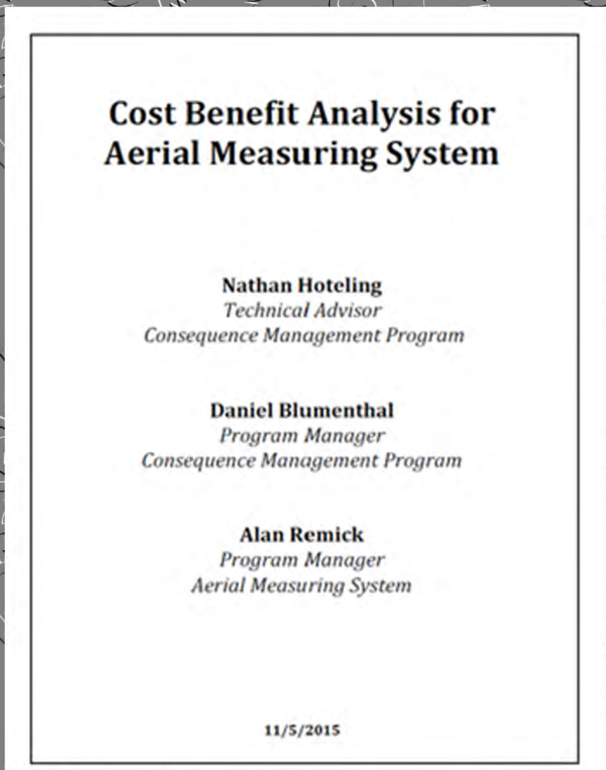
NNSA

Cost


Cost Benefit Analysis for Aerial Measuring System

Nathan Hoteling
Technical Advisor
Consequence Management Program

Daniel Blumenthal
Program Manager
Consequence Management Program

Alan Remick
Program Manager
Aerial Measuring System

11/5/2015

- A 2015 DOE study estimated the cost of evacuating or sheltering a population following a radiological event.
- The time the population was evacuated or sheltered was determined by how quickly measurements could be made to determine the extent of the contaminated area.
- An ARM program without dedicated aircraft could reduce these costs by 1/3.
- An ARM program with dedicated aircraft could reduce these costs by 2/3.
- Because of the costs of maintaining an ARM program, major events see a bigger cost reduction.

Questions for Presenter(s)

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Part 3

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Who?

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How?

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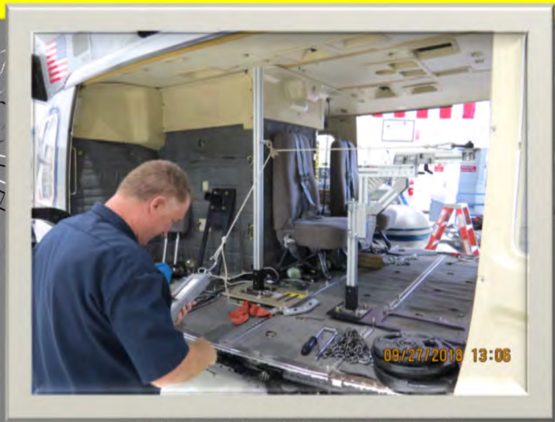
Q&A

ARM Mission Personnel

Trained Personnel

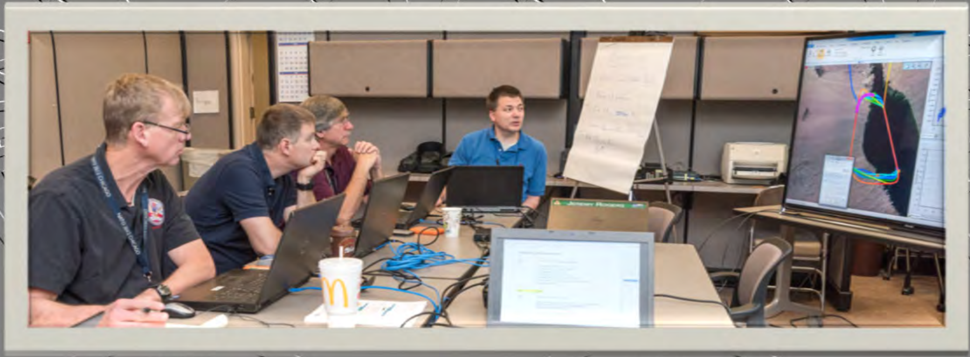
Pilots

AVIATION



Aircraft Mechanics

Equipment Operators



Data Analysts

SCIENCE

Pilots

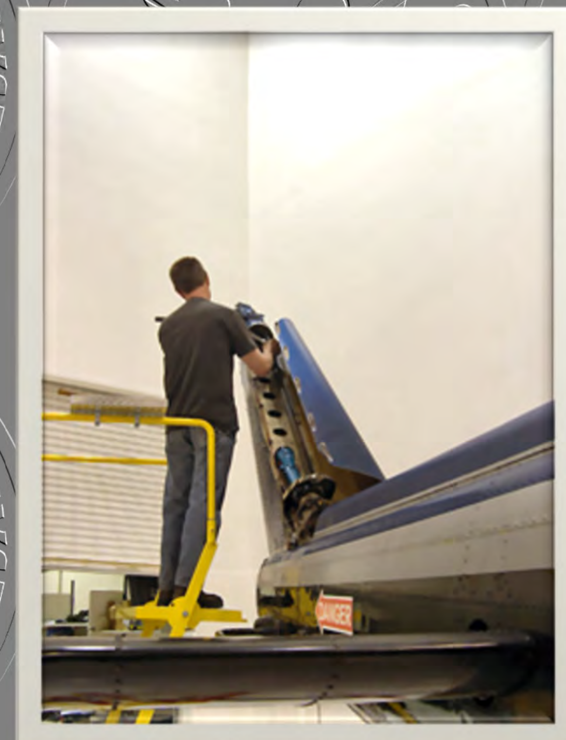
Pilots – one or two highly qualified individuals with experience in low level precision flying:

- Military
- Law Enforcement
- Commercial
- If asked for recommendation of previous experience, Search and Rescue (SAR) is good
- Deploys on the mission

Aircraft Mechanics

Ensures the reliability and airworthiness of the aircraft by performing inspections, completing all necessary preventative maintenance during required intervals, performing repairs as necessary. Assist the equipment operator and pilot with the loading and securing or equipment and cargo.

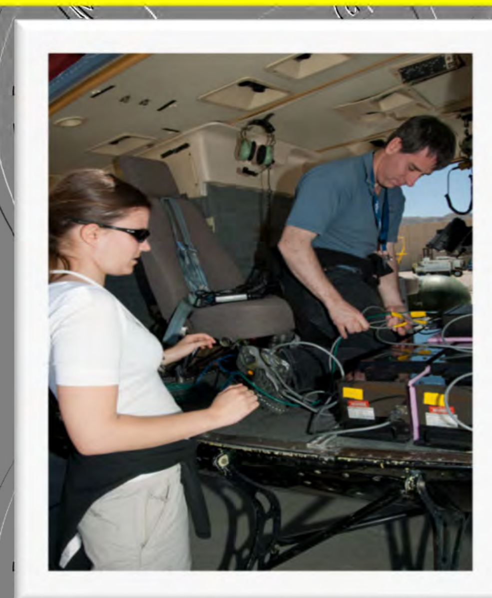
- The mechanic or aircraft crew chief can verify the mounting of radiation detection equipment.
- May deploy depending on the mission.



Science Team

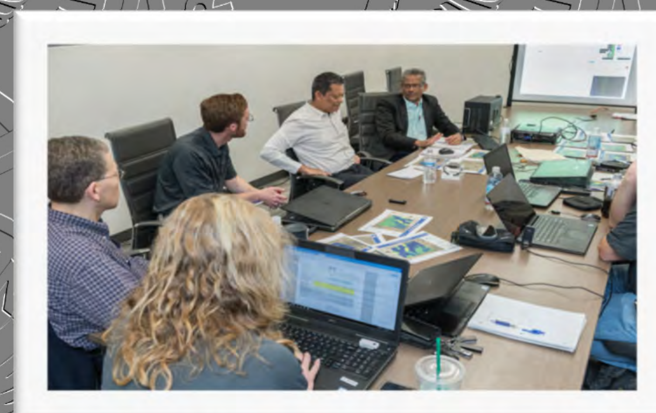
Mission Manager

Equipment Operator



The feature that distinguishes the radiation detection process from being qualitative (in terms low/high expressed in counts per second) from quantitative measurements (expressed in terms of physical quantities like grays/hour or becquerels/m²) is the **science support team,** trained in acquisition and analysis of aerial data. The team typically consists of an acquisition team and a data analysis team.

Data Team



Mission Manager/Leader

An individual, usually a radiation scientist, assigned to supervise all activities necessary for planning and conducting AMS missions. Responsible for the mission planning and the deployment of AMS assets into the field. Directs survey actions during mission and adjusts priorities as additional information is gathered. Deploys on the mission.

Some of the typical functions and responsibilities of Mission Manager

Coordinate with the representatives of the involved organizations to develop aerial monitoring mission plan.	Additional Responsibilities
Ensure that the plan considers as a minimum the following: • Mission type • Mission location • Safety considerations • When the mission will occur • How the mission will be conducted • Who will be involved in the conduct of the mission • What completion results are expected • Mission execution	• Provide the team with an initial briefing of the overall mission, mission radiological hazards and mitigations (turnback limits) • Brief and update the team on the final mission plans and overall objectives. • Direct the data acquisition activities as specified by the controlling agency. • Determine when it is necessary to modify the original radiation monitoring plan to ensure that the safest and most efficient operation is conducted • Generate a report of the survey results • Brief the customer on the findings and final data products

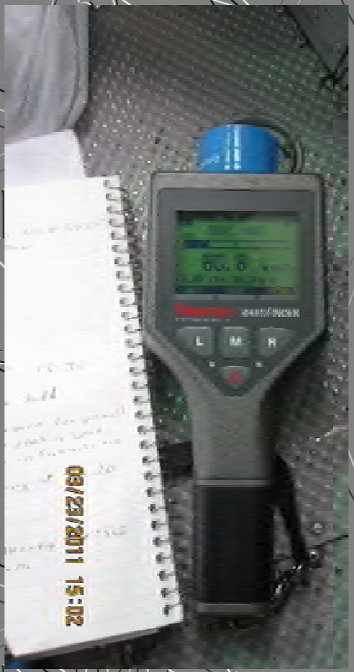
In-Flight Radiation Safety

Mission Manager/Scientist has to monitor the radiation levels on board the aircraft

US DOE Emergency Worker Exposure Turn-Back Guidance

DOE Safety Limits:
Dose rate 1 mSv/h (100 mR/h) and/or
Total dose 5 mSv (500 mR)

Incident Response Limits:
Investigate: 0.015 Sv (1.5 R)
Administration Control: 0.025 Sv (2.5 R)
Maximum Allowable Limit: 0.05 Sv (5.0 R)



Dose rate meter used by AMS in Fukushima response

Other countries may use different limits, for example IAEA Operational Intervention Levels (OILs)

Question for Audience:

- What are your dose limits?
- What are your turn-back limits?
- Are they based on international standards (IAEA)?
- Are they specific to your country/organization?

Equipment Operator

Qualified technician, engineer, or scientist that installs and verifies operability of detection equipment in the aircraft. Assists the Mission Manager with planning, and operating equipment during flights. Deploys on the mission.

In particular:

- Inspect and check the equipment to verify its readiness
- Coordinate all equipment installation onboard mission aircraft with the Aircraft Mechanic
- Install/secure and operationally check required mission equipment
- Verify any supplemental equipment that has been loaded (like health physics instruments)
- Conduct data acquisition on the aircraft as outlined in the mission plan
- Upon return to home base, restore all equipment to survey ready status

Data Team

Data Team: Individuals, usually radiation scientists or technologists with strong analytical and GIS [Geographic Information System] backgrounds, that act as the liaison to the response organization throughout a mission, and are responsible for receiving and analyzing the field data, with the ultimate goal of delivering a scientifically defendable product to decision makers regarding public health and safety. May deploy depending on the mission.

In particular:

- Assist in mission planning
- Collect/obtain necessary geo-referenced data (maps, aerial photos)
- Develop the necessary maps needed for the surveys
- Monitor the flight telemetry of data.
- **Develop data products following a survey (the biggest challenge of all).**

Data Analysis Tools

Radiation Data Analysis Software

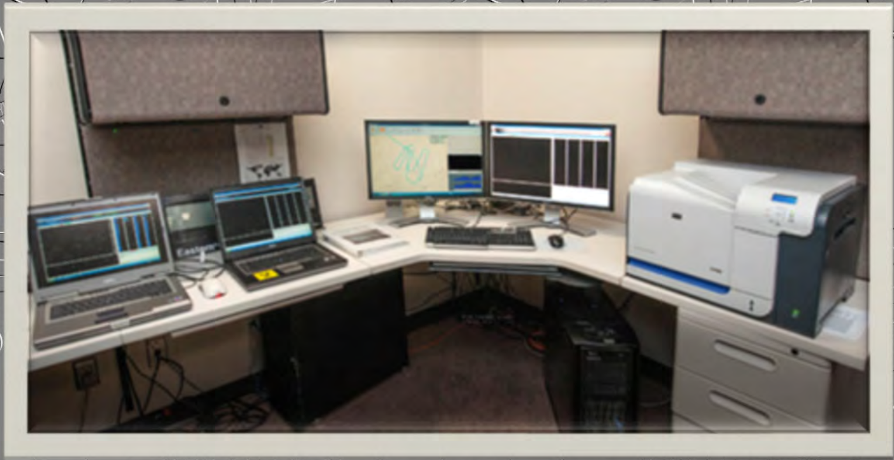
- **Commercial**, as provided by radiation detection system manufacturer, e.g. RadAssist by RSI or Mirion analysis suite
  - AGAMA software developed by Czech National Radiation Protection Institute (SÚRO), with co-operation: Nuvia CZ
- **In House** developed software for the aerial monitoring assets

GIS mapping software

- Commercial, e.g. ArcGIS by ESRI *https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview*
- Open-source, e.g. QGIS *https://www.qgis.org*

Hardware

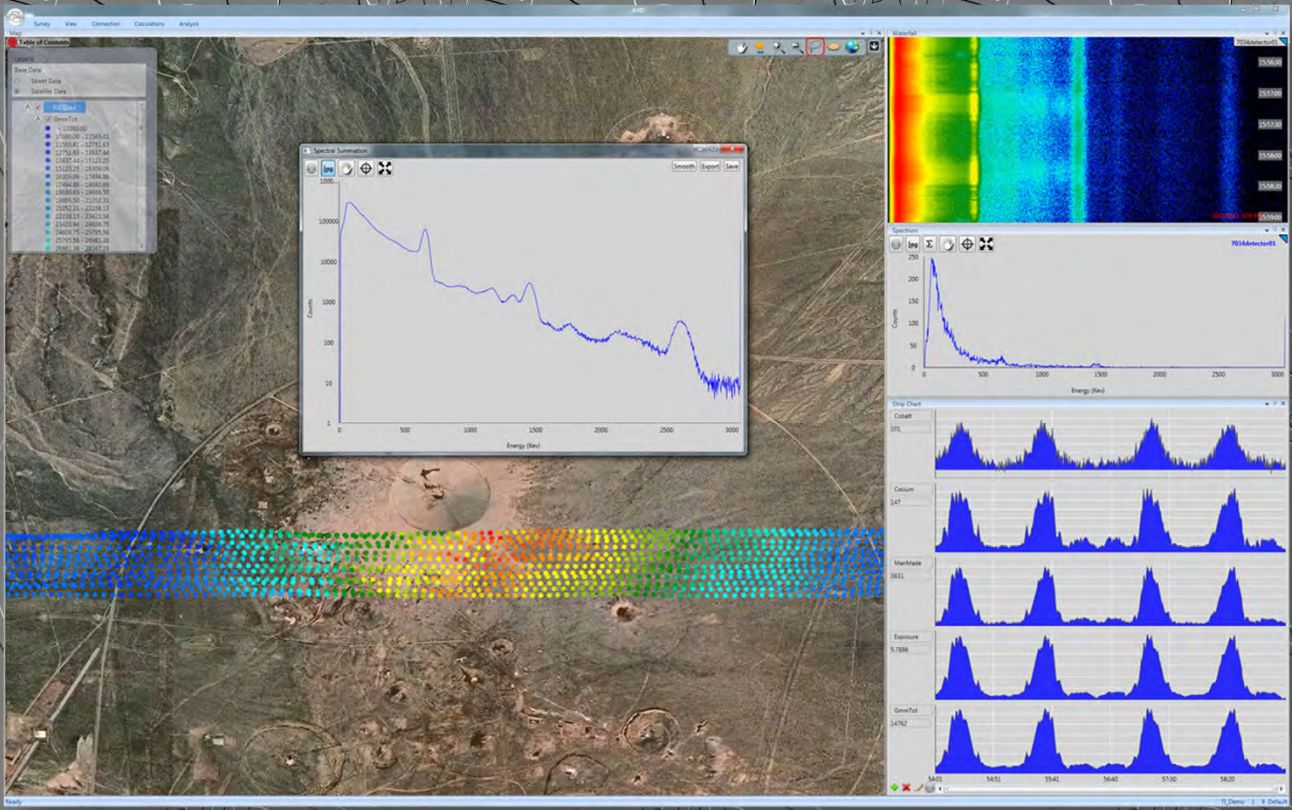
- Computers, printers, plotters



Question for Audience: 

- What data analysis software are you using now?
- What gamma spectroscopic software do you use now?
- Do you have access to GIS capabilities?
- Will you be interested in developing or acquiring software specific to aerial measurements?

AMS Data Tools



In 2010 AMS initiated development of a software package for **Advanced Visualization and Integration of Data (AVID)**

The software provides AMS with:

- Data storage and archiving
- Spectral Analysis
- Rapid Calculations
- Rapid Map Production
- Export of GIS file formats

Aviation and Science = One Team

ARM is an unique combination of Aviation (pilots, mechanics) and Science (scientists, engineers) working together to collect information necessary for the protection of the public and the environment.

Questions from the Audience

Introduction to Aerial Radiological Measurements

Presented by

Aerial Measuring System

U.S. Department of Energy

Part 4

Course Outline

What?

What is ARM?

Why?

Reasons for Use of ARM

Who?

Aviation and Science Team

How?

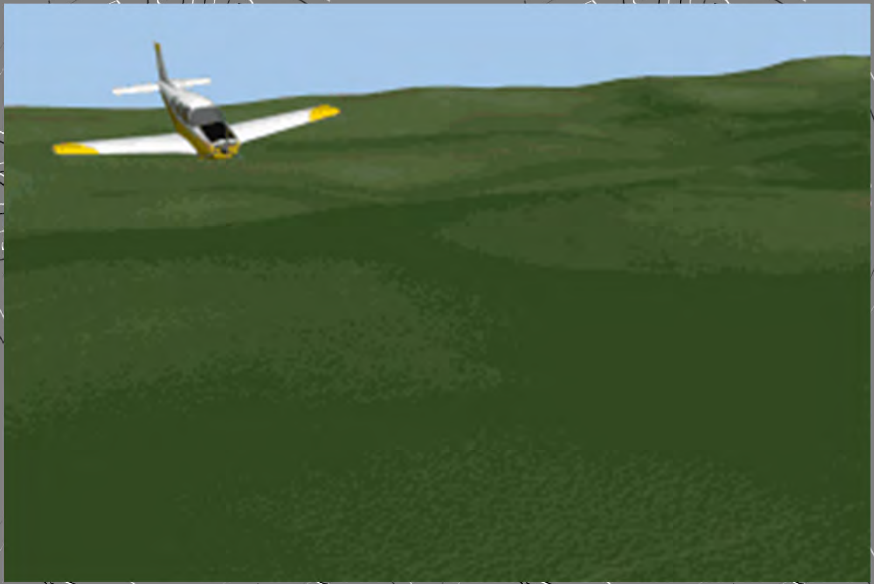
Equipment, Basic Mission Profiles, Data Analysis

Q&A

How?
Aerial Response to a Nuclear Power Plant Accident (or Other Radiation Dispersal Incident)

Question for audience: 

What methods can be used to disperse radioactive material resulting in similar effects (denying access, slowing emergency response and mitigation activities, etc.:



Nuclear Reactor Accident Scenario

A commercial nuclear reactor accident occurred resulting in the release of airborne radioactive material. The site engineers quickly stabilize the reactor and the release ends after 10 minutes. The site engineers estimate that approximately 40,000 GBq (1080 Ci) of Cesium-137 was released.

Emergency managers are requesting guidance on protective action measures for the general public and areas predicted to have ground contamination.

Nuclear Reactor Accident Scenario

An plume model prediction is prepared to aid the emergency managers in developing protective action guidance and for planning the aerial and ground monitoring response for consequence management.

An aerial mission will be conducted to rapidly map the ground contamination deposited downwind of the nuclear reactor site ***in an initial single flight***. The goal is to determine the extent (width) of the ground contamination and the center line (trajectory). The plume model predictions will be used to estimate the survey area and optimize the flight parameters.

(MBq/m2) Extent Area	Population
>0.10 9.7 km 5.8 km2	200
>0.01 27.1 km 67.3 km2	4,620
>0.0010 67.4 km 1,201 km2	11,900

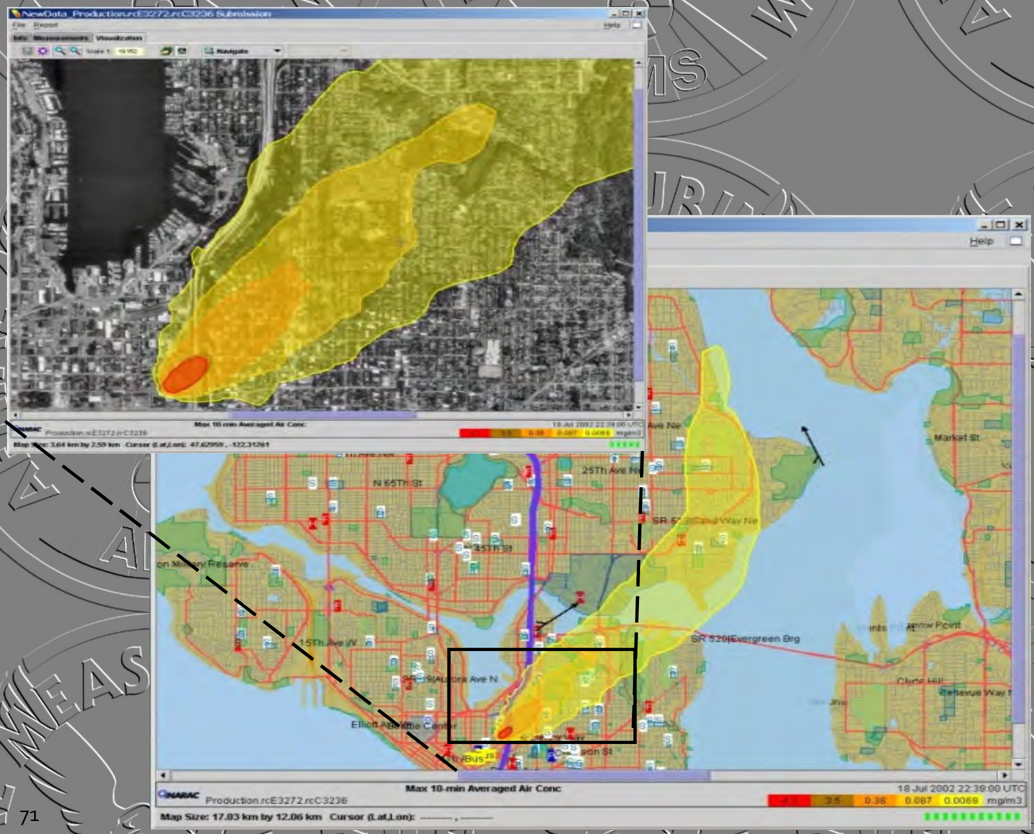
Question for the Audience:

- Where would you get the model prediction for atmospheric release of radioactive material?
- Does your country have such capabilities?
- Will you contact IAEA for assistance?
- Any other methods?

Where to get model predictions?
International Exchange Program (IXP)

Real-time computer predictions for atmospheric transport of radioactivity from a nuclear accident or incident

- **Contact**
  - Call DOE 24-hour 001-202-586-8100
  - Request IXP assistance
  - Or request access via the IAEA
  - Submit request via IXP web site at https://ixp.llnl.gov, results in 10 minutes
- **Scientists**
  - Lawrence Livermore National Laboratory
- **Map Products**
  - Exposure rates
  - Plume deposition
  - Ground contamination
  - Protective action recommendations



Aerial Mission Planning – Initial Flight

IXP predicted survey area

6-12 miles (10-20 km) wide
15 miles (24 km) downwind
15 lines, 1 mile (1.6 km) spacing
Line length 8 miles (13 km)
120 miles (190 km) of lines
14 turns at 1 minute/turn
Time: 90 minutes

Aircraft altitude

1000 feet (300 m) AGL

Aircraft speed

100 miles/hour (90 knots)

Water line

Time: 30 minutes

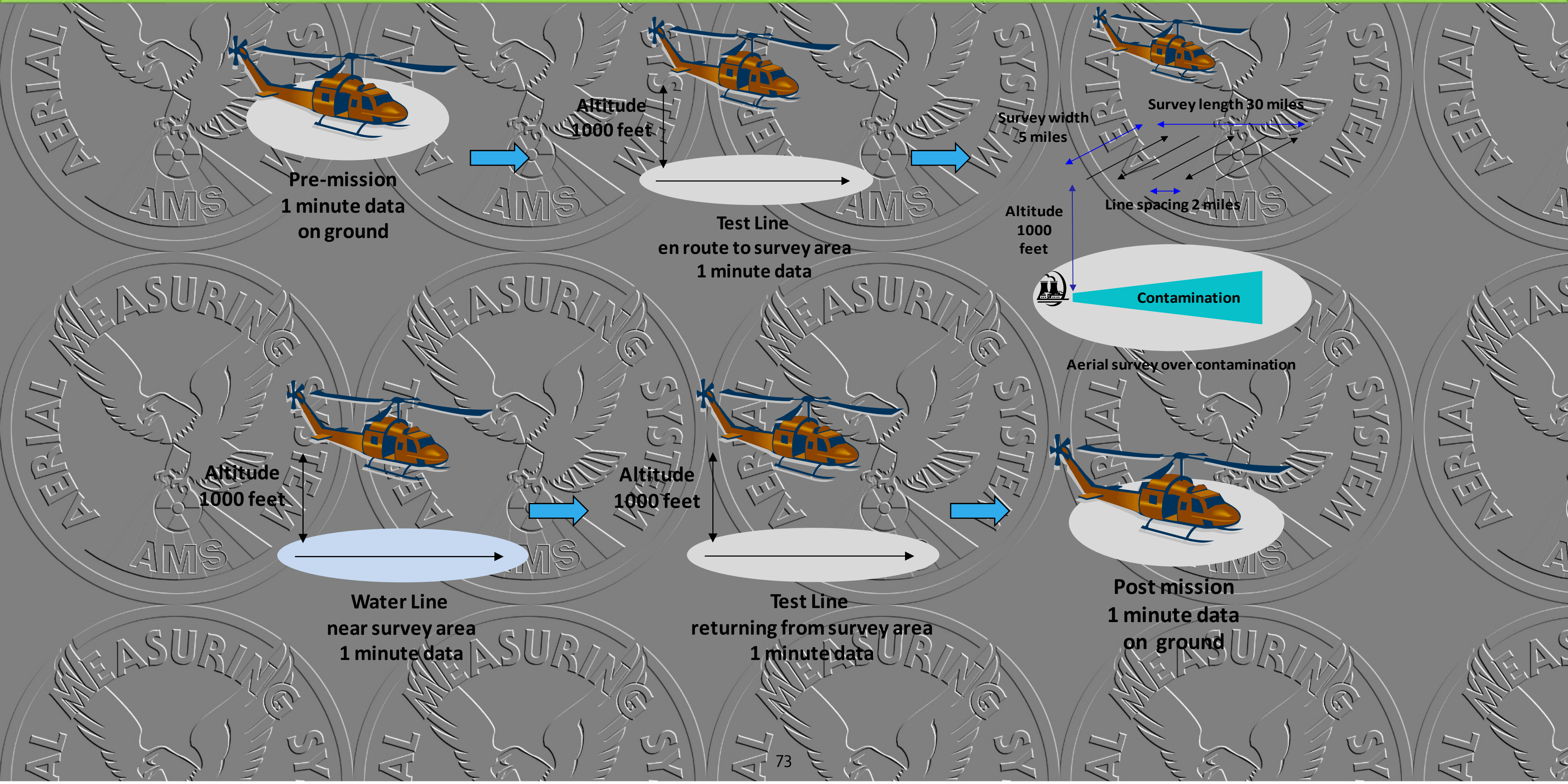
Roundtrip transit from airport to survey site

Time: 60 minutes (15 minutes in/45 out)

Total flight time

Time: 180 minutes (3 hours)

Flight Profile for a Nuclear Power Plant Accident



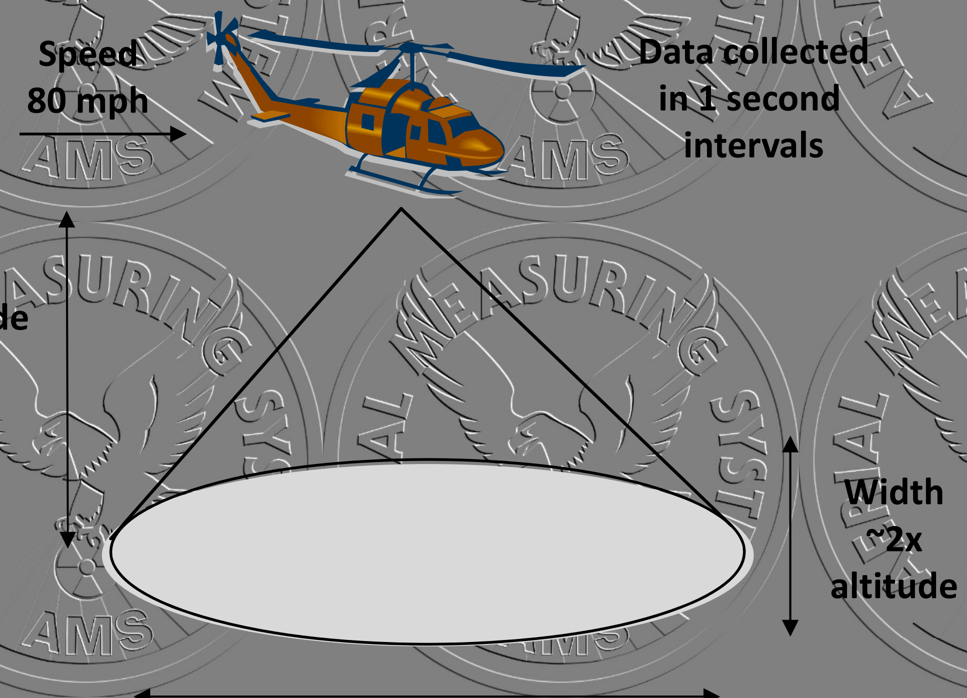
Question for Audience:

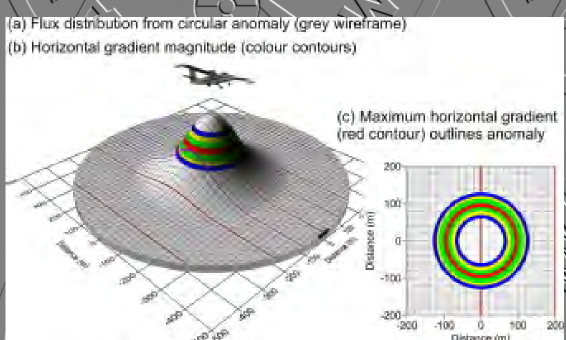
- From the presentations you saw so far, what would be the ARM weakness in term of radiation data acquisition?

Answers:

- Spatial Resolution
- Detection Sensitivity
- Minimum Detectable Activity (MDA)

Aerial Measurement Ground Footprint - Example



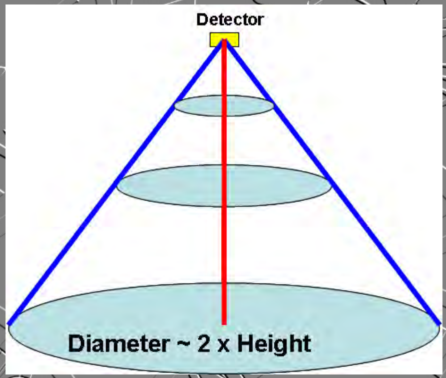


Enhancing the resolution of airborne gamma-ray data using horizontal gradients by David Beamish published in Journal of Applied Geophysics Volume 132, September 2016, Pages 75-86.

Altitude Tradeoffs

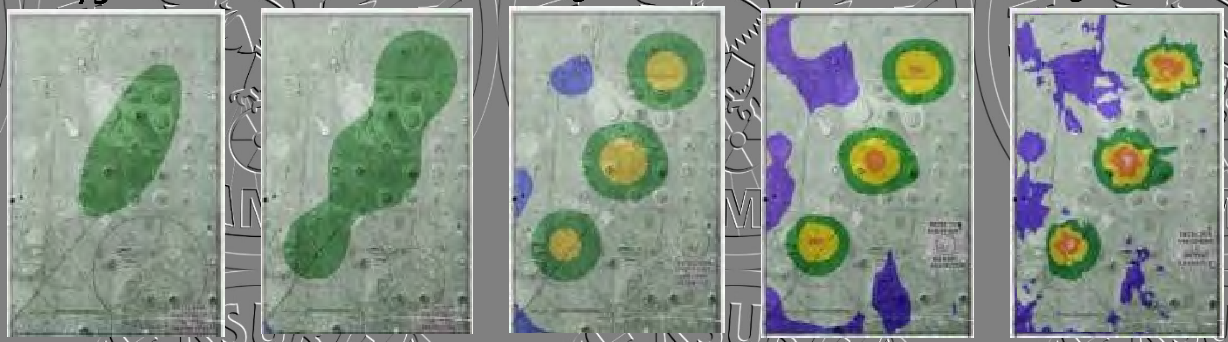
Low detector

- High Resolution
- Discrete sampling
- Slow coverage
- $1/R^2$ minor loss
- Atmospheric attenuation is small



High detector

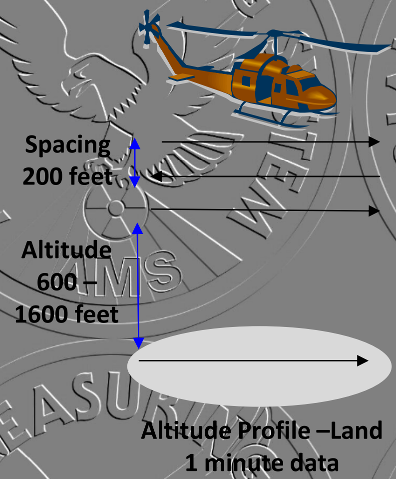
- Low resolution
- Area averaging
- Rapid coverage
- $1/R^2$ significant loss
- Atmospheric attenuation is large

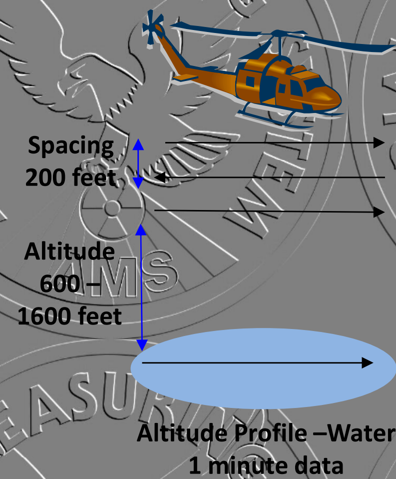


Average Air Attenuation Coefficient for Gammas

Over land measure gammas from:

- Terrestrial
- Aircraft
- Crew
- Radon
- Cosmic





Over water measure gammas from:

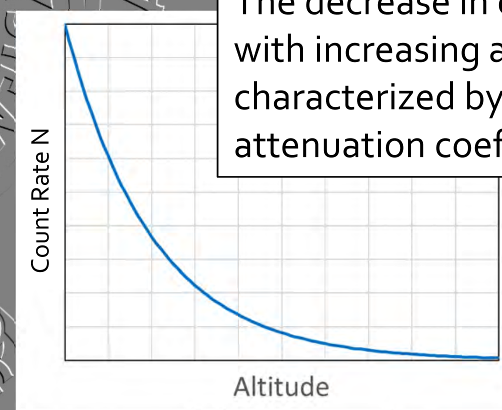
- Aircraft
- Crew
- Radon
- Cosmic

Background subtraction gives net gammas from natural terrestrial radiation

Land (cps) – Water (cps) = N(alt) (cps)

The signal from the ground is attenuated (decreased) by the amount of air between the ground and the detector:

$$N(1m) = N(alt)e^{\mu_{air} \times alt}$$



The decrease in count rate with increasing altitude is characterized by the air attenuation coefficient μ_{air}

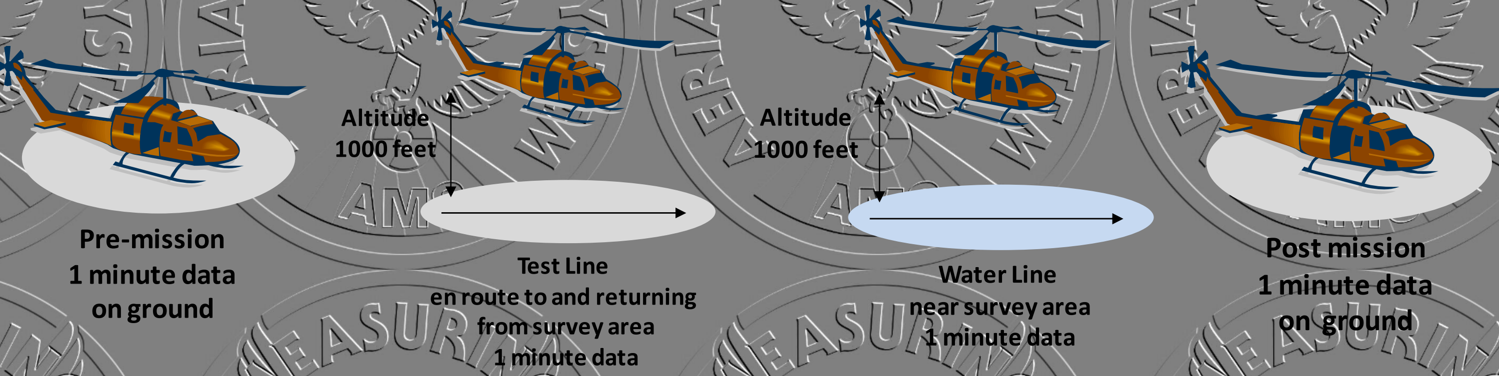
Question for the Audience:

- If you have to plan an aerial mission what factors would you discuss with the pilots?

Answers:

- Altitude
- Ground speed
- Line spacing
- Aircraft endurance (flight time)
- Test Line location
- Water Line Location

Data Quality Control/Background Subtraction

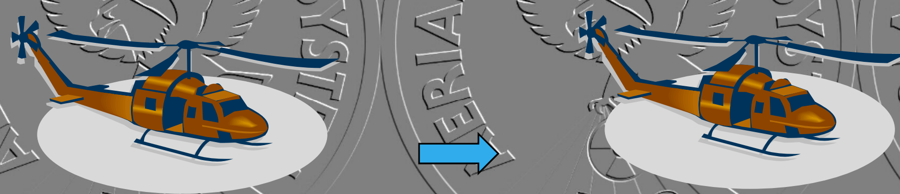


Measurement on the ground – before and after each flight (same lift off/landing location)

Test line – before and after each survey area, same altitude as survey (select area en route defined by markers, fences, telephone poles, etc., which is relatively flat, open and even terrain and no contamination)

Water line – each flight, at least 300 m from land, same altitude as survey

Data Quality Control/Energy Calibration



Pre-mission Energy Calibration → **Pre-mission 1 minute data on ground**

Energy Calibration – prior to each flight, check energy calibration of each detector using a check source (a small amount of a known radioactive isotope) and/or natural background radiation. Modern software will maintain this calibration during a survey.

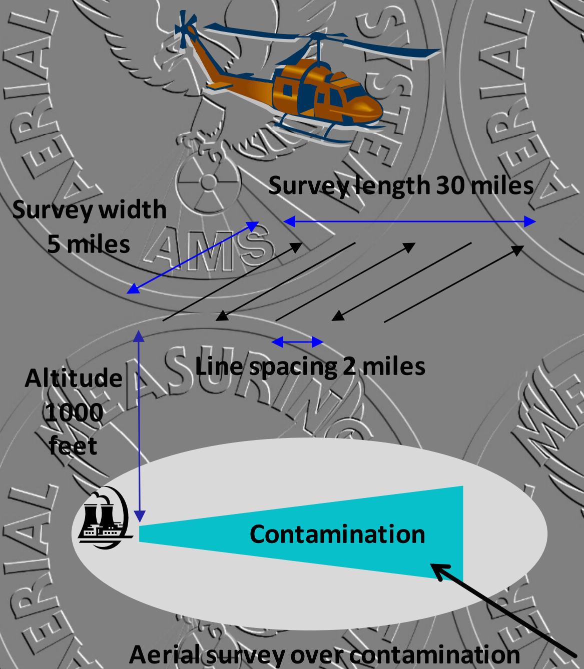
System Setup – verify detectors are collecting data and count rates reproducibly, GPS is operating and proper street map or satellite imagery is displayed. (GPS may not work in a hangar.)

Count Rate to Exposure Rate Conversion Factor

Ground Truth - measure 1 meter exposure rate in the survey area using a Pressurized Ionization Chamber (PIC) in μR/h

Conversion factor (CF), is derived from the net counts at 1 m over calibration area and PIC measurements using the following equation:

$$CF = \frac{\text{Ground Truth Exposure Rate } (\frac{\mu R}{h})}{\text{Net(cps) at 1 m}}$$

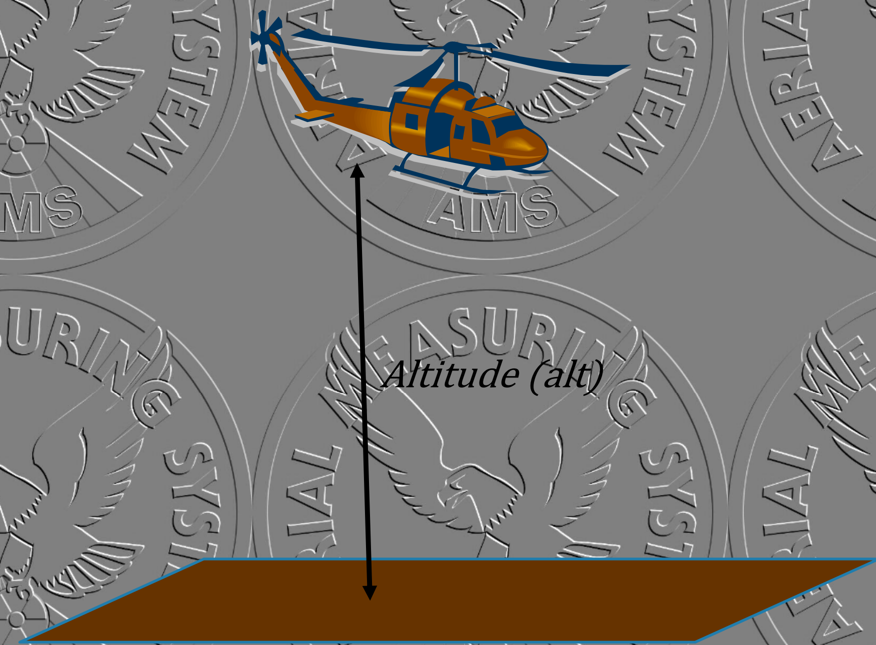


PIC

Aerial data is typically reported as exposure rate at 1 meter

Exposure Rate Calculations

Bringing it all together



Background subtraction gives net gamma count rate from natural terrestrial radiation

$$Land(\text{cps}) - Water(\text{cps}) = N(alt)(\text{cps})$$

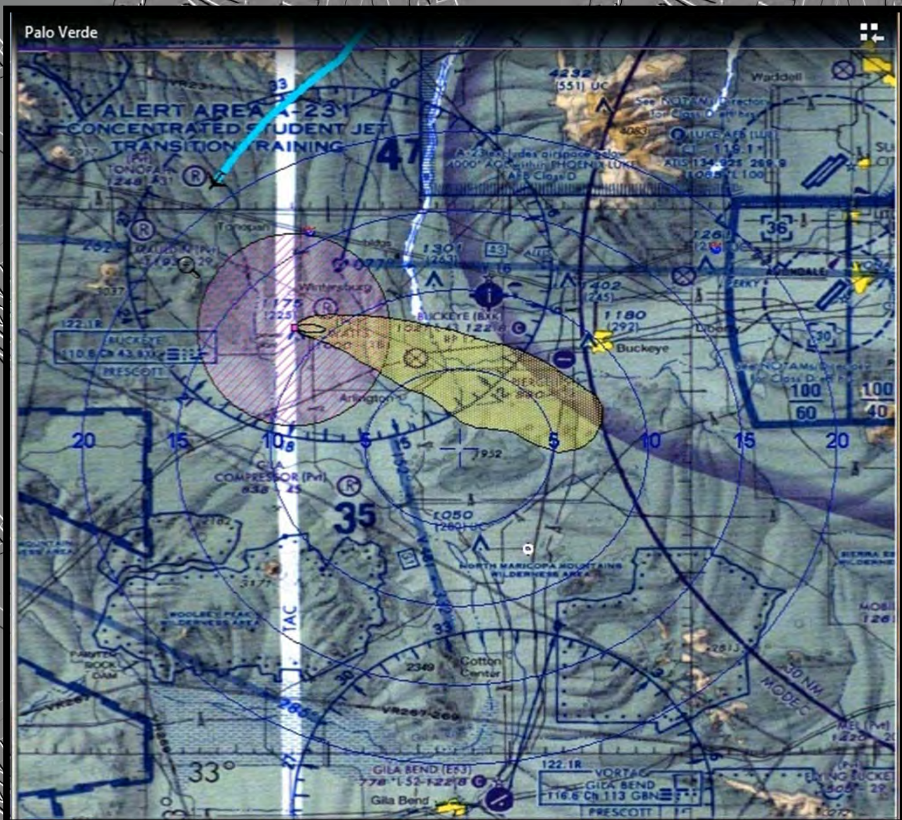
The net count rate is corrected for air attenuation to give the count rate at 1 m above ground level,

$$N(1\text{m}) = N(alt) \times e^{\mu_{air} \times alt}$$

Finally, the count rate at 1 m is converted to an exposure rate,

$$Exp\ Rate\ (1\text{m}) = CF \times N(1\text{m}) = CF \times [Land(\text{cps}) - Water(\text{cps})] \times e^{\mu_{air} \times alt}$$

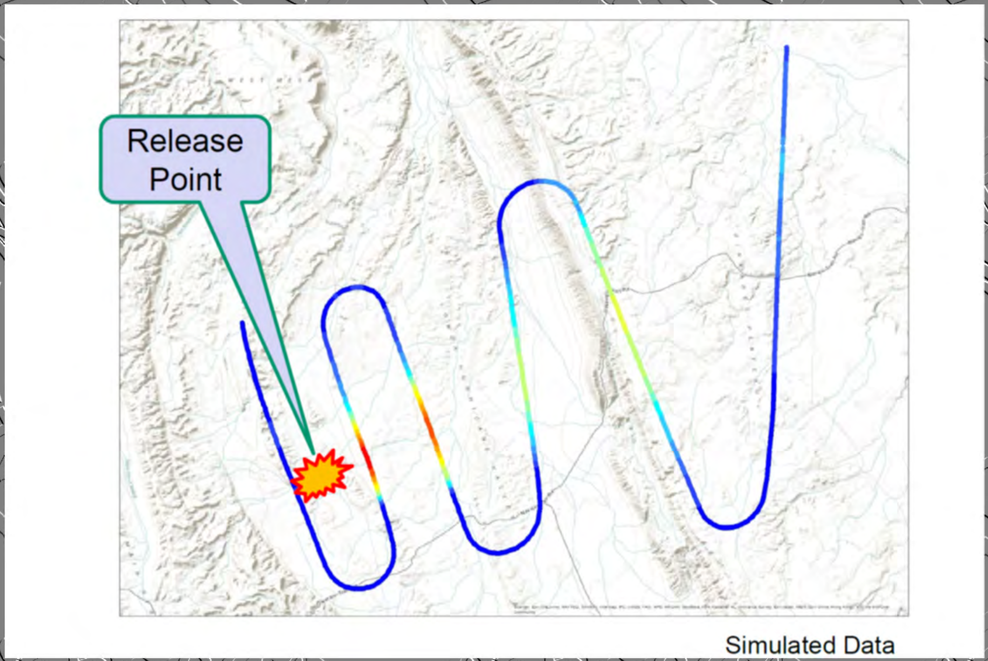
Example of the aerial response to NPP accident (simulated contamination)



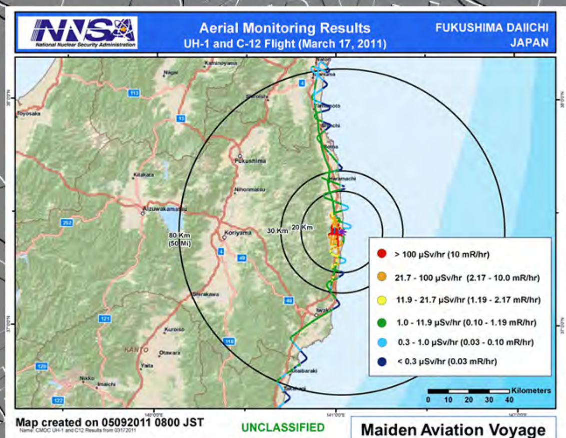
Typical flight pattern in response to a release from a nuclear power plant in the US, that includes parallel lines over the Emergency Planning Zone (EPZ) and serpentine lines to map the extent of the ground contamination.

Aerial Data – “Bread Crumb” Plot

Result: Easy visual assessment of the extent of ground contamination

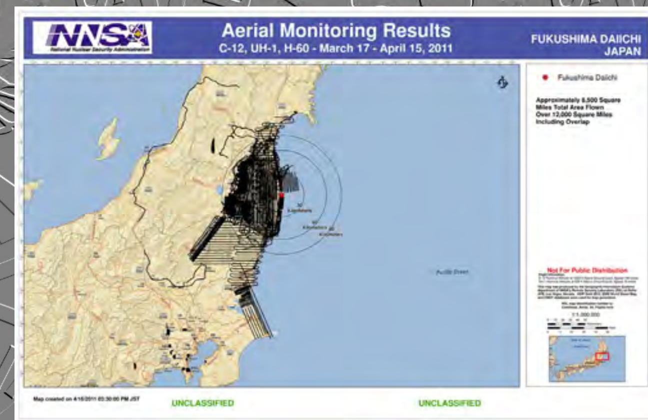


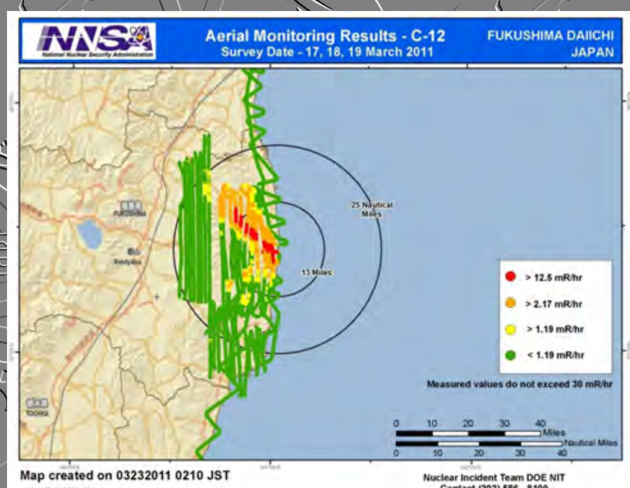
Real World Example of AMS Response to NPP Accident

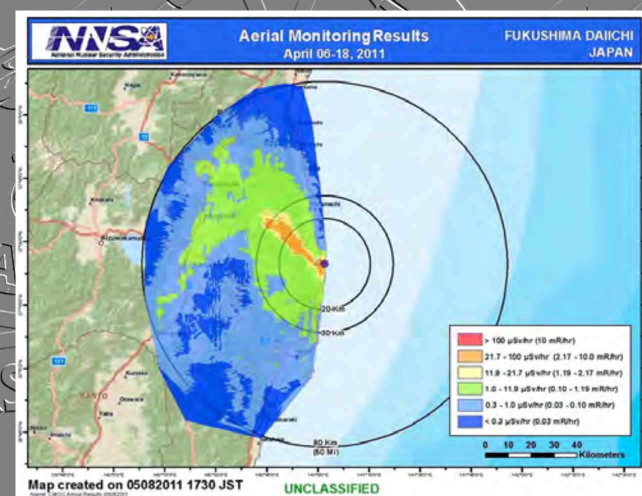


Daily aerial measuring missions over US installations and in the area around the FDNPP

- 85 flights
- 507 flight hours







Question for Audience:

What are other situations where aerial radiation detection could be useful?

Aerial Radiological Search for a Lost or Stolen Radiation Source

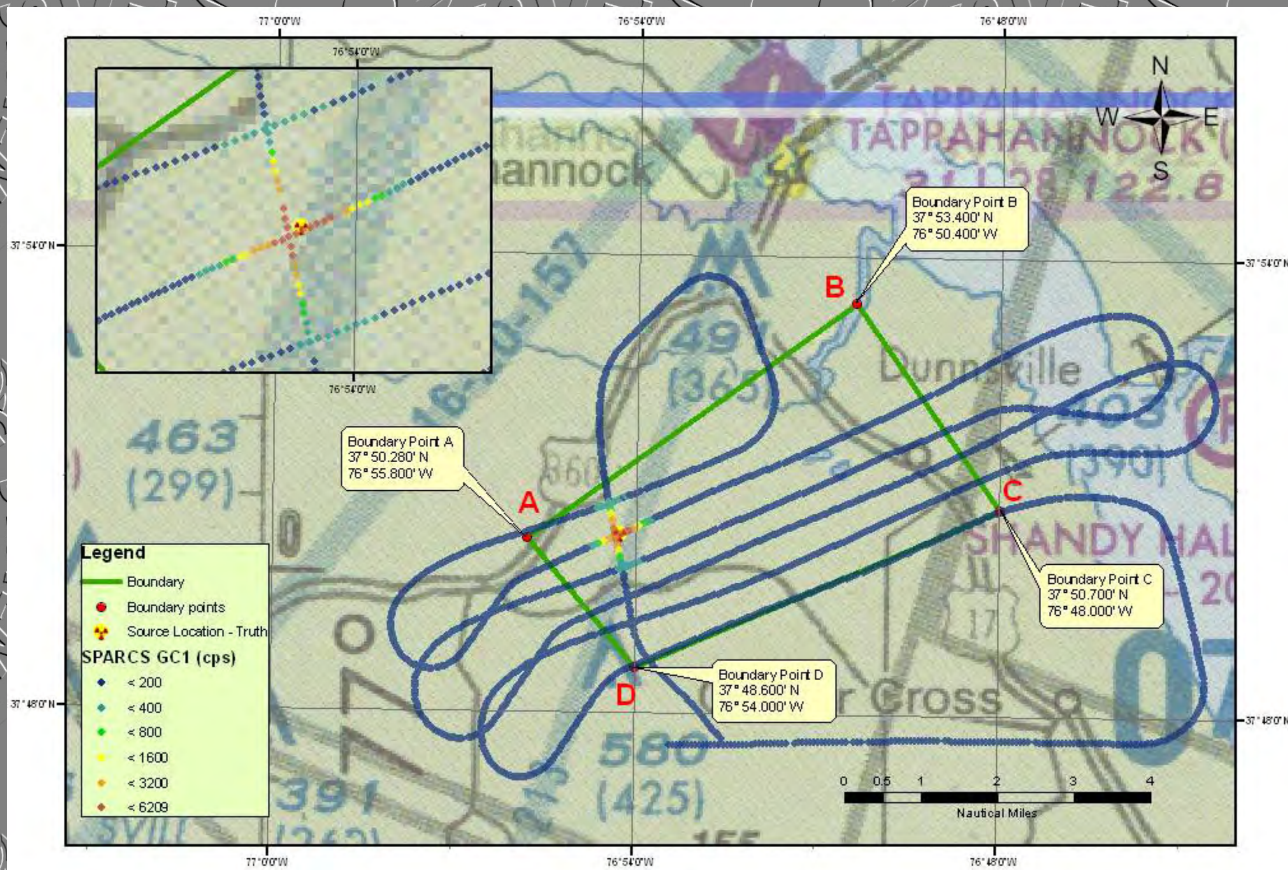
Mission Objective

The primary mission objective is to locate lost or stolen radioactive material.

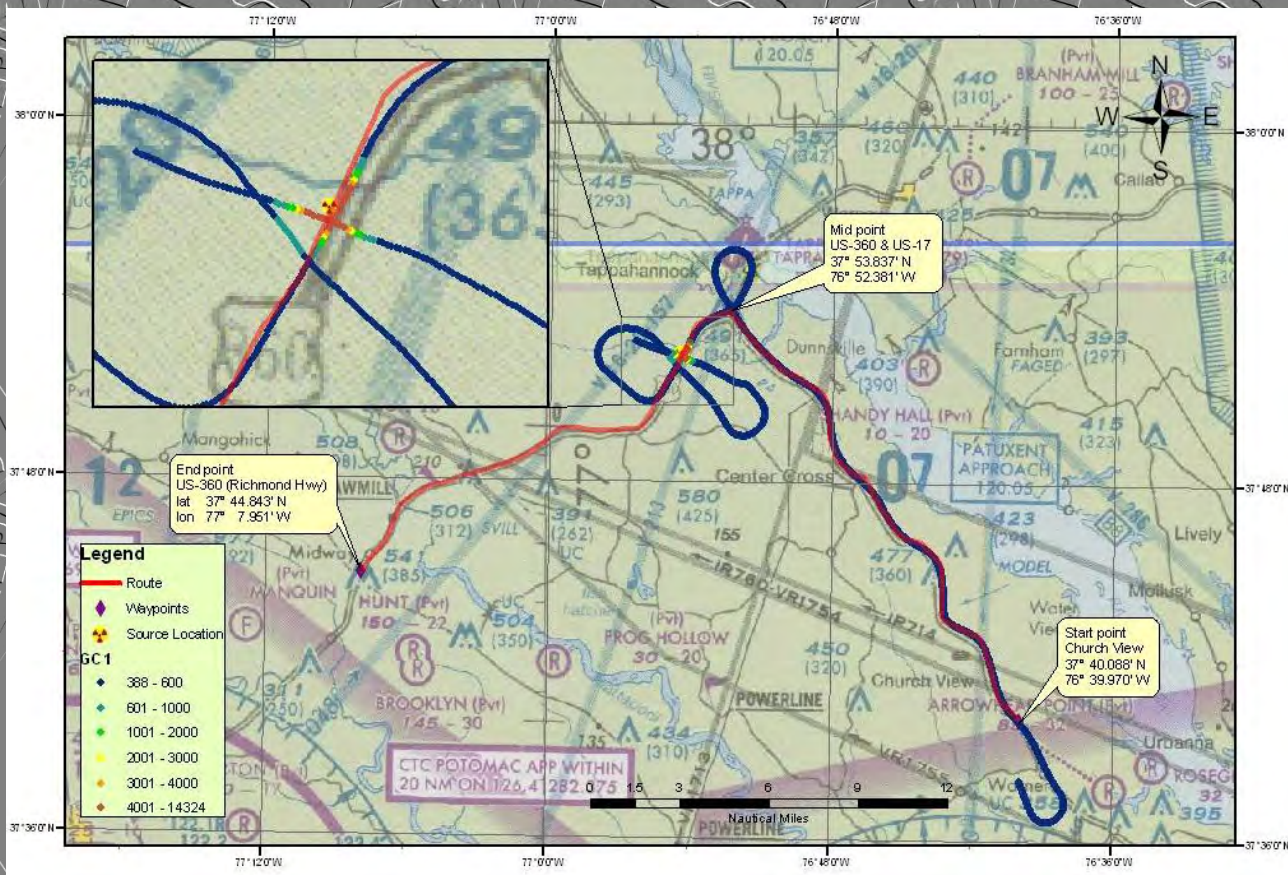
There are two variations for this mission:

- The lost source is suspected to be on or near a geographical feature (road, railroad line, river, canal, power line, etc.).
- The lost source survey area encompasses a broad geographic area usually defined by a polygon shape.

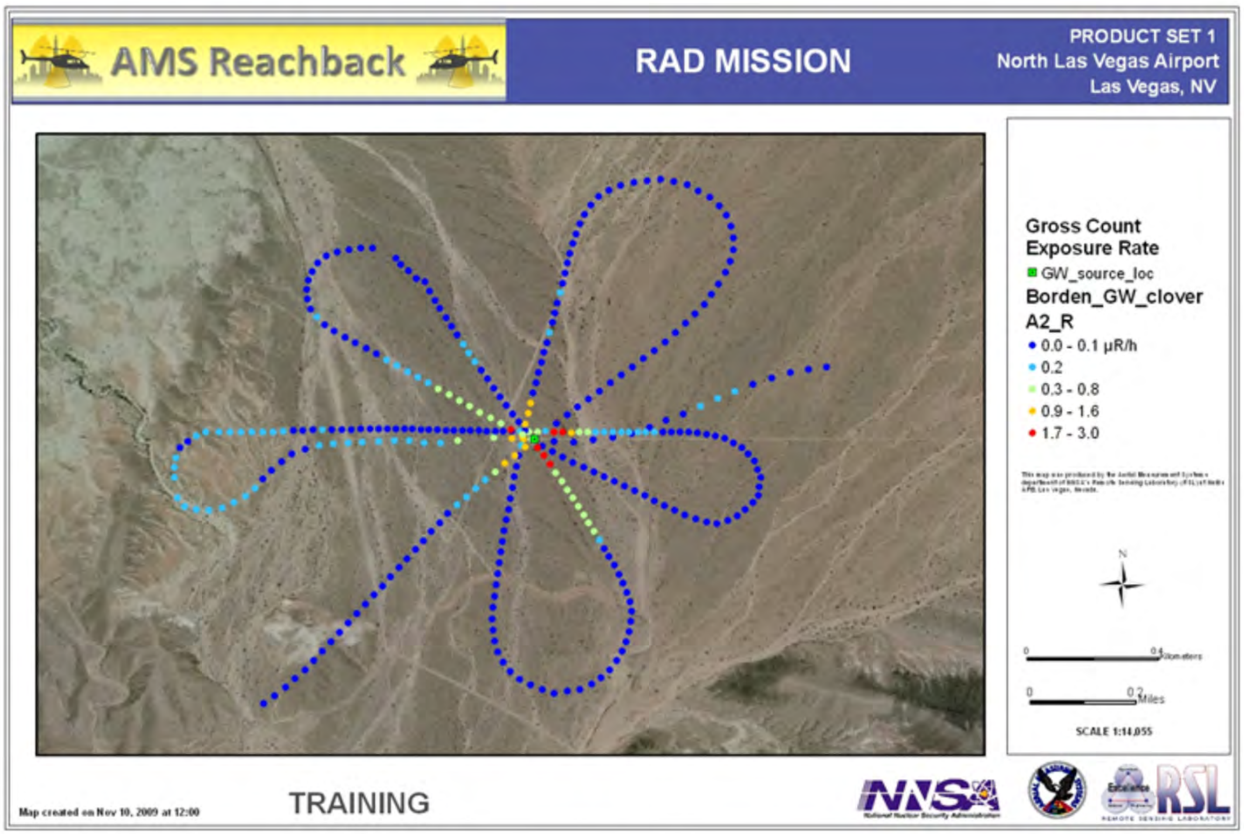
Lost Source – Grid Survey



Lost Source – Road Survey

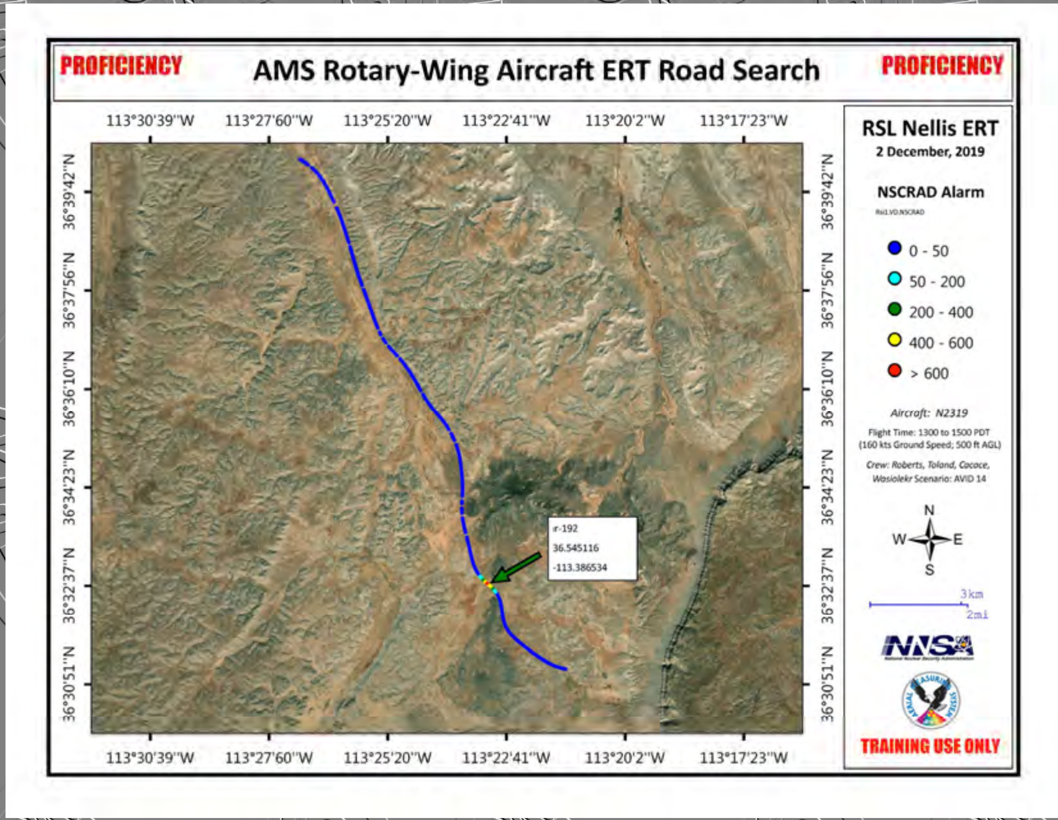


Extreme Source Localization



Anomaly Detection Mission Results

- Anomaly Isotopic Identification
- Location:
  - latitude, longitude
- Map



Aerial Mission Flight Notes

Keeping notes about each mission objectives, parameters is critical for future data analysis

Good:
Paper and pencil

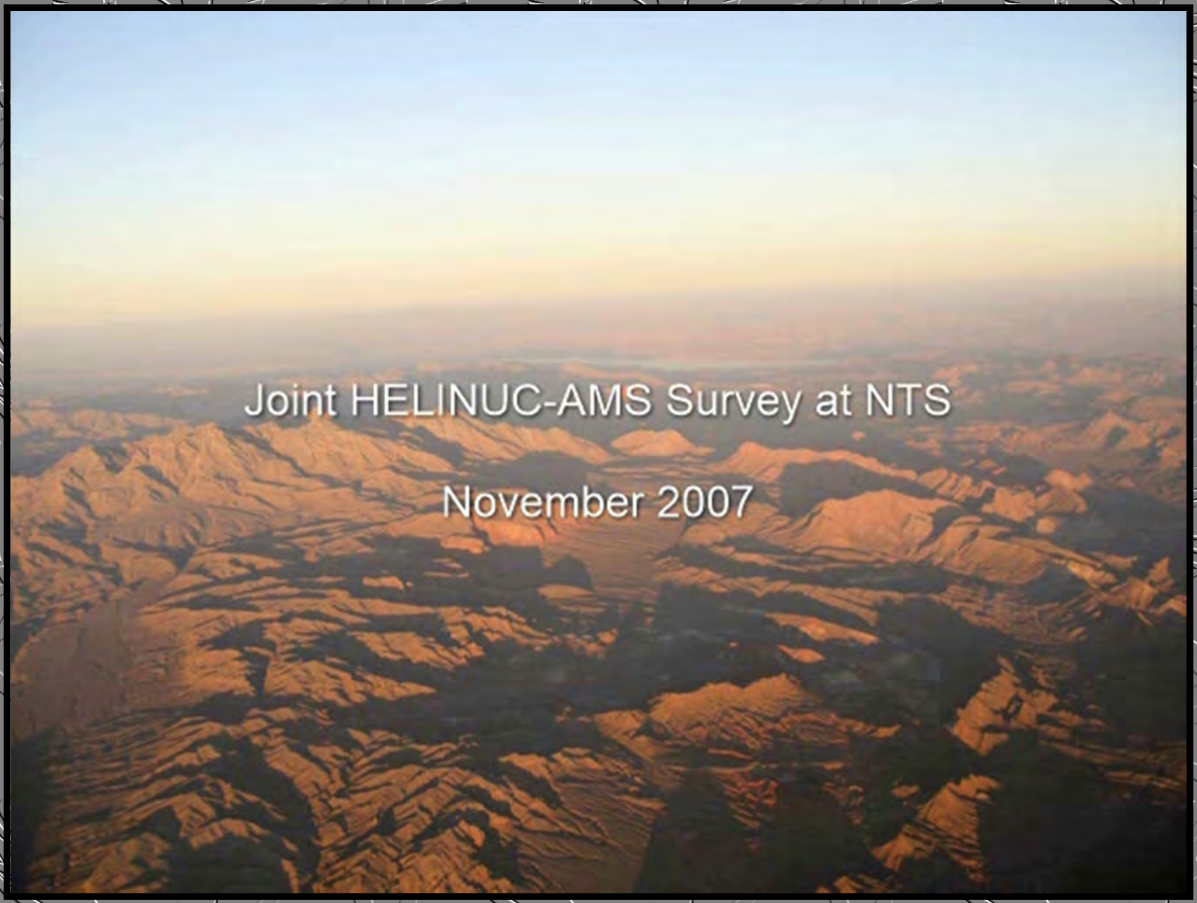
Better:
Specially developed form for flight notes

SURVEY LOCATION: PAGE _1___ OF ____

START TIME	END TIME	LINE #	COMMENTS	FLIGHT#	DATE:
				Aircraft type	
			Record start/end times of each task or flight line	Aircraft tail number	
				Pilot 1	
			Pre-flight 1 minute ground data	Pilot 2	
			Test line at survey altitude	Operator 1	
			Water line at survey altitude	Operator 2	
			Test line at survey altitude	Detector System	SPARCS-A
			Post flight 1 minute ground data		
				Detectors - SPARCS-A	
			Altitude Profile 1 minute at 600, 800, 1000, 1200, 1400, 1600 feet (land)	Detectors	Calibration
			Altitude Profile 1 minute at 600, 800, 1000, 1200, 1400, 1600 feet (water)	1 - 5 x 10 x 40 cm	
				1 - 5 x 10 x 10 cm	
		1	Survey line 1	1 - 2.5 x 2.5 cm	
		2	Survey line 2	Flight Parameters	
		3	Survey line 3		
				Survey Altitude (feet)	
				Speed (knots)	
				Line spacing (feet)	
				Temperature	
				Air Pressure	
				Heading 1	
				Heading 2	
				Release Point (RP)	
				Lat	Lon
				Entry Point (EP)	
				Lat	Lon

Signatures: Team Leader_____________________ Operator(s)_____________________

Aerial Mission Execution



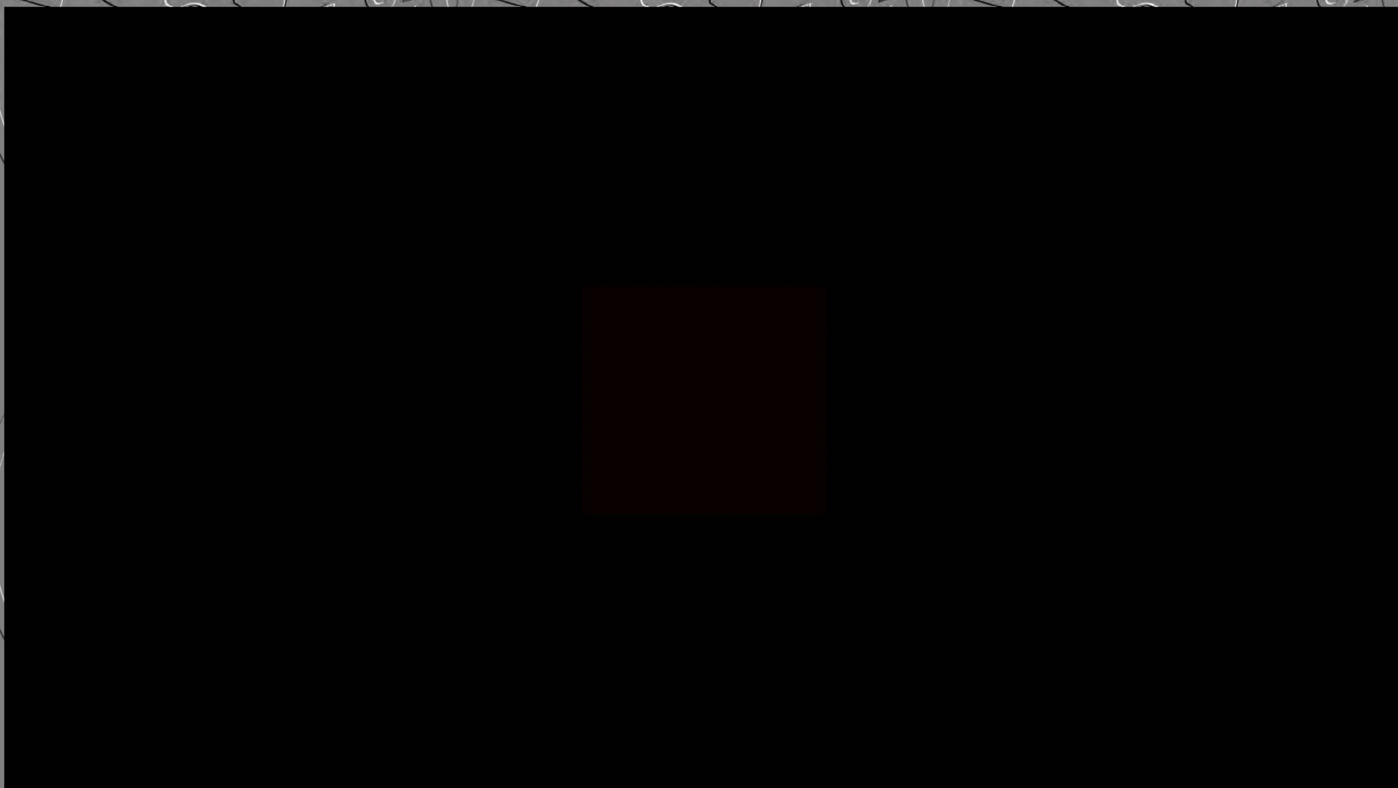
Joint French-US survey at the Nevada National Security Site in 2007

Question for Audience

What are the main advantages and disadvantages of aerial measurements?

Pluses	**Minuses**

AMS in Action



See You
in
Las Vegas

Thank you for your attention!