The Development and Performance of Automated In-Situ Systems to detect Dispersed Radiation and 'Hot Particles'

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Atomic Weapons Detonations

1952 - 1957

Monte Bello Islands

- 3 detonations

Emu Field

- 2 detonations

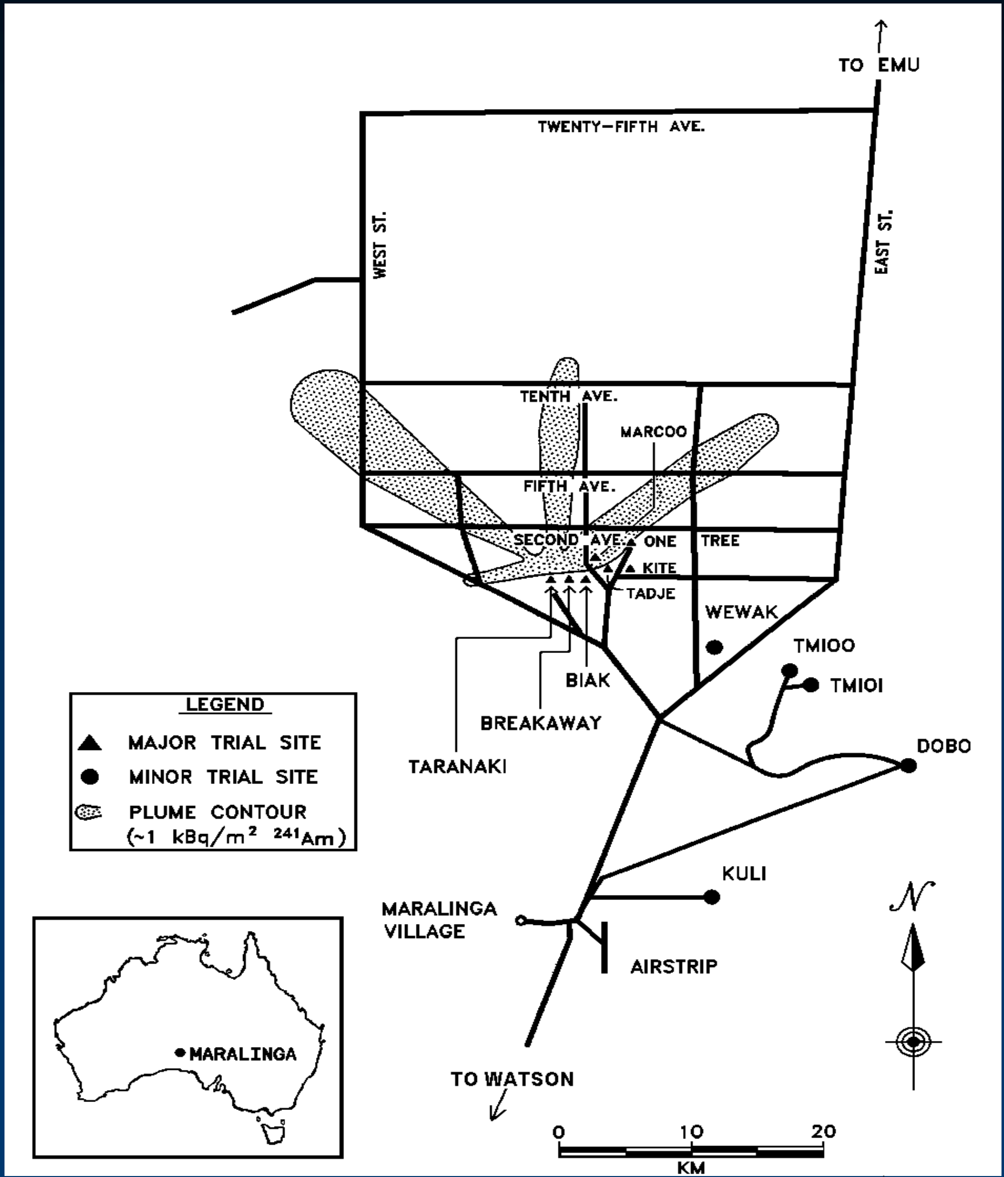
Maralinga

- 7 detonations

Contamination from detonations has largely decayed

–No longer a serious health risk

Other Atomic Tests



- 1959 – 1963
  - "Minor Trials"
- Tests to develop components
- Safety Trials
- Dispersal of radioactive material by chemical explosion
- Four Sites Contaminated with Plutonium (mostly ^{239}Pu)
  - Taranaki, Wewak, TM100, TM101

Major and Minor Tests - Maralinga

Major Tests

One Tree	Tower	15kT
Marcoo	Ground	1.5kT
Kite	Air	3.0kT
Breakaway	Tower	10kT
Tadje	Tower	1.0kT
Biak	Tower	6.0kT
Taranaki	Balloon	27kT

Minor Tests

Kuli	^{238}U/Natural U	> 7000kg
Wewak	^{239}Pu	570g
TM100	^{239}Pu	600g
	^{238}U/Natural U	86kg
TM101	^{239}Pu	600g
	^{238}U/Natural U	86kg
Taranaki	^{239}Pu	22kg
	^{238}U/Natural U#	22kg

24kg of enriched uranium also used

Plutonium Contamination at Maralinga

The plutonium contamination remaining at Maralinga on the completion of the UK weapons testing program existed in three forms:

•Fragments – Plutonium contaminated debris that was visibly identifiable when lying on the surface. This included contaminated metal, plastic, wire, lead etc.

•Particles – sub-millimetre sized pieces of soil or other materials contaminated with Plutonium. These were often indistinguishable from soil on casual inspection but had much higher activities than average for the surrounding soil

•Dust – very finely divided contaminated particles of plutonium oxides which was potentially inhalable

Detecting Plutonium

^{239}Pu

- Most significant radiological hazard
- Does not emit significant quantities of γ-rays
- Emitted x-rays are absorbed over very short distances
- Detection of α-particles is unreliable

^{241}Pu

- Minor constituent of plutonium
- Decays with a half-life of 14 years
- Produces ^{241}Am
- ^{241}Am produces a γ-ray at 59.5 keV with a probability of 36% . This γ-ray is penetrating enough to detect with Gamma Spectrometry

The Maralinga Rehabilitation Project - Early Considerations of Contamination and Use of Test Areas

- 1967 Operation Brumby
- 1972-1973 AWTSC (Atomic Weapons Tests Safety Committee)
- 1978 AIRAC (Australian Ionising Radiation Advisory Council)
- 1984 -1985 ARL (Australian Radiation Laboratory) Assessment
- 1984 Royal Commission into British Nuclear Tests in Australia
- 1986 Australian Government Response to Royal Commission
- 1986-1990 TAG (Technical Assessment Group) Study
- 1993 Formation of MARTAC (Maralinga Technical Advisory Committee)
- 1994-2000 Rehabilitation of Site

Maralinga Rehabilitation Project

AIM: RETURN SITE TO TRADITIONAL OWNERS

- ARPANSA contracted as Radiological Auditor
- Remediate plutonium contamination
- Remove and bury highly contaminated soil
- Restrict land use in moderately contaminated areas
- Soil Removed from 2.5 km^2
- Restrictions on land use placed on 400 km^2
- Remediation started in 1996, completed 2000

http://www.radioactivewaste.gov.au/framework/publications/store_and_maralinga_publications.htm

Regulatory Requirements: MARTAC Criteria - Soil Removal

Soil was to be removed if:

- The dispersed activity exceeded 40 kBq/m^2 when averaged over 1 hectare (10,000 m^2)
- The area contained fragments
- The area contained particles exceeding 100 kBq activity
- The area contained more than 1 particle above 20 kBq activity per 10 m^2

Note: All criteria refer to ^{241}Am activity with a ^{239}Pu:^{241}Am ratio of 7:1

MARTAC Criteria - Clearance

The residual contamination in areas where soil had been removed were to meet the following:

- Dispersed activity less than 3 kBq/m^2 when averaged over 1ha (10,000 m^2)
- No fragments
- No particles exceeding 100 kBq activity
- Density of particles above 20 kBq activity less than 1 per 10m^2

Note: All criteria refer to ^{241}Am activity with a ^{239}Pu:^{241}Am ratio of 7:1

MARTAC Criteria - Unrestricted Land-Use

Permanent occupancy and unrestricted land-use were to only occur in areas where:

- Dispersed activity less than 3 kBq/m^2 when averaged over 3km^2
- No fragments
- No particles exceeding 100 kBq activity
- Density of particles above 20 kBq activity less than 1 per 10m^2

Note: All criteria refer to ^{241}Am activity with a ^{239}Pu:^{241}Am ratio of 7:1

Traditional Survey Methods

Particle Detection

Manual Surveys

- Time-consuming
- Tedious
- Inefficient for large areas
- Lack complete, objective records - location and all particles

Dispersed Activity Measurements

Aerial Surveys

- Costly
- Low spatial resolution

Soil Sampling

- Time-consuming
- Unreliable - sampling errors

In Situ Spectroscopy (using a tripod)

- Time-consuming
- Small area per measurement

Operational Requirements: Dispersed Activity Measurement

- Determine average activity of large areas (1000 m^2) with a single measurement
- Provide an unambiguous measurement of ^{241}Am activity concentration
- Capable of measuring 1 kBq/m^2 ^{241}Am activity within a short timeframe (1000 s)
- Highly mobile - 20 measurements over 2 ha in 10 hours
- Record all data
- Easily maintained in the field

Engineering Solutions:
Dispersed Activity Measurement - The OKA

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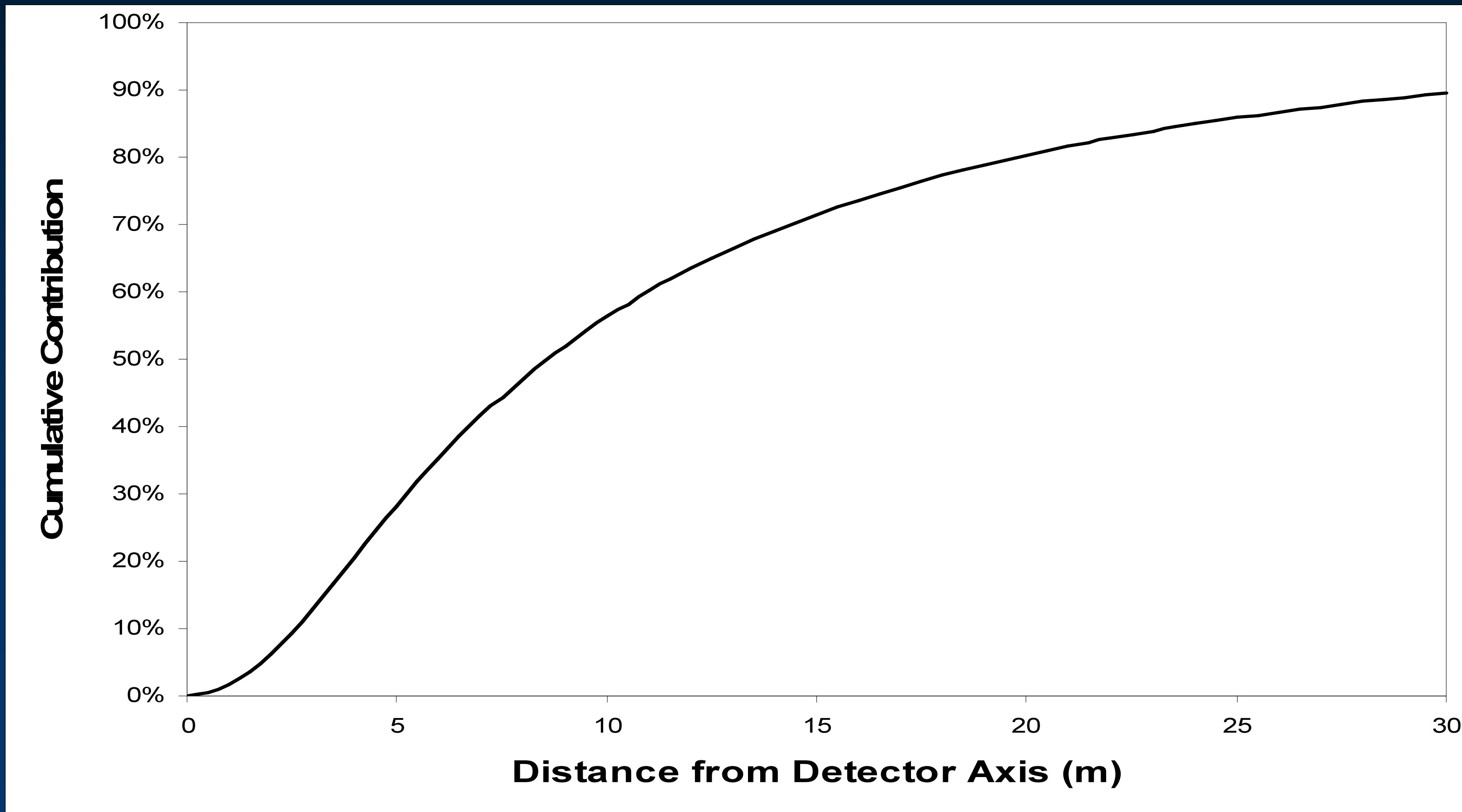
Dispersed Activity Measurement - The OKA

Australian Government
Australian Radiation Protection and Nuclear Safety Agency

Operation: The OKA Calibration

ICRU53 gives the method for calculating the conversion factor between the full-energy peak count rate and activity concentration.

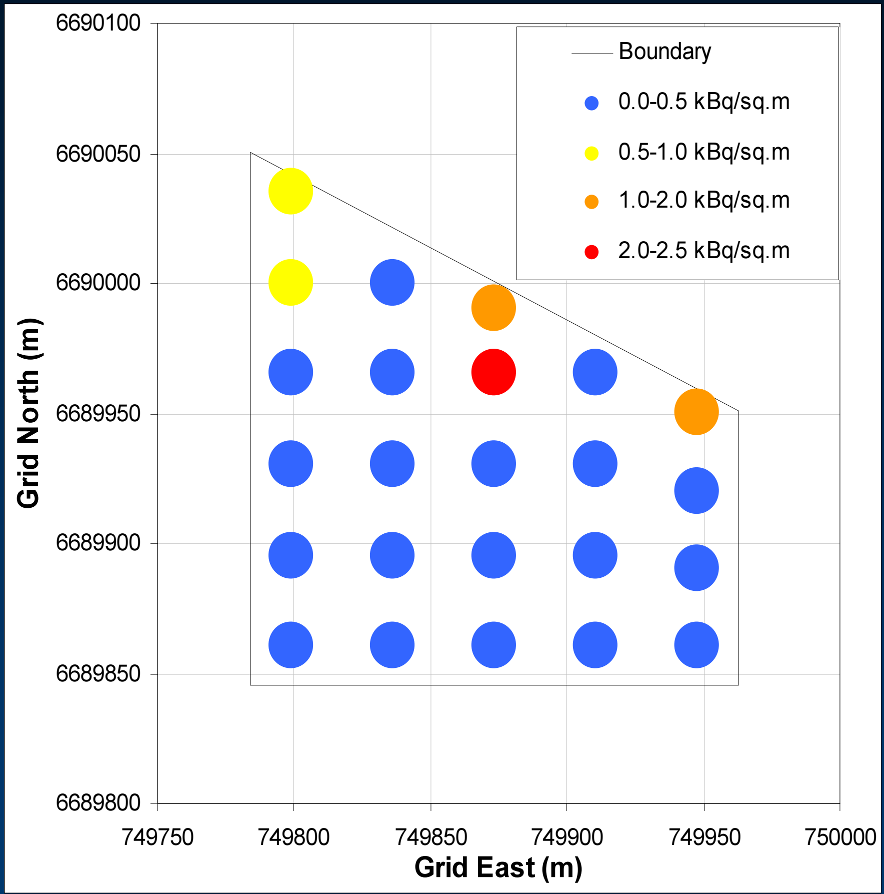


Operation: The OKA

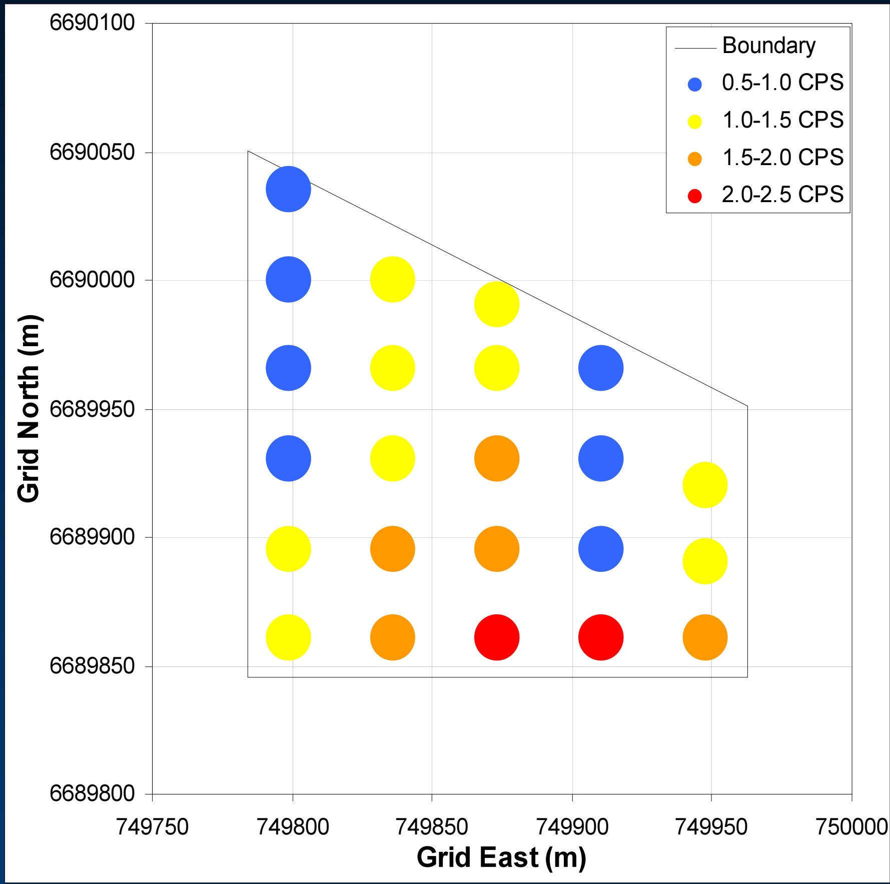
- Drive to exact measurement location (using DGPS)
- Lower boom to measurement height
- Collect spectrum
- Record Region Of Interest (ROI) information
- Calculate activity concentration
- Record GPS coordinates
- Lower boom over vehicle for travel to next location

Routinely take 20 measurements covering 20,000 m^2 per day

Performance: The OKA



^{241}Am Activity Concentrations

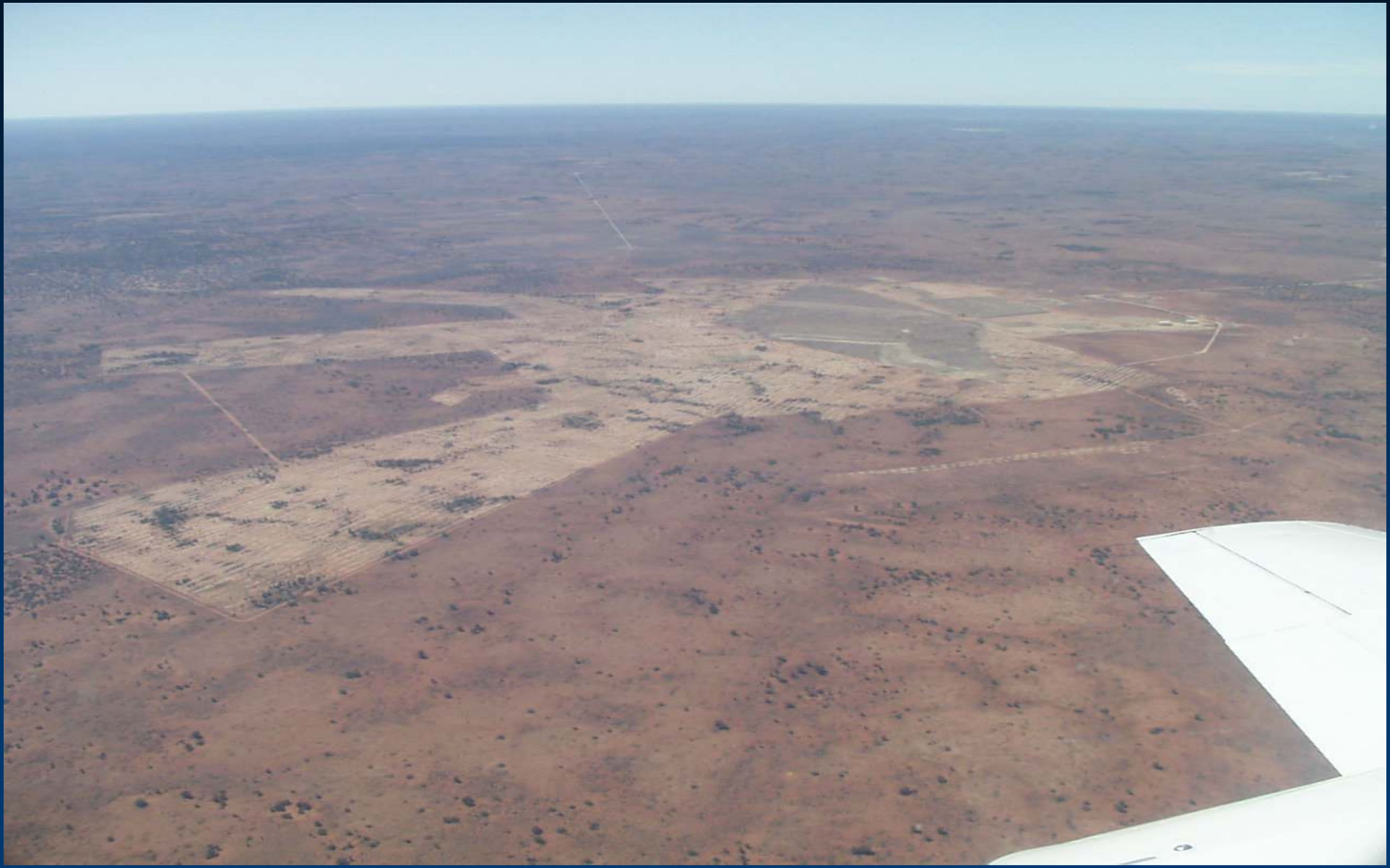


^{152}Eu (344 keV) Count Rate

Results of Dispersed Activity Measurements

Taranaki		
Work	Area (ha)	# Measurements
Soil Removal Area Verification	148	1306
Forward Area Facilities Clearance	25	179
Soil Removal Boundary Verification	85	278
Land-use Restriction Boundary Verification	N/A	669
Plume Characterisation	N/A	412
TM100/TM101		
Work	Area (ha)	# Measurements
Soil Removal Area Verification	46.9	488
Forward Area Facilities Clearance	13	118
Plume Characterisation	N/A	288
Wewak		
Work	Area (ha)	# Measurements
Soil Removal Area Verification	29	286
Forward Area Facilities Clearance	4	37
Plume Characterisation	N/A	324
Total Measurements		**4385**

Contaminated Soil Removal Area - Taranaki



Operational Requirements: Particle Detection

- Identify all particles exceeding 100 kBq ^{241}Am activity
- Measure the density of particles exceeding 20 kBq activity
- Determine the position of the particles
- Demonstrate that 100% of the area had been scanned
- Record all data
- Scan several hectares in a working day
- Easy to maintain in the field

Engineering Solutions:
Particle Detection - The Nissan

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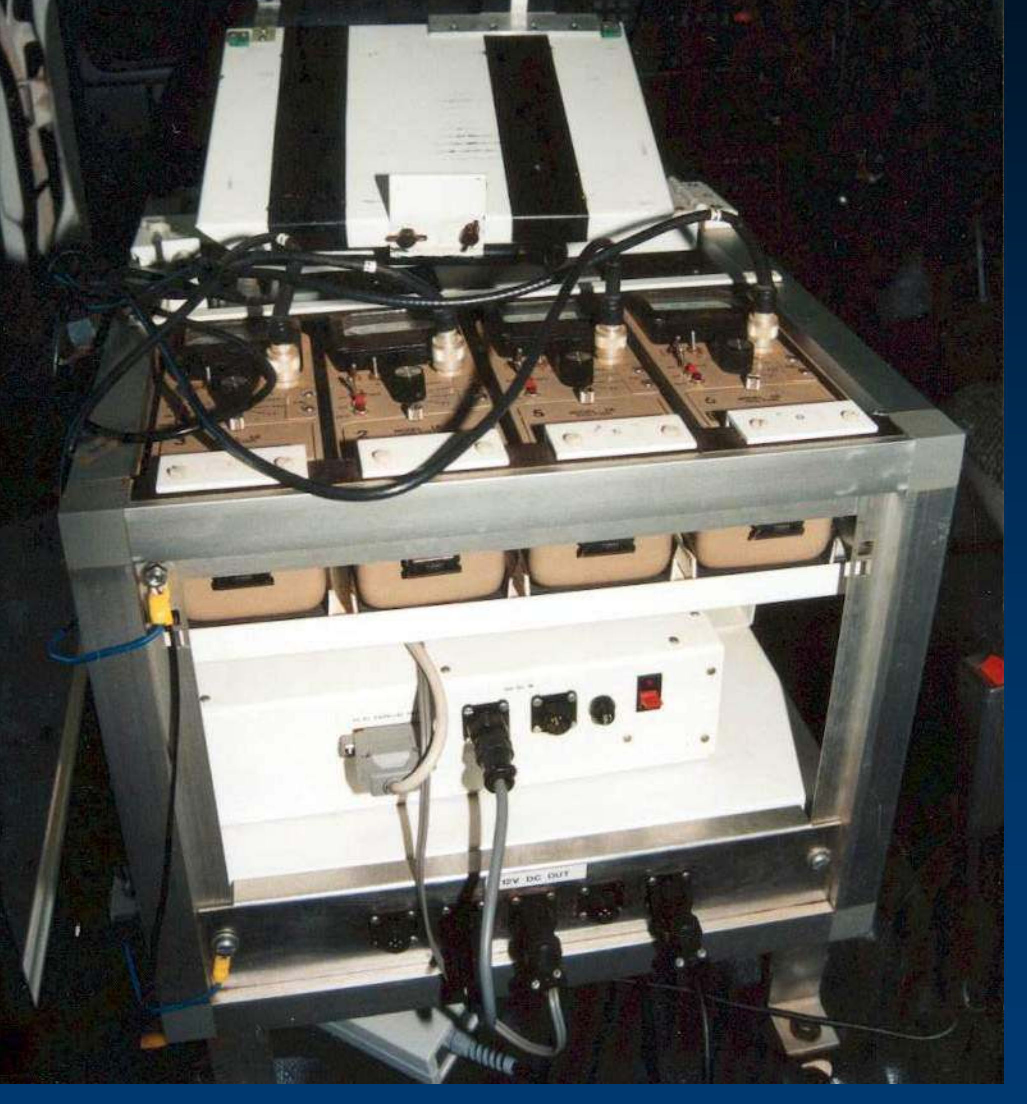


Operation: The Nissan

Setup in uncontaminated area:

- Attach detectors to vehicle
- Acquire ^{241}Am spectrum for each detector - simultaneously
- Acquire background for each detector - simultaneously
- Record settings to computer data file

Scan:

- Drive over area at speeds less than 1.7m/s (6kph)
- Drive in a decreasing spiral track
- Computer calculates count rate and particle activity for each 20cm segment of detector path

Routinely scan 30,000 m^2 each day

Operation: the Nissan Computer Display

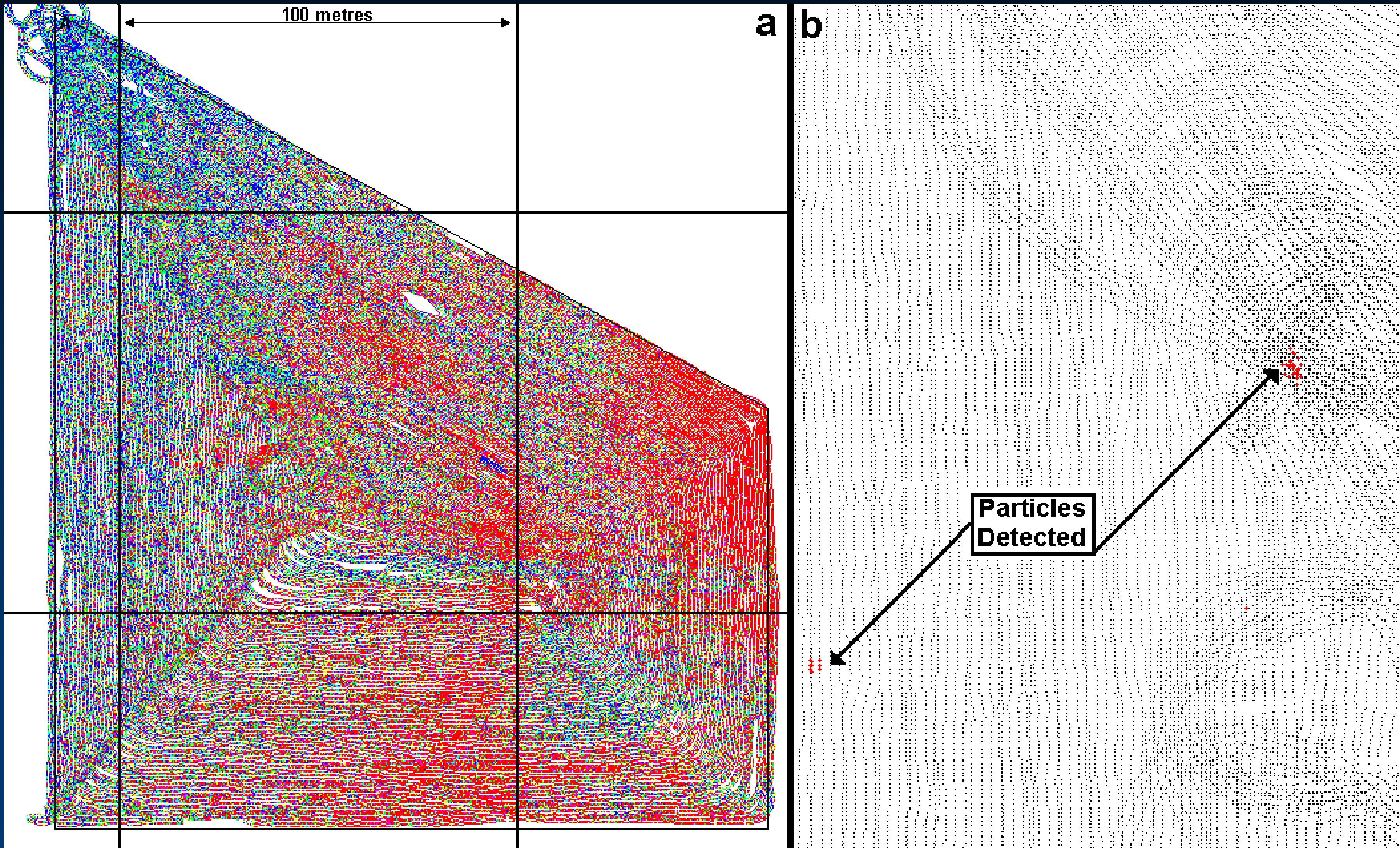
The laptop computer displays:

- The vehicle track (from the DGPS)
- The current GPS coordinates
- The High-Voltage, Threshold and Window values of each detector - with an 'out-of-acceptable-range' alarm
- The instantaneous count rate in each detector
- The position of any particle detected above a user-set activity threshold, relative to the vehicle track
- The coordinates and calculated activity of any particles detected above the user-set threshold

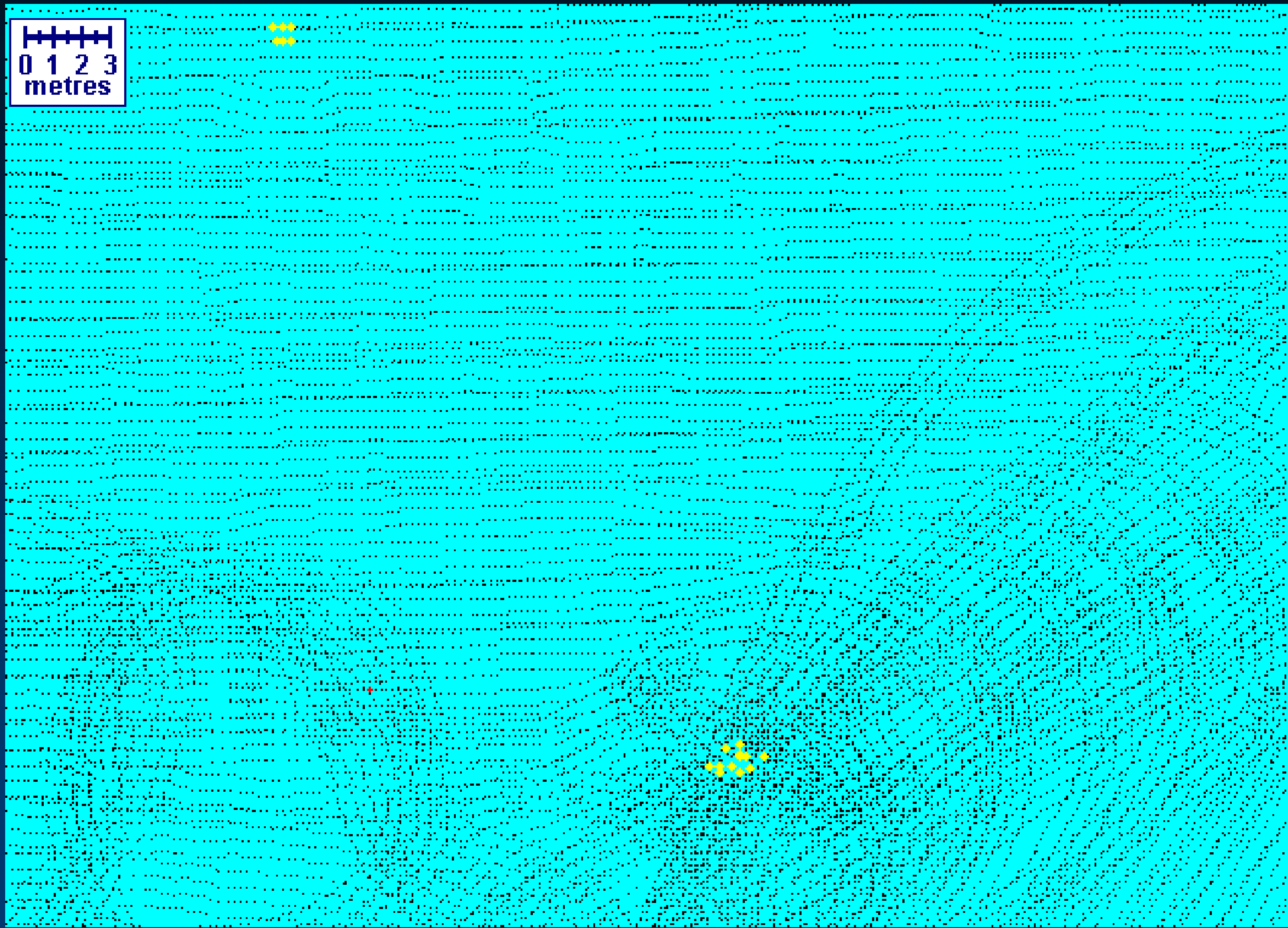
Basic Detection System

- Vehicle-Mounted
  - Speed and Operator Comfort
- Incorporate GPS
  - Accurate location of detected particles
  - Record of area surveyed
- Computerised
  - High data rate
  - Record-keeping
- Use Scintillation Detector attached to Single-Channel-Analyzer
  - Only produce signal for 60 keV

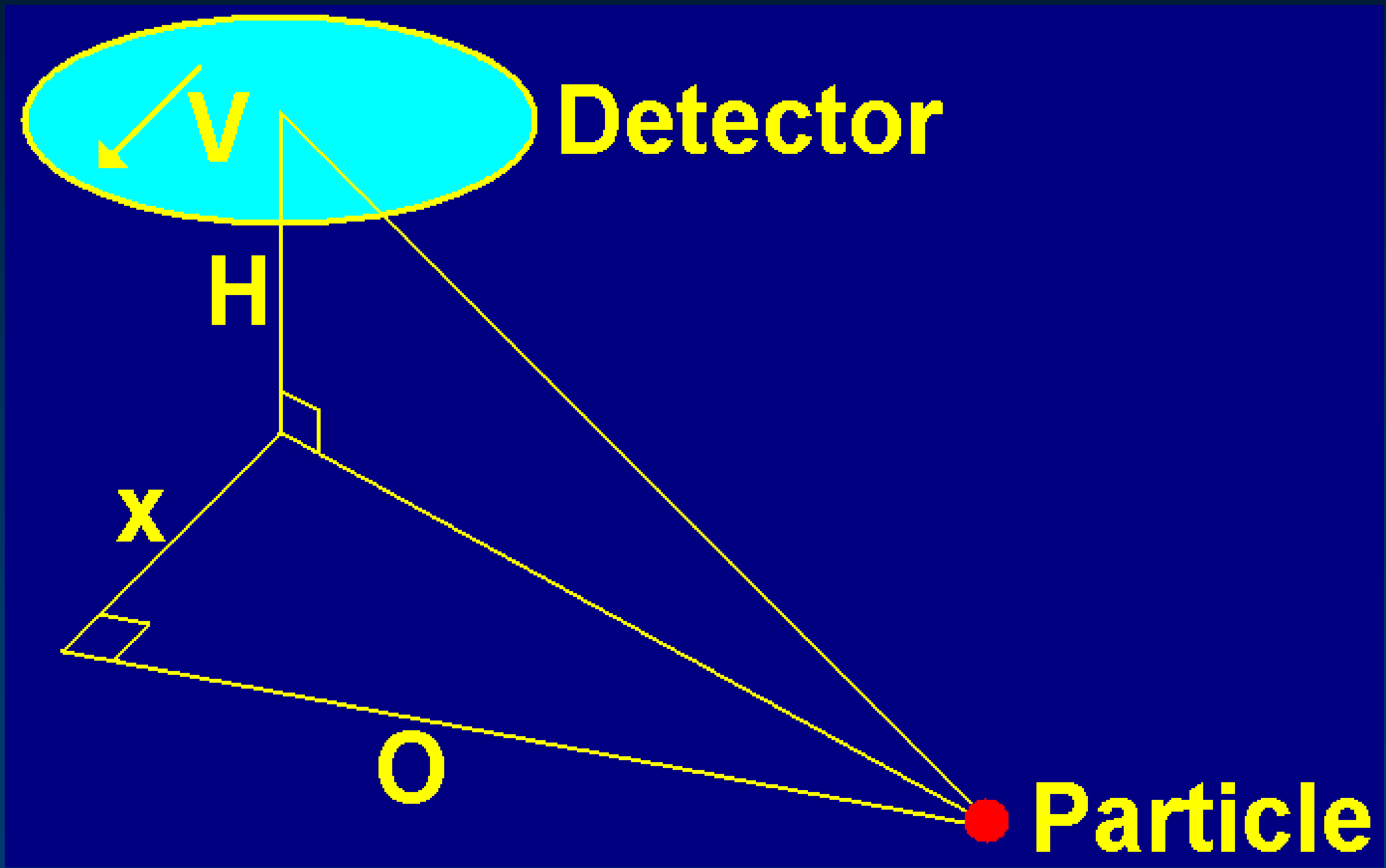
Performance: The Nissan



Particle Detection



Defining a Counting Interval - Basic Geometry



Defining a Counting Interval - Count Rate

$$R = \frac{E \cdot S \cdot H}{4 \cdot \pi \cdot (x^2 + H^2 + O^2)^{3/2}} + B$$

Emission Rate:

$$E = a \cdot \beta$$

Particle Activity = *a*
Emission Probability = β

Effective Frontal Area:

$$S = A \cdot \varepsilon$$

Detector Area = *A*
Detection Efficiency = ε

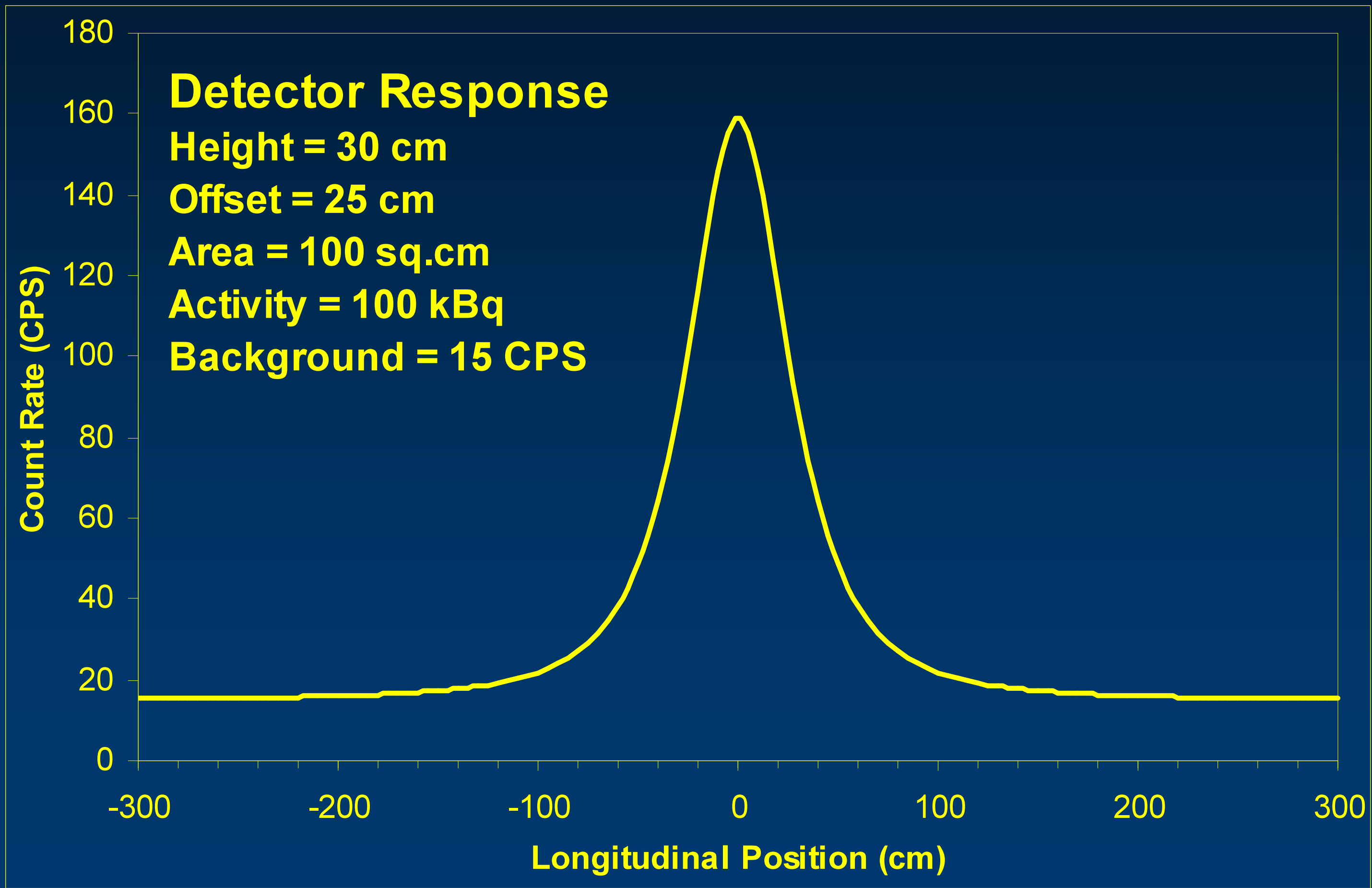
B is the rate due to sources other than particle

Defining a Counting Interval

Considerations include:

- The optimum counting interval was defined in terms of distance, NOT time
- Hall-Effect sensor on tail-shaft of vehicle
  – Used to provide a signal for the odometer and speedometer
    - Pulses every 21.3 cm
  – Depends on vehicle and tyres
    - One Interval = 3 pulses

Optimisation of Counting Interval - Detector Response



Optimisation of Counting Interval - Observed Counts

The observed counts are the time-integral of the detector response

$$C_P = \frac{E \cdot S \cdot H}{4 \cdot \pi \cdot V} \cdot \frac{1}{H^2 + O^2} \cdot \left[\frac{x_2}{\sqrt{x_2{}^2 + H^2 + O^2}} - \frac{x_1}{\sqrt{x_1{}^2 + H^2 + O^2}} \right]$$

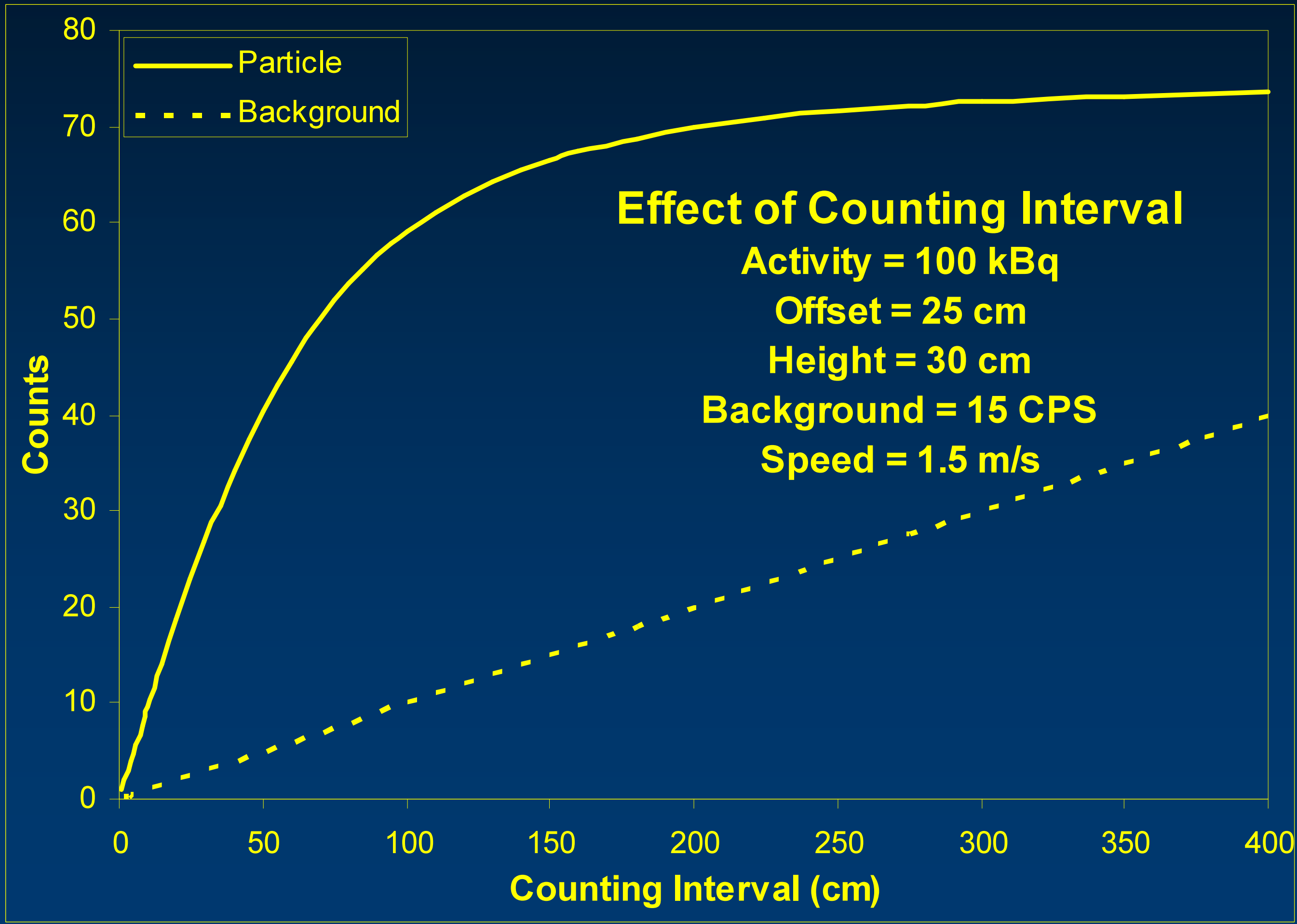
$$C_B = \frac{B \cdot (x_2 - x_1)}{V}$$

If the particle is centrally located

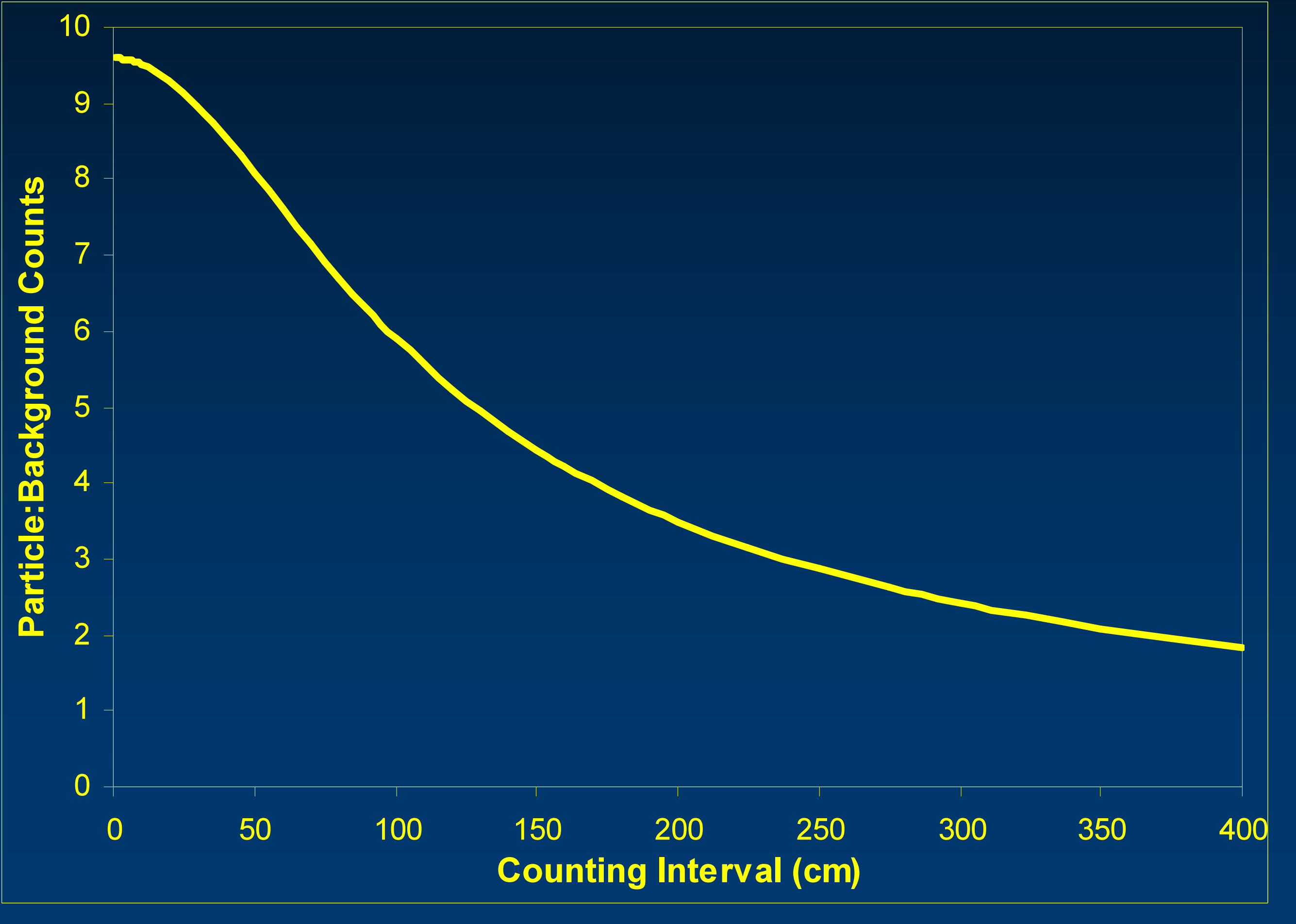
$x_1 = -x_2 = x$

and $L = 2 \cdot x$ is the length of the interval

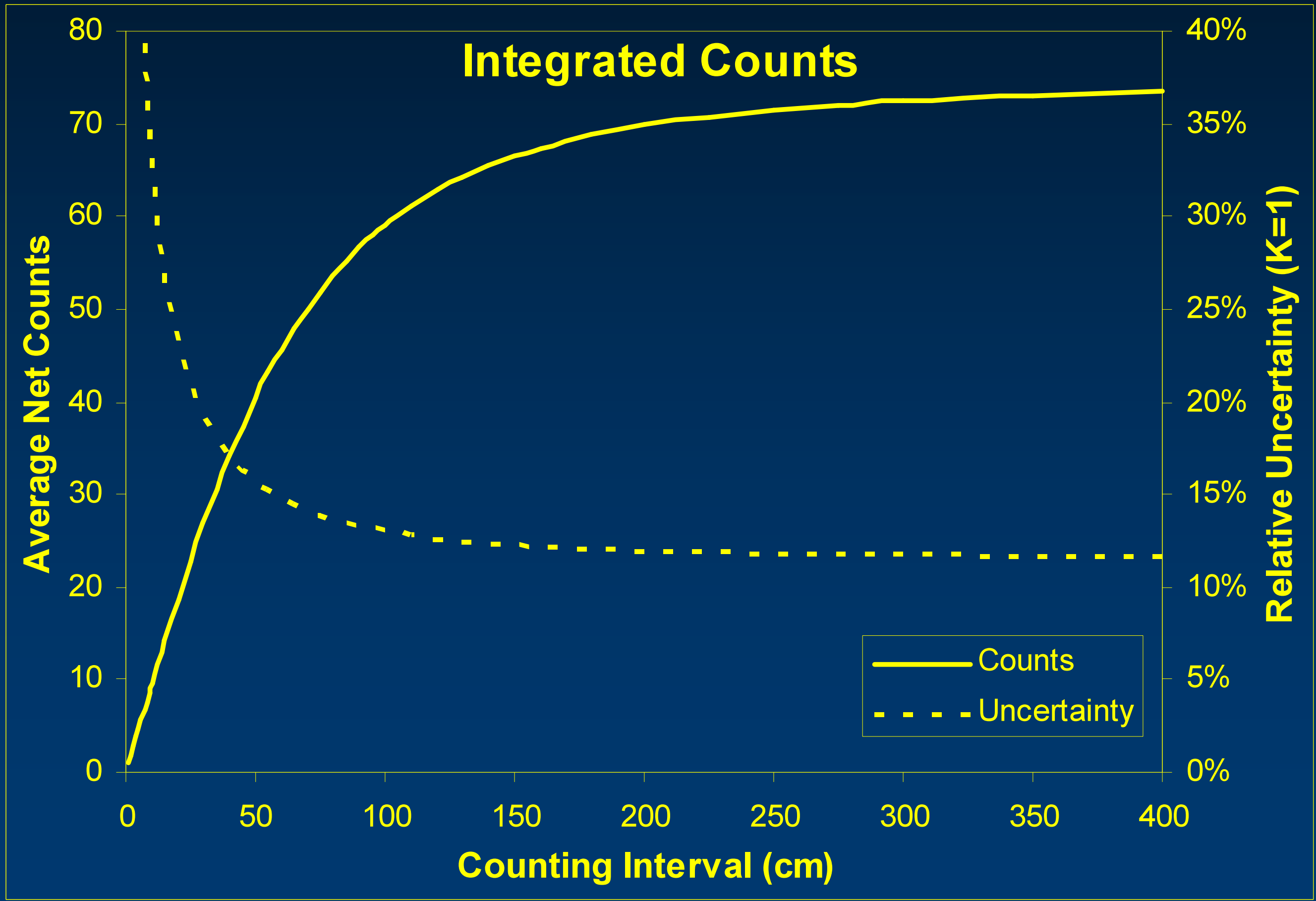
Optimisation of Counting Interval - Effect of Interval Length



Optimisation of Counting Interval - "Signal to Noise Ratio"



Optimisation of Counting Interval - Counting Uncertainty

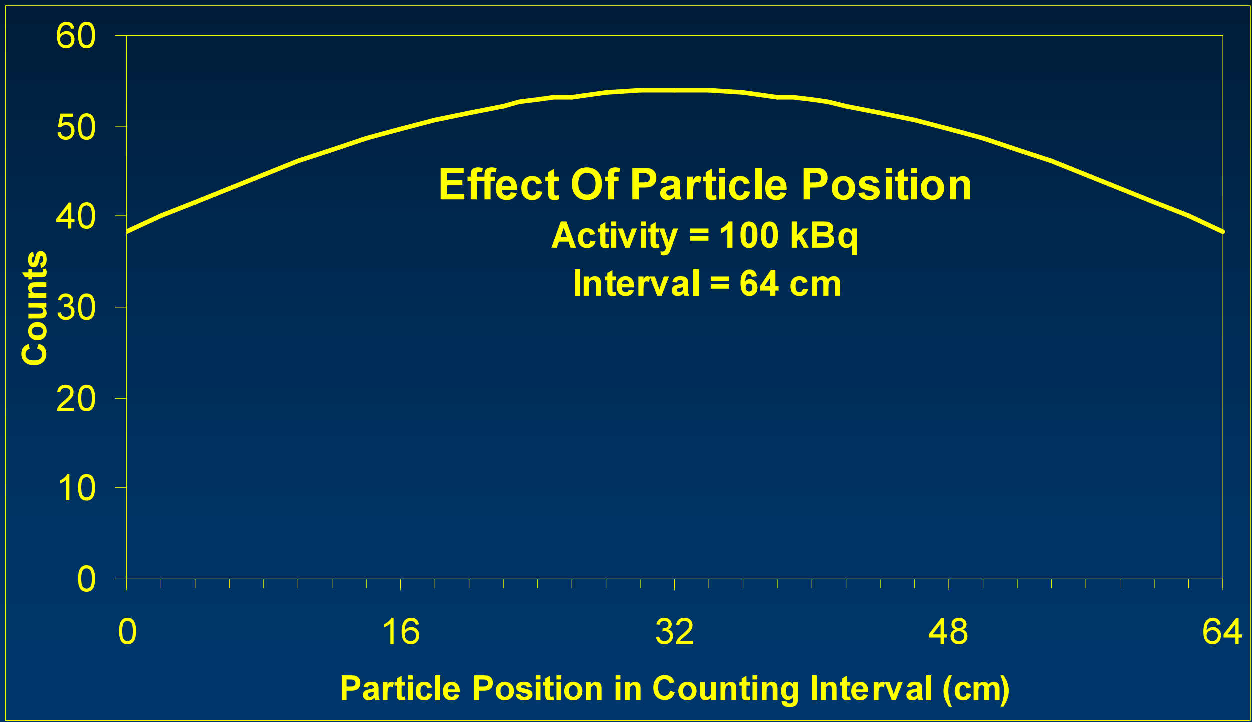


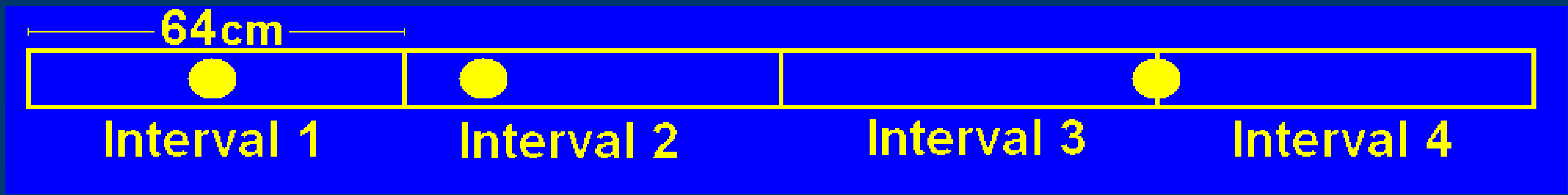
Optimisation of Counting Interval - Striking a Balance

- Maximise 'Signal to Noise'
  - Determines maximum interval length – in **distance** , not time
  - Minimise Uncertainty
  - Determines minimum interval length – in **distance**, not time
  - For:
  - *H* = 30cm, *O* = 25cm and *V* = 5 km/hr
  - Optimum counting interval is between 50 and 75 cm
  - A counting interval (distance) of between 50 and 75 cm corresponds to a counting interval (time) of between 0.3 and 0.5 seconds

Improved Counting Methodology - Random Location

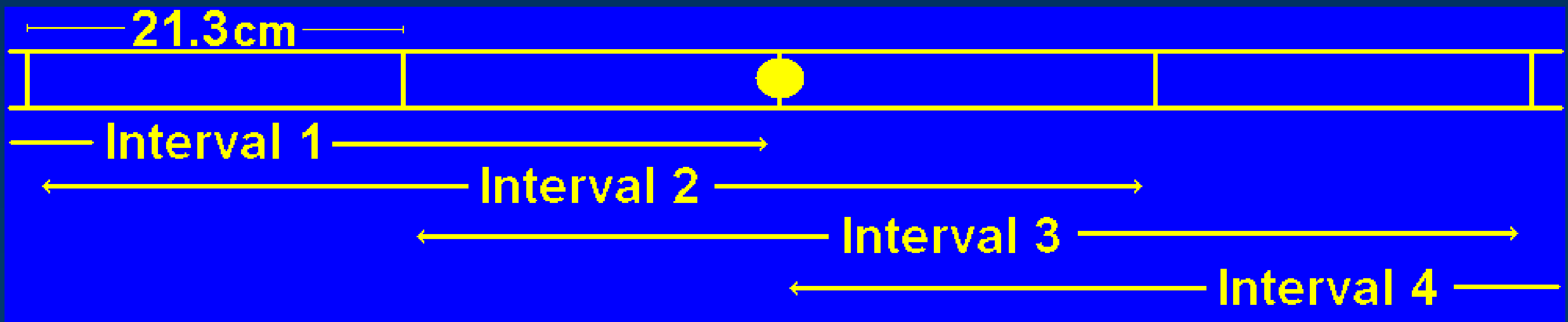
The particle is not always in the centre of the counting interval



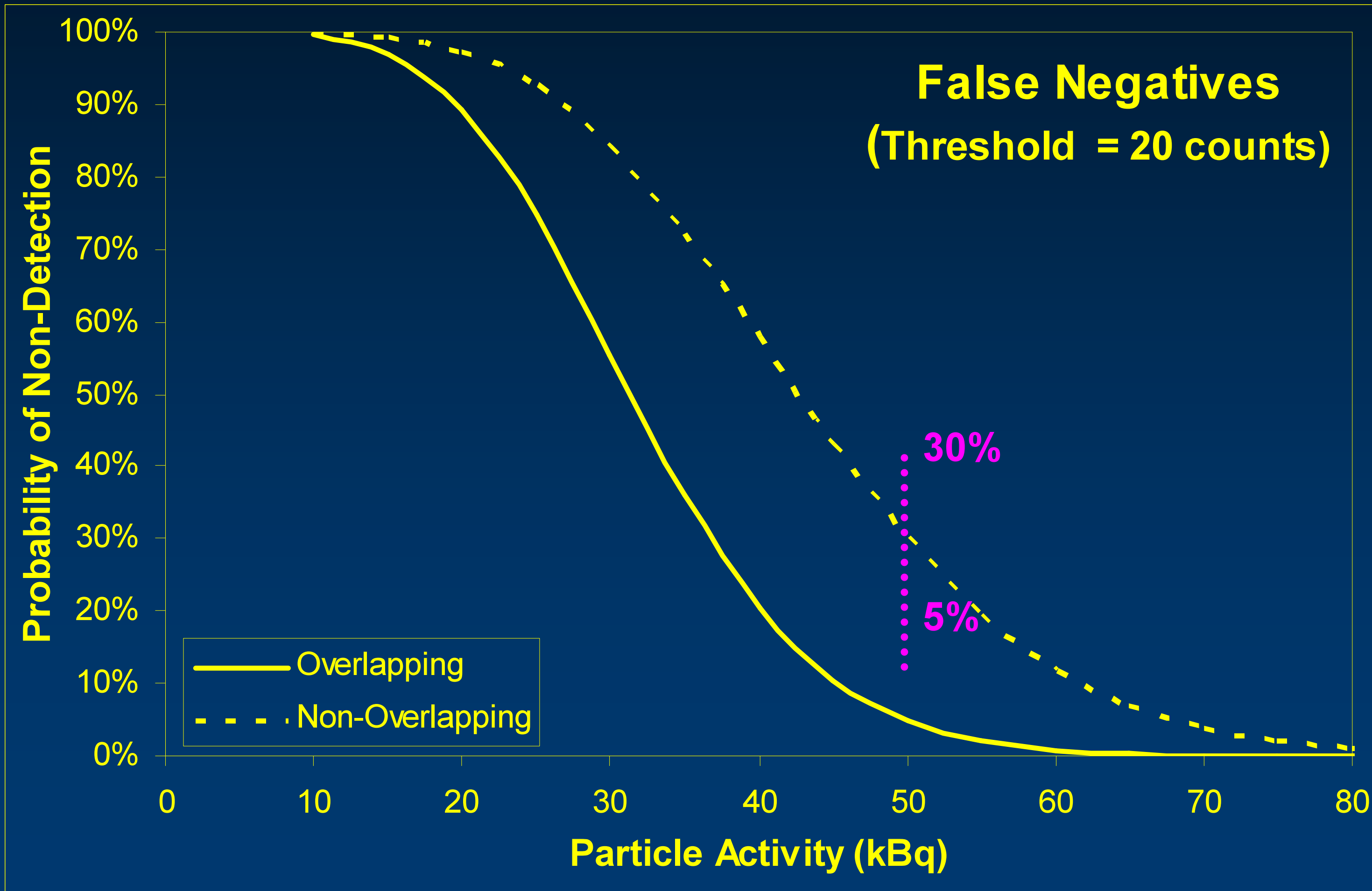


Improved Counting Methodology - Overlapping Intervals

- Interval is defined by three consecutive pulses
- Define sub-interval terminated by a single pulse
- Integrated counts is running sum over three consecutive sub-intervals



Improved Counting Methodology - Improved Detection Probability



Results of Particle Detection Scans

Region	Area (ha)	Number of Contaminated Particles Indicated	Number of Contaminated Particles Removed
Soil Removal Areas	250	~300	121
Soil Removal Boundaries	120	~250	85

Long-term Management and Post-Rehabilitation Activities - Maralinga

As part of the Maralinga Land and Environment Management Plan (MLEMP), ARPANSA conducts regular Field Surveys of the rehabilitated areas.

The objectives of the ongoing field surveys are:

- Measure the dose-rate at each of the major trial sites
- Conduct in-situ measurements of the ^{241}Am activity concentration in each of the plumes
- Conduct in-situ measurements of the ^{137}Cs activity concentration north of Breakaway
- Conduct hand-surveys for contaminated particles in the windrows north of Taranaki


TEST SITE
KITE
BRITISH ATOMIC
WAS TEST
HERE ON
11 OCT 1956
WARNING
RADIATION HAZARD
RADIATION LEVELS FOR
A FEW HUNDRED METRES
AROUND THIS POINT MAY
BE ABOVE THOSE
CONSIDERED SAFE FOR
PERMANENT OCCUPATION

THANK-YOU