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Gamma imaging for On-site Inspection

Reconstruction of an extended source in a restricted-access zone

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Canada

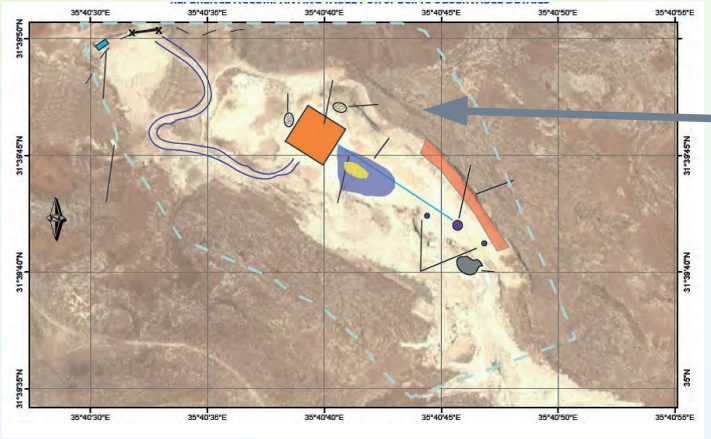
Outline

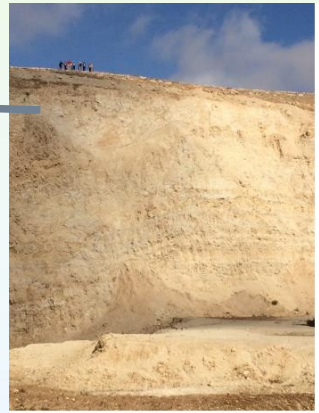
- On-site inspection and restricted-access zones
- Compton gamma imaging
- Perimeter survey and tomography methods
- Field trial results
- Conclusions

Perimeter survey in On-Site Inspection

An inspected State Party may declare up to 50 km^2 of restricted-access sites, each of area up to 4 km^2

2014 Integrated Field Exercise - Restricted Area Site N:





Development and Implementation of the 2014 Integrated Field Exercise Scenario, CTBT/PTS/TR/2015-1, June 2015

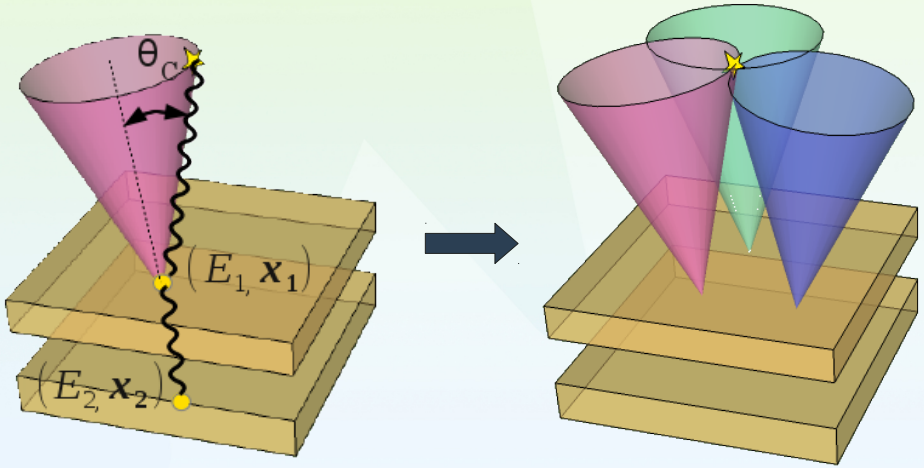
Inspected country claimed that there had been an industrial accident and it was not safe to go in.

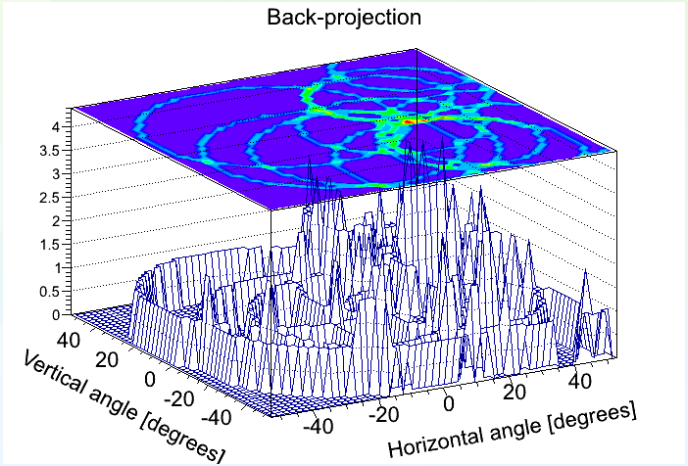
Viewing from the cliff at the perimeter of the restricted zone was deemed to be safe.

- See P.R.B.Saull (NRC) et al., *SCoTSS Gamma Imager for CTBTO On-site Inspection*, talk from CTBTO SnT 2017 for SCoTSS imager sensitivity for this geometry

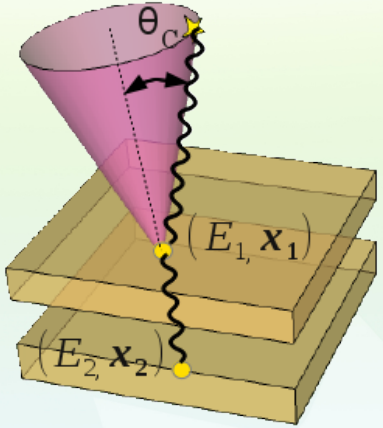
Compton gamma imaging

$$E_\gamma = E_1 + E_2; \quad \cos(\theta_C) = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_2}\right)$$

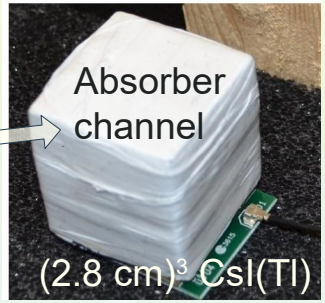


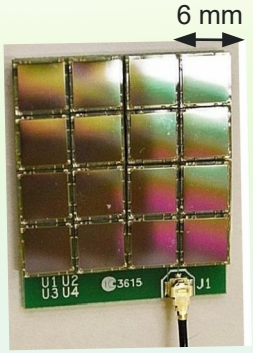


Silicon Compton Telescope for Safety and Security (SCoTSS)



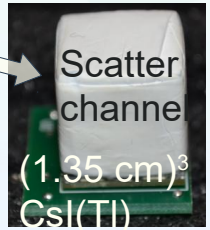
absorber layer
12 x 12
individual
CsI(Tl)

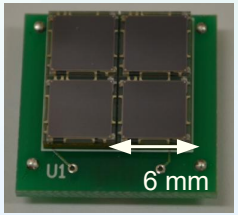




At least two energy depositions are required per incident ray. Need coincidence timing, and the energies and locations of each energy deposit.

scatter layer
12 x 12
individual
CsI(Tl)

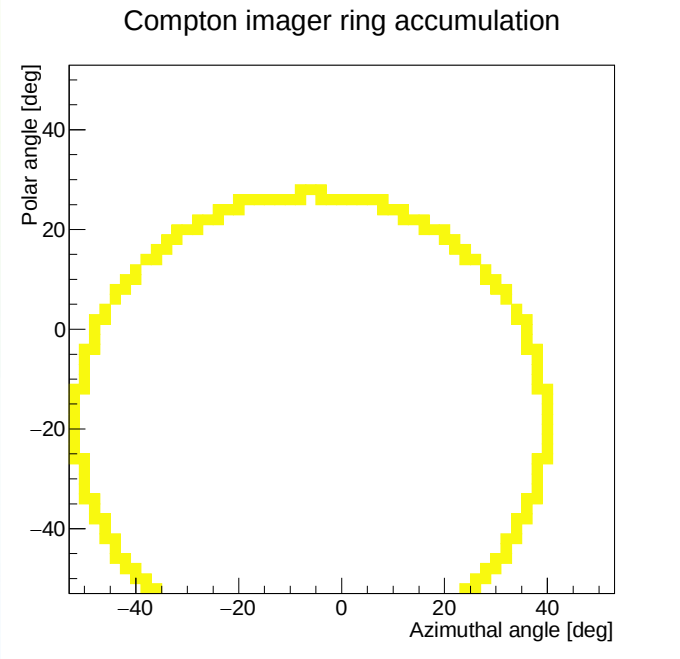




3.5 L total CsI(Tl) volume

Compton back-projection image

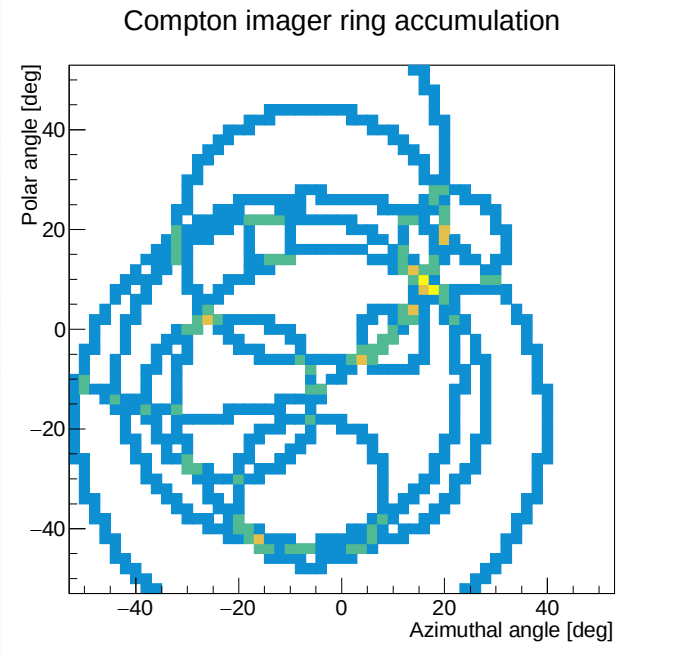
single back-projected Compton cone



Real data, March 2018, Extended source of ~10 MBq/m^2 La-140, ~200 m distant, on the horizon

Compton back-projection image

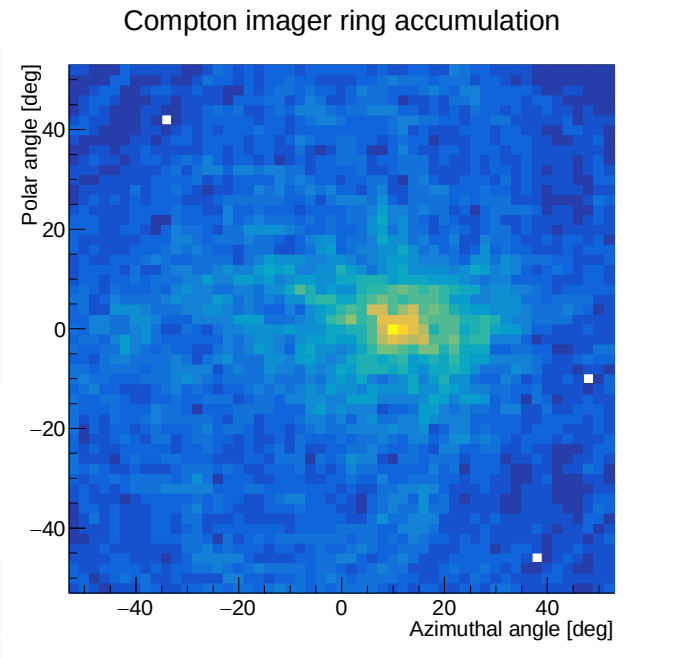
multiple back-projected Compton cones ~few s



Real data, March 2018, Extended source of ~10 MBq/m^2 La-140, ~200 m distant, on the horizon

Compton back-projection image

histogram of cone density ~few minutes

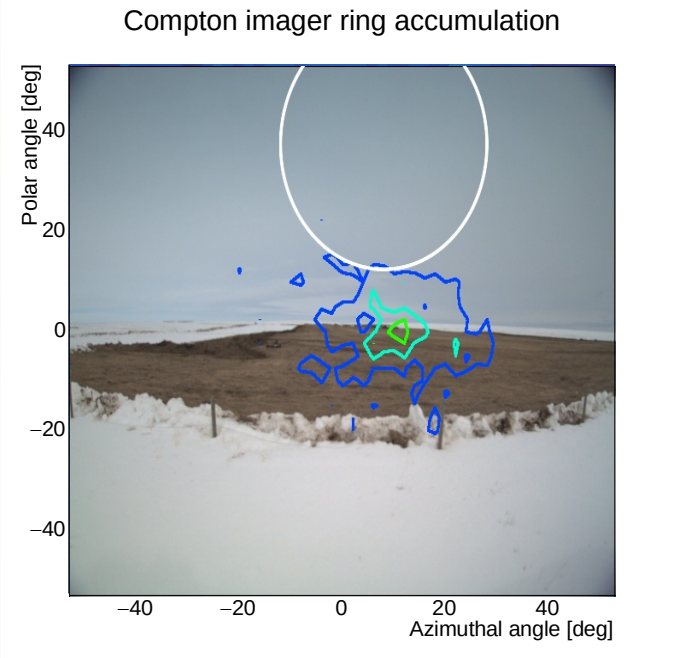


Real data, March 2018, Extended source of ~10 MBq/m^2 La-140, ~200 m distant, on the horizon

Compton back-projection image

co-registration of optical and gamma images

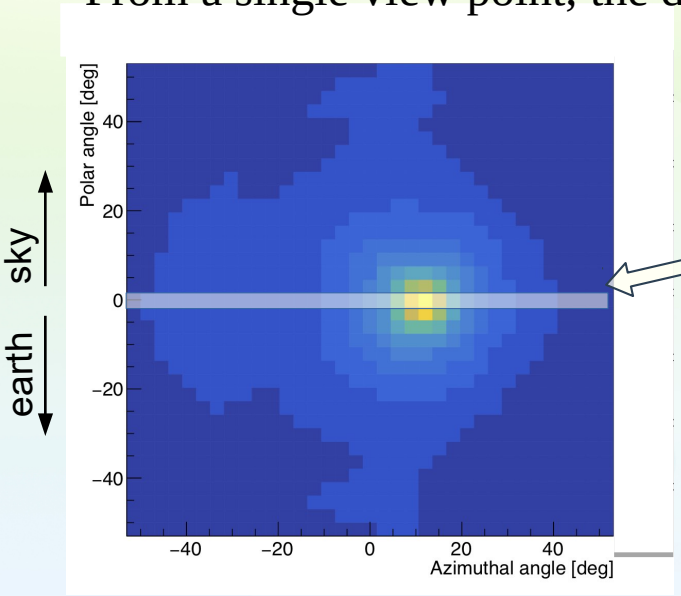
➡ Associate gamma emissions with visible features in the environment.



Real data, March 2018, Extended source of ~10 MBq/m^2 La-140, ~200 m distant, on the horizon

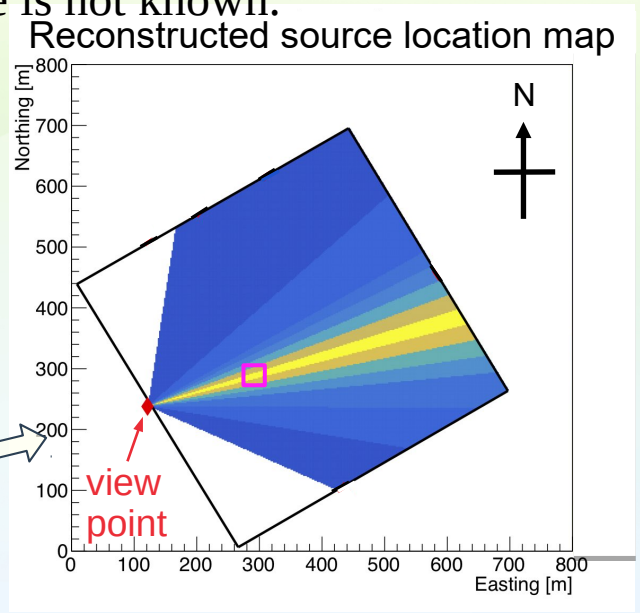
Compton imaging tomography

From a single view point, the distance to the source is not known.



Assume source near horizon

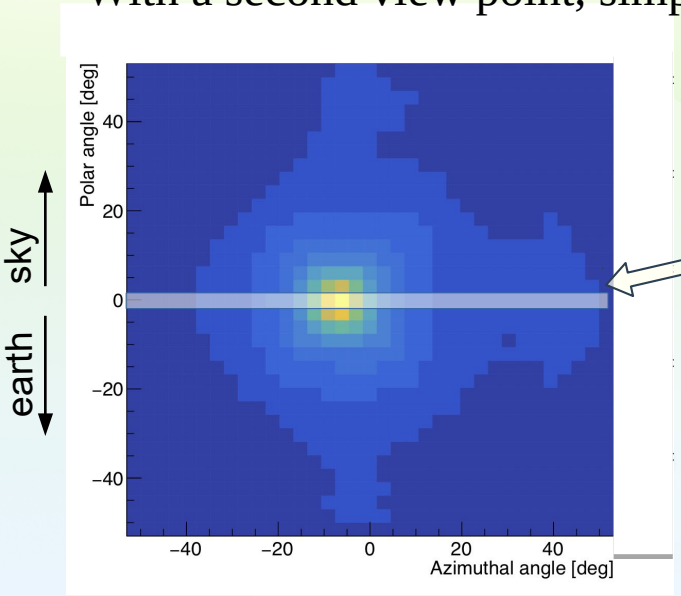
Project the azimuth distribution at the horizon out across the field



Simulated SCoTSS imager response to a point source within a large exclusion zone, from perimeter

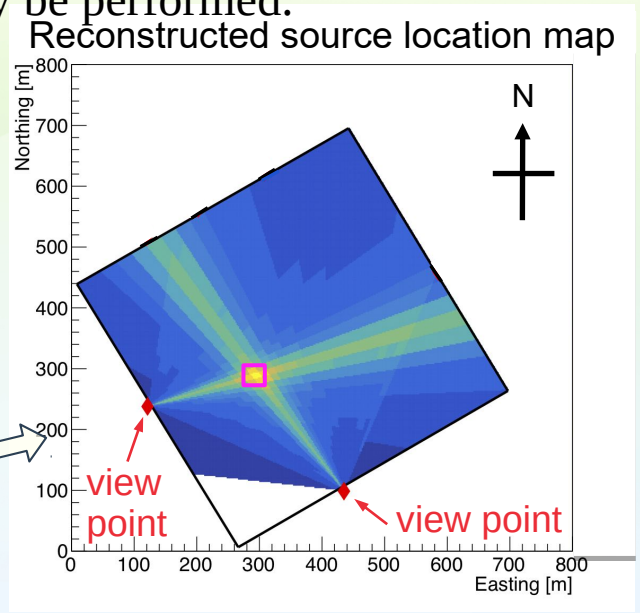
Compton imaging tomography

With a second view point, simple triangulation may be performed.



Assume source near horizon

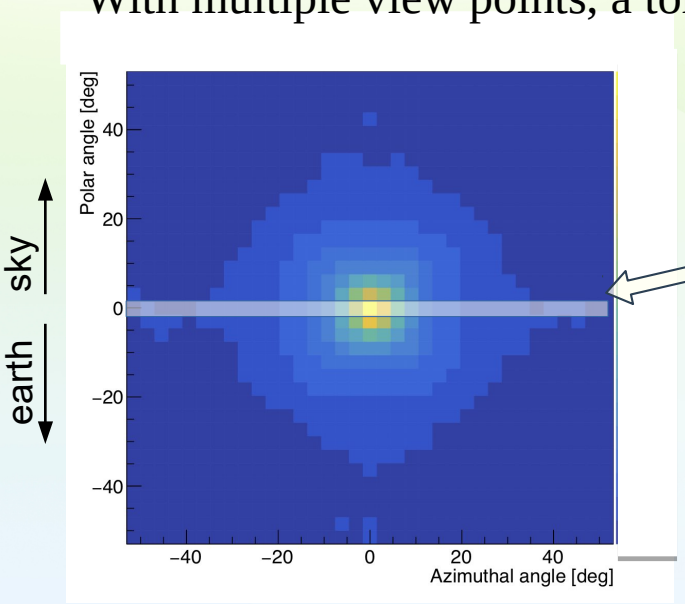
Project the azimuth distribution at the horizon out across the field



Simulated SCoTSS imager response to a point source within a large exclusion zone, from perimeter

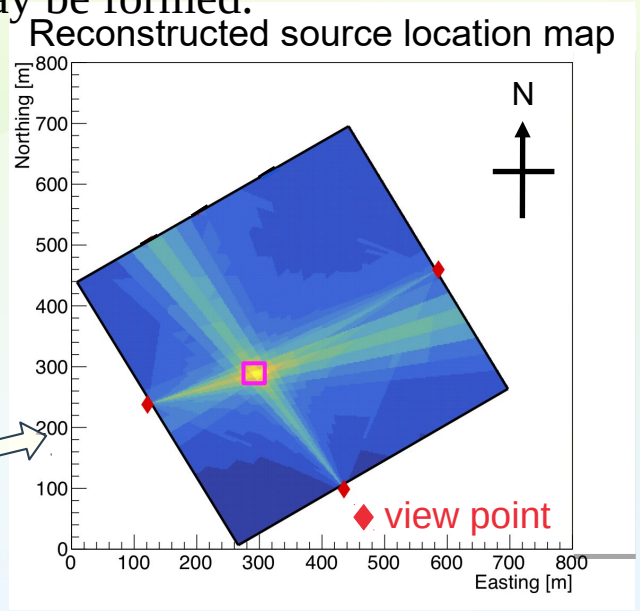
Compton imaging tomography

With multiple view points, a tomography image may be formed.



Assume source near horizon

Project the azimuth distribution at the horizon out across the field



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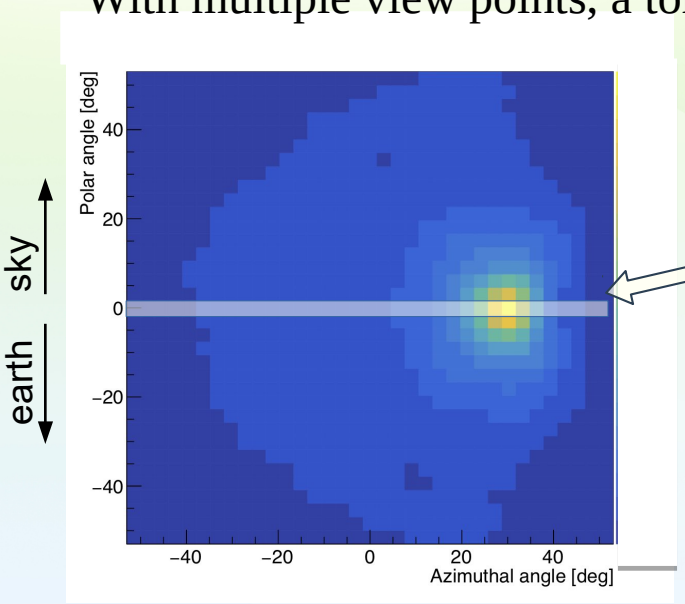
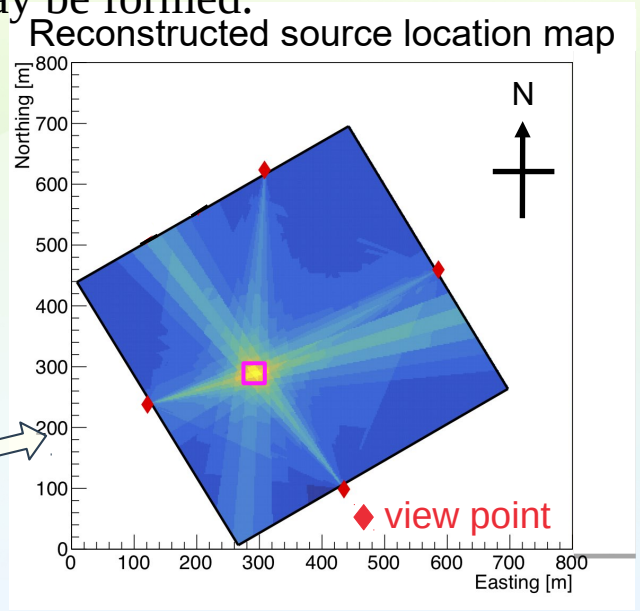


Assume source near horizon

Project the azimuth distribution at the horizon out across the field



Simulated SCoTSS imager response to a point source within a large exclusion zone, from perimeter

Compton imaging tomography

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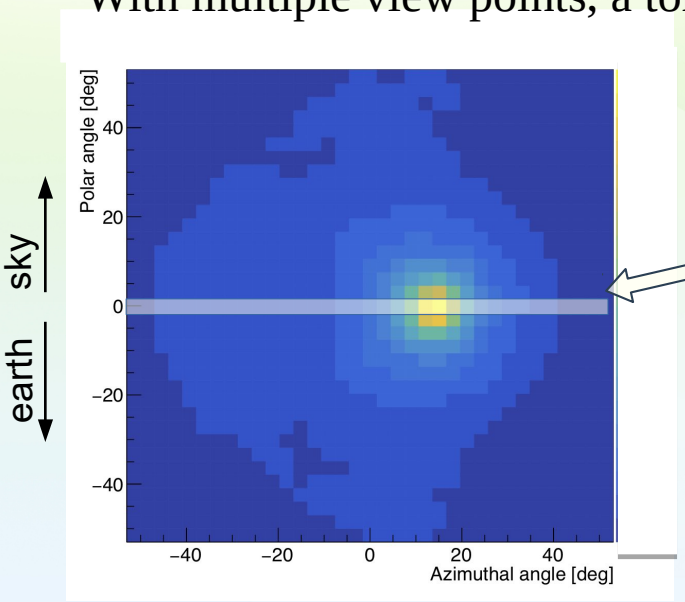
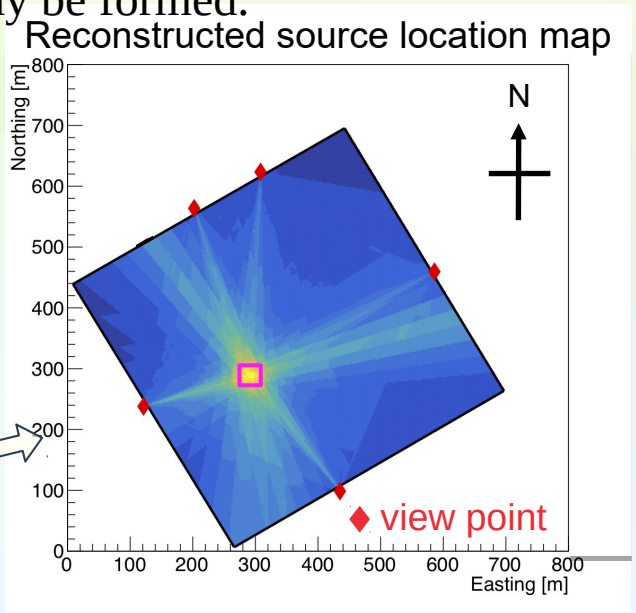


Assume source near horizon

Project the azimuth distribution at the horizon out across the field



Simulated SCoTSS imager response to a point source within a large exclusion zone, from perimeter

Compton imaging tomography

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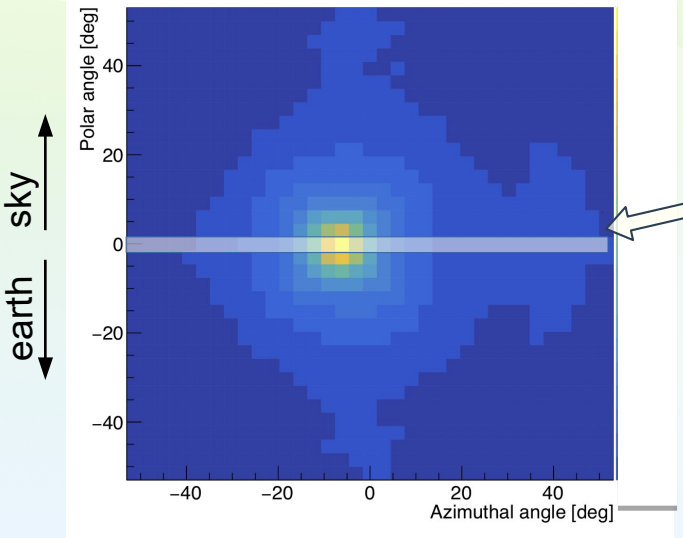

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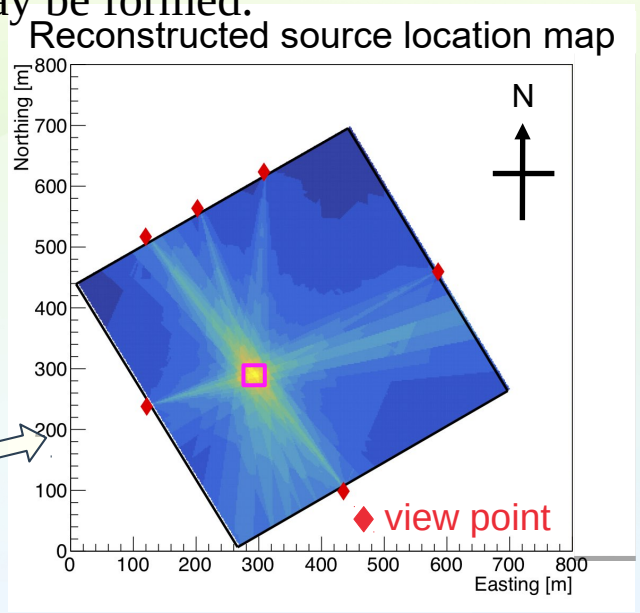
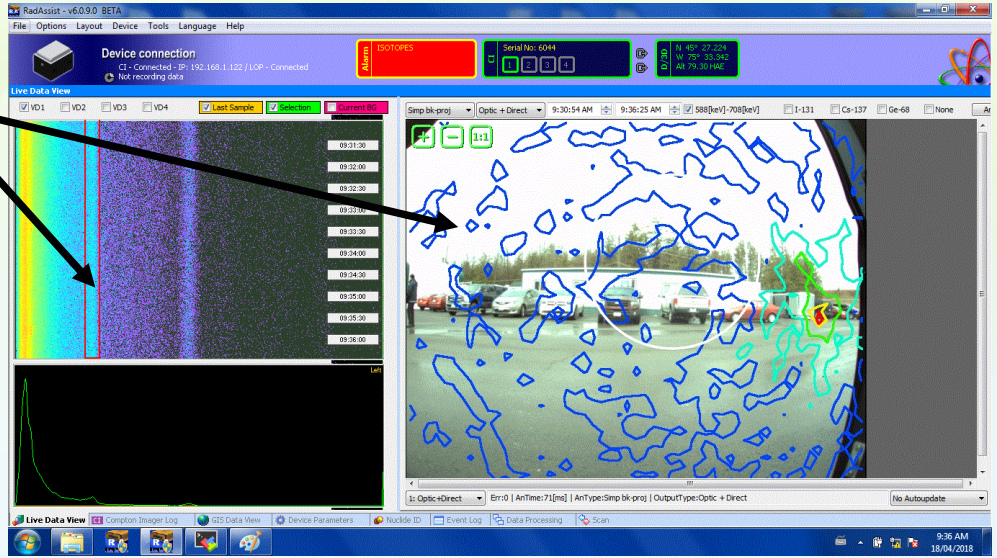


Simulated SCoTSS imager response to a point source within a large exclusion zone, from perimeter

Operational driving trial, point sources

Operational driving trial

creation of image from selected energy and time

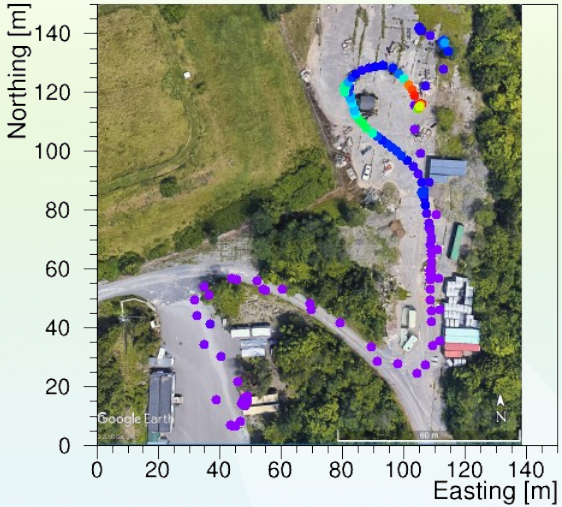


Prior to the beginning of the exercise, the source could be imaged

- from discrete location several 10's m away
- source in transportation pig, < 2.5 µGy/hr at surface of pig
  - ▷ heavy shielding causes downscatter
  - ▷ ~ natural background rate at detector.

RCMP TPOF facility exercise of federal field team support to G7 security operation, Apr. 2018

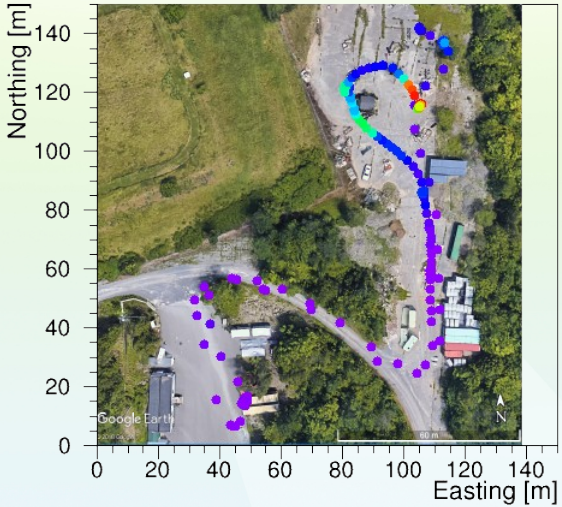
Operational driving trial



- High sensitivity permits real-time detection and alarming
- Mapping while in motion

C.M. Chen, L.E. Sinclair, R. Fortin, M. Coyle, C. Samson, *In-flight performance of the Advanced Radiation Detector for UAV Operations (ARDUO)*, Nucl. Instr. Meth. in Phys. Res. A: 2018, In press

Operational driving trial



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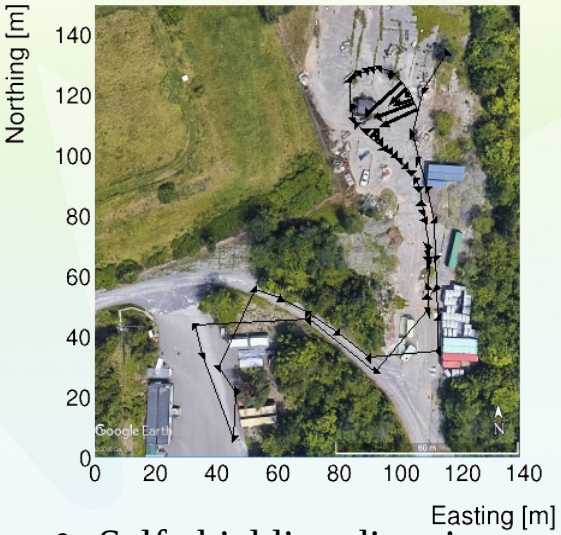
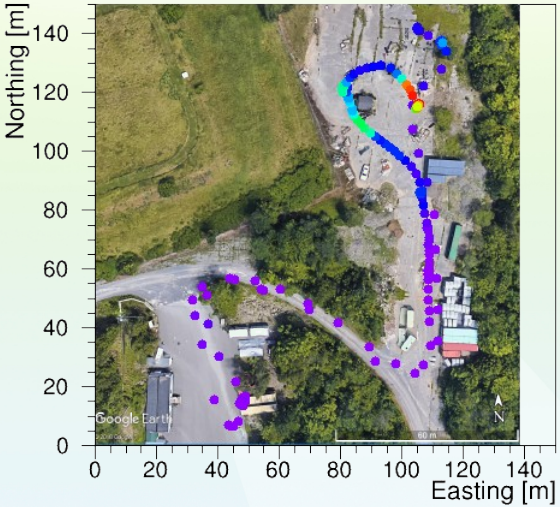


- Self-shielding direction to source
- Directions while in motion

C.M. Chen, L.E. Sinclair, R. Fortin, M. Coyle, C. Samson, *In-flight performance of the Advanced Radiation Detector for UAV Operations (ARDUO)*, Nucl. Instr. Meth. in Phys. Res. A: 2018, In press

Operational driving trial



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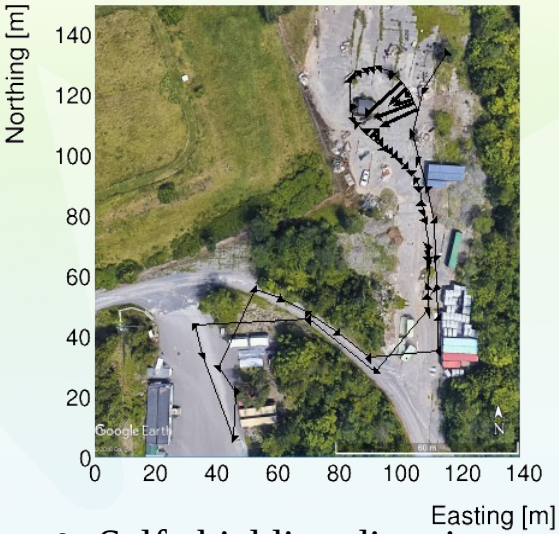
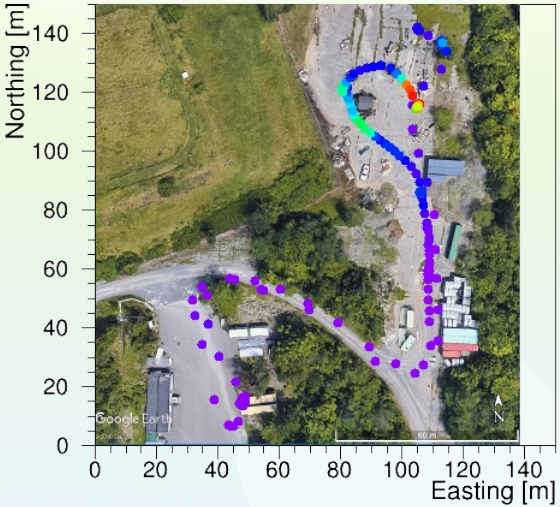


- Self-shielding direction to source
- Directions while in motion

- Compton image of source

C.M. Chen, L.E. Sinclair, R. Fortin, M. Coyle, C. Samson, *In-flight performance of the Advanced Radiation Detector for UAV Operations (ARDUO)*, Nucl. Instr. Meth. in Phys. Res. A: 2018, In press

Operational driving trial



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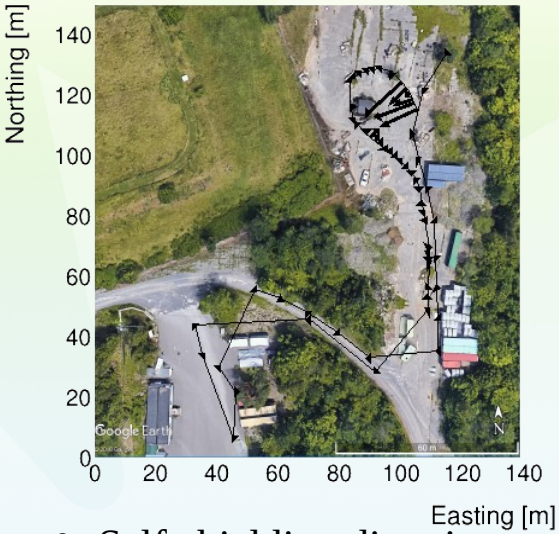

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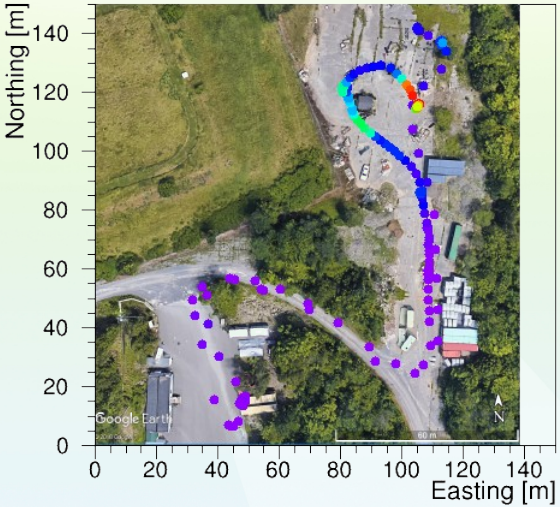
Operational driving trial



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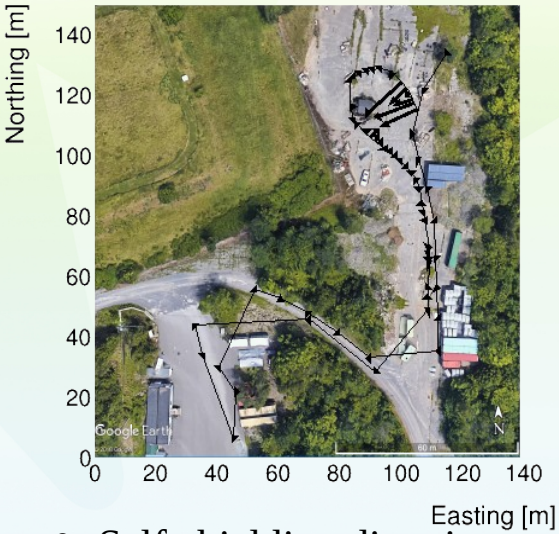

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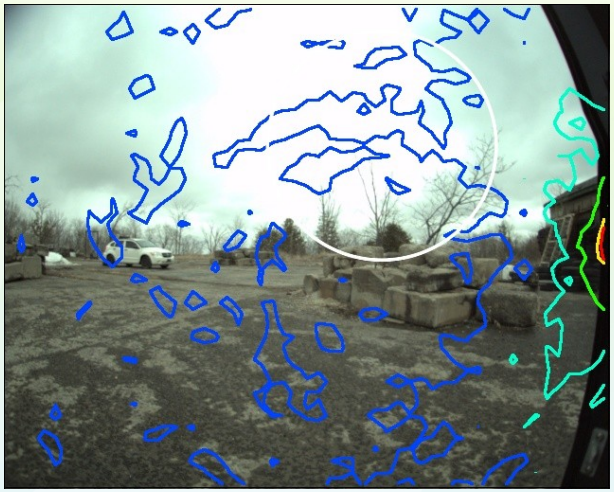

- Compton image of source

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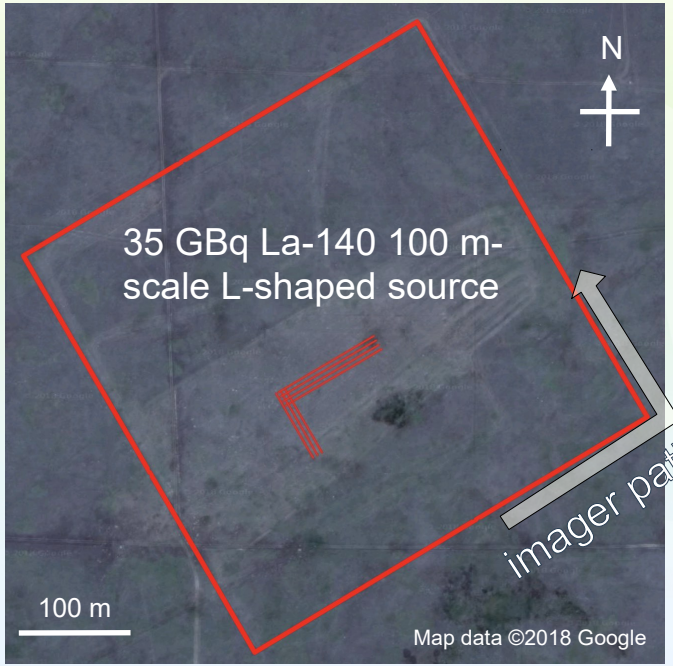
Large-scale (~100 m) dispersed source trial

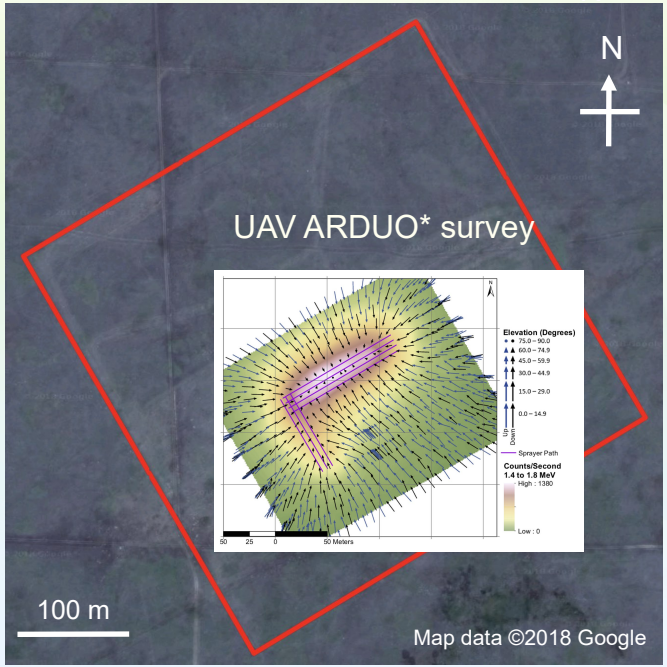
Large dispersed-source trial



DRDC Suffield Research Centre field trial March, 2018

Exclusion zone restricted imager to > 200 m from source at closest approach.

Large dispersed-source trial

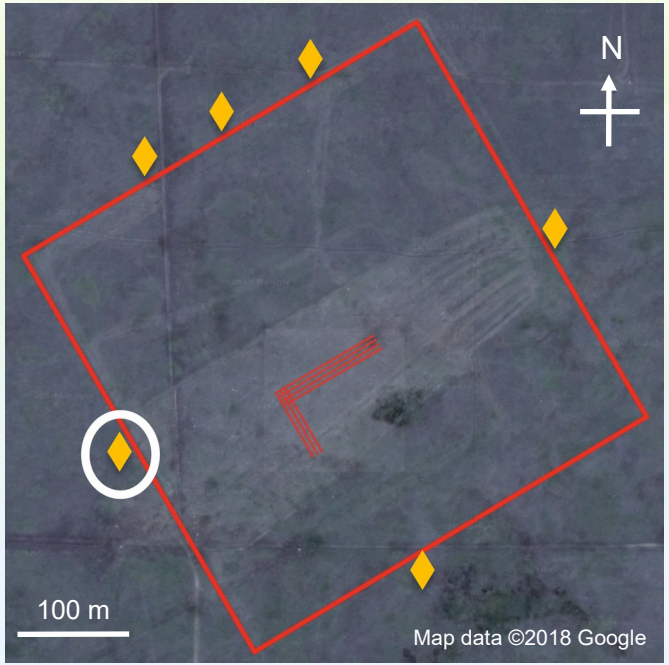


DRDC Suffield Research Centre field trial March, 2018

In fact, most of 40 GBq La-140 ended up in the long arm of the L-shape.

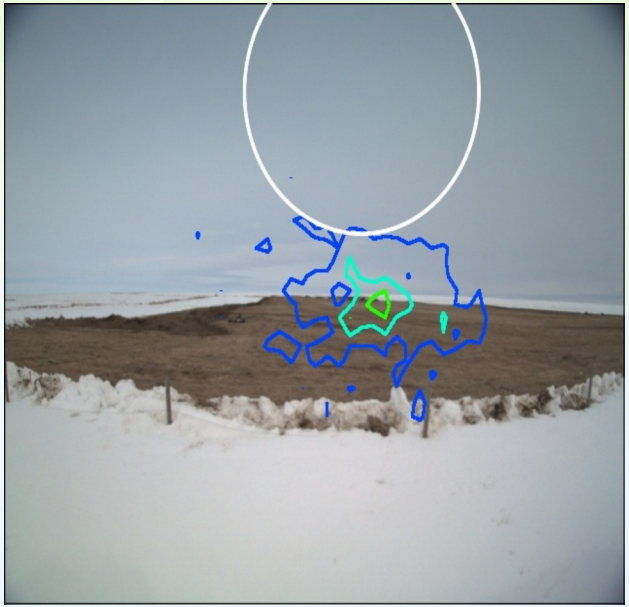
*See L.E.Sinclair (NRCan) et al., *"Unmanned Aerial Vehicles in On-site Inspection: New techniques for gamma spectroscopy survey"* poster T3.1-P47 at this CTBTO SnT 2019.

Large dispersed-source trial



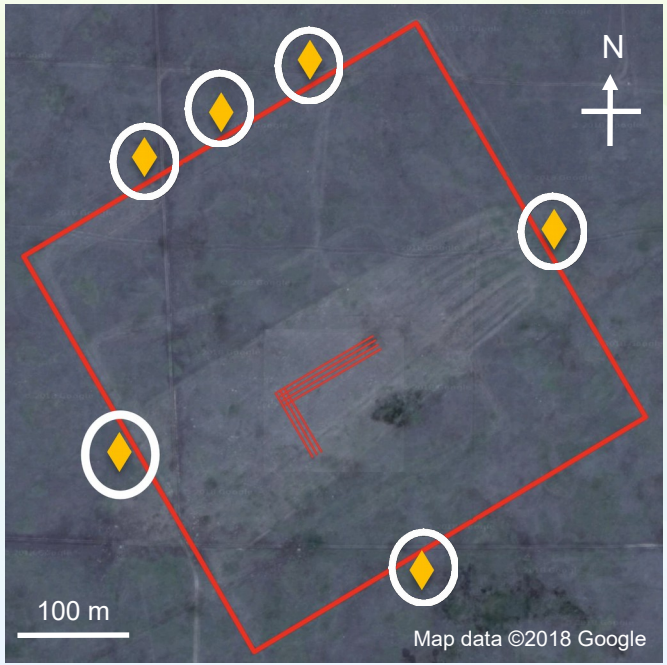
DRDC Suffield Research Centre field trial March, 2018

Single viewpoint backprojection image indicates a source near the horizon.



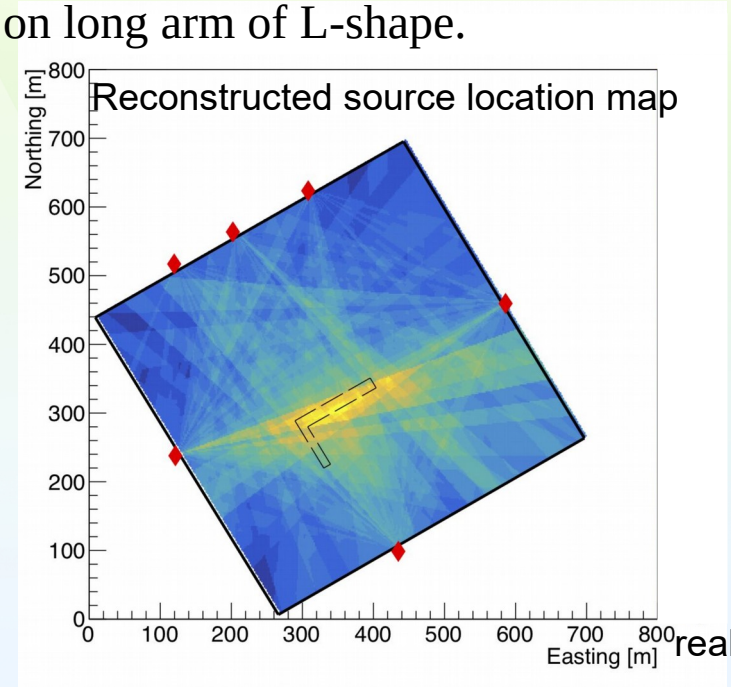
real data

Large dispersed-source trial

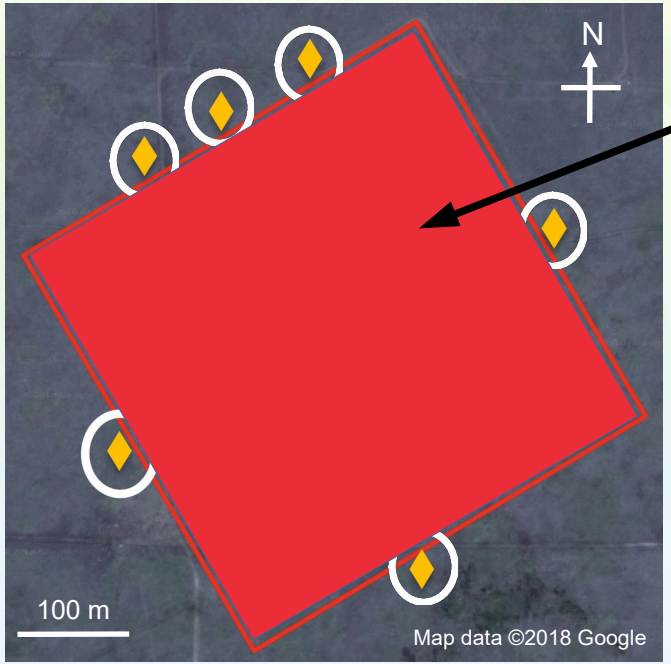


DRDC Suffield Research Centre field trial March, 2018

Six viewpoint tomographic image shows concentration of radioactivity on long arm of L-shape.



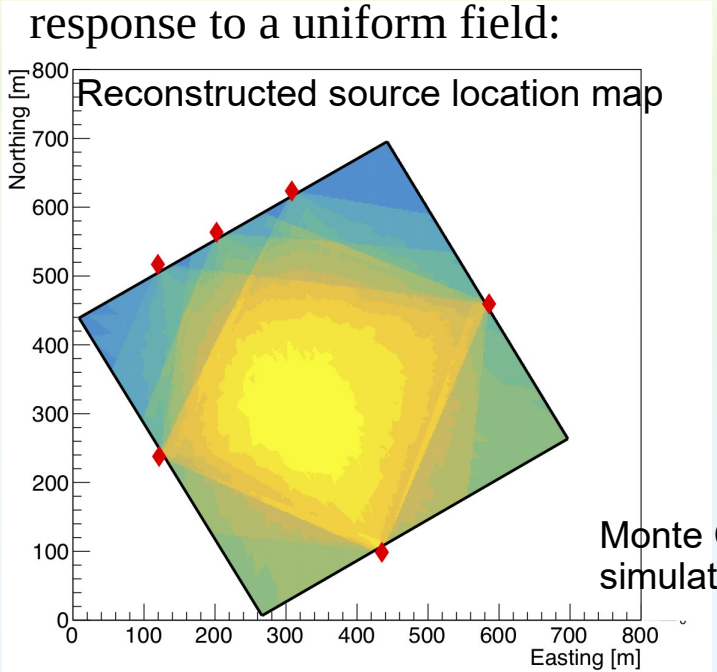
Large dispersed-source trial



Simulation of uniform field of emitters

Say the whole field had been hot, not just the L-shape

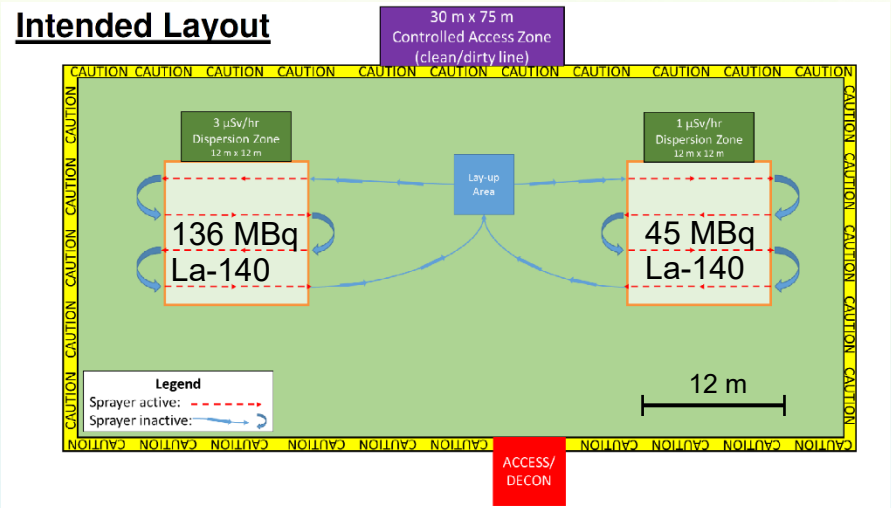
Contrast the L-shape response to the response to a uniform field:



Monte Carlo simulation

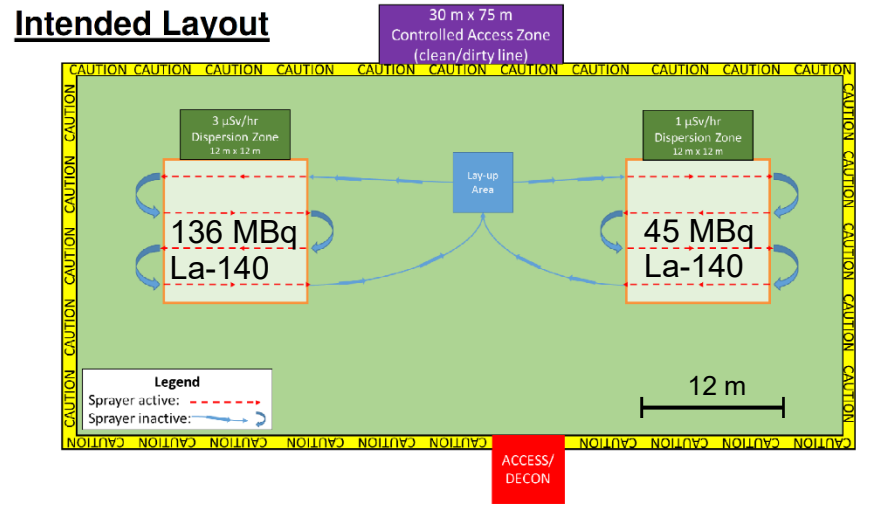
Medium-scale (~10 m) dispersed source trial

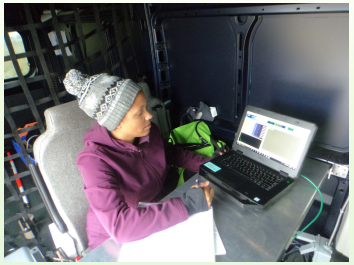
Medium dispersed-source trial

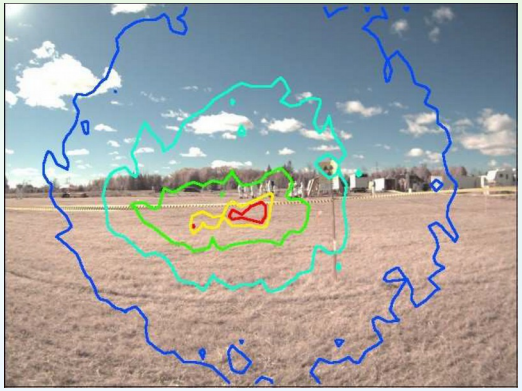


- Dispersal trials organized and lead by DN Safe, included joint operations with Federal Radiological Assessment Team ground crews.
- UAV overflights by Natural Resources Canada*.
- Health Canada, DND/Director Nuclear Safety and National Research Council conducting pedestrian survey, soil sampling, gamma imaging; Royal Canadian Mounted Police observing.

Medium dispersed-source trial



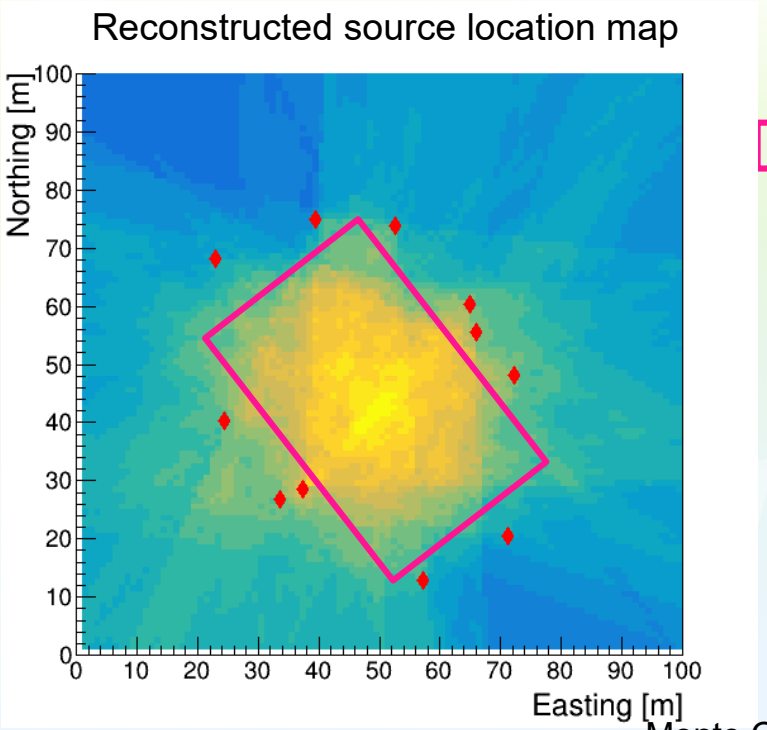




- Imager collected data at fifteen dwell points around the exclusion zone perimeter

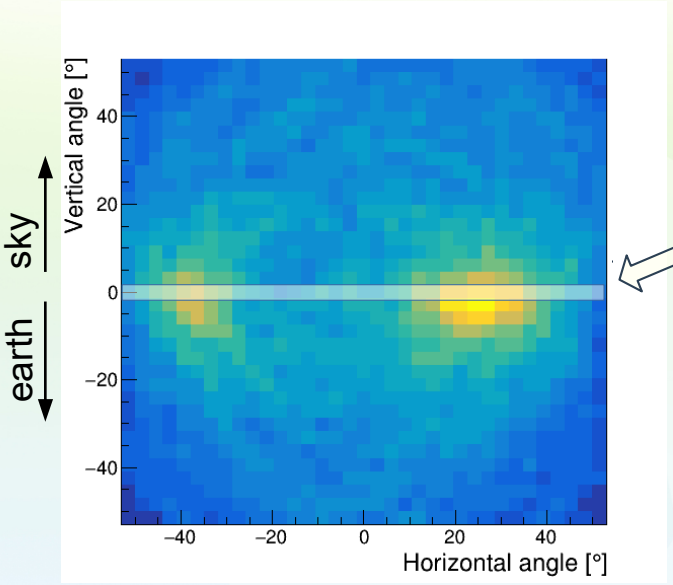
Medium dispersed-source trial

- Simulated response to a uniform field is not flat.
- Ongoing work to correct the tomography result for the response function



Monte Carlo simulation

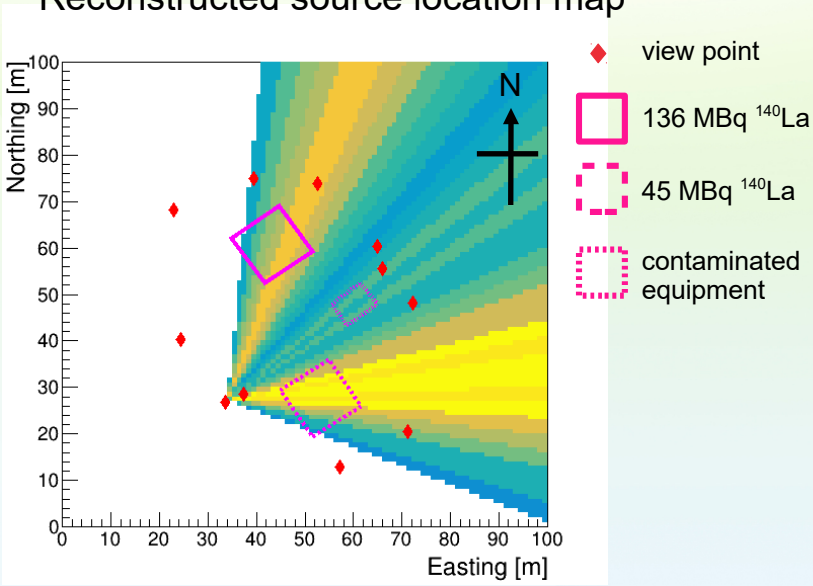
Medium dispersed-source trial



Assume source near horizon

Project the azimuth distribution at the horizon out across the field

Reconstructed source location map

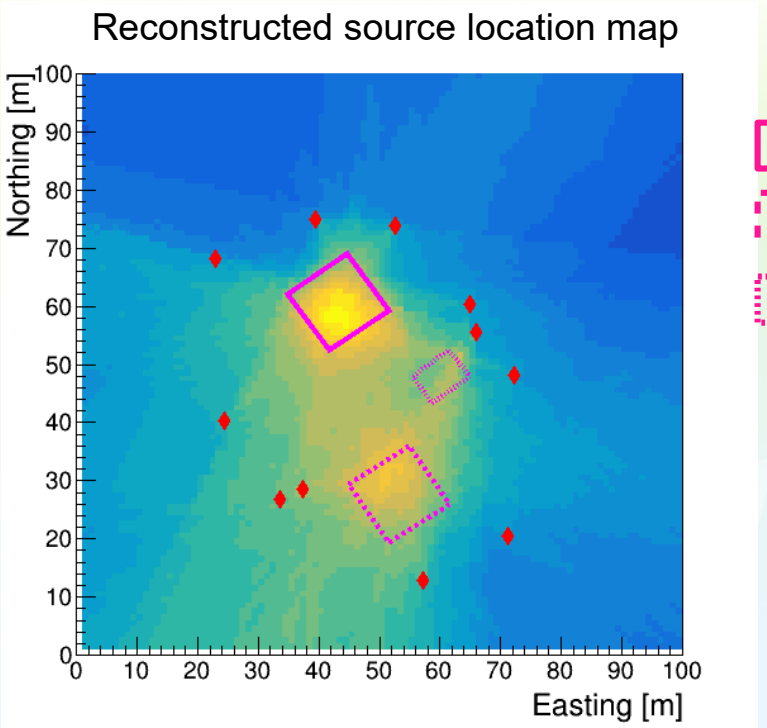


- From a single vantage point the presence of two, possibly three, sources in the distance near the horizon can be discerned.

real data

Medium dispersed-source trial

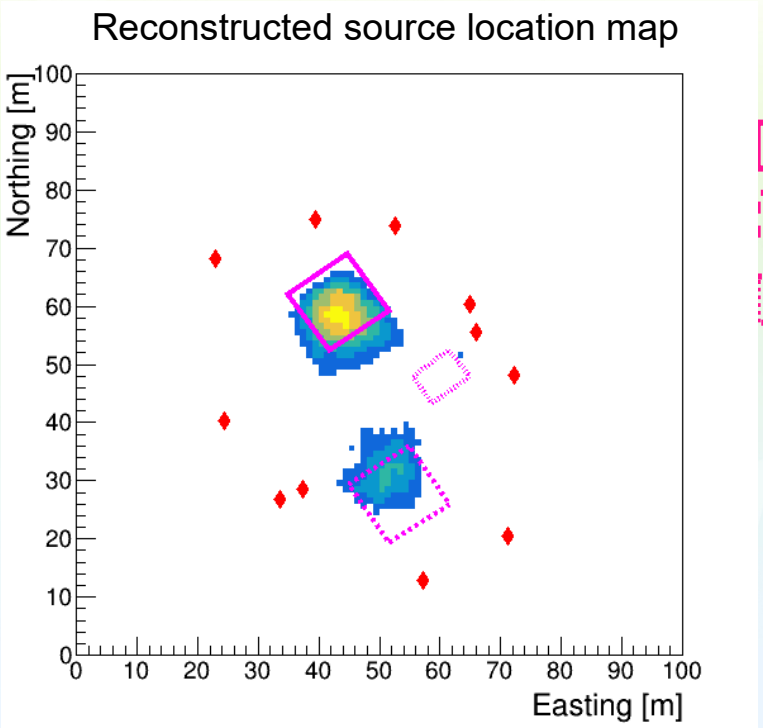
- Including all 15 vantage points:
  - the hot source location is clearly delineated
  - the weaker source presence is shown
  - a possible contribution from the contaminated equipment is suggested.



real data

Medium dispersed-source trial

- Thresholding at 60% of maximum can aid in recognizing the hotter locations



real data

Conclusions

- A high-sensitivity Compton gamma imager may be used in place of mobile radiation survey equipment to produce a map of radiation intensity
- A Compton gamma imager can show location and distribution of material in an access-denied zone from a single stationary vantage point
- Using a tomographic technique, the distribution of radioactivity within a restricted-access site may be reconstructed by measuring at multiple vantage points about the restricted-zone perimeter

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