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IAEA approach to support in-situ measurements and mapping for radiological characterization of sites

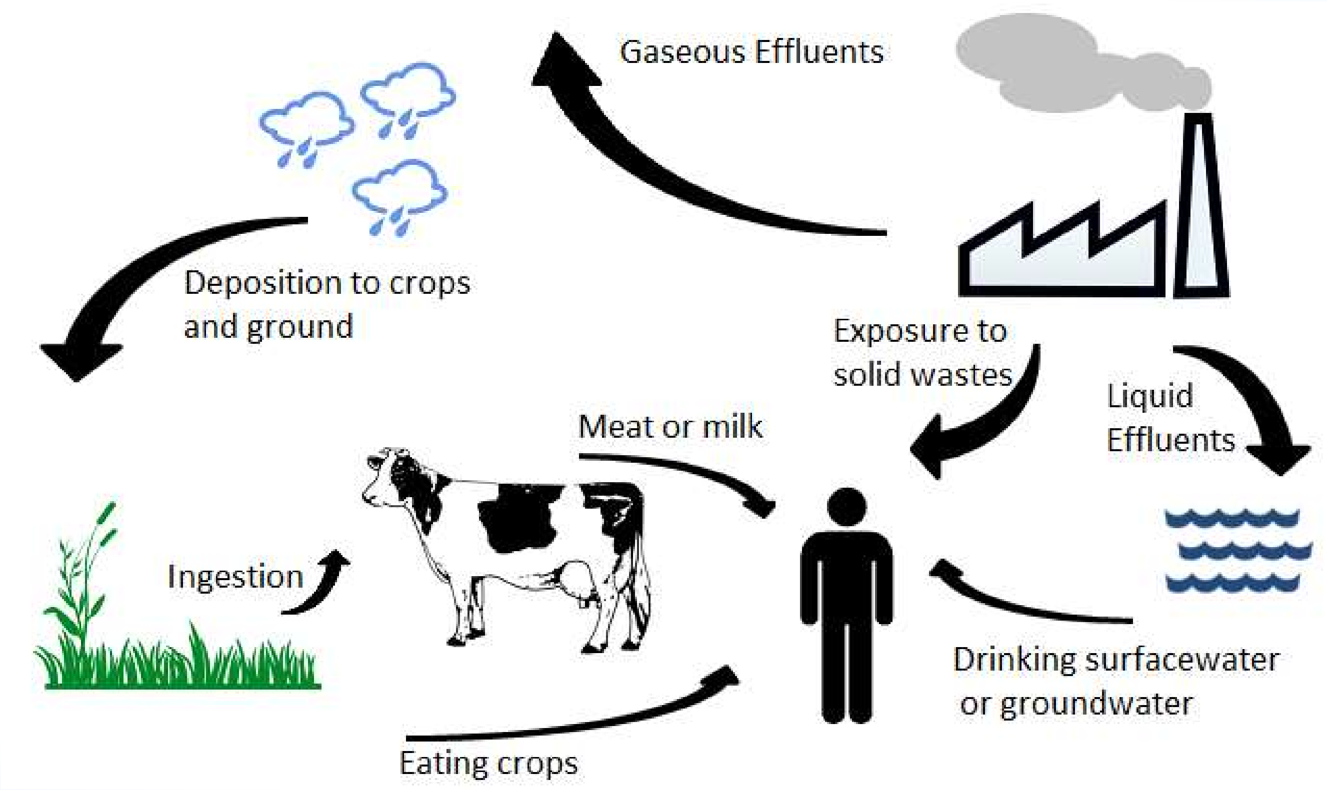
Roman Padilla Álvarez Petr Sladek
Nuclear Instrumentation Physicist
Division of Physical and Chemical Sciences,
Department of Nuclear Sciences and Applications

Outline

- Radiologically impacted sites
  - The needs for characterization
  - Site characterization: typical cases
  - Challenges
- Requirements to analytical support
  - Defining analytical requirements
  - Sampling problems
  - Analytical techniques (laboratory vs in-situ)
  - Rationale and advantages
- Description of methodologies used for field measurements
- Data representation and interpretation
  - Statistics, Creation of maps, Interpolation
- Situation in IAEA Member States and services provided by the IAEA

Needs for radiological characterization and monitoring

- Assessing the type, activity concentration and distribution of radionuclides, as well as exposure and dose in different scenarios



Typical scenarios

- Uranium or Thorium mining / milling sites
- Sites with increased amounts of NORM
  - mining of phosphate rocks, REE, bismuth, zirconium, titanium, oil, among others
- Sites affected by discharges (accidental or planned) of radionuclides
- Nuclear weapons test areas, Military sites
- Nuclear industry or other radiological facilities accidents
- Decommissioning projects

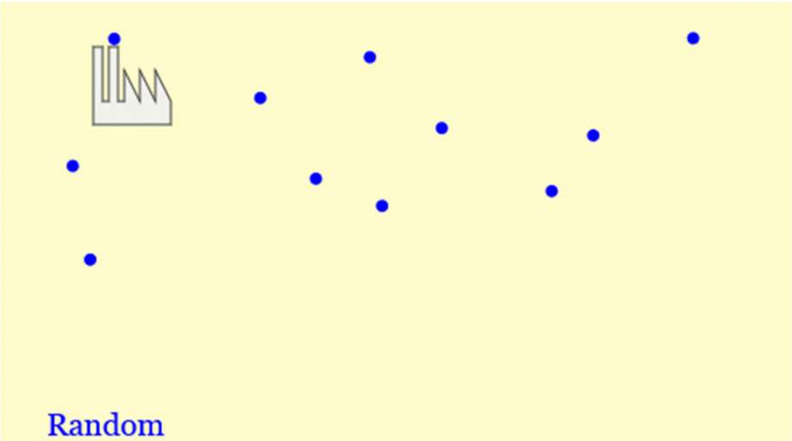
Challenges

- Samples may differ by composition and aggregation
- Heterogeneous spatial distribution of the Contaminants of Concern (COC)
- The concentration of COCs (abundance) is unknown
- Need to analyse different matrices (soil, water, biota, wastes)
- Large amount of samples required to evaluate the status and extent of the contamination

Requirements to analytical work

- Is there contamination (Y/N)
  - Trigging level against the values established by regulations
- How to assess the extent (spatial distribution) of the contamination?
  - Knowledge of previous activities + logic sampling campaign
- Accuracy required for the results…
  - High? Poor? Acceptable?
- Common needs/requirements:
  - To avoid misclassifications (false positives/ negatives)
  - To minimize hazardous exposure
  - To reduce costs
  - To shorten time delay for decision taking

Sampling and lab analysis?… or detector to the field?



- Easy validation of methods
    - High accuracy of each measurement result
- Uncertainty on sampling representativeness
- Long delay in obtaining results

- Fast collection of geo-referenced measurement results
    - Area surveyed by four people in 2.5 hours
    - 18.6 ha, Average Length of each of the followed Paths: 8100 m
- Capability of determining spatial distribution
- Difficult validation
    - 20% accuracy in results

A combination of both approaches optimizes the environmental assessment work!

Laboratory vs field measurements

Laboratory	Feature	Field (in-situ)
Solids, liquids	**Sample aggregation**	Solids, water, gaseous
Required	**Sub-sampling**	Not required
Up to 1	**Sample size (kg or L)**	10 - 100
Subject to sampling strategy	**Sample representativeness**	Volume / area size defined by energy of radiation
Minutes to hours	**Measurement time**	Seconds to minutes
0.5 – 5	**Relative accuracy (%)**	10 – 20
Moderate to High	**Costs**	Low to moderate

A combination of both approaches optimizes the characterization of sites!

The pro's of in-situ approach

- Is there contamination (Y/N)
  - Trigging level against the values established by regulations
    - Presence or not is unequivocable
- How to assess the extent (spatial distribution) of the contamination?
    - Knowledge of previous activities + logic sampling campaign
    - In-situ measurements can be obtained with linked GPS coordinates and time stamp
- Accuracy required for the results…
  - High? Poor? Acceptable?
- Common needs/requirements:
  - To avoid misclassifications (false positives/ negatives)
  - To minimize hazardous exposure
  - To reduce costs
  - To shorten time delay for decision taking

Advantages of in-situ measurements, summarized

- Compact instruments are easy to transport to remote locations
- Deployable in different ways (walk, car borne, UAV)
- Surface dose rate measurements in the field provide a fair indication of external exposure to living organisms
- Measured signal originates from a large volume sample
  - Measurement time can be significantly reduced as compared to sampling, followed by laboratory measurements
  - The measured values can be integrated over large volume or limited to smaller sampling analogue by proper collimation
  - Risks of missing relevant/representative points while doing spot sampling are avoided
- Large areas can be surveyed within short time
- Allow identifying sampling spots for laboratory analysis, if needed
- Combined with GPS recording allow producing informative maps

Methodologies for depth profile measurements

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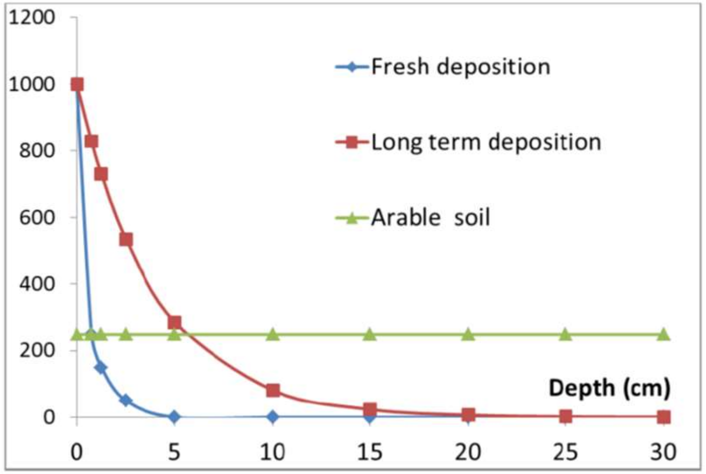
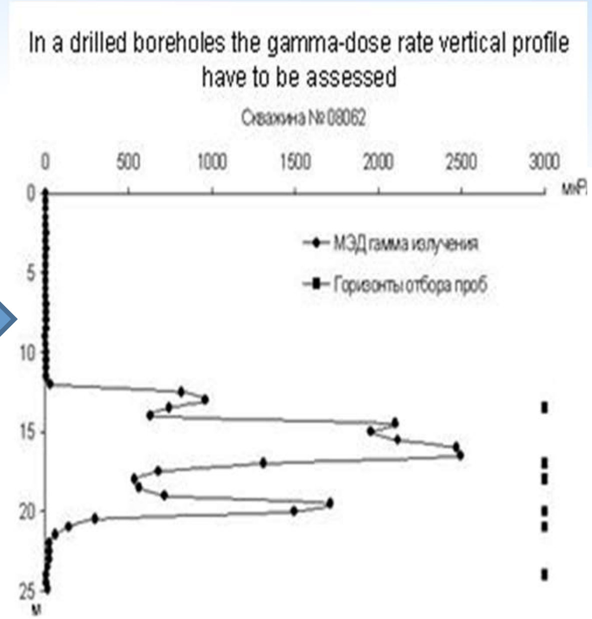




For laboratory:
Core sampling: ~ 5 to 20 cm each
(depending on intended further use of the site)

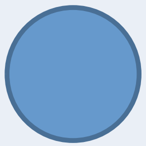
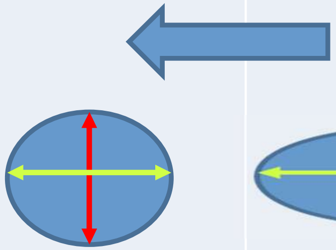
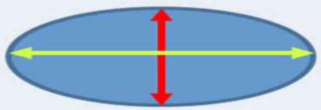
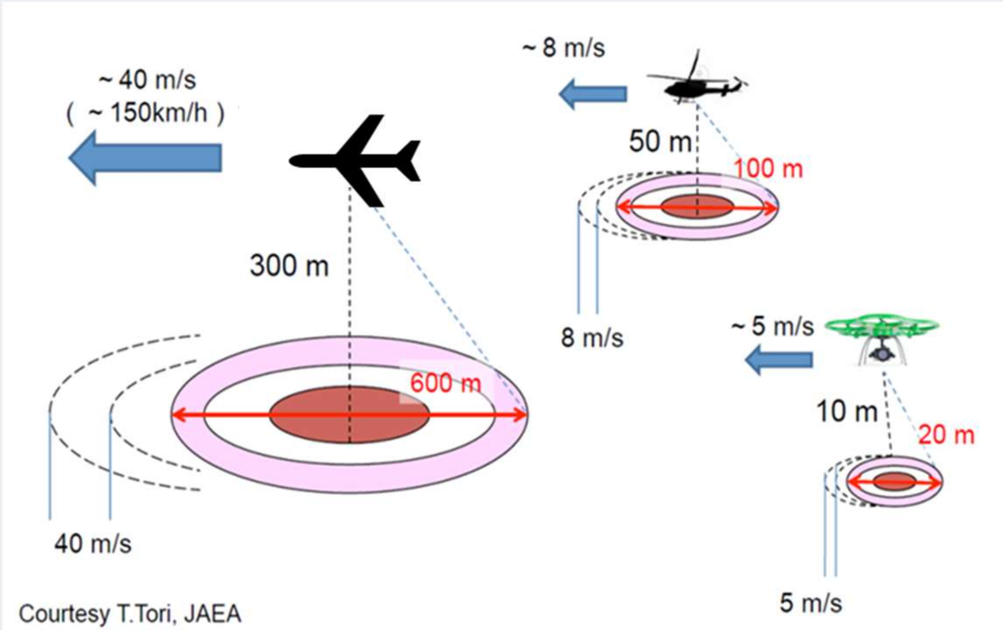
In-situ:
Bore hole measurements
~ 10 cm depth interval

Methodologies for surface measurements

Ground level				Aerial	
	Stationary	**Backpacks / HH**	**Car-borne (*)**	**Different platforms**	
				 	
Common detectors	HPGe Scintillator	Scintillators, GM, Ionization Chambers	HPGe, Large volume Scintill.	Arrangement of large crystal /plastic Scintillators	GM, Light weight Sc, CZT

(*) *Mike Davies et al 2007 J. Radiol. Prot. 27 A51,* https://doi.org/10.1088/0952-4746/27/3A/S07

Methodologies for surface measurements

	Ground level			Aerial		
	Stationary	Backpacks/ HH	Car-borne	Different platforms		
Data logging period T (s)	10 – 10^3	~ 5 to 10	~ 1 - 2	~ 1		~ 1
Distance to surface H (m)	1	1	~ 0.15	300 - 1000	50 - 100	10
Measured effective area	 d ~ 10 m	 Width ~ 10 m, Length = 10 + V*T	 Width ~ 3 - 4 m, Length = Width+ V*T	 Width ~ 2 H, Length ~ 2H + V*T		

V [m/s]. T [s]

GPS logging

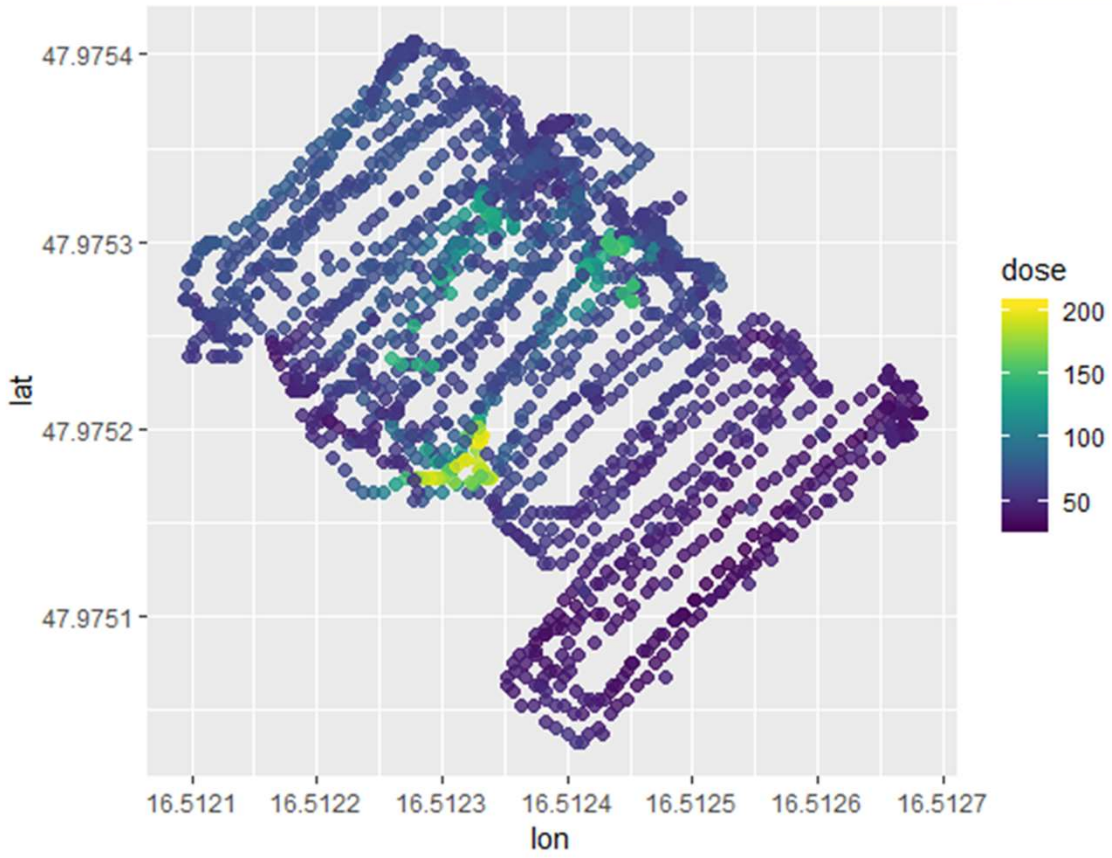
Accuracy in coordinate readings:

- For cheap devices
  - usually 3-5 m,
  - possible only in open areas
  - Affected by multiple reflections in proximity of buildings

- Choices for better accuracy
  - Down to cm reange
    - OmniStar: Satellite base augmentation system, requires subscription
    - Differential Global Positioning Systems (DGPS), using reference radio beacons, possible in non-open environments

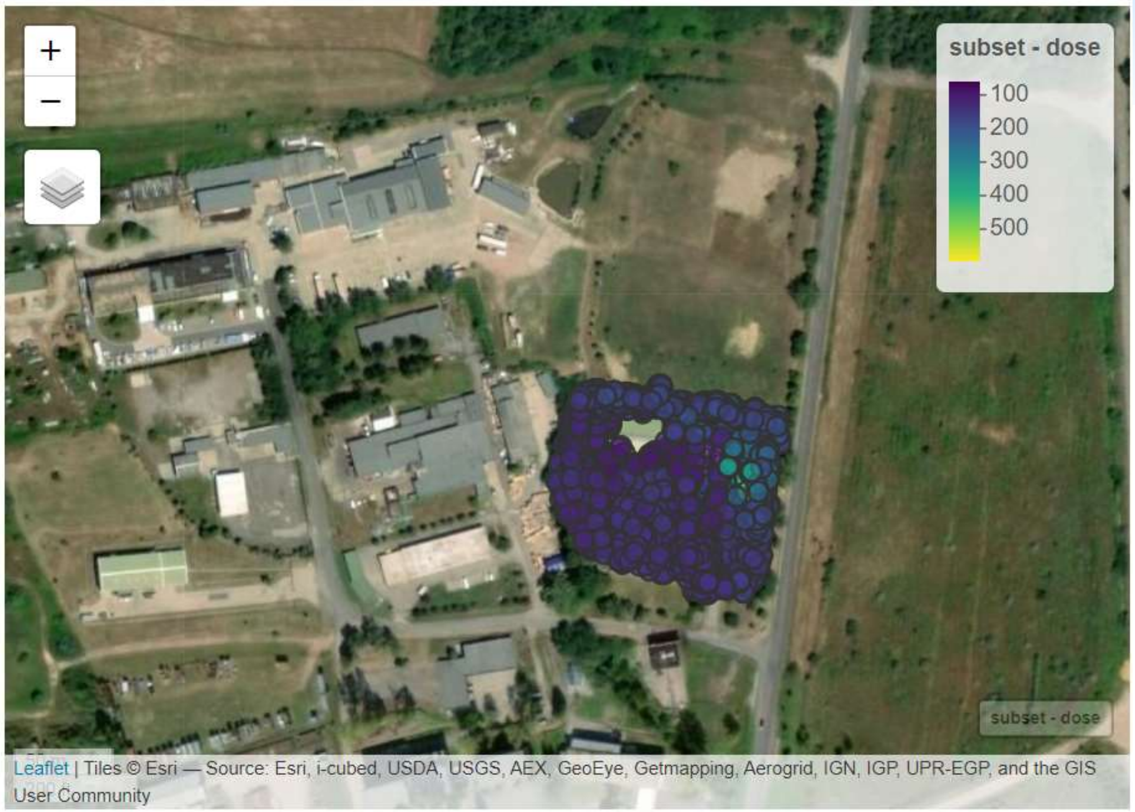
Data representation: Waypoints

- Simplest representation
  - Agree with end-user on colors to be used!
  - Select ‘warm’ colors depending on threshold levels to be verified



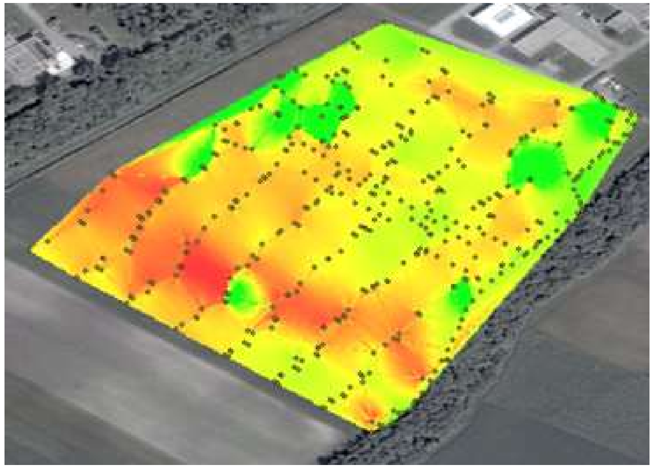
Data representation: Superposition of measurement results in maps

- Requires additional software
  - Proprietary or open source
- Maps available from proprietary sources or from Open Maps
- For using maps in reporting, verify copyright and license conditions

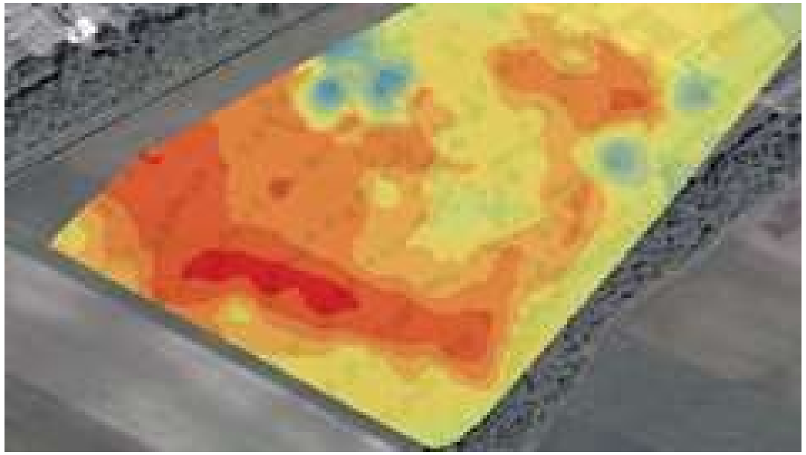


Interpolation

- Pursues to estimate the values in non-measured spots
- Several techniques are available
- Different software packages available



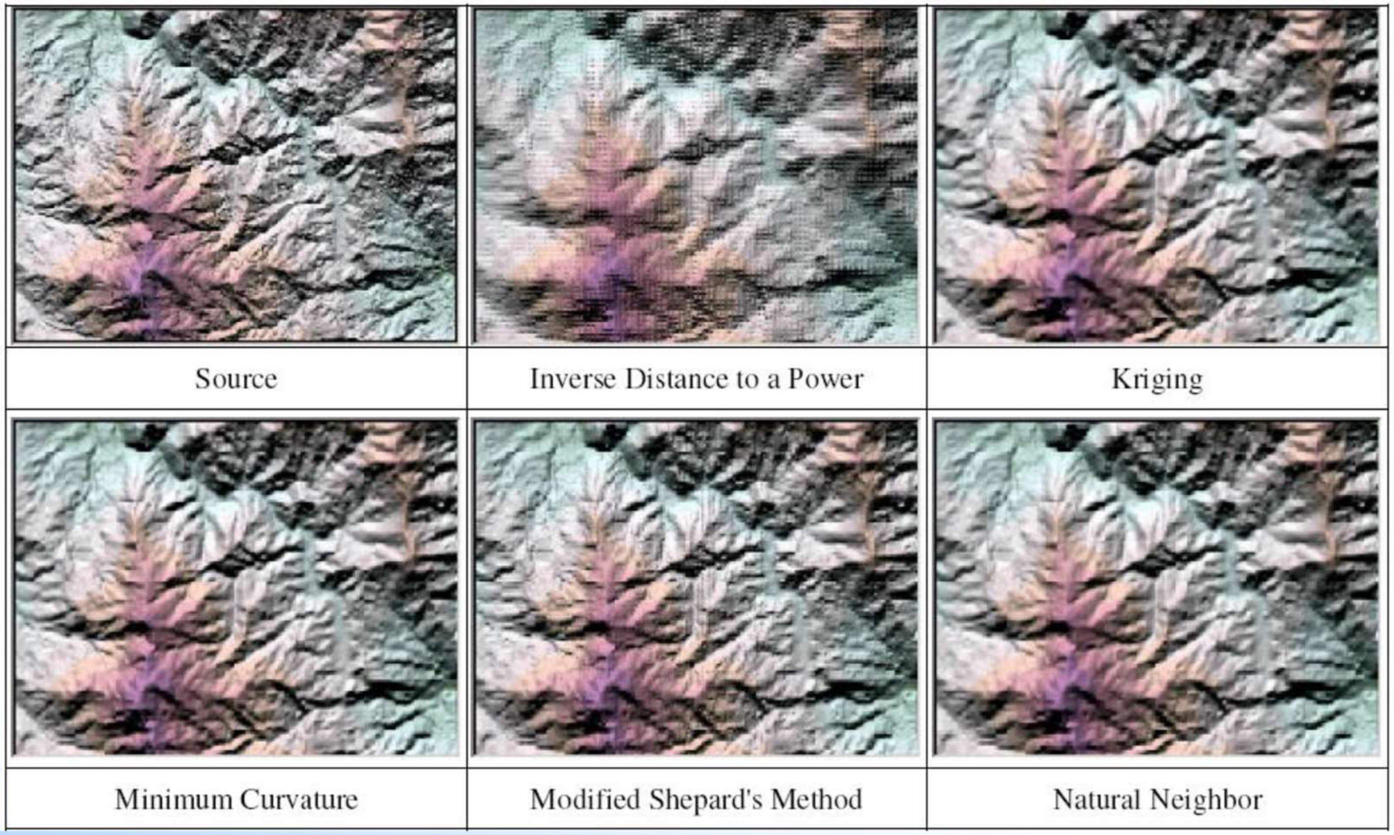
Natural neighbor interpolation:
Finds the closest subset of input samples to a query point and applies weights based on proportionate areas



Kriging: based on the regionalized variable theory, the spatial variability of measurement results is evaluated and can be used to statistically evaluate the uncertainty of prediction and to calculate probabilities of exceeding a given threshold

Comparison among different interpolation techniques:

- Source data: Altitude in digital terrain model (5 m grid)
- Data set was taken with a 40 m separation
- Interpolation was made as to create a 5 m grid



Current needs in IAEA Member States

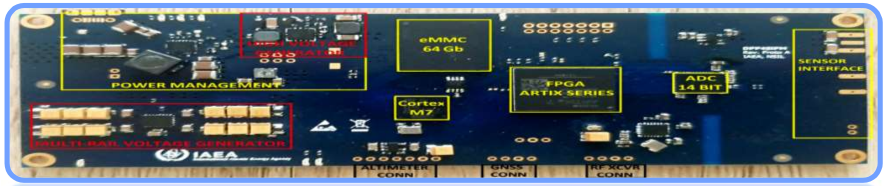
- There is an uneven level of experience and access to such techniques in the IAEA Members States
- The latter sometimes leads to characterization mainly based on laboratory-based measurements
- Need to provide comprehensive guidelines that can be used by the IAEA MSs in implementing site characterization works

Services provided by NSIL

- Development and testing of new detectors
- Characterization demonstrations
- Training activities
  - Fellowships / Scientific visits
  - Training Workshops
  - Technical and consultancy meetings
- Online resources at Nuclear Science and Instrumentation Portal
- R-tool data visualization, mapping and interpolation

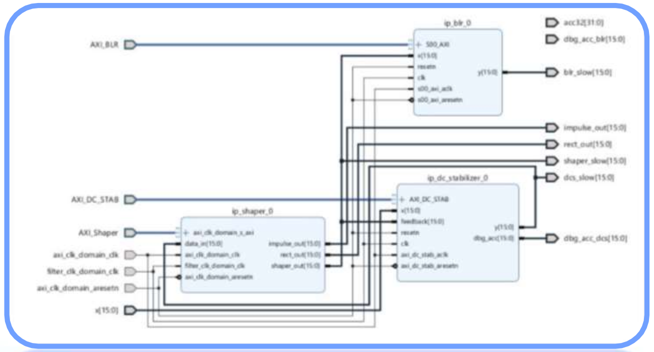
Development and testing of radiation detectors

Digital Pulse Processor for UAV (MCA)



Application of DPP Module on UAV

GNSS Antenna, Laser Altimeter,
RF Communication,



New Firmware for DPP

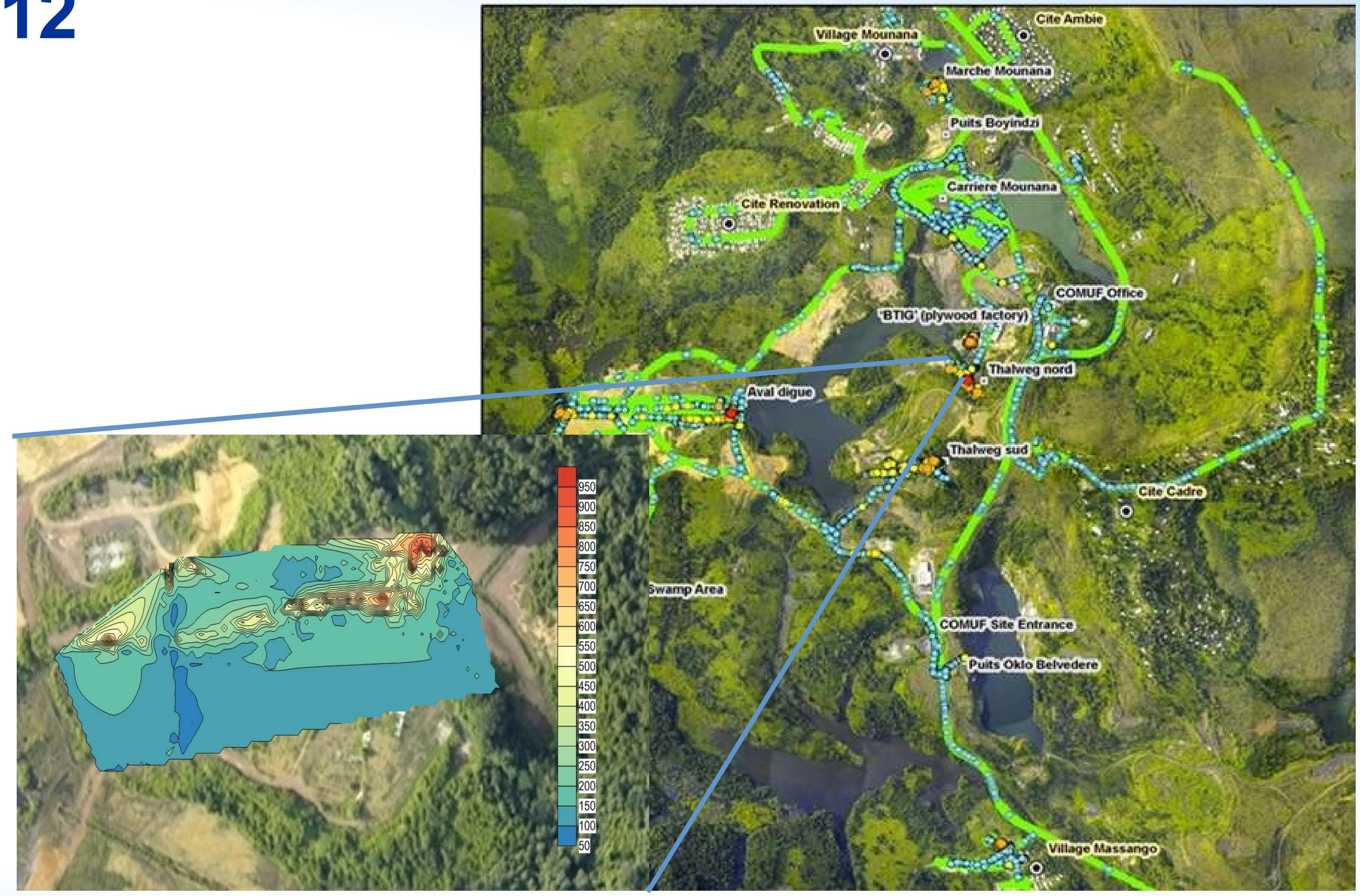
New Type of
SiPM Detectors

Demonstrations in countries

- Based on petitions originating from MSs
  - Implemented within Regular budget (NSIL)
  - As part of Technical Cooperation projects
    - Gabon (Remediated areas former Uranium mine and facilities), July 2012
    - Kyrgyzstan (Remediated areas former Uranium mine and facilities), May 2013
    - Kenya (Natural background measurements), June 2014
    - Azerbaijan (3 Remediated sites NORM in charcoal material+ 1 Waste storage area), November 2012 & September 2014
    - Mexico (NORM in oil fields), September 2014
    - Argentina (survey at a Uranium mine site) January 2016
    - Zambia (Uranium mine and facilities), April 2016
    - Japan (contaminated soil in containment areas), June 2016
    - Nepal (Co60 contaminated steel material found in public area), November 2016
    - Indonesia (NORM wastes/residues from the mining and processing of tin ores), December 2017
    - Uzbekistan (RR site after the radioactive waste disposal), June 2018
    - Brazil (Demonstration of UAV capabilities), 2019
    - Japan (assisted survey at contaminated soil temporary storage sites), July 2020
    - Lebanon (survey at metal scrapyard sites, after explosion accident), September 2020

Gabon:
Remediated areas in former Uranium mine and facilities), July 2012

Dose rate (nSv/h)	Number of measurements	(%)
< 114	61 267	56.7
114 - 250	24 771	22.9
250 - 500	11 660	10.8
500 - 1140	5 283	4.9
1140 - 10400	5 036	4.7

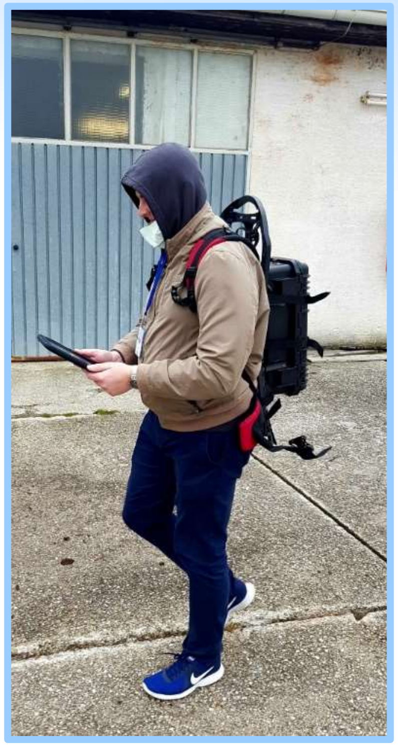


Training on use of portable detectors

RSS-131
High Pressure
Ionization Chamber

μ-DETECTIVE
HPGe In-Situ Gamma
Spectroscopy System

AEGIS
HPGe In-Situ Gamma
Spectroscopy System



PGIS (Upgrade)
Backpack Gamma
Spectrometer

Training workshops

- Joint ICTP-IAEA Workshop on Environmental Mapping: Mobilising Trust in Measurements and Engaging Scientific Citizenry, ICTP, Trieste – Italy, March 2017 (28 participants from 23 countries).
- Training Workshop on Testing and Evaluation of Spectrometric Handhelds (in coop with Nuclear Security Department), June 2018, Seibersdorf, Austria (35 participants from 18 countries)
- Training Workshop on In-situ measurements and mapping, November 2018, Seibersdorf, Austria (in cooperation with TEL, 9 participants from 9 countries)
- Training Workshop on In Situ Characterisation of Contaminated Sites and Environmental Monitoring and Mapping, May 2019, Pecs, Hungary (in cooperation with TEL concurring Training Course, 40 participants from 29 countries).
- **Joint ICTP/IAEA Workshop on Advanced Solutions for Field Measurements (SMR 3729), Trieste, 8-19 August 2022**

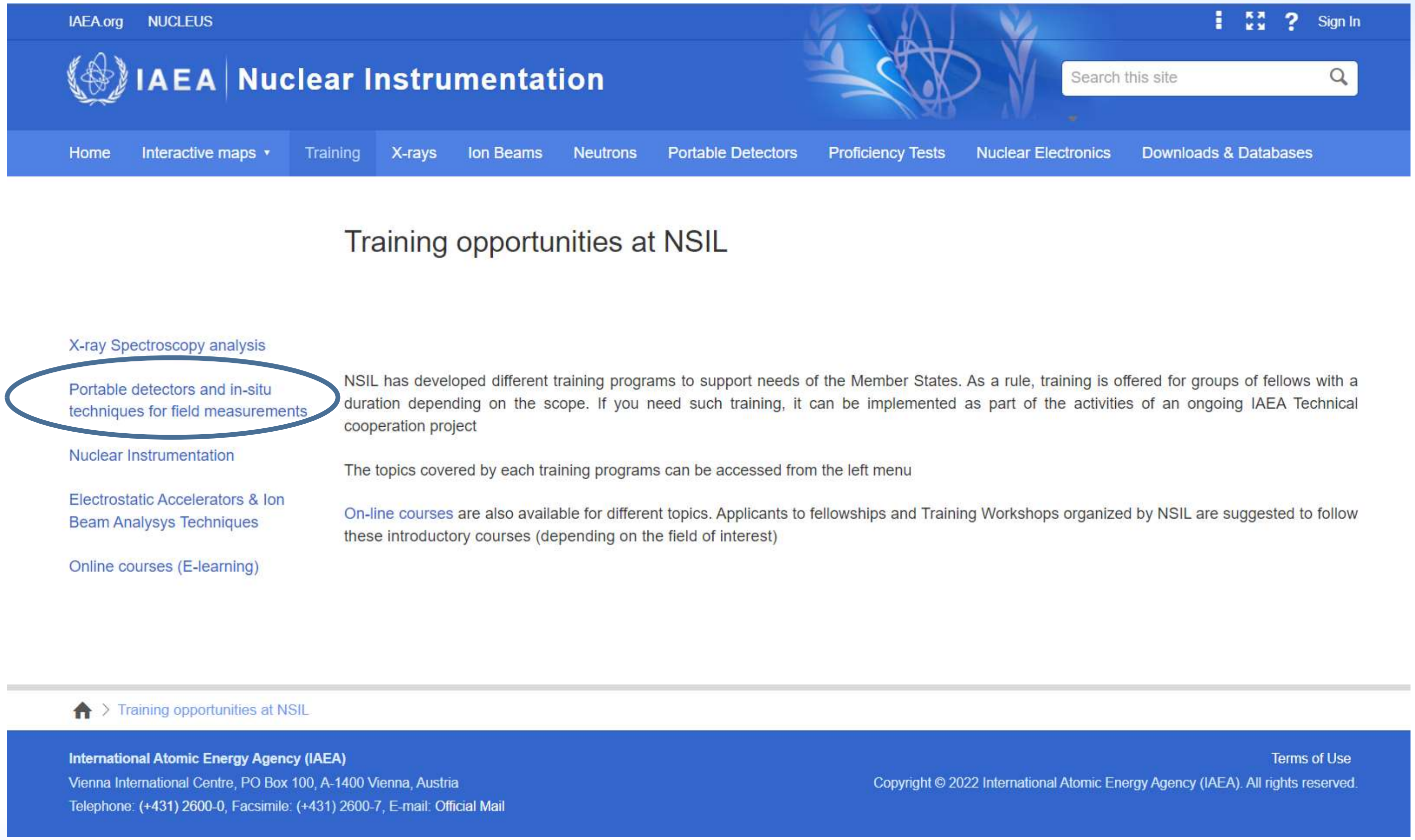
Technical and consultancy meeting

- Consultancy meetings
  - Creation of the WG, November 2013, Vienna, Austria
  - Drafting a Technical report with recommendations, May 2015, Vienna, Austria
  - Development of a Curriculum for Environmental Mapping Training Activities, December 2017, Vienna, Austria
  - Forecast of future activities, October 2019, Thurso, UK
  - …

- Technical Meetings
  - Workshop to outline the training programmes, November 2014, Vienna, Austria
  - TM on Environmental Monitoring Programmes, November 2015, IAEA, Vienna
  - TM on Current Trends and Developments in Nuclear Instrumentation, December 2018, IAEA, Vienna
  - TM on the Use of Unmanned Aerial Vehicles for Radiation Detection and Surveillance, Czech Republic, 2021

Online resources

- Nuclear Science and Instrumentation Portal
  - E-learning
  - Lectures
  - Practical demonstrations
  - Download of R-tool



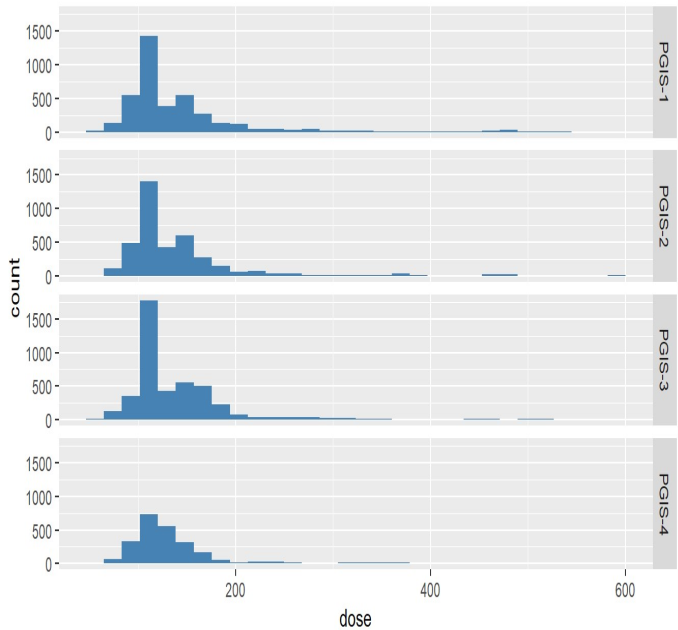
Interpolation using R

- An R-based tool has been developed at NSIL for data interpretation and production of maps, available for download from Nuclear Science and Instrumentation Portal
  - R free software environment for statistical computing and graphics has been used by a large community of Statisticians and data analysts for decades.
  - R’s killer feature is its extremely rich ecosystem of library/packages allowing to perform (among others): Statistical analysis, modelling, data cleaning, data transformation & visualization, machine learning, deep learning, GIS, Geospatial Analysis
- The R-markdown includes commented instructions guiding to the use of ‘chunks’ allowing to perform common tasks

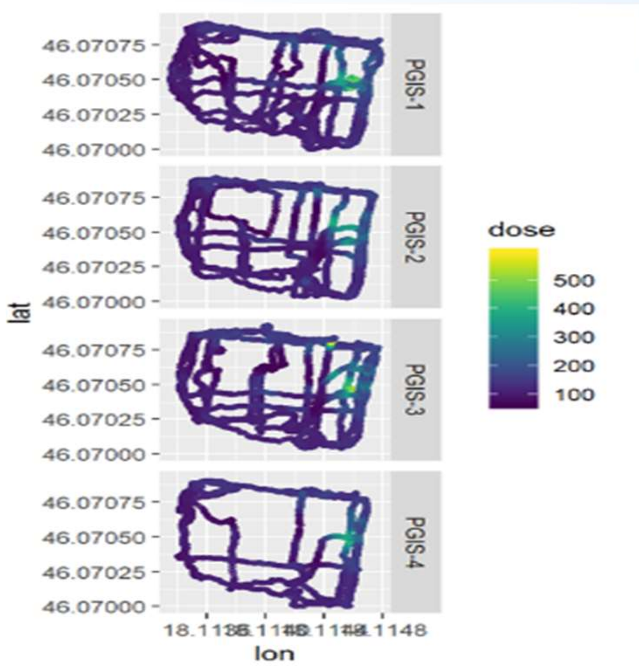
https://nucleus.iaea.org/sites/nuclear-instrumentation/Software/Forms/AllItems.aspx

Description of the R-markdown functionalities

- Exploratory data analysis
- Data cleaning, subsampling



a) Histograms of measurement results

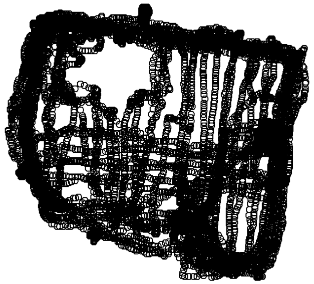


b) Measurement paths

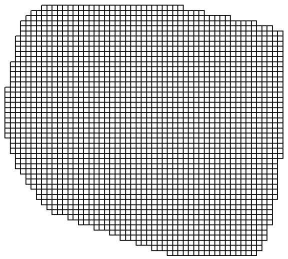
Consolidation of measurement results obtained with four different instruments

Description of the R-markdown functionalities

- Mapping (pathways, hot spots, interpolation with uncertainty, probability maps
- Generation of reports in various formats (including HTML and the possibility of interactive use of maps)

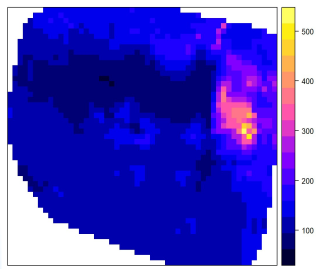


Measurement points

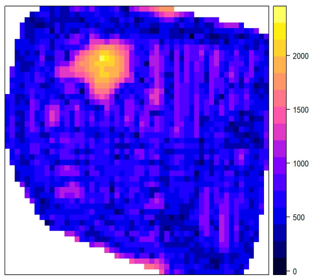


Interpolation Grid
Size: 109 x 101 m
density: 2 m

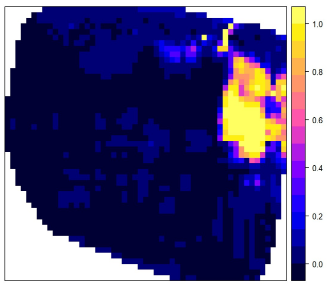
Representation using
ESRI maps



Interpolated results
(nSv/hr)



Uncertainty of
interpolation
(variance)



Probability of exceeding
A value (200 nSv/hr)

Conclusions

- In-situ techniques are:
  - An advantageous tools for screening, measurement of complex objects, assessing spatial distribution in diverse scenarios
  - Important tools in reducing the costs and time delays in site characterization
- A diversity of approaches and detectors can be used
- MonteCarlo assisted calibration of HPGe detectors allows measurement of complex geometries
- When data is collected with GPS coordinates, results can be depicted in maps and interpreted

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Thank you!