Uncertainty Assessment by Latin Hypercube Sampling for *In Situ* Gamma Spectrometry

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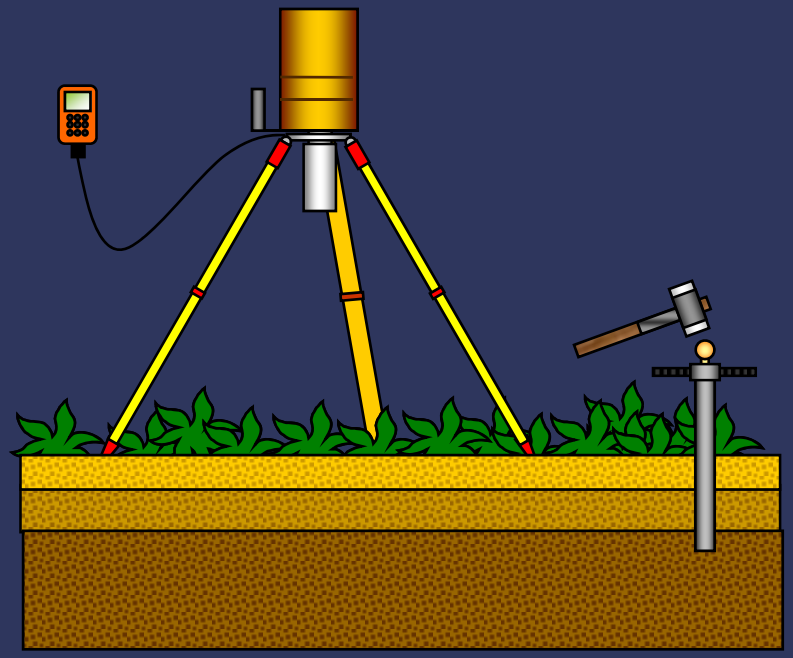
In Situ Gamma Spectrometry



- Measurements performed at the source – e.g. to determine activity inventory in/on ground
- An efficient method to assess activity ground deposition over relatively large areas
- Important method in the event of an accidental release or fallout of radionuclides into the environment

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In Situ Gamma Spectrometry

- Requires some knowledge or assumption about activity depth distribution and/or ground roughness and vegetation
- Relatively large and poorly known uncertainties → poor basis for decision making → possibly high costs for society
- Uncertainties of *in situ* gamma spectrometry often disregarded

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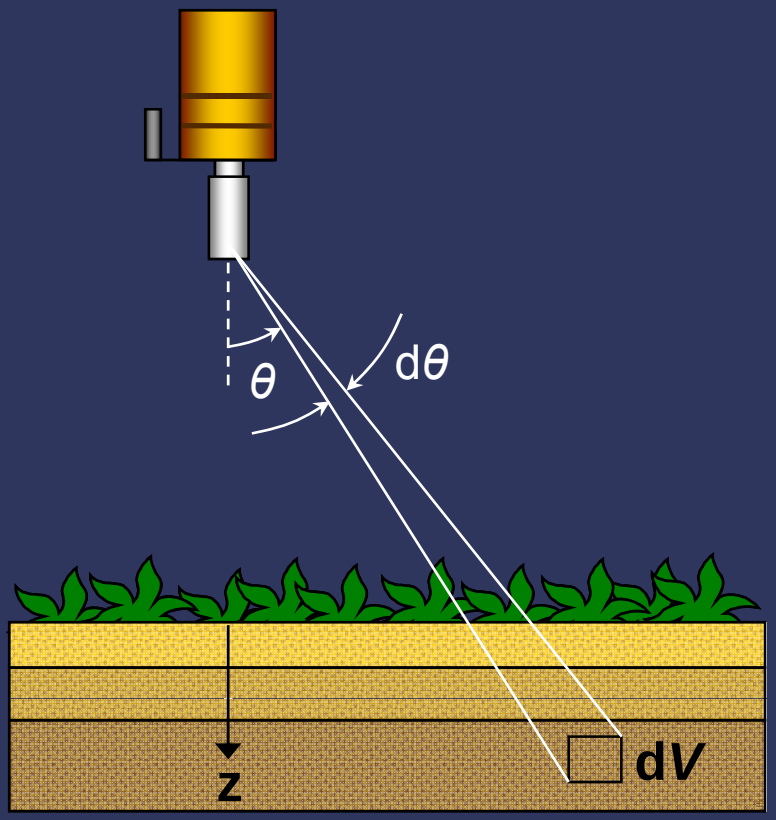
Semi Empirical Calibration



- The intrinsic detector efficiency, as a function of photon energy and angle of incidence, is determined empirically using point sources
- Expression for the contribution to the photon fluence at the detector from a volume element dV is numerically integrated over the entire volume of the source.
- Three-layer model

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Semi Empirical Calibration

- The final expression for the detection efficiency becomes

$$\frac{\dot{N}}{A_S} = \sum_i \frac{p(E)\, a_i}{2d_i} \iint \varepsilon(E,\theta)\tan(\theta) C_{tot}^{i} \mathrm{d}u_i \mathrm{d}\theta$$

where the intrinsic detector efficiency is

$$\varepsilon(E,\theta) \equiv \left(\frac{(k_1\theta + m_1)}{E} \right)^{(k_2\theta + m_2)}$$

and the total attenuation is

$$C_{tot}^{i} = \exp\left(-\mu_{air} \left(\frac{H}{\cos(\theta)} \right) \right) \exp\left(-\mu_{soil} \frac{u_i}{\cos(\theta)} \right) \prod_{n=1}^{i-1} \exp\left(-\mu_{soil} \frac{d_n}{\cos(\theta)} \right)$$

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Intrinsic Detector Calibration

- The uncertainty in the intrinsic detector calibration have been previously assessed (using GUM Workbench) and found to be 5 and 8% (1σ) for two of FOIs detectors.
- By the implementation of a new expression for the intrinsic detector efficiency this uncertainty can be reduced to about 4 %

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Combined Uncertainty

- Analytical propagation of uncertainty contributions from the source and attenuation difficult due to the complex expression
- Monte Carlo methods possible, but time consuming – a very large number of samples may be required to ensure sufficient sampling of the entire parameter space
- LHS (McKay et al, 1979) is a suitable alternative

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Latin Hypercube Sampling

- Instead of simple random sampling, each parameter distribution is divided into N equal strata
- One value sampled at random from each stratum
- Values from all parameters paired together randomly into N input vectors
- N results calculated
- The dispersion of the N results provides a measure of the uncertainty in the measurand
- LHS can handle any type of parameter distribution

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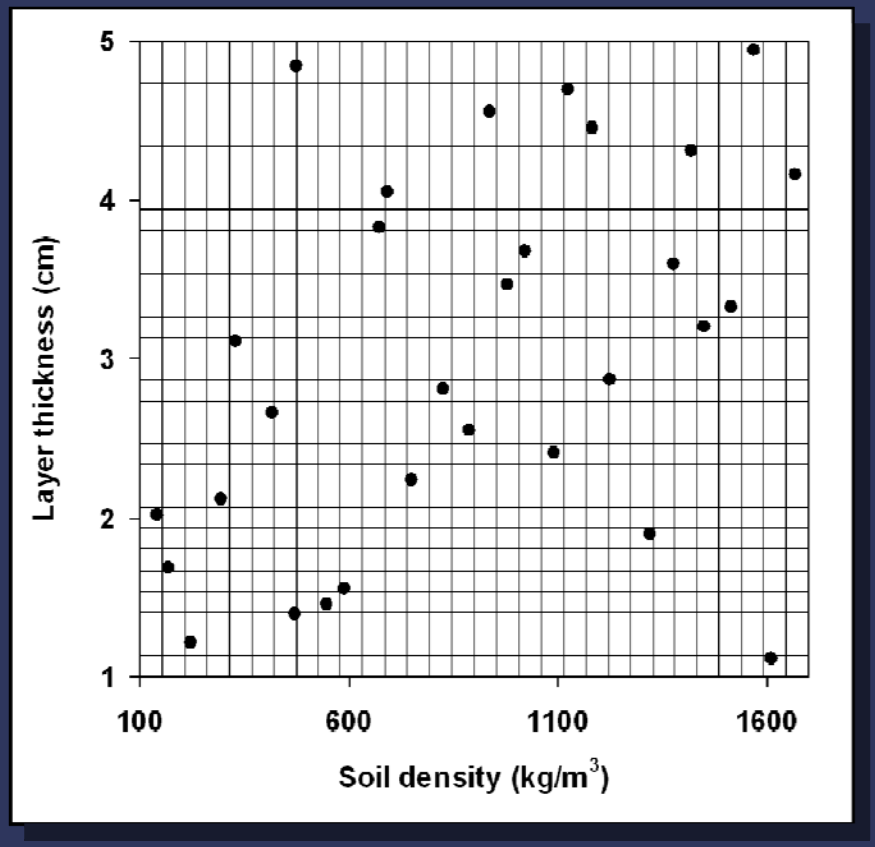
Example - Fresh Fallout

- Assumption:
  1 layer, 2 cm thick and with density 500 kg/m^3, containing all activity
- Source uncertainties:
  $1 < d < 5$ cm
  $100 < \rho < 1700$ kg/m^3
- Resulting uncertainty:
  ≈ 30-35 % (1σ)



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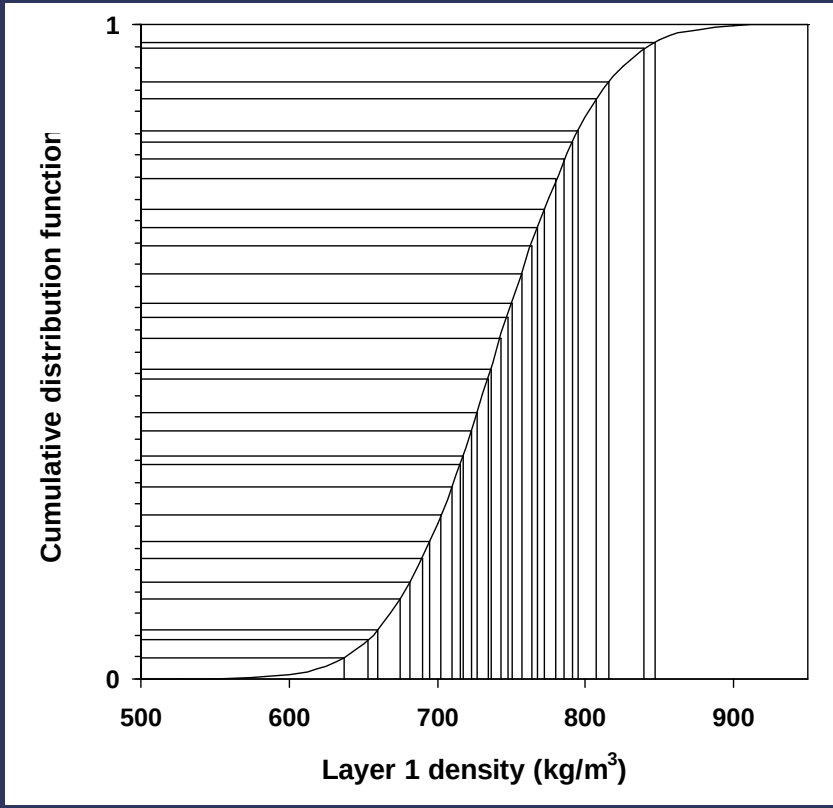
Example - Chernobyl ^{137}Cs today

- Three-layer model based on data from 17 soil samples
- Uncertainties:
  Intrinsic eff: 8%
  Densities: 4-8%
  Thicknesses: 3-14%
  Rel. activities: 10-26%



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Example - Chernobyl ^{137}Cs today

- Estimated uncertainty about 11% (1σ)
- Contribution from intrinsic detector efficiency about half of the combined variance

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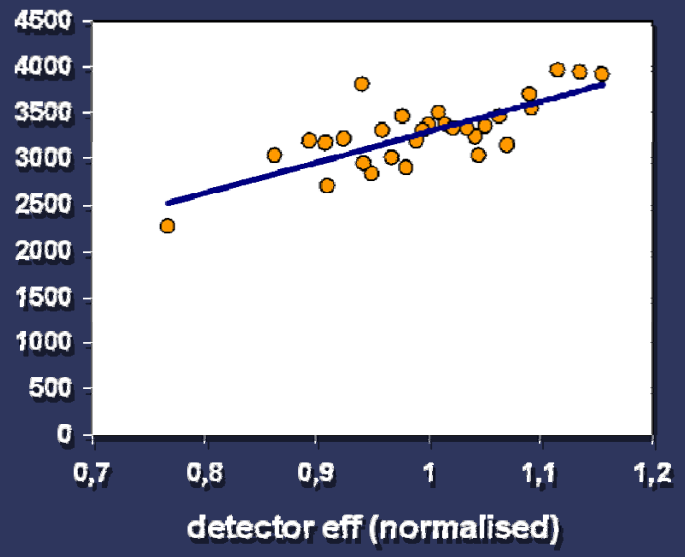
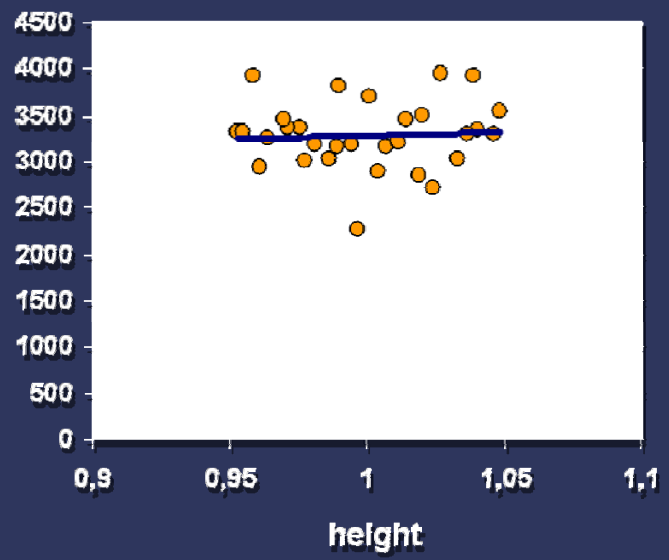
Further possibilities

- LHS enables the calculation of a complete uncertainty budget for *in situ* gamma spectrometry measurements.





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