Geostatistical mapping of CS-137 contamination depth in building structures by integrating ISOCS measurements of different spatial supports

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Overview

- Introduction
- Measurements
- Geostatistics
- Decontamination
- Conclusions
Existing studies using geostatistics for radiological evaluation
- Deal with surface activity
- Use measurements with a constant spatial support (most cases)
- Quantify the spatial structure and provide risk maps
- Try to provide guidelines for sampling optimization

Desnoyers et al. 2011

Desnoyers & Dubot 2012
**Introduction**

- Existing studies using geostatistics for radiological evaluation
  - Deal with surface activity
  - Use measurements with a constant spatial support (most cases)
  - Quantify the spatial structure and provide risk maps
  - Try to provide guidelines for sampling optimization

- We present a methodology that
  - Uses measurements to quantify the contamination depth (which is proportional to waste volume)
  - Integrates different support volumes to get
    - complete coverage
    - smaller-scale details
• Decommissioning Belgian Reactor 3

• Floor of the waste gas surge tank room (18.4 m²)

• Well shielded, isolated room, used as temporary storage of highly activated and contaminated components

• Floor composition
  • Surface epoxy layer (5-11 mm)
  • Mortar
  • Concrete (at 34-42 mm)

• Background radiation ~ µSv/h

• Hotspots ~ $10^2$ µSv/h

• Key radionuclide = Cs-137  Boden & Cantrel 2007
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In Situ Object Counting System
- High purity germanium detector with shielding and collimators
- Various core samples from the BR3 building → exponential depth distribution
- Multiple photo peak method
  - Count rate ratio of the 32 keV + 662 keV peaks
- Contamination depth is defined as depth where activity concentration < 100 Bq/dm²

Measurements

Dewey et al. 2011
\[ A_S(z) = A_S(0) \times e^{-\frac{z}{\bar{R}L}} \]

Rybacek et al. 1992
\[ R(RL) = \frac{n_1}{n_2} = \frac{a d + 1/RL}{c b + 1/RL} \]

Canberra Industries 2003
Measurements

- **A**: Floor & measurement supports
- **B**: Large-scale ISOCS results (~106 dm²)
- **C**: Small-scale ISOCS results (~16 dm²)
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Geostatistics

Variography

Experimental semivariogram

\[ \gamma^*(h) = \frac{1}{2n} \sum [g(x) - g(x + h)]^2 \]

Exponential semivariogram model

\[ \gamma(h) = (s - n)(1 - \exp(-h/a)) + n \]

Goovaerts 1997
Overview

- Introduction
- Measurements
- Geostatistics
  - Variography
  - *Spatial support*
  - Simulations
- Decontamination
- Conclusions
- Averaging over a support volume
  - Variance decreases
  - Correlation length increases
- From circle to point to square
- For simulations we need a point-scale variogram
- Block error estimate to represent averaging uncertainty: initially 1%

Sensitivity study revealed consistent results

\[ a = a_1 - l \]
\[ s = s_1 / \left( 2 \left[ \frac{a}{l} - \frac{a^2}{l^2} (1 - e^{-l/a}) \right] \right) \]

ISOCS
- ~106 dm²
- ~16 dm²
- ~9 dm²

Clark 1979

Clark 1977

Low energetic
High energetic
Overview

- Introduction
- Measurements
- **Geostatistics**
  - Variography
  - Spatial support
  - *Simulations*
- Decontamination
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http://sgems.sourceforge.net/

- Free
- State-of-the-art algorithms
- Some scripting capabilities
Geostatistics Simulations

1. Point support simulation [bssim/besim]
2. Upscaling to decontamination support [kriging]
3. Risk mapping [Postsim]
Point support simulation [bssim/besim]

Liu & Journel 2009

- Script to write SGeMS blockdata format for circular supports

Upscaling to decontamination support [kriging]

Risk mapping [Postsim]
• Realizations of contamination depth (mm)
• Conditioned on
  • Point-scale variogram
  • All ISOCS measurements
Geostatistics
Simulations

Circles

Point support simulation
[bssim/besim]
Liu & Journel 2009

Points

Upscaling to decontamination support
[kriging]

Risk mapping
[Postsim]
Geostatistics Simulations

Circles

Point support simulation
[bssim/besim]
Liu & Journel 2009

Points

Upscaling to decontamination support
[kriging]
Deutsch & Journel 1992

Squares

Risk mapping
[Postsim]

• R script to write
  SGeMS blockdata format
  for square supports
From point-scale realizations
From point-scale realizations

To decontamination-scale realizations
Geostatistics Simulations

Circles

Point support simulation [bssim/besim]
Liu & Journel 2009

Points

Upscaling to decontamination support [kriging]
Deutsch & Journel 1992

Squares

Risk mapping [Postsim]
Geostatistics Simulations

- Point support simulation (bssim/besim)
  - Liu & Journel 2009

- Upscaling to decontamination support (kriging)
  - Deutsch & Journel 1992

- Risk mapping (Postsim)
  - Remy et al. 2009
Postprocessing of 50 realizations

Probabilities of exceeding:
- A: 5 mm
- B: 10 mm
- C: 15 mm
- D: 20 mm
- E: 25 mm
Overview

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- Decontamination
- Conclusions
Overview

- Introduction
- Measurements
- Geostatistics
- **Decontamination**
  - *Decontamination plan*
  - Laser + control measurements
  - Cost benefit
- Conclusions
Decontamination
Decontamination plan

- **Area I**
  - depth of about 5 to 10 mm
  - remove epoxy layer
- **Area II**
  - depth of about 20 to 25 mm
  - remove epoxy layer and part of mortar layer
- **Area III**
  - depth of about 35 to 40 mm
  - remove epoxy layer and mortar layer
• Introduction
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• Geostatistics

• Decontamination
  • Decontamination plan
  • Laser + control measurements
  • Cost benefit

• Conclusions
Decontamination

Laser + control measurements

- Hand held scintillator measurements after first treatment
- Second iteration was necessary for four areas
- Afterwards everything below release level Cs-137: 100 Bq.dm$^{-2}$
- Removal of material for non-radiological reasons

Wall fracture?

Drain grate!
Overview

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  - *Decontamination plan*
  - *Laser + control measurements*
  - *Cost benefit*
- Conclusions
Proposed methodology allows for ~35% reduction of waste volume

Difference with the traditional approach is just the press of a button, since the algorithms can be automated

<table>
<thead>
<tr>
<th>Method</th>
<th>Volume Removed (m³)</th>
<th>Compared to traditional method (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traditional: max contamination depth + SF</td>
<td>0.83</td>
</tr>
<tr>
<td>2</td>
<td>Decontamination plan (theoretically; but additional iteration might be required)</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>Decontamination plan (in practice)</td>
<td>0.60</td>
</tr>
<tr>
<td>4</td>
<td>Decontamination plan (in practice; excl. removal for non-radiological reasons)</td>
<td>0.55</td>
</tr>
</tbody>
</table>
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Conclusions

- Subsequent geostatistical down- and upscaling risk mapping & decontamination plan
- General picture was accurate, additional treatment was required for several spots, clearly identifiable on the provided maps
- Point-scale estimates remain problematic due to the remaining uncertainties
- Estimated ~35% waste volume reduction compared to more traditional conservative approach
- Recommendations
  - Large-scale ISOCS: achieve full coverage of an area
  - Small-scale ISOCS: if higher detail (depth + location) is needed

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References

- S.C. Dewey et al., 2011, A method for determining the analytical form of a radionuclide depth distribution using multiple gamma spectrometry measurements, *Journal of Environmental Radioactivity*
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Questions?