Mapping inside nuclear installations: developments & progress within the MetroDecom project

Doru Stanga, (IFIN-HH), Johan Sand (TUT), Thierry Branger (CEA), & Sven Boden (SCK•CEN)
Some questions regarding mapping in nuclear installations in view of D&D

- What is the most frequently used measurement equipment in D&D? Is it traceable, accurate, reliable?

- Can alpha contamination be easily visualized in nuclear installations? Would it be possible in daylight conditions?

- Could a new compact gamma camera provide us reliable information regarding dose rate when several sources are present?

- Would it be possible to define an effective decontamination plan of a contaminated concrete structure, mainly based on NDA? What would be the number of sampling points?
Task 1.1: Mapping inside nuclear facilities

Topics overview

- **Surface Beta Contamination**
  improve traceability & accuracy of measurements

- **Alpha Imaging**
  develop UV based stand-off detection methods for detecting & monitoring

- **Gamma Imaging**
  realise response characteristics of the quantitative performances of the GAMPIX gamma camera (lab conditions & selected decommissioning sites)

- **Contaminated Concrete Surface**
  execute & examine case study: see separate presentation on Wednesday 12 October 2016 (Stakeholders engagement)
Surface beta contamination

Doru Stanga and Marco Capogni

National Institute of R&D for Physics and Nuclear Engineering-Horia Hulubei, IFIN-HH, P.O.Box MG-6, Bucharest-Magurele, R-077125, Romania

Instituto Nazionale di Metrologia delle Radiazioni Ionizzante, ENEA, C.R. Casaccia, P.O. Box 2400, I-00100 Rome, Italy
ISO 7503-1:2016 (Measurement of radioactivity -- Measurement and evaluation of surface contamination -- Part 1: General principles) does not provide:

1. Methodology for estimating the efficiency of contamination sources. It only provides conservative values of the activity per unit area of contamination sources
2. Methodology for evaluating the uncertainty in surface contamination measurements

High technology contamination monitors need highly advanced methods for evaluating surface contamination
A novel method for the activity measurement of large-area beta reference sources was validated using Co-60 and Cs-137 large-area sources constructed from anodized aluminum foils. The validation of the method was performed by comparing the measurement results obtained by gamma spectrometry and the novel method.

<table>
<thead>
<tr>
<th></th>
<th>Co-60</th>
<th></th>
<th></th>
<th>Cs-137</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Λ (Bq)</td>
<td>u(Λ) (Bq)</td>
<td>u(Λ)/ Λ (%)</td>
<td>Λ (Bq)</td>
<td>u(Λ) (Bq)</td>
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<td>Gamma spectrometry</td>
<td>1641</td>
<td>37</td>
<td>2.2</td>
<td>2335</td>
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<td>Novel method</td>
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<td>32</td>
<td>2.0</td>
<td>2287</td>
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<td></td>
<td>Certified values</td>
<td>1648</td>
<td>41</td>
<td>2.5</td>
<td>2337</td>
</tr>
</tbody>
</table>
Surface beta contamination monitoring
Achievements up to now (2/2)

- Tool for estimating the efficiency & activity per unit area of large beta contamination sources by the direct method of measurement

```matlab
% Computing lambda Co-60
% Input data
s_exp=2.4; uS=0.05;
Es_exp=505.3; uE=3.9; er_Es= uEs/Es_exp;
E_exp=860.8; uE=4.7; er_E= uE/E_exp;
t_exp=Es_exp/E_exp; 
er_t=sqrt(er_E^2+er_Es^2); uS=t_exp*er_t

for i=1:10000
s=s_exp+uS*randn(1); Es=Es_exp+uEs*rands(1);
t=t_exp+uS*rands(1);
q=[1.3382e-001 -1.8462e+000 8.4152e+000 -2.0697e+001
-3.0791e-001 4.1245e+000 -1.9625e+001 4.0136e+001
2.2395e-001 -2.9740e+000 1.3937e+001 -2.5099e+001
-5.2696e-002 6.9329e-001 -3.1939e+000 5.6036e+000];
p1=polyval(q(1,:), s_exp); p2=polyval(q(2,:), s_exp);
p3=polyval(q(3,:), s_exp); p4=polyval(q(4,:), s_exp);
qn=[p1 p2 p3 p4]; K1=polyval(qn,t);
p=[4.2313e-001 -5.6149e+000 2.6108e+001 -4.7587e+001
-1.0050e+000 1.3186e+001 -6.0237e+001 1.0089e+002
-7.0750e-001 -9.9850e+000 4.4457e+001 -6.9969e+001
-1.9161e-001 2.4526e+000 -1.0700e+001 1.6446e+001];
pp1=polyval(p(1,:), s_exp); pp2=polyval(p(2,:), s_exp);
pp3=polyval(p(3,:), s_exp); pp4=polyval(p(4,:), s_exp);
ppn=[pp1 pp2 pp3 pp4]; K2=polyval(ppn,t);
K(i)=K1+(K2-K1)*randn(1);
fm=1+0.015*rands(1);
lambda(i)=fm*(Es/K(i));
end

K_m=mean(K); K_std=std(K);
lambda_m=mean(lambda); lambda_std=std(lambda);
lambda_er=lambda_std/lambda_m
[lambda_m lambda_std]
clear
```
Surface beta contamination monitoring
Still under development

● Tool for evaluating the uncertainty of surface beta contamination measurements

Preliminary results
Estimation of the activity per unit area and evaluation of its uncertainty making use of a single calibration sources with certified values of the surface emission rate of beta particles and activity.

\[ \Lambda_S = \frac{\Lambda}{S} = C(R_T - B) = \frac{R_T - B}{I} = \frac{R_T - B}{S \cdot \epsilon_d} \]

\[ \delta(\Lambda_S) = \sqrt{\delta^2 (R_T - B) + \delta^2 (I)} = \sqrt{\delta^2 (R_T - B) + \delta^2 (S) + \delta^2 (\epsilon_d)} \]

Calculation of \( \epsilon_d \) is based on the results previously mentioned. Evaluation of the uncertainty of \( \epsilon_d \) is still under development.
Alpha imaging

Solar blind region spectral response studies
Spectral response studies of radioluminescence detectors

Johan Sand and Kari Peräjärvi

kari.perajarvi@stuk.fi
johan.sand@tut.fi
Alpha radiation can be detected via secondary UV emission in air

Approximately 100 photons are generated per each 5 MeV alpha particle*

Alpha radiation can be detected via secondary UV emission in air

UV emission of a point alpha source

Picture by Victor Contreras 2015
Motivation for optical alpha detection

- Characterize radiological state of a facility prior decommissioning to better plan the course of actions

- Especially useful for the remote detection of actinides which are hard-to-detect due to low gamma yields

- Surface specific technique that complements gamma cameras

- Potential for remote, automated alpha screening of medium to high activities

MOX fuel pellets imaged
Alpha imaging
Benefits and tradeoffs

**Benefits**
- Long range detection of capability
  - UV light travels long distances in air
- Detection through translucent materials
  - Gloveboxes and shielded cells

**Tradeoffs**
- Sensitivity
  - Best systems detect few kBq-level alpha sources at 1 m distance in 10 s under UV-free light
- Tolerance for background light
Support the development of light-tolerant optical alpha detection technologies by investigations on the emission spectrum

- Deep UV region (below 300 nm)
  - *no background*
- Gases used in nuclear industry
  - *nitrogen & argon*
- Detector response

**Highlights**

- First spectrally resolved measurement of radioluminescence emission of air in deep UV region
- Develop understanding on the emission spectrum in a glovebox and in a shielded cell environment
Gamma imaging

Valerie Lourenço & Thierry Branger
Institut CEA LIST- Metrology, Instrumentation and Information Department
Laboratoire National Henri Becquerel (LNHB)
Gamma Camera

GAMPIX/iPIX: a new generation of gamma camera

- Localization of radioactive hot spots
  - A major issue for decommissioning operations
  - Definition of operating scenarios, minimization of the dose received by the workers (ALARA principle)

- GAMPIX: a second generation gamma camera
  - Association of the Timepix pixelated detector with a coded mask in a unique portable system
  - Plug-and-play system, easy to deploy and to use
  - Improvement of detection sensitivity in comparison with the existing industrial reference (CARTOGAM)

- From the GAMPIX prototype (CEA LIST) to the iPix industrial system (CANBERRA)
Gamma imaging results obtained during decommissioning operations

What developments for GAMPIX in the frame of MetroDecom

- Metrological validation of GAMPIX quantitative performances
- Accuracy of the dose rate measurement associated with a given hot spot

\[ \mu \text{Sv.h}^{-1} \]
Gamma Camera
MetroDecom developments for the GAMPIX system

• Creation of reference radioactive sources
  - Point sources and extended sources
  - Different energies: energy range of interest from 59.5 keV to 1.25 MeV
  - Radionuclides of interest:
    - $^{241}\text{Am}$ (59.5 keV)
    - $^{57}\text{Co}$ (122 keV)
    - $^{137}\text{Cs}$ (662 keV)
    - $^{60}\text{Co}$ (1.25 MeV)
Point sources
Work achieved during the 2nd semester 2015

12 point sources

Leakage tests, performed on the sources according to standard ISO 9978:1992*, have shown that the sources can be considered to be leak tight.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Activity (MBq)</th>
<th>Extended relative uncertainty (k=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am</td>
<td>1,138</td>
<td>4,1%</td>
</tr>
<tr>
<td></td>
<td>0,738</td>
<td>1,5%</td>
</tr>
<tr>
<td>$^{57}$Co</td>
<td>2,18</td>
<td>19,3%</td>
</tr>
<tr>
<td></td>
<td>3,871</td>
<td>0,9%</td>
</tr>
<tr>
<td></td>
<td>5,420</td>
<td>0,8%</td>
</tr>
<tr>
<td></td>
<td>12,72</td>
<td>0,6%</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>0,782</td>
<td>3,6%</td>
</tr>
<tr>
<td></td>
<td>1,93</td>
<td>3,6%</td>
</tr>
<tr>
<td></td>
<td>2,89</td>
<td>3,6%</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>0,822</td>
<td>3,7%</td>
</tr>
<tr>
<td></td>
<td>1,69</td>
<td>3,6%</td>
</tr>
<tr>
<td></td>
<td>2,52</td>
<td>3,7%</td>
</tr>
</tbody>
</table>
Measurements with the GAMPIX system

Single sources

Decoding using MATLAB

dose proportional to the peak area

Single sources ($^{57}$Co and $^{137}$Cs)

- $^{57}$Co: Acquisition time: 3600 s (20 acquisitions of 180 s)

$$y = 46266x + 20011$$
$$R^2 = 0.9963$$

- $^{137}$Cs: Acquisition time: 36000 s (10 acquisitions of 3600 s)

$$y = 150.77x - 6.8642$$
$$R^2 = 0.9999$$
Two configurations: $^{57}$Co sources with different activities; $^{57}$Co et $^{241}$Am

- Distance between sources: 30 cm
- Distance between sources and detector: 1 m
- Acquisition duration: 3600 s, 20 acquisitions of 180 s

Objective

To check the linearity between the ratio of dose measured and the ratio of activity for the 2 sources
Good linearity

- The bigger the ratio between activities is, the bigger the uncertainty of the ratio of dose rate is.

→ Need to carry on measurements with bigger activities (activity max : 5,33 MBq)
Measurements with the GAMPIX system
Multi sources – $^{57}$Co – $^{241}$Am sources

$^{241}$Am with fixed activity, $^{57}$Co with variation of activity of the source

$$y = 68514x + 57450$$
$$R^2 = 0.9984$$

Use of more active sources, filtering with clusters
(proposed in METRODECOM2)
Gamma Camera
MetroDecom developments for the GAMPIX system

Extended Sources (first semester of 2016):
- Creation of extended sources with good homogeneity (Minimum surface: 100 cm²)
- Evaluation of the quantitative response of the GAMPIX system to extended spots (still in progress)

Homogeneity tests to produce extended sources
(\(^{57}\)Co @ 13 kBq.g\(^{-1}\)) 10 min exposure time (auto-radiography)

- ~ 10 mm\(^2\) mesh size
  - Standard deviation: 13 %
- ~ 40 mm\(^2\) mesh size
  - Standard deviation: 9 %

Suitable for GAMPIX characterization

192 deposits
125 µm thick on Terphane ® foil

64 channel multipipet
Sources fabrication

3 Extended sources prepared (dimensions: 16.5 cm x 7 cm = 115 cm²):
- $^{241}\text{Am}$ with about 2,5 kBq/cm²
- $^{57}\text{Co}$ with about 8,6 kBq/cm²
- $^{57}\text{Co}$ with about 26 kBq/cm²

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Surface activity (kBq/cm²)</th>
<th>Total activity (kBq) (3 patches-assembled)</th>
<th>Reference date</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}\text{Am}$</td>
<td>3.65</td>
<td>421</td>
<td>13/01/2015</td>
</tr>
<tr>
<td>$^{57}\text{Co}$</td>
<td>7.37</td>
<td>851</td>
<td>30/04/2016</td>
</tr>
<tr>
<td>$^{57}\text{Co}$</td>
<td>16.4</td>
<td>1899</td>
<td>30/04/2016</td>
</tr>
</tbody>
</table>
Measurements with the GAMPIX system
Extended sources of $^{57}\text{Co}$ $^{241}\text{Am}$

Experimental device
- Distance between source and detector: 1 m
- Acquisition duration: 36000 s
- High noise due to other sources near the laboratory

$^{241}\text{Am}$ (138 kBq)

$^{57}\text{Co}$ (200 kBq/g)

→ On-going measurements
Q&A