Detection and Measurement Techniques

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When to use measurement techniques?

Measurements methods
- Direct ($\alpha$, $\beta$, and $\gamma$)
- Indirect (destructive)

Pre-characterisation

Development of measurement strategy
When to use measurement techniques? Phase 1: pre-characterisation

Purpose
- Establish the isotopic vector (finger print) & their dispersion
- Listing all rooms & material

How?
- History of the installation including incidents (interview ‘previous’ workers)
- Term source (list of isotopes)
- Code to calculate activation in various material
- Code to evaluate the dispersion of the radioactivity in the installation
- Measure the nuclides (Also DTM) to ‘validate’ the Isotopic vector and the dispersion/activation profiles

Key nuclide (scaling factor – level of conservatism):
- Cs-137 Fission product, Sr-90 (pure beta)
- Co-60 Activation product (H-3 (pure low beta)– higher mobility); C-14 (pure beta), Fe-55, Ni-63 (pure beta), Mn-54, Ag-108m, Ag-110m, Sb-125, Cs-134, Ba-133, Eu-152, Eu-154, Eu-155
- Am-241 (gamma), Pu-241 (beta): Actinides (U, Pu, Cm,..)
When to use measurement techniques?
Phase 2: Clearance measurement

Based on the pre-characterisation

Grouping (measurement techniques in mind), per:
- Area/zone of the same use; history
- Fixe (building – concrete) – mobile (dismantle - metal)
- Isotopic vector (fingerprint) – activated or not
- Type of material (geometry, physiochemical form)
  ... That are candidate for Clearance

For each group: Define the clearance measurements to verify compliance to Clearance level
Measurement methods

- Direct measurements
  - Alpha & beta (Used as illustration for statistics & parameters)
  - Gamma

- Indirect/destructive measurements
  - Taking the sample
  - Treating the sample
  - Measuring the sample

- General remark
  - Lots of monitors/systems are available on market
  - Smart, Black box (algorithm,... )
Direct measurement of alpha en beta
Hand-held monitor

- Gas detector
  - Capture electron (Ionisation) – Mostly Prop. mode
  - Sealed OR Compensation gas (need a ‘loading station’)
  - Less sensitive to gamma background

- Scintillation
  - Collect the light (excitation) by PM
  - Light seal – clear when broken
  - Easy to handle

- Passivated Implanted Planar Silicon (PIPS) - semiconductor
  - Surface very small
  - Delicate
Hand-held monitor alpha en beta
First trap – High voltage (calibration)

- HV setup before calibration
  - Max efficiency
  - Min interference between channels

- Usually 0.1 - 1 % beta in alpha channel
  - Problem in pre-characterisation
    - 40 Bq/cm² (0.4 Bq/cm² - 100 times limit)
    - 0.4 Bq/cm² (0.04 Bq/cm² - 10 times limit) of non existing alpha
The min detectable energy: starts to be difficult from below C-14 (about 160 keV) & impossible for H-3 (18 keV) (Except with open window)

DTM: Low beta energy (H-3), pure gamma emitters (used in medical).
Detection limit (ISO11929) also given in KB 30-04-2010

\[
\text{Limite de détection} = \left( k_{1-\alpha} + k_{1-\beta} \right) \sqrt{R_0 \left( \frac{1}{t_0} + \frac{1}{t_b} \right) + \frac{1}{4} \left( k_{1-\alpha} + k_{1-\beta} \right)^2 \left( \frac{1}{t_0} + \frac{1}{t_b} \right)}
\]

- \( k_{1-\alpha}, k_{1-\beta} \): Probability factor \( \alpha \) and \( \beta \)
- \( R_0 \): BG (cps)
- \( t_0 \): BG measurement time (s)
- \( t_b \): Sample measurement time (s)

Operational value \( CL \) (cps)

\[
CL \text{ (cps)} = CL \text{(Bq/cm}^2\text{)} \times S_{\text{vue}} \times \eta_{\text{global}}.
\]

- \( CL \): Clearance Level (Bq/cm²)
- \( R_0 \): Surface ‘seen’ (cm²)
- \( \eta_{\text{glob}} \): Global efficiency (isotopic vector %)
High BG response - Increase measuring time (CL: 0.4 Bq/cm²)

Trouble if...
- Pre-characterization pipe contaminated inside (gamma emitters inside)
- Clearance room with gamma sources ‘next door’.
  - Method of the plate (extensive)
  - If not homogeneous → BG + measure on each point
- In-situ measurement place not ideal. E.g. movement of waste container around

<table>
<thead>
<tr>
<th></th>
<th>Min. Infl.</th>
<th>Max. infl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>170 cm²</td>
<td>170 cm²</td>
</tr>
<tr>
<td>Co-60</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>ALARM CL</td>
<td>10 cps</td>
<td>10 cps</td>
</tr>
<tr>
<td>Gamma 1 µSv/h</td>
<td>100 cps (β)</td>
<td>10 cps (β)</td>
</tr>
<tr>
<td>Meas. times</td>
<td>15 sec</td>
<td>3 sec</td>
</tr>
</tbody>
</table>

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### Hand-held monitor alpha en beta Efficiency

- Same surface, same BG
- Different efficiency for Co-60
- CL: 0.4 Bq/cm²

<table>
<thead>
<tr>
<th></th>
<th>Min. Eff</th>
<th>Max. Eff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>alpha/bèta</td>
<td>alpha/bèta</td>
</tr>
<tr>
<td>Surface</td>
<td>100 cm²</td>
<td>100 cm²</td>
</tr>
<tr>
<td>Co-60</td>
<td>10%</td>
<td>17%</td>
</tr>
<tr>
<td>ALARM CL</td>
<td>4 cps</td>
<td>7 cps</td>
</tr>
<tr>
<td>BG</td>
<td>10 cps (β)</td>
<td>10 cps (β)</td>
</tr>
<tr>
<td>Meas. times</td>
<td>10 sec</td>
<td>4 sec</td>
</tr>
</tbody>
</table>

... Measurement time
Hand-held monitor alpha en beta
Influence of the surface f.i. 600 cm$^2$ – 100 cm$^2$

Double effect on
- Area covered (600 cm$^2$ - cover 6 times the area of a 100 cm$^2$)
- Measurement time 6 times smaller (Better statistic - Signal/BG)

<table>
<thead>
<tr>
<th></th>
<th>600 cm$^2$</th>
<th>100 cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG</td>
<td>50 cps</td>
<td>8 cps</td>
</tr>
<tr>
<td>Co-60 (eff.)</td>
<td>15 %</td>
<td>15 %</td>
</tr>
<tr>
<td>Operational CL</td>
<td>36 cps</td>
<td>6 cps</td>
</tr>
<tr>
<td>Measuring time</td>
<td>0.56 sec (1 sec)</td>
<td>3.4 sec (4 sec)</td>
</tr>
</tbody>
</table>

.....But consider
- Accessibility (too big for small corner e.g. 'I' shape beam)
- Dilution ('Richtlijnen meetprocedures' – Maximum surface to be measured = 1 m$^2$)
Hand-held monitor alpha en beta
Other consideration when selecting a device

- Ergonomics factors:
  - Electronic + probe together?
  - Sound (alarm load enough & sound increase with level of activity)

- How fragile?

- Number of options - How smart?
  - Go – no go alarm
  - Indication in Bq/cm² or cps,
  - Isotope library,
  - Automatic update with BG,..
  - Blocking options (easy to use – no risk of changing setup)
Interference (searching for non-existing alpha’s)
Operator – basic training (go – no go)
Optimize the measurement time
  - Influence of BG (gamma’s)
    - Pre-characterisation – problem in contaminated area’s (with gamma emitters)
    - Clearance measurement - Problem of BG fluctuation
  - Nuclide vector will decide which detector
    - At least can measure it (C-14)
    - Best efficiency
  - Surface
    - Measurement time
    - Accessibility
    - Max 1 m²
Types:
- Hand held monitors
- Gross counting
- Spectrometry
- Gamma camera

Huge variety (from very simple to extremely complex)
- All sort of shapes
- All sort of calculation algorithms
Direct measurements - Gamma
Hand held

- Telescopic for high dose
- GM tube
  From 0.1 $\mu$Sv/h – 1 Sv/h
- Pastic scintillator
  From 50 nanoSv/h

- Pre-characterisation
- Energy range can vary (X-ray & low energy - typically starts at 7 keV – 60 keV)
Advantage
- Fast detection. E.g. 20 kg, Co-60/Cs-137 needs like 30 second
- 4 pi geometry - Not really sensitive to geometric distribution activity
- Operator: Basic training (Go-no go)

Disadvantage
- Limited in space (cut material)
- Bulk measurement no spectrometry BUT algorithm to
  - Measure Co-60 (CCM or ROI)
  - Compensate for natural activity (portmonitor) - concrete
Direct - gamma

**Gross counting less geometry – less shielding**

- Out of 4 pi geometry
  - Efficiency depends on position (sum of solid angles)
    - Level of conservatism in parameters
    - OR Alarm + x sigma

- Less shielding
  - Higher detection limit
  - Effect of fluctuation (number of BG to meas.)

- BUT
  - Better flexibility in material that can be measured.
  - Can measure material in ‘same geometry – e.g. walls with surface contamination
Direct - gamma
In-situ gamma spectrometry

- Detectors
  - Scintillators (e.g. NaI, LaBr$_3$)
  - Semiconductors (e.g. CZT, HPGe)

- Measurement
  - Gamma spectrometry
  - Individual radionuclides
Direct - gamma Detector material

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector material</td>
<td>NaI (Tl)</td>
<td>HPGe</td>
</tr>
<tr>
<td>Resolution 662 keV</td>
<td>40 keV</td>
<td>2-3 keV</td>
</tr>
<tr>
<td>Activity level</td>
<td>Rather low</td>
<td>From low to</td>
</tr>
<tr>
<td>measurement</td>
<td></td>
<td>rather high</td>
</tr>
<tr>
<td>Cost</td>
<td>Rather cheap</td>
<td>Expensive</td>
</tr>
<tr>
<td>Remarks</td>
<td>Thermal drift</td>
<td>N2 Cooling</td>
</tr>
</tbody>
</table>
Direct - gamma
In-situ gamma spectroscopy

- Method: gamma-spectroscopy, using semi-mobile and fully characterised high purity germanium detector accompanied with modeling tools to measure specific total gamma activity & single RNs (Bq.g⁻¹, Bq.dm⁻²)

- Advantage
  - Large range of geometry to be measured (small and large surfaces)
  - Direct results
  - Detailed information is obtained
  - In some cases: determination of activity depth
  - No gamma peak interferences (except X-ray radiation)

- Disadvantage
  - Long measurement time
  - Ambient dose rate should be low
  - “Semi mobile”
Direct – gamma
Gamma camera

- Previous technique
  - Pin-hole camera
  - Compton camera
  - Long time 20-40 min
  - Image problem
  - Detection limit high

- New generation
  - Multiple pin-hole
  - + Code
  - Meas. time – 1 min – 10 min.
  - Detection limit: Hot spots of ~ 1 µSv/h in contact
Huge variety

- From very simple to extremely complex
- All sorts of shapes
- All sorts of combinations
- All sorts of calculation algorithms – might have black box effect → validation with real activity

... To be adapted to shape/type of material and isotopic vector
Indirect/destructive measurements
When?

- Pre-characterisation:
  - Very often used to validate the theoretical isotopic vector and establishing scaling factor – level of conservatism
  - For DTM - Measuring in alpha/beta, low alpha/beta energy – pure beta energy
  - For Activation profiles

- Clearance:
  - Not the preferred one BUT difficult to avoid for DTM like pure alpha or beta emitters, Tritium,... if can not be scaled to an other key-isotope
  - How Representative ? (Statistical approach: homogenous – zone with high risk of accumulation of activity)
  - Expensive & long process
Indirect/destructive measurements
3 steps approach

- Taking the sample
- Treating the sample
- Measuring the sample
Indirect/destructive measurements  
Taking the sample

- Smear/wipe (Non-fixed contamination – how much is on the wipe?)
- Scratch sample
- Shave sample
- Direct mass sampling (drilling, hammering, sediments, etc)
- Core drilling
Indirect/destructive measurements
Treating the sample – prepare for measurements

- Drying
- Grinding, milling, crushing
- Combustion
- Dissolution
- Radiochemistry separation
- Preparation for measurement
Indirect/destructive measurements
Measuring the sample

- Alpha or beta total (using ZnS global) – smear or on precipitate

- Alpha spectrometry (PIPS):
  - After radiochemical separation: Th-232, U-234, U-238, Pu-238, Pu-239/240, Am-241, Cm-242, Cm-243/244
  - Direct on the wipe if not wet (absorption)

- Liquid scintillation counting (LSC)
  - After radiochemical separation: H-3, C-14, Cl-36, Ca-41, Fe-55, Ni-63, Sr-90, Pu-241
  - H-3 – on extraction from smear test

- Gamma spectrometry: Geometry of the sample important

- Mass spectrometry (ICPMS):
  - Th-232, U-234, U-235 and U-238
Sampling & analysis
Core drilling-gamma spectrometry NaI

- Cs-137
Expensive & long process

Used a lot in Pre-characterisation

Can not be avoid for DTM’s like pure alpha or beta emitters, Tritium,... if can not be scaled to an other key-isotope

How Representative?
- Statistical approach: homogenous
- Homogeneisation of rubbels
NPP, research reactors, fuel industry
- Full nuclide vector (from pre-characterisation) – per ‘group’
- Eliminate the one that contributes less so that the sum formula $< 0.99$ Art 11: 30/04/10 Richtlijnen meetprocedures – art 11 4°

Le vecteur isotopique peut être limité aux radionucléides les plus significatifs, c'est-à-dire les radionucléides dont la contribution commune dépasse 99 % lors de l'application de la règle de la somme décrite à l'annexe IB au règlement général.

- DTM still in that list ? If so
  - Spectrometry: Scaling factor from key nuclide Co-60 – Cs-137 or to Am-241
  - Bulk measurement: take them into account using average efficiency based on %

- Labs with multiple experiences or in medical sector
  - pure beta: P-33; Cl-36, Sr-90,…
  - pure gamma: Se-75, Cd-109,…
  - Link with daughter product
  - Link between isotope ?
Phase 2: Developing measurement strategies

- Group by materials, geometry, nuclide vector in a ‘scope’
- Each scope has its measurement methodology
- Try to cover all materials
Developing measurement strategies
Classification - Type of material

- Porous versus smooth surface - (contamination penetrate or not)
  - Alpha measurement big concern
  - Gamma matters less

- Flat versus complex geometry
  - Alpha/beta measurement big concern
  - Gamma matters less

- Painting, rust, physiochemical form,...
  - Alpha/beta measurement big concern
  - Gamma matters less
Deliberate dilution by adding ‘clean’ wastes in order to stay below clearance level is NOT ACCEPTABLE (art 34.2 ARBIS)

Never the less,... Unavoidable dilution may occur, and is ACCEPTABLE. Averaging value (measure) Homogeneity (extracted quantity)

Max. 1 ton en 1 m³ Art 11: 30/04/10
Richtlijnen meetprocedures
RP 113/114 – Bq/cm²
Developing measurement strategies
Natural radioactivity

Where?
- Building material (bricks tiles– K-40, – plasterboard Ra-226),
- Sand
- NORM material (e.g. ‘Plaques disjoncteur: ciment amiant réfractaire’)

Legislation
- Art 11: 30/04/10 Richtlijnen meetprocedures: Don’t have to take into account if it doesn’t come from the installation. Level’s: K-40 = 1; Ra-226+: 0.01; Th-230: 0.1; Th-232: 0.01
- Arrêté AFCN 01/03/2013 (MB 25/03/2013) - Special disposal? If K-40: 5; Ra-226+: 0.5; Th-230:10; Th-232:5

When is it a problem?
- In bulk measurement (establish a natural BG value) versus energy selective monitoring e.g. spectrometry
High level of confidence in technique & methods (validation)

Which degree of complexity

Think sustainable:
- Segregate dangerous material
- Decontamination could generate more waste
- Minimise risk,

Human factor
- Error (handheld monitor more sensitive)

Financial (Other alternatives)
Huge selection of devices on the market – possibility to combine

Measurement devices can be tricky

There is not one recipe to create methodologies
  - Inspiration from other projects
  - Balance the pre-characterisation data & measurement techniques for grouping material
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