EXTREMITY EXPOSURE IN NUCLEAR MEDICINE:
WORK PACKAGE 4 OF THE PROJECT

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Aim of this talk

To present the objectives of Work Package 4 (WP4) of ORAMED and the implemented methodology

- Context
- Selected radionuclides
- Dosimetric and detection issues
- Program and methods of measurements
- Program and methods of simulations
Why?

**Nuclear medicine**: manipulation of (unsealed) radioactive sources

→ The hands are particularly exposed to ionizing radiations

Previous experience (CONRAD Project 2005-2007):

- The doses can exceed operational limits
- Large dose gradients are observed across the hands
- Extremity dosemeters are not systematically used and frequently are not appropriately used
- Poor information is available: absence of systematic studies

Carinou, E. et al., Radiation Measurements 43 (2008) 565-570
What’s new?

✓ To perform a systematic measurement and simulation campaign
  - Measurements: Distributions of the doses across the hands
  - Simulations: Analyze separately the parameters influencing the doses

✓ To provide guidelines for reducing the doses of the medical staff

✓ To propose “levels of reference doses” for standard NM procedures

ORAMED WP4: Extremity dosimetry in nuclear medicine
Radionuclides of interest

✓ **Diagnosis** with **Tc-99m** and **F-18**

✓ **Therapy** with **Y-90** (RIT with Zevalin®; PRRT with Dotatoc) + others

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Type</th>
<th>Eγ</th>
<th>Eβ max</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc-99m</td>
<td>Pure γ emitter</td>
<td>140.5 keV (87%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-18</td>
<td>Mixed β⁺ and γ emitter</td>
<td>634 keV (97%)</td>
<td>511 keV (194%)</td>
<td></td>
</tr>
<tr>
<td>Y-90</td>
<td>Pure β⁻ emitter</td>
<td>2280 keV (100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dosimetric issues

In contact of an unshielded (5 ml) syringe

- Dose rates are VERY different
- For Y-90 the annual limit can be reached in less than 1 minute ➔ Shielding is essential
- However, the frequencies of manipulation are VERY different
Detection issues

- Photons and electrons
- Energy range: 0 - 2.28 MeV
  - Hp(0.07) range: ~10 µSv → > 100 mSv

  ⇒ TL dosemeters $^7$LiF:Mg,Cu,P adapted
  Thickness $\leq$ 100 mg.cm$^{-2}$ for F-18 and Y-90
  $\geq$ 100 mg.cm$^{-2}$ for Tc-99m

- An intercomparison exercise was organized to ensure consistency of the results between WP4 partners

  - Fields: Cs-137 and Kr-85
  - At least 2 TL dosemeters were irradiated per partner

  TL dosemeters’ response

<table>
<thead>
<tr>
<th></th>
<th>Cs-137</th>
<th>Kr-85</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_\gamma$</td>
<td>662 keV</td>
<td>$E_{\beta-\text{max}}$ = 687 keV</td>
</tr>
<tr>
<td>$E_{\beta-\text{av}}$</td>
<td>252 keV</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.00</td>
<td>1.03</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

⇒ Adequate consistency
Measurements

Protocol:

✓ A pair of gloves equipped with 11 TL dosemeters each was worn by the worker
  - 8 TLDs on palm side, 3 on nail side
  - Only 1 type of radionuclide
  - Only preparation or administration
  - During: few days for Tc-99m
    ~1 day for F-18
    a single procedure for Y-90

⇒ 1 pair of instrumented gloves = 1 measurement

✓ For diagnostic applications:
  - At least: 5 measurements per worker
    2 workers per hospital
    2 hospitals per WP4 partner

✓ For therapeutic applications:
  - As many measurements and workers as possible
Measurements

Recorded information:
- Type of radionuclide (Tc-99m, F-18, Y-90 ...)
- Hospital’s ID
- Worker’s ID
- Right- or left-handed
- Worker’s experience
  - beginner: ≤ 1 year
  - experienced: > 1 year
- Radiation protection devices used
  - vial-shield, syringe-shield, forceps, semi-automatic devices
- Total manipulated activity
- Dose measured for every TL dosemeter
+ any additional comment to help understanding some results, e.g. a contamination event

All information gathered in a common database
Measurements

Definition of the manipulated activity:

✓ For preparation
   it’s the total activity withdrawn from
   - the elution vial for Tc-99m
     which is less than the eluted activity!
   - the mono- or multi-dose vial for F-18
     which is less than the vial activity!
   - the radioactive vial for Y-90

✓ For administration
   it’s the total activity in the injection syringe
Measurements

Where?
## Measurements

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Preparation</th>
<th>Workers</th>
<th>Hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc-99m</td>
<td>178</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>157</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>F-18</td>
<td>160</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>146</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>641</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y-90</td>
<td>49</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>RIT Zevalin®</td>
<td>45</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>127</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y-90</td>
<td>20</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>SIRT SIR-Spheres®</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>I-131</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RIT</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sm-153</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>PPT</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Re-186</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyzed: 7 countries; 34 different hospitals; 124 different workers
Analysis of measurements

- Separation of **Tc-99m**, **F-18**, and **Y-90** applications
- Separation of **preparation** and **administration** stages
- Doses normalized per manipulated activity (e.g. mSv/GBq)

For **diagnostic** applications:
- Workers with **at least 4 measurements** series considered
- Doses averaged over the measurement series for each worker
- Identification of the **position receiving the maximum dose**
- Classification of workers according to their maximum doses
- Effect of **shielding**, operator’s **experience**, **nd vs D** hands
- **Ratios** Maximum dose / Dose at possible monitoring positions
- Extrapolations to **annual doses**

For **therapeutic** applications:
- Analysis focused on RIT with Zevalin® and PRRT with Dotatoc
- **All workers** were considered
- Rest of the analysis similar to that for diagnostic applications
Simulations

✓ Aims:

- To analyze separately the parameters influencing the doses
  ➔ Sensitivity study to understand intra- and inter-operator variabilities
- To calculate surface dose distributions (dose mapping) for some selected cases

✓ 6 configurations were defined
  Considered as representative of different manipulation stages
Simulations

6 defined configurations:

- Preparation
  - Holding a vial in hand
  - Holding a vial with forceps
  - Holding a syringe by the piston
  - Holding a syringe by the needle

- Administration
  - Holding a syringe in hand
  - Injecting
Simulations

From real to numerical worlds: the procedure

1. Defining the case
2. Creating a moulding
3. Scanning the moulding
4. Generating a voxel phantom
5. Adding the source and dosemeters
Simulations

✓ Tc-99m, F-18 and Y-90 considered
✓ Use of the MC code MCNPX (Pelowitz (Ed.), 2005)
✓ Their emission characteristics taken into account
✓ Dose calculated at (70 ± 5) µm in the dosemeters [Hp(0.07)]
✓ Hand phantoms and dosemeters made of ICRU-44 soft tissue (1 g.cm⁻³)
✓ For Tc-99m: only photons transported
✓ For F-18 and Y-90: photons and electrons transported
Simulations

A validation study was done
- Comparing calculations with measurements for Tc-99m and F-18

Holding a vial with forceps  Injecting  Holding a syringe

Simulations validated (see Carnicer, A. et al., poster P15)
Simulations

Parameters for the sensitivity study:
- Radionuclide
- Shielding
- Displacement of the source
- Orientation of the source
- Volume of the source

Example 1: variation of the active volume

Example 2: rotation of the syringe
Simulations

Dose mapping of the hand’s surface:

The location of the maximum can be at a different place to that of the dosemeters.

→ How large is the underestimation?

Comparison is made between the calculated doses identified as the maximum in the dosemeters and in the surface voxels.
WP4 presentations

Analysis of the measurements for diagnostic applications
  ➔ Carnicer A. et al.

Analysis of the measurements for therapeutic applications
  ➔ Rimpler A. et al.

Analysis of the Monte Carlo simulations
  ➔ Ferrari P. et al.

Guidelines
  ➔ Sans Merce, M. et al.

Training
  ➔ Sans Merce, M., Ginjaume, M. et al.
THANK YOU!