Dosimetria e Protecção Radiológica em Medicina Nuclear – tópicos seleccionados

Radiation Protection and Dosimetry in Nuclear Medicine – selected topics

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Outline

• Nuclear Medicine - facts & numbers

• The system of Radiological Protection
  ➢ Underlying “methodology”
  ➢ Justification and Optimization

• Radiation Protection and Dosimetry of the workers - occupational exposures
  ➢ Extremity dosimetry
  ➢ Optimization of the protection

• Radiation Protection and Dosimetry of the patient - internal dosimetry
  ➢ Uncertainties in organ dose calculation
  ➢ Patient tailored therapies (and diagnostic) - individual risk assessment

• The way forward - the Bonn Call for Action

• Conclusions and Outlook
Nuclear Medicine – facts & numbers
Diagnostic NM examinations Worldwide

Data from UNSCEAR 2008 report - Volume I - Annex A
### Total NM procedures Worldwide

#### Worldwide Estimates of the Total Number and Types of Medical Procedures Involving Ionizing Radiation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiologic examination</td>
<td>1380</td>
<td>1600</td>
<td>1910</td>
<td>3100</td>
</tr>
<tr>
<td>Dental radiographic examination</td>
<td>340</td>
<td>480</td>
<td>520</td>
<td>466</td>
</tr>
<tr>
<td>Nuclear medicine study</td>
<td>23.5</td>
<td>24</td>
<td>32.5</td>
<td>37</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1743</td>
<td>2024</td>
<td>2462</td>
<td>3600</td>
</tr>
</tbody>
</table>

#### Comparison of Estimated Annual Per-Capita Effective Doses from Medical Procedures in the United States, in Other Well-developed (Level I) Countries, and in the World for Selected Years

<table>
<thead>
<tr>
<th>Type</th>
<th>Dose for United States, 2006*</th>
<th>Dose for Level I Countries, 1997–2007†</th>
<th>Dose for the World, 1997–2007‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>3.01</td>
<td>2.00</td>
<td>0.613</td>
</tr>
<tr>
<td>All radiologic procedures</td>
<td>2.24</td>
<td>1.87</td>
<td>0.61</td>
</tr>
<tr>
<td>Radiographic and fluoroscopic procedures</td>
<td>0.33</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Interventional procedures</td>
<td>0.43</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>CT scanning</td>
<td>1.47</td>
<td>0.87</td>
<td>0.24</td>
</tr>
<tr>
<td>Dental radiographic examinations</td>
<td>0.008</td>
<td>0.0063</td>
<td>0.0017</td>
</tr>
<tr>
<td>Nuclear medicine studies</td>
<td>0.77</td>
<td>0.13</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Extracted from F. Mettler et al., in Radiology (2009) Data from UNSCEAR and NCRP reports
Most common radionuclides in Nuclear Medicine

- **For diagnostic**
  - **Gamma emitters**
    - $^{99m}\text{Tc}$, $^{111}\text{In}$, $^{123}\text{I}$, $^{131}\text{I}$, $^{201}\text{Tl}$, $^{133}\text{Xe}$, ...
  - $\beta^+$ emitters (and annihilation photons)
    - $^{18}\text{F}$, $^{11}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$, $^{64}\text{Cu}$, $^{68}\text{Ga}$, $^{82}\text{Rb}$, $^{86}\text{Y}$, $^{124}\text{I}$, ...

- **For therapy**
  - $\beta^-$ emitters
    - $^{90}\text{Y}$, $^{131}\text{I}$, $^{32}\text{P}$, $^{89}\text{Sr}$, $^{153}\text{Sm}$, $^{169}\text{Er}$, $^{177}\text{Lu}$, $^{186}\text{Re}$, ...
  - **Alpha emitters**
    - $^{149}\text{Tb}$, $^{211}\text{At}$, $^{212}\text{Bi}$, $^{213}\text{Bi}$, $^{223}\text{Ra}$, $^{225}\text{Ac}$, ...
  - **Auger electrons emitters**
    - $^{64}\text{Cu}$, $^{99m}\text{Tc}$, $^{111}\text{In}$, $^{123}\text{I}$, $^{125}\text{I}$, $^{161}\text{Tb}$
# Characteristics of the most frequently used radionuclides

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>“Typical” activities per patient (MBq)</th>
<th>Dose rate in contact of a 5 ml unshielded syringe (mSv.min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁹⁹mTc</td>
<td>~ 500</td>
<td>3</td>
</tr>
<tr>
<td>¹⁸F</td>
<td>~ 400</td>
<td>20</td>
</tr>
<tr>
<td>⁹⁰Y</td>
<td>~ 1000</td>
<td>700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Gamma energy (keV)</th>
<th>HVL in tissue (cm)</th>
<th>Max. range in tissue (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁹⁹mTc</td>
<td>140.5</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>¹⁸F</td>
<td>511</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>⁹⁰Y</td>
<td>2.28</td>
<td>0.9</td>
<td>11</td>
</tr>
<tr>
<td>¹⁸F</td>
<td>0.63</td>
<td>0.25</td>
<td>2.3</td>
</tr>
</tbody>
</table>
**Multimodality imaging**

**Introduction**

- **1995**: Stand-alone PET + AC Ge68 ring source
- **1998**: First SPECT/CT system
- **1999**: PET/CT prototype
- **2001**: PET/CT (128 slices) PET/MRI
- **2011**: PET/CT radiation exposure in multimodality imaging

From Klaus Bacher, Ghent University, PEDDOSE.NET Educational Presentation
The system of Radiological Protection

System of Radiological Protection

- Justification
- Optimization
- Dose Limitation
Radiation protection standards rely on current knowledge of the risks from radiation exposure. Any over-, or under-, estimation of these risks could lead either to unnecessary restriction or to a lower level of health protection than intended.
Effective dose is NOT patient-specific and should NOT be used as a measure of individual risk nor for expressing deterministic effects!!!
ICRP reference voxel phantoms (report ICRP-110)

Table 5.1 Main characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>1.63</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>60.0</td>
</tr>
<tr>
<td>Number of tissue voxels</td>
<td>3,886,020</td>
</tr>
<tr>
<td>Slice thickness (voxel height)</td>
<td>4.84</td>
</tr>
<tr>
<td>Voxel in-plane resolution</td>
<td>1.775</td>
</tr>
<tr>
<td>Voxel volume (mm³)</td>
<td>15.25</td>
</tr>
<tr>
<td>Number of columns</td>
<td>299</td>
</tr>
<tr>
<td>Number of rows</td>
<td>137</td>
</tr>
<tr>
<td>Number of slices</td>
<td>346 (+2)*</td>
</tr>
</tbody>
</table>
Justification of Nuclear Medicine imaging examinations

Oncologist (Radiation Oncologist)

Nuclear Medicine Physician

Radiologist
Justification of medical exposures:

**Level 1** deals with use of radiation in medicine in general
(In practice this is accepted as doing more good than harm, and its justification is taken for granted)

**Level 2** deals with specified procedures with a specified objective
(The aim at this level is to judge whether the procedure will improve diagnosis or provide necessary information about those exposed)

**Level 3** deals with the application of the procedure to an individual
(The particular application should be judged to do more good than harm for the individual patient)


Radiation Protection of Patients Unit, Radiation Safety and Monitoring Section, NSRW, International Atomic Energy Agency, Vienna, Austria. jfmalone@tcd.ie

Abstract

OBJECTIVES: The Radiation Protection of Patients Unit of the International Atomic Energy Agency (IAEA) is concerned about the effectiveness of justification of diagnostic medical exposures. Recent published work and the report of an initial IAEA consultation in the area gave grounds for such concerns. There is a significant level of inappropriate usage, and, in some cases, a poor level of awareness of dose and risk among some key groups involved. This article aims to address this.

METHODS: The IAEA convened a second group of experts in November 2008 to review practical and achievable actions that might lead to more effective justification.

RESULTS: This report summarises the matters that this group considered and the outcome of their deliberations. There is a need for improved communication, both within professions and between professionals on one hand, and between professionals and the patients/public on the other. Coupled with this, the issue of consent to imaging procedures was revisited. The need for good evidence-based referral guidelines or criteria of acceptability was emphasised, as was the need for their global adaptation and dissemination.

CONCLUSION: Clinical audit was regarded as a key tool in ensuring that justification becomes an effective, transparent and accountable part of normal radiological practice. In summary, justification would be facilitated by the “3 As”: awareness, appropriateness and audit.
Justification of Medical Exposures in Diagnostic Imaging (3)

- Referral Guidelines & Appropriateness Criteria
Justification of Medical Exposure in Diagnostic Imaging (4)

Optimization
Diagnostic Reference Levels (DRLs)
EURATOM Council Directive 97/43 
(European Union) - DRLs

Article 4 (Optimization)

2. Member States shall:
(a) promote the establishment and the use of diagnostic reference levels for radiodiagnostic examinations, as referred to in Article 1 (2) (a), (b), (c) and (e), and the availability of guidance for this purpose having regard to European diagnostic reference levels where available;
(...)

EU Directive 97/43 EURATOM

"Diagnostic Reference Levels: dose levels in medical radiodiagnostic practices or, in the case of radio-pharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied."
DRLs in Nuclear Medicine
DRLs in Nuclear Medicine
European countries

Fig 3.2. Comparison of DRLs for bone imaging, Tc-99m phosphates and phosphonates.

Fig 3.3. Comparison of DRLs for myocardial perfusion, Tl-201 chloride.

Extracted from the Dose DataMed II project report - Part 2
Diagnostic reference levels for adult Nuclear Medicine examinations:
- Exist in 64% of the countries,
- 33% of the countries have no DRLs

Nuclear Medicine DRLs in European countries:
- 65% are based on countries’ own national dose surveys
- 35% are based on published values

All DRLs are set based on administered activity (in MBq)

This reference administered activity is not based on the 75th percentile but on the administered activity necessary for a good image during a standard procedure

There is a large variation between DRLs given by countries
Radiation Protection and Dosimetry of the workers
Staff exposure in Nuclear Medicine

- Staff members are exposed to IR during:
  - Preparation
  - Administration

- The patient himself becomes a radioactive source!

- Exposure to
  - $\gamma$ radiation ($^{99m}\text{Tc}, ^{18}\text{F}, ^{123}\text{I}$, etc.)
  - $\beta$ radiation ($^{32}\text{P}, ^{68}\text{Ga}, ^{90}\text{Y}, ^{188}\text{Re}, ^{131}\text{I}, ^{153}\text{Sm}$, etc.)
  - Mixed fields!

- Doses to:
  - Extremities
  - Skin
  - Other radiosensitive organs
Exposure of extremities preparation + administration

Generator
Elution vial
Labelling vial

Labelling with Tc-99m

Injection in diagnostics
$^{131}$I capsules - Dose rates (source-detector distance = 0.2 m)
Patient as a source
Dose rates vs distance

### Table 2
Mean dose rate after application of 0.7 GBq $^{99m}$Tc ($N = 18$), 0.37 GBq $^{18}$F ($N = 21$), and 10.5 GBq $^{131}$I-MIBG ($N = 2$) immediately after application of the radiopharmaceutical.

<table>
<thead>
<tr>
<th>Distance from patient [m]</th>
<th>Photon dose equivalent rate $\dot{H}_x$ [mSv/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{99m}$Tc-HDP</td>
</tr>
<tr>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>0.5</td>
<td>0.02</td>
</tr>
<tr>
<td>1</td>
<td>0.007</td>
</tr>
<tr>
<td>2</td>
<td>0.003</td>
</tr>
<tr>
<td>5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Survey-meter: FH-40 G-L.

**F. Sudbrock et al. / Radiation Measurements 46 (2011) 1303-1306**
90Y / Zevalin®
Skin dose measurements (ORAMED)

Table 2
Maximum skin dose measurements (ORAMED) for dominant hand (with and without outliers).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>With outliers</td>
<td>0.3–78.3</td>
</tr>
<tr>
<td>Without outlier</td>
<td>1.0–11.9</td>
</tr>
</tbody>
</table>

Table 3
Maximum skin dose measurements (ORAMED) for dominant hand in RIT with 90Y/Zevelin.

<table>
<thead>
<tr>
<th>Procedure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation Administration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>In RIT</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparation</td>
<td>0.4–39.4</td>
</tr>
<tr>
<td>Administration</td>
<td>0.1–7.1</td>
</tr>
</tbody>
</table>

Fig. 1. ORAMED standard skin dose measuring positions.
Optimization of the protection Shielding

- Lead gloves
- Vial shield
- Syringe shield
- Lead box
- Activimeter
Optimization of the protection Distance

Tongs/Twisers/Forceps

Automatic dispensers
Exposure of staff in NM (ORAMED) Conclusions

- Skin dose monitoring is a compulsory precautionary measure for personnel in nuclear medicine performing radionuclide therapy.
- Exposures during the preparation were higher than during the administration of the radiopharmaceuticals to the patients.
- There is sufficient potential to further improve radiation protection standards and to decrease exposure of staff.
- Risk awareness and training have an effect on staff exposure.
- The usage of shielding for vials and syringes is an essential precondition for low exposures.
- The usage of pincers and forceps to avoid direct contact and to enlarge the distance to the source significantly affects exposures.
- The omission of shielding and protective tools cannot be compensated by increased working speed.
Radiation Protection and Dosimetry of the patient

Internal Dosimetry

The two systems/methodologies differ more in notation, application, and end-purpose than in substance.
Absorbed Dose

The MIRD methodology (S-factors)

- The mean absorbed dose $D_{rk}$ in a target "region" (organ or tissue) $r_k$ is the sum of the contributions, $S(r_k \leftarrow r_h)$, arising from nuclear transformations of the radionuclide in various source "regions" $r_h$

$$D_{rk} = \sum_h \tilde{A}_h S(r_k \leftarrow r_h)$$

$\tilde{A}_h$ is the time-integrated or cumulated activity, equal to the total number of nuclear transformations in $S$ in time interval $\tau$

$$\tilde{A}_h(\tau) = \int_{t_0}^{t_0+\tau} A_h(t) \, dt$$
Absorbed Dose
The MIRD methodology (\(S\)-factors)

\( S(r_k \leftarrow r_h) \) is the absorbed dose in \( r_k \) per unit cumulated activity in \( r_h \)

\[
S(r_k \leftarrow r_h) = \frac{k}{m_{rk}} \sum_i Y_i \cdot E_i \cdot \varphi_i(r_k \leftarrow r_h)
\]

- \( Y_i \) - yield per disintegration
- \( E_i \) - average energy (MeV)
- \( \varphi_i(r_k \leftarrow r_h) \) - fraction of absorbed energy in target organ region \( r_k \) per emission in source organ region \( r_h \)
- \( m_{rk} \) - mass of target organ (g)
- \( k \) - constant
SEE(T ← S) - Specific Effective Energy, source (S), target organ (T)

\[ \text{SEE}(T \leftarrow S) = \sum_i \frac{Y_i \cdot E_i \cdot w_i \cdot A F_i(T \leftarrow S)}{M_T} \]

- \( Y_i \): yield per disintegration
- \( E_i \): average energy (MeV)
- \( w_i \): radiation weighting factor
- \( AF_i(T \leftarrow S) \): fraction of absorbed energy in target organ T per emission in organ S
- \( M_T \): mass of target organ (g)

Units: MeV/disint./g
Committed equivalent/effective dose
The ICRP methodology

- Number of decays, \( U_s \) (in 50 years, for instance)
  - Activity in source organ, \( S \)

- Committed equivalent dose ("dose integrated over 50 years")

\[
H_T(\Delta t) = \sum_s U_s(\Delta t) \cdot SEE(T \leftarrow S)
\]

\[
U_s(\Delta t) = \frac{A_0}{\lambda_{\text{eff}}} \left(1 - e^{\lambda_{\text{eff}} \Delta t}\right)
\]

- Committed effective dose ("dose integrated over 50 years")

\[
E(\Delta t) = \sum_T w_T \cdot H_T(\Delta t)
\]

\( \Delta t = 50, 70 \) years

\( \lambda_{\text{eff}} \) - effective removal constant
How to calculate the committed effective dose

- **Committed effective dose** ("dose integrated over \( \tau \) years")

\[
E(\tau) = e(\tau) \cdot A
\]

- \( e(\tau) \) coefficients, tabulated in ICRP-72, ICRP-119 publications for:
  - Different radionuclides
  - Different incorporation pathways
    - Ingestion
    - Inhalation
  - Integrated effects from intake time up to the age of 70 years
    \((\tau = 50 \text{ years for adults}, \tau = 70 \text{ years for non adults})\)
(Other) ICRP Publications

ICRP Publication 130
Occupational Intakes of Radionuclides
Part 1 (due September 2015)
“One would expect that, in the near future, a rigorous calculation of the propagation of error (or propagation of uncertainty), including the fit process, will be performed and the errors reported”

Internal Dose Calculations

Uncertainties

\[
D_{rk} = \sum_h \tilde{A}_h S(r_k \leftarrow r_h)
\]

\[
S(r_k \leftarrow r_h) = \frac{k}{m_{rk}} \sum_i Y_i \cdot E_i \cdot \varphi_i(r_k \leftarrow r_h)
\]

✓ Uncertainty in \(Y_i\) and \(E_i\) is small/negligible

✓ The bulk of the uncertainty comes from:

  ▪ \(\varphi_i(r_k \leftarrow r_h)\) - fraction of absorbed energy in target organ region \(r_k\) per emission in source organ region \(r_h\)

  ▪ \(m_{rk}\) - mass of target organ (g)

  ▪ \(\tilde{A}_h\) - cumulated activity
Internal Dose Calculations Uncertainties

\[ D_{r_k} = \tilde{A}_h S(r_k \leftarrow r_h) \]

- Cumulated activity determination:
  - Measurements
  - Experiments
  - Calibration factors
  - Modelling and computation (biokinetic models, etc.)
  - Etc.

- Absorbed dose calculation
  - Phantoms
  - Modelling and computation (biokinetic models, Monte Carlo simulations, etc.)
  - Organ masses
  - Correction factors
Internal Dose Calculations
Uncertainties

• The absorbed dose and mass terms are based on standardized individuals, that is
  - reference man
  - reference woman
  - reference pediatric individuals

• The anthropomorphic phantoms, that have been derived to represent these standard individuals, when used in these calculations provide doses to the supposedly median individual in a reference group.

• Nuclear medicine patients vary substantially in body size and shape, and the dose estimates for these standard individuals are accurate for only a small percentage of the individuals encountered in actual practice.
### Variability of organ masses

#### TABLE 3
Reported Variability of Organ Mass for Several Organs in Men, According to Subject Height

<table>
<thead>
<tr>
<th>Organ</th>
<th>144&lt;H&lt;165</th>
<th>165&lt;H&lt;175</th>
<th>176&lt;H&lt;190</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>344 ± 75</td>
<td>360 ± 75</td>
<td>381 ± 56</td>
</tr>
<tr>
<td>Right lung</td>
<td>616 ± 20</td>
<td>625 ± 207</td>
<td>741 ± 274</td>
</tr>
<tr>
<td>Left lung</td>
<td>523 ± 190</td>
<td>551 ± 178</td>
<td>658 ± 257</td>
</tr>
<tr>
<td>Liver</td>
<td>1,455 ± 370</td>
<td>1,637 ± 369</td>
<td>1,831 ± 384</td>
</tr>
<tr>
<td>Spleen</td>
<td>120 ± 51</td>
<td>150 ± 88</td>
<td>180 ± 90</td>
</tr>
<tr>
<td>Pancreas</td>
<td>138 ± 35</td>
<td>143 ± 39</td>
<td>147 ± 39</td>
</tr>
<tr>
<td>Right kidney</td>
<td>150 ± 49</td>
<td>157 ± 36</td>
<td>170 ± 37</td>
</tr>
<tr>
<td>Left kidney</td>
<td>155 ± 53</td>
<td>164 ± 38</td>
<td>175 ± 38</td>
</tr>
<tr>
<td>Thyroid</td>
<td>25 ± 7</td>
<td>25 ± 13</td>
<td>25 ± 9</td>
</tr>
</tbody>
</table>

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Towards patient-tailored therapies (and diagnostic), & “individual” risk estimation
Article 4 (Optimization)

1. (a) All doses due to medical exposure for radiological purposes except radiotherapeutic procedures referred to in Article 1 (2) shall be kept as low as reasonably achievable consistent with obtaining the required diagnostic information, taking into account economic and social factors.

(b) For all medical exposure of individuals for radiotherapeutic purposes, as mentioned in Article 1 (2) (a), exposures of target volumes shall be individually planned; taking into account that doses of non-target volumes and tissues shall be as low as reasonably achievable and consistent with the intended radiotherapeutic purpose of the exposure.

* Radiotherapeutic: pertaining to radiotherapy including nuclear medicine for therapeutic purposes.
Computational Phantoms for medical dosimetry (1)

- stylized (or mathematical)
  - Flexible, allowing changes in organ size, body shape, and extremity positioning, but generally deficient with respect to anatomic realism

- voxel (or tomographic)
  - Three dimensional array of voxels, each with a unique organ identity, elemental composition, and density. Very difficult to alter to represent the body morphometry

- hybrid
  - Based upon NURBS and/or polygon mesh surfaces. Preserve both the anatomic realism of voxel phantoms and the mathematical flexibility of stylized phantoms
Computational Phantoms for medical dosimetry (2)

- Phantom Morphometric Categories:
  - **Reference**
    - Reference phantom defined typically as an individual at 50th height/weight percentile in a given human population → ICRP 110
  - **Patient-specific**
    - Uniquely match the body morphometry and organ anatomy of an individual medical patient
  - **Patient-Dependent Phantoms**
    - Match patient to phantom using a large library of phantoms covering a broad range of body shapes and sizes
Radiation Protection and Dosimetry
Changing the paradigm...?

Effective dose

Reference individual

ICRP phantom library

Effective individual risk

Adult male, Adult female, Pediatric male, Pediatric female

Broad range of body sizes (height/weight)
Patient dependent phantoms

From Ted Lazo (NEA) @ Article 31 (2014) meeting
Patient dependent phantoms

From Cassola et al., “Standing adult human phantoms based on 10th, 50th and 90th mass and height percentiles of male and female Caucasian populations”, PMB (2011)
Use of non-reference phantoms
Accuracy of dose calculations

From Ted Lazo (NEA) Article 31 (2014) meeting
Thw way forward
Bonn Call for Action (1)
The way forward
Bonn Call for Action (2)

✓ 01) Enhance the implementation of the principle of justification
✓ 02) Enhance the implementation of the principle of optimization of protection and safety
✓ 03) Strengthen manufacturers’ role in contributing to the overall safety regime
✓ 04) Strengthen radiation protection education and training of health professionals
✓ 05) Shape and promote a strategic research agenda for radiation protection in medicine
✓ 06) Increase availability of improved global information on medical exposures and occupational exposures in medicine
✓ 07) Improve prevention of medical radiation incidents and accidents
✓ 08) Strengthen radiation safety culture in health care
✓ 09) Foster an improved radiation benefit-risk-dialogue
✓ 10) Strengthen the implementation of safety requirements globally
Conclusions and outlook
Overcoming data & conceptual gaps (1)

✓ With computed tomography (CT) likely to become sub-mSv in coming years, positron emission tomography (PET), single photon emission computed tomography (SPECT) and some of the nuclear medical examinations will become focus of attraction as “high-dose” examinations, even though they are less-frequent ones

✓ Further insight into radionuclide metrology is highly desirable

✓ Transition from dose to a representative phantom to dose to individual patient is a MUST and is underway

✓ Better dosimetry of beta-emitters is needed

✓ Nanometric modelling of biological effects and “dose” for alpha-emitters and Auger-electron emitters is mandatory
Conclusions and outlook
Overcoming data & conceptual gaps (2)

✓ Need for improved understanding of stochastic risks from ionizing radiation

✓ Need for better understanding the limitations of the effective dose concept in medical dosimetry

✓ Need to consider alternative means of assessing stochastic risk such as the use of organ doses and BEIR VII risk model