Keynote Lecture 3a
Active Methods & Instruments for Personal Dosimetry of External Radiation in Europe
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Co-authors: M.Ginjaume and F.Vanhavere
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- Calibrations and Standards

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Legal requirements in european countries

The 96/29 EU directive is widely spread in Europe for external radiation:

- Individual monitoring is practiced in most countries for category A workers
- Individual monitoring systems are delivered by accredited services
- Individual monitoring record: passive dosemeters are mostly used.
- Optimisation of doses: APD are considered better tools for day-to-day, job-to-job processing data
The 96/29 European Union directive is based on ICRP recommendations

- Directive does not specify type of dosemeters for individual monitoring
- but
- In several European countries APD are considered better tools for optimisation of ALARA principle because of:
  - Instant direct reading
  - Daily dose recording
  - Data transfer to and from computer network
  - Lower dose sensitivity
  - Alarms
In most EU countries, passive dosemeters are obligatory and used for dose recording. In some countries, the legislations do not specify the type of dosemeter to be used. APDs are mostly required in particular situations:

- Licence conditions in some workplaces
- Obligatory for potential high dose level situations
- Itinerant workers
- Obligatory in France together with passives
Calibrations and Standards

- Calibration and testing specified by member states
- ISO Standard 17025 is progressively being applied in Europe
- IEC Standards for APD are less well known and national calibration and testing are applied
- Progress still to be done to harmonise standards practices (EURADOS)
<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 1525</td>
<td>Radiation protection instrumentation – X, gamma, high energy beta and neutron radiations – Direct reading personal dose equivalent and/or dose equivalent rate monitors. IEC 1525, 1996</td>
</tr>
<tr>
<td>IEC 1323</td>
<td>Radiation Protection Instrumentation – Neutron radiation - Direct reading personal dose equivalent and/or dose equivalent rate monitors IEC-1323 (1995)</td>
</tr>
</tbody>
</table>
APDs commercially available are based on:

**Geiger-Müller**
- Pulse type ion chambers, electrons collected apply a constant electric field, low efficiency

**Silicon diodes**
- Ionisation process and charge collection ~10 times more efficient than for GM type detectors

**Direct ion storage (DIS)**
- Ionisation chamber combined with MOSFET data storage device (active and passive device)

**(Bubble detectors)**
- Passive device but direct reading
Figure 1a Photon sensitive ion chamber
Wall Material: Graphite or Teflon

Figure 1b Neutron/photon sensitive ion chamber
Wall Material: A-150/PE containing $^6$Li or $^{10}$B
EURADOS consortium
Working group: Harmonization of individual monitoring in Europe

Report on APD in preparation
To be published in RPD

- Status of implementation of direct reading devices in EU countries
- APD catalogue of gamma and beta
- APD catalogue for neutrons
- APD problems and advantages for users
APDs
\( \gamma - \beta \) from EURADOS catalogue
APD catalogue for gamma and beta measurements

Overview of the main characteristics of some APDs used in Europe. A set of 22 dosimeters produced by 15 manufacturers was selected.

- **General information:** manufacturer and type, year introduced, type of application, type of detector.
- **Radiological performance:** measured quantities, type of radiation measured and energy response, range, angular response.
- **Physical characteristics:** dimensions, weight, battery type and life-time for typical use.
- **Environmental performance:** electromagnetic fields sensitivity.
- **Mechanical performance:** acoustic sensitivity and shock resistance.
- **Dose recording procedure:** manual reading, reading equipment, software.
- **Type test:** lab that conducted the type testing, standard followed or approval.
## Table 2: Main Characteristics of a set of 22 photon APD (information provided by manufacturers)

<table>
<thead>
<tr>
<th>APD Reference</th>
<th>Energy range (keV)</th>
<th>Angular response</th>
<th>Weight (g)</th>
<th>Volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>% 99Cs</td>
<td>% 137Cs</td>
</tr>
<tr>
<td><strong>AEA Tech. DoseGuard S10</strong></td>
<td>60</td>
<td>3000</td>
<td>80%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Aloka PDM112</strong></td>
<td>40</td>
<td>1000</td>
<td>50%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Automess ADOS</strong></td>
<td>70</td>
<td>3000</td>
<td>15%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Canberra Dosicard</strong></td>
<td>50</td>
<td>2000</td>
<td>0°-45° 20%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Comet APD (Panasonic Ind. Eur.)</strong></td>
<td>20</td>
<td>1600</td>
<td>0°-60° 20%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Dositec L36</strong></td>
<td>60</td>
<td>6200</td>
<td>0°-90° 25%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Fuji Electric NRY 20001</strong></td>
<td>50</td>
<td>6000</td>
<td>25%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Graetz ED 150</strong></td>
<td>50</td>
<td>2000</td>
<td>0°-60° 20%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>MGP DMC 2000S</strong></td>
<td>50</td>
<td>6000</td>
<td>20%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>MGP DMC 2000X</strong></td>
<td>20</td>
<td>6000</td>
<td>30%</td>
<td>IEC 61283</td>
</tr>
<tr>
<td><strong>MGP DMC 2000XB</strong></td>
<td>20</td>
<td>6000</td>
<td>30%</td>
<td>IEC 61526</td>
</tr>
<tr>
<td><strong>MGP SOR/R</strong></td>
<td>50</td>
<td>6000</td>
<td>IEC 61283</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Mini Instruments 6100</strong></td>
<td>30</td>
<td>1000</td>
<td>20%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Polymaster PM1203</strong></td>
<td>60</td>
<td>1500</td>
<td>25%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Rados DIS-1</strong></td>
<td>15</td>
<td>9000</td>
<td>30%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Rados RAD-51/51T</strong></td>
<td>60</td>
<td>3000</td>
<td>25/35%</td>
<td>IEC 61283</td>
</tr>
<tr>
<td><strong>Rados RAD-60/62</strong></td>
<td>60</td>
<td>3000</td>
<td>25%</td>
<td>IEC 61283</td>
</tr>
<tr>
<td><strong>Rados RDD-20/RDR-20</strong></td>
<td>50</td>
<td>1500</td>
<td>30%</td>
<td>IEC 61283</td>
</tr>
<tr>
<td><strong>Saic PD-2i/PD-3i</strong></td>
<td>55</td>
<td>6000</td>
<td>25%</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>Saphydose Gamma</strong></td>
<td>50</td>
<td>1300</td>
<td>30%</td>
<td>IEC 61283</td>
</tr>
<tr>
<td><strong>Siemens EPD1, EPD2 (Mk1)</strong></td>
<td>20</td>
<td>10000</td>
<td>20%</td>
<td>IEC 61526</td>
</tr>
<tr>
<td><strong>Siemens Mk2</strong></td>
<td>15</td>
<td>7000</td>
<td>20%</td>
<td>IEC 61526</td>
</tr>
</tbody>
</table>
**APD Energy range from constructors**

**Figure 4.3: Energy range within a +/- 30% of \(^{137}\text{Cs}\) response**

<table>
<thead>
<tr>
<th>Photon Energy (keV)</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
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<tbody>
<tr>
<td>Siemens Mk2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siemens EPD1, EPD2 (Mk1)</td>
<td></td>
<td></td>
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<tr>
<td>Saphydose Gamma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saic PD-2i/PD-3i</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rados RAD-60/62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rados RAD-51/51T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rados DIS-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polimaster PM 1203</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini Instruments 6100</td>
<td></td>
<td></td>
</tr>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>MGP DMC 2000X</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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</tr>
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<tr>
<td>Aloka PDM 112</td>
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</tr>
<tr>
<td>AEA Tech. DoseGuard S10</td>
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<td></td>
</tr>
</tbody>
</table>

2004 May the 24th IRPA 11 Keynote Lecture 3a
New developments

For high doses
- Detectors based on industrial diamonds
  - Biological tissues equivalent, resistant to high doses but low detection efficiency compared to silicon
  - Suitable for measurements in radiotherapy

Low doses
- CCD coupled with Caesium iodine detectors and MOS detectors
  - Down to μSv region

Extremity
- Small sensors coupled with pocket size readout unit
  - Few data published
  - No specific standards yet
APDs for neutrons
APD catalogue for neutrons

Figure 5.1 Response as a function of the energy for some commercial APDs

Figure 5.2 Response as a function of the energy of APD prototypes
The Saphydose-n individual electronic

Poster section 3h35 ID 288
back to the keynote

after a few commercials
Evaluation of Individual Dosimetry in Mixed Neutron and Photon Radiation Fields

E. C. project November 2002 – April 2005

Oral section 3a-347 E. Schuhmacher et al.

Poster ID 730 V. Lacoste et al., Neutron spectrometry in workplaces of European nuclear industry
Poster ID 759 F. Vanhavere, M. Coeck, Improvements in the Neutron Shielding around the VENUS Reactor Facility at the Belgian Nuclear Research Centre
Session: 3b External Exposure

Poster ID 670 M. Reginatto et al., Dose Equivalent Response Of Neutron Dosemeters Determined Using Unfolding Methods

Poster ID 288 T. Lahaye et al., Individual electronic neutron dosimetry in workplaces of European power plants and fuel processing facilities

2004 May the 24th IRPA 11 Keynote Lecture 3a
IM 2005
European workshop on individual monitoring of ionising radiation

April 11 - 15, 2005
Renaissance Penta Hotel
Vienna / Austria

organised by the
ARC Seibersdorf research GmbH
Health Physics Division

in co-operation with
the European Radiation Dosimetry Group
EURADOS and IAEA
Calibration and testing

**ISO 4037 and IEC-61526 standards for γ and β**

- Reference radiation quality recommended:
  - Filtered X-ray radiation in the range 12 to 300 keV
  - Gamma sources $^{137}\text{Cs}(662\text{ keV})$ and $^{60}\text{Co}(1.25\text{ MeV})$
- Calibration on ISO 4037-3 defined phantoms (table)

**For neutrons IEC-13233 standard**

- Reference radiation quality recommended:
  - Thermal
  - Mono-energetic up to 15 MeV

**For both: environmental tests:**

- Electromagnetic compatibility, humidity, temperature, drop test, etc...
From EURADOS report
Calibration and testing from users questionnaire

- No periodic calibration
- Periodic internal radiological test
- Periodic external calibration

NPP Fuel Cycle Research Industrial Medical

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Measured quantities

- **H***: The ambient dose equivalent is an isotropic quantity.
- **H_p**: The personal dose equivalent is a directional quantity.

\[ H_p (10) = \text{dose equivalent at 10 mm in the body at the location where the personal dosemeter is worn (chest)} \]
ICRP60 recommends the effective dose \( E \) for radiological protection

\( E \) is not measurable but can be approximated, for individual monitoring, by the operational quantity \( H_p(10) \)

\[
H_p = \int \int h_p(E, \alpha) \Phi_{E, \alpha} dE \, d\alpha
\]

\( h_p(E, \alpha) \) is defined between 0° and 75°; new coefficients calculations are in progress for higher angles

\( H_p \) accurately estimates \( E \) only for certain geometries and energy field distributions see fig (5)
FIG 5 Ratio personal dose equivalent Hp to effective dose equivalent as a function of the energy for photons at AP, ROT and PA field geometry.
Accuracy of Hp measurements with personal dosemeters

- Dosemeter reading should be tested in workspaces conditions
  - Spectrometric measurement at workplaces
  - Test on phantoms

**Difficulties:**
- Workplace field conditions are sometimes difficult to reproduce
  - *Simulated workplaces fields*
- Iso phantoms represents only average workers, i.e.: workers morphology is not taken into account
  - *Instrumented antropomorphic phantoms*
- Hp accuracy in laboratory conditions may be ~10 to 20% (95%CL)
- In workplaces:
  - Hp measured/ Hp reference = 1.5 for low doses and for neutrons

To be published

See Poster ID 730
Neutron spectrometry in workplaces of European nuclear industry
Neutron fluence energy distribution for different directional intervals from 0° to 50° at the **CANEL/T400** calibration area.

APD use in workplaces

- APD should be adapted to the workplace field
- More reliable APD use in power plants
  - Centralize recording
  - Individual use
- In hospitals
  - Energy range not always adapted
  - Manual recording
- In some power plants, systematic comparison with passives performed
  - Differences between 3 and 8%
  - When > 10% differences are investigated
Photon field measurements in workplaces from ref: [Burgess], [d’Errico] [Ambrosi]
APD energy response compared with photon spectra in nuclear industry (Janwillem van Dijk)
APD energy response compared to hot cells spectra
Comparison of X-ray spectral distribution in medical sector with some APD response as a function of the energy.

![Graph showing comparison of X-ray spectral distribution and APD response across different energy levels for various medical devices.](image-url)
Neutron spectra measurements
EVIDOS

Fuel rods in a rack

E$_\Delta\Phi$/\Delta E (cm$^{-2}$ s$^{-1}$)

Neutron Energy (MeV)

POINT 1

POINT 2a

POINT 2b

POINT 3

Poster ID 730  V.Lacoste et al., Neutron spectrometry in workplaces of european nuclear industry
APD problems and advantages for users (from EURADOS report)

The ideal dosemeter for users

- cheaper dosemeters
- better environmental characteristics
- longer battery life
- better radiological response:
  - most end-users make the assumption that present dosemeters measure the radiation quantities adequately
- NPP only wish for an electronic neutron dosemeter
- better mechanical characteristics were not considered a high priority
Several national intercomparisons were performed

*Based on standards*

**EURADOS-AIEA intercomparison project**

**Objectives:**
- Verify performance of the different APD types available on the market
- Help the participating APD suppliers/Member States in achieving a sufficiently accurate dosimetry
- Provide guidelines for improvements.

**No budget available**
- Irradiation time foreseen by some EURADOS standard laboratories
- AIEA organiser
- Hope to have devices from constructors
ISO 4037 and IEC-61526 standards radiation tests

- Reproducibility of the reading
- Repeatability of the reading
- Dose equivalent rate dependence
- Relative intrinsic error
- Response as a function of radiation energy
- Response as a function of radiation angle of incidence
- Retention of reading
- Accuracy of alarm levels
- Response time
Intercomparisons

FIG 7 Measured [Tex] response as function of energy of some commercial APD
## EURADOS-AIEA intercomparison preliminary protocol

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy response Photon</td>
<td>$S$-$Co$, $S$-$CS$, $N$-30, $N$-80, $N$-300</td>
<td>0.1 mSv per quality</td>
</tr>
<tr>
<td>Dose rate response Photon</td>
<td>$S$-$Cs$</td>
<td>10 mSv (at 1Sv/h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 µSv (at 1 mSv/h)</td>
</tr>
<tr>
<td>Angular response Photon</td>
<td>$S$-$CS$</td>
<td>1 mSv</td>
</tr>
<tr>
<td></td>
<td>(Horizontal rotation)</td>
<td>(for each angle: 0°, 45°, 60°)</td>
</tr>
<tr>
<td>Electromagnetic interference</td>
<td>Mobile phone</td>
<td>Dose set to lower limit of effective range of measurement</td>
</tr>
<tr>
<td>Mixed field Photons</td>
<td>$N$-30 + $S$-$CS$</td>
<td>1 mSv</td>
</tr>
<tr>
<td></td>
<td>0° angle</td>
<td></td>
</tr>
<tr>
<td>Response Beta</td>
<td>To be defined</td>
<td>1 mSv</td>
</tr>
<tr>
<td></td>
<td>0°</td>
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</tr>
</tbody>
</table>
CONCLUSIONS AND FUTURE NEEDS

- APDs for $\gamma/\beta$ as reliable or better than passives
- Experience in power plants confirm the advantages of APDs over conventional dosimetry mainly because of alarm features and direct reading allowing better optimisation of practices
- Improvements needed for extremity, low doses, high intensity and neutrons
CONCLUSIONS AND FUTURE NEEDS

- Improvements on effective dose assessment by:
  - Angular and energy spectrometry in workplaces
    - Choice of detectors and calibration practices
    - Simulated workplaces fields calibrations
  - Type testing and standard
    - Harmonize practices in Europe
    - Standards for extremity needed
  - APD use for legal Record?