STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Monitoring of dose to lens, skin, and extremities: ISO 15382

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BVS-ABR, Brussels, 2016

Introduction

- The human body has to be protected from effects of ionizing radiation.
  - Limitation of stochastic effects: limit on effective dose
  - Tissue reactions (deterministic effects) are covered by the dose limits for specific organs
- These separate dose limits are needed
  - in case of localized exposures, the skin doses can exceed the limits even when the effective doses can be lower than its limit.
- Monitoring the skin, the extremities and the lens of the eye is not always straightforward
  - Specialized dosimetry is needed
  - Many practical problems
    - Monitoring is often not done as it should be, or not done at all.

ISO standards

- Technical committee 85: *Nuclear energy, nuclear technologies, and radiological protection*

- Sub Committee 2: *Radiological protection*:
  - Lead by Alain Rannou (IRSN)
  - 82 standards
  - 26 participating countries

- Working Group19: *Individual monitoring of external radiation*
  - Lead by François Queinnec (IRSN)

General outline: ISO 15382 standard

- The old version of the ISO standard 15382 (2002)
  - Mainly treated issues on beta radiation for nuclear power plant workers
- The main objective of the revision of the 15382 standard:
  - to take into account the new situation due to the evolution of the ICRP recommendation for eye lens doses
  - Focus also on medical exposures

⇒ New title : "***Procedures for monitoring the dose to the lens of the eye, the skin and the extremities***"

- **Final version published in December 2015**

General objectives

- The questions on which the new standard gives guidance are:
    - How to determine the need to use dosemeters ?
    - How to ensure that individual monitoring is appropriate to the nature of the exposure ?
    - How to design a monitoring program which ensure compliance with legal individual dose limits ?
    - How to choose the type of dosemeters ?
    - How to choose positioning of the dosemeters ?
    - How to use correction factors ?

SKIN and EXTREMITY DOSIMETRY

Quantities: how to measure the extremity doses?

- Skin and extremity monitoring:
  - measurement of $H_p(0,07)$, the equivalent dose to the skin
- The ICRP recommended dose limits :
  - an equivalent dose limit to the extremities (hands and feet) or the skin of 500 mSv in a year.

The equivalent dose limits for the skin apply to the average dose over 1 cm^2 of the most highly irradiated area of the skin.

- In practice, an estimate of equivalent dose to the skin is a conservative estimate of equivalent dose to the extremities;

.

What depth is sensitive layer of the skin?

- ICRP: sensitive cell depth: between 20 and 100 µm

- But:
  - Surface fingers: 200-500 µm
  - Side fingers: 250 µm
  - Side and back of hands: 70 µm
  - Individual variability

- Recommendation: use 70 µm, thus $H_p(0.07)$

When monitoring?

- in situations with nonhomogeneous exposure conditions for which the whole-body monitoring does not provide an adequate estimate of the dose to the skin or the extremities
  - Exposures can be significant when weakly penetrating radiation such as low energy photons or beta radiation is present.
  - Workplaces where extremities are particularly close to the radiation emitter or radiation beam
    - E.g. nuclear medicine, and dismantling applications.

Monitoring levels and periods

- The following monitoring levels are recommended:
  - 3/10th of the limit, as recommended in European BSS
- for the extremities or the skin, this means monitoring should be undertaken if there is a reasonable probability to receive a dose greater than 150 mSv per year;
- For dose levels expected to be lower than the recommended monitoring levels, a survey, demonstrating that the levels are not exceeded, should be sufficient.
- For doses above the monitoring level, a monitoring period of one month is recommended

Characterisation of radiation fields

- Characterization of the radiation fields is important to determine the need for and the type of monitoring required.
  - Photon fields (X and gamma radiation) of any energy can contribute to the skin and extremity exposure.
  - Electrons (beta radiation) with energy above 60 keV penetrate 0,07 mm of tissue

- In medical fields, the type of radiation and radionuclides are very well known.
- In nuclear installations, low energy betas are to be expected in the vicinity of unsealed radioactive materials. In nuclear installations handling used fuel as well as in nuclear reactors experiencing fuel leakage high energy betas (above 700 keV) should be expected.

Assessment of dose levels prior to monitoring

- Prior to routine monitoring, it is important to assess the dose levels in a workplace field situation in order to decide which method and period of routine monitoring is necessary.

- The doses obtained should be extrapolated to annual doses and compared with the monitoring levels

- The assessment should be repeated when the working conditions or workload change significantly, or if the effect of such changes cannot be estimated with confidence.

1. Indications of workplace monitoring

- In work situations with radiation fields that are predictable over a long period: possible to estimate the worker doses using workplace measurements at relevant locations.
- For determining the directional dose-equivalent rate H'(0,07)/t, suitable dose-equivalent rate meters (i.e., with thin walls and small detector thickness) shall be used. If protective clothing is worn, H'(0,07) shall be measured behind the respective layer of clothing.
- The measurement position shall be representative of the exposure conditions of the person surveyed.
- If tools are used, measurements shall be performed at the distance appropriate for the use of such tools.

2. Indications of whole body monitoring

- A dosemeter worn on the trunk is used for the estimation of effective dose.
  - The results from the whole body dosemeter can give an indication of the level of exposure to the extremities or the skin, provided the exposure conditions and the radiation field characteristics (especially the spatial distribution) are taken into account.

- When the whole body dosemeter is worn under the protective clothing, its reading strongly underestimates the dose to the unprotected extremities and can therefore not be used to provide an indication of the level of these doses.

3. Indications of literature

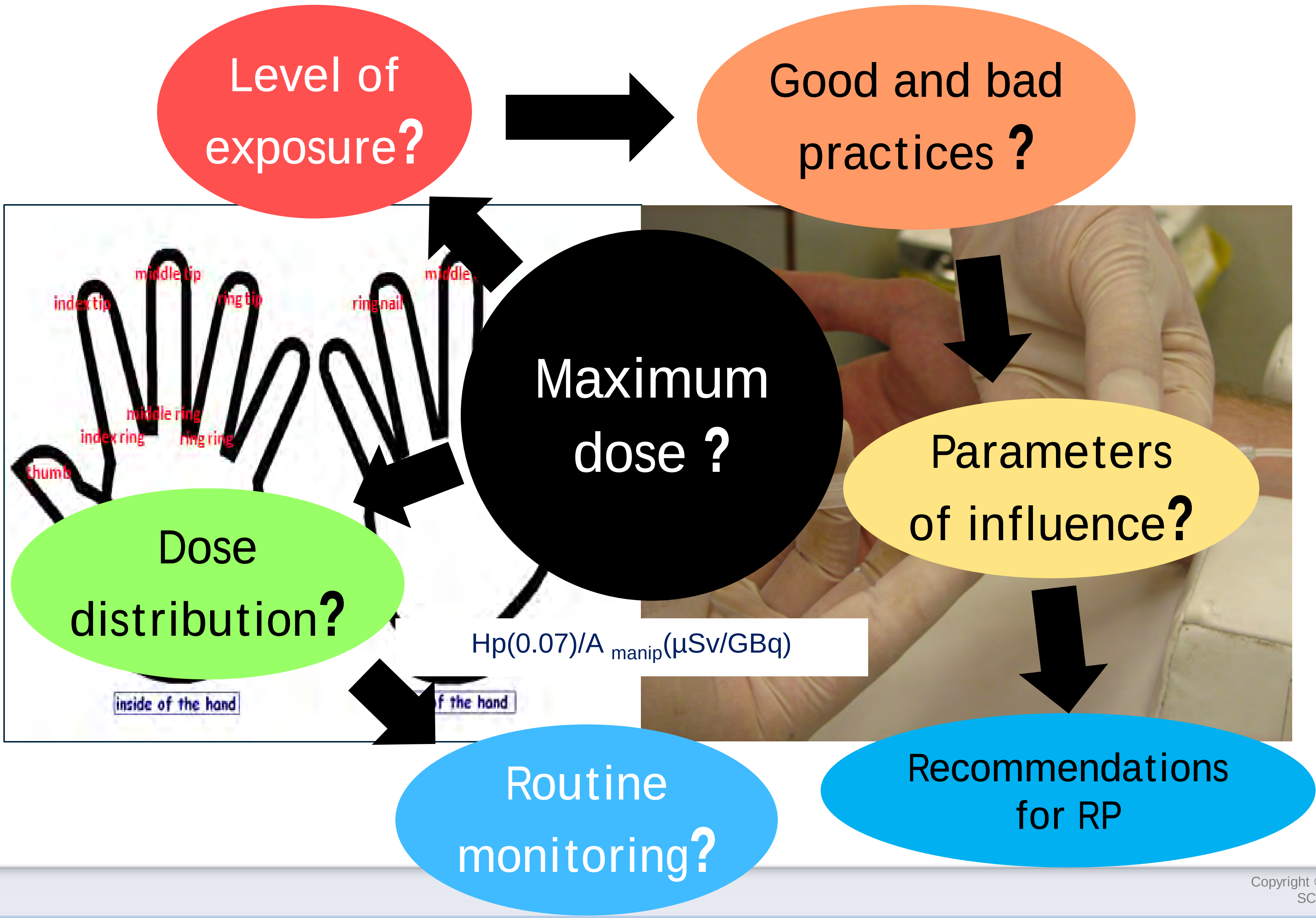
- In the literature, some typical dose values are given for various workplace situations.
- When using literature it should be ensured that the data are truly representative of the current workplace conditions regarding the radiation source, the geometry and types of protective measures

3. Indications of literature

Martin and Whitby: with good practices it is possible to stay within the limits

Group	Range of annual doses [mSv]
Interventional radiologists (hands)	10-200
Interventional radiologists (legs)	10-200
Interventional radiologists (legs, with shield)	1-15
Cardiologists (hands)	5-100
Cardiologists (legs)	5-100
Cardiologists (legs, with shield)	0.5-10
Radiopharmacy staff	10-200
Nuclear medicine staff	5-40

3. Indications of literature: ORAMED

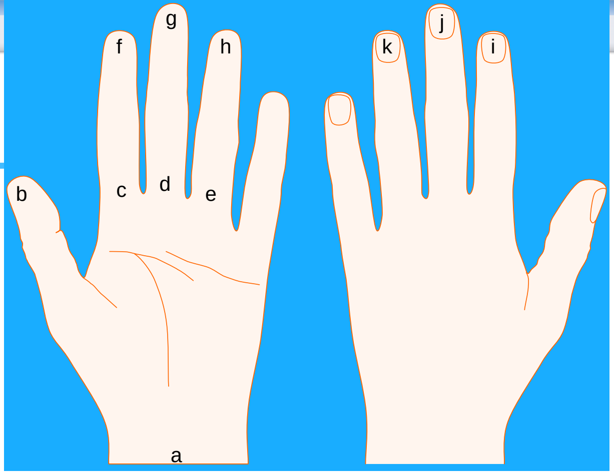


ORAMED: Measurements

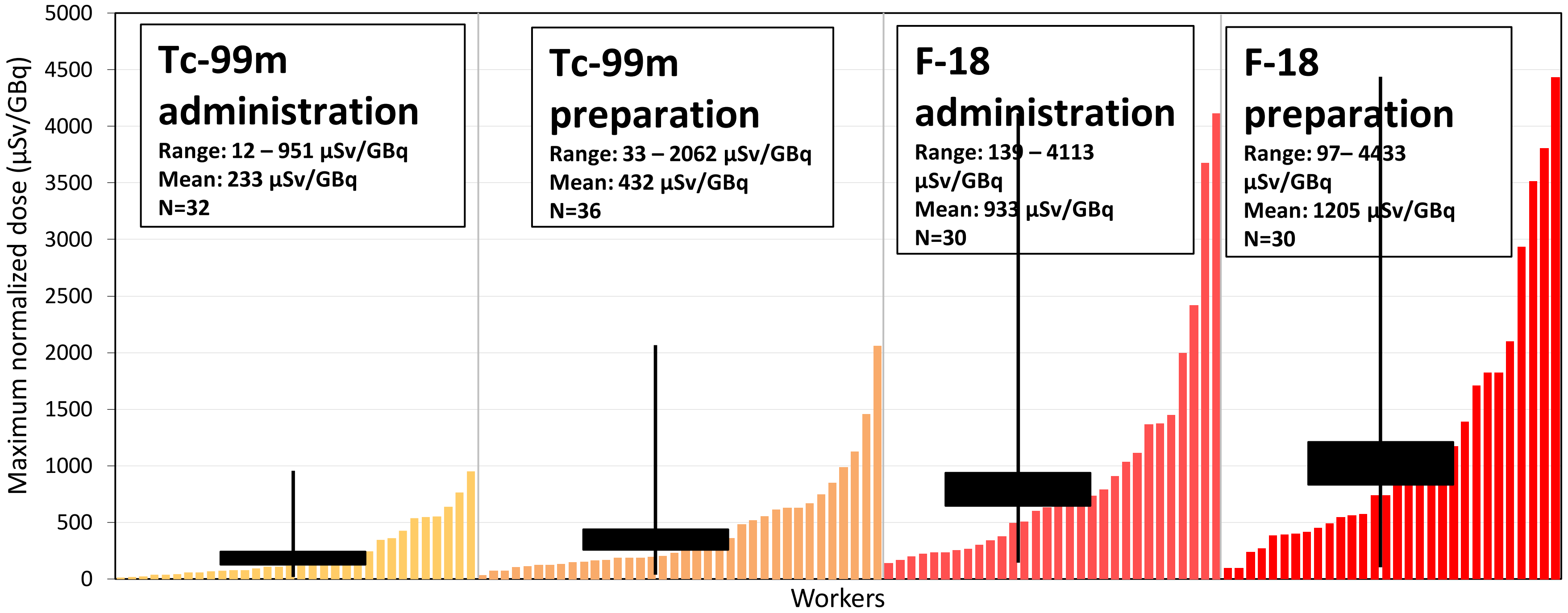
Common protocol:

- ✓ A pair of gloves equipped with 11 TL dosemeters each was worn by the worker
  - – During: few days for Tc-99m
    ~1 day for F-18
    a single procedure for Y-90
- ✓ For diagnostic applications:
  - – At least: 5 measurements per worker

Analyzed: 7 countries; 34 different hospitals; 124 different workers, more than 600 measurements

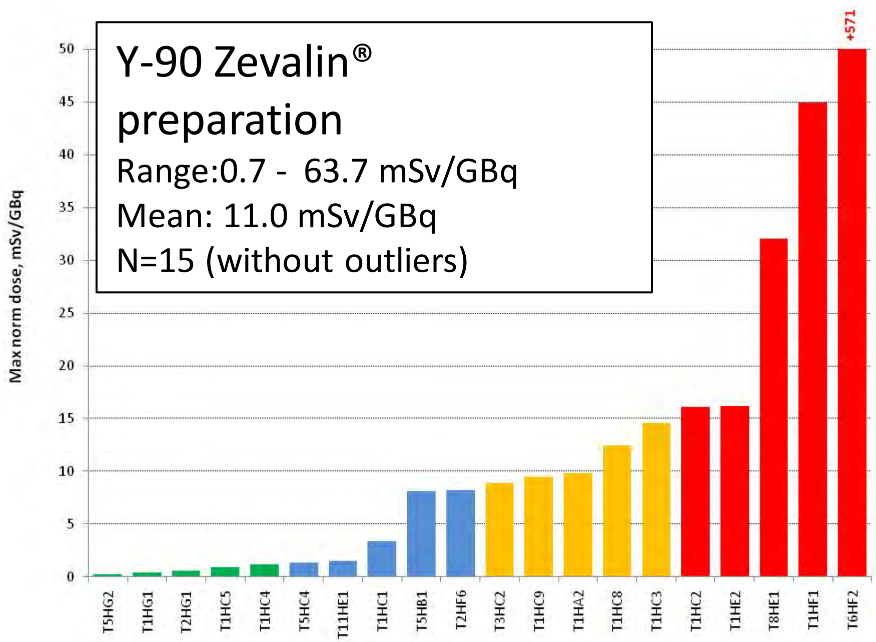


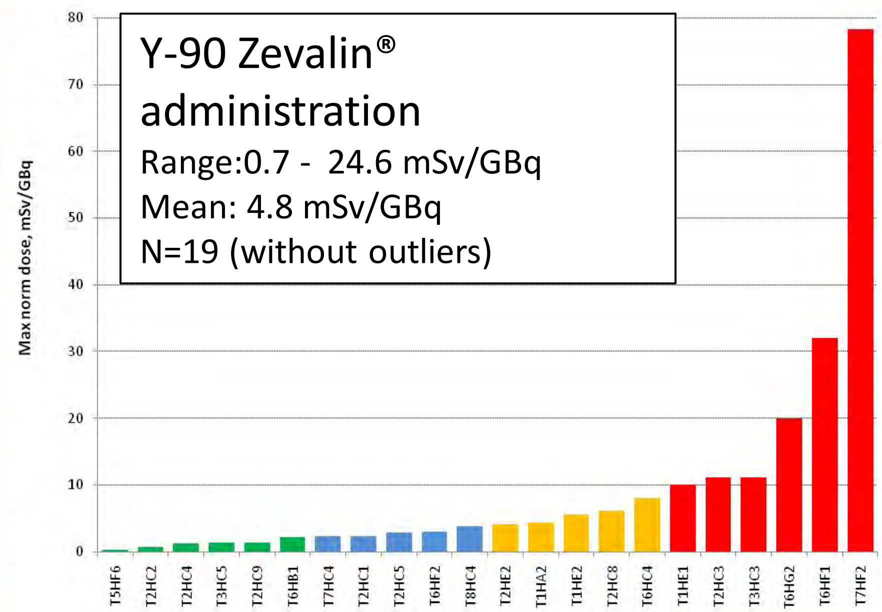
Overview on finger doses in diagnostic NM



- Very large range of maximum finger doses among the same procedure.

Overview on finger doses in therapy NM

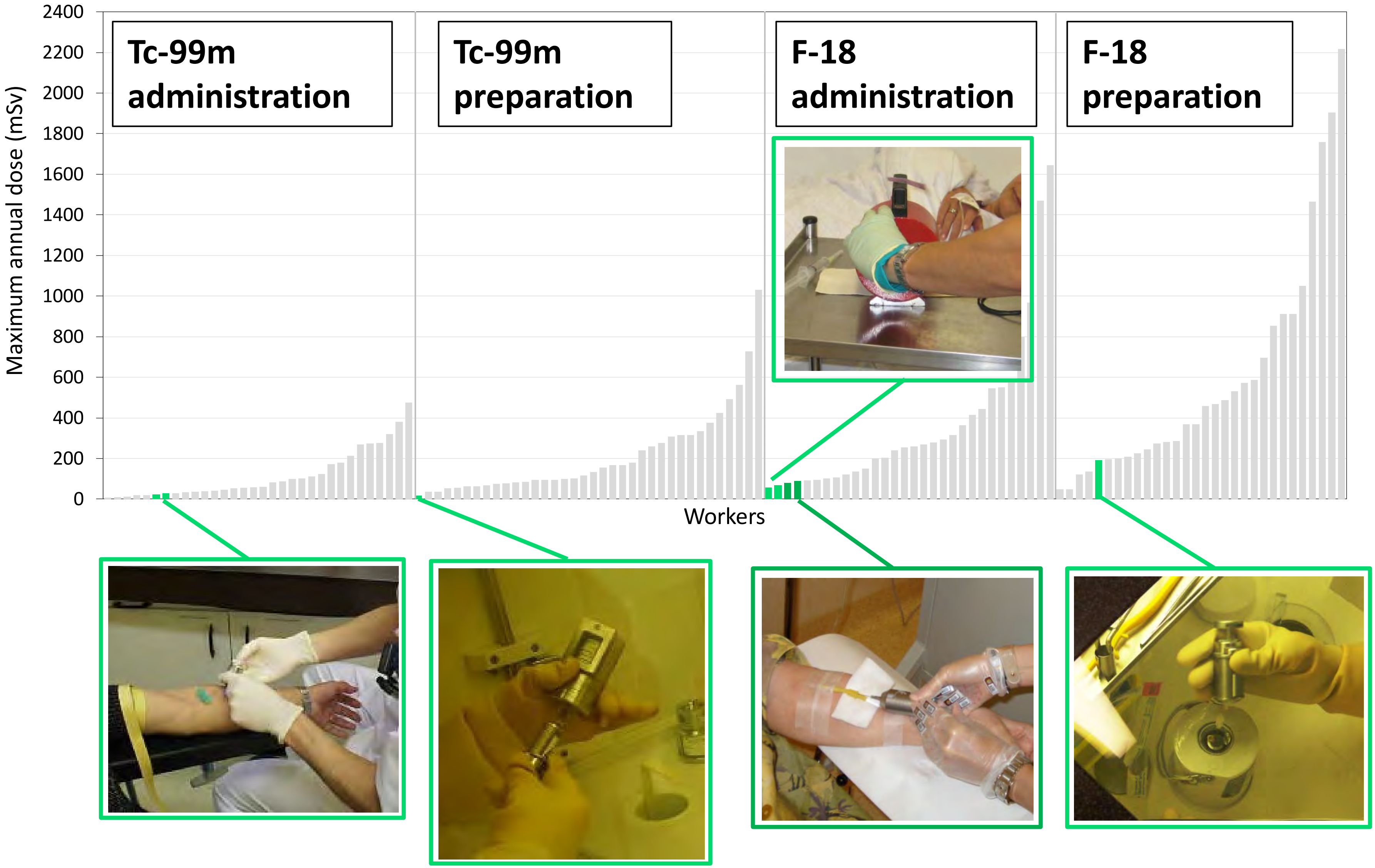




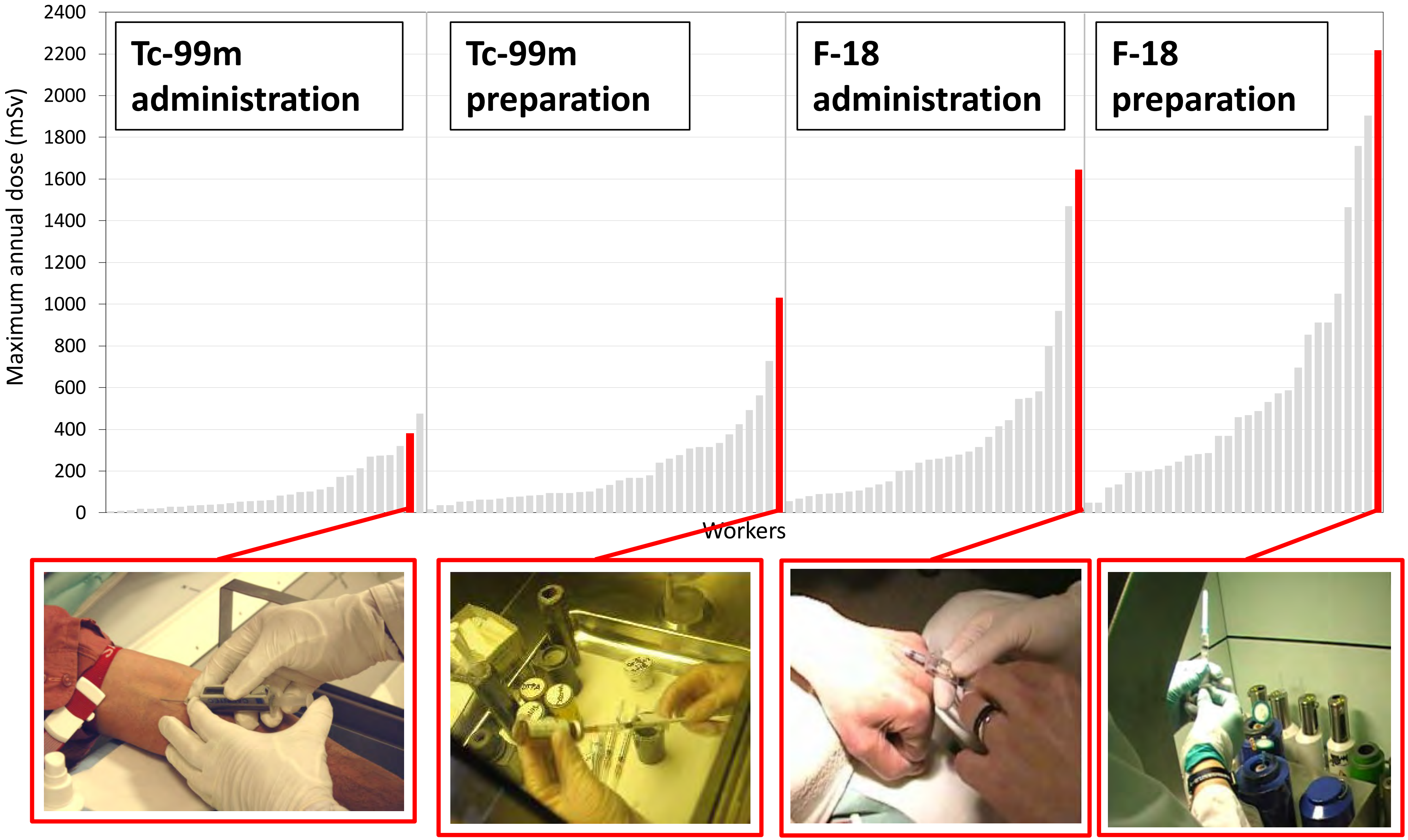
- Very large range of maximum finger doses among the same procedure

- Very large doses even for a single procedure.

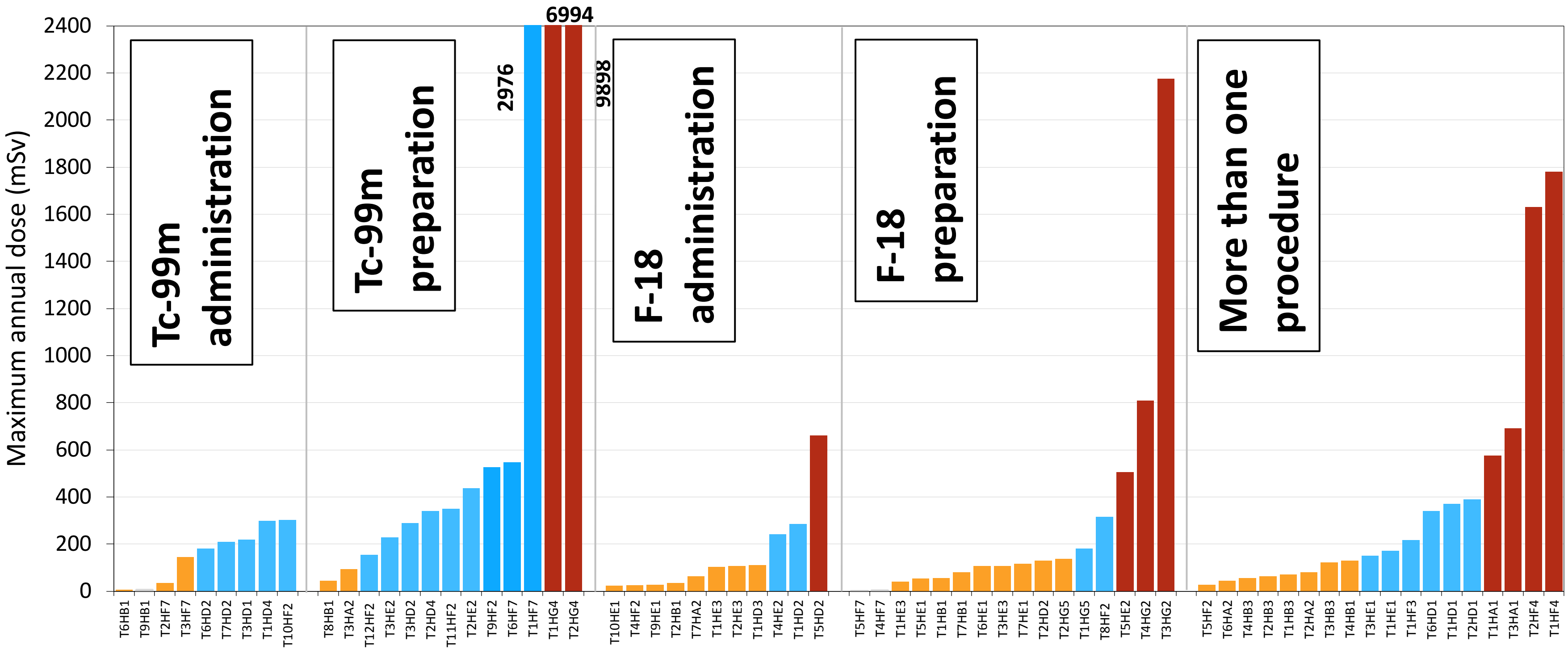
Good practices



Bad practices



Annual dose estimation



D < 150 mSv → 49%

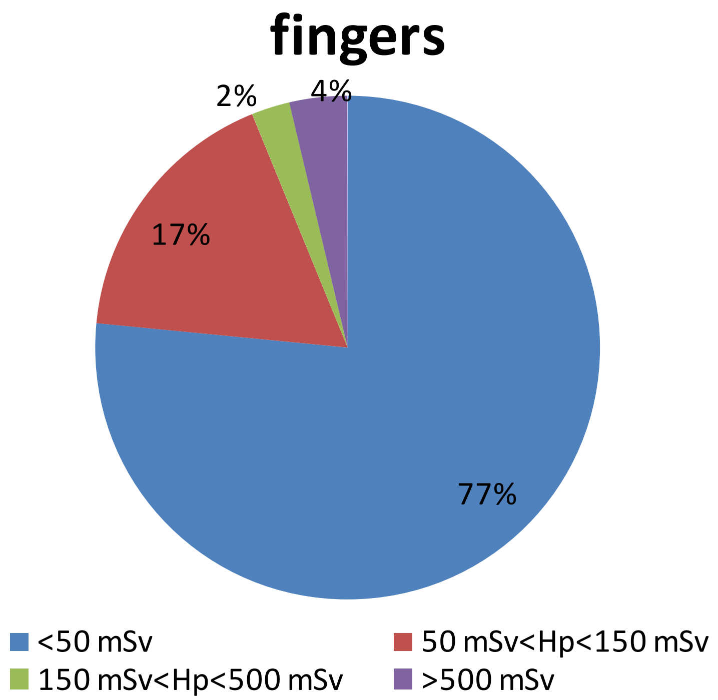
150 mSv < D < 500 mSv → 31%

D > 500 mSv → 19%

Some workers were monitored for only one type of procedure for the ORAMED project when actually they performed more.

ORAMED: Extremity doses in interventional procedures

- Wide range of staff doses
  - Importance of protective measures, personal habits
- Feet and legs can have higher doses



4. Indications from simulations

- Numerical simulations can be very powerful and can provide important information on the parameters affecting and influencing the doses

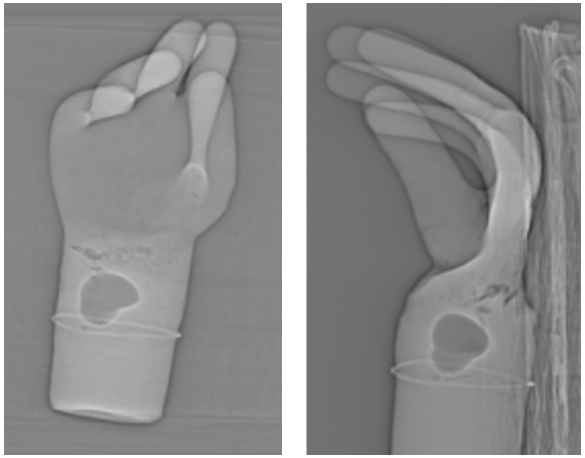
- Simulations are often complex and time consuming

From real to numerical world

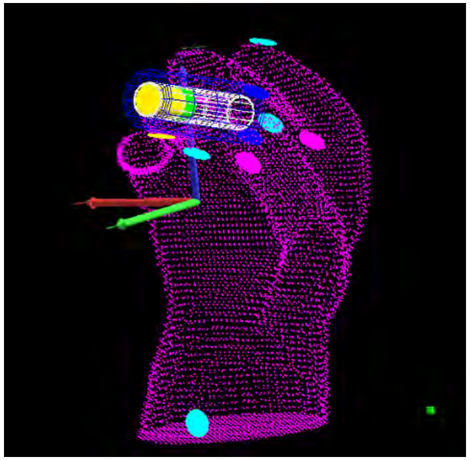
1. Defining the case

2. Creating a moulding

3. Scanning the moulding



4. Generating a voxel phantom



5. Adding the source and dosemeters

5. Indications from confirmatory measurements

- Measurements to assess the level of doses to the workers in the specific workplace field.

- Confirmatory measurements can be used as guidance in determining whether the monitoring level might be reached.

- Shall fulfil the following requirements:
  - the confirmatory measurements shall mimic routine measurements:
  - the working procedures shall not be changed because of the confirmatory measurements
  - the confirmatory measurements shall be performed for a minimum of 3 consecutive periods. The intention is to have a representative sample of the annual doses.

Locations for monitoring

- The skin of the extremities is the limiting organ rather than the extremity itself.
  - Therefore, an extremity dosemeter becomes a skin dosemeter
  - Shall be placed as close as possible to the most exposed part of the skin surface.

- In non-uniform fields, it is often difficult to place one single extremity dosemeter at the most highly exposed part of the skin since this part is not known a priori.

- In addition, it is not always the hands or fingers that are the most exposed area, also legs or feet can be the most exposed area.

Locations for monitoring

- For direct or close handling of radioactive sources, finger-stall dosemeters on the fingertip, or ring dosemeters should be used on the finger which is frequently the most exposed.

- The dosemeter should be oriented towards the radiation source.

- For nuclear industry fields, interventional radiology, or other similar radiation fields, either a ring dosemeter or a wrist dosemeter worn at the most exposed hand shall be used.

- The dosemeter shall be worn under protective clothing, especially inside gloves, if such clothing is worn.

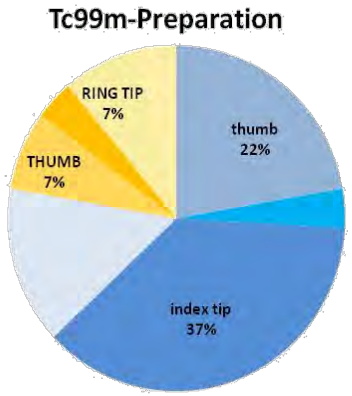
- The dosemeter can also be worn outside the protective clothing, but under an appropriate thickness of material that approximates the type and thickness of the protective clothing.

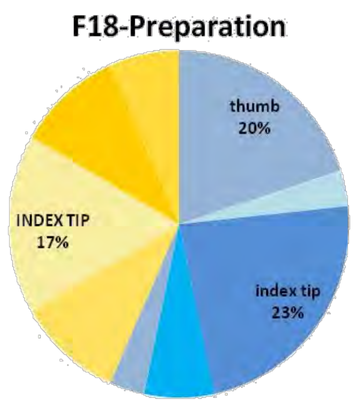
Application of correction factors

- Common extremity monitoring positions, such as the base of the fingers or the wrist, often underestimate the maximum dose.
    - To estimate the maximum skin dose from a routine dosemeter, a correction factor shall be established and employed.
- This value could be determined independently for each worker by individual measurements for a short trial period.
- Existing correction factors can be employed considering the routine monitoring position.

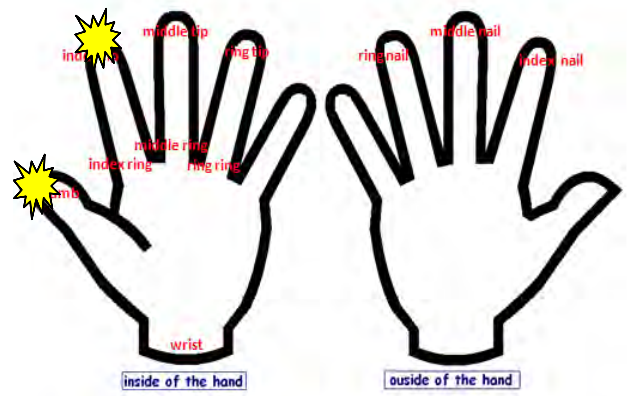
ORAMED: Frequency where maximum is found

Preparation

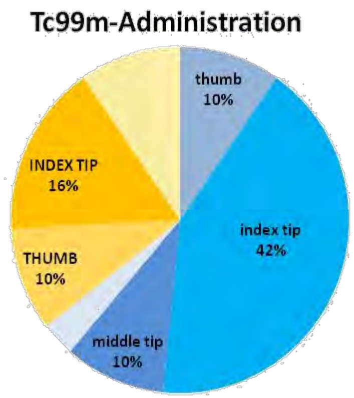


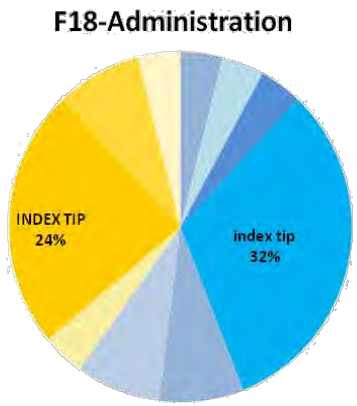


Tc-99m



F-18





Administration

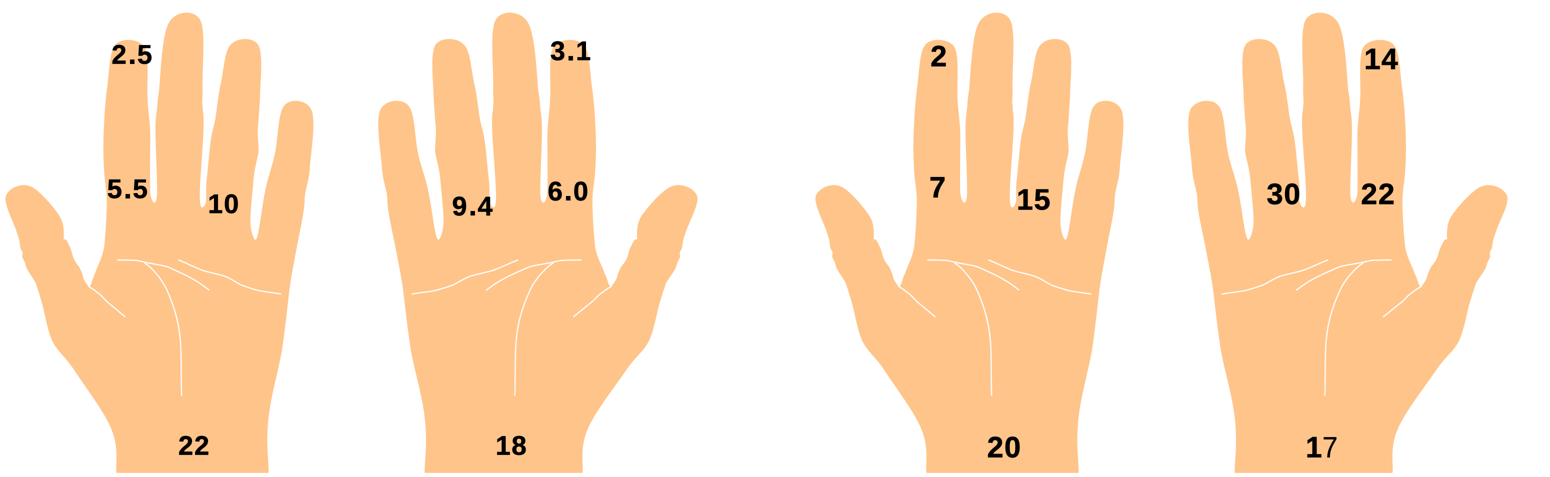
The most exposed positions on the hand are the tip of the index finger and the thumb, usually of the non-dominant hand.

Non dominant hand

DOMINANT HAND

Recommendation ORAMED

A rough estimate of the maximum dose to the hand can be obtained by multiplying the reading of the dosemeter worn in the base of the index of the non dominant hand by 6.



Diagnostics

Therapy

Application of correction factors

- C. Martin (Nucl Medicine Communication): tip of index finger is likely to receive highest dose
  - This position recommended for monitoring
  - Base of index finger receives factor 2-4 less than of tip dose
  - Higher factors when not using syringe shields
- Other studies:
  - Ranges from 1.4 to 7.0 for different manipulations and operators
- For nuclear medicine, ICRP Publication 106 recommends placing the routine dosemeter on the base of the middle finger with the detector positioned on the palm side. In this case, a correction factor of 3 (6 if the dosemeter faces the back) can be applied to get the value at the tip of the finger.

- Martin, Whitby: Interventionalists and cardiologists
  - During percutaneous procedures: tips of middle and ring were highest, but only 20-30% higher than base
  - Ring dosemeters are ok: ring or middle finger on both hands

Types of dosemeters

- The dosemeters used for extremity monitoring are generally based on passive techniques and made of thermoluminescent (TL) materials
  - other methods, such as film badges, optically-stimulated luminescence (OSL) and radiophoto luminescence (RPL) can also be used.
  - Electronic devices, e.g. made of small silicon probe(s) wire-connected with a command and reading box are available.

- Many whole body dosemeters are also capable of measuring skin doses through $H_p(0,07)$. In principle these dosemeters can also be used to measure the skin dose on different parts of the body.

- The technical specifications for extremity dosimetry systems measuring the quantity $H_p(0,07)$ shall be as defined in **IEC 62387** for passive dosemeters and **IEC 61526** for active dosemeters.

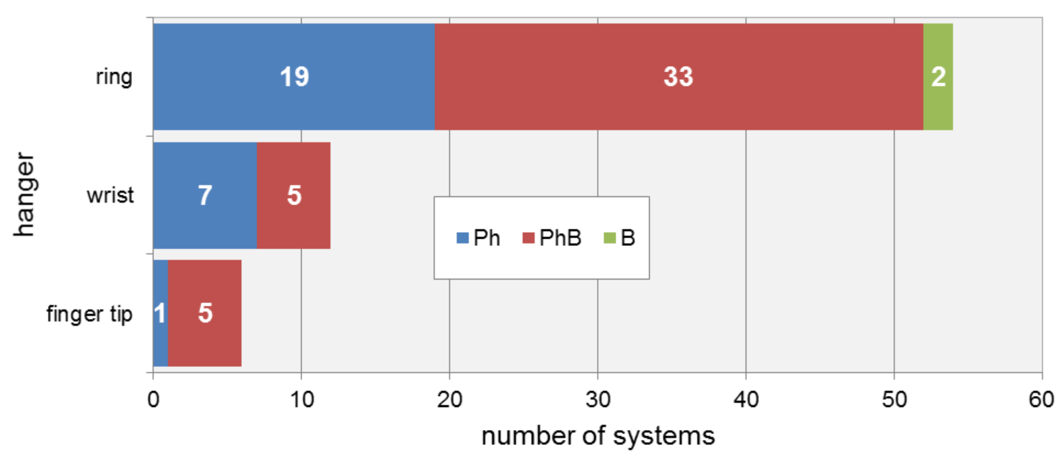
EURADOS intercomparisons on EXTREMITY dosemeters (2015)

A.F. McWhan, M. Figel, T.W.M. Grimbergen,
A. M. Romero, H. Stadtmann, Ch. Gärtner

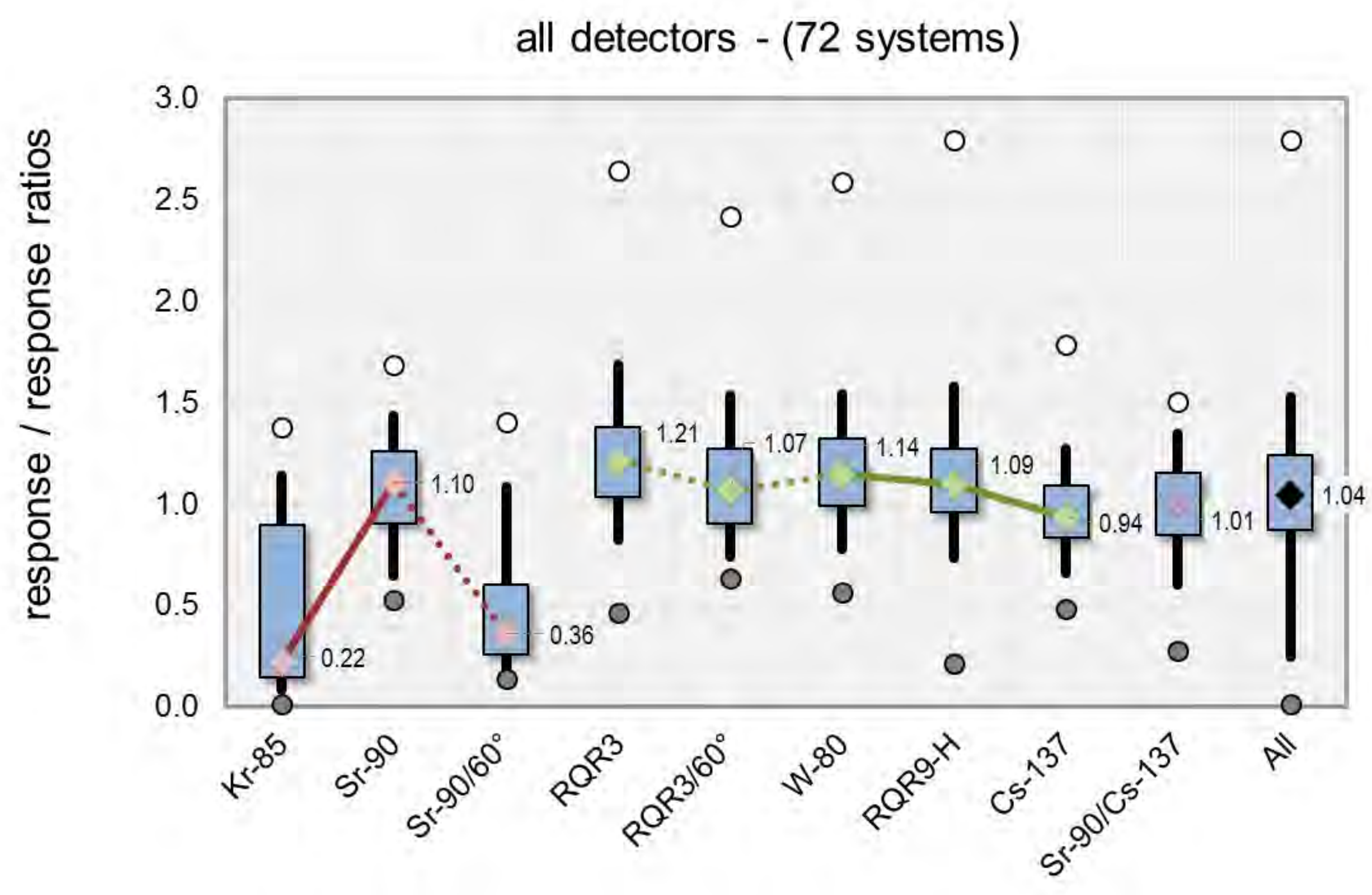
European Radiation Dosimetry Group

Dosemeter types

detector type	systems	% of all	% of type
TLD	**69**	**96%**	
LiF:Mg,Ti	36	50%	52%
LiF:Mg,Cu,P	29	40%	42%
$Li_2B_4O_7$:Cu	3	4%	4%
LiF:Mg,Ti/LiF:Mg,Cu,P	1	1%	1%
Other	**3**	**4%**	
AlO	2	3%	67%
LiF T-100	1	1%	33%
All	**72**	**100%**	

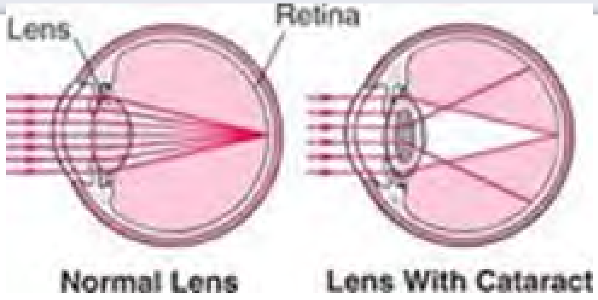


All response values



EYE LENS DOSIMETRY

What is cataract?



- Cataract: “loss of transparancy of the lens of the eye”
  - Starts with lens opacities
- Cataract: most frequent cause for blindness worldwide
  - Genetic component
  - Age related effect
  - Additional risk factors include
    - Sunlight, alcohol intake, nicotine consumption, diabetes, use of corticosteroids
  - Also induced by RADIATION…

- Types of cataract: nuclear, cortical, posterior subcapsular
- Radiation: mainly posterior subcapsular (but not exclusively)

Former ICRP position

- Former ICRP
  - Cataract induction = deterministic effect with definite threshold
    - Acute exposure: 0.5-2 Gy
    - Prolonged exposure: 5 Gy (detectable opacities)
    - Prolonged exposure: 8 Gy (visual impairment)
  - Latency period that can last for decades
  - Dose limits:
    - 150 mSv/year for professional exposure

ICRP position: recent developments

- Now better techniques, better dosimetry
  - Recent findings of radiation induced cataract at lower doses
  - No indication that fractionated is less harmful then acute exposures
- ICRP 118:
  - threshold dose around 0.5 Gy for acute exposures
  - Not certain there is a threshold
  - Idem for fractionated exposures (but for opacities instead of cataract)

- **ICRP statement 2011:**
  - **new proposed eye lens limit: 20 mSv per year**

  (averaged over 5 year, with not more than 50 mSv/year)

Practical implications of changed dose limit

- International Basic Safety Standards was approved by the Board of Governors of the International Atomic Energy Agency (IAEA) at its meeting in September 2011
- The revised dose limit was incorporated into the BSS.
- European BSS also took over de new limit
- This new limit will come in EC national legislations, latest 2018
- New documents:
  - IAEA Tech doc 1731: "Implications for occupational radiation protection of the new dose limit for the lens of the eye"
  - IAEA Safety Guides: Occupational Radiation Protection
    - Includes monitoring for external radiation (and lens of the eye)
  - Report IRPA task group
  - **ISO 15382**

Quantities: how to measure the eye lens doses?

- Dose limit: 20 mSv/year
  - for $H_{T,\ eyelens}$: equivalent dose at the eye lens

- Not directly measurable
  - Need for operational quantity: $H_p(3)$
  - $H_p(3)$: Equivalent dose at 3 mm depth

- Operational quantity > limiting quantity

- $H_p(3)$ hardly used
  - Few dosemeters are designed for $H_p(3)$, but now increasing

- Also, Rolf Behrens (PTB) has shown in many publications:
  - $H_p(0.07)$ or even Hp(10) can sometimes be used as a good operational quantity

Monitoring levels and periods

- The following monitoring levels are recommended:

  - 3/10th of the limit, as recommended in European BSS

  - For the lens of the eye: if there is a reasonable probability to receive a dose in a single year greater than 15 mSv or in consecutive years greater than 6 mSv per year.

  - For dose levels expected to be lower than the recommended monitoring levels, a survey, demonstrating that the levels are not exceeded, should be sufficient.

- For doses above the monitoring level, a monitoring period of one month is recommended

Characterisation of radiation fields

- Characterization of the radiation fields is an important step to determine the need for and the type of monitoring required.
  - Photon fields (X and gamma radiation) of any energy can contribute to the skin, extremity and lens of the eye exposure.
  - Electrons (beta radiation) with energy above 700 keV penetrate 3 mm of tissue and can contribute to the dose to the lens of the eye.

- In medical fields, the type of radiation and radionuclides are very well known.
- In nuclear installations, low energy betas are to be expected in the vicinity of unsealed radioactive materials. In nuclear installations handling used fuel as well as in nuclear reactors experiencing fuel leakage high energy betas (above 700 keV) should be expected.

Assessment of dose levels prior to monitoring

- Prior to routine monitoring, it is important to assess the dose levels in a workplace field situation in order to decide which method and period of routine monitoring that is necessary.
- The doses obtained should be extrapolated to annual doses and compared with the monitoring levels
- The assessment should be repeated when the working conditions or workload change significantly, or if the effect of such changes cannot be estimated with confidence.

1. Indications of workplace monitoring

- In work situations with radiation fields that are predictable over a long period: possible to estimate the worker doses using workplace measurements at relevant locations.

- For area dosemeters measuring the quantity H'(3), no International Standard is yet available.

2. Indications of whole body monitoring

- The results from the whole body dosemeter can give an indication of the level of exposure to the lens of the eye, provided the exposure conditions and the radiation field characteristics (especially the spatial distribution) are taken into account.

- When the whole body dosemeter is worn under the protective clothing: can therefore not be used to provide an indication of the level of the eye lens doses.

Whole body monitoring: collar dosemeter

- Some studies suggest estimating the dose to the lens of the eye from a well-placed dosemeter at collar level

  - Generally: this might be acceptable in homogenous fields with higher energy radiation
    - But not recommended in other fields.

  - For example, for interventional radiology different correction factors have been published to convert collar doses (above the lead apron) to doses to the lens of the eye for interventional procedures.

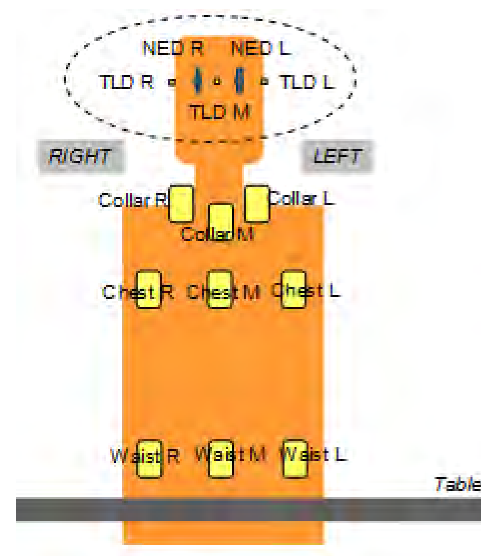
    - Such correction factors are very dependent on the type of procedure, personal habits, the exact place of the above apron dosemeters and the protection measures taken, so they cannot be applied to all routine cases.

    - No defined conversion factors to suggest…

- Such a system can however provide good indications of when dedicated eye dosimetry is required

Correlation between whole body dose and eye lens doses: ELDO project (IRSN+SCK•CEN)

- Material and methods
  - X-ray systems: 1 single-tube Philips (Optimus 50) and 1 bi-plane Siemens (Axiom Artis)
- Set-up
  - Worker: Rando phantom, Patient: PMMA slab phantom
  - 70-110 kVp
  - PA, AP, RLAT, Oblique,…
  - Position worker and field size changed
  - Dosemeters above lead apron: eye, collar, chest, waist level
  - 50 set-ups
  - Without protection



No good correlation between eye lens and collar doses

Ratio of average **left eye** lens dose and whole body dose measured at different locations, considering **all projections and operator positions**.

	Collar L	Collar M	Collar R	Chest L	Chest M	Chest R	Waist L	Waist M	Waist R
Ratio	3.3	2.1	11.5	0.8	1.2	2.5	1.5	1.8	8.0
Standard deviation	**42%**	48%	81%	90%	73%	100%	159%	143%	147%

Best correlation: between 1,9 and 4,7: factor of 3

Ratio of average **left eye** lens dose and whole body dose measured at different locations, considering projections and operator positions for **CA&PTCA and RF ablations**.

	Collar L	Collar M	Collar R	Chest L	Chest M	Chest R	Waist L	Waist M	Waist R
Ratio	4.0	2.6	12.8	0.7	1.0	1.9	0.5	0.7	3.7
Standard deviation	**41%**	40%	56%	52%	56%	50%	46%	64%	101%

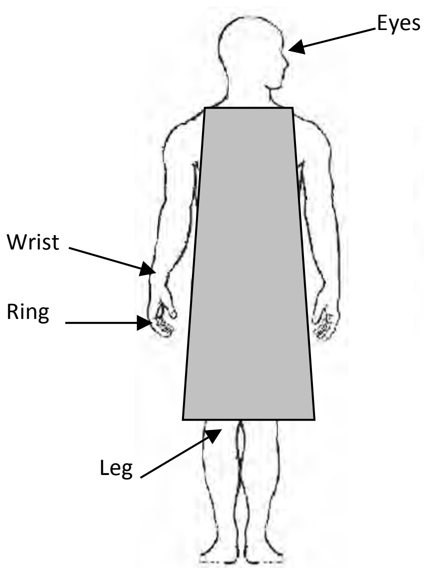
Reduced uncertainties

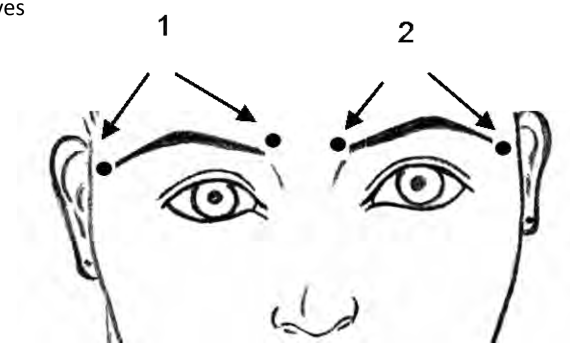
3. Indications of literature

- In the literature, some typical dose values are given for various workplace situations. These can in principle be used to judge if monitoring is needed.

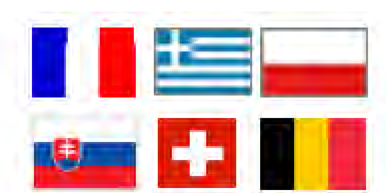
- When using literature it should be ensured that the data are truly representative of the current workplace conditions regarding the radiation source, the geometry and types of protective measures

ORAMED: Eye lens doses in interventional procedures





- Two measurement for eye doses
  - Middle eye
  - Left/right eye
    - Depending on tube location
- TLD in bag
- >1300 measurements in IC and IR



Annual doses ERCP:
Low, monitoring normally not needed

Operator	Procedure	# procedures	Annual dose [mSv]
1	ERCP	100	**50**
2	ERCP	107	**3,9**
3	ERCP	30	**0,3**
4	ERCP	70	**0,6**
5	ERCP	110	**2**
6	ERCP	100	**0,2**
7	ERCP	300	**0,4**
8	ERCP	1281	**17**
9	ERCP	689	**6**
10	ERCP	70	**0,7**
11	ERCP	107	**5**
12	ERCP	250	**2**
13	ERCP	125	**1,2**
14	ERCP	150	**1,4**
15	ERCP	230	**2**
16	ERCP	36	**3,4**
17	ERCP	150	**9**

Annual doses CA/PTCA:
Can be high, monitoring recommended or required

Operator	Procedure	# procedures	Annual dose [mSv]
1	CA/PTCA	260	**10**
2	CA/PTCA	230	**28**
3	CA/PTCA	750	**47**
4	CA/PTCA	1200	**69**
5	CA/PTCA	1000	**46**
6	CA/PTCA	710	**10**
7	CA/PTCA	900	**26**
8	CA/PTCA	600	**11**
9	CA/PTCA	630	**11**
10	CA/PTCA	630	**12**
11	CA/PTCA	500	**5**
12	CA/PTCA	1000	**27**
13	CA/PTCA	500	**30**
14	CA/PTCA	600	**9**
15	CA/PTCA	1100	**9**

Half are above 20 mSV !!!

Annual doses both PM&ICD and RF ablations: monitoring might be required

Operator	Procedure	# procedures	Annual dose [mSv]
1	PM&ICD+RF abl	150+60	**88+63**
2	PM&ICD+RF abl	190+190	**24+13**
3	PM&ICD+RF abl	90+190	**25+7**
4	PM&ICD+RF abl	110+50	**0.8+1.5**
5	PM&ICD+RF abl	40+20	**4+0.1**
6	PM&ICD+RF abl	40+20	**7+0**
7	PM&ICD+RF abl	80+350	**1+5**

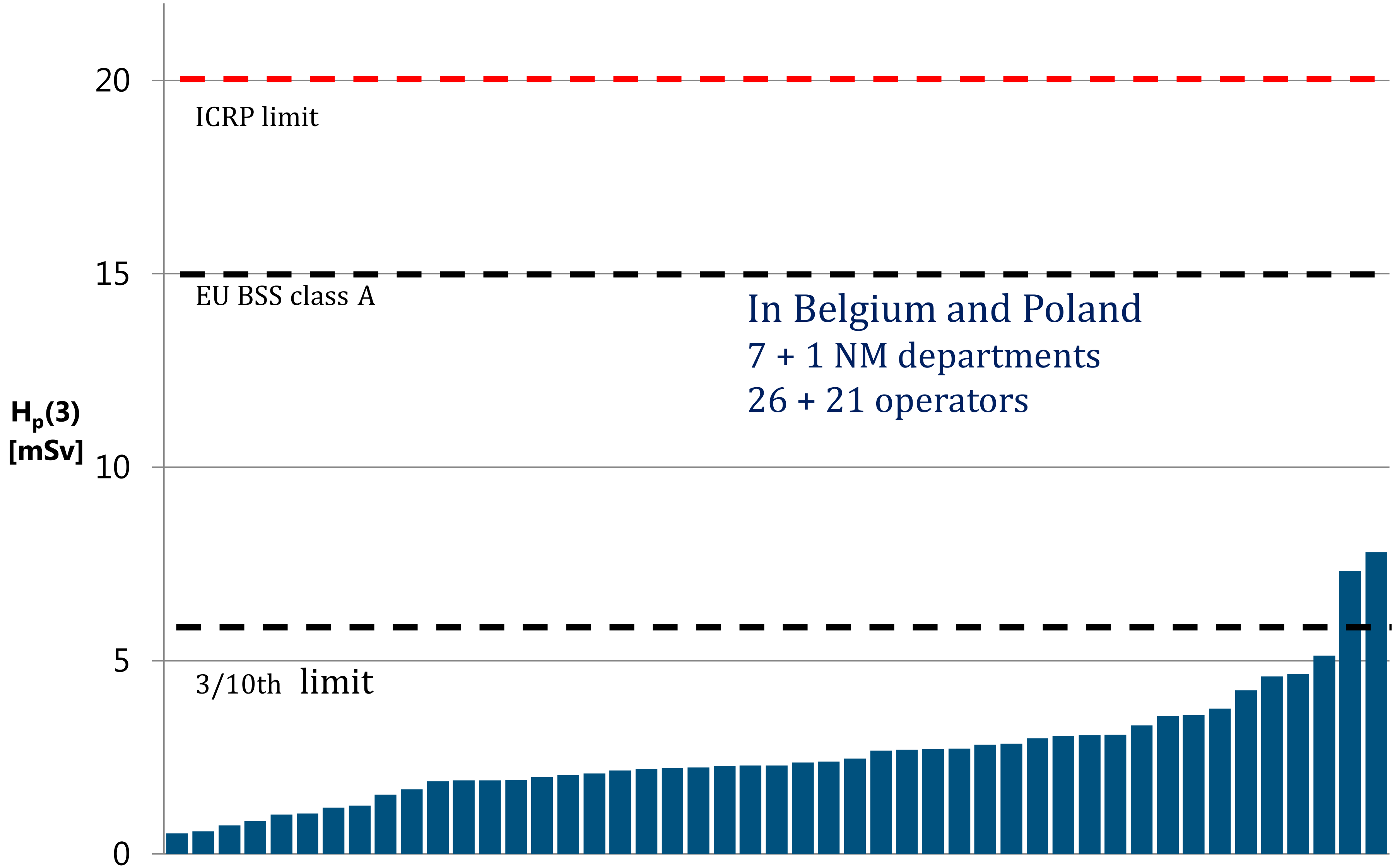
Annual doses:

Embolizations and DSA: often combinations different type of procedures: difficult to estimate monitoring is required

Operator	Annual dose [mSv]
1	**27**
2	**23**
3	**6**
4	**4**
5	**15**
6	**4**
7	**11**
8	**31**

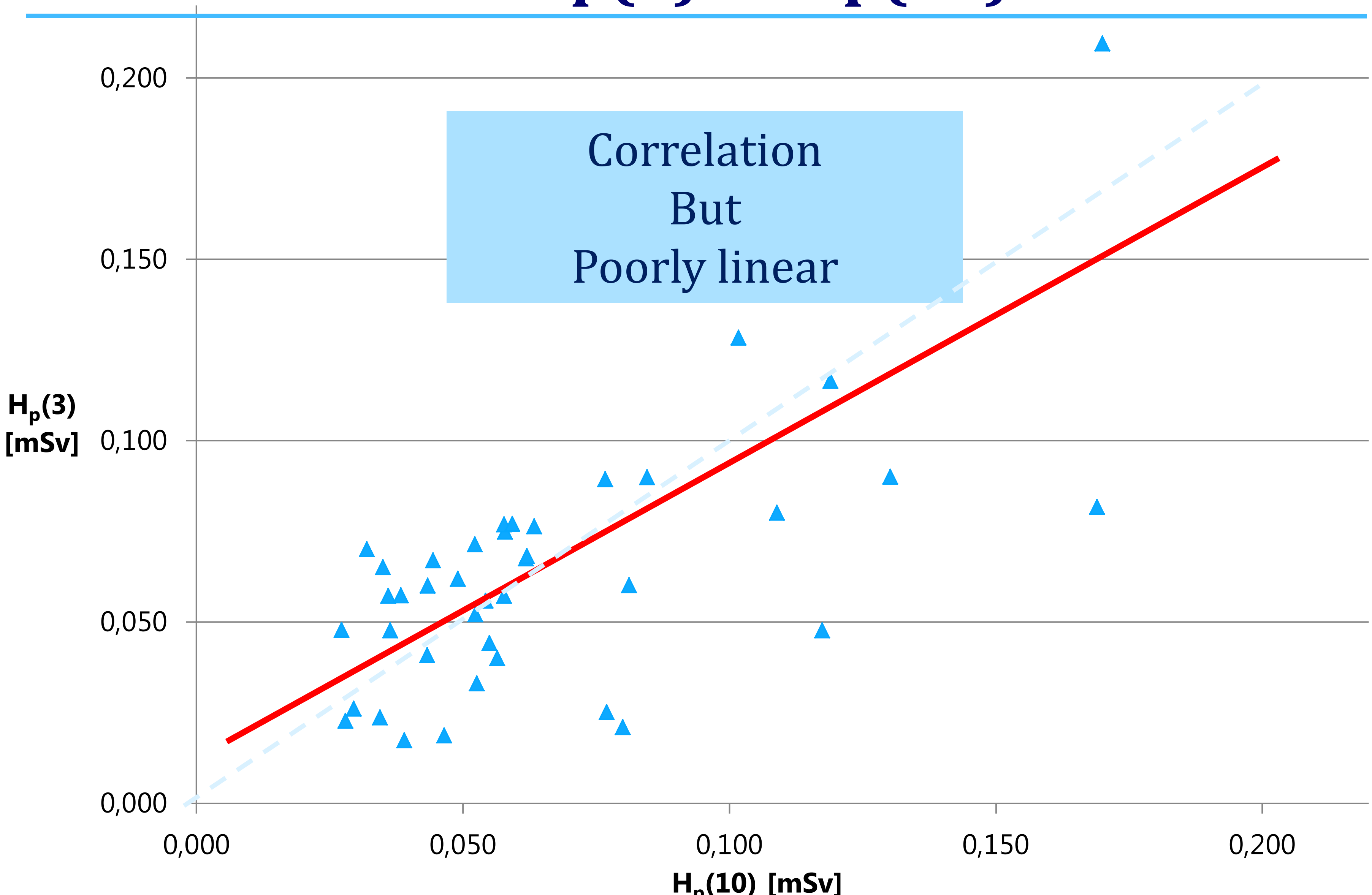
Operator	Annual dose [mSv]
9	**14**
10	**10**
11	**7**
12	**14**
13	**20**
14	**49**
15	**85**
16	**9**

New study : Annual eye lens doses (diagnostic)



Weekly dose extrapolated to annual dose

Hp(3) Vs Hp(10)



Correlation
But
Poorly linear
$H_p(3)$ [mSv]
0,200
0,150
0,100
0,050
0,000
0,000
0,050
0,100
0,150
0,200
$H_p(10)$ [mSv]

4. Indications from simulations

- Numerical simulations can be very powerful and can provide important information on the parameters affecting and influencing the doses

- Simulations are often complex and time consuming

- When using simulations, it is necessary to validate the results with measurements.

5. Indications from confirmatory measurements

- Measurements to assess the level of doses to the workers in the specific workplace field.

- Confirmatory measurements can be used as guidance in determining whether the monitoring level might be reached.

- Shall fulfil the following requirements:
  - the confirmatory measurements shall mimic routine measurements:
  - the working procedures shall not be changed because of the confirmatory measurements
  - the confirmatory measurements shall be performed for a minimum of 3 consecutive periods. The intention is to have a representative sample of the annual doses.

Monitoring the lens of the eye

- Locations to monitor
  - The dosemeter:
    - as close as possible to the eye
    - if possible in contact with the skin
    - faced to the radiation source
    - interventional radiology: the side closest to the X-ray tube
  - When using protective lead glasses or face masks
    - dosemeter shall be worn preferably behind them
    - This is often not very practical
      - a dosemeter above on the outside or next to the lead glasses can be chosen
      - It can be an option to cover the front of the dosemeter with a filter that mimics the attenuation by the lead glasses
- In practical situations, dosemeters are often placed in various positions: above the eyes, at the forehead, at the side of the head, between the eyes

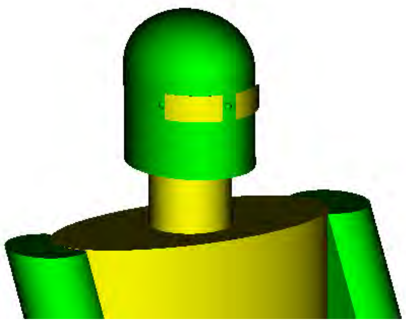
Application of correction factors

- If the dosemeter for the lens of the eye is not worn optimally (not close to the lens of the eye or behind shielding like e.g., lead glasses), then appropriate correction factors shall be applied.
  - These factors shall normally be determined by means of measurements, possibly accompanied by numerical simulations.

- Correction factors to be used should be conservative and are likely to be in the range of 0,2 to 0,3. If no facility or expertise is available to assess protection, then a correction factor of 0,5 may be applied..

Lead glasses: ORAMED study

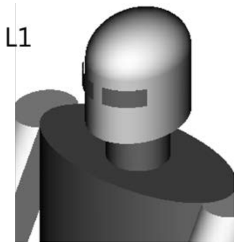
- The radiation attenuation factor of the eyeglass lenses is not an adequate descriptor
  - Maybe a factor of 100
- There is always backscatter in the head



	Left eye Ratio with/without glasses	
	PA	**CRA20**
No lead glasses	**1**	**1**
Small lens (0.5 mm Pb)	**0.30**	**0.28**
Large lens (0.5 mm Pb)	**0.15**	**0.14**
Small and thick lens (1.0 mm Pb)	**0.26**	**0.25**
Large and thick lens	**0.14**	**0.13**

Results Monte Carlo study ELDO (Struelens, Farah, Koukorava)

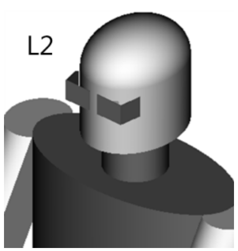
- *Space between glasses and head*



reference

L1

Left eye	PA	0,15	0,27	0,47
	LLAT	0,12	0,32	0,55



L2

reference

Right eye	PA	0,41	0,77	0,96
	LLAT	0,75	0,94	0,98

Conclusion: ELDO

- Considering ALL parameters, the average protection efficiency:
  - L1:
    - Left eye: 0,26 +/- 63%
    - Right eye: 0,79 +/- 30%
  - L2:
    - Left eye: 0,60 +/- 39%
    - Right eye: 0,69 +/- 39%
- Difference in protection of left and right eye for L1
  BUT actual dose received by right eye is also lower than left eye

- Protection of the eye depends on
  - Type of lead glasses (shape, how it fits, thickness)
  - The working procedure (beam projections, positions of the operator)

Types of dosemeters

- Doses to the lens of the eye: by measuring the operational quantity $H_p(3)$.
- Dosemeters designed to measure $H_p(3)$ were very rare in the past, but recently specifically designed $H_p(3)$ dosemeters became available
- If the radiation field is well known in advance, $H_p(3)$ monitoring can be performed by the use of dosemeters type tested and calibrated in terms of other quantities, i.e., $H_p(0,07)$ and $H_p(10)$

Exemples of avalable dosemeters

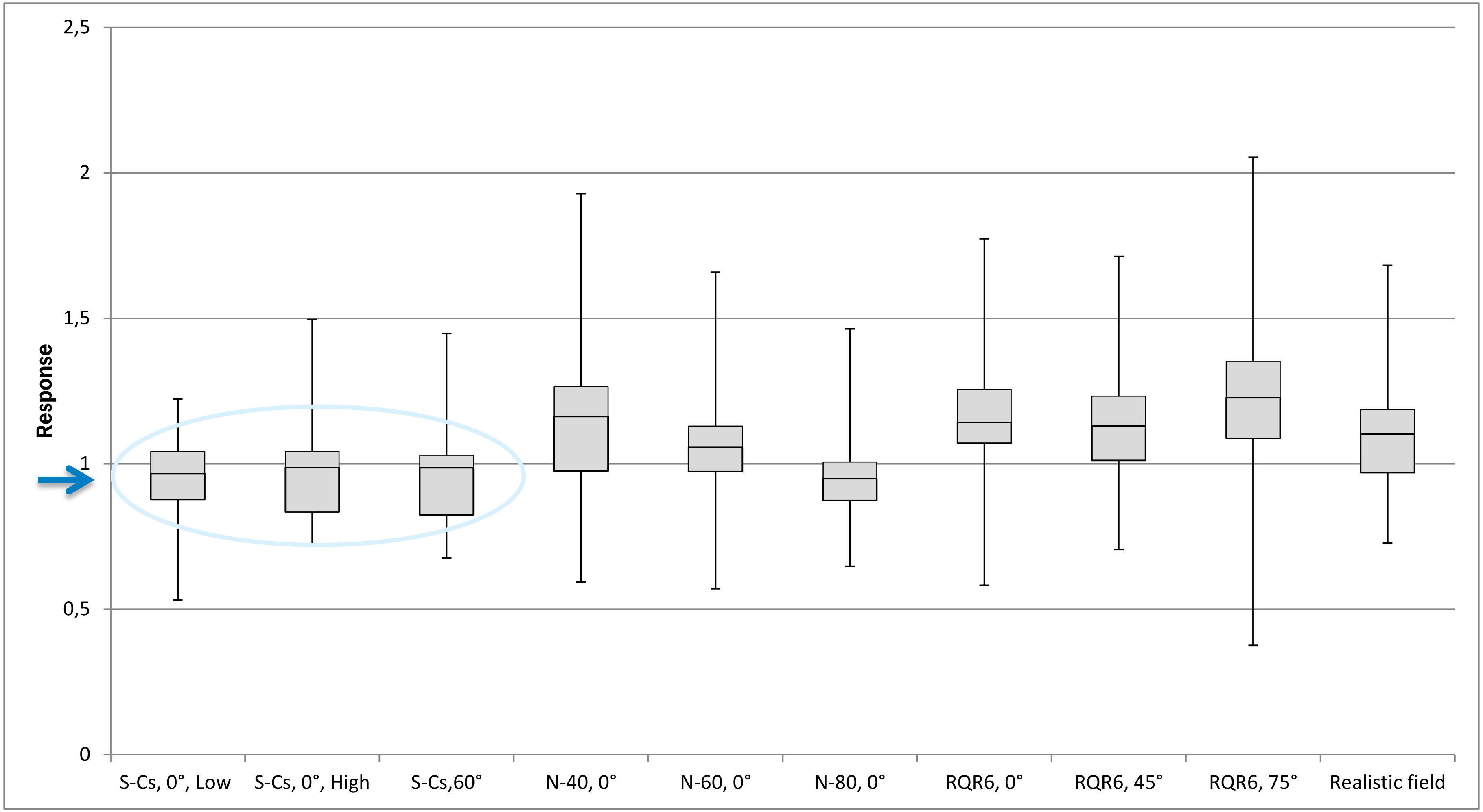
AV-Controlatom Belgium

IRSN France

EYE-D™ (Radcard)

DOZIMED S.R.L. Roumania

Results: EURADOS intercomparison exercise of eye lens dosemeters for medical applications



In conclusion

- Monitoring the skin, the extremities and the lens of the eye is not always straightforward
    - Specialized dosimetry is needed
- Many international documents available and under development
- ISO 15382: can give you guidance for skin, extremity and eye lens monitoring