Skin dose rate conversion factors after contamination with radiopharmaceuticals: influence of contamination area, epidermal thickness and percutaneous absorption

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Skin contamination radiopharmaceuticals?

Directly
- Spills
- Removing needles/catheters
- Body fluid of patients / laboratory animals

Cross contamination
- Contaminated surfaces
- Contaminated tools / protective equipment

High amounts can lead to high skin doses
Refresher: skin structure

~ 70 µm on most body sites

Sensitive basal layer
Refresher: skin dose in radiation protection?

Equivalent skin dose $H_{\text{skin}}$ (Sv)

- Special occupational skin dose limit for localised exposures: 500 mSv.y$^{-1}$
- To be averaged over any 1 cm$^2$ area of exposed skin, regardless of the area exposed, at the nominal depth of nominal depth 70 µm.
  - Highest contaminated 1 cm$^2$ important!
- Approached by operational quantity “$H_p(0.07)$”
Incidence after survey in the field of nuclear medicine

Mean incidence: 40 cases out of 560 inspections (7%)  
 Mostly very localised (80% at volar fingertips)  
 Contamination activities over 1 cm$^2$: 0.2 – 500 kBq
Calculation of cumulated skin dose

2 important factors:

- Contamination activity (Bq) + course of the contamination activity in time

- Radionuclide related equivalent skin dose rate conversion factor ($\text{mSv.h}^{-1}.\text{Bq}^{-1}$)
Quantification of the activity of a skin contamination

Limited accuracy with common contamination monitors

Calibrated gamma spectrometer

- Enables to identify/quantify the contamination activity accurately
- Quantification over 1 cm$^2$ (1cm$^2$-collimator)
Contamination area

Contamination spot

Detector

Measured activity: 1 kBq

Contamination area = 1 cm²

Skin surface
Simplified geometry
MCNP-simulations

Air

Skin tissue

Disk source of 1 cm$^2$

Dose averaging area 1 cm$^2$
(basal layer epidermis)

70 µm

Equivalent skin dose = energy deposition over 1 cm$^2$ area
Influence of contamination area (MCNP)

Limited underestimation ~ 10%
If 1 cm² is used
Low-energy electrons in skin contamination dosimetry

Limited dose contribution when handling syringe (electrons stopped in liquid/wall)

Very large dose contribution for contaminations!

Not only for pure $\beta$-emitters: $^{18}\text{F}$, $^{90}\text{Y}$,…
Also for typical radionuclides:
$^{99m}\text{Tc}$ (9% electrons 120 keV)
$^{111}\text{In}$ (5% 219 keV, 8% 145 keV,…)

...
Epidermal thickness at the hands

- ~ 70 µm on most body sites
- Wrist: ~ 80 µm
- Volar fingertips: ~ 370 µm
- Back of the hands: ~ 85 µm
- Sides of fingers: ~ 220 µm
- Backs of fingers: ~ 140 µm
- Wrist: ~ 80 µm

Epidermal thickness at the hands is important for understanding potential skin dose after contamination with radiopharmaceuticals.
Influence of epidermal thickness (MCNP)

- **Skin dose after contamination with radiopharmaceuticals**
- **P. Covens**
- **50 years BVS-ABR**
- **April 10, 2013**

### General
- Electron dose: $98\%$
- Dose rate conversion factor: $2.2 \times 10^{-1}$ mSv/h/kBq

### Back of the fingers
- Electron thickness: $140 \mu m$
- Electron dose: $99\%$
- Dose rate conversion factor: $1.2 \times 10^{0}$ mSv/h/kBq

### Side of the fingers
- Electron thickness: $220 \mu m$
- Electron dose: $98\%$
- Dose rate conversion factor: $6.1 \times 10^{-1}$ mSv/h/kBq

### Volar fingertips
- Electron thickness: $370 \mu m$
- Dose rate conversion factor: $3.4 \times 10^{-1}$ mSv/h/kBq

### Conversion Factors
- $^{99m}Tc$: $>99\%$ Electrons
- $^{18}F$: $99\%$ Electrons
- $^{131}I$: $98\%$ Electrons

### Specific Dose Rate Conversion Factors
- **General**: $2.2 \times 10^{-1}$ mSv/h/kBq
- **Back of the fingers**: $12 \times 10^{0}$ mSv/h/kBq
- **Side of the fingers**: $6.1 \times 10^{-1}$ mSv/h/kBq
- **Volar fingertips**: $3.4 \times 10^{-1}$ mSv/h/kBq
Decontamination

Typical course:

First decontamination important!

Remaining activity difficult to remove (percutaneous absorption)

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50 years BVS-ABR
April, 10 2013
Disk source on the top of skin: a snapshot!

Disk source on top of skin surface = snapshot!!

Detector will hardly observe a difference (D1 >> D2, limited attenuation of photons)

Bolzinger et al. 2010: 1 h after contamination 95% of Na$^{99m}$TcO$_4$ already located in the dermis! (Study using Franz diffusion cells)
Influence of percutaneous absorption (MCNP)

- **Disk source on top**: 
  - $^{99mTc}$: $2.7 \times 10^{-3}$
  - $^{18F}$: $5.1 \times 10^{-1}$
  - $^{131I}$: $3.4 \times 10^{-1}$

- **100% in epidermis**: 
  - $^{99mTc}$: $1.1 \times 10^{1}$
  - $^{18F}$: $1.5 \times 10^{1}$
  - $^{131I}$: $1.2 \times 10^{1}$

- **100% in dermis**: 
  - $^{99mTc}$: $4.1 \times 10^{-2}$
  - $^{18F}$: $7.0 \times 10^{-1}$
  - $^{131I}$: $5.4 \times 10^{-1}$

- **Bolzinger et al. 2010 (5% epidermis, 95% dermis)**: 
  - $^{99mTc}$: $4.4 \times 10^{-2}$

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50 years BVS-ABR
April 10, 2013
Contamination of 500 kBq $^{99m}$Tc measured over 1 cm$^2$ at the volar fingertips

Follow-up course of contamination by repeated quantification

Calculation total cumulated skin dose using appropriate skin dose rate conversion factors

$H_{\text{skin}} = 809$ mSv

Source on skin surface, 70 µm epidermal thickness

$H_{\text{skin}} = 10$ mSv

Source on skin surface, 370 µm epidermal thickness

$H_{\text{skin}} = 165$ mSv

Percutaneous absorption, 370 µm epidermal thickness
Conclusion

Contamination area: limited influence in calculating \( H_p(0.07) \), averaged over 1 cm\(^2\):

- Use of \( H_p(0.07) \) and source located on the skin surface
  - Miles from equivalent dose to basal layer
  - Epidermal thickness at specific body sites
  - Percutaneous absorption

\( H_p(0.07) \) remains important!

- Practical optimisation of radiation protection
- Proper evaluation needed if values \( \sim \) dose limit
Thank you for your attention!

Read more: *Journal of Radiological Protection* 33:381-393 (2013)