Skin contamination of nuclear medicine workers: incidence, routes, dosimetry and decontamination

Peter Covens
Introduction
Daily practice in nuclear medicine

Repeated manipulation of concentrated sources
High localised skin doses expected

External irradiation  Skin contamination
The skin in radiation protection

Skin structure

Epidermis
Dermis
Hypodermis

Epidermal thickness
~ 70 µm on most body sites

Stratum Germanitivum
(Sensitive basal layer)

Skin effects after high localised radiation exposure

- Erythema, desquamation, necrosis, dermal atrophy, ...
- Function of total dose and the time over which this dose is received
- Do NOT necessarily find their origin in the basal layer
The skin in radiation protection

International recommendations on localised skin radiation dose, $H_{\text{skin}}$:

1. Yearly skin dose limit for workers: **500 mSv**

   “To prevent cosmetically unacceptable skin effects after protracted exposure over many years”

2. To be averaged over any **1 cm$^2$** area of exposed skin.

3. Skin dose should be assessed at a depth of **70 µm** and approached by the operational quantity “$Hp(0.07)$”

Epidermal thickness ~ 70 µm on most body sites

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Localised skin doses in nuclear medicine

Skin doses from external irradiation
Localised skin doses in nuclear medicine

Skin doses from sealed manipulations
Localised skin doses in nuclear medicine

Skin doses from sealed manipulations

Many studies (local/multi-centre) have demonstrated...

- Very non-uniform distribution of skin doses across the hands
- Skin dose at fingertip >>> routine dosimeter locations
- Skin dose limit of 500 mSv/y can be exceeded at fingertips for high workload
- Optimisation/automation: substantial dose reduction!

Skin doses from skin contamination

Droplet from a 2 ml syringe with typical ref activity \(^{18}\)FDG

Theoretical skin dose \(Hp(0.07) = 470\) mSv!

Skin dose from sealed manipulations: tip of the iceberg?!
Important factors related to skin contamination dose

- Contamination incidence
- Contamination activity
- Efficacy of decontamination
- Skin contamination dosimetry
How can contaminations occur?

**Directly**

- Accidental spills
- Removal needles/catheters
- Contact body fluids of patients

**Cross contamination**

- Contaminated surfaces
- Contaminated tools / protective equipment
Detection and quantification of contaminations

Contamination check by workers

- Should be part of standard safety protocols
- Asks for self-discipline
- Quantification mostly limited by...
  - “yes/no”, “highly/moderately/slightly”

Contamination check by health physics experts / occupational physicians

- Difficult at a later stage (short-live radionuclides)
- Preferably on-site during daily nuclear medicine practice
Contamination incidence during 10-month on-site survey

Mapping the contamination incidence among nuclear medicine workers

On-site survey 10 months

Protocol based on fast detection/localisation/quantification

560 inspections carried out over 10 months
40 contaminations found (7% of the cases)

Very localised contamination spots
67% at volar fingertips
Contamination routes during 10-month on-site survey

- **Contaminated syringe shield (cross contamination):** 12 (31%)
- **Removal catheter/butterfly needle:** 11 (26%)
- **Contact with body fluid patient:** 2 (5%)
- **Unknown reason (cross contamination?):** 15 (38%)
Contamination activities during 10-month on-site survey

Qualification/quantification using portable $\gamma$-spectrometer

Identification of the radionuclide

Activity (Bq) over 1 cm$^2$ in the highest contaminated area

Contamination Activity (Bq)

- $^{99m}$Tc
- $^{18}$F

up to 0.5 MBq
Contamination skin doses during 10-month on-site survey

Qualification/quantification using portable $\gamma$-spectrometer

Identification of the radionuclide

Activity (Bq) over 1 cm$^2$ in the highest contaminated area

Skin dose? $H_p(0.07)$ (mSv)

Contamination Activity (Bq)

- up to 0.5 MBq

Activity ($Bq$) - $99m^{Tc}$, $18F$
Contamination skin doses during 10-month on-site survey

Qualification/quantification using portable $\gamma$-spectrometer

Identification of the radionuclide

Activity (Bq) over 1 cm$^2$ in the highest contaminated area

2 important factors:

Course of the contamination activity in time

Radionuclide related skin dose rate conversion factor (mSv.h$^{-1}$.kBq$^{-1}$)
Course of the contamination activity in time

Follow-up of each contamination by repeated quantification procedures

Very poor efficacy of the decontamination procedure!
Efficacy of decontamination of $^{99m}$Tc-labelled radiopharmaceuticals: >90%

Limited literature data

On-site survey:

⇒ Study the efficacy of decontamination in vitro using pig skin samples
Efficacy of decontamination in vitro

108 pig skin samples contaminated, successive quantification, decontamination

Factors:
- Radiopharmaceutical
- Decontamination agent
- Absorption time

Radiopharmaceuticals:
- \( \text{Na}^{99m}\text{TcO}_4 \)
- \( 99m\text{Tc-HDP} \)
- \( 99m\text{Tc-Tetrofosmin} \)
- \( ^{18}\text{FDG} \)

Immediate decontamination
- Decontamination after 30’
- Decontamination after 60’

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Efficacy of decontamination in vitro

108 pig skin samples contaminated, successive quantification, decontamination

Factors: radiopharmaceutical absorption time decontamination agent

Typical course during decontamination of pig skin samples:

1st decontamination effective, subsequent are less effective!

Factors influencing 1st decontamination during on-site survey already occurred before detection!

Course during on-site survey:

Factors influencing 1st decontamination?
Factors influencing the 1\textsuperscript{st} decontamination

- **Radiopharmaceutical**
- **Absorption time**
- **Decontamination agent**

**Multi-Factor ANOVA**

Absorption time has no influence!

Only for Na\textsuperscript{99m}TcO\textsubscript{4} a dedicated decontamination agent has a positive effect over neutral hand soap.
Skin dose rate conversion factors

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Skin dose rate calculated through Monte Carlo Simulations

Skin dose rate = energy deposition rate over the cylinder

Score energy deposition in the cylinder!!

Dose averaging area 1 cm² (basal layer epidermis)

Skin tissue
Air

Skin surface

Circular radiation source

Activity (Bq)

Circular collimator

Contamination area

Score energy deposition in the cylinder!!
Skin doses of contaminations during on-site survey

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Skin dose rate conversion factor (mSv.h(^{-1}).kBq(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{99m})Tc</td>
<td>2.17 (10^{-1})</td>
</tr>
<tr>
<td>(^{18})F</td>
<td>1.61</td>
</tr>
</tbody>
</table>

> 99% skin dose delivered by electrons

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Factors influencing skin dose rate conversion factors

Present skin dose rate conversion factors

- Circular source of 1 cm² on top of the skin surface
- Depth of the basal layer (epidermal thickness): 70 µm

Real situation?

- Size of the contamination area?
- Epidermal thickness?
- Percutaneous absorption?
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Size of the contamination area

Quantification procedure assumes exactly 1 cm²

Case of the highest skin dose during the on-site survey

Contamination area: limited influence on skin dose rate:
⇒ Quantification over 1 cm²: good approach

![Diagram showing quantification procedure and contamination area sizes](image)

- Measured activity in concentrated spot (e.g. 1 mm²)
- Measured activity part of a large spot (e.g. 100 cm²)

<table>
<thead>
<tr>
<th>Size</th>
<th>Cumulated Skin dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm²</td>
<td>809 mSv</td>
</tr>
<tr>
<td>1 mm²</td>
<td>820 mSv</td>
</tr>
<tr>
<td>100 cm²</td>
<td>843 mSv</td>
</tr>
</tbody>
</table>
Epidermal thickness

Dose rate conversion factors simulated at a depth of 70 µm (basal layer)

- ~ 70 µm on most body sites
- ~ 370 µm at the volar fingertips!

Monte Carlo Simulations

Epidermal thickness: large influence on the skin dose
Range in tissue is limited for low energy electrons!
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1 h after contamination: 95% of absorbed Na\textsuperscript{99m}TcO\textsubscript{4} already located in the dermis!

Percutaneous absorption of the radiopharmaceutical occurs!

Monte Carlo Simulations

Source on the skin surface: snapshot!

Percutaneous absorption continuously influences skin dose rate

Cumulated Skin dose

Source on the skin surface

Epidermis

1 cm\textsuperscript{2} 70 \mu m epidermis

1 mm\textsuperscript{2} 100 \mu m epidermis

10 mSv

1 cm\textsuperscript{2} 370 \mu m epidermis

809 mSv

820 mSv

843 mSv

Dermis: 1 mm

165 mSv

5% 95%

370 \mu m epidermis

820 mSv

843 mSv

Poor efficacy of successive decontaminations

Cumulated Skin dose

Remaining activity (%)

0% 100%

T(h)

Epidermis 370 \mu m

Skin contamination by radiopharmaceuticals and decontamination strategies

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Exposure pathways

Skin doses from sealed manipulations

- Inevitable!
- Very non-uniform distribution of skin doses across the hands
- Skin dose at fingertips >> routine dosimeter locations
- Skin dose limit of 500 mSv/y can be exceeded at fingertips for high workload!
- Automatic dispensing and injection: substantial dose reduction!

Skin doses from skin contamination

- Only present after contamination
- Highly influenced by the incidence
- Poor efficacy successive decontamination
- Skin dose limit of 500 mSv/y can be exceeded for a single contamination!
- Influenced by epidermal thickness/percutaneous absorption!
Exposure pathways

Skin doses from sealed manipulations

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Skin doses from skin contamination

Skin dose limit of 500 mSv/y can be exceeded for a single contamination!

⇒ Localised skin doses can > 20 Sv after a professional career of e.g. 40 years!
Skin effects?

Reported skin effects among workers in nuclear medicine?

Only from accidental high and acute exposure (high energy beta-emitters)!

Exposure pattern among nuclear medicine worker in routine

Repeated at low-moderate dose rates

Very localised

Protracted (many years)

Studies are lacking, clinical effects not reported

Cremonesi et al, 2006
Values that make up the dose limit statement?

- **500 mSv/y**
  - To avoid late dermal atrophy / telangiectasia
  - Seen as effect among RT-patients after 30-40 Sv, 2 Sv fractions
  - 6 weeks

- **70 µm (basal layer)**
  - Conservative approach! Targets at different depths!
  - Target depth: 150-500 µm (vascularised region of the dermis)
  - Hp(0.07) ideal scientific approach to assess potential late skin effects?

- **1 cm²**
  - To avoid acute ulceration after hot particle exposure!
  - (1 Sv within 1 h)
To conclude...

...and take home messages

1. Skin contaminations regularly occur in nuclear medicine!

Primarily caused by cross contaminations!

- Contaminated syringe shield (cross contamination): 12 (31%)
- Removal catheter/butterfly needle: 11 (26%)
- Contact with body fluid patient: 2 (5%)
- Unknown reason (cross contamination?): 15 (38%)

Regular inspections increase awareness and identify bad habits

![Graph showing contaminations over months](chart.png)
To conclude...  
...and take home messages

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2 Decontamination?

**ASAP!**
- >90% is removed
- Reduces high dose rate
- Reduces cross contamination risk

![Graph showing remaining activity vs. time](image)

**Dedicated decontamination agents?**
- Generally no added value
- Neutral hand soap easily available in all imaging / injection rooms
To conclude...
...and take home messages

3 Estimating /evaluating skin contamination doses

Hp(0.07) as a measure for $H_{\text{skin}}$?

- Not ideal in relation to potential late skin effects of localised exposure
- Large influence of epidermal thickness / percutaneous absorption

Use of Hp(0.07) in practical radiation protection?

- Yes!
- Conservative approach
- Standard tool
Thank you!

Ready to answer your questions