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Radiation protection in nuclear medicine – part 2

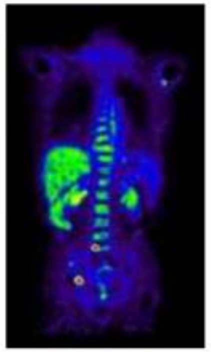
Radiation protection in nuclear medicine

- Patient dosimetry
- Pregnant patients
- Breastfeeding patients
- Female workers
- Exposure to public
- Comforters and carers

Patient dosimetry

- CT: anatomical imaging

- External dosimetry
  - Calculations based on measurements of the dose to a reference phantom
  - Published information on radiation dose to reference CT patients
  - Individualised dose calculations now also possible



- SPECT or PET: physiology and molecular imaging

- Internal dosimetry
  - Calculations based on measurements on patients
  - Complicated compartment model calculations
  - Published information on organ dose and effective dose to reference patients
  - Individualised dose calculations not possible or very difficult (need for multiple measurements)

Patient dosimetry: effective dose usage

- Main uses of effective dose E
- Radiation protection planning and regulation
  - Used to set dose limits for occupational and public exposure
  - Facilitates comparison of different exposure situations by providing a single risk-related quantity.
- Optimization and dose management
  - Helps in the application of the ALARA principle
  - Supports risk-informed design of shielding and operational procedures.
- Standardization and communication
  - Provides a common reference for regulators, health physicists, and radiological protection professionals.

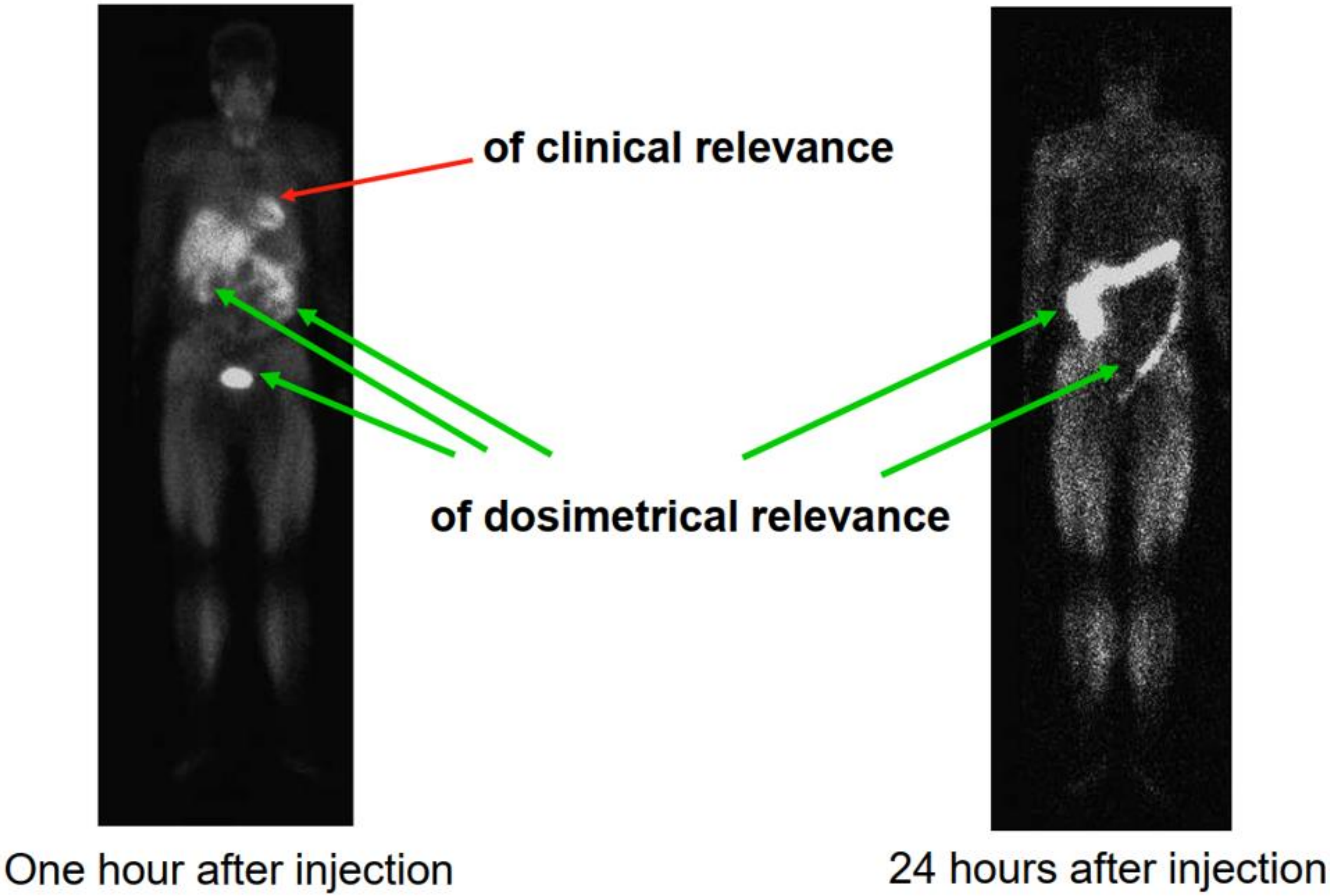
Patient dosimetry: effective dose usage

- Limitations of effective dose E
- Effective dose is a conceptual, population-averaged quantity — not a direct physical or measurable dose.
- 1. Not applicable to individual risk
  - Based on reference person models (male/female averaged anatomy, fixed tissue weighting factors).
  - Cannot predict individual health risk, which depends on age, sex, genetic factors, and specific exposure geometry.
- 2. Large uncertainty for non-standard exposure conditions
  - Derived for low-LET and low-dose-rate conditions typical of occupational or public exposure.
  - Its use in high-dose-rate, space radiation, or internal contamination scenarios introduces uncertainty because of mixed radiation fields and complex biological effects.
- 3. Approximation in environmental and medical contexts
  - In medical imaging or therapy, where dose distributions are highly non-uniform, effective dose can only provide a very rough estimate of population risk.
  - It’s unsuitable for patient-specific risk assessment.
  - Effective dose can be used to compare different medical modalities, not to estimate individual risk

Patient dosimetry

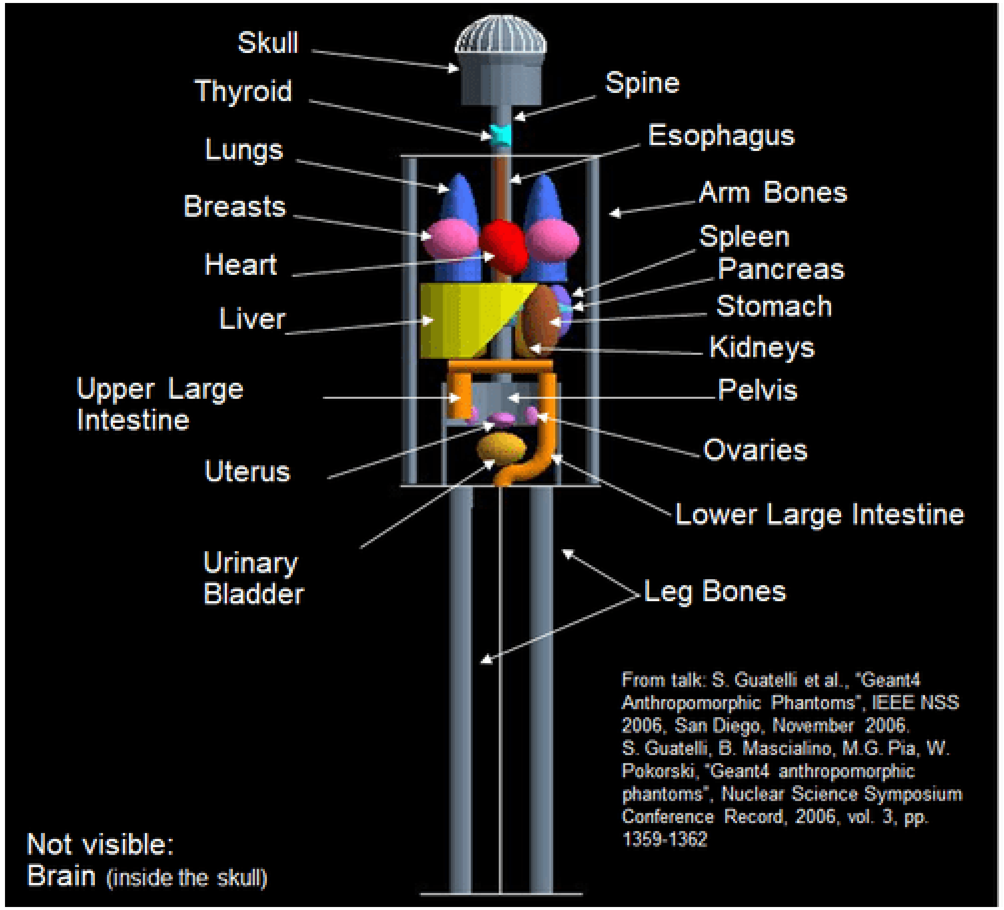
- Information needed for dose calculation
  - Physical parameters
    - Physical half life
    - Decay data for the radionuclide
    - Administered activity
  - Biological parameters
    - Activity content in the source organ
    - Retention of activity in the source organ
    - Mass of the target organ
    - Shape, size, location and composition of the source and target organ

- Biodistribution of radiopharmaceuticals:



Patient dosimetry

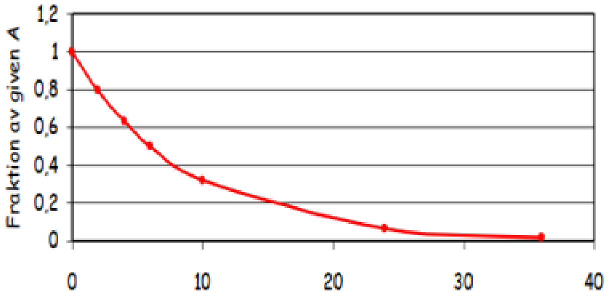
- MIRD scheme: Medical Internal Radiation Dosimetry
- Used a simple model of the human body and considers organs to be source organs which contain the radiopharmaceutical, and target organs, for which the dose is calculated.
- Source and target organs
- Organs can be both source and target



Mean absorbed dose to a tissue or organ T, $\bar{D}_T$

$$\boxed{\bar{D}_T = \sum \tilde{A} \cdot S_{T \leftarrow S}}$$ [mGy]

$\tilde{A}$ - Cumulated activity [MBq ·h]



Biokinetic data can be collected using techniques that vary in complexity. These should be chosen with regard to the accuracy required for the particular task.

$S_{T \leftarrow S}$ The S-value, corresponds to:
Mean absorbed dose per unit cumulated activity [mGy/ MBq · h]

Energy absorption or Physics term

S-coefficient

Equivalent dose to a target per transformation in the source region (or equivalently, the equivalent dose rate per activity.)

$$S_w(r_T \leftarrow r_S) = \sum_R w_R \sum_i E_{R,i} Y_{R,i} \Phi(r_T \leftarrow r_S, E_{R,i})$$

Radiation weighting factor
(equivalent → effective dose)

Energy and **yield** of radiation emission from the radionuclide (ICRP Pub. 107)

$$S_{w-beta}(r_T \leftarrow r_S) = \int_{i=0}^{imax} w_R E_{R,i} Y_{R,i} \Phi(r_T \leftarrow r_S, E_{R,i})$$

Specific Absorbed Fraction

$$\Phi\left(r_T \leftarrow r_S, E_{R,i}\right) = \frac{\phi\left(r_T \leftarrow r_S, E_{R,i}\right)}{m_T}$$

Absorbed Fraction – fraction of energy emitted from a source region which is deposited in a target region

Mass of Target – should be consistent with the geometry used to compute ϕ

79 source regions (from biokinetic models)
43 target regions (from definition of effective dose targets plus others)
6 ages (newborn, 1y, 5y, 10y, 15y, adult)
2 sexes
4 radiation types (alpha, electron, photon, neutrons from spontaneous fission)
28 (electron, photon) or 24 (alpha) points on energy grid
→ **more than 3 million data points!**

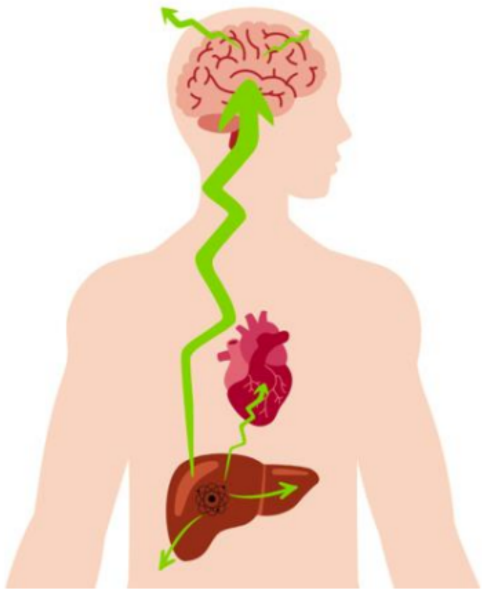
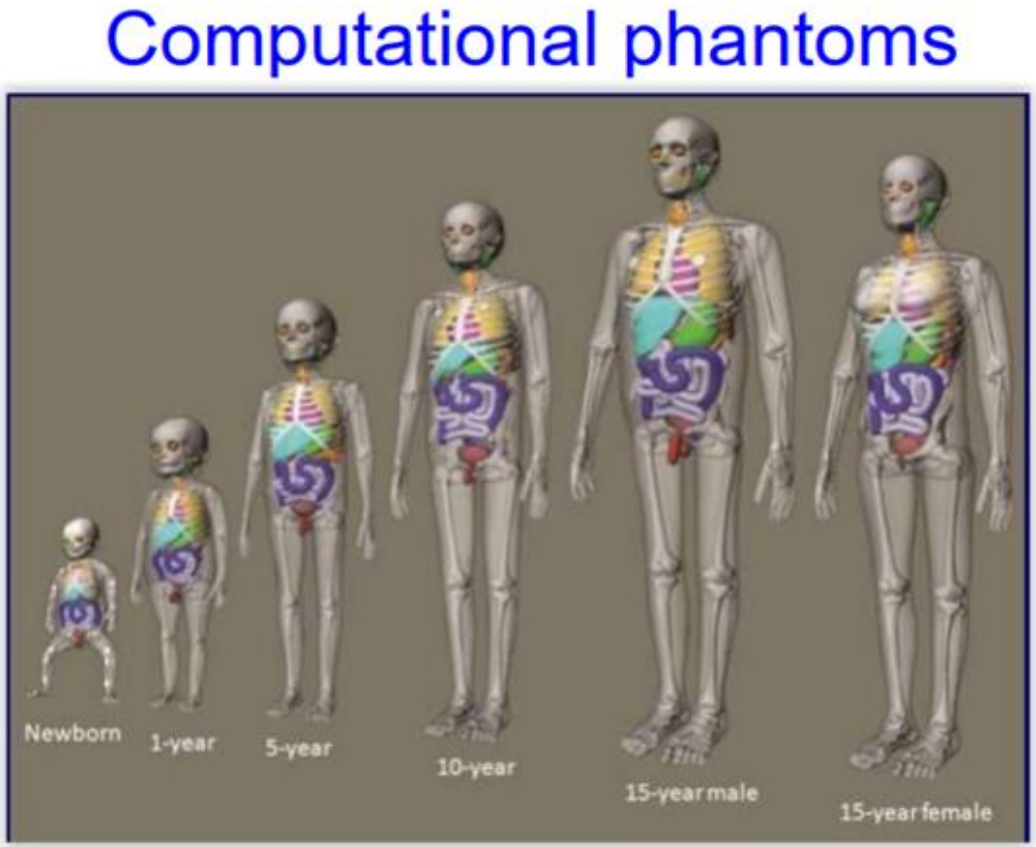
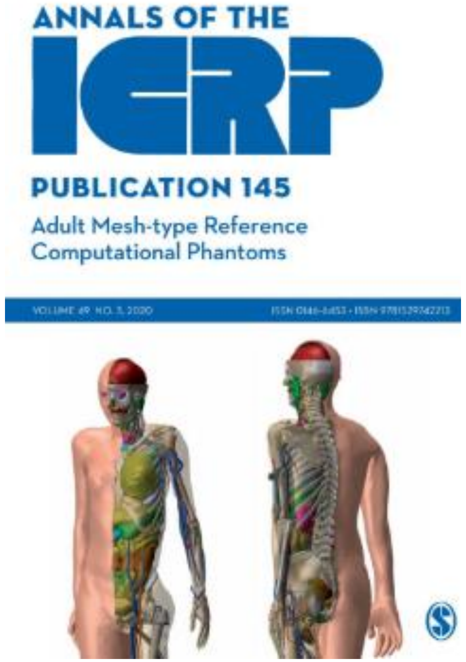


Image courtesy of Charlotte White

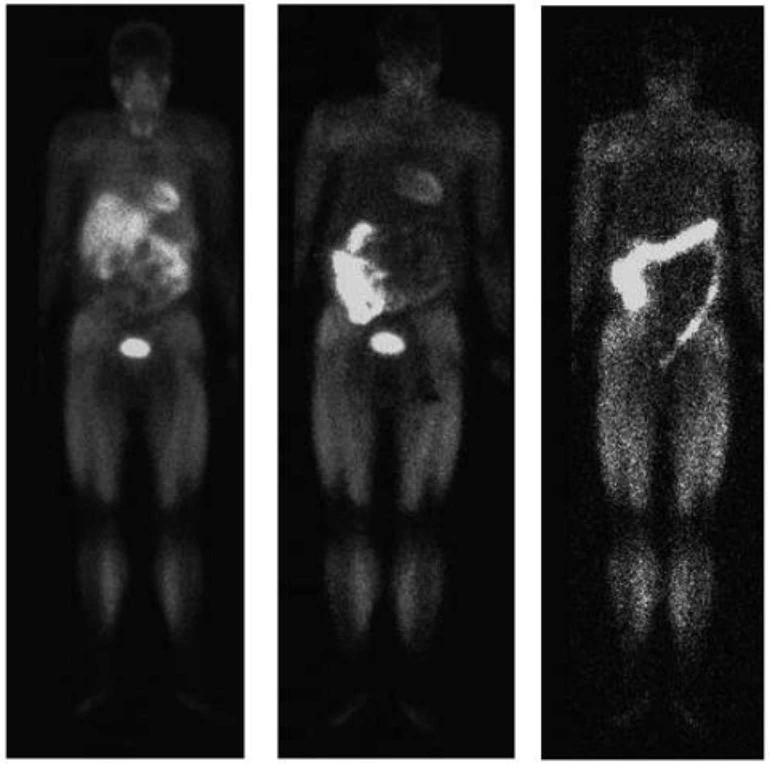
Patient dosimetry

- Mass of target organ
- Shape, size, location and composition of the source and target organs
- Can be found in ICRP publications

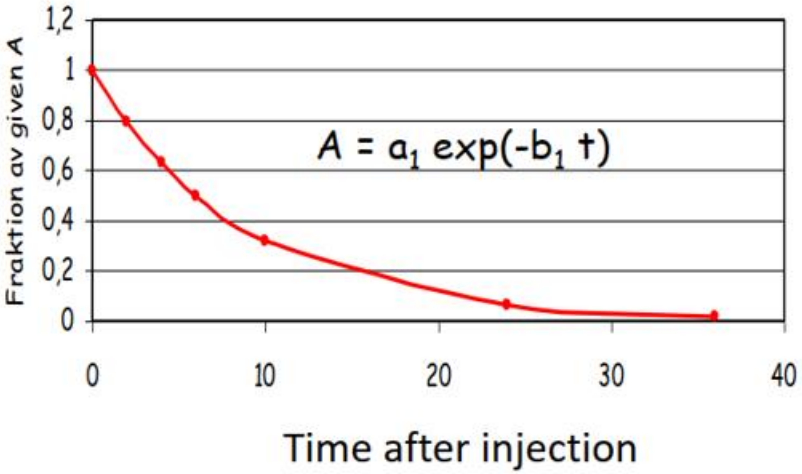




- Biokinetic studies



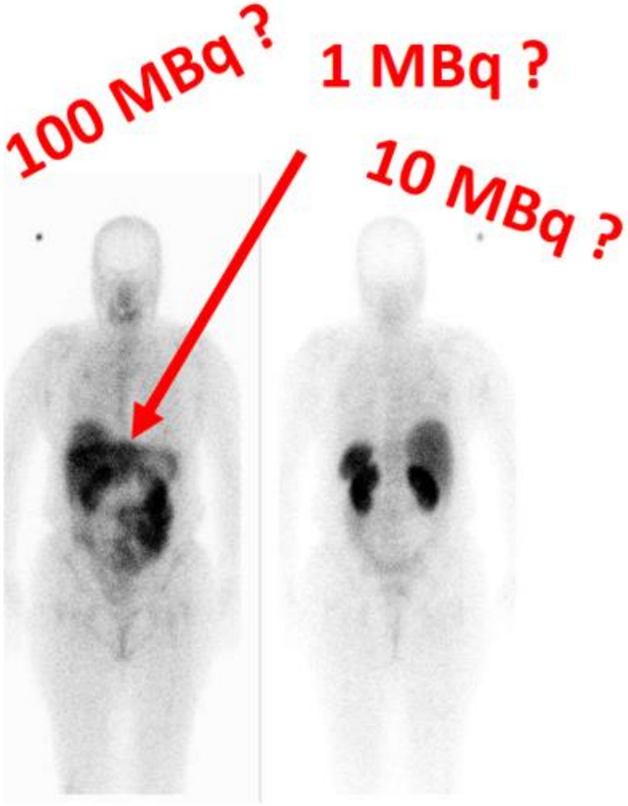
15 minutes after injection | 6 hours after injection | 24 hours after injection



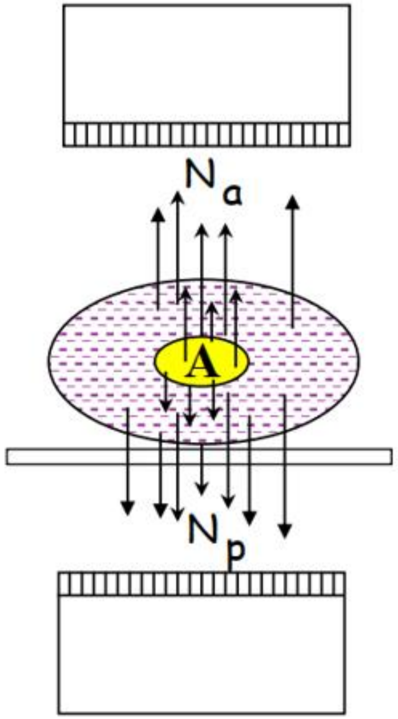
For most organs and for total body

Blood samples
Faeces samples
Urine samples
Exhaled air
Tissue samples

- Quantification of activity in organs



Regions of interest

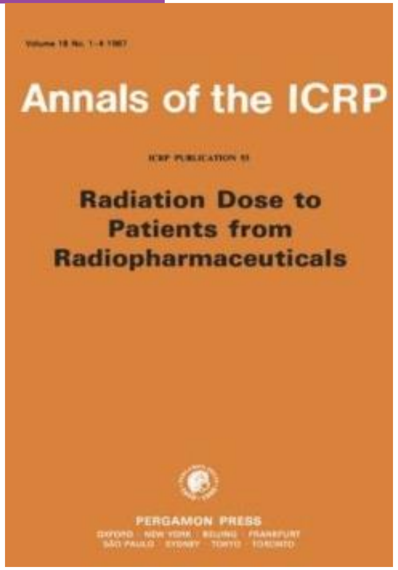


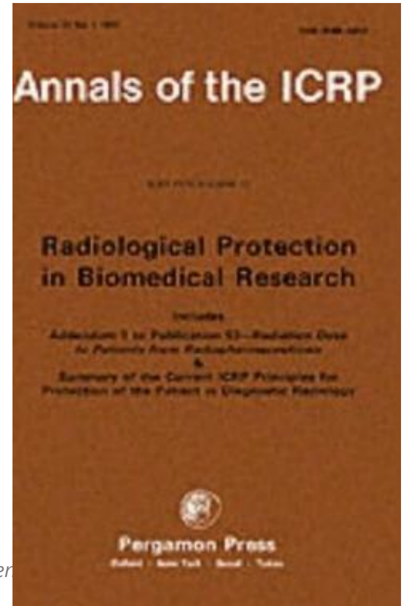
Correction for:

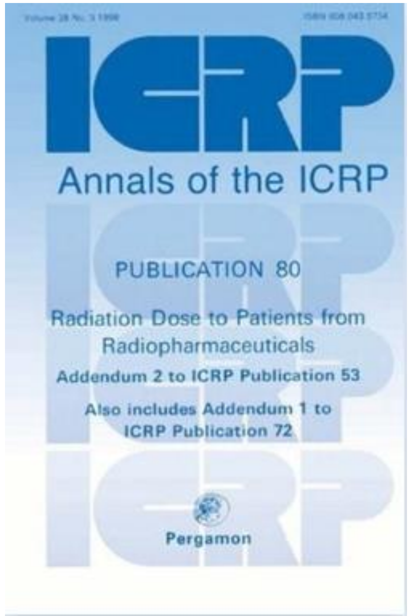
- Over- and underlying activity
- Attenuation of the radiation
- Scattered radiation
- Sensitivity of camera

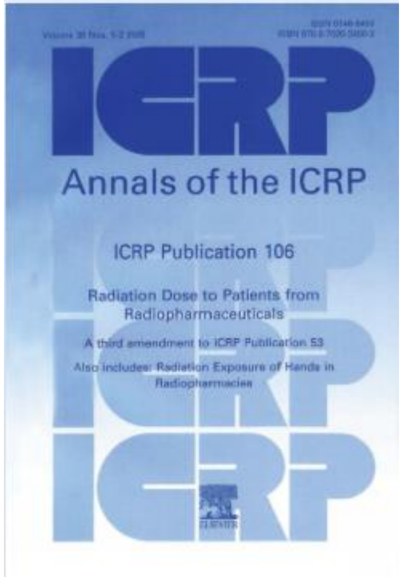
Patient dosimetry

- ICRP has issued a number of reports addressing the radiation dose to patients from radiopharmaceuticals for diagnostic nuclear medicine procedures
- First report: ICRP 53 (1988): calculations of organ absorbed dose and effective dose equivalent per unit activity administered for some 120 radiopharmaceuticals
- Over the years, ICRP has provided reports, amendments, and corrections. These provide dose coefficients for administered activity to absorbed dose to organs (in mGy MBq^{-1}) and effective dose (in mSv MBq^{-1}) based on known biokinetic model and the fraction of emitted energy absorbed per mass of the target of reference individuals (1-, 5-, 10- and 15-year-olds and adult)





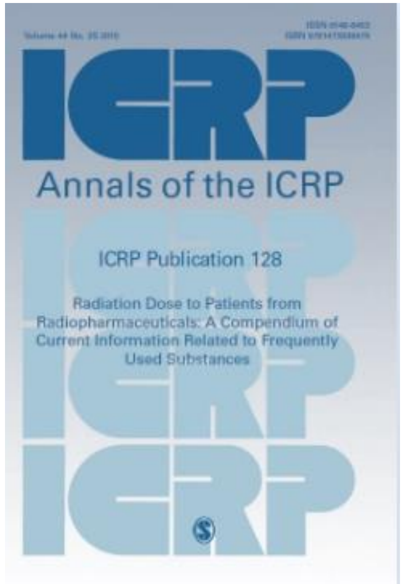


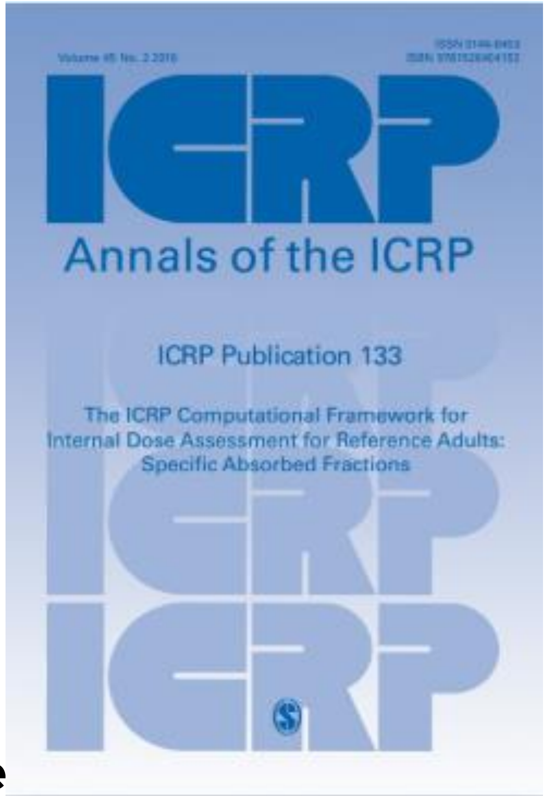


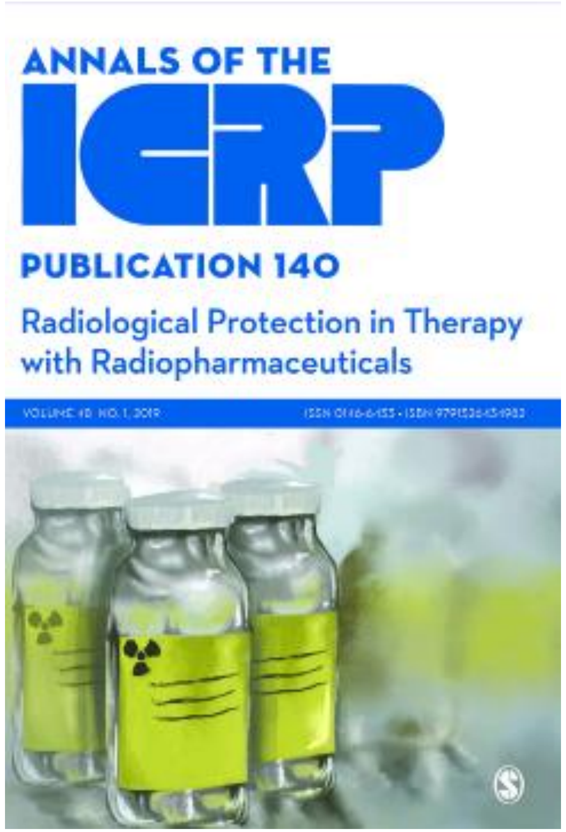
Patient dosimetry

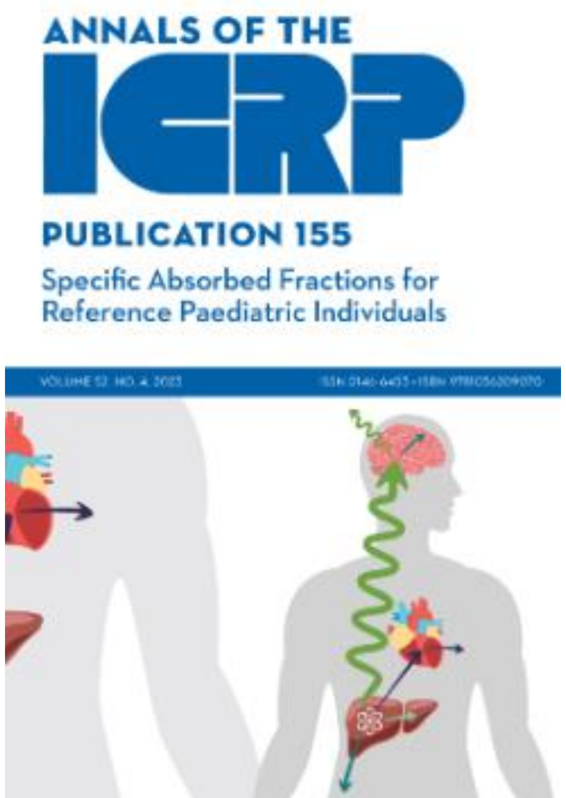
- *Publication 128* dealt with 19 PET radiopharmaceuticals labelled with positron emitters such as ^{11}C, ^{15}O, ^{18}F, ^{68}Ga, ^{82}Rb, and ^{124}I

- New publications deal with new weighting factors, phantom models, isotopes…









Software and applications

•**ICRP Dose Viewer app:** A mobile application for both Android and Apple devices that provides direct access to updated ICRP dose coefficients for different intake scenarios, including diagnostic nuclear medicine, making it easy for patients, workers, and the public to find dose values without manual calculation.

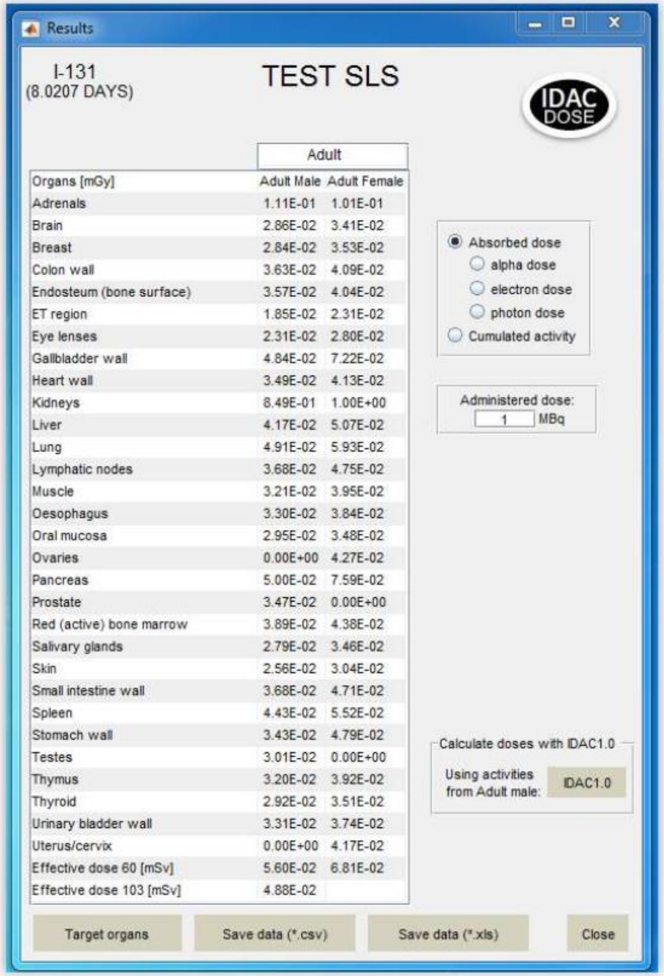
•**IDAC-Dose**: A computer program based on the ICRP's internal dose assessment framework. It uses the ICRP's adult and pediatric computational phantoms to estimate organ doses for diagnostic nuclear medicine.

•**NCINM (National Cancer Institute dosimetry system for Nuclear Medicine):** A calculator that uses the ICRP phantoms and biokinetic models to estimate organ and effective doses for patients undergoing nuclear medicine procedures.

•**DCAL**: Another computer program that follows the ICRP computational framework. It is used for calculating dose coefficients for occupational and environmental exposures, and its version 2022 has been used by the ICRP.

ICRP Dose calculation software IDAC 2.1

Cumulated activity (h) in source organ



	Adult	
Organs [mGy]	Adult Male	Adult Female
Adrenals	1.11E-01	1.01E-01
Brain	2.86E-02	3.41E-02
Breast	2.84E-02	3.53E-02
Colon wall	3.63E-02	4.09E-02
Endosteum (bone surface)	3.57E-02	4.04E-02
ET region	1.85E-02	2.31E-02
Eye lenses	2.31E-02	2.80E-02
Gallbladder wall	4.84E-02	7.22E-02
Heart wall	3.49E-02	4.13E-02
Kidneys	8.49E-01	1.00E+00
Liver	4.17E-02	5.07E-02
Lung	4.91E-02	5.93E-02
Lymphatic nodes	3.68E-02	4.75E-02
Muscle	3.21E-02	3.95E-02
Oesophagus	3.30E-02	3.84E-02
Oral mucosa	2.95E-02	3.48E-02
Ovaries	0.00E+00	4.27E-02
Pancreas	5.00E-02	7.59E-02
Prostate	3.47E-02	0.00E+00
Red (active) bone marrow	3.89E-02	4.38E-02
Salivary glands	2.79E-02	3.46E-02
Skin	2.56E-02	3.04E-02
Small intestine wall	3.68E-02	4.71E-02
Spleen	4.43E-02	5.52E-02
Stomach wall	3.43E-02	4.79E-02
Testes	3.01E-02	0.00E+00
Thymus	3.20E-02	3.92E-02
Thyroid	2.92E-02	3.51E-02
Urinary bladder wall	3.31E-02	3.74E-02
Uterus/cervix	0.00E+00	4.17E-02
Effective dose 60 [mSv]	5.60E-02	6.81E-02
Effective dose 103 [mSv]	4.88E-02	

Absorbed dose (mGy/MBq) in target organ

Pregnant patient

- Thousands of pregnant women are exposed to ionizing radiation each year
- For most patients radiation exposure is medically appropriate and the radiation risk to the embryo/fetus is minimal

- There are occasions when the fetal dose will result in significant harm to the embryo/fetus

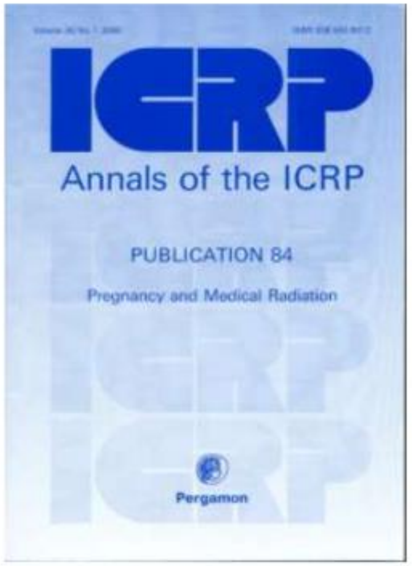
Pregnant patient

- General guidelines

- Prevent unnecessary irradiation of the embryo/fetus
- Avoid unnecessary anxiety
- Make the “right” decisions concerning the management of the pregnant patient in case of intentional or accidental administration of radiopharmaceuticals

International Commission on Radiological Protection (ICRP)

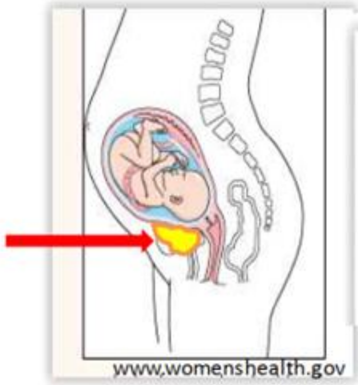
ICRP Publication 84 Pregnancy and Medical Radiation



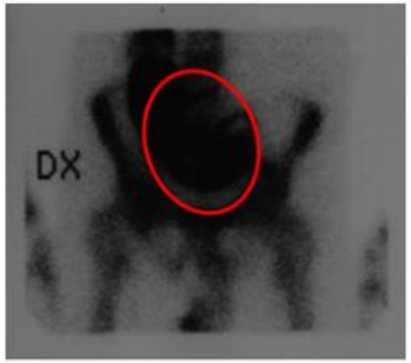
Pregnant patient

- Irradiation of the embryo/fetus in Nuclear Medicine

  - The embryo/fetus may be **irradiated externally** from activity in the mother



  - Some radiopharmaceuticals may cross the placenta and concentrate in fetal tissue i.e. **internal exposure** of the fetus



Radiation-related risks throughout the pregnancy is related to the:

- The stage of pregnancy at the time of irradiation
- The absorbed dose to the embryo/fetus (mGy)

The radiation risk is most significant during the organogenesis and in the early fetal period, somewhat less in the second trimester and least in the third trimester

Most risk | Less risk | Least risk

ICRP publication 84

Pregnant patient

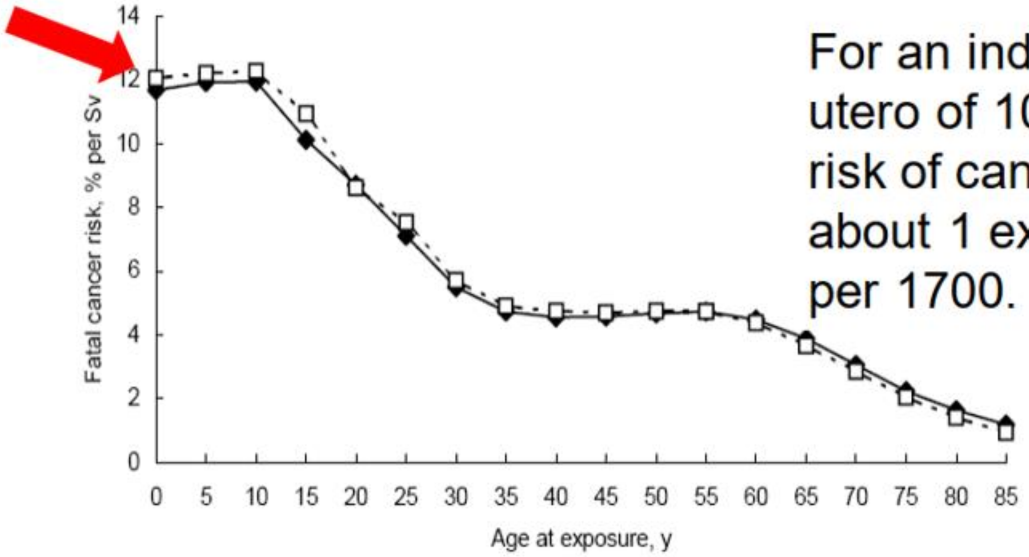
- Effects early after conception: 0-2 weeks
  - Failure to implant
  - Miscarriage
- Effects on embryo/fetus during growth
  - Lethal effects
  - Malformations
    - Malformations have a threshold of 100-200 mGy or higher and are typically associated with central nervous system (CNS) problems
    - During 8-25 weeks post conception the CNS is particularly sensitive to radiation
  - Mental retardation
    - Fetal doses in excess of 100 mGy can result in some reduction of IQ
    - Fetal doses in the range of 1000 mGy can result in severe mental retardation and microcephaly, particularly during 8-15 weeks and to a lesser extent at 16-25 weeks

ICRP publication 84

Pregnant patient

- Cancer effects

    - Ionizing radiation increases the risk for leukemia and also other types of cancer in children and adults
    - The risk of carcinogenic effects on the embryo/fetus is assumed to be in same order as in children



For an individual exposed in utero of 10 mGy, the absolute risk of cancer at age 10-15 is about 1 excess cancer death per 1700.

Total fatal cancer risk for uniform whole body exposure as a function of age at exposure and sex

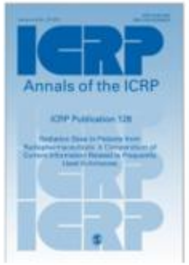
Doll and Wakeford ,1997

Pregnant patient

- KEEP THE PERSPECTIVE!!
- Most diagnostic procedures are done with short-lived radionuclides that do not cause large fetal doses
  - Prenatal doses from most properly performed diagnostic procedures present no measurable increased risk of prenatal death, malformation or mental impairment
- In some circumstances, the exposure is inappropriate and the unborn child may be at increase risk of harm to health
  - Some radionuclides do cross the placenta and can pose fetal risks, like ^{131}I
- Informed consent and understanding
  - The pregnant patient of worker has the right to know the magnitude and type of potential radiation effects that might result from an in-utero exposure
  - Commmunication should be related to the level of risk.
    - Communication that the risk is negligeable is adequate for very low dose procedures (<1 mGy to the fetus)
    - If fetal doses are above 1 mGy, a more detailed explanation should be given

Pregnant patient

- How to estimate the fetal dose
  - Fetal dose = organ dose
  - External dose from activity in the organs of the mother



- **Dose to uterus of the mother**

ICRP Publication 106 and 128
"Radiation Dose to Patients from Radiopharmaceuticals"

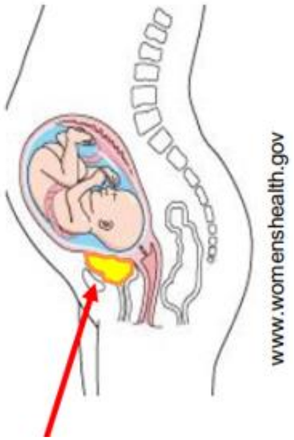
Table. Absorbed dose per unit A [mGy/MBq]

Radiation dose to patients from radiopharmaceuticals

Table C.31. Absorbed doses for ^{18}F-fluoro-2-deoxy-D-glucose.

	Absorbed dose per unit activity administered (mGy MBq^{-1})				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.2E−02	1.6E−02	2.4E−02	3.9E−02	7.1E−02
Bone surfaces	1.1E−02	1.4E−02	2.2E−02	3.4E−02	6.4E−02
Brain	3.8E−02	3.9E−02	4.1E−02	4.6E−02	6.3E−02
Breast	8.8E−03	1.1E−02	1.8E−02	2.9E−02	5.6E−02
Gallbladder wall	1.3E−02	1.6E−02	2.4E−02	3.7E−02	7.0E−02
Gastrointestinal tract					
Stomach wall	1.1E−02	1.4E−02	2.2E−02	3.5E−02	6.7E−02
Small intestine wall	1.2E−02	1.6E−02	2.5E−02	4.0E−02	7.3E−02
Colon wall	1.3E−02	1.6E−02	2.5E−02	3.9E−02	7.0E−02
(Upper large intestine wall	1.2E−02	1.5E−02	2.4E−02	3.8E−02	7.0E−02)
(Lower large intestine wall	1.4E−02	1.7E−02	2.7E−02	4.1E−02	7.0E−02)
Heart wall	6.7E−02	8.7E−02	1.3E−01	2.1E−01	3.8E−01
Kidneys	1.7E−02	2.1E−02	2.9E−02	4.5E−02	7.8E−02
Liver	2.1E−02	2.8E−02	4.2E−02	6.3E−02	1.2E−01
Lungs	2.0E−02	2.9E−02	4.1E−02	6.2E−02	1.2E−01
Muscles	1.0E−02	1.3E−02	2.0E−02	3.3E−02	6.2E−02
Oesophagus	1.2E−02	1.5E−02	2.2E−02	3.5E−02	6.6E−02
Ovaries	1.4E−02	1.8E−02	2.7E−02	4.3E−02	7.6E−02
Pancreas	1.3E−02	1.6E−02	2.6E−02	4.0E−02	7.6E−02
Red marrow	1.1E−02	1.4E−02	2.1E−02	3.2E−02	5.9E−02
Skin	7.8E−03	9.6E−03	1.5E−02	2.6E−02	5.0E−02
Spleen	1.1E−02	1.4E−02	2.1E−02	3.5E−02	6.6E−02
Testes	1.1E−02	1.4E−02	2.4E−02	3.7E−02	6.6E−02
Thymus	1.2E−02	1.5E−02	2.2E−02	3.5E−02	6.6E−02
Thyroid	1.0E−02	1.3E−02	2.1E−02	3.4E−02	6.5E−02
Urinary bladder wall	1.3E−01	1.6E−01	2.5E−01	3.4E−01	4.7E−01
Uterus	1.8E−02	2.2E−02	3.6E−02	5.4E−02	9.0E−02
Remaining organs	1.2E−02	1.5E−02	2.4E−02	3.8E−02	6.4E−02
Effective dose (mSv MBq^{-1})	1.9E−02	2.4E−02	3.7E−02	5.6E−02	9.5E−02

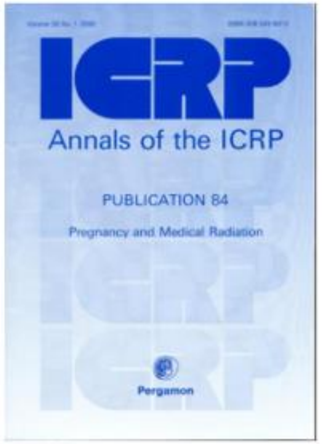
The physical half-life of ^{18}F is 1.83 h.



Pregnant patient

- How to estimate the fetal dose
  - Fetal dose = organ dose
  - External dose from activity in the organs of the mother

- **Dose to the embryo/fetus**
  - ICRP Publication 84



ICRP Publication 84
Pregnancy and Medical Radiation

Approximate whole body fetal dose (mGy) from common nuclear medicine procedures

Procedure	Activity (MBq)	Early pregnancy	9 months
$Tc\text{-}99^m$			
Bone scan	750	4.7	1.8
Lung scan	240	0.9	0.9
Liver colloid scan	300	0.6	1.1
Thyroid scan	400	4.4	3.7
Renal DTPA	300	9.0	3.5
Red blood cell	930	6.0	2.5
I-123 thyroid uptake	30	0.6	0.3
I-131 thyroid uptake	0.55	0.04	0.15

www.icrp.org

Pregnant patient

- How to estimate the fetal dose
  - Fetal dose = organ dose
  - External dose from activity in the organs of the mother

- **Dose to the embryo/fetus**
  - Russell et al., Health Phys, 1997:756-769
  - Russell et al., Health Phys, 1997:747-755

Internal dosimetry

$$\boxed{\bar{D}_T = \sum \tilde{A} \cdot S_{T \leftarrow S}} \quad [\text{mGy}]$$

$\tilde{A}$ - Cumulated activity [MBq ·h]

$S_{T \leftarrow S}$ - S-value [mGy / MBq ·h]

Target organ = fetus

Source organs = the activity in the organs of the mother

S-values (or SAFs) are based on <u>mathematical</u> phantoms describing a pregnant female in early pregnancy, first trimester, second trimester and third trimester

Pregnant patient

- How to estimate the fetal dose
  - Fetal dose = organ dose
  - External dose from activity in the orans of the mother

▪ Dose to the embryo/fetus

Russell et al., Health Phys,1997:756-769

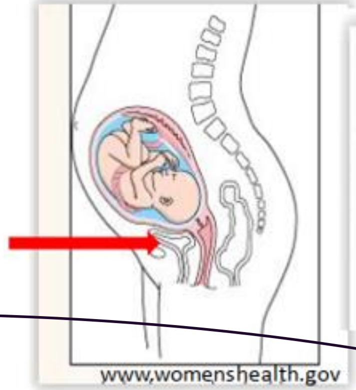
"Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals"

Table 3a. Absorbed Dose Estimates to the Embryo/Fetus Per Unit Activity of Radiopharmaceutical Administered to the Mother (maternal contributions only).

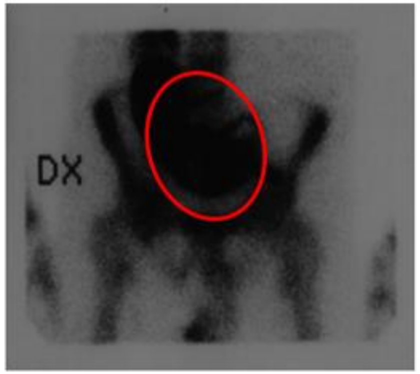
Radiopharmaceutical	Early mGy/MBq	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
I Rose Bengal	[illegible]	[illegible]	[illegible]	[illegible]
^{111}In DTPA	6.5×10^{-2}	4.8×10^{-2}	2.0×10^{-2}	1.8×10^{-2}
^{111}In Pentetreotide	8.2×10^{-2}	6.0×10^{-2}	3.5×10^{-2}	3.1×10^{-2}
^{111}In Platelets	1.7×10^{-1}	1.1×10^{-1}	9.9×10^{-2}	8.9×10^{-2}
^{111}In Red Blood Cells	2.2×10^{-1}	1.3×10^{-1}	1.1×10^{-1}	8.6×10^{-2}
^{111}In White Blood Cells	1.3×10^{-1}	9.6×10^{-2}	9.6×10^{-2}	9.4×10^{-2}
^{99m}Tc Albumin Microspheres	4.1×10^{-3}	3.0×10^{-3}	2.5×10^{-3}	2.1×10^{-3}
^{99m}Tc Disofenin	1.7×10^{-2}	1.5×10^{-2}	1.2×10^{-2}	6.7×10^{-3}
^{99m}Tc HEDP	7.2×10^{-3}	5.2×10^{-3}	2.7×10^{-3}	2.4×10^{-3}
^{99m}Tc HMPAO	8.7×10^{-3}	6.7×10^{-3}	4.8×10^{-3}	3.6×10^{-3}
^{99m}Tc Human Serum Albumin	5.1×10^{-3}	3.0×10^{-3}	2.6×10^{-3}	2.2×10^{-3}
^{99m}Tc MAG3	1.8×10^{-2}	1.4×10^{-2}	5.5×10^{-3}	5.2×10^{-3}
^{99m}Tc MIBI-rest	1.5×10^{-2}	1.2×10^{-2}	8.4×10^{-3}	5.4×10^{-3}
^{99m}Tc MIBI-stress	1.2×10^{-2}	9.5×10^{-3}	6.9×10^{-3}	4.4×10^{-3}
^{99m}Tc RBC-Heat Treated	1.7×10^{-3}	1.6×10^{-3}	2.1×10^{-3}	2.2×10^{-3}
^{99m}Tc Teboroxime	8.9×10^{-3}	7.1×10^{-3}	5.8×10^{-3}	3.7×10^{-3}

Irradiation of the embryo/fetus in Nuclear medicine

- The embryo/fetus may be **irradiated externally** from activity in the mother



- Some radiopharmaceuticals may cross the placenta and concentrate in fetal tissue i.e. **internal exposure** of the fetus



- **Dose to the embryo/fetus**

Russell et al, Health Phys 1997:747-755

"Placental transfer of radiopharmaceuticals and dosimetry in pregnancy "

Russell et al., Health Phys,1997:756-769

"Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals"

Table 3b. Absorbed Dose Estimates to the Embryo/Fetus Per Unit Activity of Radiopharmaceutical Administered to the Mother (maternal and fetal self dose contributions).

Radiopharmaceutical	Early mGy/MBq	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
^{67}Ga Citrate	9.3×10^{-2}	2.0×10^{-1}	1.8×10^{-1}	1.3×10^{-1}
^{123}I Sodium Iodide	2.0×10^{-2}	1.4×10^{-2}	1.1×10^{-2}	9.8×10^{-3}
^{131}I Sodium Iodide	7.2×10^{-2}	6.8×10^{-2}	2.3×10^{-1}	2.7×10^{-1}
^{99m}Tc DMSA	5.1×10^{-3}	4.7×10^{-3}	4.0×10^{-3}	3.4×10^{-3}
^{99m}Tc DTPA	1.2×10^{-2}	8.7×10^{-3}	4.1×10^{-3}	4.7×10^{-3}
^{99m}Tc DTPA Aerosol	5.8×10^{-3}	4.3×10^{-3}	2.3×10^{-3}	3.0×10^{-3}
^{99m}Tc Glucoheptonate	1.2×10^{-2}	1.1×10^{-2}	5.3×10^{-3}	4.6×10^{-3}
^{99m}Tc HDP	5.2×10^{-3}	5.4×10^{-3}	3.0×10^{-3}	2.5×10^{-3}
^{99m}Tc MAA	2.8×10^{-3}	4.0×10^{-3}	5.0×10^{-3}	4.0×10^{-3}
^{99m}Tc MDP	6.1×10^{-3}	5.4×10^{-3}	2.7×10^{-3}	2.4×10^{-3}
^{99m}Tc Pertechnetate	1.1×10^{-2}	2.2×10^{-2}	1.4×10^{-2}	9.3×10^{-3}
^{99m}Tc PYP	6.0×10^{-3}	6.6×10^{-3}	3.6×10^{-3}	2.9×10^{-3}
^{99m}Tc RBC-in vitro	6.8×10^{-3}	4.7×10^{-3}	3.4×10^{-3}	2.8×10^{-3}
^{99m}Tc RBC-in vivo	6.4×10^{-3}	4.3×10^{-3}	3.3×10^{-3}	2.7×10^{-3}
^{99m}Tc Sulfur Colloid-normal	1.8×10^{-3}	2.1×10^{-3}	3.2×10^{-3}	3.7×10^{-3}
^{99m}Tc Sulfur Colloid-Liver Disease	3.2×10^{-3}	2.5×10^{-3}	2.8×10^{-3}	2.8×10^{-3}

Pregnant patient

- Radio-iodine easily crosses the placenta and therapeutic doses can pose significant problems for the fetus, particularly permanent hypothyroidism
- Also diagnostic levels of radio-iodine may pose serious health effects of the fetus
- If pregnancy is discovered early after administration, the effects could be decreased by administration of stable iodine to the mother

Warning!
Radioactive iodine. In particular therapy!

- Radioiodine administered to a woman, after 8-10 weeks post-conception ➡ the fetal thyroid concentrates iodide which crosses the placenta

Examples:

Administration:	***Mean dose to the fetus:***	***Dose to the fetal thyroid:***
a) 30 MBq $^{123}I^-$ to the mother	a) 0.3 mGy	a) 300 mGy
b) 0.4 MBq $^{131}I^-$ to the mother	b) 0.1 mGy	b) 300 mGy
c) 500 MBq $^{131}I^-$ to the mother	c) 100 mGy	c) 600 Gy (!)

- High fetal thyroid doses from radioiodide can result in permanent hypothyroidism

Pregnant patient

Pregnant patient
Action plan

START

Personnel ask the patient:
- ***Are you pregnant?***
- ***When did you have last menstruation?***

Certainly No → **Perform the procedure according to current routines**

Certainly Yes → **Physician decides:** ***Is the procedure justified also with respect to foetal exposure?***

- ***Yes*** → **Personnel: Take measures to reduce radiation dose to embryo/foetus**
- ***No*** → **Consider alternative diagnostic procedures (non-ionizing) or postpone to after birth**
  Note! Breastfeeding

Don´t know → **Physician decides:** ***Is the procedure acute?***

- ***Yes*** → **Ask the patient to do a pregnancy test** → **Personnel ask the patient:** ***Are you pregnant?***
- ***No*** → **Consider alternative diagnostic procedures (non-ionizing) or postpone to after birth**
  Note! Breastfeeding

Less activity and longer measurement time

Unintentional embryo/fetal exposure – What to do?

Termination of pregnancy at fetal doses of less than 100 mGy is NOT justified based upon radiation risk

If the fetal dose is more than 500 mGy, this may pose significant fetal harm

Fetal doses between 100-500 mGy require individual validation of the risk

S. Leide-Svegborn 2018

Pregnant patient: conclusion

- Unintentional embryo/fetal exposure: What to do?
  - Determine the absorbed dose to the embryo/fetus (mGy)
  - Most diagnostic procedures do not cause large fetal doses
  - Encourage the mother to drink more than usual and to frequently voiding of urine: this will reduce the fetal dose
  - Radio-iodine may cause significant fetal thyroid damage: give the mother stable iodine
  - Inform patient, physicians, and report to authorities

Breast feeding

- Breastfeeding is important for the infant and the mother

- Health benefits for the infant
  - Short term: safe, contains antibodies that protect the infant for childhood illnesses
  - Long term: less risk for type II diabetes, less risk for overweight or obesitas, perform better in intelligence tests
- Health benefits for the mother
  - Reduces risk of breast and ovarian cancer, type II diabetes and postpartum depression

- Do not terminate breastfeeding if not absolutely necessary

- How can risks and benefits be weighted?

Breast feeding

- Risks?

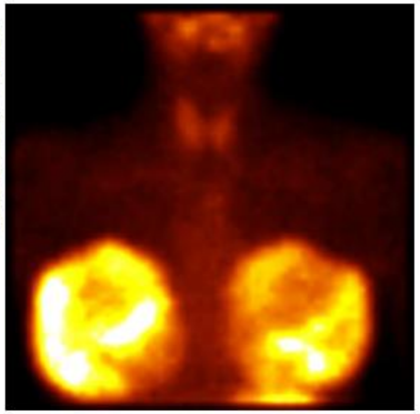
- For the infant:
  - Cancer induction
  - Serious thyroid diseases, e.g. hypothyreos, cancer

- For the mother
  - Serious risk if examination or therapy is not performed

- Breastfeeding interruption to be considered: temporarily or permanent

Breast feeding

Sten Carlsson, Uddevalla

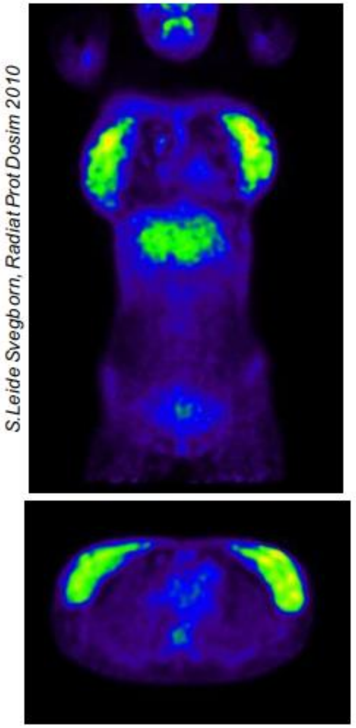


Thyroid scintigraphy

^{99m}Tc-pertechnetate, 200 MBq

In breast milk
10-20 % of A_{mother}

S.Leide Svegborn, Radiat Prot Dosim 2010

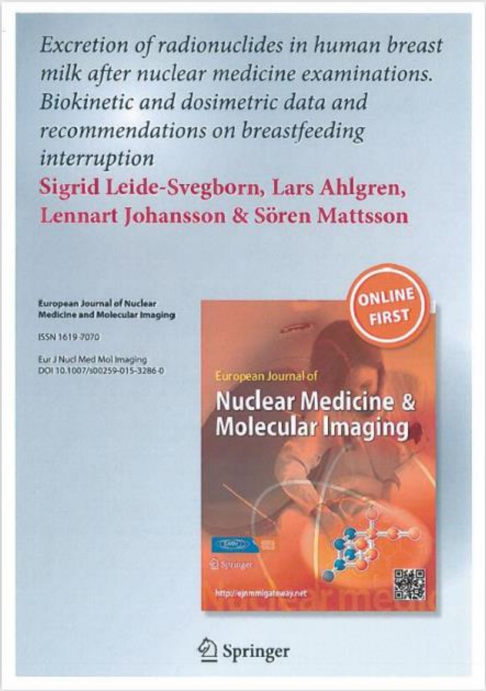


Lymphoma PET/CT
^{18}F-FDG, 277 MBq

In breast milk
0.07 % of A_{mother}

Recommendations on breastfeeding interruption

- Papers in international scientific journals, such as
  - Mountford and Coakley *(Nucl Med Commun. 1989)*
  - Stabin and Breitz *(J Nucl Med. 2000)*
  - Leide-Svegborn *et al., (Eur J Nucl Med Mol Imaging. 2016)*
- Local, regional or national guidelines
- ICRP recommendations, ICRP Publication 128
- **IAEA recommendations**




ORIGINAL ARTICLE

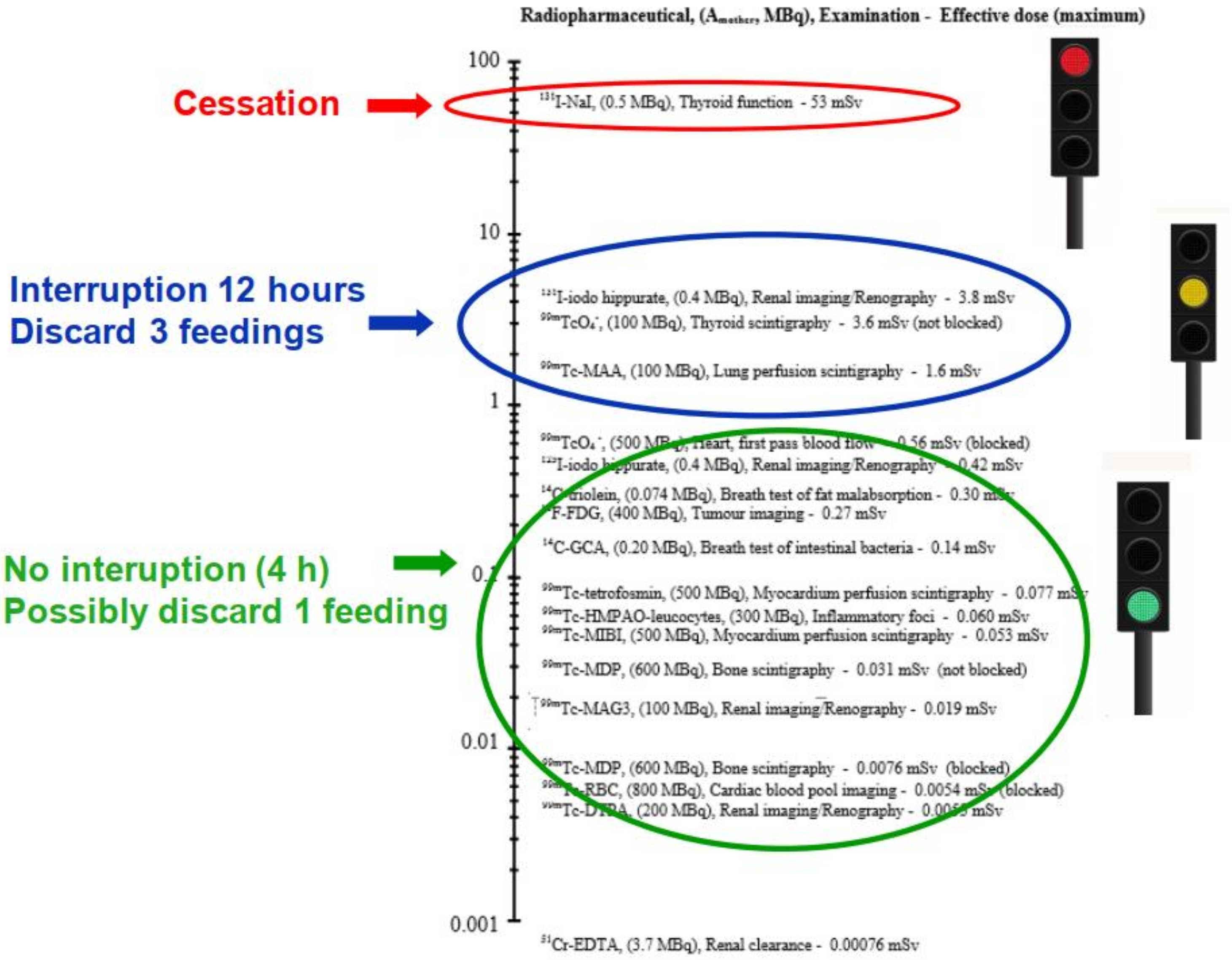
Excretion of radionuclides in human breast milk after nuclear medicine examinations. Biokinetic and dosimetric data and recommendations on breastfeeding interruption

Sigrid Leide-Svegborn[1] · Lars Ahlgren[1] · Lennart Johansson[2] · Sören Mattsson[1]

Abstract

Introduction

Breast feeding



Breastfeeding patient
Action plan

START

Personnel ask the patient: *Are you breastfeeding?*

Certainly YES

Physician decides:
Is the procedure justified also with respect to irradiation of infant?

YES

Personnel:
Take measures to reduce radiation dose to the infant

NO

Consider alternative diagnostic procedures or postpone to after natural cessation of breastfeeding

Certainly NO

Perform the procedure according to current routines

OBS!
Do not forget external irradiation of the infant, from activity in the breasts

Breast feeding

- Breastfeeding patient in practice
- If the procedure is justified
  - Give breastmilk to the infant just prior to administration of the activity
  - If the procedure is not acute: express breastmilk in advance. Keep it in the refrigerator or freezer

Breast feeding

Recommendation on breastfeeding interruption – IAEA (proposal)

Radio-pharmaceutical	Most common clinical use	Typical adm. activity (MBq)	Feeding interruption time (hours)
^{99m}Tc-DMSA	Renal cortical imaging	80-200	4 h (1)
^{99m}Tc-DTPA	Renal imaging and function (GFR)	40-400	4 h (1)
^{99m}Tc-ECD	Brain perfusion	800	4 h (1)
^{99m}Tc-HMPAO	Brain perfusion	500	4 h (1)
^{99m}Tc-phosphates	Bone scan	800	4 h (1)
^{99m}Tc-MIBI	Myocardial perfusion, Parathyroid scan	250-700	4 h (1)
^{99m}Tc-tetrofosmin	Myocardial perfusion	250-700	4 h (1)
^{99m}Tc-sulphur colloids	Liver scan	200-400	4 h (1)
^{99m}Tc-DTPA aerosol	Lung ventilation imaging and function	50	4 h (1)
^{99m}Tc-technegas	Lung ventilation imaging	40	4 h (1)
^{99m}Tc-MAG3	Imaging and function of kidneys and urinary tract	40-400	4 h (1)

Breast feeding

Recommendation on breastfeeding interruption – IAEA (proposal) , cont´d

Radio-pharmaceutical	Most common clinical use	Typical adm. activity (MBq)	Feeding interruption time (hours)
^{99m}Tc-pertechnetate	Thyroid scan, Meckels diverticulum	100-400	12 h [2]
^{99m}Tc-MAA	Lung perfusion	40-150	12 h
^{99m}Tc-HMPAO WBC	Infection imaging	180-400	48 h
^{99m}Tc-labelled RBC	Radionuclide ventriculography	800	12 h
^{99m}Tc-Mebrofenin/ Disofenin and other iminodiacetic acid derivatives	Hepato-biliary imaging and function	300	4 h [1]
^{99m}Tc-human albumin nanocolloidal particles	Sentinel nodes Liver scan, bone marrow scan	5-120 120-200	4 h [1]
^{123}I-MIBG	Neuroblastoma imaging	400	> 3 weeks or complete cessation [3]
^{123}I-NaI	Thyroid imaging and function	20	> 3 weeks or complete cessation [3]
^{123}I-ioflupane (FP-CIT)	Dopaminergic neurotransmission (D1) in movement disorders	150-250	> 3 weeks or complete cessation [3]

Breast feeding

Recommendation on breastfeeding interruption – IAEA (proposal) , cont´d

Radio-pharmaceutical	Most common clinical use	Typical adm. activity (MBq)	Feeding interruption time (hours)
^{123}I-hippurate	Imaging and function of kidneys and urinary tract	20-40	12 h [4]
^{131}I-NaI	Dosimetry and therapy	Any	Complete cessation [5]
^{131}I-MIBG	Neuroblastoma imaging and therapy; pheochromocytoma	Any	> 3 weeks or complete cessation
^{11}C-labelled		Any	No
^{13}N-labelled		Any	No
^{15}O-labelled		Any	No
^{18}F-FDG	Tumours and infection imaging	400	4 h [6]
^{51}Cr-EDTA	Glomerular filtration rate	2	No
^{67}Ga-citrate	Tumours and infection imaging	200	> 3 weeks or complete cessation
^{68}Ga-DOTA-conjugated peptides	Tumours imaging	100-200	6 h
^{111}In-octreotide	Neuroendocrine tumours (somatostatin receptors)	100-200	No
^{201}Tl-chloride	Myocardial perfusion	100	96 h

Breast feeding

- Uncertainties!!!

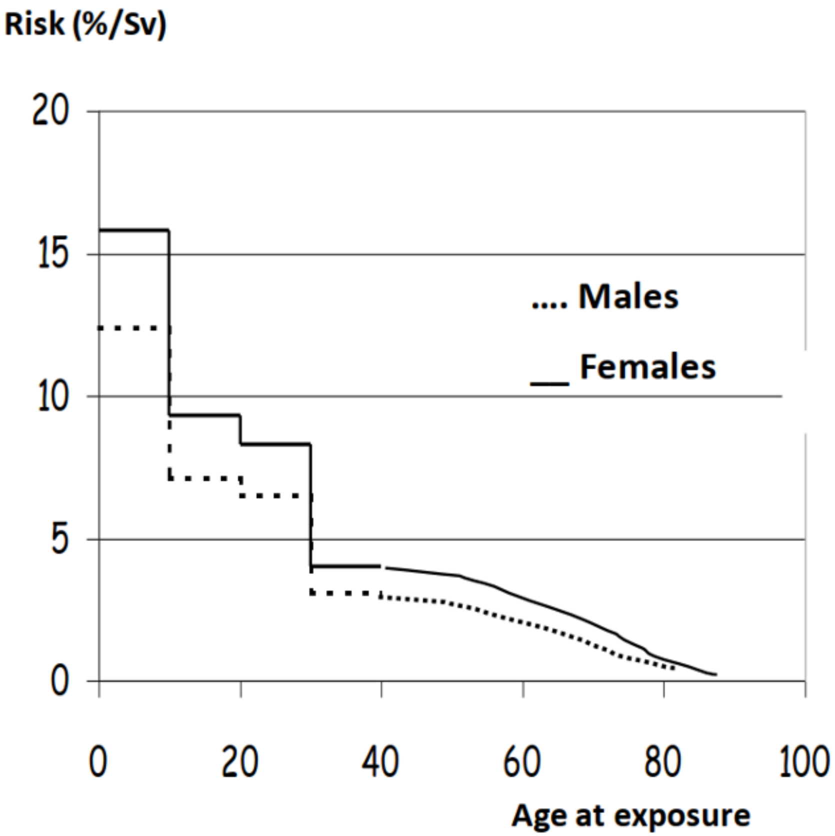
- All recommendations are based on measurements including several assumptions
  - Limited reliable scientific data
    - epidemiological studies and radiobiology experiments
  - Individual variations (excretion, age,…)
  - Biokinetic behavior of the radiopharmaceutical
  - Often adult biokinetic models used
  - Mathematical phantoms have limitations

Female workers

- Woman are known to be more radio-sensitive

- Occupational radiation protection for woman is the same as for men
- No special limits
- No discrimination

- Different when they are pregnant!
- Also different when they are breastfeeding



Female workers

- Management of pregnant workers
  - Dose limits for the fetus are those for the general public
    - 1 mSv per year
  - Once the pregnancy has been declared and the employer notified, additional protection for the fetus should be considered
  - The working conditions of a pregnant worker, after the declaration of pregnancy, should be such that it is unlikely that the dose to the fetus will exceed 1 mGy during the reminder of the pregnancy
  - It is important not to create unnecessary discrimination against pregnant women

- Double responsibility
  - The woman herself has to declare the pregnancy to the management as soon as the pregnancy is confirmed
  - The employer should carefully review the exposure conditions of the pregnant woman
    - In particular the employment should be such that the probability of high accidental doses and intakes is insignificant
  - The worker should be informed of potential risks

Female workers

- Options to consider
  - No changes in assigned working duties
  - Change to another area where the radiation exposure might be lower
  - Change to a job that has essentially no radiation exposure

- In certain countries there might be specific regulations
- Should be based on a discussion with the employee

Female workers

- Dose level to the fetus
  - Additional monitoring, e.g. by a active personal dosemeter during pregnancy
  - Dose to the worker is not the same as the dose to the fetus
  - But dose at the position of the pelvis will normally be a conservative estimate

Female workers

- Change to another area where the radiation exposure may be lower

- In nuclear medicine, the recommendation is to, if possible
  - Avoid working with PET radiopharmaceuticals or with patients that have been administered with PET substances
  - Avoid working with high-activity procedures
  - Avoid spending a lot if time in the radiopharmacy or working with of radioiodine or ^{99m}Tc-gas/aerosols

- Change to a job that has essentially no radiation exposure

- This is sometimes requested by pregnant workers who realise that risks may be small but do not wish to accept any increased risk

Female workers

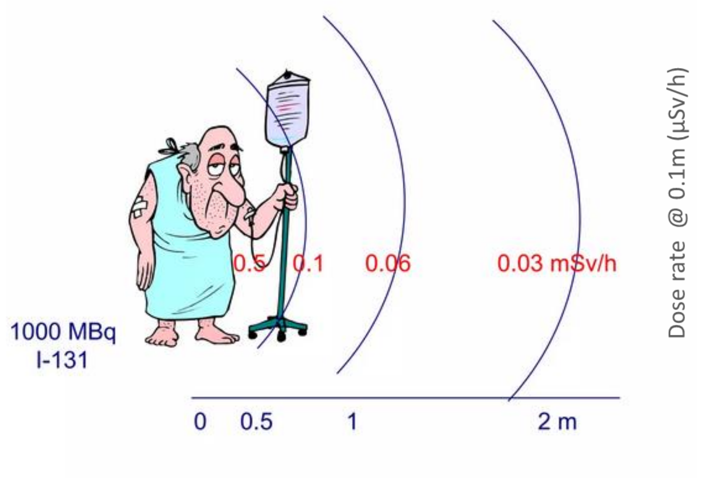
- Management of breastfeeding workers

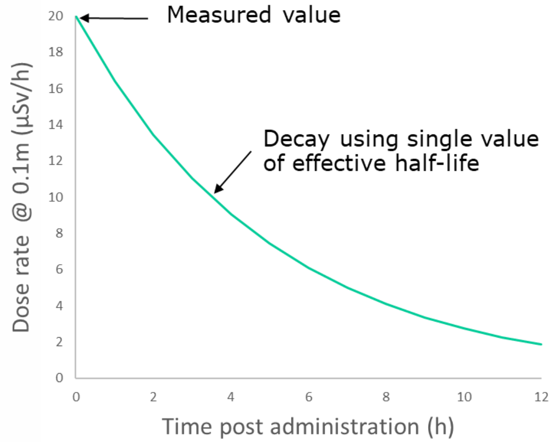
- In radiology or radiotherapy: no problem at all

- In Nuclear Medicine
  - Recommendation to avoid handling of large amount of radionuclides or working with solutions of radioiodine or ^{99m}Tc-gas/aerosols where the risk of internal contamination is not insignificant

ICRP Publication 106

Other exposures in nuclear medicine





Dose rate @ distance from patient → Dose rate < patient release criterion → Exposure of …

- Public
- Caregiver
- Family

Nuclear medicine patient as a radioactive source

- Physically large source
- Patient-specific biokinetics change the activity distribution over time
  - Isotope- and pharmaceutical-specific
- Combination of ‘point measurement’ and ‘unique effective half life’

⇒ can result in errors for typical ‘close-contact scenarios’

Exposure of public

- Public radiation exposure includes exposed members of the general public, workers who are not designated as nuclear or radiation workers, and unintentional patient-to-patient exposure after PET radiopharmaceutical administration.
- Public dose limits are based on the sum of internal and external exposures from sources related to practices that are justified.
- The recommended annual public dose limits are: effective dose -1 mSv, lens of eye dose - 15 mSv, and skin dose - 50 mSv.

Exposure of public

- The radiation dose reduction to members of the public is achieved through a reduction in the patient activity which is due to physical radioactive decay and biological elimination
  - Adequate combinations of distance from, and shielding of, injection/uptake rooms.
  - Limit access to the injection/uptake areas to essential staff and patients i.e. no general public access including those accompanying patient (e.g. family, friends, non-health care worker caregivers) unless there are compelling circumstances.
  - Dedicated 'hot patient' toilets with shielding from public areas (e.g. waiting room, adjacent offices etc.)

Exposure of public

- In general, radiation dose rates are sufficiently low post imaging patients that they do not pose a radiation risk to those around them. Taking this dose rate constant into account, public dose limits (1 mSv per year) will not be exceeded.

- The general advice is not to bring children, especially young children, and by extension pregnant women, to the imaging centre and for family/caregivers to wait in the waiting room during patient uptake and imaging

- Upon leaving the PET/CT imaging department, patients should be reassured that they, from a radiation point of view, pose no significant risk to those around them, including children and pregnant women.

Who are "comforters and carers"?

- In nuclear medicine, **comforters and carers** are *individuals who willingly and voluntarily help in the care, comfort, or support of patients undergoing a medical exposure*. Examples:
- A parent holding a child during an imaging procedure
- A spouse accompanying a patient receiving radionuclide therapy

Comforters in nuclear medicine

IAEA Basic Safety Standards (BSS, GSR Part 3, 2014)

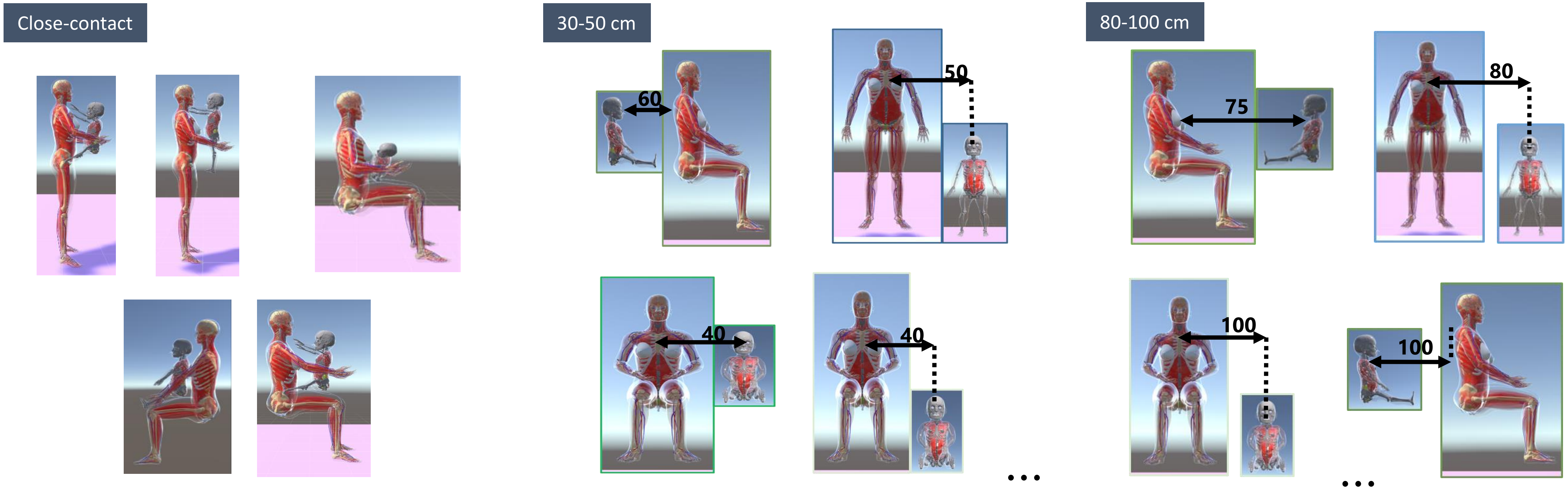
- Comforters and carers are explicitly recognized not as occupationally exposed workers and not as general public.
- Their exposure must be constrained, like a medical exposure, but not subject to the same dose limits as for the public.
- The dose constraint (not limit) recommended by IAEA and ICRP for comforters and carers is typically around 5 mSv per episode.
- Thus, legally:
    - Comforters and carers are not considered members of the public for radiation protection purposes.
    - They are recognized as voluntary, non-occupationally exposed individuals receiving medical exposure.

- Comforters should receive clear information about potential exposures and how to minimize them (e.g., distance, shielding, time).
- Facilities must justify their involvement and optimize the exposure.

Comforters in nuclear medicine

Category	Definition	Example	Legal Treatment	Typical Dose Limit/Constraint
Occupational exposure	Work-related exposure	Nuclear medicine technologist	Dose limit (20 mSv/year, averaged)	Limit
Medical exposure (patient)	Exposure for diagnosis/treatment	Patient receiving PET/CT	No dose limit	Optimized for benefit
Medical exposure (comforter/carer)	Voluntary helper supporting a patient	Parent holding child	Dose constraint, not a limit	~5 mSv per exposure episode
Public exposure	All other persons	Hospital visitor	Dose limit (1 mSv/year)	Limit

Comforters in nuclear medicine

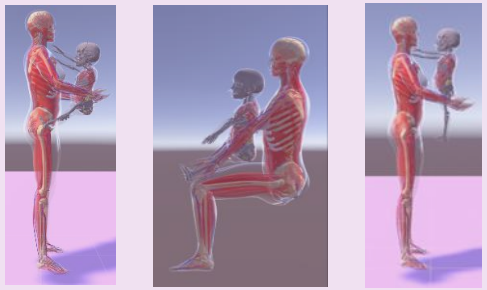


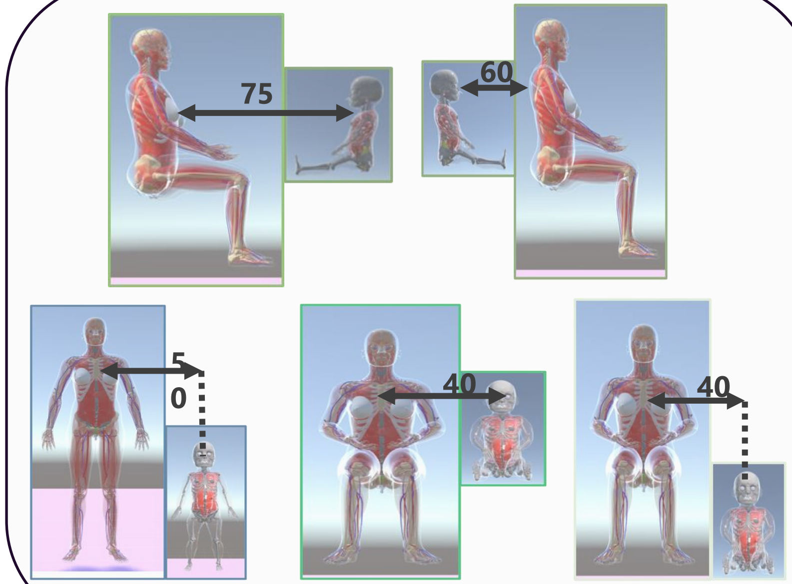
Application of computational approach

- Impact of different postures on the external dose rates
- CASE STUDY: "Mother – child" configurations

Comforters in nuclear medicine

Close-contact postures





SCENARIO 1

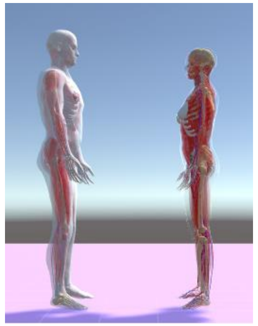
- Mother = hyperthyroidism patient (out-patient)
- I-131 ; A_{adm} = 400 MBq
- $\dot{H}^*(10)$ @ 1m = 20 µSv/h → reached after 2 min (typical release criterion)

'Effective dose' to the child after 14 days if

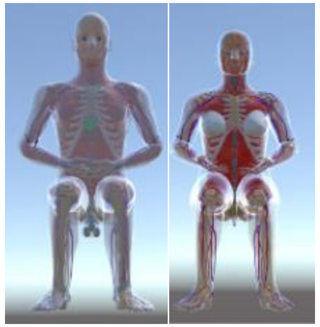
- 1h physical contact / day
- 6h social contact / day

	Range of Effective dose (µSv)
Day 1	391 - 624
Day 2	63 - 285
Day 3	48 - 253
Day 4	42 - 224
Day 5	39 - 205
Day 6	36 - 187
Day 7	33 - 170
Day 8	30 - 156
Day 9	27 - 142
Day 10	25 -130
Day 11	23 - 119
Day 12	21 - 109
Day 13	19 - 99
Day 14	18 - 90
Day 15	18 - 90
Total	**831 - 2883**

Future



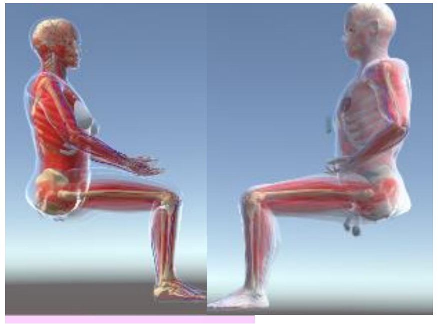
- Tool of organ absorbed dose rates per unit of administered activity for **a large variety of close-contact configurations, for a range of radiopharmaceuticals** (both for diagnostic and therapeutic procedures)
- Incl. patient-specific information to account for individualized features



$\Rightarrow$ evaluate the expected exposure to caregivers or the public for specific scenarios as **part of risk assessment studies**

$\Rightarrow$ with choice of appropriate dose constraints

$\rightarrow$ facilitate the setting of **hospital release criteria and patient restrictions**



Staff radiation protection in nuclear medicine

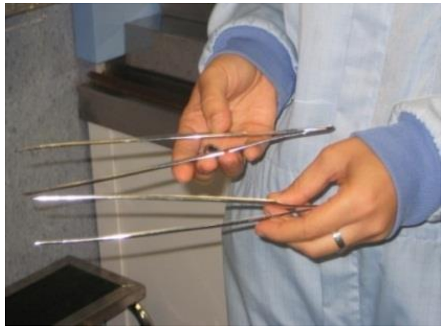
Staff radiation protection in nuclear medicine

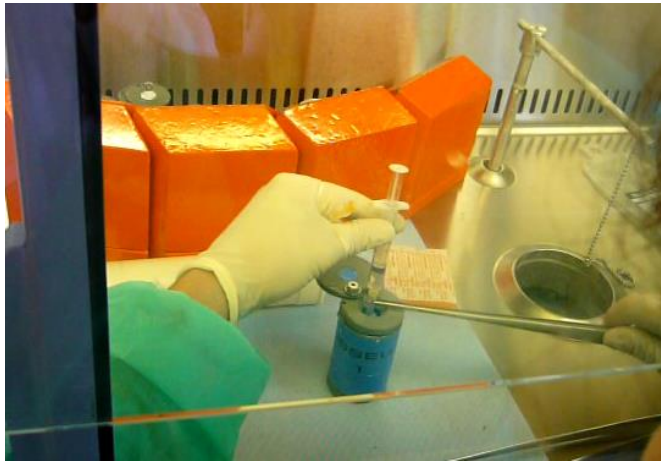

Avoid contamination
INTERNAL
Don´t eat, drink or smoke in the lab.
Use laboratory clothing
Use gloves
nitrile or vinyl
Wash and measure hands
Use protective paper
Sigrid Leide-Svegborn, 2018

Optimization of radiation protection

- Use distance

  – **Use long tweezers for handling of sources**





Optimization of radiation protection

- Automatic dispensing and infusion systems

Intego™, MEDRAD

Iride, Comecer

Posijet® Lemer Pax

Optimization of radiation protection

Intego™, MEDRAD

Lena Jönsson, SUS Lund

- Flushing
- Radiopharmaceutical withdrawal
- Activity determination
- Radiopharmaceutical injection
- Saline flushing/injection
- Radiation shielding

Optimization of radiation protection

- Minimize time of exposure
  - Experience plays a role
  - Practising without activity
  - Using shielding can slow down procedure

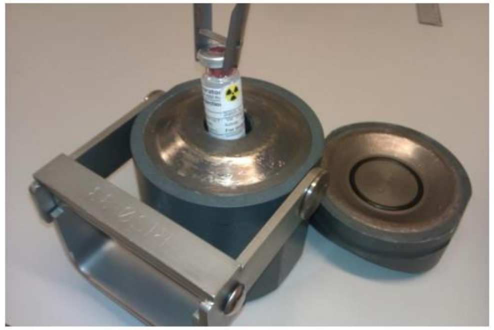
Optimization of radiation protection

- Use shielding
  - For syringes and vials
  - Avoid touching unshielded sources

Optimization of radiation protection

Shielding in PET

14 mm Wolfram – 97% is attenuated
9 mm Wolfram – 88 % is attenuated



- High photon energy: 511 keV (^{99m}Tc: 140 keV)
- High dose rate coefficient from an routine patient: 40 µSv/h at 1m (^{99m}Tc: 6 µSv/h)
- Short physical half-life: 1.8 h (^{99m}Tc: 6.02 h)

Optimization of radiation protection

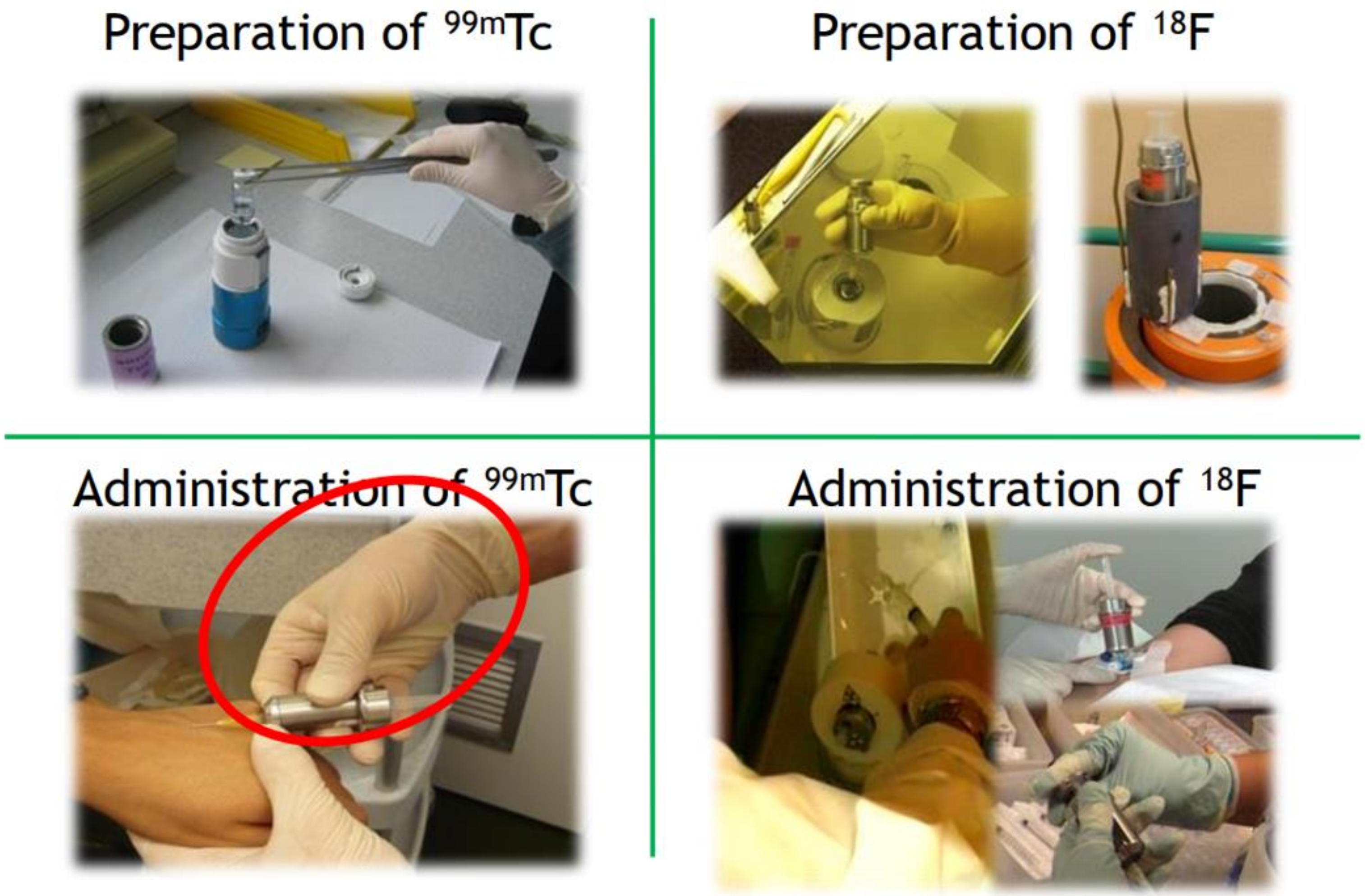
PET and lead apron ?

20 min at 1 m distance

	Without	With
400 MBq ^{99m}Tc	2,7 µSv	0,6 µSv
400 MBq ^{18}F	12 µSv	11 µSv

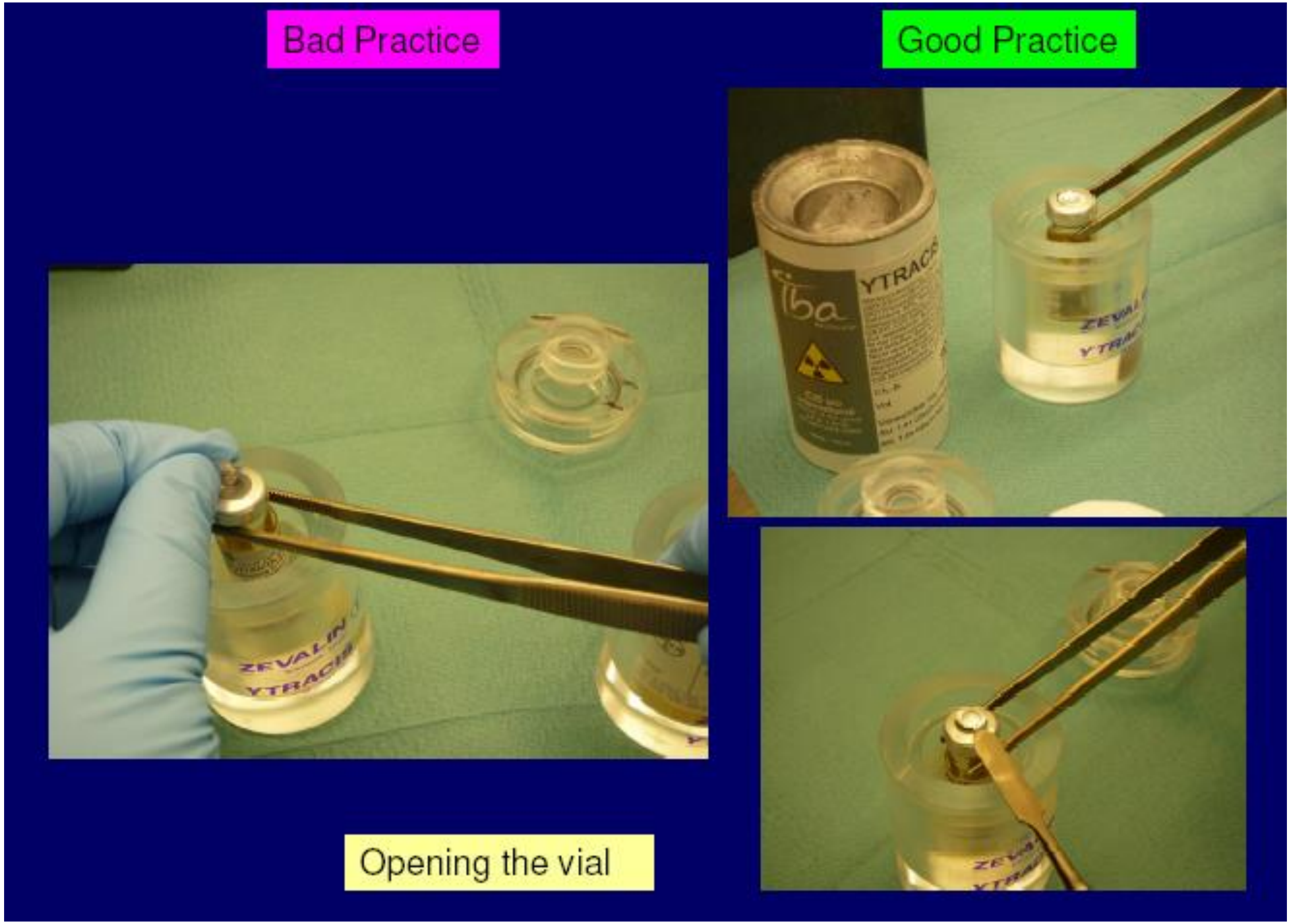
Lead apron
0,5 mmPb

- Examples of good and bad practices

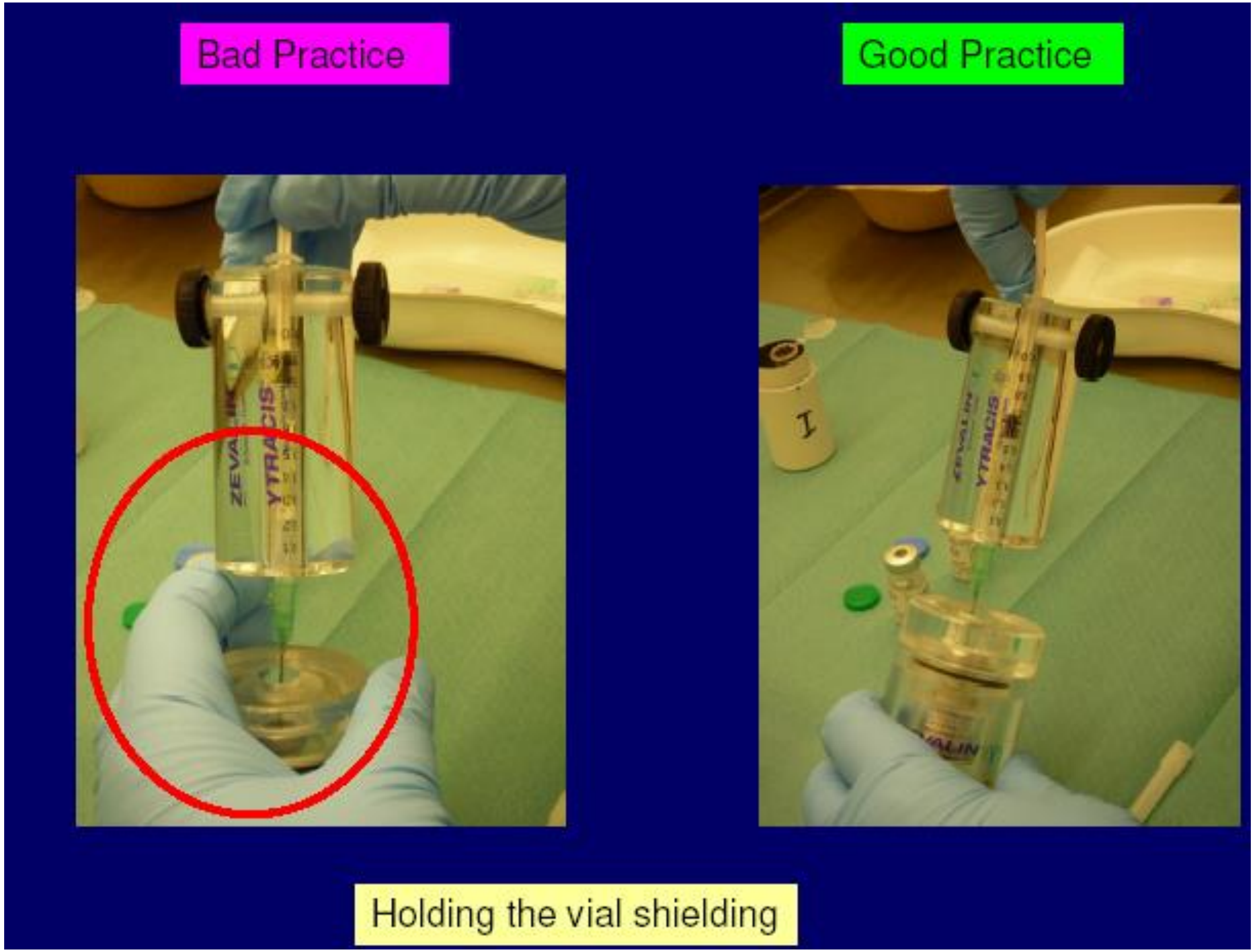


(Carnicer, A. et al. Occupational Exposure: With Special Reference to Skin Doses in Hands and Fingers. In Radiation Protection in Nuclear Medicine (Ed) Mattsson, S. Hoeschen, C. Springer 2013)

- Examples of good and bad practices



- Examples of good and bad practices



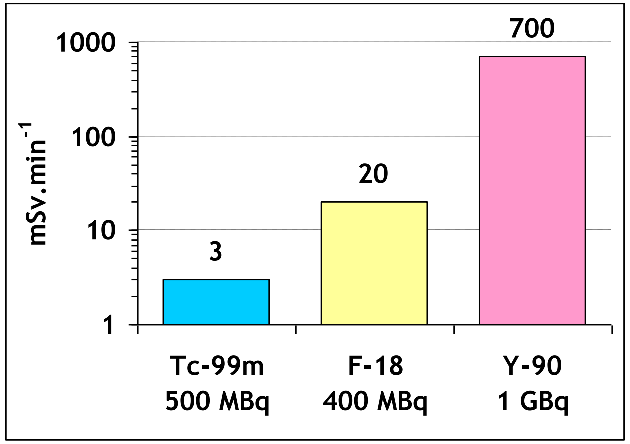
Staff radiation protection in nuclear medicine

Staff radiation protection in nuclear medicine

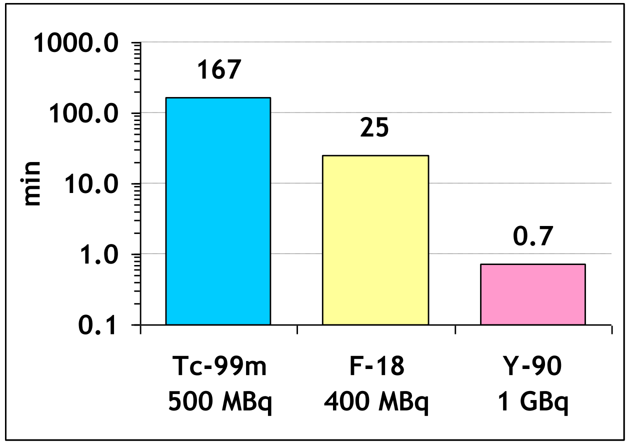
Dose rates in nuclear medicine can be high

- Non-shielded syringe

Dose rate (in mSv.min⁻¹)

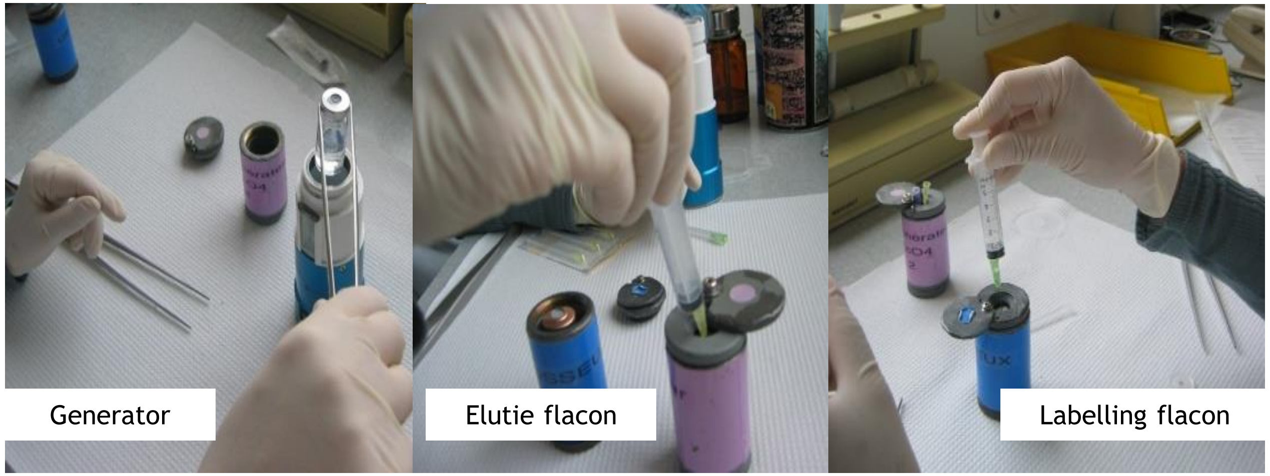


Time (in min) to reach 500 mSv



Risk for external irradiation

- Manipulation of sources: irradiation of whole body, eye lens and extremities



Labelling met Tc-99m

Injectie bij diagnose

Risk for external irradiation

- After injection: irradiation by patient

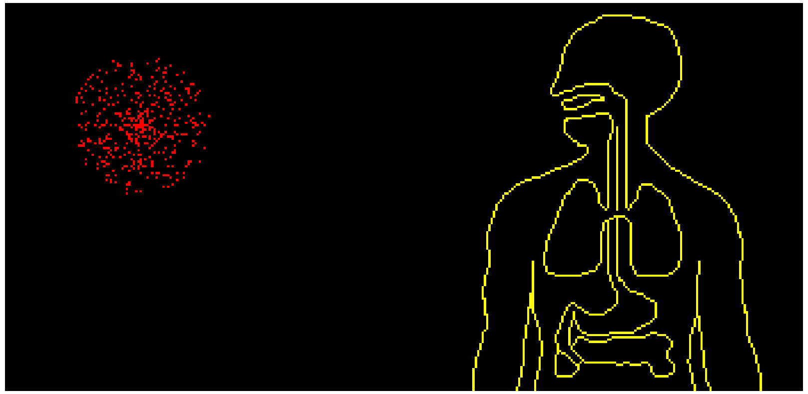
Risk for contamination

Dose rate > 200mSv/h
5 cm above contamination
for therapy

Source: Ilona Barth and Arndt Rimpler

Risk for internal contamination

- Inhalation
- Ingestion



Who should be monitored?

- Those working with radioactive substances…
  - Preparation and administration of radiopharmaceuticals
  - Performing patient examinations
  - Performing quality control of the equipment

Optimization of radiation protection

- Recommendations
  - The dispensing protocol and the use of shielding devices in any radiopharmacy should be assessed carefully to optimize the strategy
  - Shielding of the syringe is the most important factor affecting finger dose, and syringe shields should be used as much as possible
  - Vials from which radioactive liquid is withdrawn should always be shielded
  - The choice of the manipulation technique only has a minor influence on finger dose. The most important factor is that the staff are able to use the technique effectively
  - All staff should undergo a period of intense training in which they practice manipulations using non-radioactive liquid prior to undertaking any dispensing
  - Careful positioning of materials within the dispensing cabinet is important for streamlining the procedure and minimizing doses to the hands
  - For injections, prior venous cannulation allows the injection to proceed more rapidly.