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Incorporation of radionuclides by workers:
Measurements vs. evaluation with GEANT4 simulations

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Presentation overview

- **Context**
  - Risk of internal contamination at CERN & internal monitoring in Switzerland.
- **Approach for internal monitoring programme**
  - Instrument characterisation procedure.
  - Measurements & MC simulations.
- **Prospects & preliminary considerations**
  - Geometry evolution and practical example.
- **Conclusions**

Context

Major event at CERN : commissioning of the **CERN-MEDICIS*** facility *(since 2018)*

- Aim : production of (exotic) radioisotopes for medical applications.
- Handling of unsealed sources, high activity, short half-life (^{149}Tb, ^{47}Sc, …).
- Radionuclides shipped to the partner centres (such as university hospitals) :

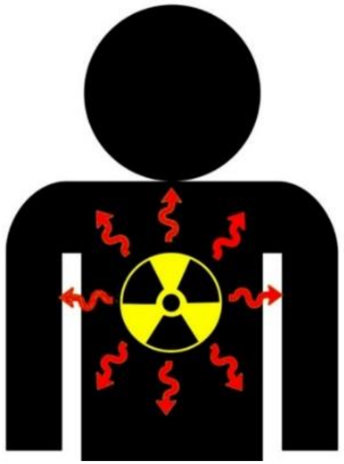
  → radiolabelling tests / dosimetry ⇢ radiopharmaceuticals.

→ Increase risk of internal contamination among the workers.

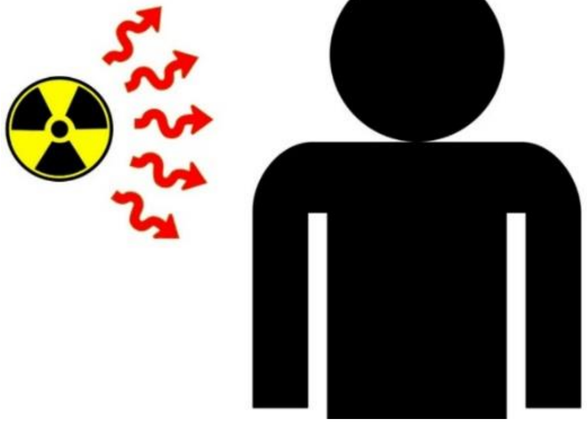
→ Update the internal monitoring programme for the workers.

* MEDICIS Promed : Medical Isotopes Collected from ISOLDE.

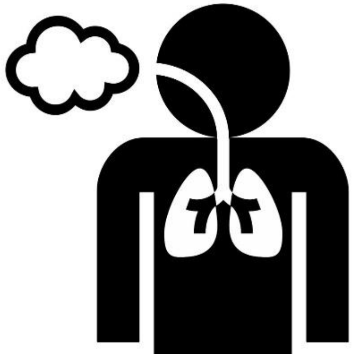
Internal contamination and internal monitoring programmes



VS

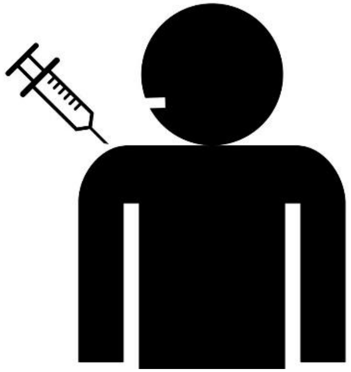


Internal contamination and internal monitoring programmes

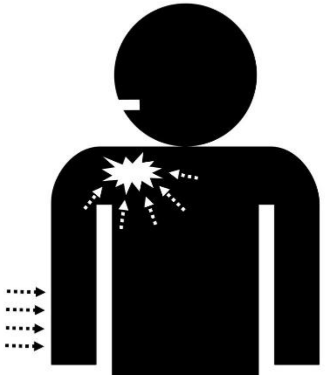


Inhalation

Ingestion



Injection



Absorption
(skin or wounds)

- The stochastic risk associated to an internal contamination is quantified by the committed effective dose E_{50} (Sv).

- No operational quantity directly measurable.
- E_{50} can be retrospectively assessed through :
  - <u>***in vivo*** measurements (radiations emitted from the body);</u>
  - ***in vitro*** measurements (of a biological sample).
- An internal monitoring programme aims to verify that*:
  - The workers are efficiently **protected** against the risk of intake of radionuclides.
  - The protection complies with **legal requirements**.
- The new internal monitoring programme at CERN is inspired by the Swiss regulation (annual limit: $E_{50} = 1$ mSv).

* According to the **ISO 20553**:2006 standard.

Internal monitoring in Switzerland

In CH (and CERN): occupationally exposed worker > 1 mSv/y.

screening measurement

↓

above threshold ?

NO → no further measurements

YES → incorporation measurement (quantify A_{intake} and E_{50})

(by accredited laboratory !)

- Periodic, rapid & easy measurement, done by workers themselves (ideally) using conventional RP instruments.
- Threshold → should guarantee detection of intakes leading to annual E_{50} > 1 mSv.

Adapt the Swiss approach

Define a general & pragmatic approach to set up *in vivo* screening measurements to detect intakes leading to an annual $E_{50} > 1$ mSv.

- Task-related operations → time of potential intake is known.
- Rapid turnover of CERN workers: ~~periodic~~ screening
- Determine the minimum detectable dose associated to the screening measurement $(E_{50,min})$.
- Limit the number of authorised operations for each worker, so that annual $E_{50} < 1$ mSv.

$$E_{50,min} = MDA \cdot \frac{e_{inh}}{m(T)}$$

- Dose per unit intake (Sv/Bq).
- Dosimetric models.
- Radionuclide.

- Minimum detectable activity (Bq).
- Instrument (characteristic limits, efficiency).
- Phantom.

- Retention or excretion function (Bq per inhaled Bq).
- Biokinetic models.
- Radionuclide, elapsed time.
- *(Biokinetic model solver → **not in the aim of this talk**)*

Instrument choice

Pros	Cons	Pros	Cons
easy & quick	no nuclide identification	nuclide identification (+ mixtures)	complex & longer
cost-friendly	higher MDA (and $E_{50,min}$)	lower MDA (and $E_{50,min}$)	costly

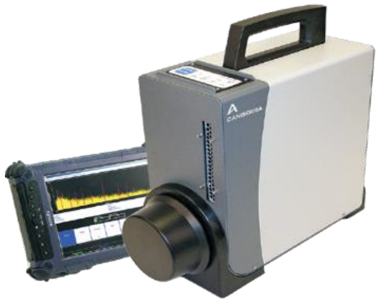
6150AD-b/H

CoMo 170

FHZ 512 BGO

LB 1234

LB 6393



Falcon 5000 (HPGe)

2x2 NaI(Tl)

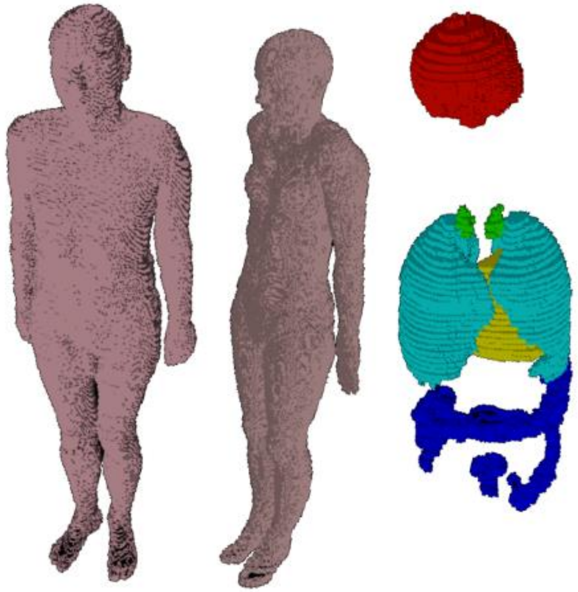
Conventional RP instruments

Spectrometers

Pictures: https://www.nmas.no/produkt/59556475/scintillator-probe
http://www.laurussystems.com/products/products_pdf/LS_thermo_FH-40.pdf
http://www.tridinamika.com/shop/products/saphymo-como-170-300/
https://all-pribors.ru/opisanie/43292-09-falcon-5000-45430
https://www.directindustry.it/prod/canberra-industries/product-23661-555299.html

Phantom choice

simple → *complex*



- Create a robust model & validate each step with MC simulations

ICRP phantom picture by Dr. Laurent Desorgher.

MDA (conventional RP instruments)

$$MDA = CL \cdot CF$$

CL **: characteristic limit**

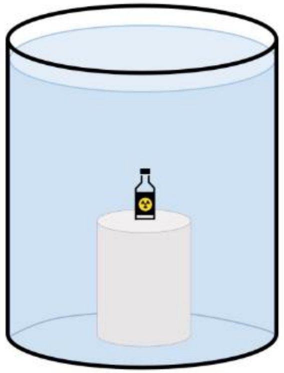
(mesurand in: nSv/h or cps)

- Decision threshold & detection limit.
- Found according to ISO 11929 standard.
- Determined for different background values.

CF **: conversion factor mesurand – activity**

(Bq/(nSv/h) or Bq/cps)

- Obtained by placing known (reference) sources inside a simplified torso phantom :



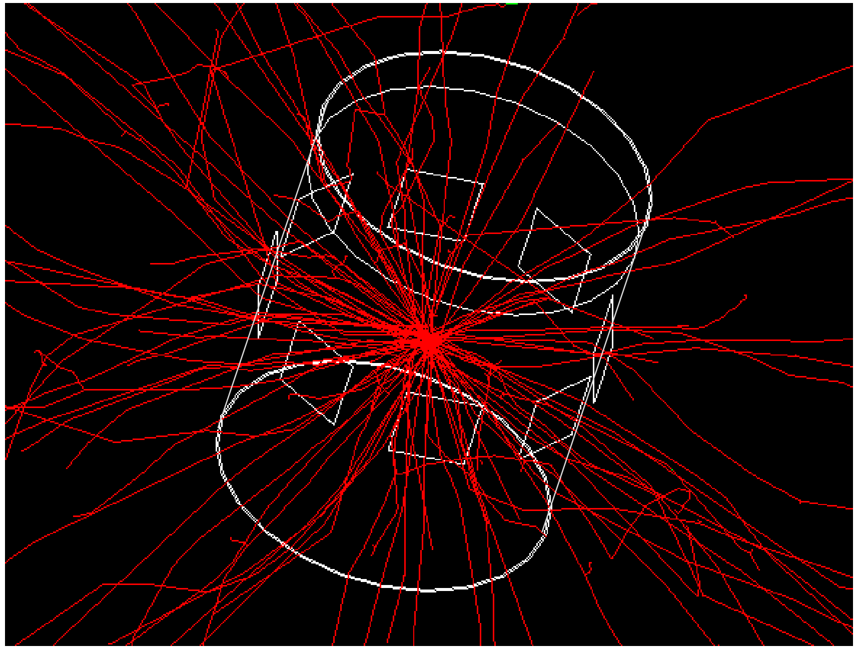
^{57}Co *(124 keV)*, ^{133}Ba *(268 keV)*, ^{137}Cs *(662 keV)*, ^{60}Co *(1253 keV)*

S Medici, P Carbonez, J Damet, F Bochud, C Bailat, A Pitzschke. “Detecting intake of radionuclides: In vivo screening measurements with conventional radiation protection instruments.” *Radiation Measurements* (2019).

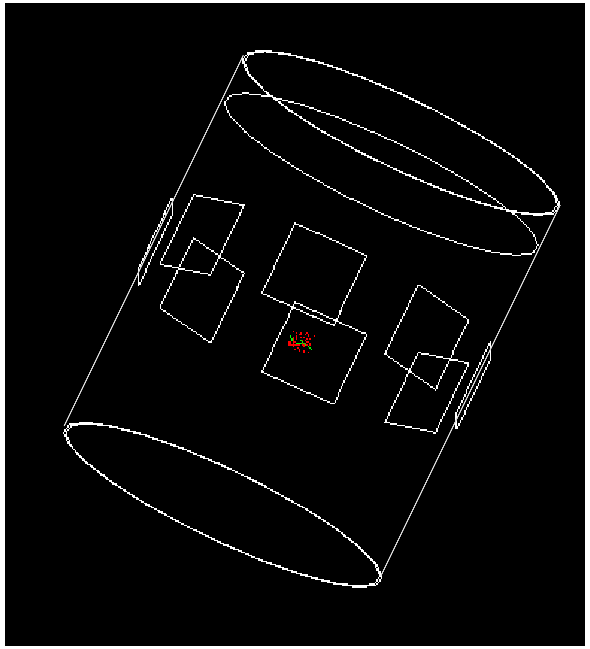
Conversion factor (CF) : considerations

- We characterised our instrument with common reference sources.
- **Q**: can we estimate *CF* for untested radionuclides ?

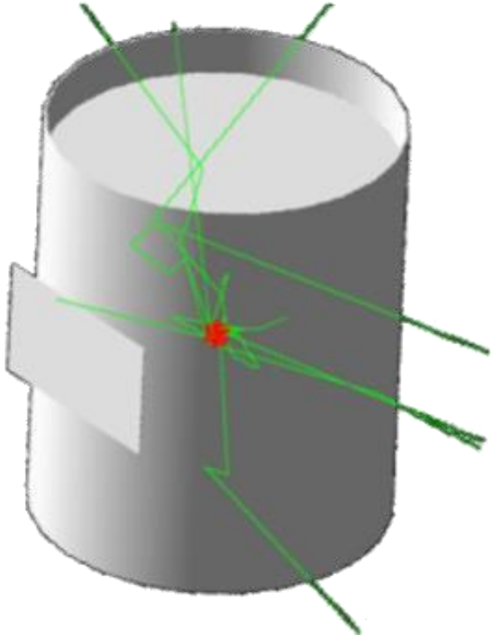
→ **R:** MC simulations ?



Phantom filled with **air**

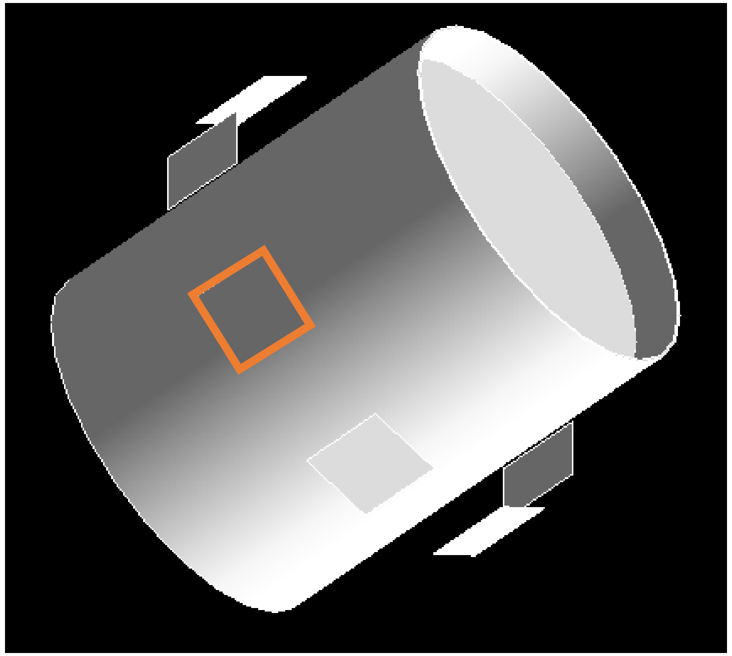


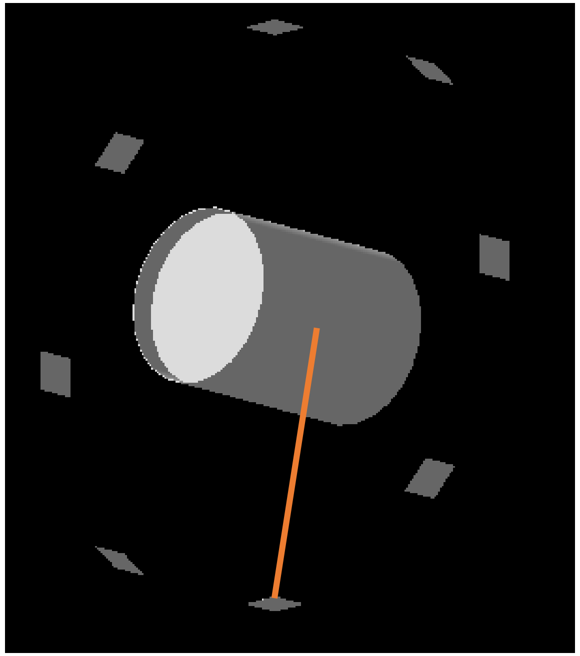
Phantom filled with **water**



Geant4 MC vs experimental results

- Simulate H*(10) at different distances from the phantom surface.
- Tally size = average sensitive surface of the tested RP instruments.
- Tally positioning ≡ RP instruments positioning





MC simulations performed with the help of Dr **Laurent Desorgher** (IRA/CHUV).

Geant4 MC

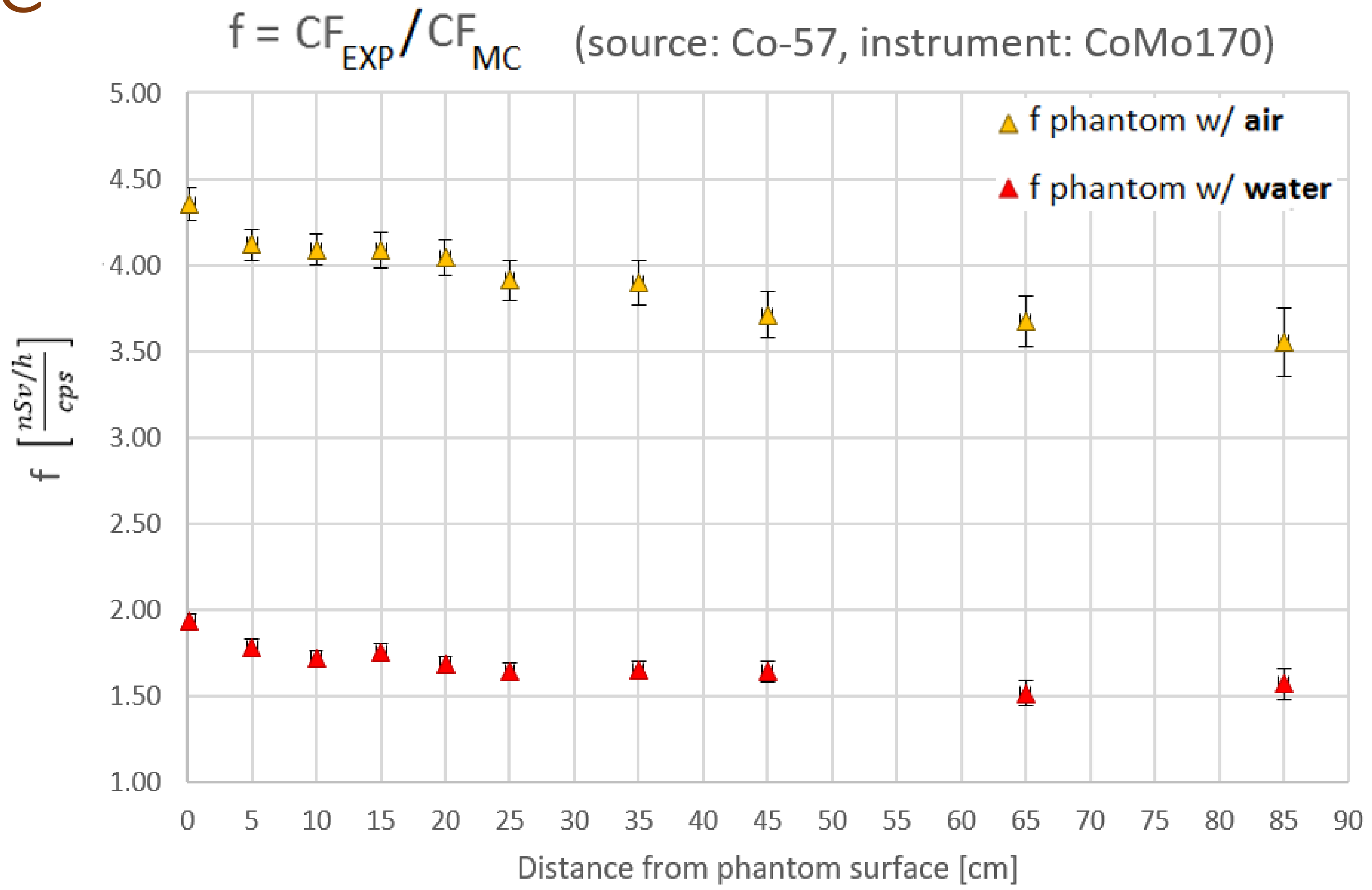
- MC validation with phantom filled with air :
  - good agreement (< 10%) with the theoretically expected results.

- Comparison between :
  - experimental CF_{EXP} (in $\frac{kBq}{cps}$ or $\frac{kBq}{nSv/h}$) ;
  - simulated CF_{MC} (always in $\frac{kBq}{nSv/h}$) .

- $CF_{EXP} = f \cdot CF_{MC}$
  - f includes the instrument's energy dependence, conversion factor between count rate and dose rate, geometry, ...

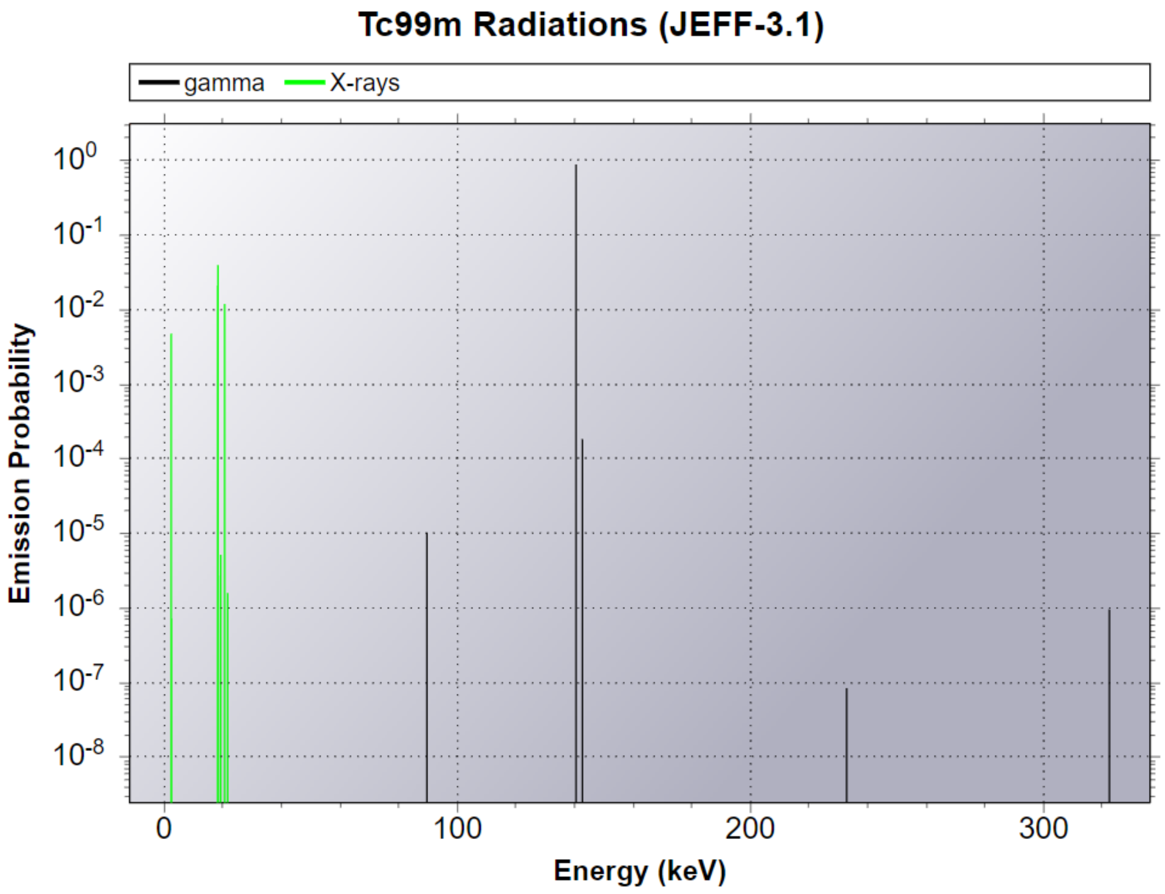
Geant4 MC

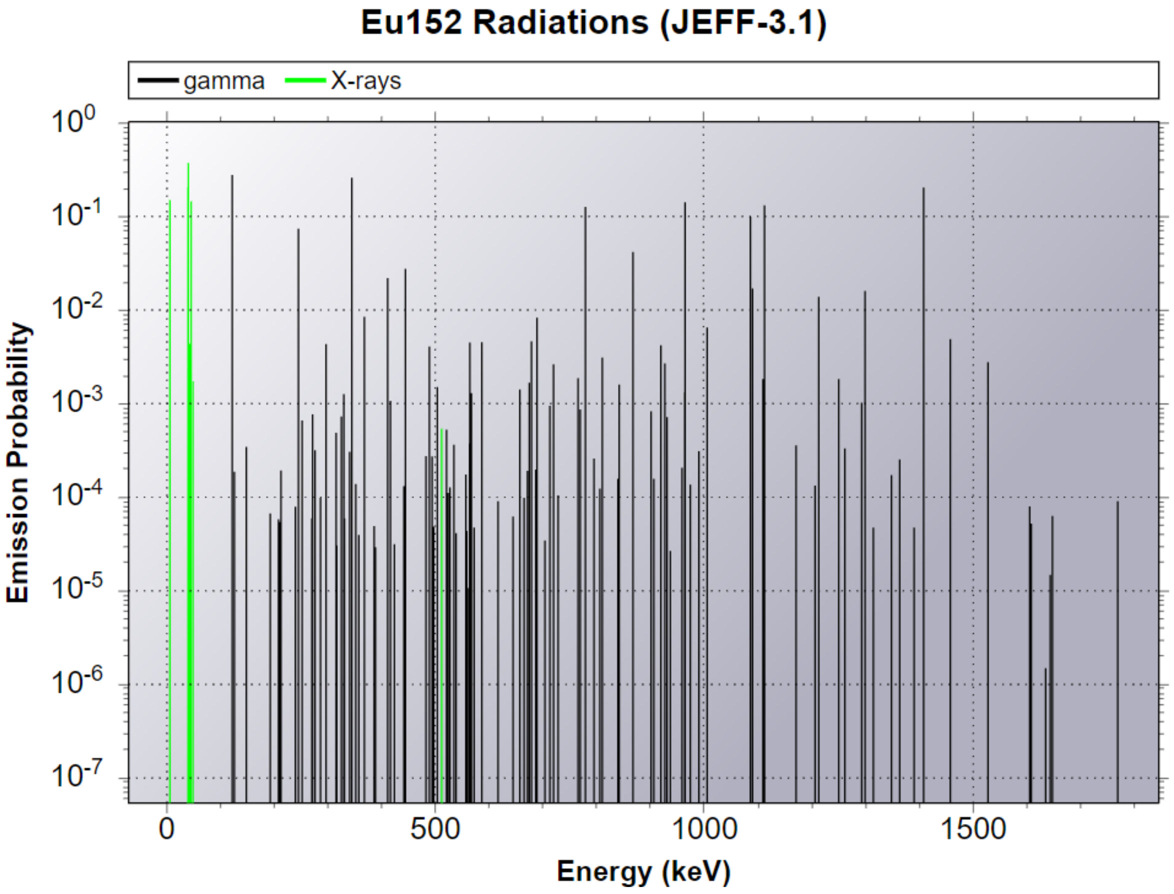
$$f = \frac{CF_{EXP}}{CF_{MC}}$$



Find experimental CF for untested radionuclide

- Find instruments' response for two untested radionuclides: ^{99m}Tc & ^{152}Eu

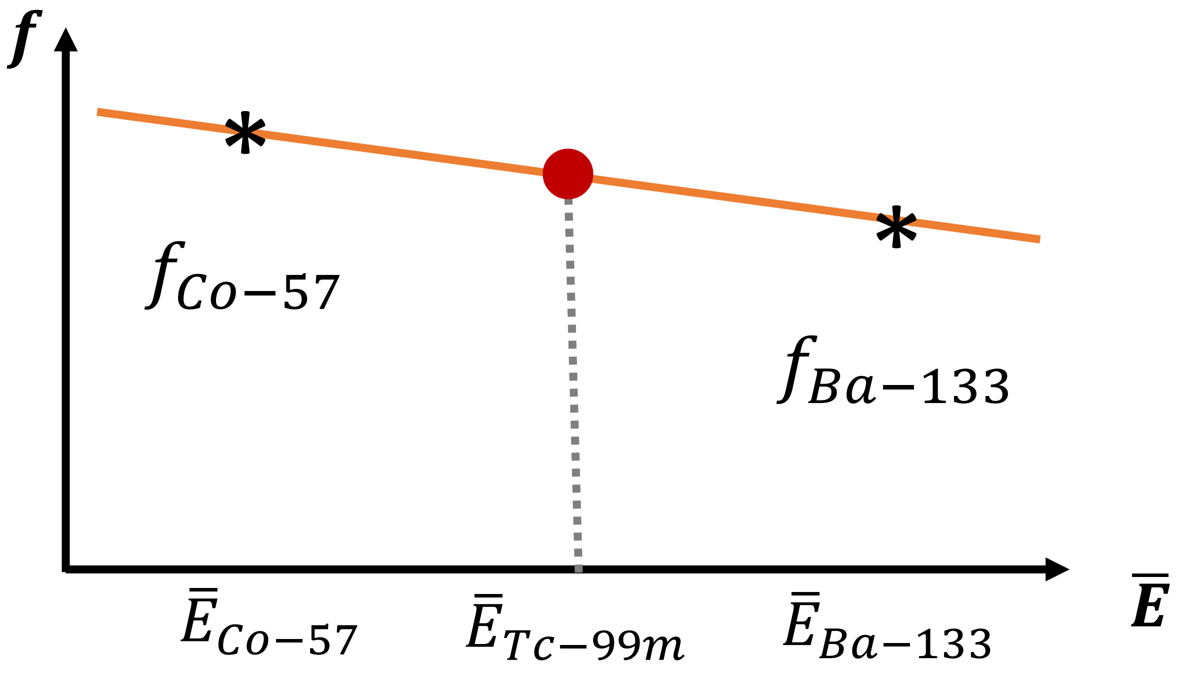




Source : Nucleonica - nuclear science internet portal (www.nucleonica.com)

Find experimental CF for untested radionuclide

$$f_{Co-57} = \frac{CF_{EXP,Co-57}}{CF_{MC,Co-57}} \quad \text{and} \quad f_{Ba-133} = \frac{CF_{EXP,Ba-133}}{CF_{MC,Ba-133}}$$



$$f_{Tc-99m} = \frac{CF_{EXP,Tc-99m}}{CF_{MC,Tc-99m}}$$

$\bar{\boldsymbol{E}}$ = *average energy (weighted by photon emission probability* $p_{\%}$ *)*

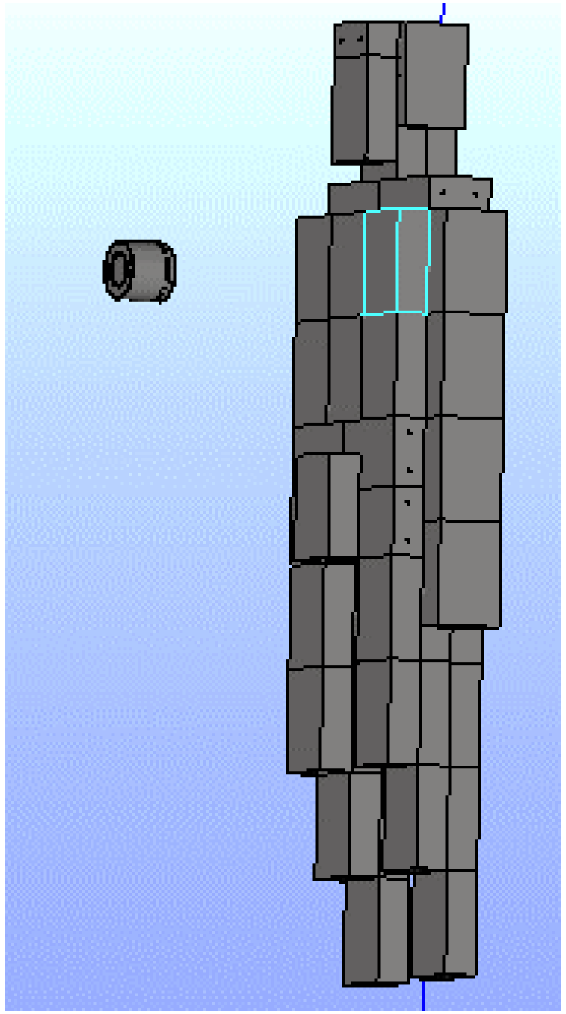
Find experimental CF for untested radionuclide

Energy range for interpolation (influencing : $p_{\%}$, $\bar{E}$, and CF_{MC}) **= 40 keV – 3 MeV**

	Relative difference between estimation and measured values	
Instrument	**Tc-99m**	**Eu-152**
6150AD-b/H	-3%	+8%
FHZ 512 BGO	+45%	-27%
CoMo 170	-6%	+13%
LB 6393	+5%	+3%
LB 1234	+3%	-15%

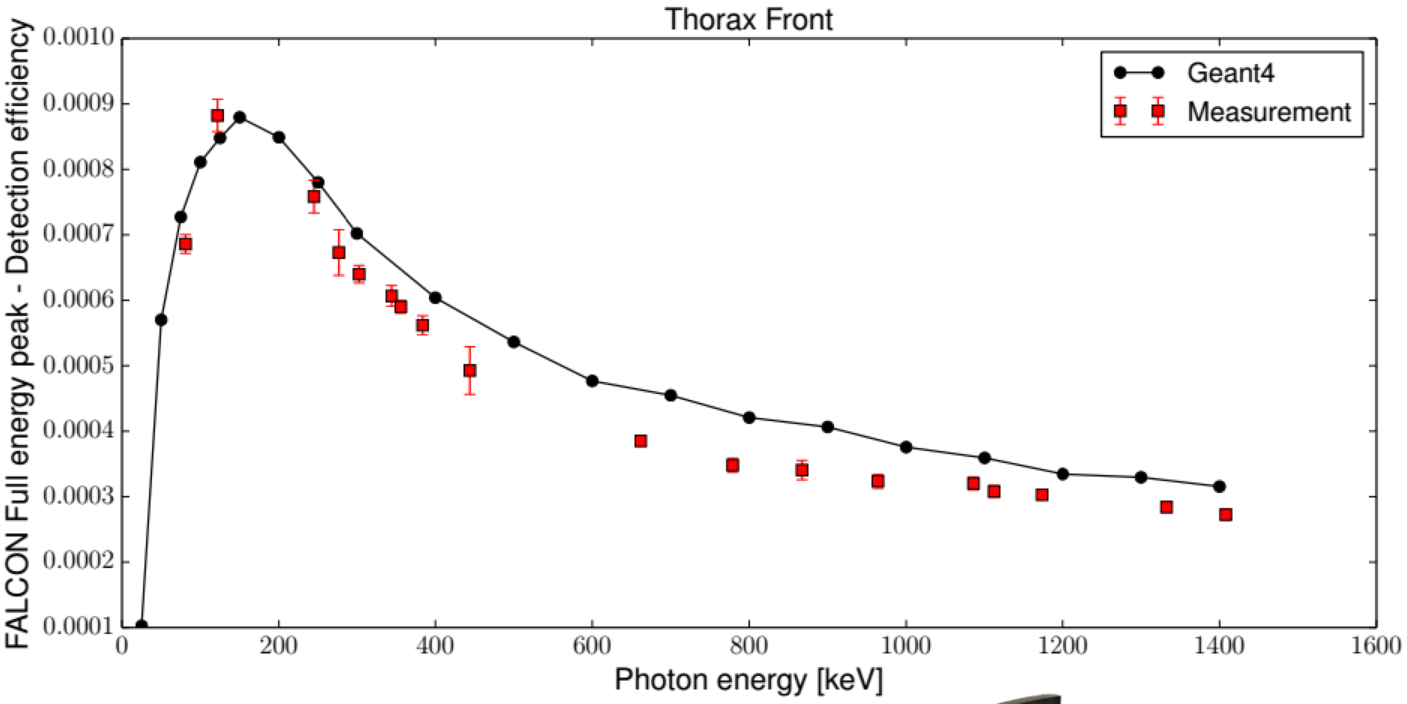
Prospects: from simple to more complex geometry

- Extend the approach to more realistic /anthropomorphic geometries.
- More realistic CF estimates.
- Different filling geometries.
- Test portable γ-spectrometers:
  - Radionuclide identification.
  - Radionuclide mixtures.

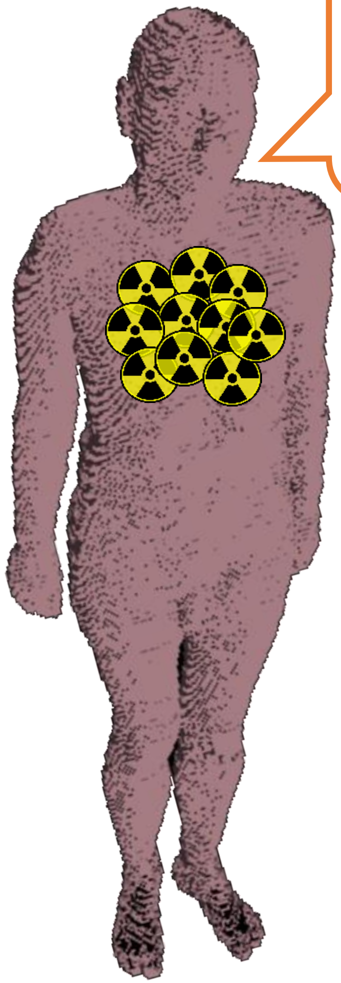


Geant4 model of the IGOR phantom by Dr L. Desorgher

Prospects: from simple to more complex geometry



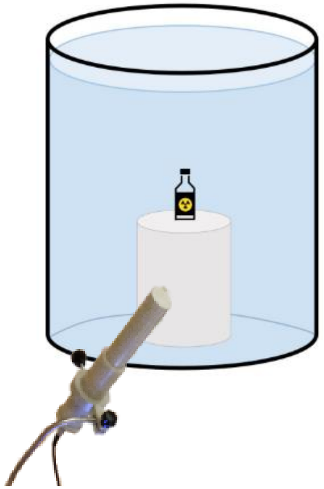
From physical to voxel phantoms

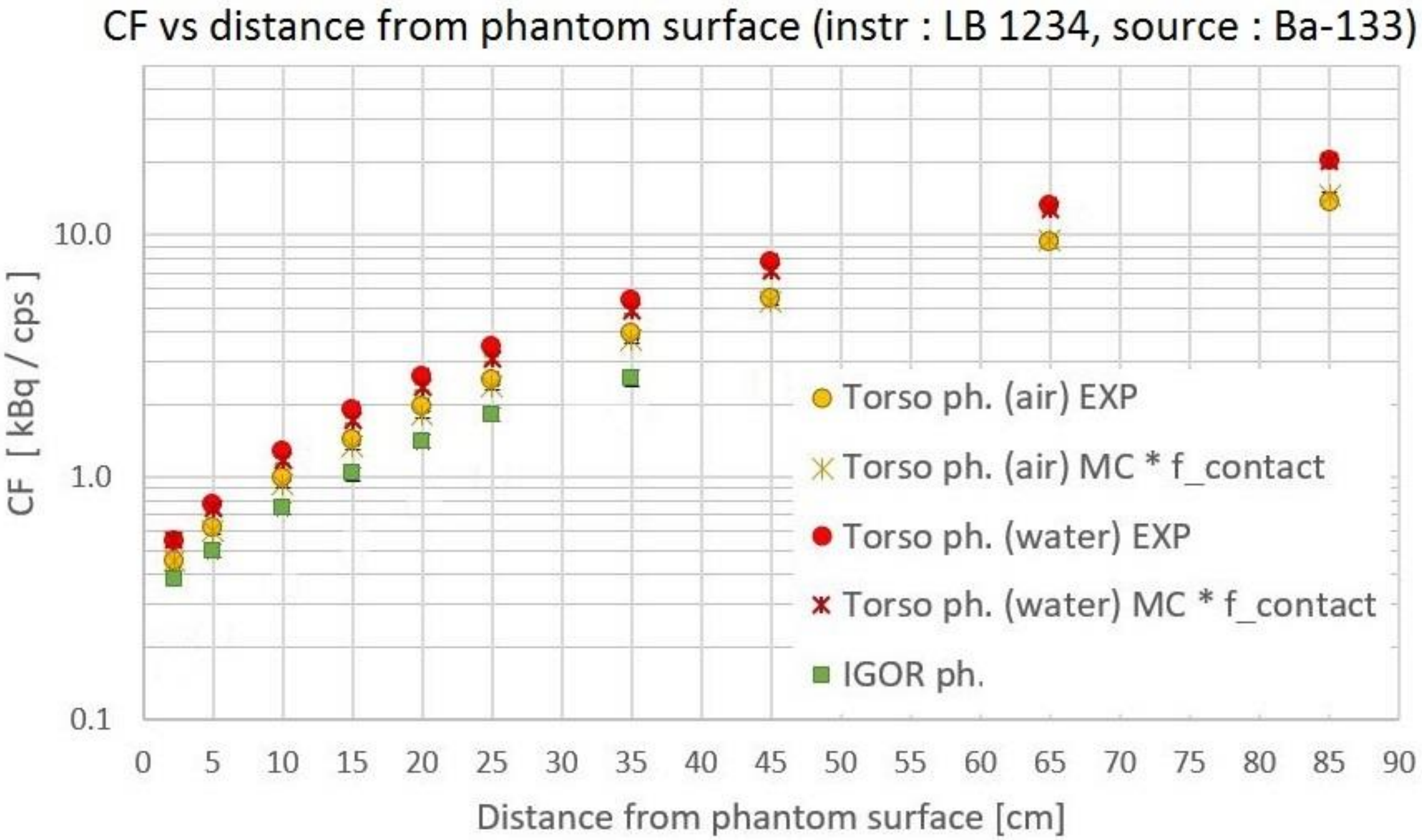


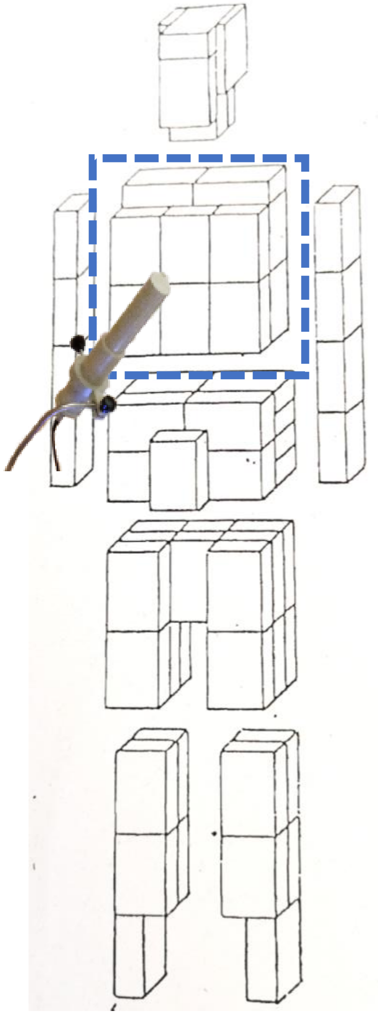
Efficiency curve + comparison?

Courtesy from Dr L. Desorgher

Torso phantom : a **conservative** approach for RP officers ?







$CF_{torso\ ph.}$ **always more conservative** than $CF_{IGOR\ ph.}$ (factor between 1.2 and 6.5 for all tested sources)

$E_{50,min}$ assessment: practical example

$$E_{50,min} = MDA \cdot \frac{e_{inh}}{m(T)}$$

- Example : CERN-MEDICIS **terbium** collections + **scandium** offline separation.
- Screening measurement : half an hour after the suspected intake (***T*** = 30 min).
- Intake via inhalation : AMAD = 5 µm, default absorption type.
- Screening measurement position : chest.
- $\boldsymbol{e_{inh}}$ from ICRP 68, ***m(T)*** from our biokinetic model solver.
- Background = 100 nSv/h.

$E_{50,min}$ [µSv] (rounded up to nearest 10), CL = detection limit (β=5%)

Instrument	^{149}Tb	^{152}Tb	^{155}Tb	^{47}Sc
CoMo 170	170	30	20	140

Conclusions & prospects

- Validated the proof of concept:
  - The Swiss approach can be adapted to the CERN requirements.
  - Multiple screenings before exceeding the annual E_{50} limit of 1 mSv.

- Evaluated the performance of 5 conventional instruments widely used at CERN.
  - Screening measurement proposals :
  - ^{149}Tb, ^{152}Tb, ^{155}Tb, ^{111m}Cd, ^{199m}Hg, ^{47}Sc, ^{175}Yb, ^{194}Hg/ ^{194}Au.

- The screening measurement proposals have been tested by the local experts and improved thanks to their feedback.

- Explore the possible use of portable γ-spectrometers (***ongoing***):
  - Radionuclide identification / mixture.

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Thank you *for your attention*

Questions?