EURADOS developments on emergency internal dosimetry

María Antonia López (CIEMAT, Spain)

June 14th, 2023
EURADOS Annual Meeting
Porto, Portugal

INTERNAL DOSIMETRY IN RADIOLOGICAL/NUCLEAR EMERGENCIES

EURADOS Strategic Research Agenda (SRA) -

Vision 3: Towards an Efficient Dose Assessment in case of radiological Emergencies

✓ **Challenge 1:** To quantify doses from internal emitters after accidents

INTERNAL DOSIMETRY IN RADIOLOGICAL/NUCLEAR EMERGENCIES

- ✓ Improvement of **in vivo monitoring techniques for adults and children**

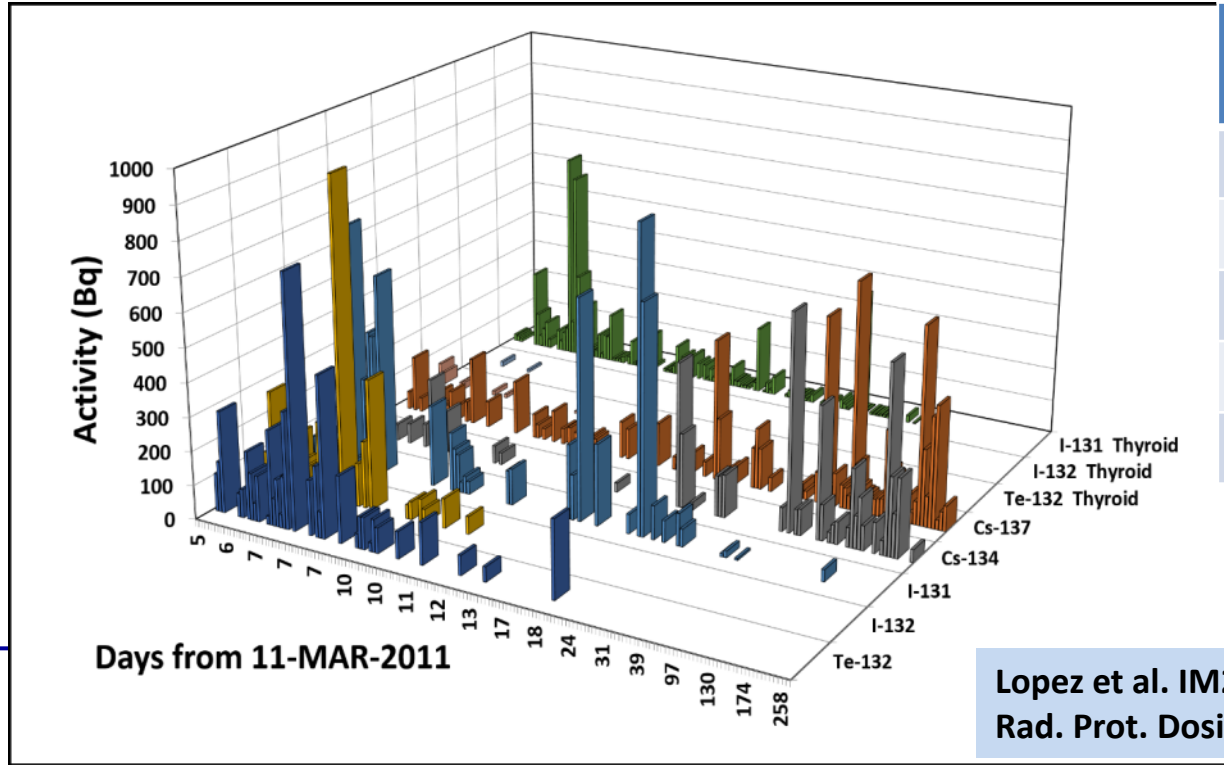
- ✓ **Wound Intakes:** Calibration, monitoring, dosimetry and clinical management

- ✓ **Rapid in vitro emergency bioassay** methods for alpha emitters (actinides) and ^{90}Sr.

- ✓ To link internal dosimetry after accidental intakes of radionuclides with **biological dosimetry methods** –

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

EURADOS SURVEY ON IN-VIVO MONITORING DATA OF EXPOSED FOREIGNERS IN JAPAN AFTER FUKUSHIMA DAIICHI NPP ACCIDENT



Radio-nuclide	$T_{1/2}$
^{131}I	8.02 d
^{132}I	2.30 h
^{132}Te	3.20 d
^{134}Cs	2.07 y
^{137}Cs	30.17 y

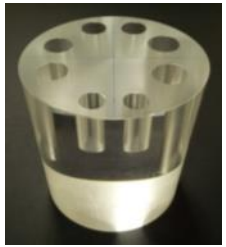
Lopez et al. IM2015
Rad. Prot. Dosimetry 2016

IMPROVEMENTS ON IN VIVO MONITORING FOR ADULTS AND CHILDREN

❖ **CATHYMARA Project** (EC - OPERRA) – EURADOS WG7, WG6 – Chair D. Broggio (IRSN)
Child and Adult Thyroid Monitoring After Reactor Accident

✓*Technical recommendations and guidelines on* ***Thyroid Monitoring of population***
✓***Dose assessment of radioiodine in the thyroid*** *after a nuclear accident*

Cathymara Phantom (SCK-CEN) - **Age-dependent thyroid calibration**




IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

❖ **CATHYMARA Project** – **TECHNICAL RECOMMENDATIONS**

- ✓**To Perform iodine measurements in thyroid 1-7 days after incorporation** via inhalation in the initial phase post nuclear accident
- ✓To perform measurements with **germanium detectors** for at least a representative group of the exposed population, to identify the isotopes incorporated, especially those of short half life
- ✓To use age dependent **"Dose content" functions Z(t) Gy.Bq^{-1} and Z(t) Sv Bq^{-1}** for dose assessments using monitoring data

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

❖ **CATHYMARA Project** – **TECHNICAL RECOMMENDATIONS (Cont.)**

✓To promote participation in **intercomparison exercises** and nuclear emergency panels

✓To promote **citizen participation** in thyroid measurements: to provide detection equipment, training, tools and database access for recording results

✓To initiate constructive dialogues with members of **civil society**

https://www.researchgate.net/project/CAThyMARA-Child-and-Adult-Thyroid-Monitoring-After-Reactor-Accident-OPERRA-Project-number-604984

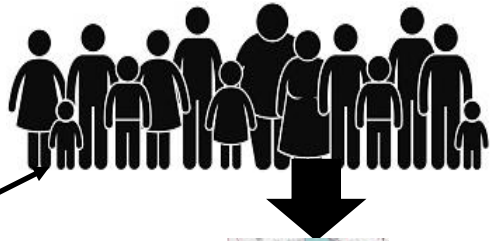
IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

❖ **CONFIDENCE Project** (EJP CONCERT, EC H2020) – EURADOS WG3, WG7, WG10

Coping with uncertainties for improved modelling and decision making in nuclear emergencies

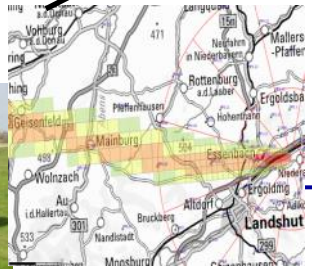
WP2 - *Improvement in* ***individual dose measurements techniques*** *following nuclear emergencies for improving situation awareness and risk estimation*

1.- Environmental monitoring



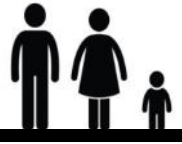
Potentially affected population group

identifies



Individualized Dose calculation

Critically exposed subgroup

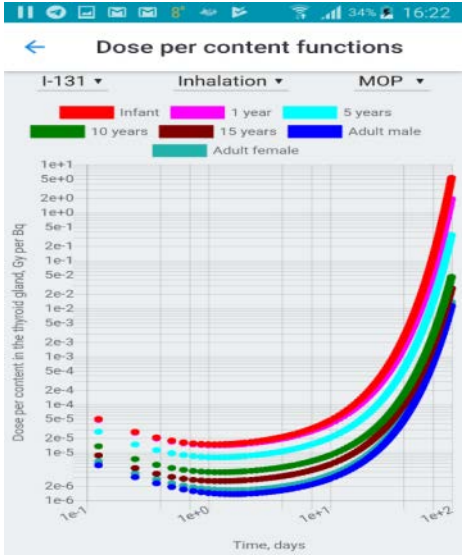


2.- Individual dose measurements

Individual doses

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

❖ CONFIDENCE Project



- ✓ **Calculation of "Dose per content"** function $\mathbf{Z_{I\text{-}131}(T,A)}$**; A= age group**
  - Directly **relates the measured ^{131}I activity content in the thyroid $\mathbf{M_{I\text{-}131}}$ (Bq)** at the time *T* after the intake, **with the committed absorbed dose to the thyroid at the 30th day**, e.g. from a single acute intake of ^{131}I:

$$D_{I-131}^{Th(30d)}(T,A) = M_{I-131}(T) \cdot z_{I-131}^{Th(30d)}(T,A)$$

- ✓ Correction of the ^{131}I dose in case of **intakes of all short-lived radioiodines and ^{132}Te**

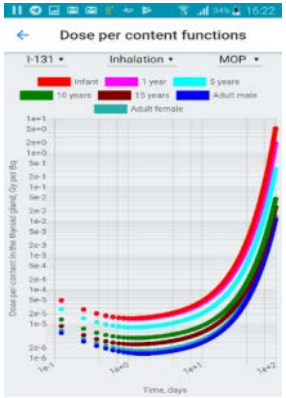
IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

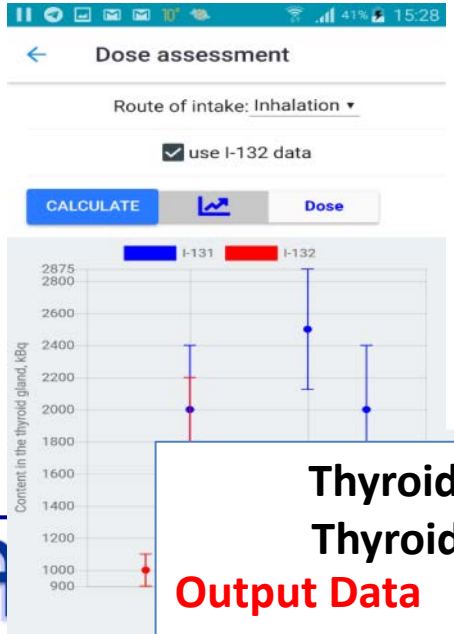
❖ **CONFIDENCE Project**

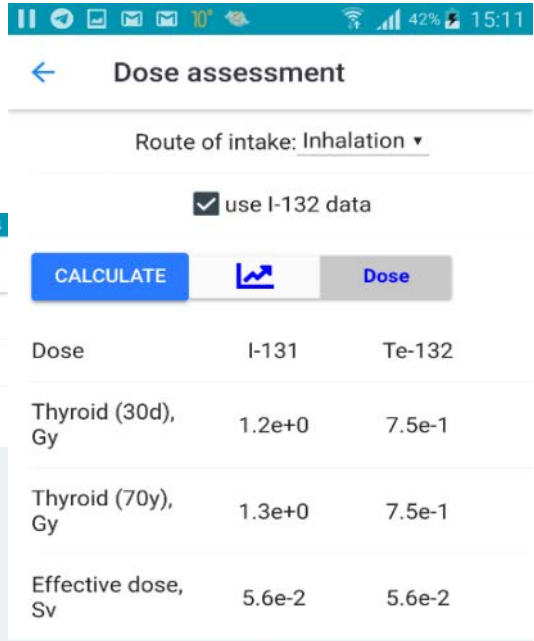
IDOSE: Data Processing App for Dose Assessment of radioidine intakes (smart phones/tablets)

Dose per content" $Z_{I\text{-}131}$ (T,A)

A= age group:
- Infant
- 1-y old child
- 5-y old child
- 10-y old child
- 15-y old child
- Adult male
- Adult female







Input Data:
- Time of Intake T
- Location
- Birth Date, sex
- Counting Date
- Activity M(kBq)

→ ^{131}I, ^{132}I

Output Data
- Thyroid absorbed dose (30 d) Gy
- Thyroid absorbed dose (70 y) Gy
- Effective dose Sv

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

- **EIVIC Project** – (EC DG-ENER) "**European In-vivo Counting Intercomparison Exercise**"

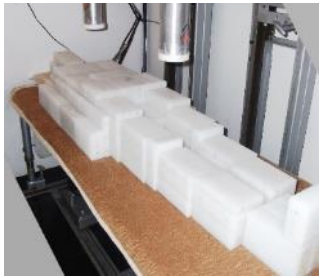
  IRSN, BfS and EURADOS (CIEMAT, KIT) – Chair: Didier Franck (IRSN, France)

  41 Whole Body Counters (WBC) – **21 COUNTRIES (18 from EU)**

Aims:

– Comparation of results of WBCs using different detector systems, calibration phantoms, counting geometries,...

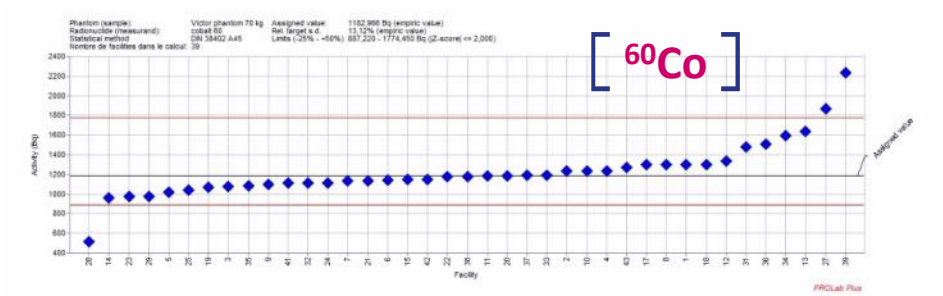
– Preparedness for cross-border collaboration in emergencies



Transport and shipment of 2 brick phantoms with radioactive rods simulating homogeneous internal contamination of an adult man in different intake scenarios

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

- **EIVIC Project** "**European In-vivo Counting Intercomparison Exercise**"
  - ✓ **Task 1** – Identification/quantification of Co-60, Ba-133, Cs-137
  - ✓ **Task 2** – Emergency scenario: Cs-134 and Cs-137
  - ✓ **Task 3** – Medicine: Ge-68 and Y-88
  - ✓ **Task 4** – Calibration: Ba-133 and Eu-152 (suitable only with HP Ge detectors)

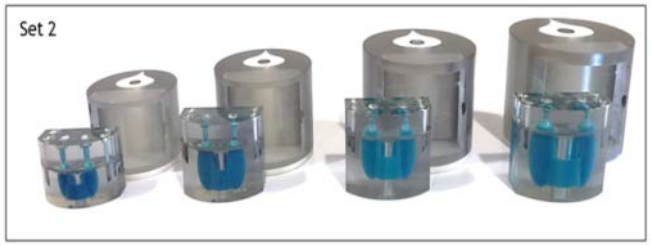


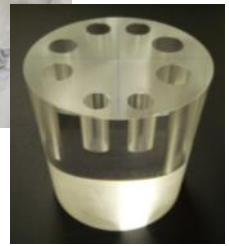
- **Good results in most cases:**
  - for NaI(Tl) and HP Ge detectors
  - using brick and bottle phantoms for calibration
  - Accredited or not labs
- **Next step: children monitoring**

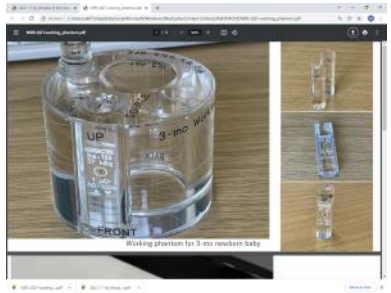
IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

- **EURADOS Intercomparison of age-depedent thyroid phantoms at CIEMAT WBC**

  EURADOS WG7/TG - J.F. Navarro/B. Pérez (CIEMAT, Spain)







IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

- **Age-dependent neck/thyroid phantoms:** to define tissue equivalent materials, thyroid volume, overlying tissue thickness, thyroid lobe dimension,…

Laboratory	Technician (Yes/no)	Age-dependent Phantom and sources	Activity range (mock Ba-133)
BfS (Germany)	No	Ba-133 (5y,10y, adult).	Ba-133 (2.83 kBq/source)
IRSN (France)	No	Ba-133 (5y,10y,15y,adult).	0,4 -1 kBq Ba-133 (april 2016)
SCK-CEN (Belgium)	Yes	Ba-133 (1y,5y,10y,15y) Ba-133&Cs-137(adult)	20-22 kBq children 16KBq adult
STUCK (Finland)	No	Ba-133 (6y,14y,20y)	7,6 KBq, 14,7 kBq y 35,2 kBq (2002)
SURO(Czech Rep.)	Yes	Ba-133 (3-6 y,11-15 y) Adult	2,8 kBq;6 kBq children 12 kBq adult
CIEMAT (Spain)	Yes	Ba-133 &Cs-137 (1y, 5y,10y,15y) adult male, female	6,5 kBq- 6.7 kBq
NIRS_QST(Japan)	No	Ba-133 (adult, 5 years; 3 months) filled at CIEMAT	Ba-133 (point source) 3 kBq Ba-133 & Cs-137 (vial 1ml) 3,2 kBq

IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

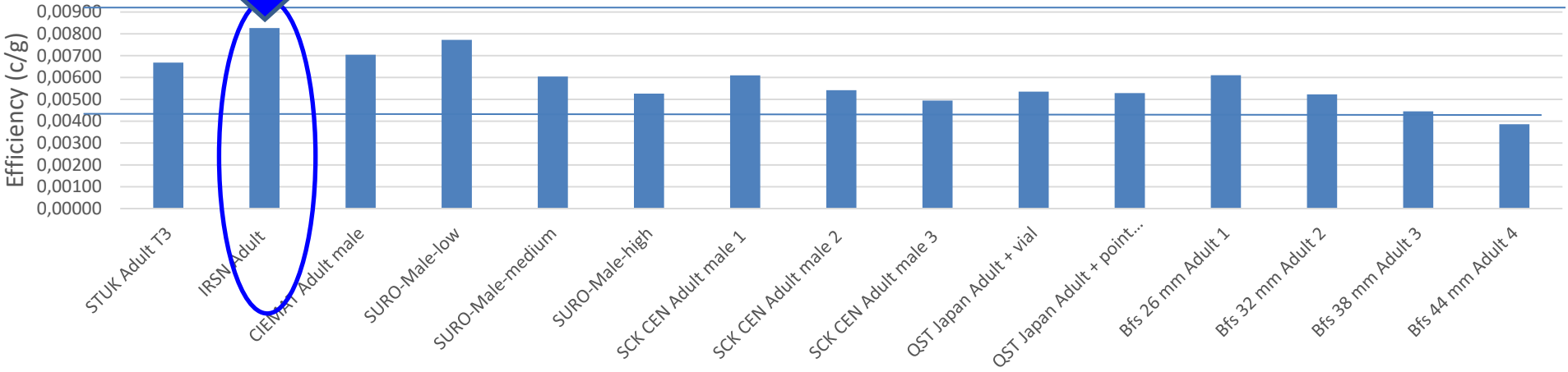
Counting Efficiency, measurement with the same Ge detector, CIEMAT WBC
Comparison of Eff (c/g) - age-dependent thyroid phantoms

IRSN

ADULT MALE THYROID PHANTOMS . **d= 10cm**

Efficiency (c/g) CIEMAT BE Ge detector

AMD ~ 8 Bq

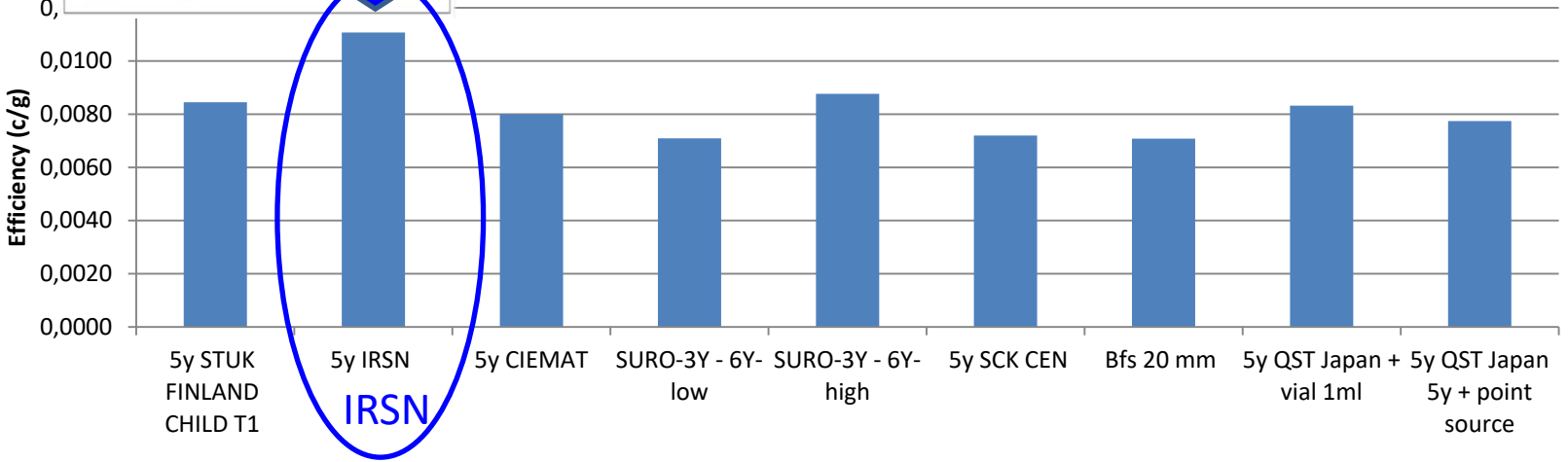


IN VIVO MONITORING TECHNIQUES FOR ADULTS AND CHILDREN

Intercomparison of Eff (c/g) - age-dependent thyroid phantoms at CIEMAT WBC

5 Y OLD CHILD - THYROID PHANTOMS . **d= 10 cm**

Efficiency (c/g) CIEMAT BE Ge detector



MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

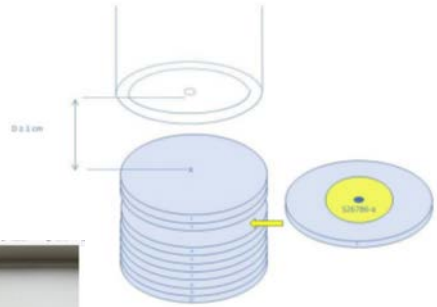
❖ **EURADOS/IRSN Intercalibration and Intercomparison for wound monitoring**

Didier Franck, Tiffany Beaumont - IRSN, France.

IRSN Wound Calibration Phantoms: simulation of puncture wounds

2022-2023 ; 19 participanting laboratories (Europe + Health Canada)

- The phantoms are composed of 10 tissue equivalent plates with a diameter of 10 cm and a thickness of 0.2 cm.
- 3 source plates:
  phantom n°1
  phantom n°2
  phantom n°3



MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

❖ **EURADOS/IRSN Intercalibration and Intercomparison for wound monitoring**

1. Exercise 1 – Calibration using **Wound Phantom 1**

The radionuclides and activities of the sources are known

Radionuclides: ^{22}Na, ^{133}Ba, ^{137}Cs, ^{241}Am - Detector-phantom distance ≥ 1 cm

The available depths are 2, 4, 6, 8, 10, 12, 14 and 16 mm, from top to bottom.

2. Exercise 2 – Measurement of **Wound phantom 2:** identification/quantification

The position of the sources is known. The source is at depths = 4 and 16 mm.

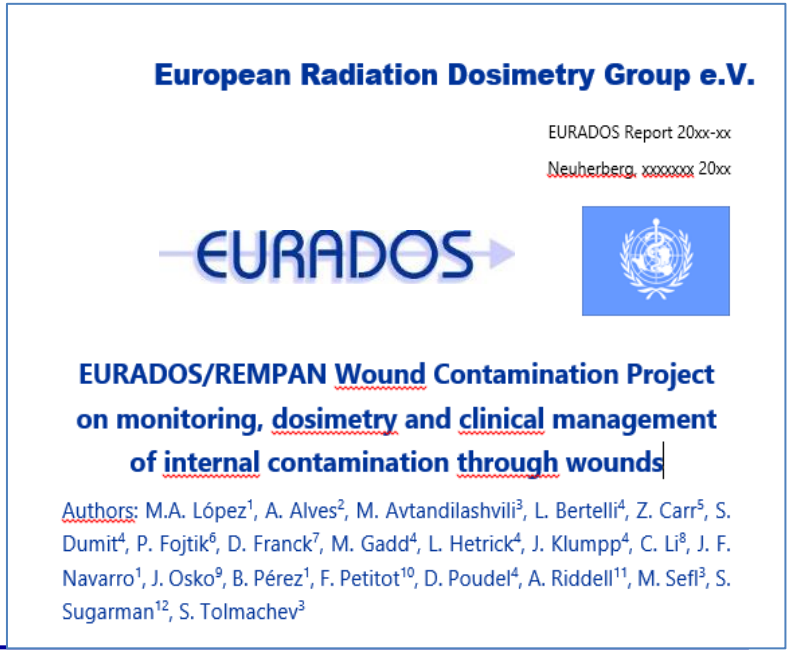
3. Exercise 3 – Measurement of **Wound phantom 3:** identification/quantification

The position of the sources (the depth) is unknown.

MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

❖ **THE EURADOS/REMPAN Wound Project –** Monitoring, dosimetry and clinical management of internal contamination trough wounds. EURADOS Report.
M.A. López (CIEMAT, Spain)
2022-2023

- **LANL, USTUR, SummitET, US**
- **IRSN, CEA, France**
- **CIEMAT, Spain**
- **Health Canada**
- **IRD, Brazil**
- **SURO, Czech Republic**
- **NCBJ, Poland**



European Radiation Dosimetry Group e.V.

EURADOS Report 20xx-xx

Neuherberg, xxxxxxx 20xx

EURADOS

EURADOS/REMPAN Wound Contamination Project on monitoring, dosimetry and clinical management of internal contamination through wounds

Authors: M.A. López[1], A. Alves[2], M. Avtandilashvili[3], L. Bertelli[4], Z. Carr[5], S. Dumit[4], P. Fojtik[6], D. Franck[7], M. Gadd[4], L. Hetrick[4], J. Klumpp[4], C. Li[8], J. F. Navarro[1], J. Osko[9], B. Pérez[1], F. Petitot[10], D. Poudel[4], A. Riddell[11], M. Sefl[3], S. Sugarman[12], S. Tolmachev[3]

MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

❖ **Monitoring, dosimetry and clinical management of internal contamination trough wounds**

- The management of wounds is **case-specific**, but **general procedures** are recommended:

  ✓ Rapid response on wound decontamination, excision of tissues and chelation therapy

  ✓ **ISO 20031:2020:** guidelines on the monitoring and dosimetry for wound contamination

  ✓ The **CDG (Clinical Decision Guidance)** quantity was proposed in **NCRP Report 161** to assist in making treatment decisions for individuals who have had radionuclide intakes.

MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

- Direct measurements of **local activity retained in the wound site**
- In vivo/In vitro bioassay to determine **systemic contamination**

- **Dose assessment:**

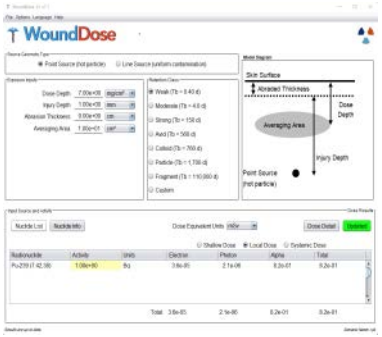
  ✓**Injection models**, assuming direct uptake into the blood (highly soluble compounds)

  ✓**NCRP 156 Model**: biokinetic model for radionuclide contaminated wounds

  ✓**DTPA Therapy model**

MONITORING AND DOSE ASSESSMENTS - WOUND CONTAMINATION

- **Wound Dose assessment – available software**



✓**VARSKIN+** US Nuclear Regulatory Program
Implements the NCRP 156 model to calculate (point and line sources):
(1) local dose to tissues surrounding the injured skin,
(2) committed organ/effective dose

✓**IMBA** UK Health Security Agency (UKHSA).
ICRP 60/78/68 system. To deal with intakes from contaminated wounds, selecting wound retention categories for retention of the NCRP 156 model.

✓**TAURUS** UKHSA, using new ICRP/OIR Models. Injection exposures.
Advanced version will include wound dosimetry.

✓**AIDE** Luiz Bertelli (LANL). New version available soon including wound intakes.

✓**Idode** Guthrie Miller. Modelling tool for building chelation models and a variety of biokinetic models: wound models and systemic models. Free code.

IN VITRO EMERGENCY BIOASSAY

- **EURADOS Study on Screening and rapid in vitro emergency bioassay methods for alpha emitters (actinides) and ^{90}Sr -** I. Sierra (CIEMAT)

  Objective: Review of methods with sensitivity enough to meet the requirements for emergency bioassay in typical nuclear accidents

  - ✓ Measurements of large number of biological samples
  - ✓ Radiochemistry processes and sample turnaround to be shortened
  - ✓ To involve in vitro and non-in vitro labs in an emergency network

IN VITRO EMERGENCY BIOASSAY

❖ **EURADOS Guidance Report on screening and rapid in vitro emergency bioassay**

1.- **Bioassay monitoring:** Determination of activity in Biological Samples in emergency
2.- **Types of Samples**
3.- **Techniques** of measurement
4.- **Screening methods**
5.- **Rapid methods**
6.- **International Recommendations**
7.- **Lessons learned in real emergency scenarios**
8.- **Technical Recommendations**, gaps, action protocols...
9.- **Emergency network** of laboratories


Chapter 4: Screening Methods (Triage)

Purpose and Scope

In the timeframe immediately following a nuclear/radiological incident or accident, the first concern of the intervention teams is first of all to realize that it is to gather as much information as possible about the impact of the contamination as fast as possible. This information is of crucial importance for the decision makers to define an adequate planning of the actions that need to be taken (such as evacuation of people, closing off of working areas, providing necessary medical aid, samples to be taken, analyses to be performed, decontamination measures, ...).
This general sentence should be part of the introduction. At this point of the text should be clear that we are speaking of internal contamination

Screening methods are the first solution provided by nuclear metrology to produce fast and relatively reliable results to estimate the severity of the event in terms of radiological risks and damages.
Screening methods for bioassay measurements focus more specific on estimating the impact of the internal contamination of the people involved in the incident and the population living close to the place that is affected by the contamination. More specific, these methods focus on the main entry ways of outside radioactive matter to the human body by inhalation, ingestion and possibly infiltration through open wounds (see Figure 1).

Since wounded people will receive immediate medical aid and will be prone to proper registration and medical follow up, they should also be subjected to measuring the longer term impact of a possible internal contamination by taking urine and/or fecal samples. Therefor it serves little use to spend extra time in trying to take blood samples or other samples related to the wounds for screening and probably even taking nasal swabs can be omitted.

Finally, ingestion of radioactive matter without simultaneous inhalation of the same matter is highly unlikely in the case of a nuclear incident. Therefor taking saliva samples to estimate the amount of radioactivity ingested by the people involved might not be the best approach for immediate measurements, although it might be considered as an alternative method depending on the nature of the incident.

Because of the above considerations measuring the possible inhalation of radioactive contamination by taking nasal swabs (also called nose blows) seems to be the best approach to get as much information as possible in a short period after the occurrence of the nuclear incident.

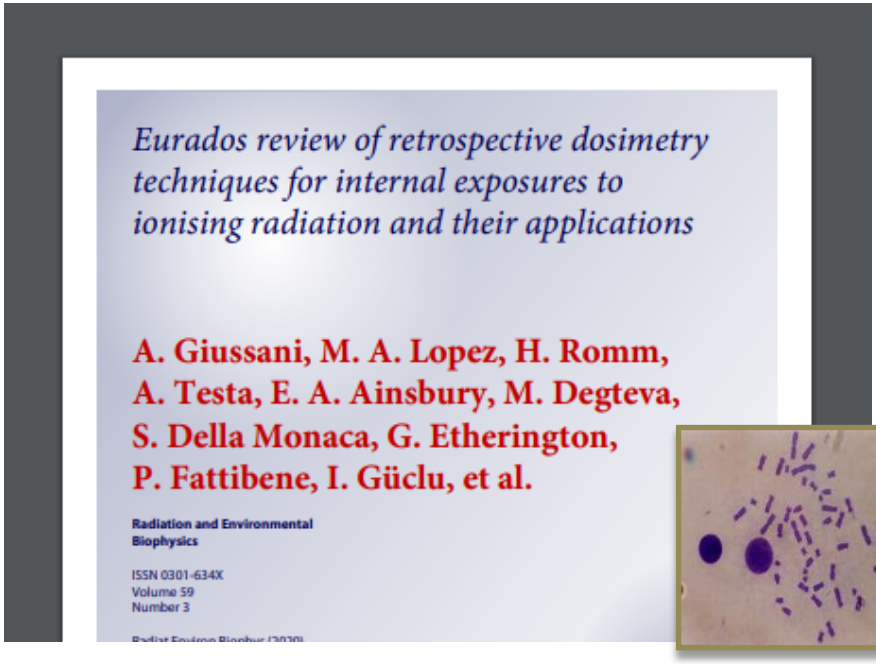
Figure 1: Possible pathways for internal contamination of the human body

BIOLOGICAL DOSIMETRY METHODS FOR INTERNAL EXPOSURES

Collaboration of A. Giussani, M.A. López (WG7) + L. Ainsbury (WG10)

❖**EURADOS Review 2020**

Evaluation of the usefulness and limitations of biological and EPR dosimetry in cases of internal and mixed internal/external exposures.



❖ **EURADOS WG10/WG7 Workshop**

European Radiation Protection Week

ERPW2022, Estoril, 9 October 2022

BIOLOGICAL DOSIMETRY METHODS FOR INTERNAL EXPOSURES

- Induction of chromosome aberrations have been observed in peripheral blood lymphocytes of subjects internally contaminated,
- Is it possible to derive a meaningful estimate of radiation dose of the incorporated radionuclides?

- **The challenges**:

  ✓ To identify scenarios of incorporated radionuclides where biodosimetry and EPR methods may be applied
  ✓ To identify calibration methods for generating calibration curves to be used for internal emitters.
  ✓ To develop well defined studies under controlled conditions.

BIOLOGICAL DOSIMETRY METHODS FOR INTERNAL EXPOSURES

✓**Best case intake scenario**: radionuclide with rapid absorption into the blood after incorporation and **homogeneous distribution of the contaminant inside the body**

- **H-3 (HTO) –** case study Lloyd et al.
  - o Committed Effective Dose E(50) Sv obtained from concentration of tritium in urine.
  - o Cytogenesis dosimetry: in vitro calibration curves mixing tritium with lymphocytes. Good agreement (DC, FISH) with E(50) in one contaminated individual
- **Cs-137 –** case study Goiania: high influence of external exposures
  - o Agreement only in few cases of the cytogenesis dosimetry with the committed internal doses calculated from whole body measurements
- **I-131** - Therapy of **patients with differentiated thyroid carcinoma (DTC),**
  - o Receiving radiodine treatments for the ablation of remnant tissues after thyroidectomy. The uptake of iodine in the thyroid is very low and an homogeneous whole body internal irradiation can be assumed

INTERNAL DOSIMETRY IN RADIOLOGICAL/NUCLEAR EMERGENCIES

CONCLUSIONS – EURADOS actions on internal dosimetry for emergency:

- ✓ Improvement of **in vivo monitoring techniques for adults and children: measurements of radioiodine in thyroid and gamma emitters in total body**
- ✓ **Procedures on** calibration, monitoring, dosimetry and clinical management in case of **wound contamination**
- ✓ **Guidance on rapid and screening methods of in vitro bioassay** for alpha emitters (actinides) and ^{90}Sr.
- ✓ Study on the application of **biological dosimetry techniques** in case of accidental intakes of radionuclides

THANKS FOR YOUR ATTENTION