Lessons learned in EURADOS useful for the dosimetry of wildlife

- EURADOS Background/History
- EURADOS Structure
- Some specific EURADOS activities “relevant” to wildlife dosimetry

Rick Tanner

(Chairman, EURADOS WG6: Computational Dosimetry

Public Heath England, Chilton, Didcot, UK)

EURADOS e.V.: a sustainable network

Werner Rühm (*Chairman*)

Filip Vanhavere (*Vice-Chairman*)

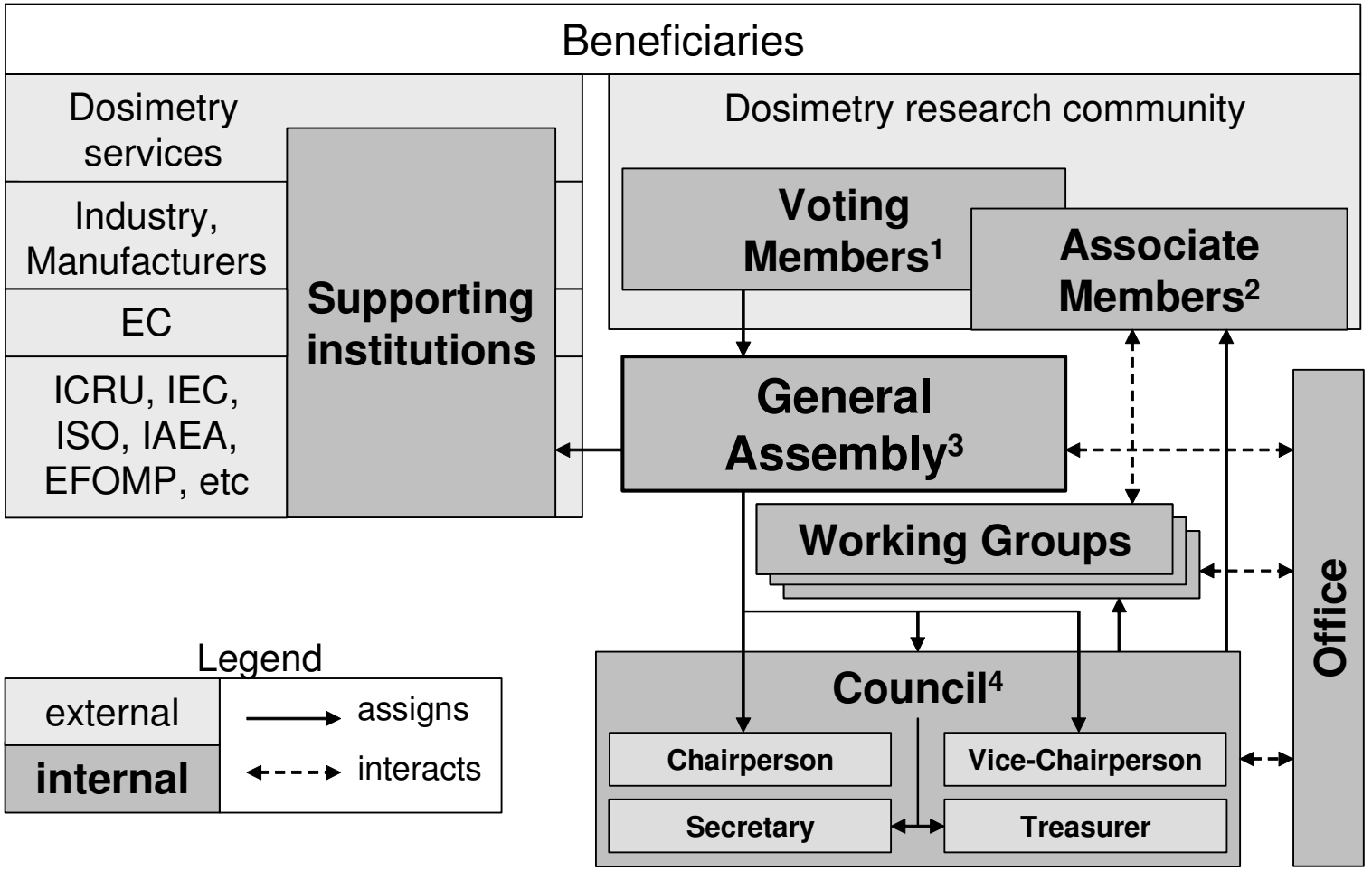
Helmut Schuhmacher *(Treasurer)*

Jean-François Bottollier-Depois *(*Secretary*)*

Elena Fantuzzi, Roger Harrison, Joao Alves, Paola Fattibene, Zeljka Knezevic, Maria Antonia Lopez, Sabine Mayer, Saveta Milanic, Stefan Neumaier, Pavel Olko, Hannes Stadtmann, Rick Tanner, Clemens Woda (Council Members and WG Chairs)

[Other contributors acknowledged where relevant]

Structure of EURADOS



[1] Institutions performing or promoting research

[2] Scientists contributing to EURADOS' objectives

[3] Composed of representatives from Voting Members

[4] 8-12 members, including Chairperson and Vice-Chairperson

EURADOS Voting Members

59 Voting Members from 28 European countries (Feb 2013)

Working Groups: Status 2013

Presently EURADOS runs 8 WGs, each consisting of 15 to 30 members

- **WG2: Harmonization of Individual Monitoring in Europe**
- **WG3: Environmental Radiation Monitoring**
- **WG6: Computational Dosimetry**
- **WG7: Internal Dosimetry**
- WG9: Radiation protection Dosimetry in Medicine
- **WG10: Retrospective Dosimetry**
- WG11: High-Energy Radiation Fields
- WG12: European Medical ALARA Network

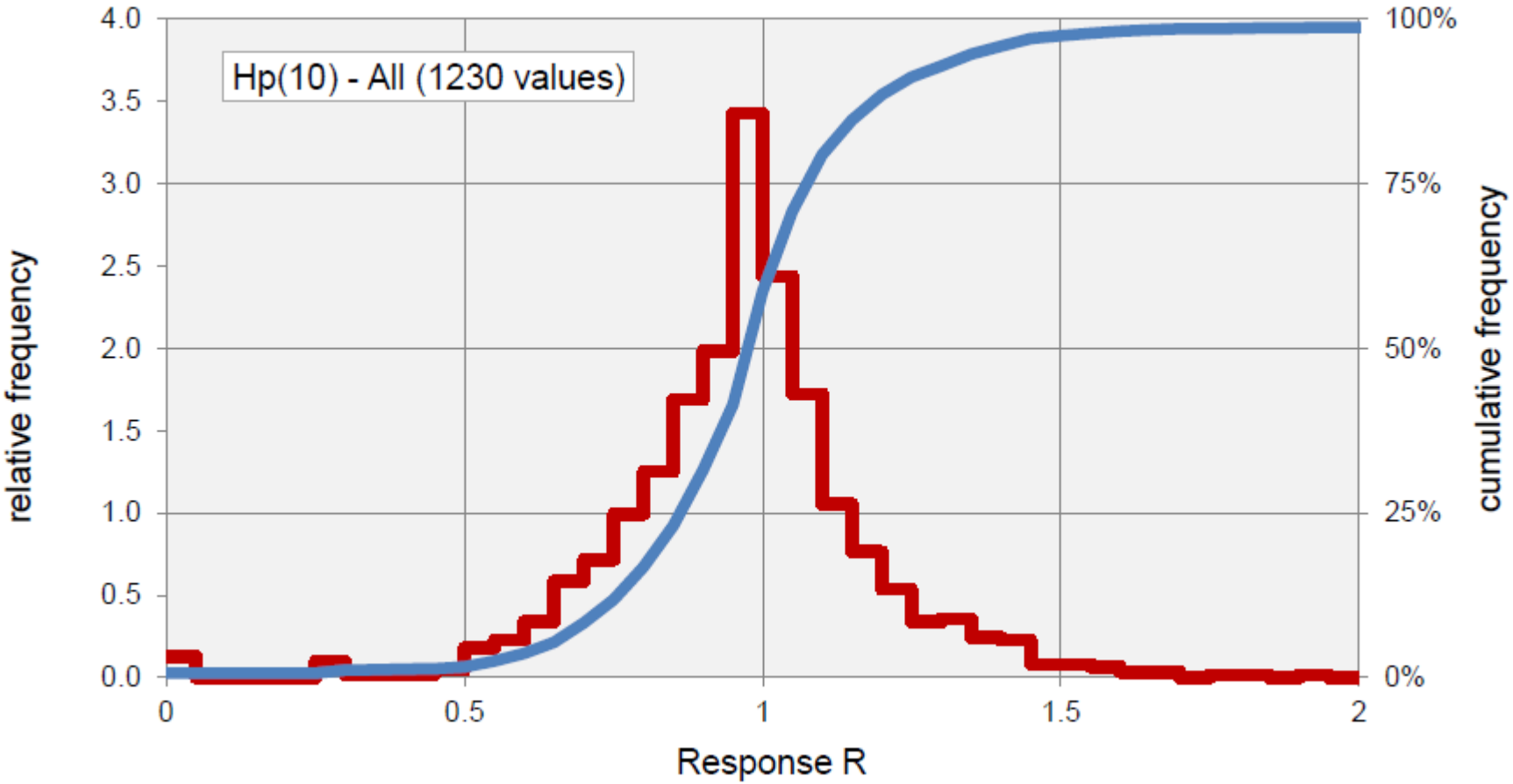
Intercomparisons and benchmarks (self-supporting actions)

- EURADOS Intercomparisons for whole body photon dosemeters (WG2: 2008, 2010, 2012)
- EURADOS Intercomparison for whole body neutron dosemeters (WG2: 2012)
- EURADOS Intercomparison for extremity dosemeters (2009)
- Intercomparison on Monte Carlo modelling of in vivo measurements of lung contamination with a Livermore phantom (WG7 & WG6)
- EURADOS Intercomparisons of Early Warning Network Systems (WG2: 2006, 2009, 2012)
- 2nd Intercomparison of the usage of Monte Carlo (WG6, 2004)
- 1st Intercomparison of the usage of Monte Carlo (WG6, 2000)
- 3rd European intercomparison exercise on internal dosimetry (1998)
- Trial performance tests in individual monitoring of external radiation (1998)

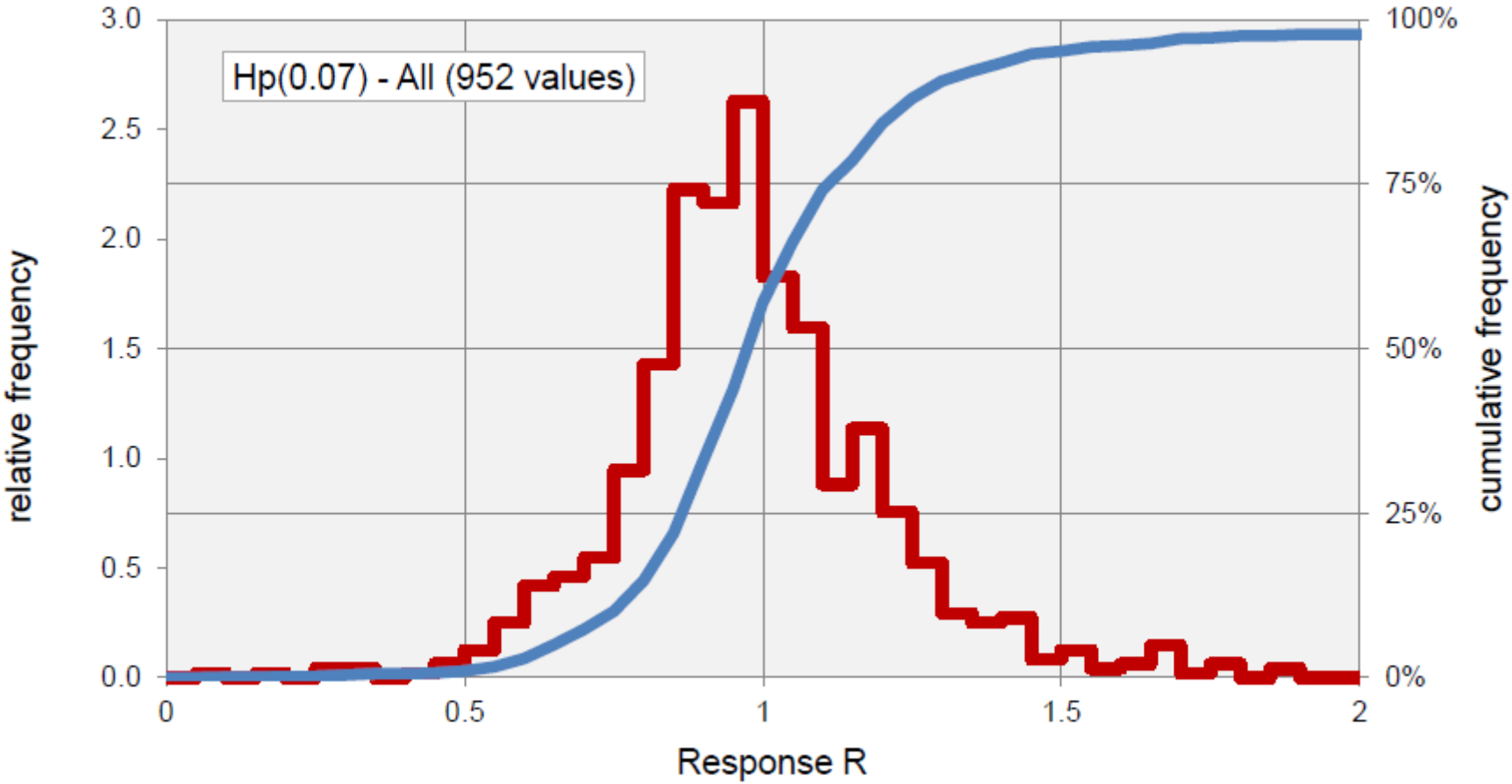
Intercomparison 2008 for Whole Body Dosemeters in Photon Fields

T. W. M. Grimbergen, M. Figel, A. M. Romero,
H. Stadtmann and A. F. McWhan

All $H_p(10)$ results



All $H_p(0.07)$ results

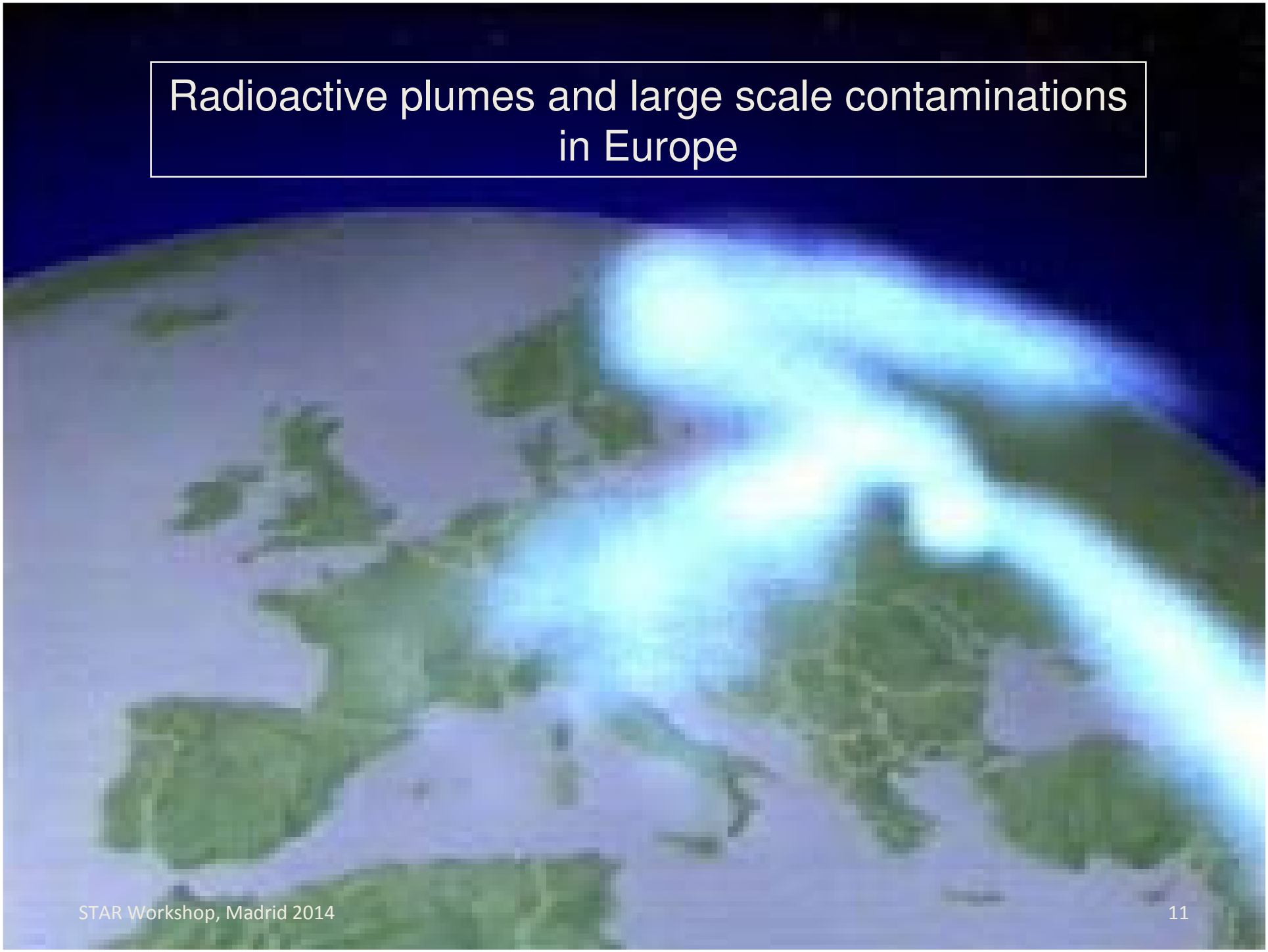


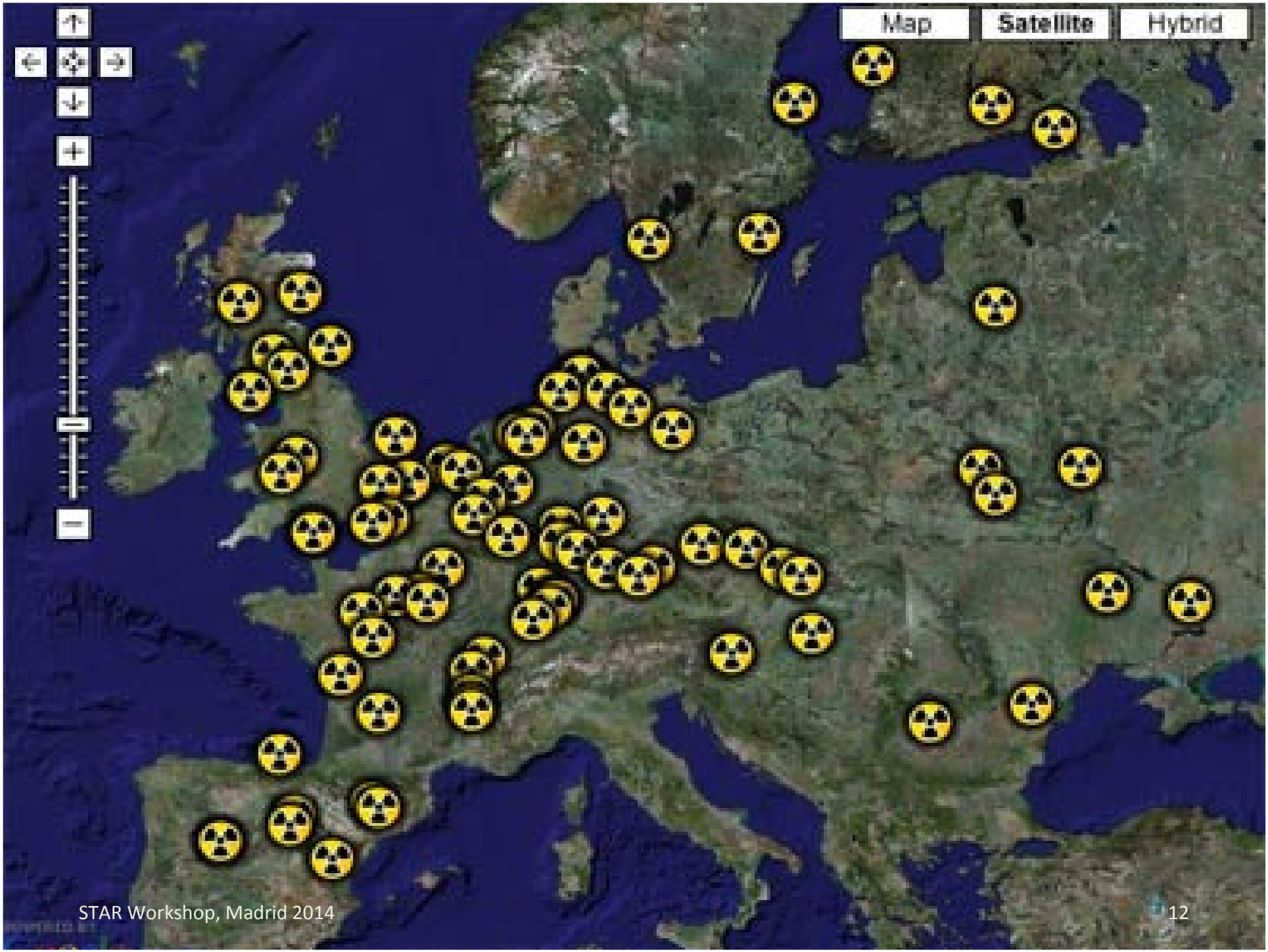
EURADOS WG3 intercomparisons and the harmonization of environmental radiation monitoring

S. Neumaier and H. Dombrowski

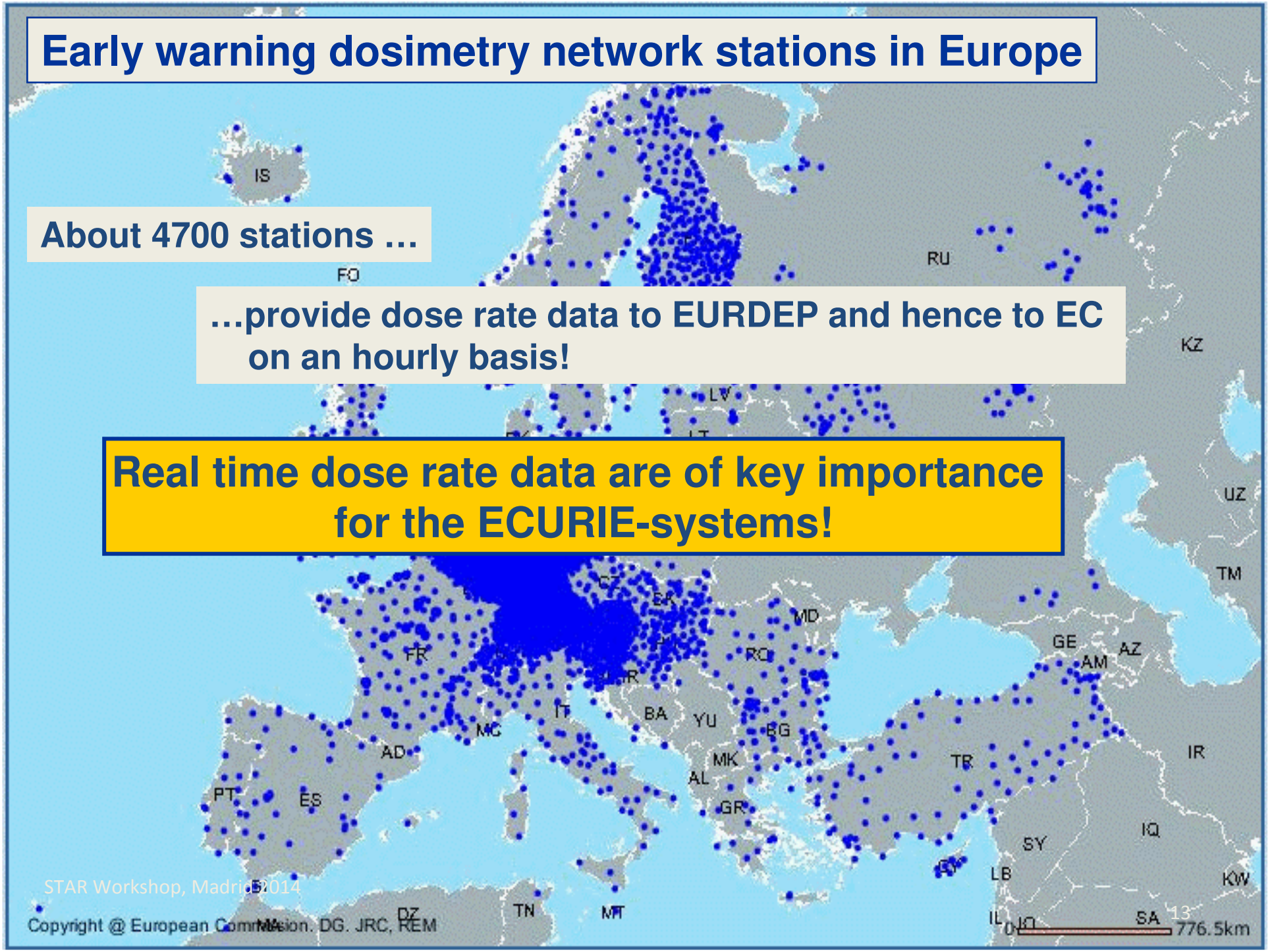
Physikalisch-Technische Bundesanstalt (PTB),
Bundesallee 100, 38116 Braunschweig, Germany

Radioactive plumes and large scale contaminations in Europe




Map
Satellite
Hybrid

Early warning dosimetry network stations in Europe

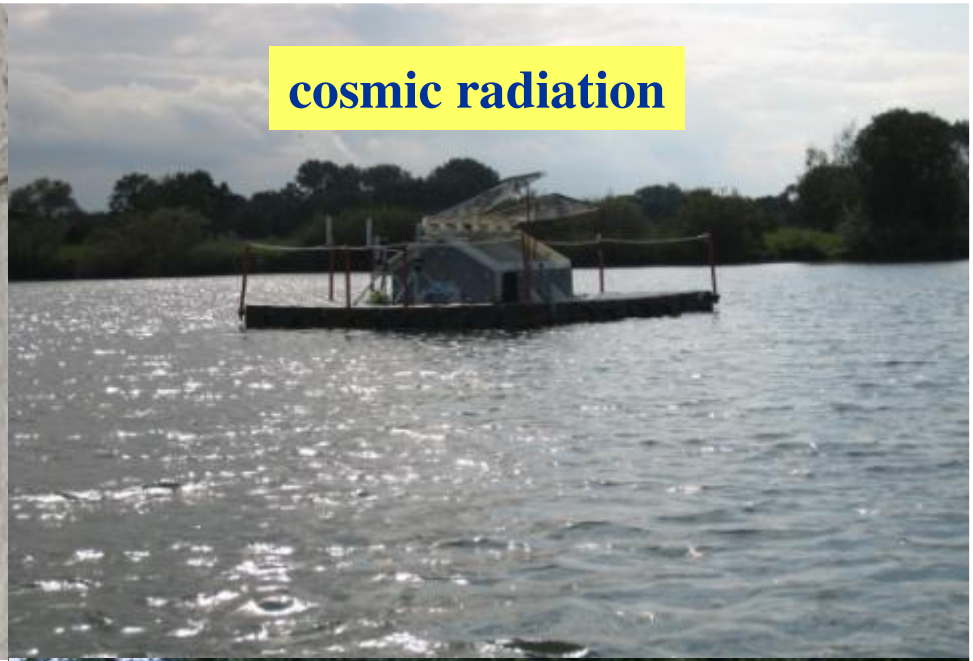


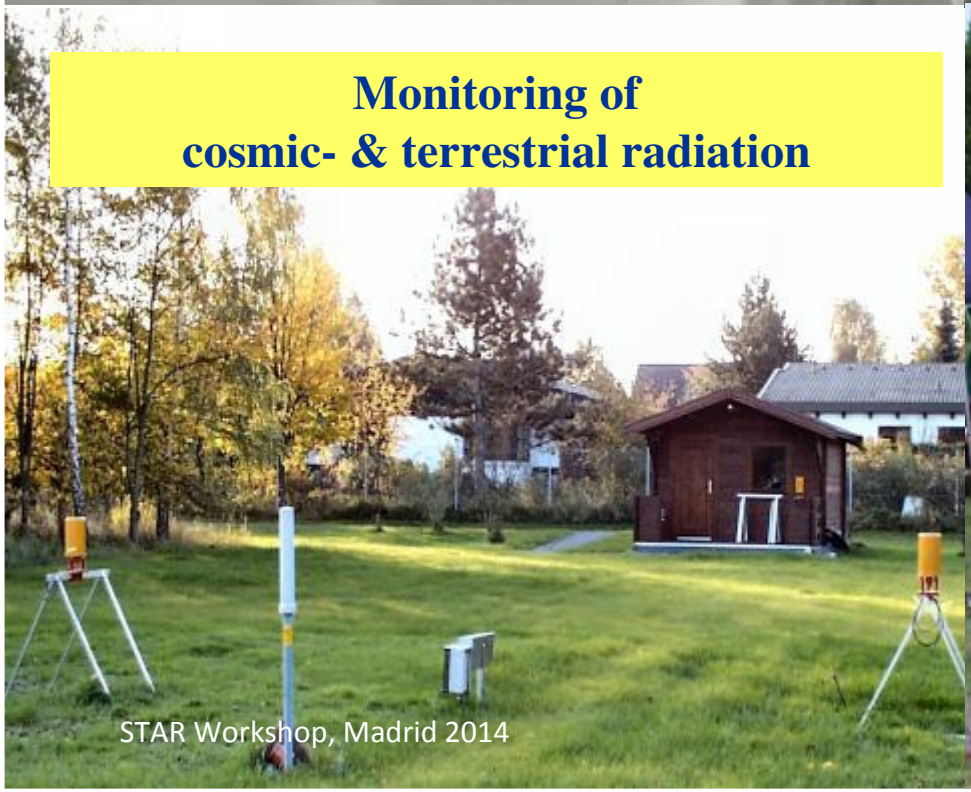
About 4700 stations …

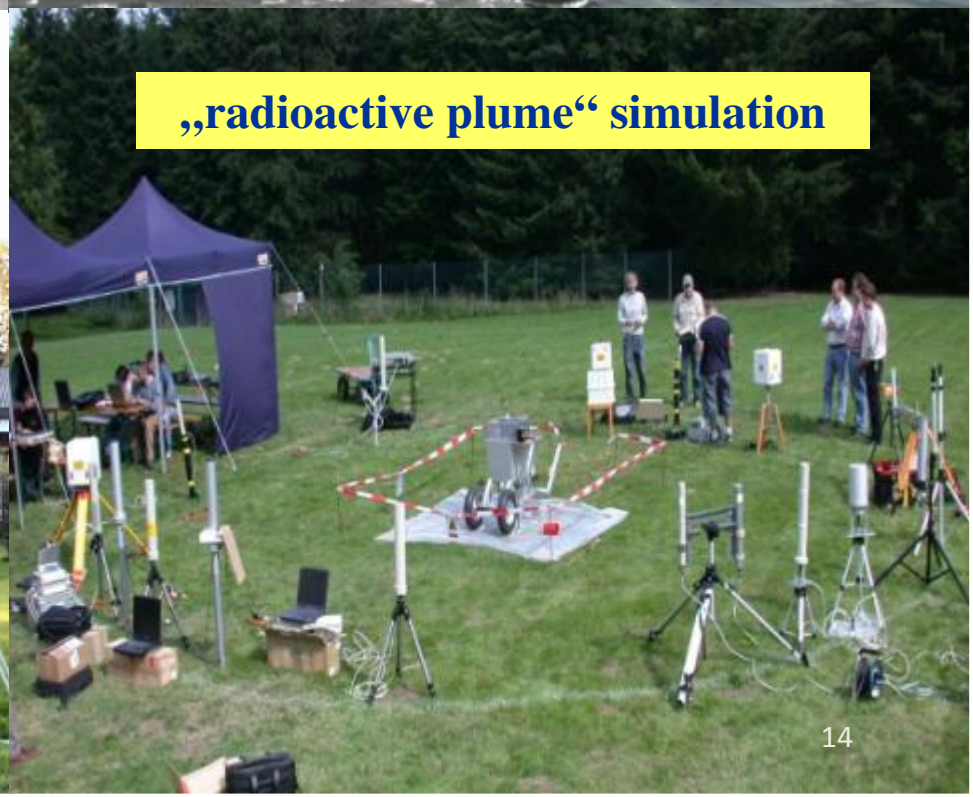
…provide dose rate data to EURDEP and hence to EC on an hourly basis!

Real time dose rate data are of key importance for the ECURIE-systems!

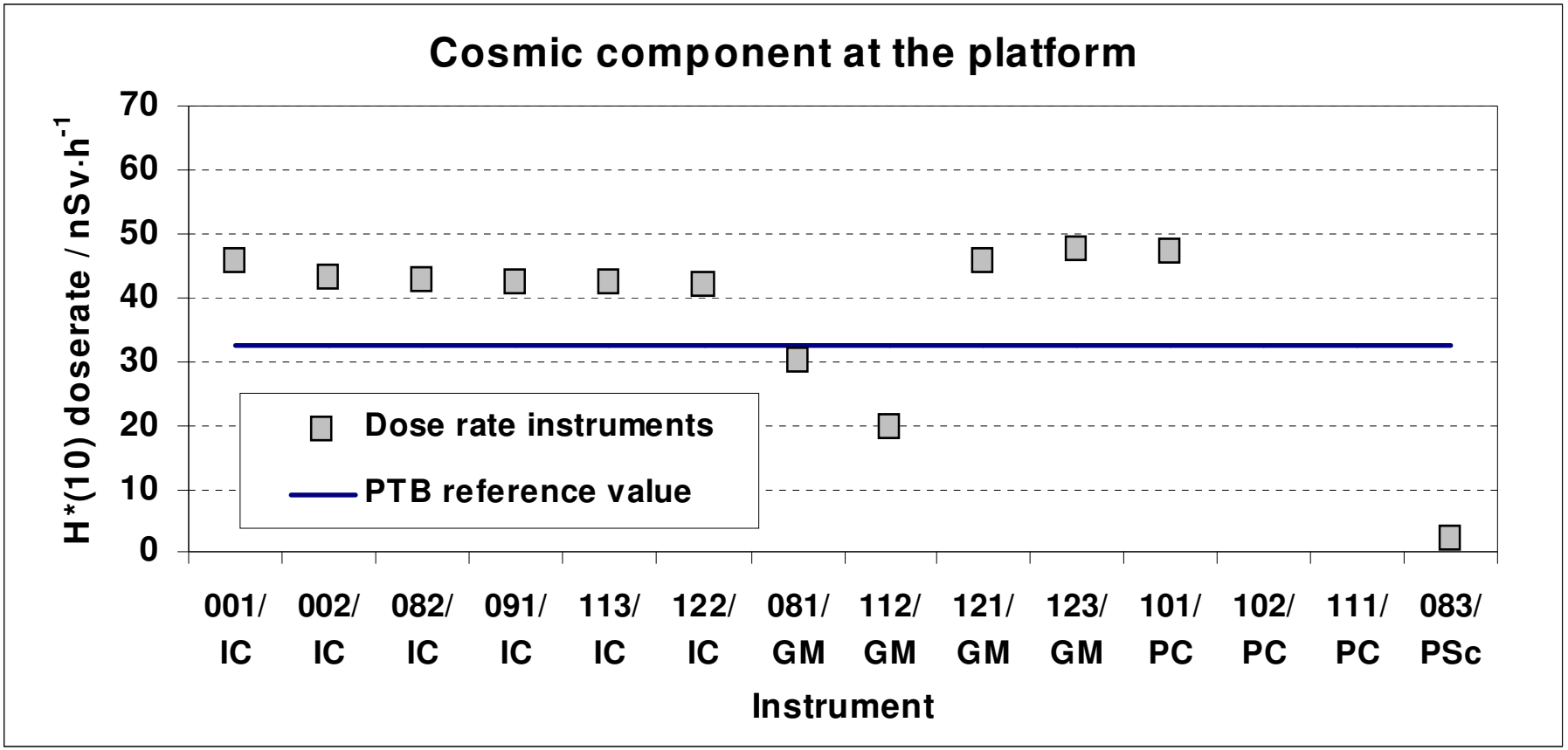

-430 m: „radiation free“ environment


cosmic radiation


Monitoring of
cosmic- & terrestrial radiation


„radioactive plume“ simulation

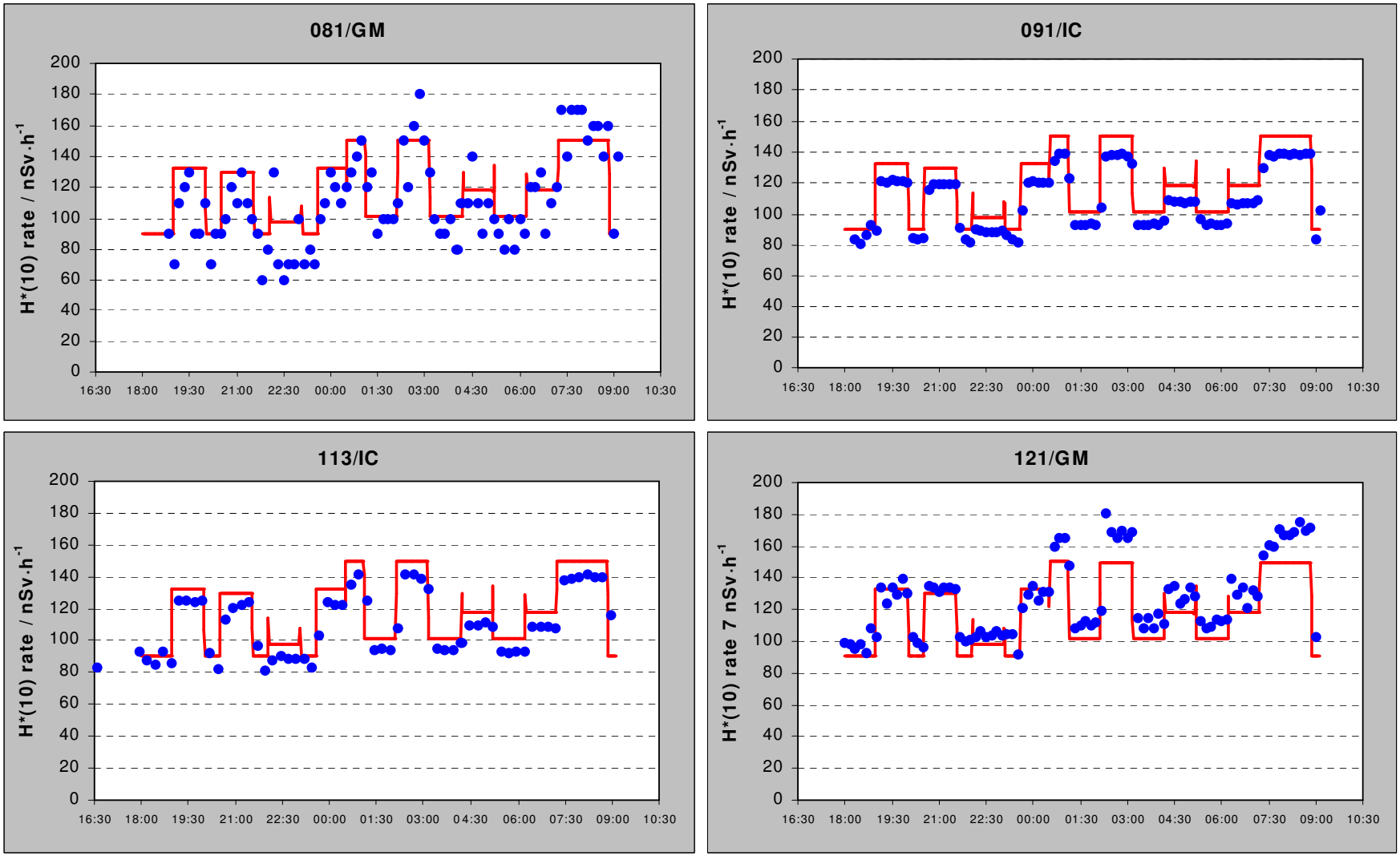
Response to cosmic radiation: r_{SCR}



$r_{SCR} = (R_{platform} - R_B) / H^*(10)_{SCR}$

PTB reference value: $H^*(10)_{SCR} = (36 \pm 3)$ nSv h^{-1}

Plume simulation: Results

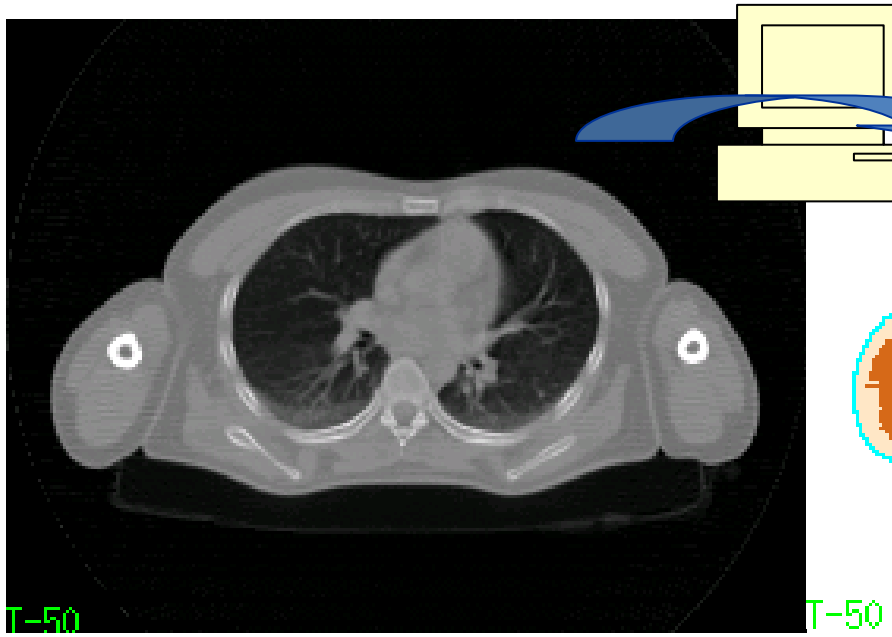


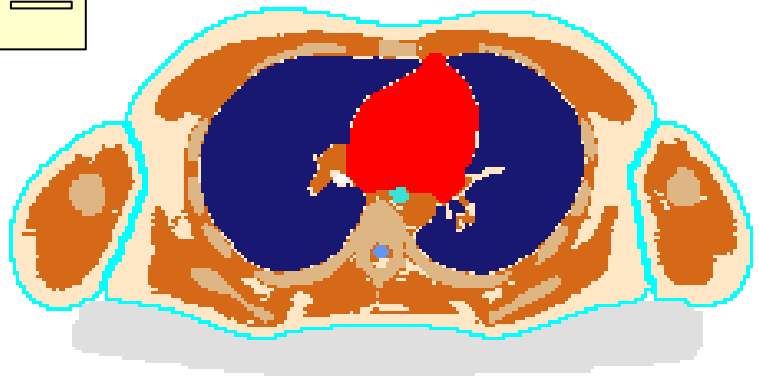
CONSTRUCTION OF VOXEL MODELS FROM 3D MEDICAL IMAGE DATA

Maria Zankl, HGMU, Germany

Construction of voxel models from 3D medical image data

Image processing software





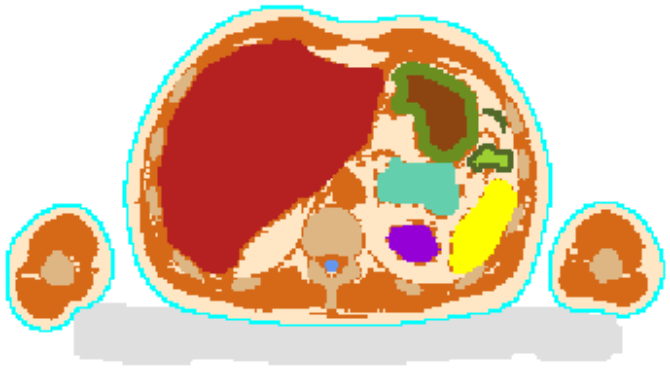
Original CT slice
Grey values: absorption properties

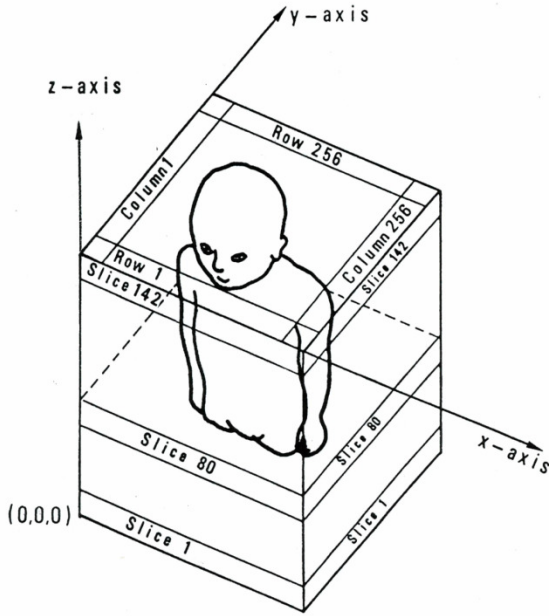
Segmented slice
Colours: identification numbers assigned to individual organs

Segmentation

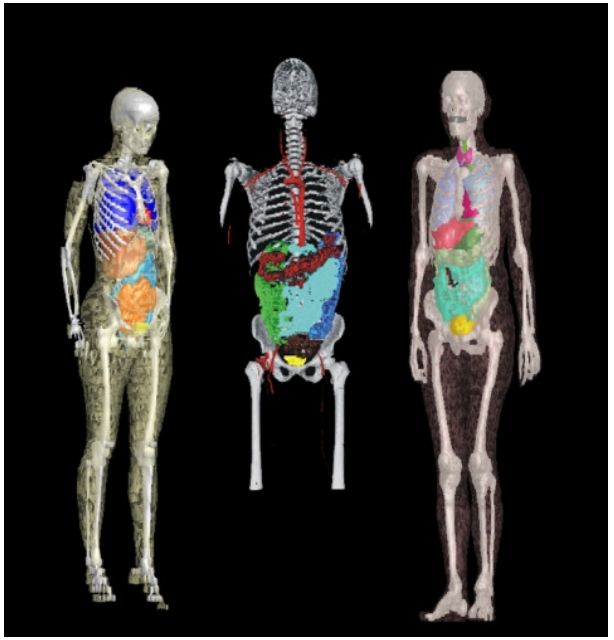
- Identifying individual organs in all slices
- Assigning appropriate organ identification numbers to all pixels in all slices
  - Easy for
    - Tissues with high contrast (use grey value thresholds)
    - Small body sections
      (often: manual drawing of organ boundaries)
  - Difficult in all other cases due to
    - Large range of grey values within individual organs
    - Largely overlapping grey values ranges between organs
    - Large number of organs and slices to be segmented

Segmented data





Stack of slices
→ 3D array of volume elements (voxel)



Data per slice arranged in columns and rows of picture elements (pixel)

Irene Visible Human Golem

w_T – development

Organ	1977	1990	2007
Gonads	0.25	0.20	0.08
Bone marrow (red)	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Thyroid	0.03	0.05	0.04
Bone surfaces	0.03	0.01	0.01
Remainder	0.30	0.05	0.12
Colon	-	0.12	0.12
Stomach	-	0.12	0.12
Bladder	-	0.05	0.04
Liver	-	0.05	0.04
Oesophagus	-	0.05	0.04
Skin	-	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01

Remainder

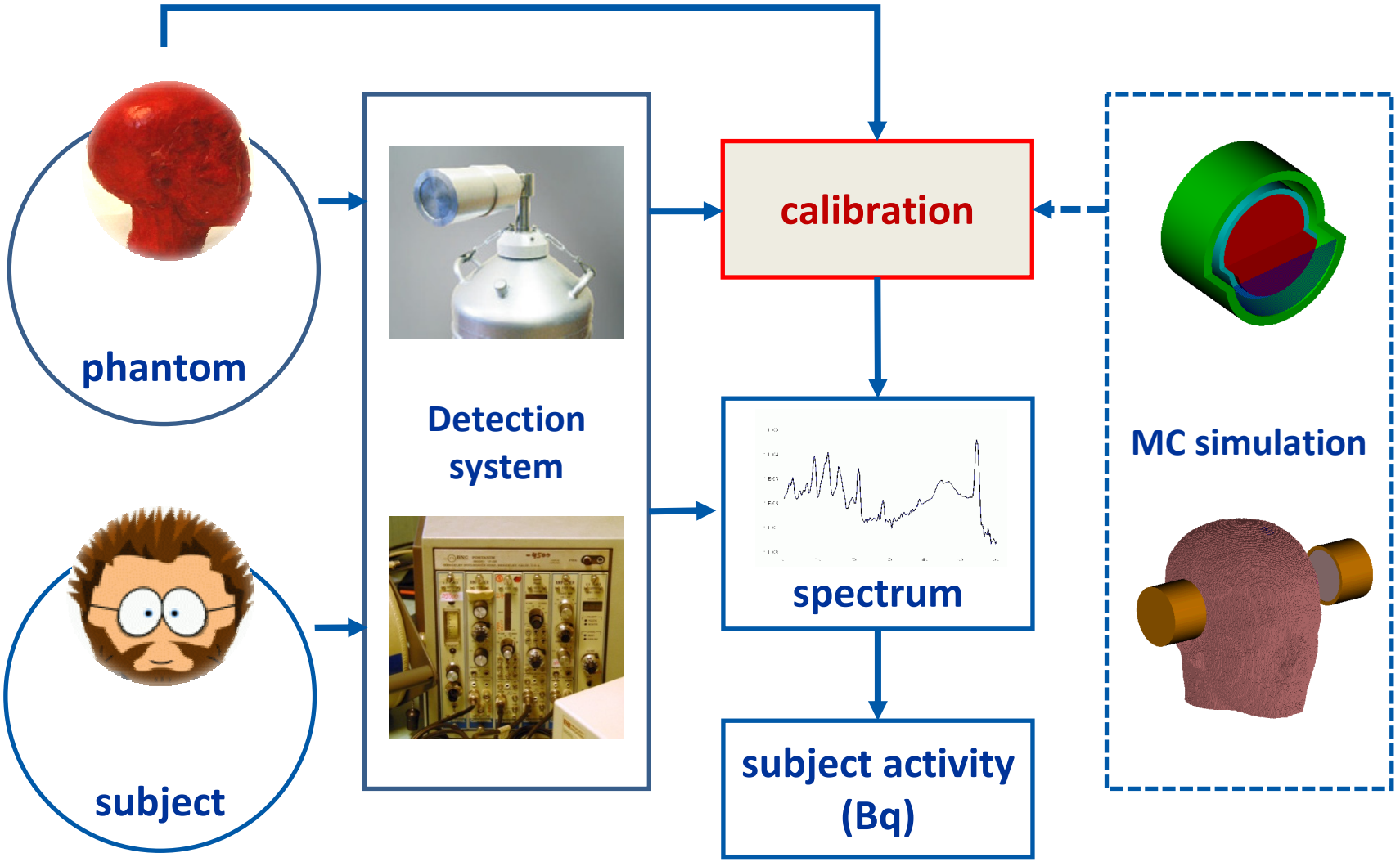
ICRP60: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus

ICRP103: adrenals, extrathoracic tissue, gall bladder, heart wall, kidneys, lymph nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix

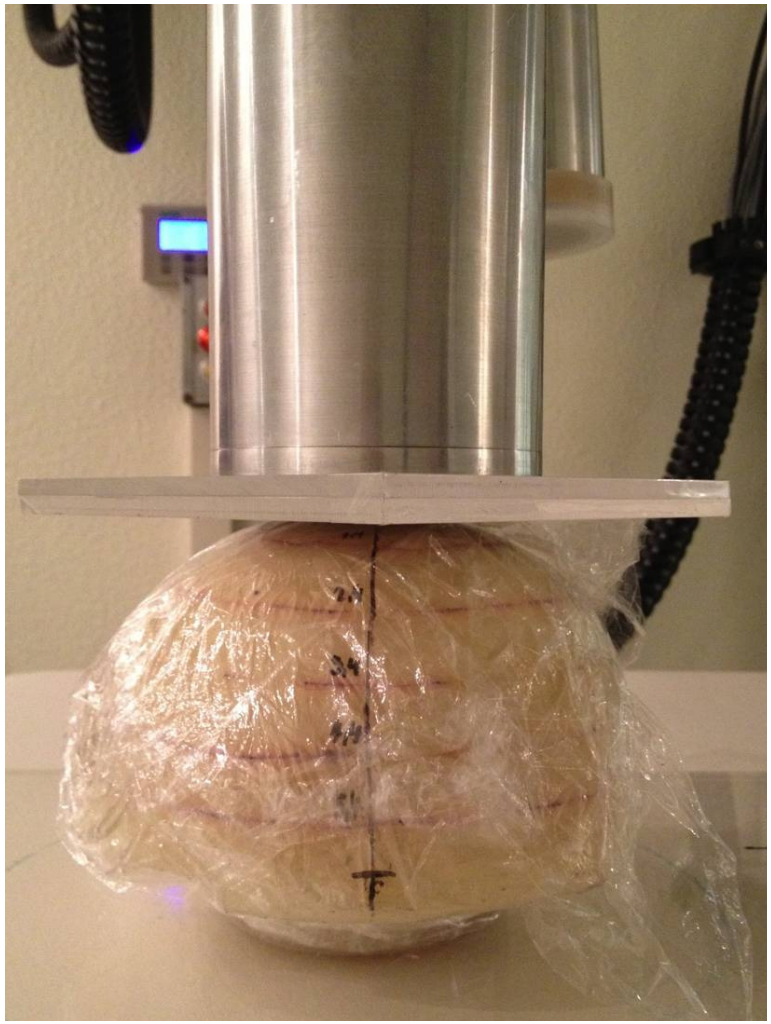
EURADOS WG6/7 INTERCOMPARISON EXERCISE ON MC MODELLING FOR THE IN-VIVO MONITORING OF AM-241 IN SKULL PHANTOMS (PART I).

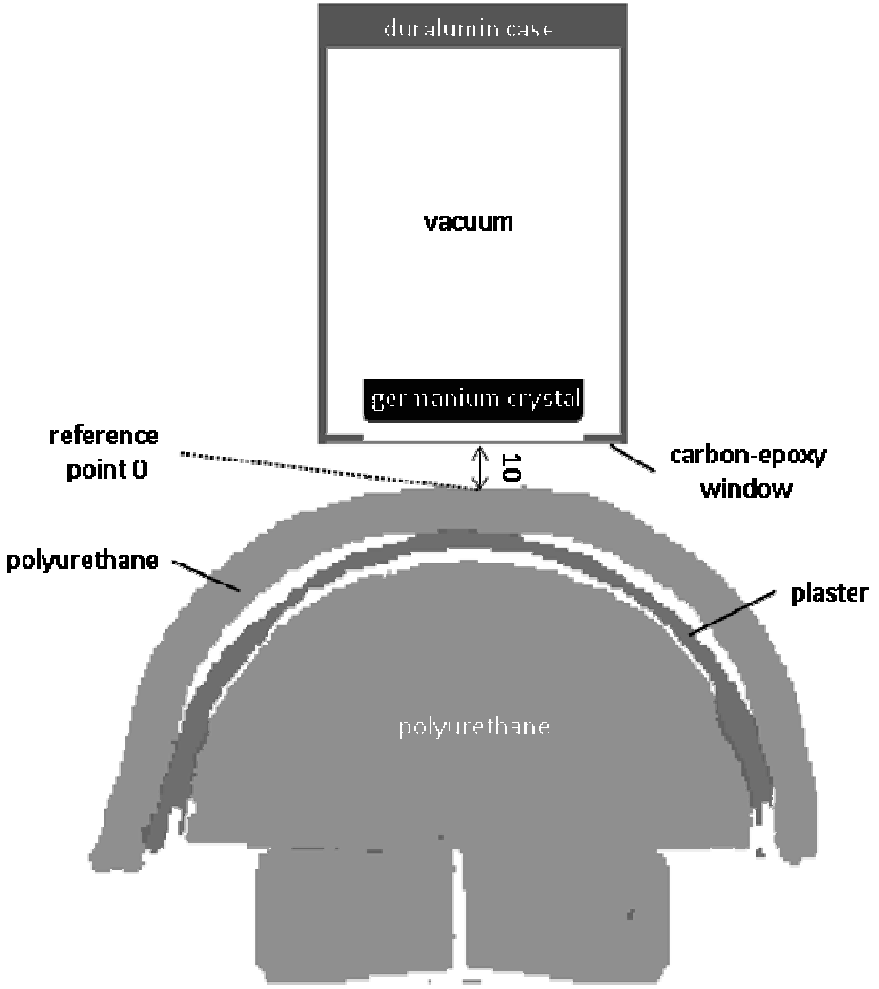
Tomas Vrba, Pedro Nogueira, David Broggio, Margarida Caldeira, Kevin Capello, Karin Fantínová, Catarina de Sousa Figueira, John Hunt, Debora Leone, Manohari Murugan, Olaf Marzocchi, Montse Moraleda, Jakub Osko, Arron Shutt, Soheigh Suh, Masa Takahashi, Maria A. Lopez, Rick Tenner

Introduction to in-vivo measurement method

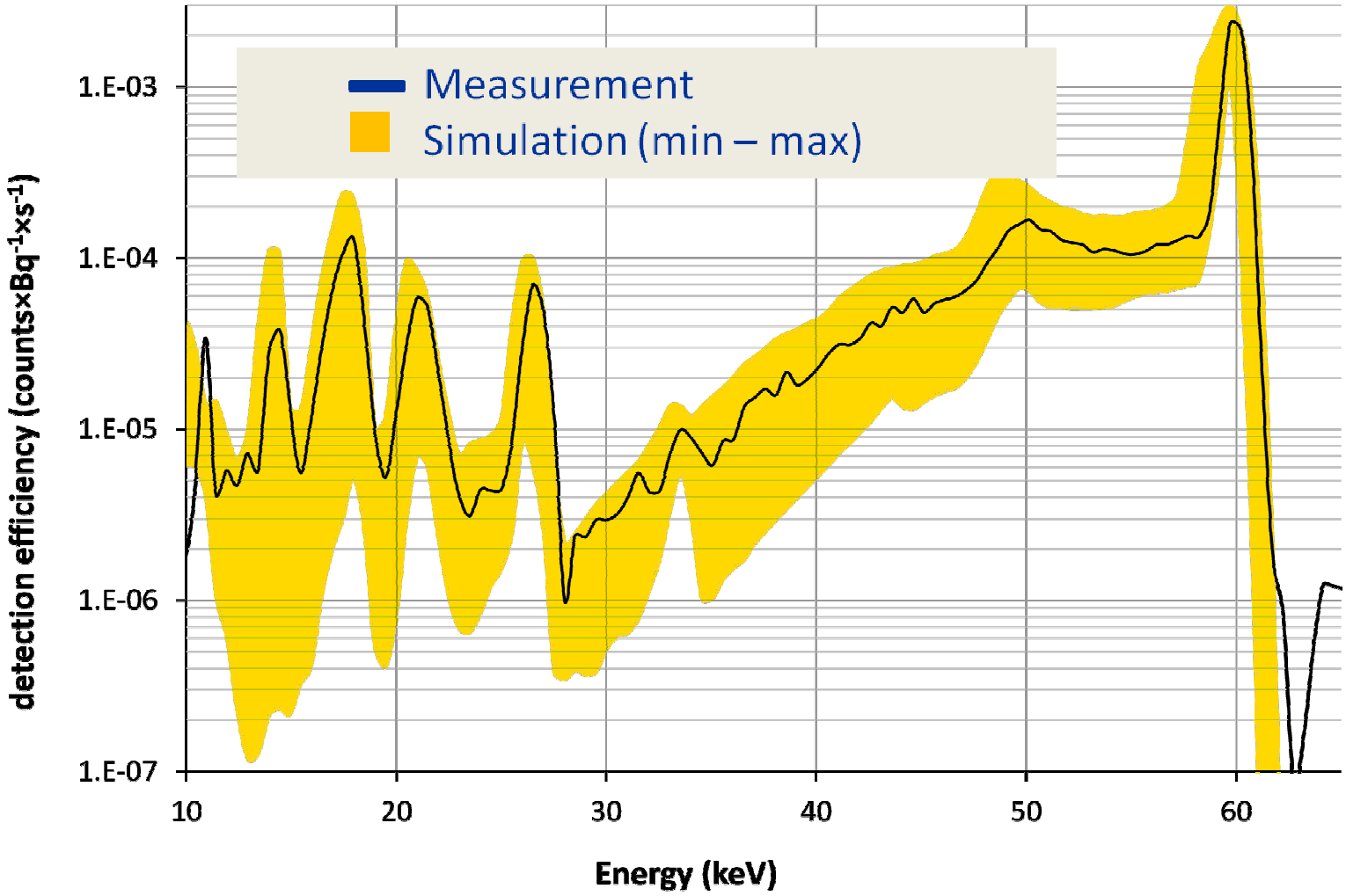


Geometry




duralumin case
vacuum
germanium crystal
reference
point 0
10
carbon-epoxy
window
polyurethane
plaster
polyurethane

Deviation from the measurement – before correction



Observed error in simulation

4 results – material description

- Erroneous density or composition
- Wrong assignment of material to the object in simulation (swapping)

3 results – normalization to (counts×s^{-1}×Bq^{-1})

- Missing or applied in an opposite way

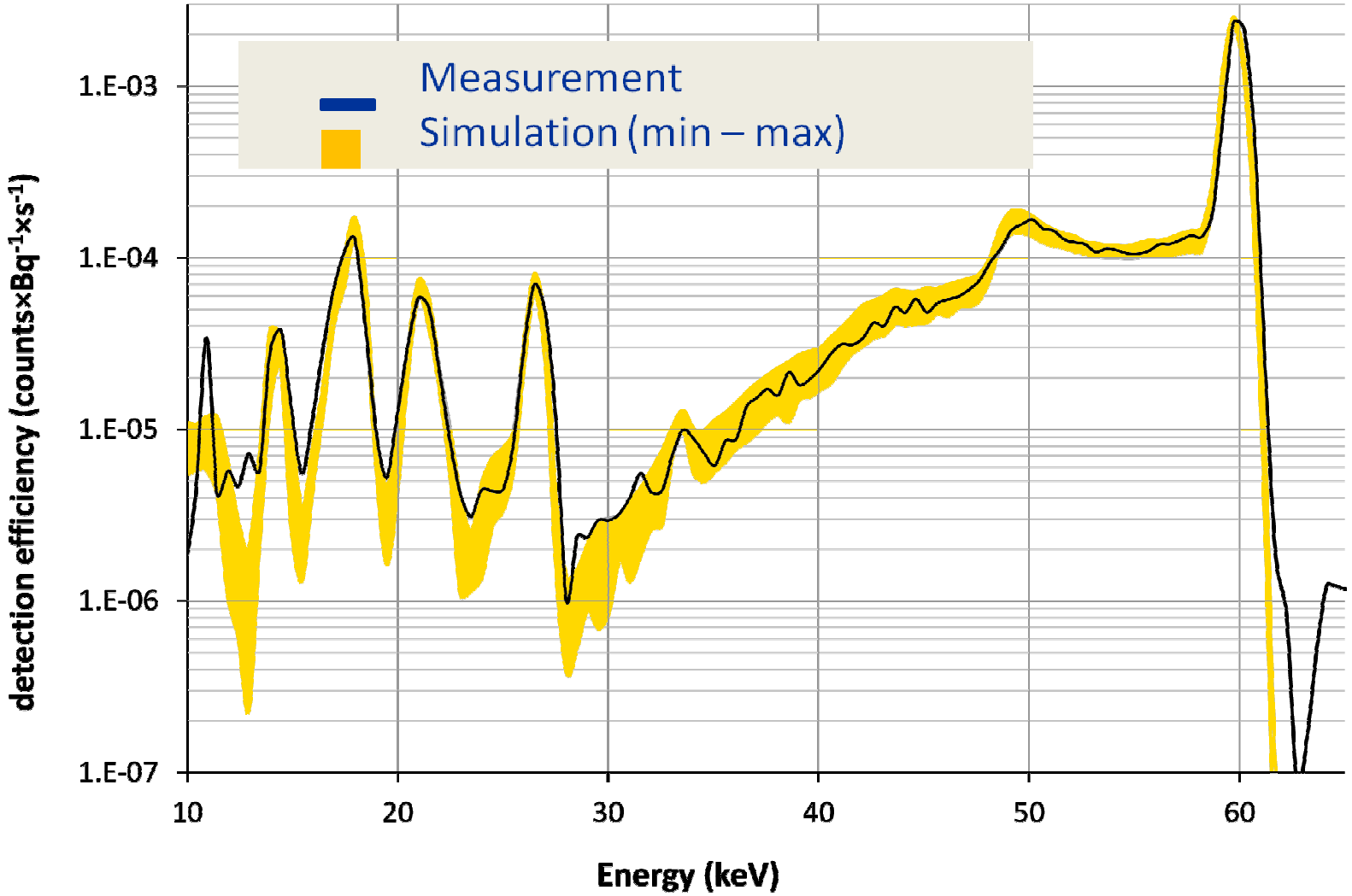
2 results – geometry

- Incorrect position of the detector
- Missing part of the detector
- Wrong shape

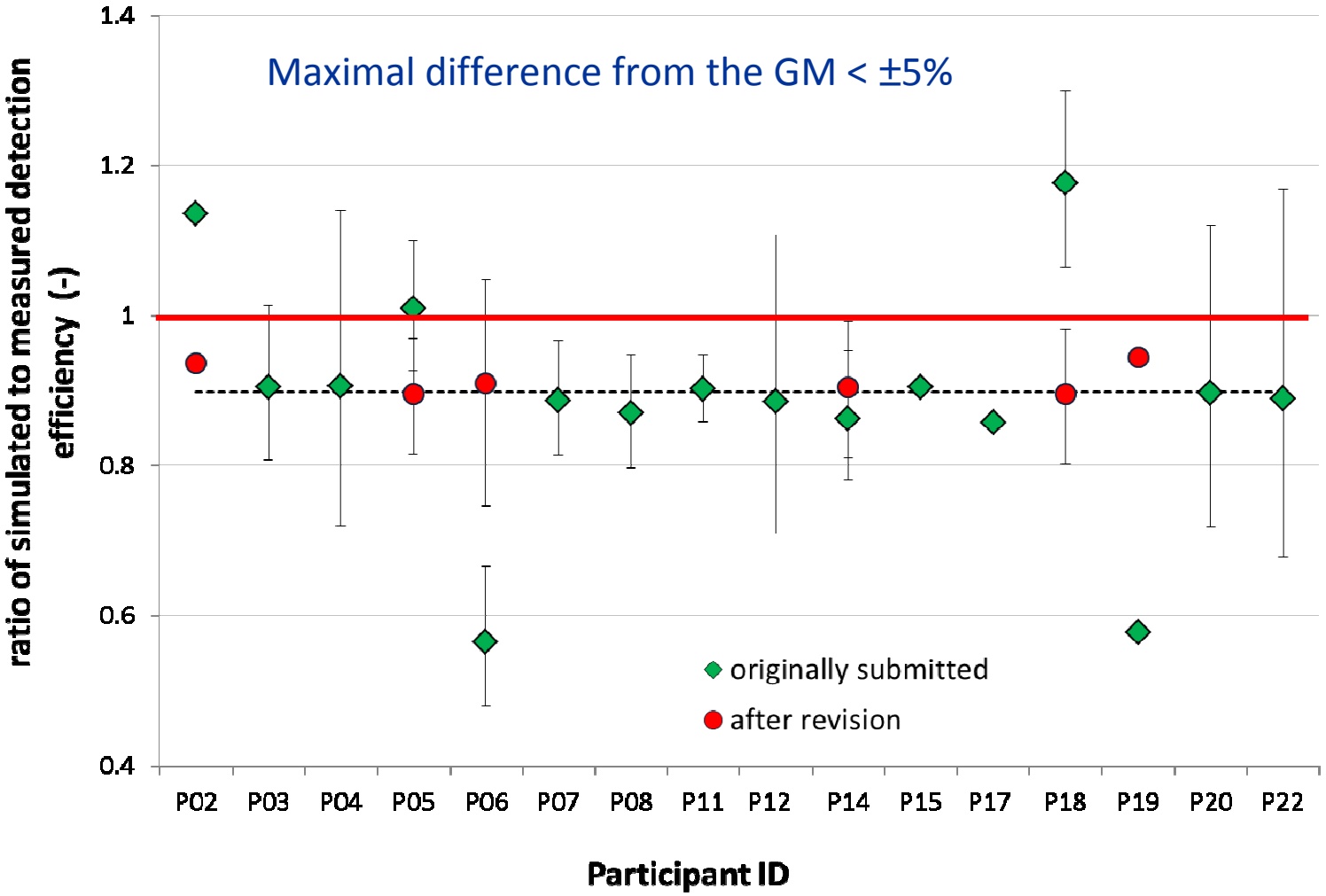
1 result – inappropriate source sampling

- repeated structure (non existing cell addressed)

Deviation from the measurement – after correction



Relative detection efficiency at 59.54 keV



Toxicology of the actinides used in the nuclear industry

Dose estimates based on numerical methods -

Ongoing projects at the Radiation Toxicology Laboratory, CEA, France

Stéphanie Lamart

Radiation Toxicology Laboratory
French Alternative Energies and Atomic Energy Commission (CEA)

Note: wolf dosimetry contribution from David Broggio (IRSN) omitted following presentation from Tom Hinton (IRSN)

Radiation Toxicology Laboratory

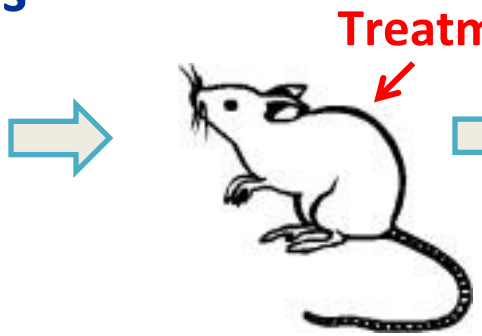
Research objectives and activities

- To characterize the **biokinetics of radionuclides** (actinides)
  - **Transfer rates** between biological compartments
  - **Retention** in tissues
  - **Excretion**
- To study the **radiation toxicity**
- To develop **treatment** strategies

Experimental methods

Contamination

- **Pu isotopes, Am-241**
- **Inhalation or wound**



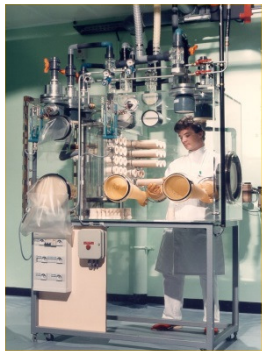
Rat model

Urine
Faeces
Tissues

- **Spectrometry**
- **Histology**

Experimental techniques

CONTAMINATION



Glove box to expose rats to aerosols

DIRECT ACTIVITY MEASUREMENTS

Ge detector for X and γ spectrometry

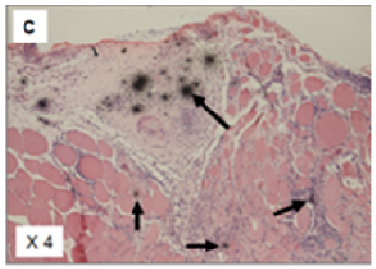
Automatic spectrometry of tissue and excretas samples

INDIRECT ACTIVITY MEASUREMENTS

Liquid scintillation

Separation of isotopes + alpha spectrometry

BIOLOGICAL ANALYSIS



Autoradiography and histology

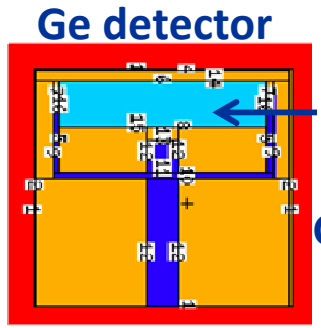
Numerical calibration of a Ge detector to improve the assessment of the retained activity in samples and whole animal body

Background

- Low levels of retained activity
- Significant attenuation of low-energy X and γ rays (tens of keV)
- Complexe geometry of samples (urine, faeces, tissue, whole animal body)
- Simple geometry of calibration sources

→ Numerical calibration of detectors

Methods



Numerical model of a Ge detector

- Modelling of the detector geometry based on the technical drawing, material composition and density
- Simulation of the measurements conducted with physical sources of calibration to validate the numerical model
  - Point sources
  - Uniform source in a Petri dish (physical model of a urine sample)
- Use of a numerical model of a rat to derive numerical calibration factors and radiation doses
- Numerical tools: MCNPX, GEANT4

LESSONS LEARNED FROM THE ICRP SYSTEM ON INTERNAL DOSIMETRY

Dietmar Noßke, BFS, Germany

« Some of the results presented in this document were obtained in the frame of a collaboration agreement with AREVA. The release of this document falls under the rules of this agreement »

Lessons learned from the ICRP system on internal dosimetry - I

ICRP has been developing and publishing human models for internal dosimetry for > 50 years: still continuing to improve its biokinetic and dosimetric models to become more realistic and to meet more and more requirements.

ICRP Publication 2 (1959)

•Purpose: to calculate "permissible doses for internal radiation" (maximum permissible burden in whole body and maximum permissible concentration in air and water).

•Biokinetic models based on fractions reaching whole body and organs of reference for ingestion and inhalation and biological half times; simple "lung model" and a gastrointestinal tract model.

•Dosimetric models based on sphere geometries (radius dependent on organ considered).

Lessons learned from the ICRP system on internal dosimetry - II

ICRP Publication 30 (1979)

•Purpose to calculate annual limits on intake for workers; for this organ and effective doses were needed.

•Biokinetic models: Integration of gastrointestinal tract model, lung model and systemic models;

- systemic models in most cases simple models with transfer compartment (blood) and subsequent distribution to organ compartments from which activity is directly excreted;
- retention characterised by (sums of) exponential functions.

•Dosimetric models based on mathematical phantoms representing reference man and his organs; also irradiation from other source regions are considered.

Lessons learned from the ICRP system on internal dosimetry - III

ICRP Publications 56 (1990)

•Purpose to calculate age-dependent doses for members of the public

•Biokinetic models: Gastrointestinal tract model of ICRP 30, respiratory tract model of ICRP 66, systemic models extended by excretion rates, in some cases more realistic physiologically-based recycling models and independent daughter kinetics.

•Dosimetric models based on mathematical phantoms of reference persons of various ages (newborn, ages 1, 5, 10, 15 years and adult)

ICRP Publication 88 (2001)

•Purpose to calculate doses to the embryo and foetus after activity intakes by the mother

•Biokinetic models: In most cases the models of the ICRP 56 series and activity concentration ratios foetus/mother and foetus/placenta.

•Dosimetric models based on mathematical phantoms of the pregnant female and the foetus for different times of pregnancy.

Lessons learned from the ICRP system on internal dosimetry - IV

ICRP Publication 95 (2004)

•Purpose to calculate doses to infants from ingestion of radionuclides in mother's milk after activity intake by the mother

•Biokinetic models: In most cases the models of ICRP 67 with transfer factors from blood to breast and milk

•Dosimetric models based on the infant and young child phantoms of ICRP 67.

ICRP OIR series (2014)

•Purpose to calculate more realistic doses and bioassay data for workers

•Biokinetic models: Alimentary tract model of ICRP 100, modified respiratory tract model of ICRP 66; systemic models are recycling models with independent daughter kinetics.

•Dosimetric models are based on voxel phantoms of the adult male and female; calculation of effective dose according to ICRP 103.

Lessons learned from the ICRP system on internal dosimetry - V

What to do for wildlife dosimetry?

It depends on: purpose for which internal doses are needed and consequently what level of accuracy is needed?

- Models similar to ICRP 2 or ICRP 30 might be sufficient for environmental radiation protection purposes.
- A higher level of accuracy as intended by the OIR reports is mainly needed for bioassay interpretation (is this needed for wildlife?) but also for epidemiological studies and radiation effect research.

APPLICATION OF RETROSPECTIVE DOSIMETRY TO WILDLIFE DOSIMETRY

Francois Trompier, IRSN, France,
Paola Fattibene, ISS, Rome,
Clemens Woda, HGMU, Germany,
Kai Rothkamm, PHE, UK

Section abridged following presentation of Tom Hinton (IRSN) due to overlap of material

Application of EPR to wildlife?

Past studies have demonstrates that EPR dosimetry could be applied to animal teeth (cows, mice, dogs and walrus)

- •EPR signal in animal and human teeth is similar
- •Linear responses of the EPR signals to laboratory doses observed above 0.5 Gy
- •Mammalian animal teeth are similar to humans' and radiation sensitivity is also similar
- •Herbivore animal and human teeth are different. Radiation sensitivity of mice is (30 – 50)% the human teeth sensitivity

The X-band EPR approach requires whole extracted teeth: the method remains limited to dead animals (hunted, cadavers,…)

Quantity of available enamel in some animals may be very small compared to human teeth.

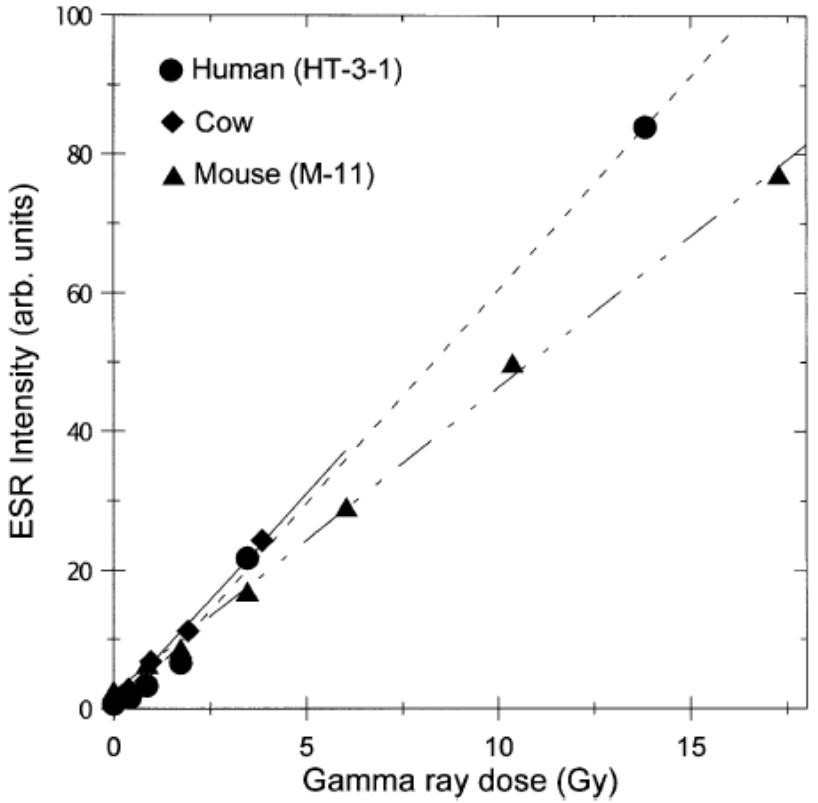
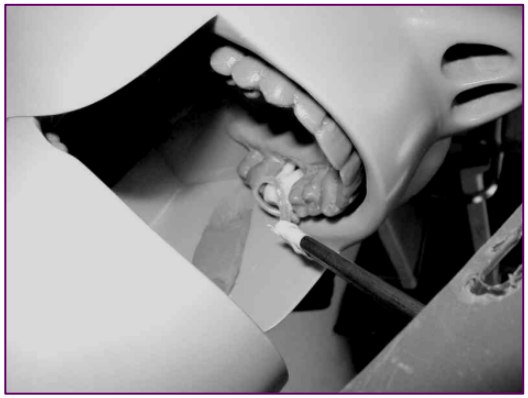


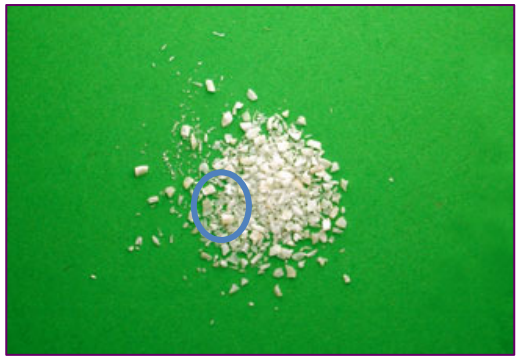
Fig. 2. Dose response of the ESR signal of CO_2^- in tooth enamel of human, cow and mouse teeth. The lines indicated were obtained by the least-squares method. The response of cow coincides with that of human while the slope is lower for mouse tooth.

Toyoda et al., 2003

Alternative approaches applied to humans

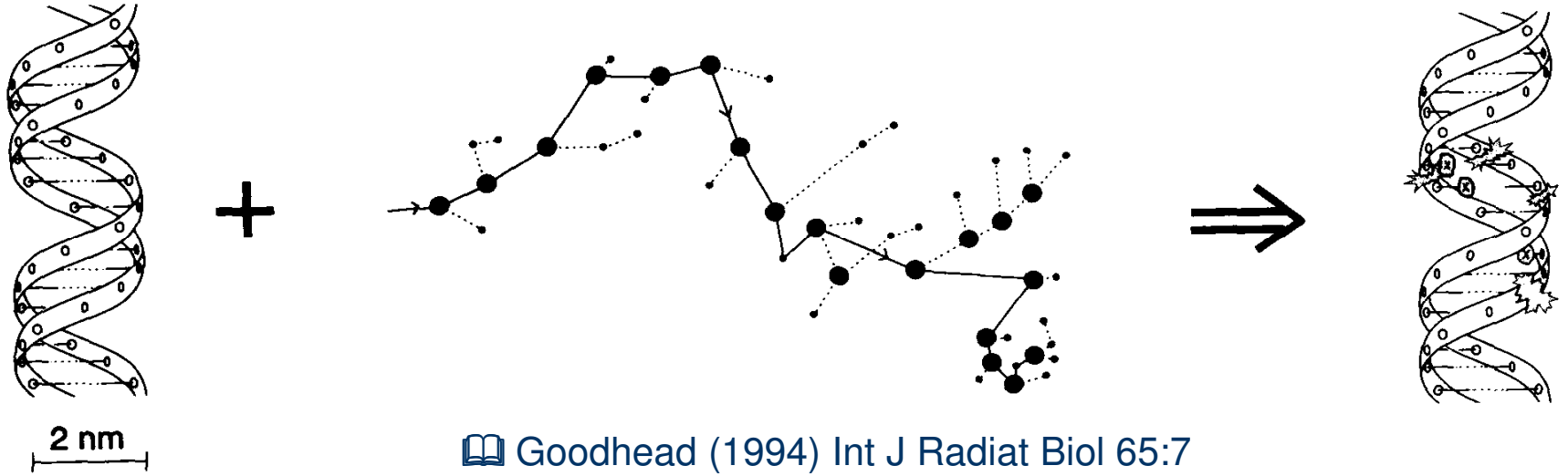
- *in vivo* EPR:
  - Detection limit still high (ca. 2 Gy)
  - Recent developments in EPR technology (X-band in vivo EPR, pulsed in vivo EPR) seems to enough promising to envisage in vivo measurements in near future.
- Q-band EPR:
  - Much more sensitive for small samples (1-5 mg) than the classical X-band spectroscopy
  - Mini-biopsies of a few mg is enough to achieve a detection limit of hundreds of mGy
  - The quantity needed could make the collection from living animals possible
  - This approach has been already used on humans accidentally irradiated (Trompier et al., 2014).





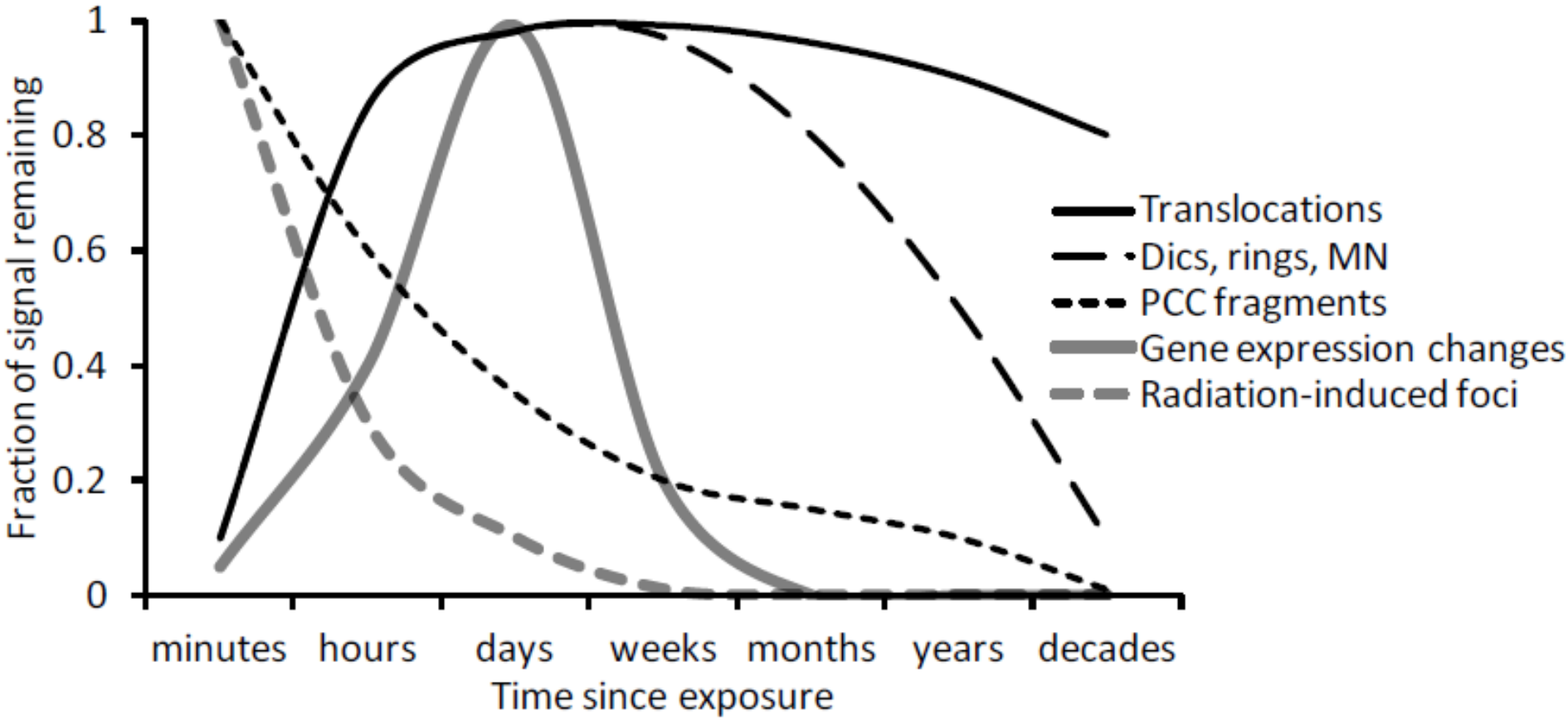
Spectrum of biological damage induced by ionising radiation

Damage induced by 1 Gy X-rays in a human cell:	**physical**	• 100,000 ionisations in the cell nucleus • 2,000 direct ionisations in the DNA
	biochemical	• 1,000 single-strand breaks • 1,000 damaged bases • 150 DNA protein crosslinks • **35 double-strand breaks**
	cellular	• **0.1 dicentrics / micronuclei** • 0.3 lethal events • 10^{-5} *hprt* mutations



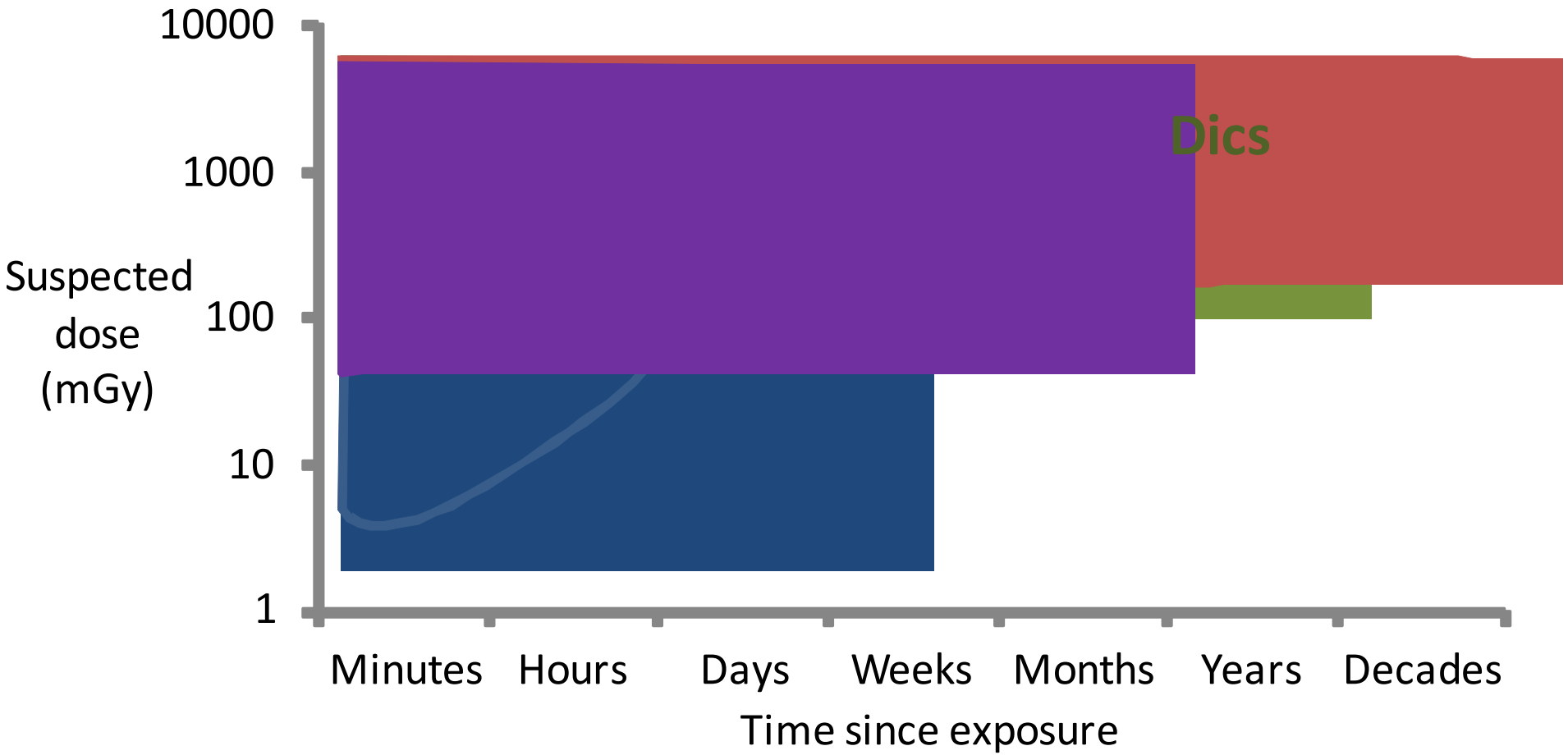
📖 Goodhead (1994) Int J Radiat Biol 65:7

Biodosimetry markers are not stable over time



Manning & Rothkamm (2013) Br J Radiol 86, 20130173

Sensitivity ~100 mGy whole body dose for cytogenetic markers



Summary

- Wildlife dosimetry is not part of the remit of EURADOS
- EURADOS has a long history of promoting methods for measurement for human exposure that can benefit wildlife dosimetry
- Methods are being developed within EURADOS working groups and at home laboratories that might have benefits for wildlife dosimetry
- In particular, intercomparisons act as a vital component of QA providing checks on accuracy
- Training initiatives (not focussed on here) provide an important method of promoting good practice