

CONTRIBUTION OF COMPUTATIONAL DOSIMETRY TO THE MANAGEMENT OF RADIOLOGICAL ACCIDENTS

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Context

[**RADIOLOGICAL ACCIDENTS AND MEDICAL MANAGEMENT**

- ~ 600 radiation overexposure accidents between 1980 and 2013 (from Coeytaux et al., 2015)
 - 2390 overexposed people – 190 died
 - 32% radiation therapy, 31% fluoroscopy, 27% industry
 - Most common type of irradiation: local or partial body irradiation

Medical management of victims of external exposure : priority to diagnosis

- Identification of potential victims
 - Diagnosis
 - Treatment
- } Small-scale accidents

} Medium to large-scale accidents



Industrial applications



Civil nuclear



Medical use



Defense

Context

[*MEDICAL MANAGEMENT AND DOSIMETRY*

- | Dose is an indicator of tissue or organ damage that helps clinicians to :
 - assess radiation-induced damage
 - define the therapeutic strategy

- | **Dosimetry challenge** : assessment of the dose and the dose distribution within the body

- | Dosimetric needs and methods vary depending on the type of accident (whole body versus local irradiation, small versus medium/large scale accidents, ...)

How to assess the dose?



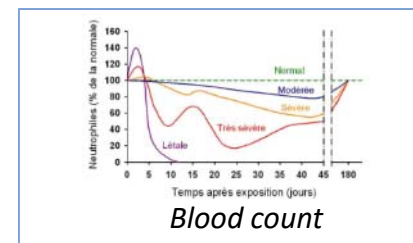
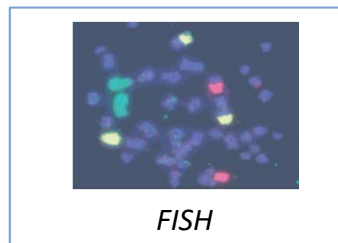
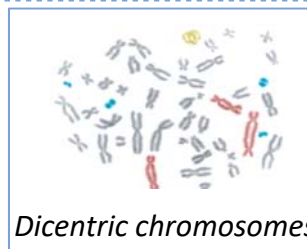
**CLINICAL
DOSIMETRY**



	0.5-1 Gy	1-3.5 Gy	3.5-5.5 Gy	5.5-10 Gy	10-30 Gy	>30 Gy
nausée	5-20% <24h	50-90% <12h	100% <12h	100% <12h	100% 5 min	
vomissement	15-50% <24h	90-100% <12h	100% <12h	100% <12h	100% 5 min	
anorexie		60-90% <12h	100% <12h	100% <12h	100% <1h	
fatigue		10-80% >days	80-100% >days	50-100% <24h	90-100% <6h	
fièvre		50% <12h	100% <12h	100% <12h	100% 5 min	
Maux de tête				80-100% <24h	100% <6h	
hypo-tension						



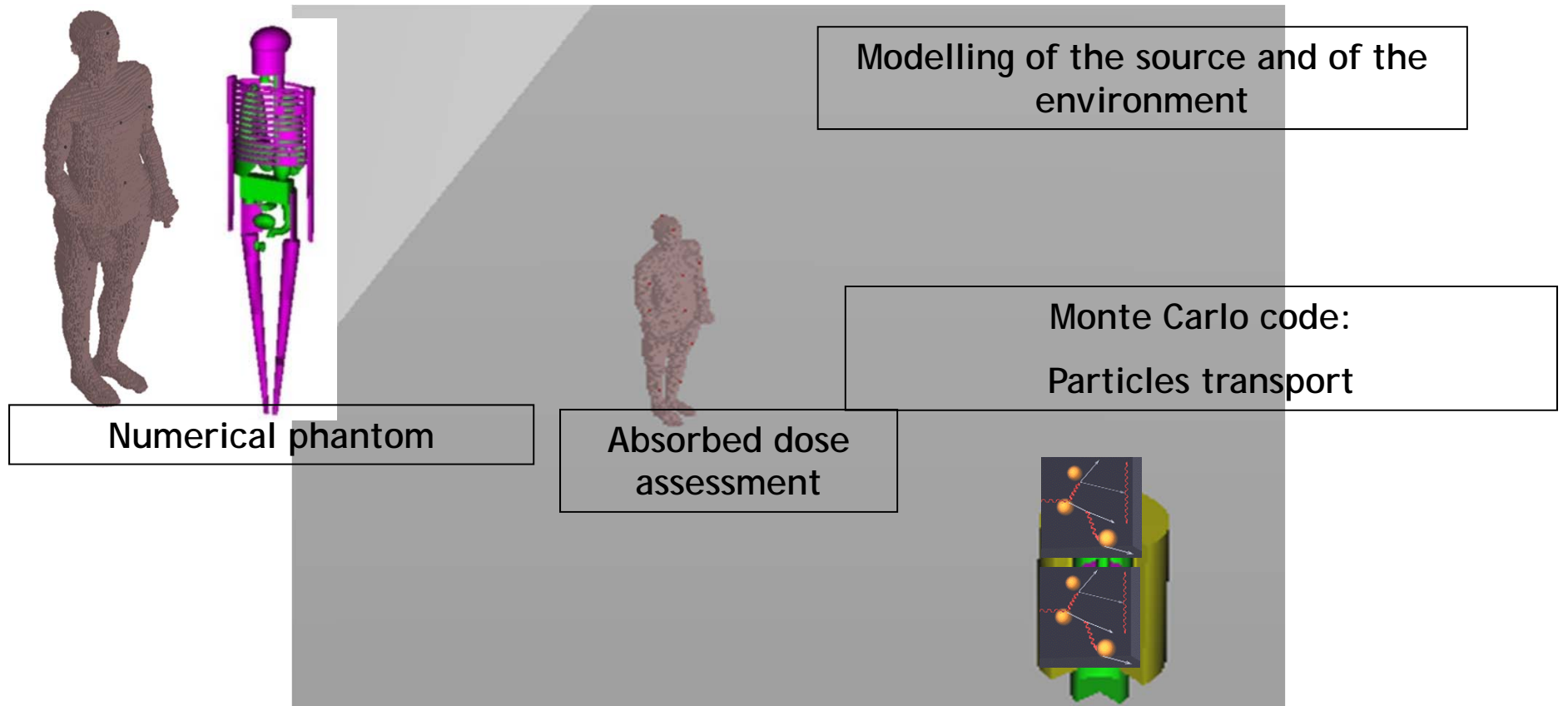
**BIOLOGICAL
DOSIMETRY**



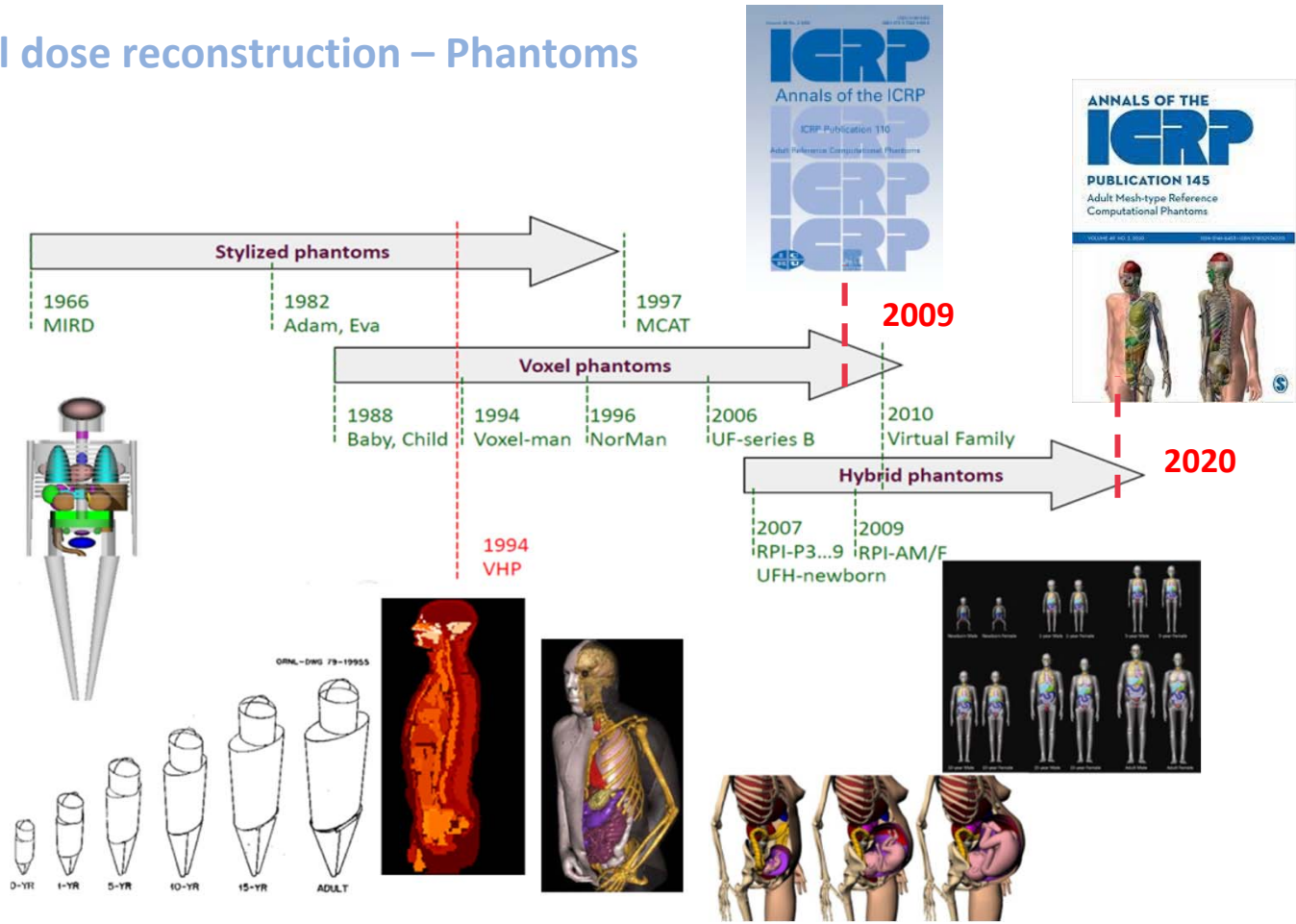
**PHYSICAL
DOSIMETRY**



Numerical dose reconstruction - principle



Numerical dose reconstruction – Phantoms



Diagnosis and definition of the therapeutic strategy – Medical need

■ Whole body irradiation

- Key clinical issue : spontaneous secondary resumption of bone marrow activity ?

Are there areas of bone marrow underexposed?

- Support of computational dosimetry : heterogeneity of the dose distribution within the body, in particular at the level of the bone marrow areas

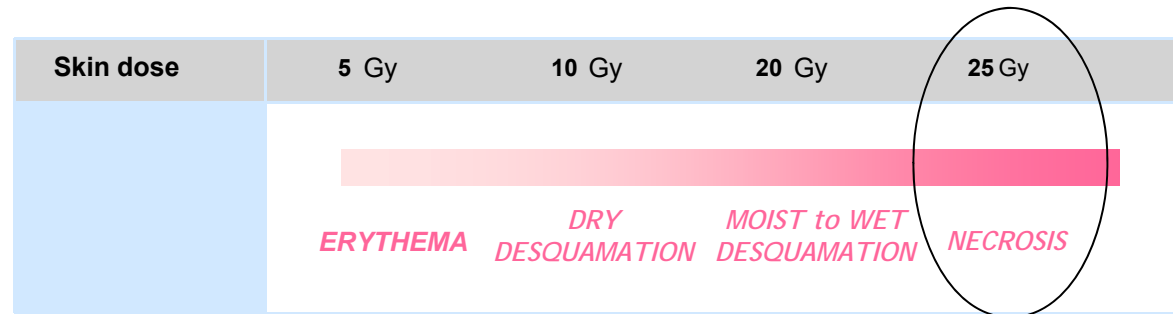
No need for anatomical precision

Use of generic phantoms (stylized, voxel, MESH)

Diagnosis and definition of the therapeutic strategy – Medical need

Local irradiation

- Tissue necrosis if dose > 25 Gy



- Key clinical issue : surgery?

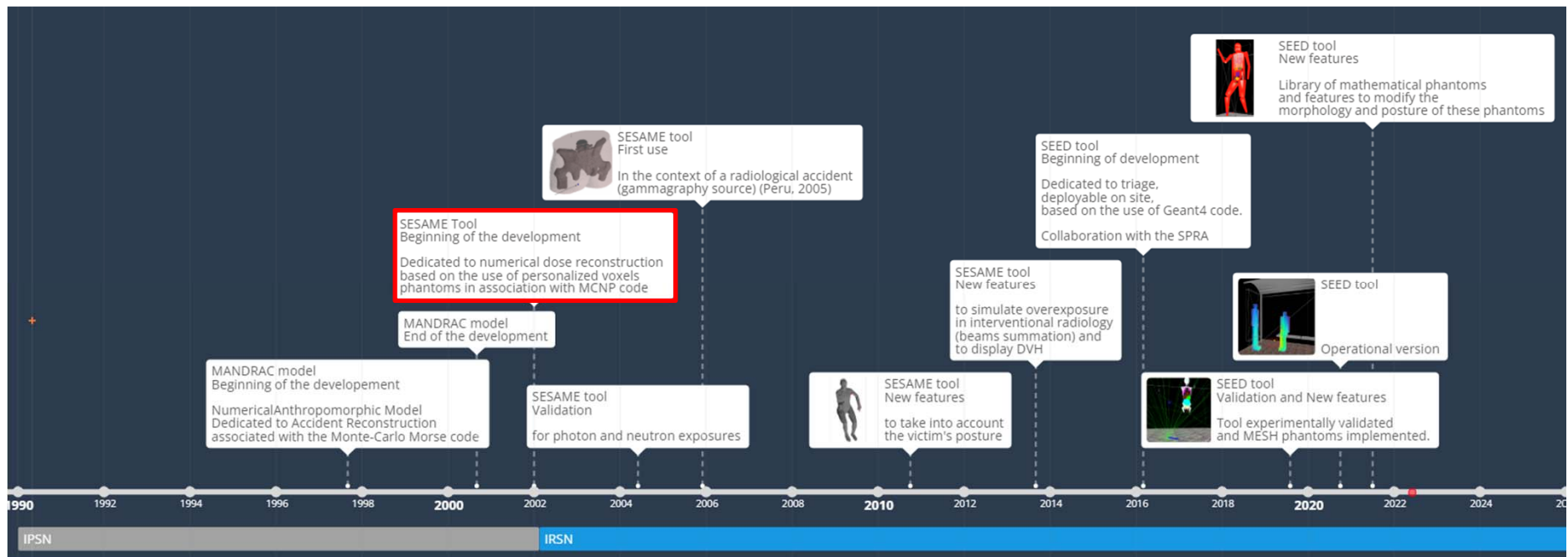
Is there any tissue irradiated at more than 25 Gy that needs to be removed?

- Support of computational dosimetry : to define the dose distribution at the lesion level

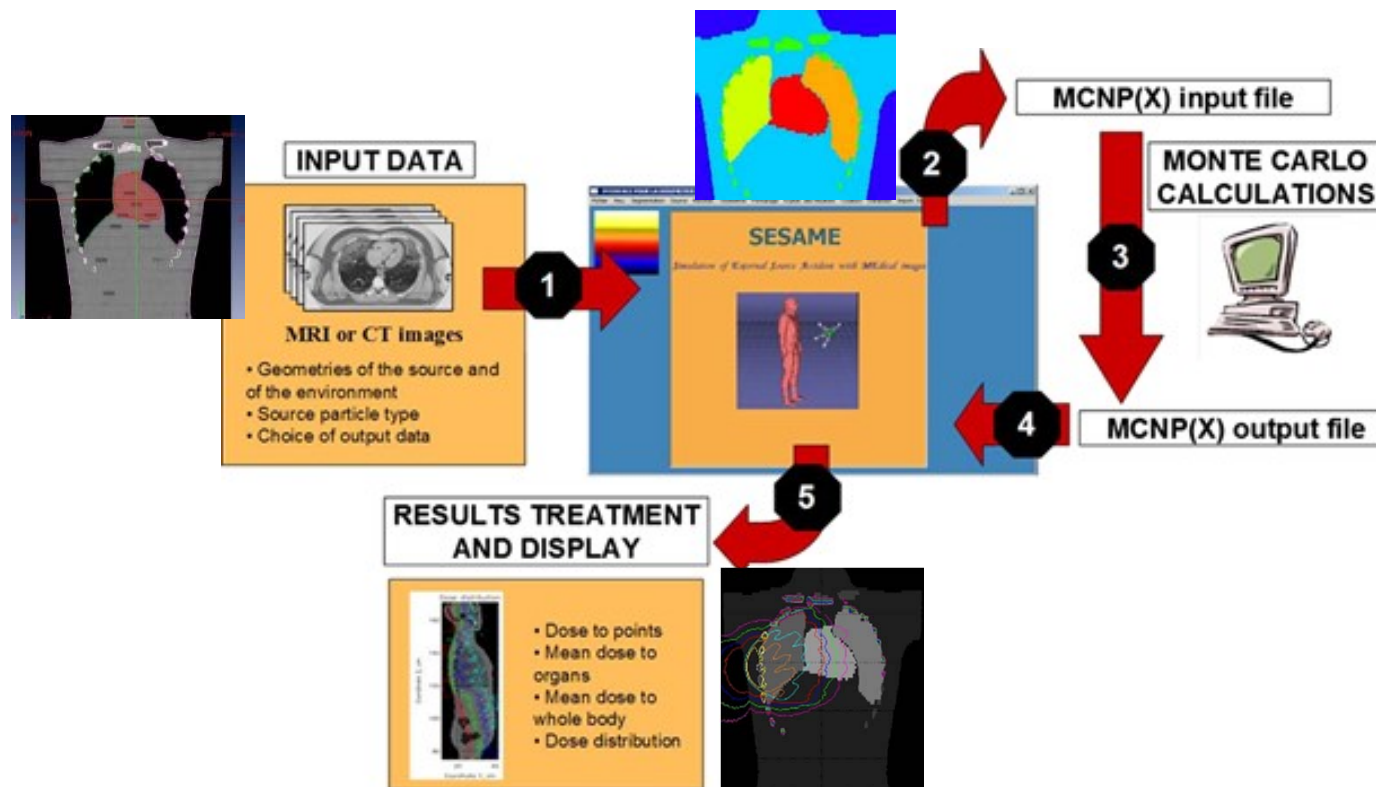
Need for anatomical precision

Use of personalized voxel phantoms created from the victim's images

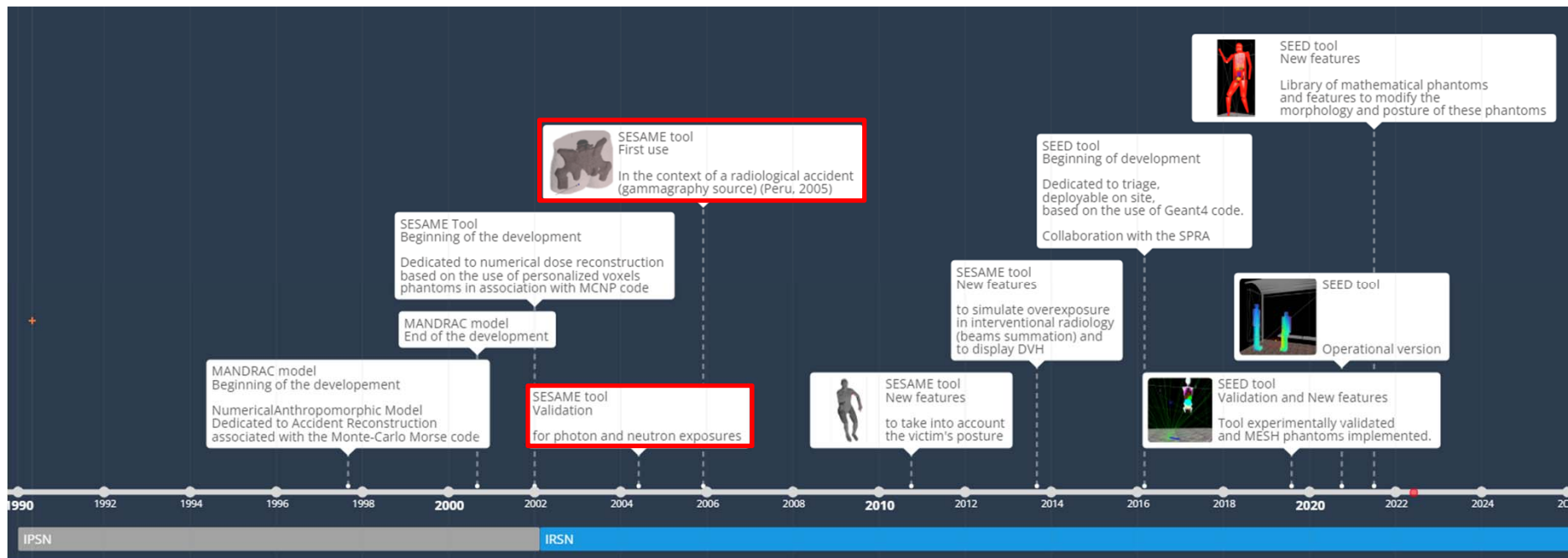
Numerical dose reconstruction at IRSN – Timeline of evolution



Localized irradiation– SESAME tool (Simulation of External Sources Accident with Medical images) (Huet *et al.*, 2009)

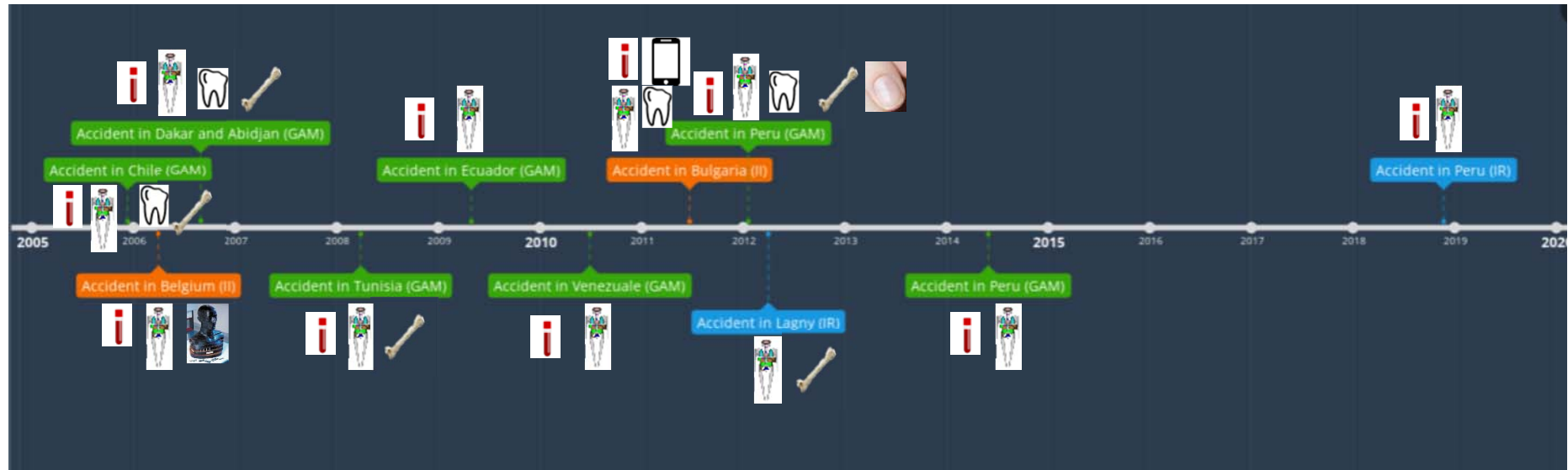


Numerical dose reconstruction at IRSN – Timeline of evolution



Lemosquet *et al.*, 2004; Huet *et al.*, 2009; Huet *et al.*, 2019

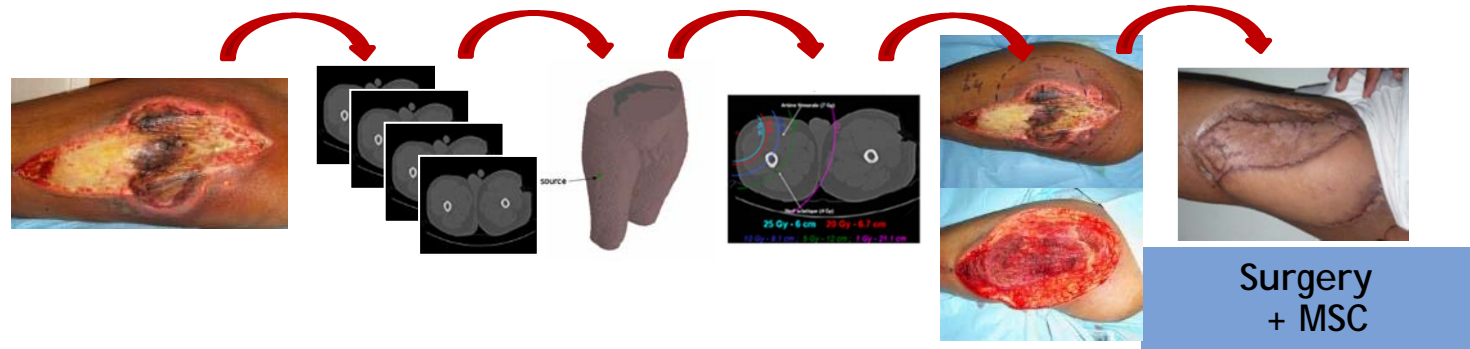
Dose assessment in case of radiological accidents



Some case studies to be presented in the talk given by JF Bottollier-Depois

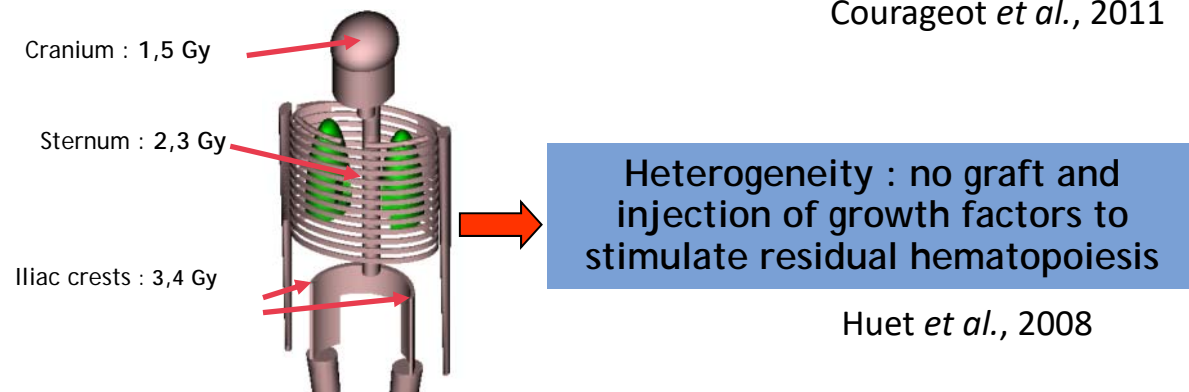
Medical management of small scale accidents – contribution of computational dosimetry

To guide the surgery



Courageot *et al.*, 2011

To assess the dose heterogeneity to guide treatments for hematopoietic syndrome

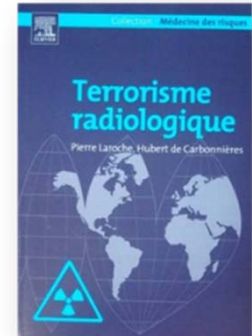


Huet *et al.*, 2008

Dosimetric triage - context

- Primary purpose of the initial-phase dose assessment : identify individuals in potential danger of short-term deterministic effects
- No example of large-scale-event case studies in which initial-phase dose assessments for large numbers of people were carried out following acute exposure -> conceptual approaches
- European consensus concerning the medical management of mass radiation exposure (Vaux de Cernay, 2005) :
 - time to onset of early phase clinical signs of acute radiation syndrome (first 24h)
 - importance and rapidity of the drop of blood lymphocytes (first 48 h)
 - Non specific

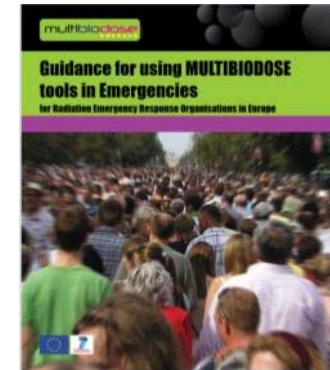
➔ Need for complementary and alternative methods



Dosimetric triage

Multibiodose project

- 7 dosimetric assays tested
- dosimetric triage categorisation in three different categories



Current R&D in biological and physical dosimetry worldwide

- To reduce the time of analysis and to lower the detection limits of the techniques used for diagnosis
- To investigate less invasive methods, new materials and new biomarkers
- To develop tools deployable on site

Table 9.1 Radiation Dose Triage Levels for Symptoms and Medical Care Suggested by the Multibiodose Project in the European Union (Jaworska et al., 2014).

Category	Triage dose	Symptoms and care
Low	<1 Gy	Unlikely to develop symptoms of acute radiation syndrome (ARS); no immediate care required
Medium	1 to 2 Gy	May experience mild or delayed ARS symptoms; follow-up care may be necessary
High	>2 Gy	Moderate-to-urgent care may be required

Increase triage capacity and harmonize practice

- Laboratory network
- Intercomparisons
- Training



Dosimetric triage - Derivation of dose conversion coefficients (1)

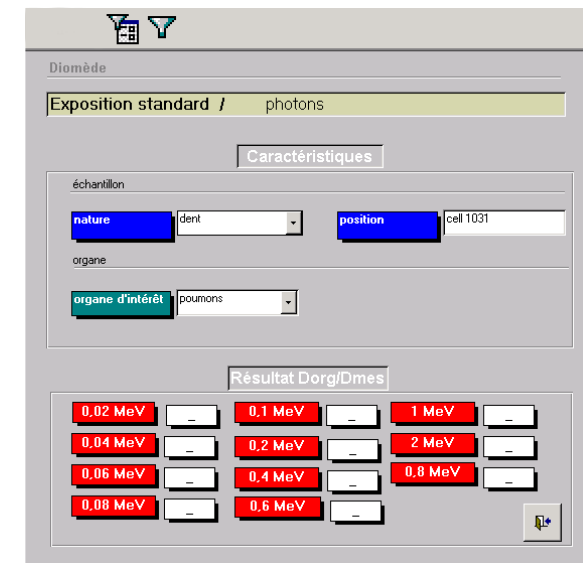
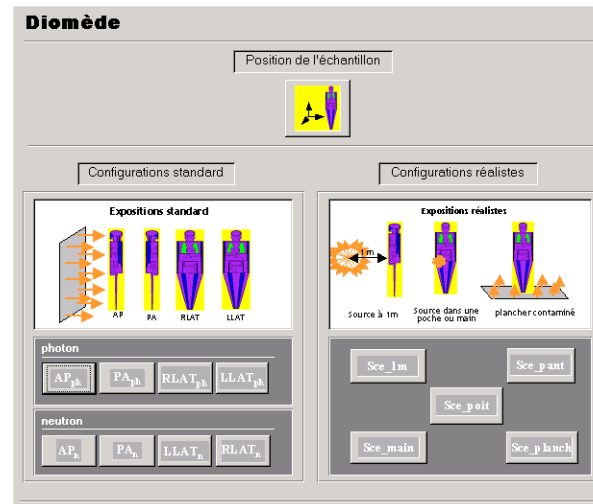
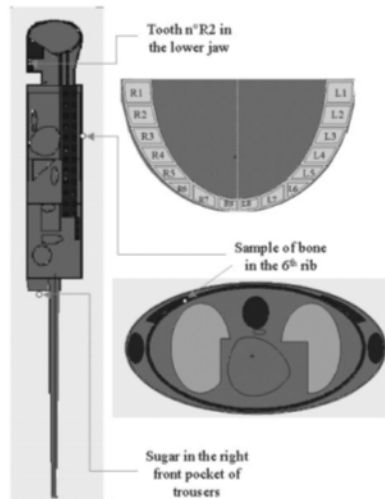
■ **Objective** : convert the measured physical dose of a sample into an organ dose or a “whole-body” dose

■ **Method**

- Modelling of one or several locations of the sample
- Modelling of several geometries of exposure
- Calculation of predetermined conversion coefficients with a Monte Carlo code

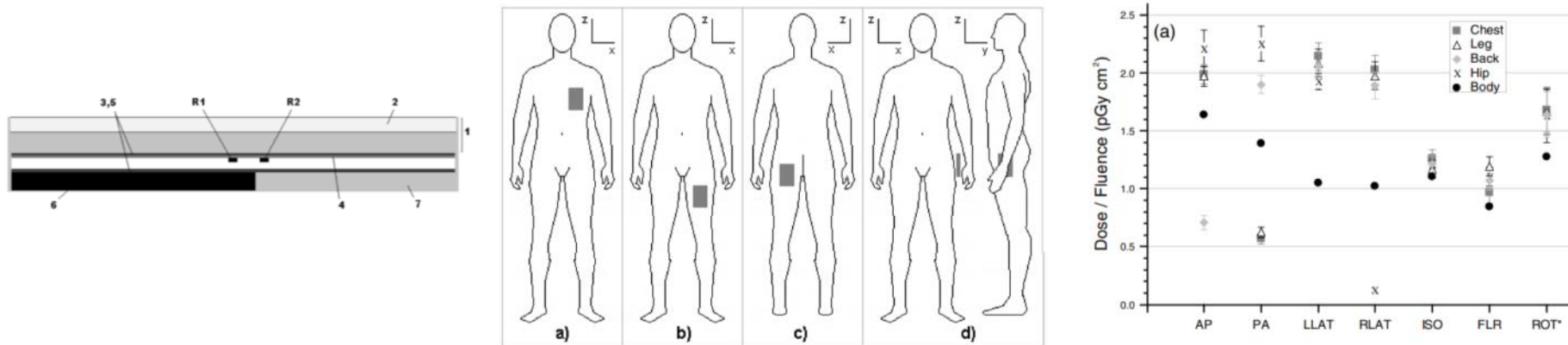
Dosimetric triage - Derivation of dose conversion coefficients (2)

- Whole body and organ dose conversion coefficients from EPR fortuitous dosimeter (Hervé *et al.*, 2007)
 - Exposure: standard exposures (AP, PA, RLAT, LLAT), source at 1 m, in a pocket, a hand and contaminated ground
 - Sources : monoenergetic photons and neutrons, ^{60}Co , ^{137}Cs , ^{192}Ir , ^{252}Cf and AmBe
 - Type of samples / location : teeth, bones, sample in a pocket (sugar for instance)
 - MCNPX 2.4 code and MIRD phantom with modified head



Dosimetric triage - Derivation of dose conversion coefficients (3)

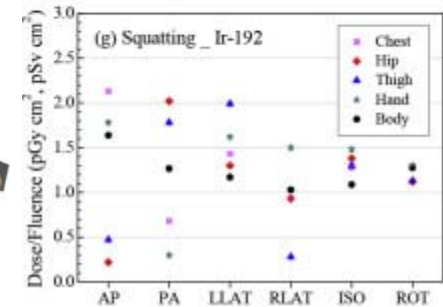
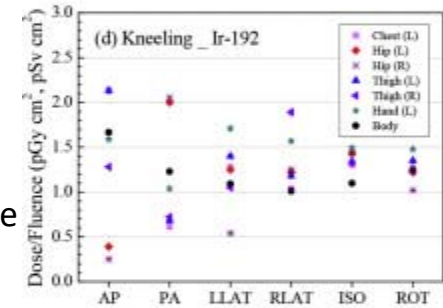
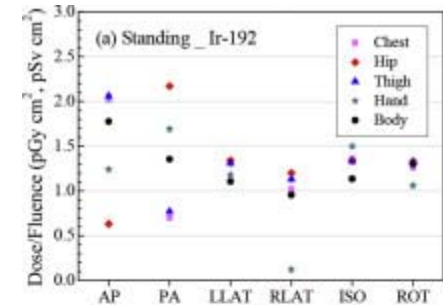
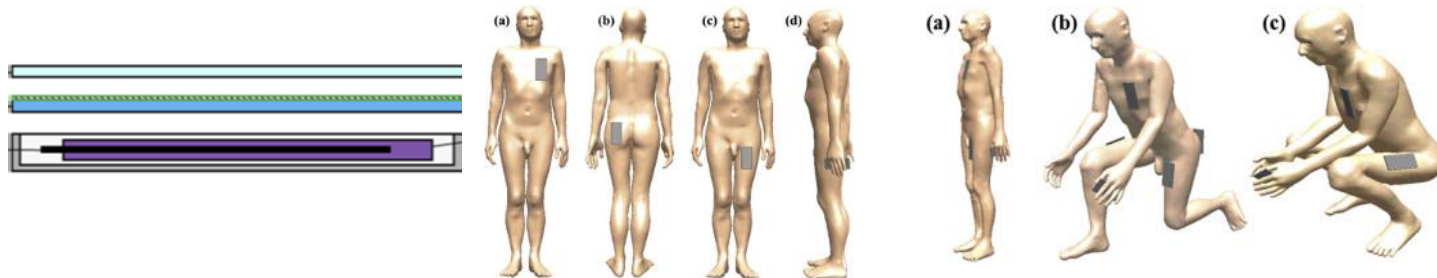
- Whole body dose conversion coefficients from mobile phone samples (Eakins and Kouroukla, 2015)
 - Exposure: standard exposures (AP, PA, RLAT, LLAT, ISO), rotational and contaminated ground
 - Sources : ^{60}Co , ^{137}Cs , ^{192}Ir
 - Type of samples / location : resistors (aluminium oxide) / chest, leg, back and hip
 - MCNPX code, ICRP 110 reference male phantom, modelling of the mobile phone



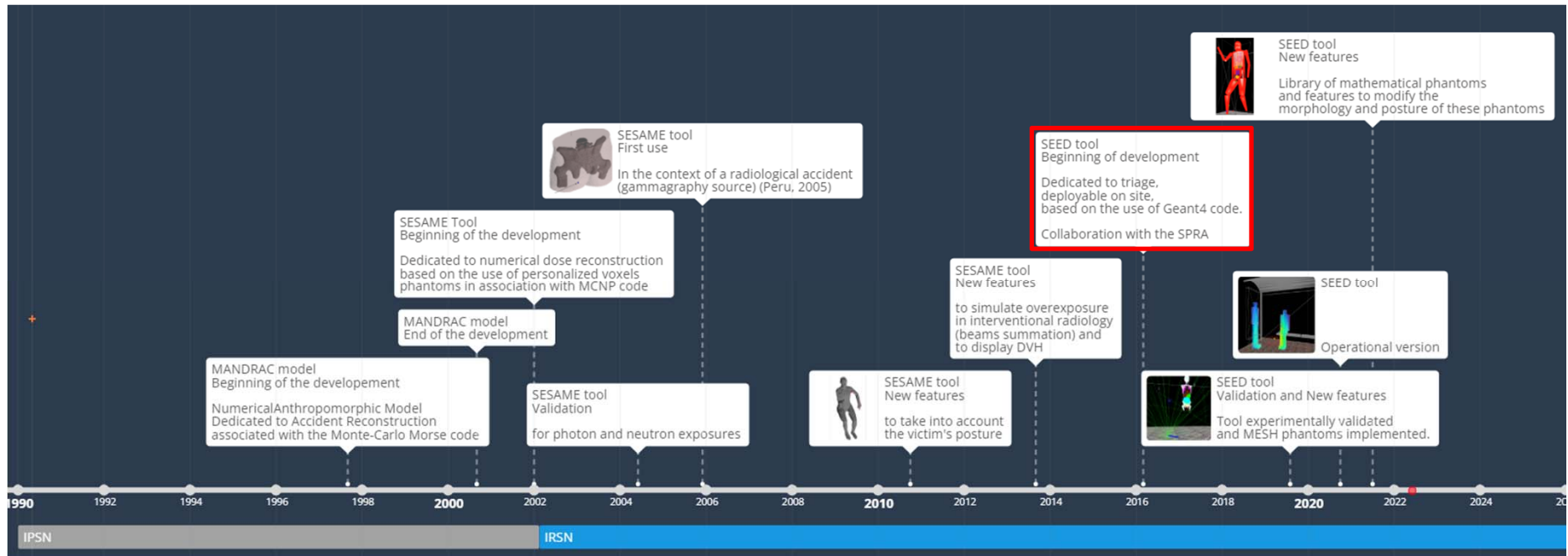
Dosimetric triage - Derivation of dose conversion coefficients (4)

Whole body dose conversion coefficients from mobile phone samples (Kim *et al.*, 2019)

- Exposure: standard exposures (AP, PA, RLAT, LLAT, ISO) and rotational
- Sources : ^{60}Co , ^{137}Cs , ^{192}Ir
- Type of samples / location : display glass / chest, hip, thigh and hand
- Three different postures: standing, kneeling, squatting
- Geant4 code, ICRP 145 mesh reference male phantom, modelling of the mobile phone



Numerical dose reconstruction at IRSN – Timeline of evolution



Dosimetric triage – SEED tool (Simulation of External Exposures and Dosimetry)



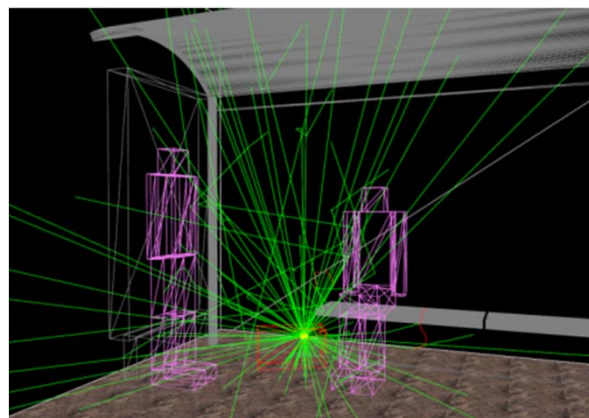
- Collaboration SPRA/IRSN
- Powerful mobile and autonomous computer (72 cores) deployable on site
- Developed in C++, Geant4 / GATE Monte-Carlo code



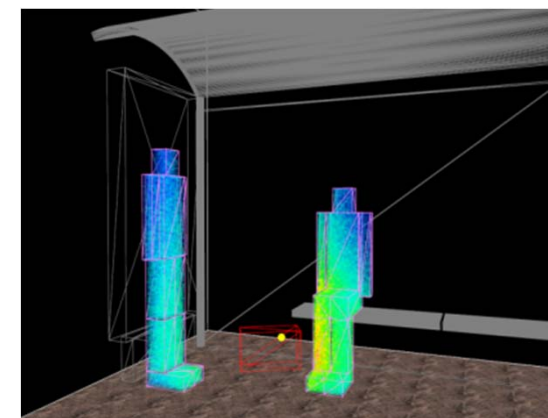
Collection of input data



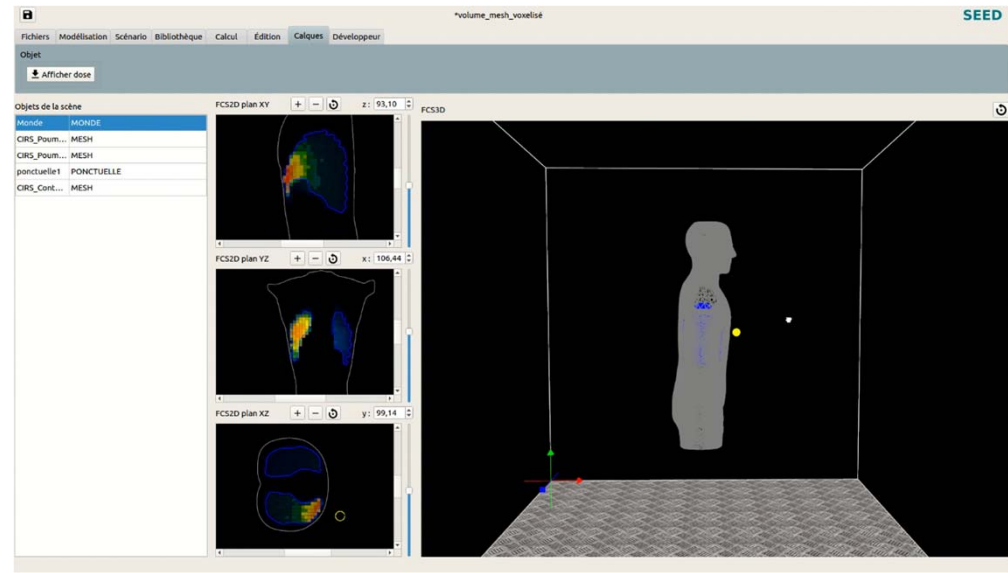
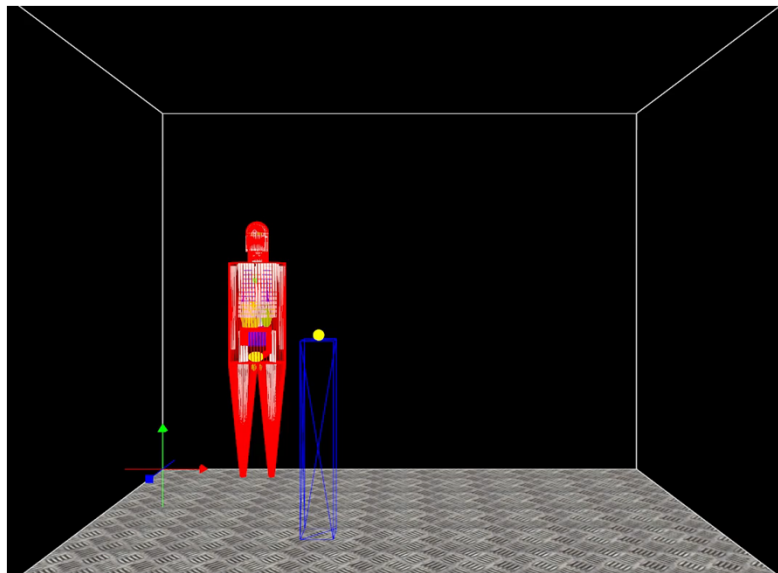
Scene modelling



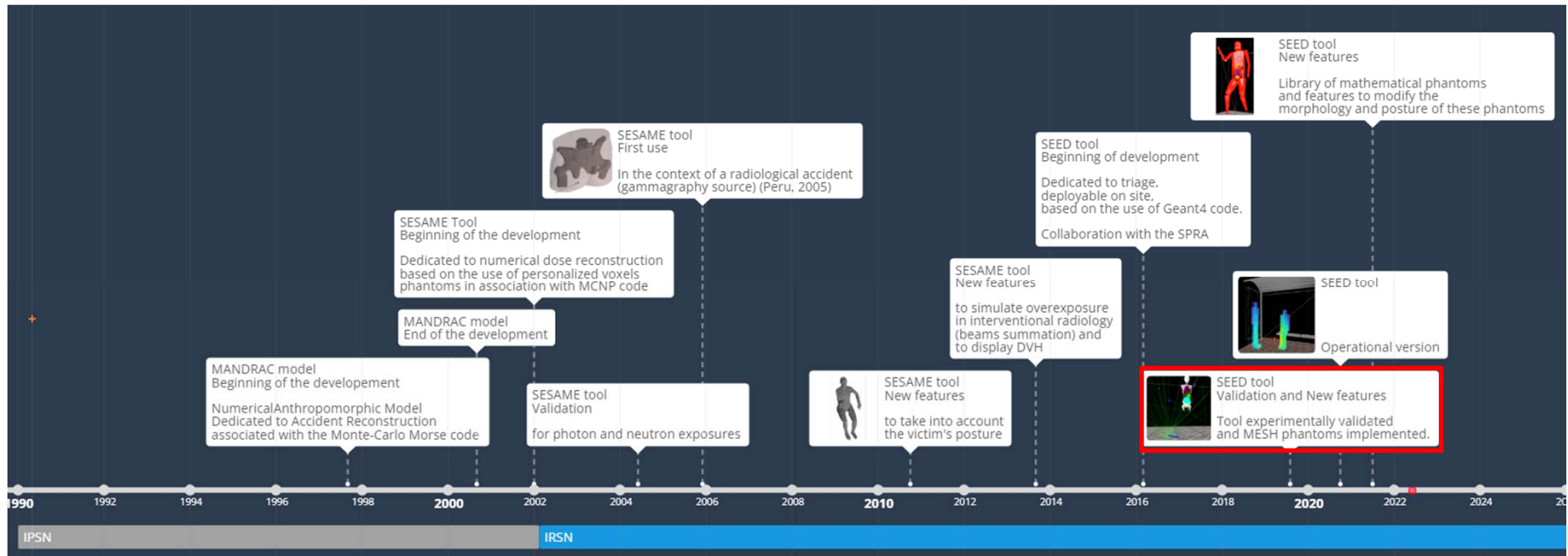
Results display



Dosimetric triage – SEED tool (Simulation of External Exposures and Dosimetry)



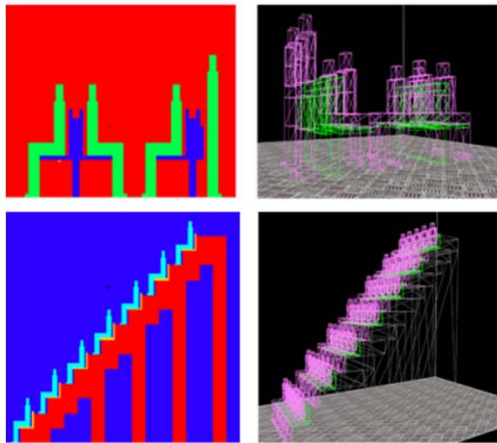
Numerical dose reconstruction at IRSN – Timeline of evolution



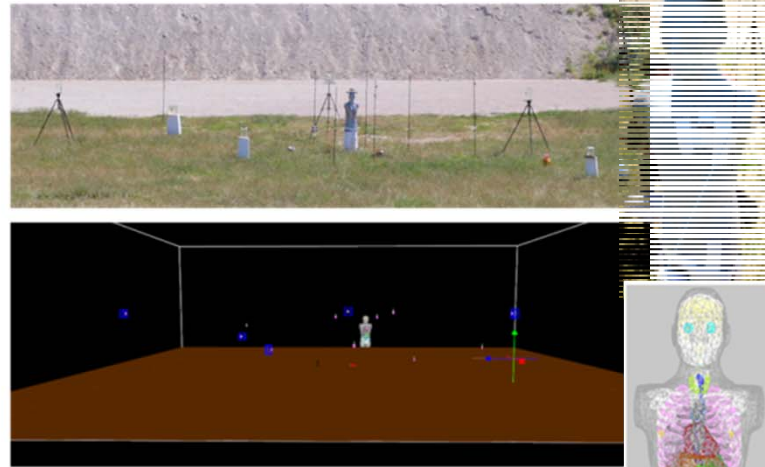
Dosimetric triage – SEED tool



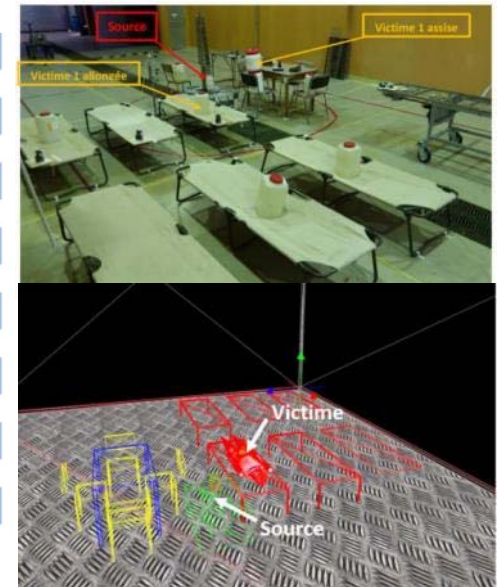
VALIDATION STEPS



2018
Comparison with another
Monte-Carlo code
(Entine *et al.*, 2022)



2019
Comparison with experiments
(Entine *et al.*, 2022)



2022
Deployment of the tool on site

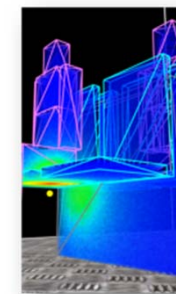
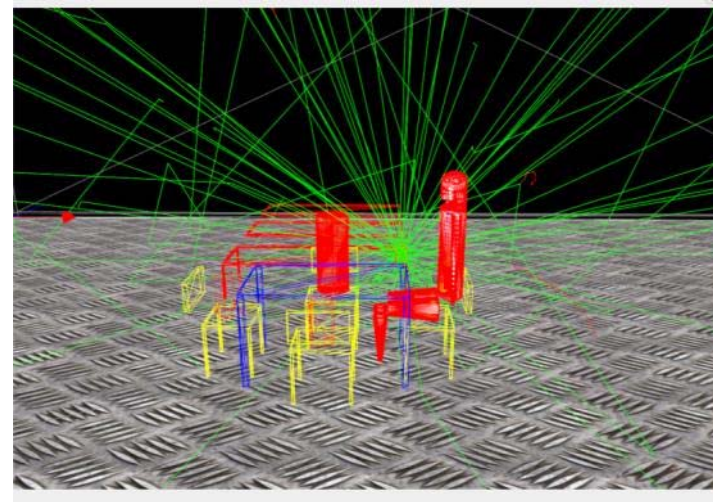


Dosimetric triage – SEED tool

[ONGOING AND FUTURE DEVELOPMENT

- Improvement of ergonomics and ease of use
 - Libraries (anthropomorphic phantoms, furniture, sources, ...)
 - Modeling aids (copy/paste, ...)

- Place of the tool in the dosimetric arsenal
 - Integration of other dosimetric information (dose rate measurement, dose from a sample,...)
 - In field exercises



Conclusion

- Valuable contribution of computational dosimetry to the management of radiological accidents for small scale accident
 - for diagnostic purposes
 - alone or in combination with other dosimetric techniques

- Initial-phase dose assessments for large numbers of people (medium/large scale accidents)
 - conceptual approaches but computational dosimetry may have a valuable contribution
 - Gap: individual dose assessment with confidence

Goals, research questions and directions of research of computational modeling

(Fattibene *et al.*, 2023)

Research questions	End goal	Possible directions of research	In which circumstances are the exposure conditions known with sufficient detail to allow dose conversion coefficients to be accurately computed and applied in large-scale scenarios?	Dose assessment for large- and small-scale events	Analyze the types of situations in which ignorance of the precise exposure conditions may either be minimized or have minimal impact, within an acceptable level of agreement also to be established.
How to ease and improve the dose reconstruction?	Dose assessment and dose mapping for small-scale events	Develop libraries of phantoms, sources, shielding, etc. Develop implementable computational tools [131] Develop means to perform calculations 'on the fly', to generate conversion coefficients immediately after events rather than relying on pre-tabulated databases	Under what sets of situations might the dose to the fortuitous dosimeter be a sufficiently reliable indicator of the dose to the individual?	Dose assessment for large- and small-scale events	Develop consensus on what level of discrepancy and/or conservatism is acceptable for triage dosimetry seeking collaboration among involved figures, such as experts in RD, crisis management units and medical experts.. Generate a database of such conditions and the associated limitations/uncertainties of reporting dosimeter doses 'as is'.
How to harmonize? Which dose quantity is needed?	Dose assessment for large-scale and small-scale events and dose mapping for small-scale events	Train modellers in computational techniques Support the benchmarking of application through the setup of intercomparison exercises Support collaboration between different experts in RD, and between experts in RD, crisis management units and clinical staff.	How best to provide dose harmonization from multiple materials (fortuitous dosimeters, radiation monitors, ...), either co-located or spatially distributed?	Dose assessment for large- and small-scale events	Develop methods to inter-relate such doses, both to each other and to the individual.

Thank you for your attention

The first 48 hours : Primary scoring

	Score 1	Score 2	Score 3
average delay before symptoms appear	less than 12 hrs	less than 5 hrs	less than 30 min
cutaneous erythema	0	+/-	+++; before 3 hrs
asthenia	+	++	+++
nausea	+	+++	++++
vomiting per 24 hrs	maximum 1	1 to 10	above 10; intractable
diarrhea/number of stools per 24 hrs	maximum 2 - 3; bulky	2 - 9; soft	above 10; watery
abdominal pain	minimal	intense	excruciating
headache	0	++	excruciating; signs of intra-cranial HT
temperature	below 38°C	38 - 40 °C	above 40 °C
blood pressure	normal	normal - possible temporary decrease	systolic below 80
temporary loss of consciousness	0	0	+ / coma

depletion of blood lymphocytes			
	at 24 hours	at 48 hours	
	above 1 500 / μ l	below 1 500 / μ l	below 500 / μ l
	above 1 500 / μ l	below 1 500 / μ l	below 100 / μ l
	outpatient monitoring	hospitalisation for curative treatment	hospitalisation (MOF predicted)

Small scale accident - Dose conversion coefficients

Whole body and organ dose conversion coefficients for industrial sources (Kim et al., 2018; Han et al., 2019)

- Exposure: three distances (0.5, 10, and 30 cm) in four directions (front, back, right, and left) at five levels (ground, mid thigh, lower torso, mid torso, and upper torso)
- Sources : ^{60}Co and ^{192}Ir point sources
- Calculation of source self-shielding factors
- Geant4 code, MRCP phantoms (ICRP 145) and 10th and 90th percentile MESH phantoms

Capsule-wall thickness	Radioactive material thickness							
	1 mm		2 mm		3 mm		4 mm	
	^{192}Ir	^{60}Co	^{192}Ir	^{60}Co	^{192}Ir	^{60}Co	^{192}Ir	^{60}Co
1 mm	0.840	0.972	0.717	0.965	0.627	0.958	0.556	0.949
2 mm	0.803	0.953	0.694	0.947	0.606	0.938	0.536	0.929

