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The Hague, The Netherlands

Encouraging Sustainability in Radiation Protection

POSTERS

Volume 1

- Communication
- Education
- Nuclear Emergencies
- Security
- Physics, Chemistry & Biology

IRPA 2018 Posters
Volume 1:
Communication, Education, Nuclear Emergencies, Security and Physics, Chemistry & Biology

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IRPA 2018 Posters - Volume 1

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Communication

New web-based application for public consultation of the Spanish Radiological Environmental Monitoring Data

Radiological Environmental Monitoring Department (AVRA) - Deputy Direction for Environmental Radiation Protection (SRA)
Spanish Nuclear Safety Council (CSN)

S. Luque, C. Rey, P. Martínez, A. Ortiz, B. Sánchez, J.A. Trinidad, I. Marugán, R. Salas, L. Ramos

CSN SPANISH NUCLEAR SAFETY COUNCIL

WHY?

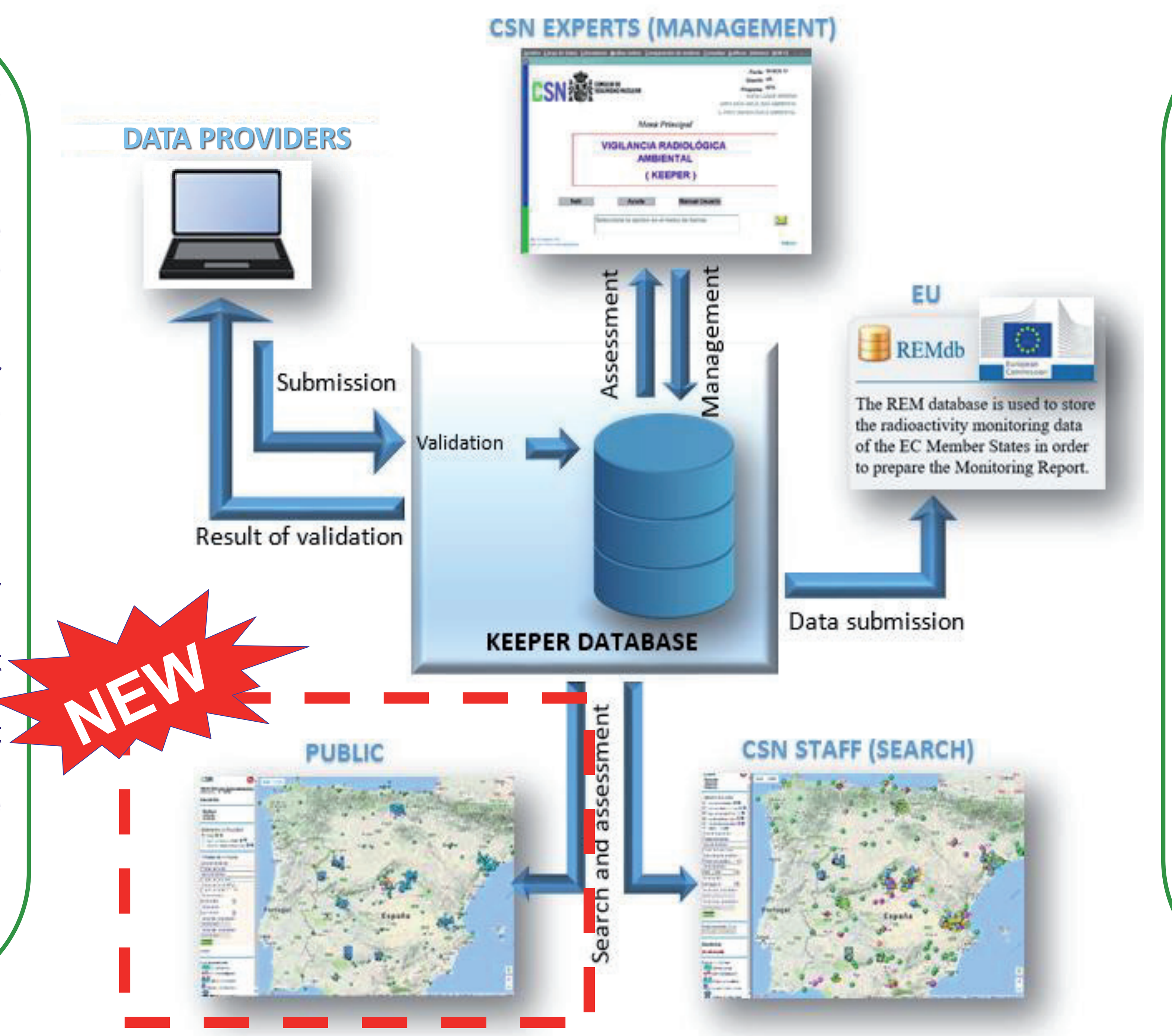
- Article 35 of the Euratom Treaty requires that each Member State shall establish facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil and to ensure compliance with the basic safety standards.
- Art. 2 of the Law of creation of the CSN states that this organization is responsible for the *"Monitoring of the radiological quality of the environment"* and for the *"Information to the public opinion on matters within its competence"*.
- Law 27/2006 of July 18, which regulates the rights of access to information, public participation and access to justice in environmental matters, states that the public has the right to access to environmental information held by public authorities in a easy to use electronic format within public telecommunication networks.

WHAT?

KEEPER is a huge database that contains data since 1993 of the following monitoring programs:

- Radiological environmental monitoring **programs around nuclear and fuel cycle facilities (PVRA)** carried out by licensees (following Safety Guide 4.1 of the CSN).
- Radiological environmental **quality control monitoring programs (CC)** around nuclear and fuel cycle facilities carried out by licensees (5-10% of the licensees programs – shared samples, different laboratory).
- Radiological environmental monitoring **independent programs around nuclear and fuel cycle facilities (PVRAIN)** carried out by the CSN (5-10% of the licensees programs, same sampling points and moment but independent sampling and laboratory)
- **National monitoring network (REM)** not associated to facilities, carried out by 21 research laboratories under agreement with the CSN.
- **Special monitoring programs** (accidents, radioactively contaminated areas, etc)

KEEPER



WHO?

KEEPER has different modules and interfaces for different objectives and users, as follows:

- The **AVRA team** (in the heading of this poster), who manages and assesses the data, provided with built-in graphical and statistical tools.
- The **Data Providers**, who can submit to the heart of KEEPER and self-validate their own data.
- The **European Union**, for which KEEPER has a module to generate the files to be submitted to the EC Radioactivity Environmental Monitoring Database (REM) in accomplishment of arts. 35 and 36 of the Euratom Treaty.
- The **CSN staff**, who can make use of all of the data within keeper.
- The **Public**, who, since feb. 2017 can consult the monitoring data of the PVRA and REM programs from 2006 to the last reviewed monitoring campaign (currently, 2016).

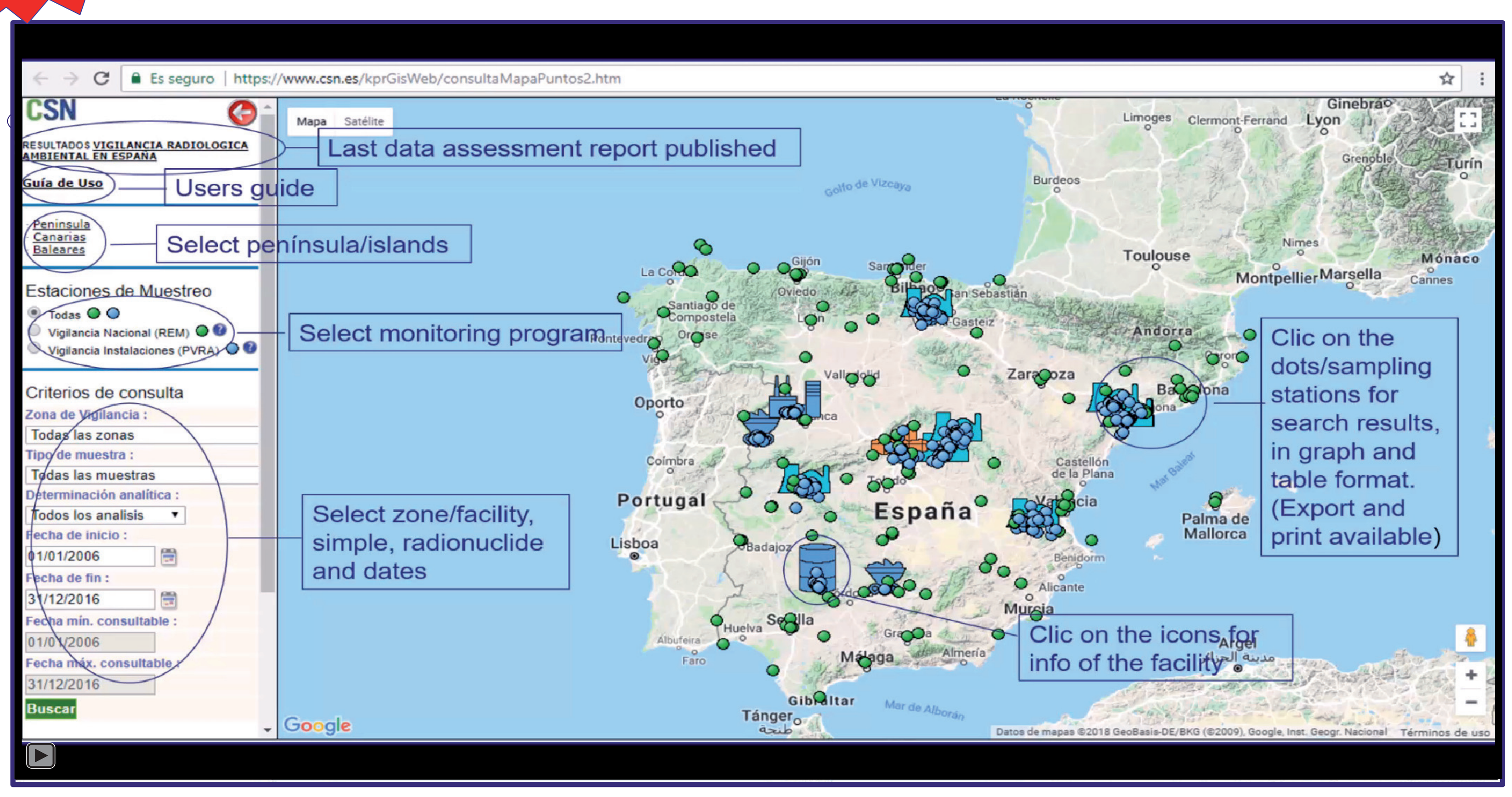
AN INTEGRATED SYSTEM FOR THE MANAGEMENT OF THE SPANISH RADIOLOGICAL ENVIRONMENTAL MONITORING DATA

WHERE?

- The module for the **submission of the data** is hosted in the public **CSN website** (access with official digital certificate).
- **KEEPER Database** and the generator of **CE REM** files is in the **CSN's internal network** protected with user and password.
- The module for the whole **CSN staff**, is hosted in the **CSN's internal network (only consultation)**
- The module for the public, is hosted in the CSN website: https://www.csn.es/kprGisWeb/consultaMapaPuntos2.htm

HOW?

NEW **KEEPER for the public**. Launched in february 2017



SO...

KEEPER is a powerful tool which eases the accomplishment of the CSNs obligations in radiation protection of public and environment and improves its engagement with transparency

THE EUROPEAN HEALTH PHYSICS MAILING LISTS RADSAFE-EU AND RADSAFE-D — A MEANS OF COMMUNICATION IN RADIATION PROTECTION SINCE MORE THAN TWENTY YEARS

P. Hill

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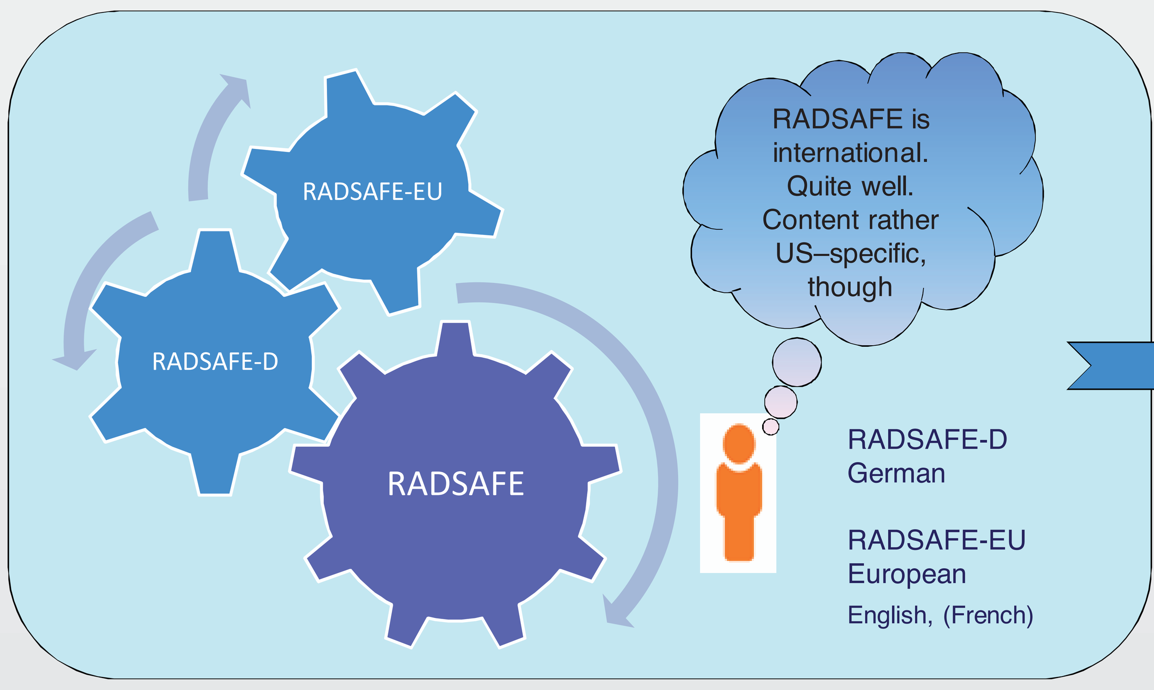
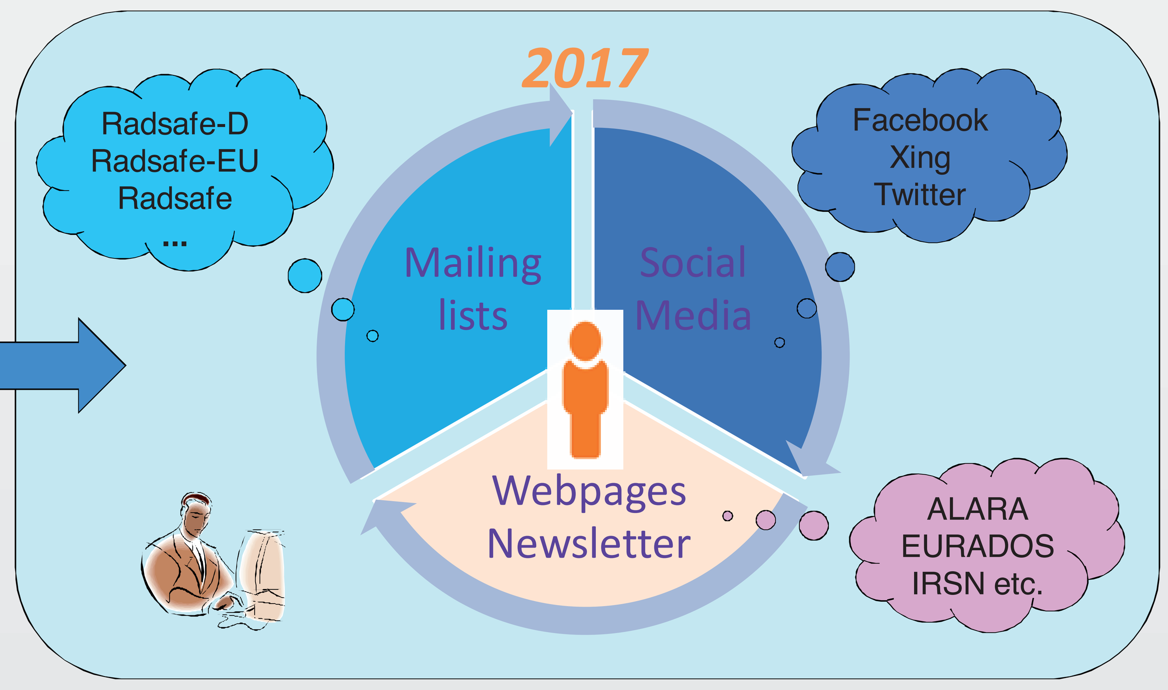
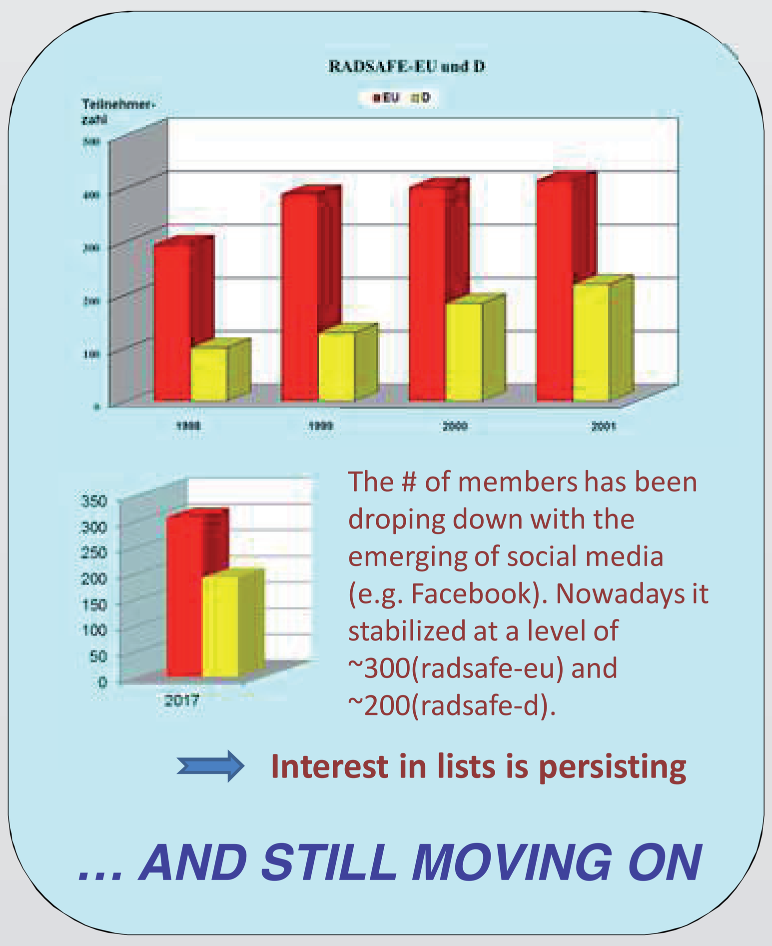
Introduction

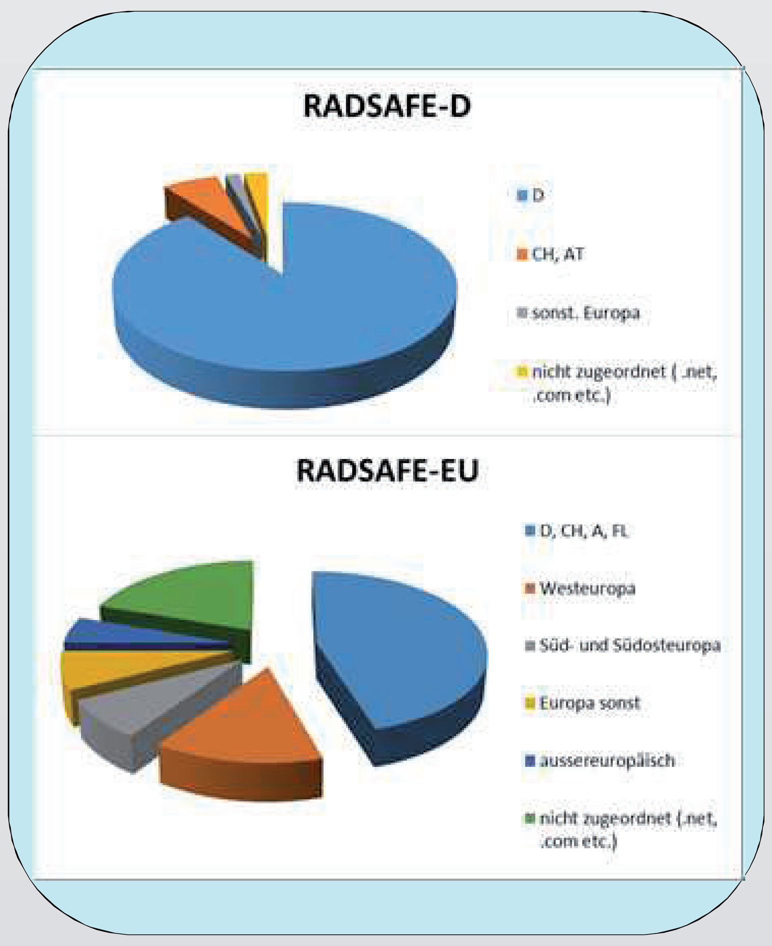
In 1997 the radiation protection mailing lists RADSAFE-EU and RADSAFE-D were initiated by Forschungszentrum Jülich GmbH. The initiative did drive at using the Internet to better communicate in matters of radiation protection both in the German-speaking regions as well as on a more European level. The chosen way of communication should enable an interaction between the participants. The lists also should supplement the international mailing list RADSAFE. Nowadays radiation protection mailing lists are just one of several pillars of professional electronic communication. However they are not out of date. This is shown clearly by the persisting interest of users.

P A R T I C I P A T E

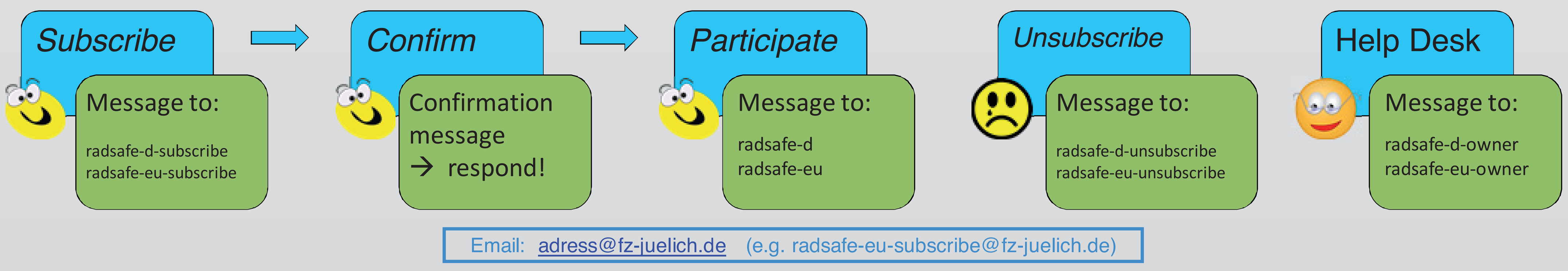








C O M M U N I C A T E



Final remarks

The international mailing list RADSAFE presently sponsored by an US university still persists. For spanish-speaking people the list RADIOPROTECCION had been created on the initiative of members of the Peruvian Health Physics Association. The latter is amended by a Facebook group.

Overall it can be concluded that health physics mailing lists are still a valid option for communication in radiation protection. Though some of them already exist since over 20 years it is always worth to participate.

Literature (german)

1. B. Breustedt, Ch. Geisse, P. Hill, *Internet für Netzwerker*, StrahlenschutzPRAXIS, 16(1), S. 22-25, 2010
2. P. Hill, *Strahlenschutzkommunikation über die Mailinglisten Radsafe-D und Radsafe-EU – 20 Jahre und es geht weiter,* Das neue Strahlenschutzrecht – Expositionssituationen und Entsorgung; Jahrestagung 2017 des Fachverbandes für Strahlenschutz e.V. Hannover, 09.-12. October 2017 / ed.: Ch. Tschentke, J.-W- Vahlbruch – FS-2017-175-T – ISSN 1013-4506 – S. 254 – 259

Towards guiding principles for IRPA communication and engagement with the public:

The Work of the IRPA Task Group on Public Understanding of Radiation Risks

Yoshida H[1], Cole P[2], Perko T[3], and other members of the IRPA Task Group on Public Understanding of Radiation Risks

1. Graduate School of Pharmaceutical Sciences, Tohoku University, 6-3 Aoba, Aramaki, Aoba-ku, Sendai, 980-8578, Japan.
2. Radiation Protection Office, University of Liverpool, Liverpool, L69 7ZE, UK.
3. Nuclear Science and Technology Studies, Institute for Environment, Health and Safety, Belgian Nuclear Research Centre SCK·CEN, Boeretang 200, B-2400 Mol, Belgium.

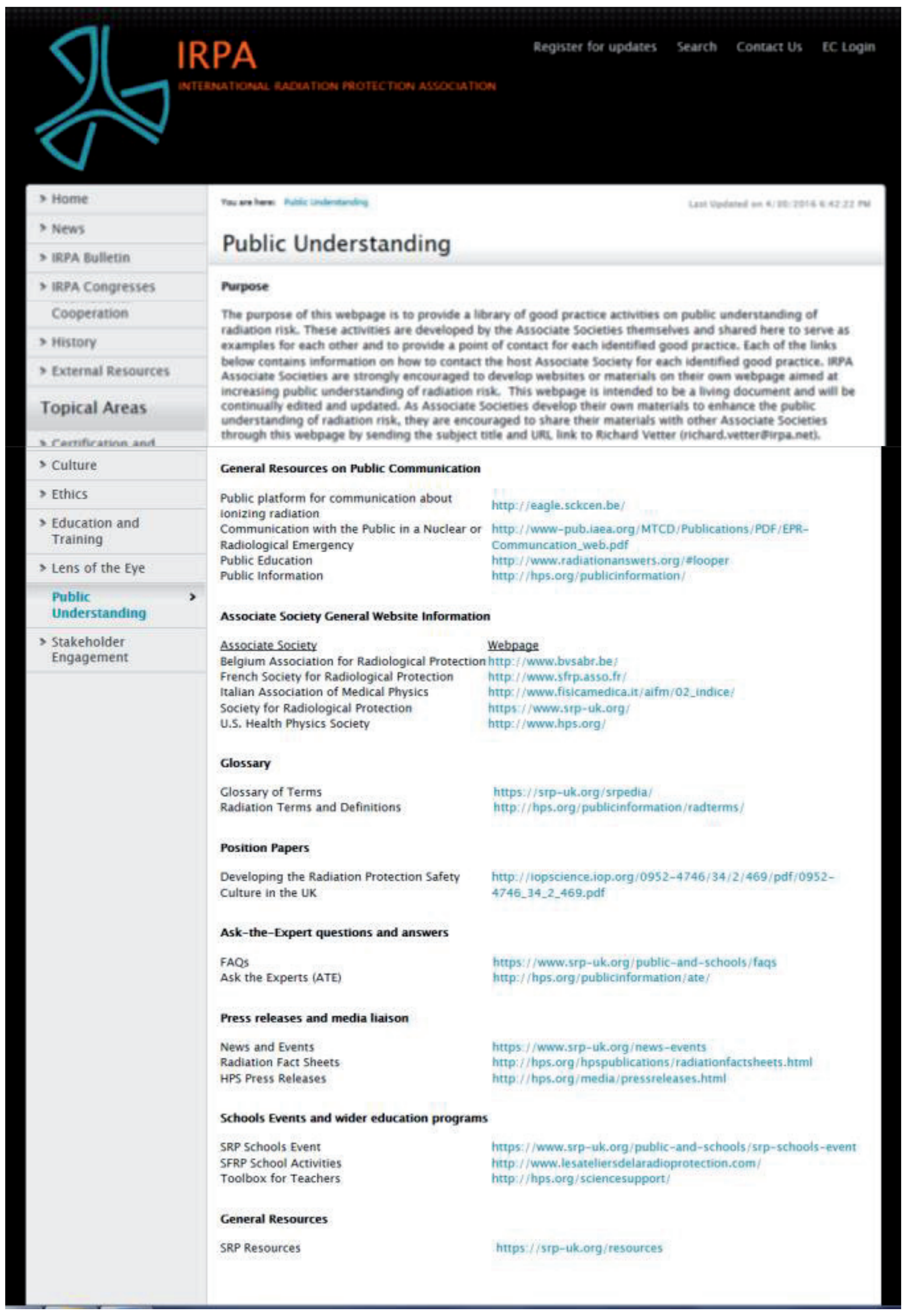
IRPA Work on Public Understanding of Radiation Risk?

The Task Group on Public Understanding of Radiation Risk was established in 2014 with the aim of encouraging and supporting Associate Societies in the development of effective means of enhancing public understanding of radiation risk through the sharing of good practice, ideas and resource materials. The TG is currently chaired by Dr Hiroko Yoshida – Executive Council Member – from Tohoku University in Japan.

What's been accomplished so far?

Stories in the media demonstrate that the general public has a poor understanding of radiation risk. IRPA believes that one of the responsibilities of the Associate Societies of IRPA is to inform the public about radiation risk. IRPA encourages the Associate Societies of IRPA to develop effective means of enhancing public understanding of radiation risk in their regions of the world through the sharing of good practices, ideas and resource material.

Up to now the group's endeavours have focussed on promoting the study of public (including media) engagement with radiation protection issues and the publication of articles thereon plus the development of a library of good practice activities which have been made available on a dedicated IRPA webpage.



The way forward – 1

To develop the IRPA guiding principles for communicating and stakeholder engagement with the public. The proposed work plan is:

a) To develop methodology and protocol for engaging with IRPA membership in order to garner 'guideline' ideas.

b) To organise and host international and regional workshops specifically on 'communication and stakeholder engagement of IRPA' to collect good practices, explore ideas and identify needs for inclusion in the 'guidance' at different radiation protection events.

c) To conduct the first of these workshops at the RICOMET 2018 conference in Belgium, and improve the workshop methodology.

d) Present results from these workshops and first draft guidance document at IRPA EC 2019

e) To revise the first draft of the IRPA Principles based on feedback to a second draft which will be presented to IRPA 2020 in Korea for approval and subsequent launch.

Invitation

In case you wish to organise a national or international workshop in the context of IRPA communication and engagement with public, kindly contact Dr Hiroko Yoshida, Chair of the TG on Public Understanding at hiroko@m.tohoku.ac.jp

The way forward – 2

The development of a 'soft skills' tool pack to facilitate IRPA AS to hold training sessions for radiation protection professionals on communicating with the public and stakeholder engagement. It is essential that radiation safety professionals obtain some rudimentary skills in communicating the concepts of risks and benefits to non-specialists including the media. Such 'tool packs' will need to take into account a variety of languages and cultures but may include slide sets, desktop exercises, case studies, links to expert science communicators, and feedback questionnaires.

Education

Current activities of EUTERP, the European Training and Education in Radiation Protection Foundation

Allisy P.J., Coeck M., Draaisma F.S., Hoyler F., Paynter R., Stewart J.

Background

European Commission concerns prompted the formation of the EUTERP Foundation :

- Lack of mobility of radiation protection experts (RPEs) across the European Union
- Differing interpretations of both the knowledge and training requirements for RPEs in different member states

EUTERP aims

- A common understanding of the role of the RPE
- Consistent education and training requirements for RPEs
- Mutual recognition for RPEs
- Appropriate training for RPOs and all radiation workers
- Liaison with all stakeholders that have RP education and training in their activities

EUTERP activities

- Encouraging National Contact Points in all European states
- Reference syllabus for training of RPEs
- Development and testing of modular training courses
- Stakeholder participation in training developments
- Liaison with HERCA on the recognition of RPEs
- Partner in the ENETRAP III project
- Development of the EUTERP website www.euterp.eu
- Newsletters and regular information dissemination
- Organization of workshops on RP training topics
- Collaboration with international conferences – e.g. ERPW 2017, France, autumn 2017; European IRPA Congress, summer 2018

Main achievements

- Self-sustainable entity since June 2010 with a dynamic web site and a growing number (25) of EUTERP Associates
- Advice to the EU on the definitions, roles and duties of the RPE and RPO for the EU BSS 2013 (Guidance published)
- 3 Workshops: Cyprus autumn 2011; Croatia, spring 2014; Greece, autumn 2015; **next Workshop, Malta, 10 to 12 April 2019**
- European RP course and opportunities database on the EUTERP web site is under beta-testing by the Associates

Conclusion

EUTERP provides a portal for radiation protection education and training activities in Europe. It liaises with other European organizations, participating in projects and events to develop and enhance training activities, and promote a common understanding of training requirements for all persons involved in activities using ionizing radiation.

REGISTER NOW FOR OUR NEWSLETTER ON WWW.EUTERP.EU
and stay informed on education and training in radiation protection throughout Europe

EUTERP Associates

INTERVENTION BY INTERVISION

RADIATION SAFETY CULTURE IN THE NETHERLANDS

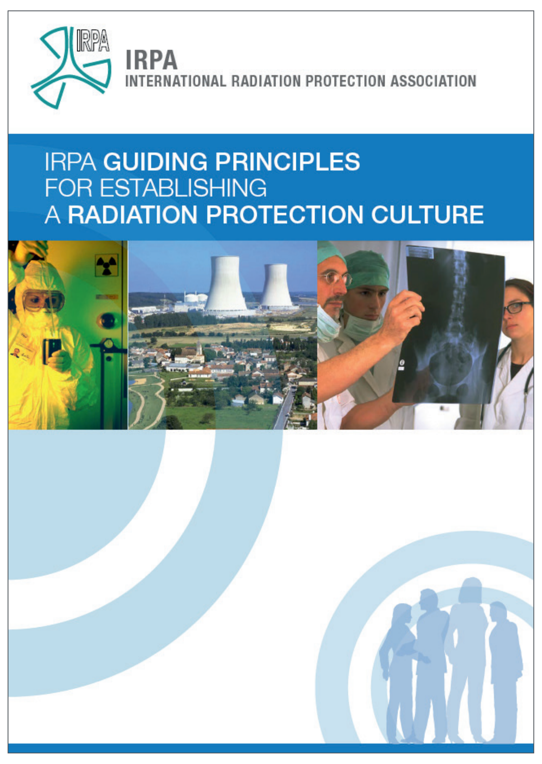
Bert Metz (NRG), Frank Guldenmund (TUD), Linda Janssen – Pinkse (NKI-AVL), Jacques Smeekens (De Federatie)
Contact: metz@nrg.eu
Nuclear Research and consultancy Group (NRG), P.O. Box 25, 1755 ZG Petten, The Netherlands – www.nrg.eu

INTRODUCTION

Following the initiative by IRPA to promote and improve Radiation Safety Culture worldwide, the Dutch Society for Radiation protection (NVS), in collaboration with the Nuclear Research and Consultancy Group in Petten (NRG) has started a project to investigate the possibilities to stimulate Radiation Safety Culture in The Netherlands.

IRPA GUIDING PRINCIPLES FOR ESTABLISHING A RADIATION PROTECTION CULTURE

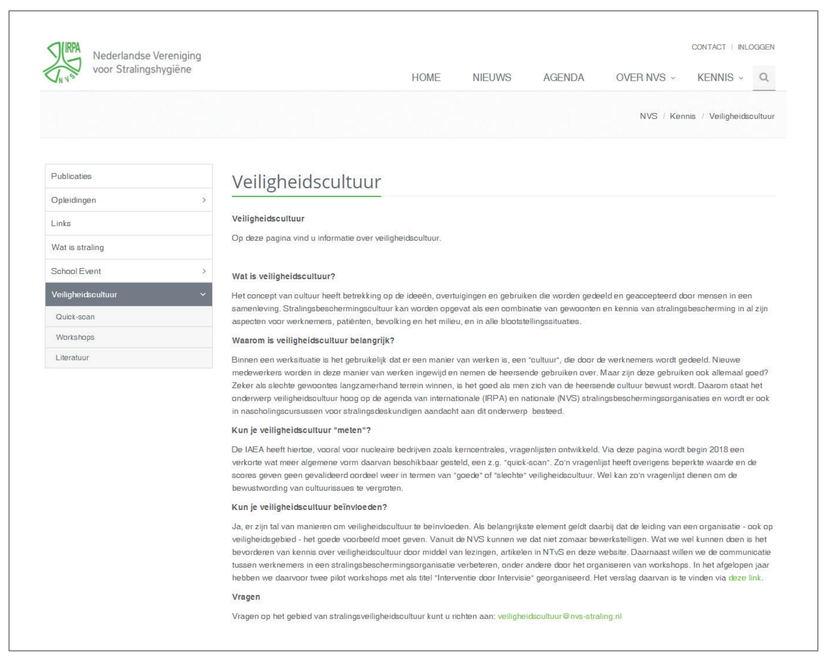
The IRPA Guiding Principles for Establishing a Radiation Protection Culture, in particular Chapter 8 "The role of the associate societies " were taken as a starting point for this project. Attention was paid to the following subjects: lectures and courses on safety culture, development of a website on radiation protection culture and the adaptation of an IAEA questionnaire to a safety culture 'quick-scan'.


IRPA
INTERNATIONAL RADIATION PROTECTION ASSOCIATION
IRPA GUIDING PRINCIPLES FOR ESTABLISHING A RADIATION PROTECTION CULTURE

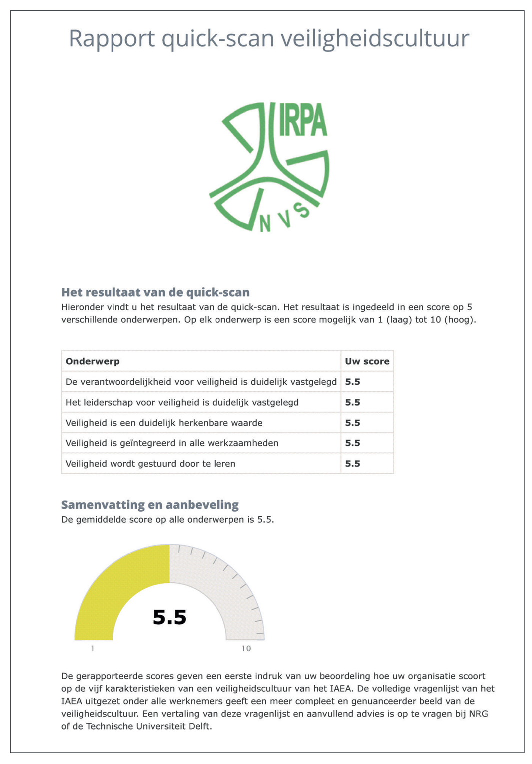
IRPA Guidelines


Veiligheidscultuur en gedragsverandering in de stralingsbescherming

Lecture Programme


Veiligheidscultuur

Web Pages on Safety Culture


Rapport quick-scan veiligheidscultuur

Quick-Scan report

INTERVISION WORKSHOPS

In parallel to the more traditional way of disseminating information on safety culture, by means of lectures and courses, an alternative way of directly engaging radiation protection experts was investigated. As a means to achieve this goal the applicability of the method of intervision was proposed, where intervision stands for a learning method for a group of equals guided by a process supervisor, focusing either on improving personal functioning or on improving working processes.

This active method of exchanging information seemed well-suited to improve radiation safety culture, and fulfils a number of possibilities that IRPA mentions in its *"Guiding Principles for establishing a Radiation Protection Culture"*:

1. *Modelling, reinforcing and coaching safety behaviours;*
2. *Creating positive and total awareness about Radiation Protection at working places;*
3. *Establishing adequate and proper communication processes among all the practitioners involved.*

For an intervision training to be successful, IAEA in its Safety Report *'Performing Safety Culture Self assessments'* recommends that participants should feel free to speak about problematic work situations.

4. *Therefore, a psychologically safe environment, a so-called 'shared space' should be created.*

In conclusion we found that each of these recommendations can be fulfilled to some degree by the method of intervision.

Training communication skills with the help of a professional actor

MAIN FINDINGS: RECOMMENDATIONS FOR SUCCESSFUL INTERVISION

For intervision to be successful, the following recommendations were found to be effective:

Intervision should be:
- confidential,
- empathetic and
- disciplined.

Typically an intervision session should contain the following steps:
- Introduction
- Choice of work problem
- Analysis of the problem
- Awareness & deeper understanding

www.nrg.eu

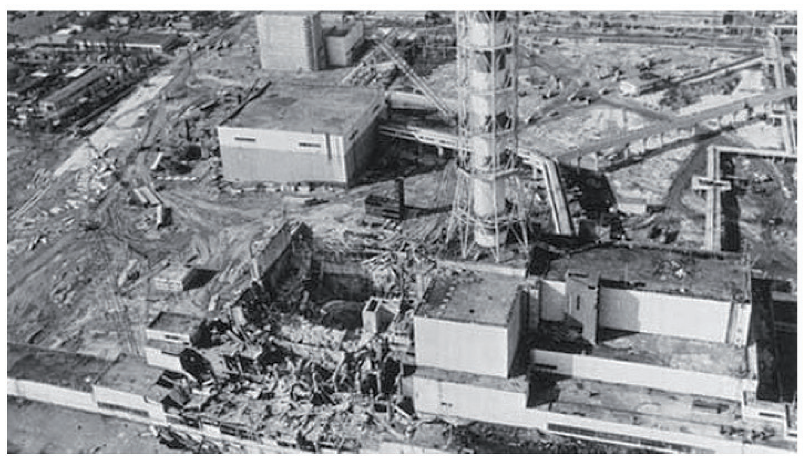
This project is financed by the Dutch Ministry of Economic Affairs

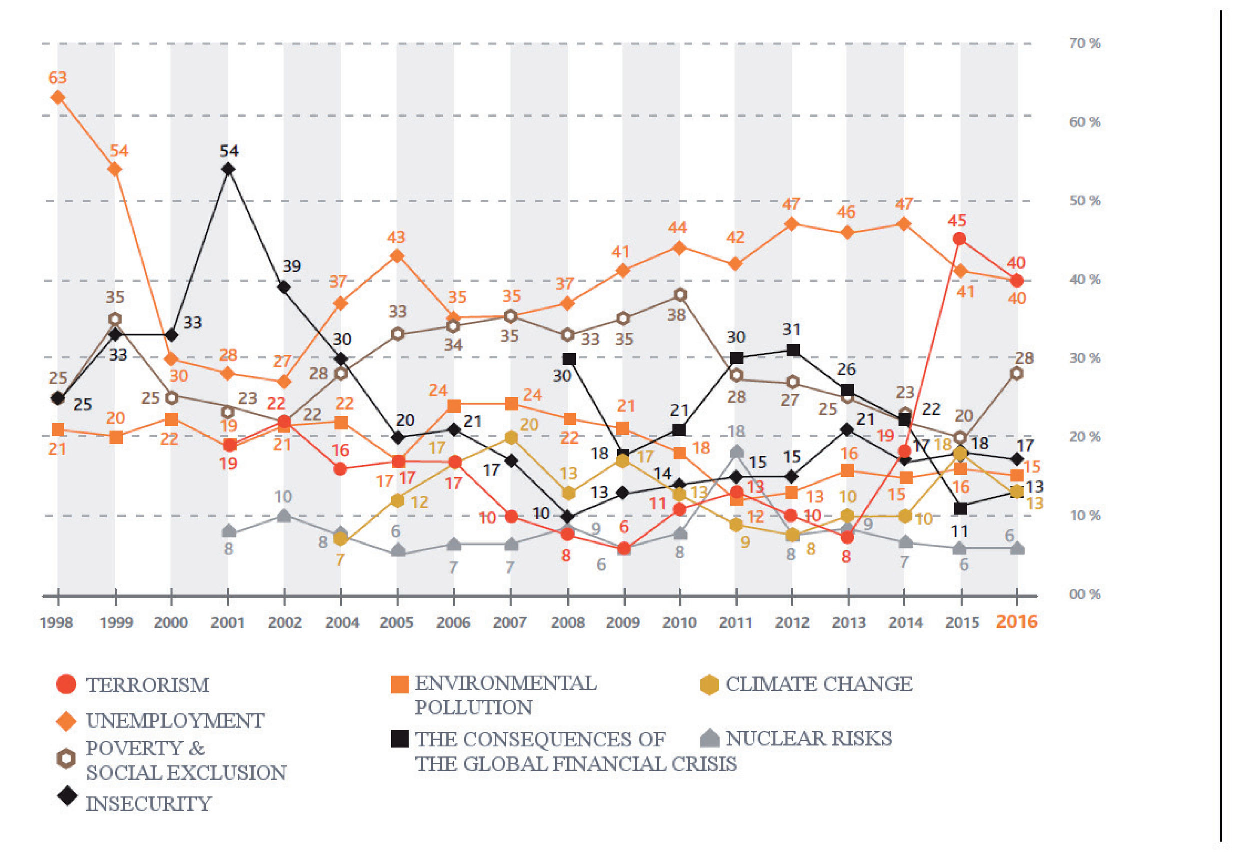
IRSN's Information and Education Strategy for the Public to enhance their Radiation Protection and Nuclear Safety Culture

Fabrice Ecrabet[a]*, Ilma Choffel de Witte[a], Geneviève Baumont[b]
[a]Institut de Radioprotection et de Sûreté Nucléaire
[b]Centre Recherche Innovation Scientifique

1. HISTORICAL BACKGROUND

A lack of information in the past by Health Crises and Environmental Accidents, such as Chernobyl and Asbestos, led to a lack of Trust and Rising Expectations from the Public:
- Desire for transparency and acces to Information
- Desire to participate
- Desire for justice





Today, better Regulations (e.g. yearly IRSN Survey on Risk perception showing Public Concerns)

2. IRSN's INFORMATION AND EDUCATIONAL STRATEGY

"Public Open House Events"
part of the Face-to-Face Formula

4 Pillars :
- Using IRSN's Knowledge and Skills
- Using adapted tools
- Using the Soft & Hard Sciences for message development
- Using Crisis Management Drills

Traditional Tools :
(Annual Reports,Websites, Magazines, Press Conferences, etc.)

New Tools:
Social Media

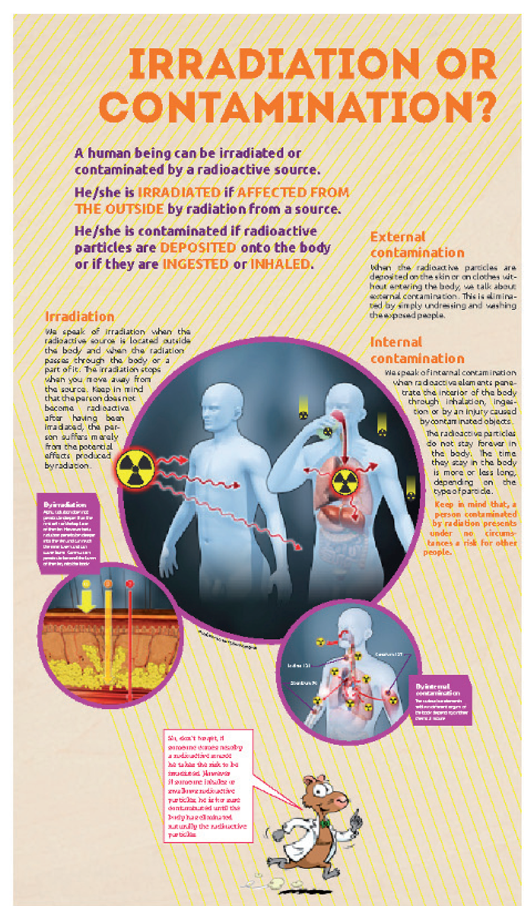
3. EXAMPLE: "RADIOACTIVITY, HUNDREDS OF QUESTIONS, ONE EXHIBITION"

A Common Thread: develop the Risk Culture of future Citizens by explaining the Issues concerning each type of Radioactivity (Natural and Artificial)

Modular Exhibition divided in 10 sequences

Multimedia Content designed for Interactivity with the Public

Positive Feedback on the Exhibition from 30.000 Visitors since 2014



Accessible Contents without Jargon, using images

RADIATION IN MEDICINE: APPLICATION FOR ANDROID DEVICES

Z. Aza[1], C. Ferrer[1], R. Plaza-Núñez[1], C. Huertas[1], R. Plaza[1], A. Serrada[1], C. Candela[2], D. Faro[3]
[1]Hospital Universitario La Paz, Medical Physics and Radiation Protection Service Madrid, Spain
[2]Centro Nacional de Dosimetría, Valencia, Spain
[3]Developer

INTRODUCTION

The purpose of this application is to familiarize users or patients' relatives with the effects of ionizing radiation used in diagnostic imaging, both in radiology and nuclear medicine, since the number of radiological examinations has increased progressively over the last few years. Although dose reference levels (DRLs) can be found in official national and international documents, usually patients do not know their existence or how to get to them. The most relevant and updated information has been summarized for adults, children and pregnant women. The user is able to design a personal history of medical examinations on the device and it is included a summary about the magnitudes and units used in radiological protection, as well as the dose limits for exposed workers and members of public. The application contains other useful information, such as a monthly natural radiation map in Spain.

MATERIAL AND METHODS

The application has been developed for Android devices, from Jelly Bean versions (Android 4.1) to the most recent, including 95.2% of active devices in the Google Play Store. Java and Android Studio are the language and the integrated development environment (IDE) used. The documents used to collect the information are the Spanish DOPOES and DOMNES projects, the 2011 version of Spanish Protocol for Quality Control of Radiodiagnosis, the document "Recommended procedures for energy X-ray dosimetry between 20 and 150 keV in radiodiagnosis" of the Spanish Society of Medical Physics (SEFM), and documents 52, 80, 84, 103 and 106 of the International Commission on Radiological Protection (ICRP).

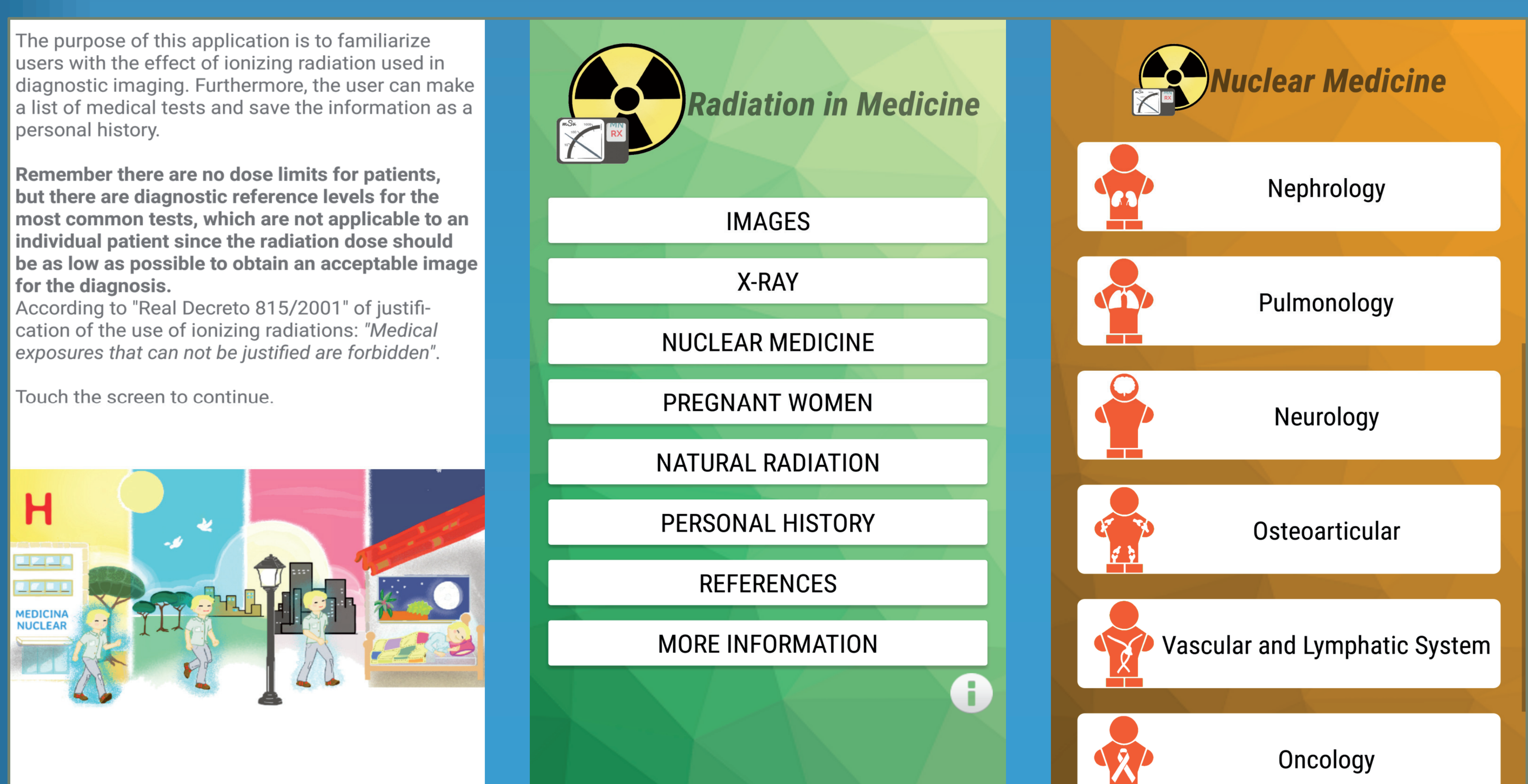


Figure 1. Some screens of the APP: Splash, Main Menu and Nuclear Medicine Menu

RESULTS

There are different sections in the main menu of the application: "*Images*", "*X-Ray*", "*Nuclear Medicine*", "*Pregnant women*", "*Natural Radiation*", "*Personal History*", "*References*" and "*More information*". In "*Images*" section we have include original drawings used to explain some of the procedures realized in diagnostic imaging. In "*X-Ray*" section there are four subsections, for adults, children, CT and other procedures, where it is indicated the average effective dose received in each test. The "*Nuclear Medicine*" section has been divided according to the different organs involved in each process. The most common tests performed with scintigraphy and PET-CT are included, and the average effective dose related to them is compared to natural radiation. The "*Pregnant Women*" section is a summary of the document 84 of the ICRP. The map of the "*Natural Radiation*" section shows information of the Spanish Dosimetry National Center (CND), which displays the distribution of the environmental radiation in μSv / month. In "*More information*" we have added a brief explanation of the magnitudes and units used in Radiological Protection, the weighting factors for different tissues and types of radiation, the radiation limits for professionally exposed workers and members of public and information on the different signals in the areas of Radiodiagnosis and Nuclear Medicine.

CONCLUSIONS

We have developed a simple and intuitive application for Android devices, in which the most relevant and updated information on Radiological Protection can be found based on the Spanish Legislation, the national projects DOMNES and DOPOES and the most recent documents of the ICRP related with radiological protection in pediatric radiology, radiopharmacy and pregnancy. In addition, useful information for exposed workers is included, as well as a map of the typical monthly natural radiation in Spain. It is indicated that there is no limit of radiation for patients. For more individualized information, it is recommended to contact a Radiological Protection or Medical Physics Unit at your Hospital.

To download the APP visit the link:
https://play.google.com/store/apps/details?id=es.radiofisicahospitalaria.radiacionenmedicina

Or scan the QR code:

Figure 2. QR code

CONTACT

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zulima.aza@gmail.com

RADIATION PROTECTION TRAINING IN UPDATED SLOVENIAN LEGISLATION: WHAT IS IMPROVEMENT AND WHAT IS NOT

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Milan Čopič Nuclear Training Centre
Jožef Stefan Institute, Ljubljana, Slovenia,
matjaz.kozelj@ijs.si

ABSTRACT: System of radiation protection training in Slovenia has been designed in legislation approved during harmonisation process prior to joining EU in 2004. Rules related to radiation protection training from the year 2004 were detailed and particular. Courses were defined for exposed workers and two types of radiation protection officers. Rules related to radiation protection training were changed last year. Majority of courses from previous Rules were shortened, and have become more specific and adjusted to changes in technology. The most important and, in our opinion, most questionable change is removal of additional training for persons responsible for radiation protection from legislation. Considering the duties and responsibilities of these persons, basic course for exposed workers cannot provide necessary knowledge and skills for their work. It is up to legislator to correct this deficiency in a new version of Rules, which is expected in near future.

Change of Rules in the year 2017

- The system of radiation protection training in Slovenia was defined during harmonisation process. In Rules from the year 2004, programmes of courses for exposed workers and two types of radiation protection officers (a person responsible for radiation protection and a member of radiation protection unit) were described. Only authorised radiation protection experts (legal persons!) should perform training.
- The new Rules were approved last year. They are formally based on the old Act from 2002 and the old Directive but could be considered as a first version of the updated training requirements. The new Act based on the new Directive 2013/59/EURATOM was approved in December 2017.
- In the new Rules from the year 2017 courses were defined for exposed workers, workers, who work under supervision, workers, who manage radiation sources (but are not considered exposed workers), and radiation protection officers. Courses are listed in Table 1 and Table 2.
- The main differences between courses in the new and the old Rules are:
  - Most courses are shorter,
  - Most courses are more specific,
  - Additional specific courses were introduced which are “tailored” for particular source/facility by authorised radiation protection or authorised medical physics expert,
  - Additional training for persons responsible for radiation protection has been cancelled (only training for exposed workers is required).
- Training of all workers in nuclear and radiation facilities has been unchanged.

Table 2: Duration of radiation protection courses for radiation protection officers in Slovenia according to Rules from 2017

Type of facility/practice			**Changes with regard to Rules from 2004.**
Nuclear and radiation facilities	Staff members of the radiation protection units in NPPs and reactors	200 h	**No changes**
	Staff members of the radiation protection units in other nuclear and radiation facilities	80	**No changes**
All other practices (including outside undertakings in nuclear facility)	Persons responsible for radiation protection	Basic course only	**-4 hours**

CONCLUSIONS

- **The new Rules from the year 2017 have considerably changed radiation protection training in Slovenia. While requirements for training of workers in nuclear and radiation facilities were not changed, duration and contents of required training for other practices were modified.**
- **Duration of courses was shortened, which we have found justified in some cases, but not in all. One of the consequences of this modification is increased number of different courses, which is not beneficial for a small country like Slovenia, which has a small number of exposed workers.**
- **Training of staff members of radiation protection units in nuclear and radiation facilities was not changed, while required additional training for persons responsible for radiation protection in other facilities was removed from the legislation.**
- **Considering the duties and responsibilities of a person responsible for radiation protection, we think that this change has not been properly justified and will have negative consequences on radiation safety in facilities. Since new Rules are expected in near future, we hope that this deficiency will be corrected, but current discontinuation could have longer consequences.**

Table 1: Duration of radiation protection courses for exposed workers in Slovenia according to Rules from 2017

(* Courses where contents and duration are defined by Authorised radiation protection expert during the licencing process as a part of the document Assessment of radiation protection)

Type of facility/practice		Exposed workers	Workers, who manage radiation sources	Exposed workers who work under supervision	**Changes with regard to Rules from 2004.**
Nuclear and radiation facilities	NPPs and nuclear reactors	40 h	/	8 h	**No change**
	Other nuclear and radiation facilities	40 h	/	8 h	**No change**
Medicine and veterinary medicine	Dentistry and bone densitometry	/	8 h	/	**-4 h/0, instead of RP training courses are related only to protection of patients**
	Diagnostic radiology	16 h	/	8 h	**-8 h**
	Intervention radiology	20 h	/	8 h	**New course (separated from diagnostic radiology)**
	Nuclear medicine	24 h	/	8 h	**-8 h**
	Tele radiotherapy	24 h	/	8 h	**No change**
	Brachytherapy	24 h	/	8 h	**-8 h**
	Other practices in medicine and veterinary medicine	*	*	*	**Course for veterinary medicine was 16 hours.**
Exposure from natural sources	Exposure to radon	4 h	/	/	**-2 h**
	Exposure of air crew	4 h	/	/	**-2 h**
Industry and other activities	Industrial radiography	36 h	/	/	**No change**
	Use of unsealed sources (Categories I & II)	36 h	/	8 h	**-4 h/0**
	Baggage and packages X-ray screening	8 h	/	/	**No change**
	Field measurement of density and humidity, portable XRF spectrometry, use of HAAS	20 h	/	/	**No change**
	Use of unsealed sources (Category III)	12 h	/	/	**-12**
	Other practices	* (at least 8 hours)	8 h	/	**-12 or less**

Nuclear Emergencies

A SITE SPECIFIC ACCIDENTAL AQUATIC TRANSPORT MODEL FOR RADIOACTIVE RELEASE TO THE DANUBE AT THE PAKS NNP

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Introduction

To determine the environmental radiation burden of a possible accidental liquid radioactive emission, we need to consider the radionuclide transport in the Danube. Therefore, modeling the migration of radioactive material is crucial. Our objective is to create a dynamic transport decision support program with realistic local parameters what describes the hydrological properties. The general equations for the calculations of the hydrological part of the transport can be found in many literature, these equations are not detailed enough to be used for an accidental site specific release. Therefore, local geological and hydrological parameters of the Danube are used to transform the equations to site specific ones.

Methodology

- The primary focus during the modeling is given to the section of the Danube under Paks NPP (in Hungary).
- The general hydrological equations are converted into site specific ones using the site specific hydrological variables
- The receptor point is the first town under the NPP at same riverbank called Gerjen, approximately 10 km south from the NPP
- The calculation of the activity concentration rely on the 2D advective-diffusion equation:

$$C(x,y,t) = \frac{M}{h4\pi t\sqrt{D_x D_y}} \exp\left(-\frac{(x-ut)^2}{4D_x t} - \frac{y^2}{4D_y t} - \lambda t\right)$$

Where x,y are the directions in downstream and lateral [m], M is the activity of the released contaminant [Bq], A is the cross section area [m^2], t is the time [s], $D_{x,y}$ are the diffusion terms in direction x,y [m^2/s], u is the average flow velocity [m/s], λ is the decay constant [1/s].

- The model calculates the actual hydrological variables from the daily measured stream stage (f [m]) using the cross section shape of the river and the measured flow rate curve (Figure 1). The calculated parameters are:
  - the depth of the river (h [m])
  - the width of the river (B [m])
  - the flow rate of the river (Q [m^3/s])
  - The average flow velocity (u[m/s])

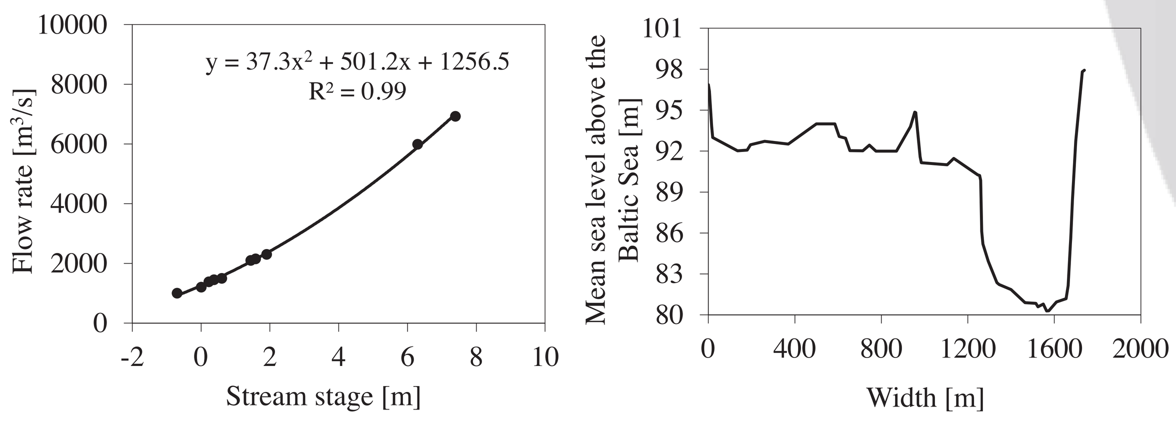


Figure 1: Measured flow rate curve on the left, and the cross sectional shape of the Danube on the right

The dissolved nuclides interact with the sediment and biota:

- To calculate the activity concentration in the suspended sediment (C_{sus} [Bq/kg]) the following equation is used:

$$C_{sus} = C\,\frac{0.001\,K_d}{1+0.001\,S_s\,K_d}$$

where C is the activity concentration is water [Bq/m^3], K_d is a distribution coefficient describing the exchange processes of radionuclides between the dissolved and the sediment phase [l/kg], 0,001 is a converter factor for K_d, to turn l/kg into m^3/kg, S_s is the suspended sediment load [kg/m^3].

- Correlation between the suspended sediment load and the flow rate from 2007 until 2012 is shown in Figure 2:

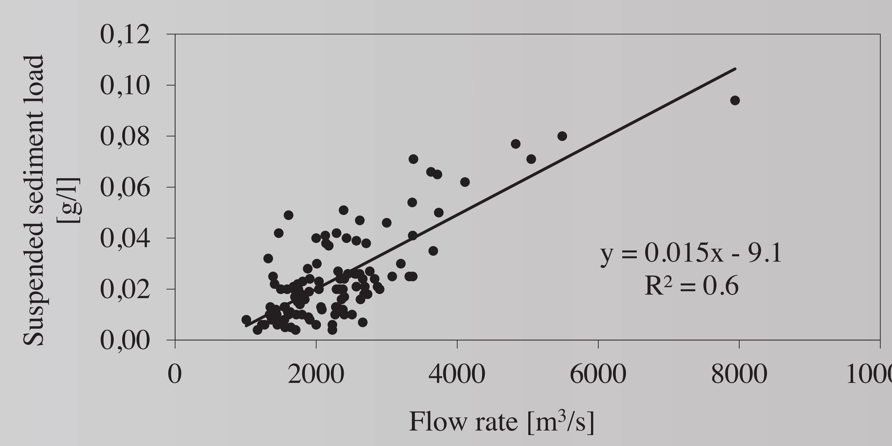


Figure 2: Correlation between the suspended sediment load and the flow rate from 2007 until 2012

- Activity concentration in the bottom sediment is assumed to be 10% of the concentration in the suspended sediment in the whole riverbed area between the release point and the receptor point.
- Activity concentration in fish (C_{fish} [Bq/kg]) is given by

$$C_{fish} = \frac{\sum_{Te} C \cdot k_f/1000}{w} \qquad k_f = \frac{D_{max}\,T_e}{86400}$$

Where C_{fish} is the activity concentration in the fish [Bq/kg], $\sum_{Te}C$ is the accumulation time-integrated activity concentration in water, k_f is the uptake rate [kg], w is the weight of the fish [kg], T_e is the accumulation time [s], D_{max} is the maximum daily intake [%] which depends on the water temperature. A fish with a weight of 10 kg at water temperature 10-15 °C intakes the 5% of it's whole weight daily. At a temperature of 20-25°C this amount is 10%.

Results

- One of the most important parameter is the river stream stage while it changes daily (Figure 3).
- Analyses where carried out for isotope I-131 based on a hypothetical aquatic release of 1 GBq activity. The release was taken as an instantaneous emission from a shore side point source.

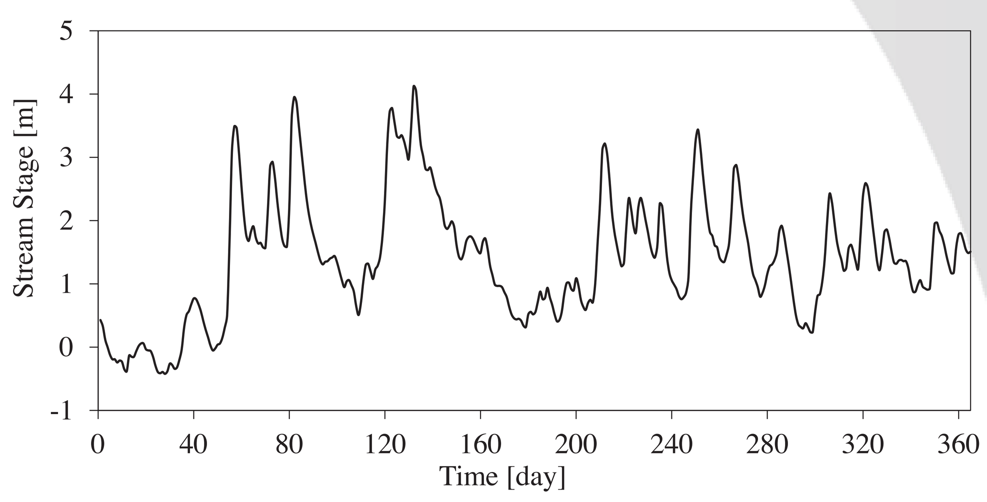


Figure 3: The daily change of the stream stage in 2017 for Paks.

- The ever measured lowest and highest stream stage values for Paks are: -0.58 m and 8.91 m.
- Calculations were made with these two values, and it can be seen on Figure 4 that there is a magnitude difference between the maximums.

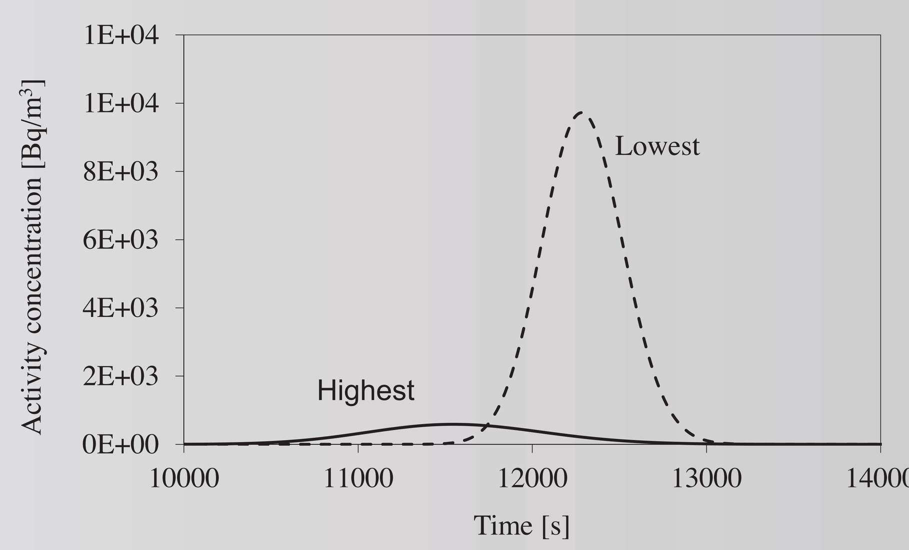


Figure 4: Activity Concentration at shore side for the lowest and highest measured stream stage

- Studies were made to see the connection between the stream stage and the activity concentration in water, suspended sediment and in the fish (Figure 5-7) .
- In all the three cases it can be noticed that increase of the water level decreases the activity concentration in the media.

Figure 5

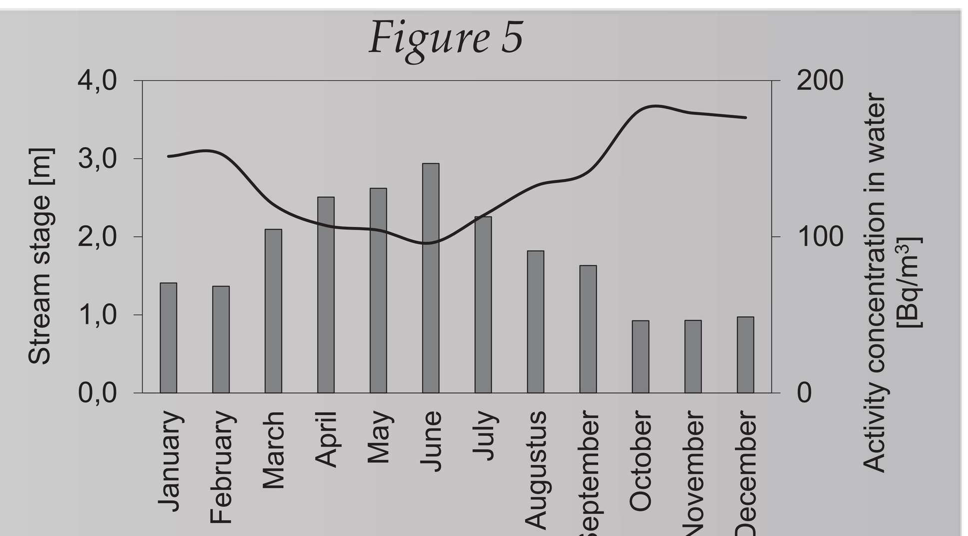


Figure 6

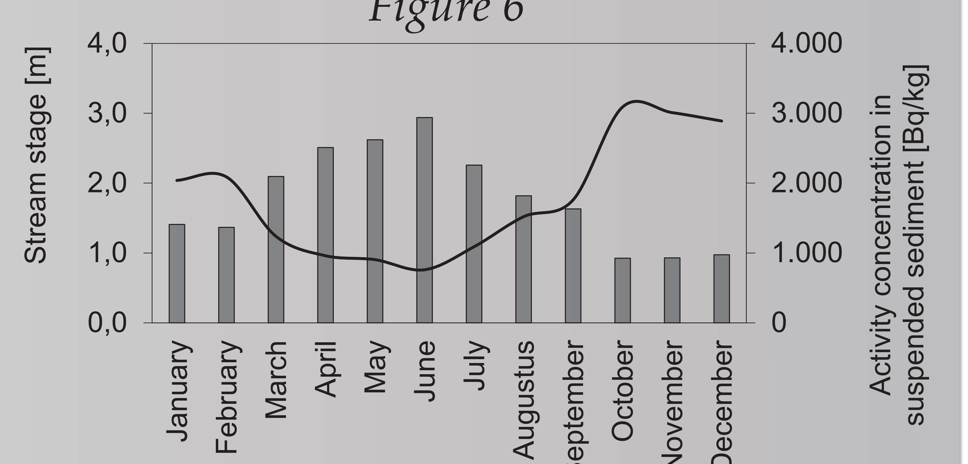
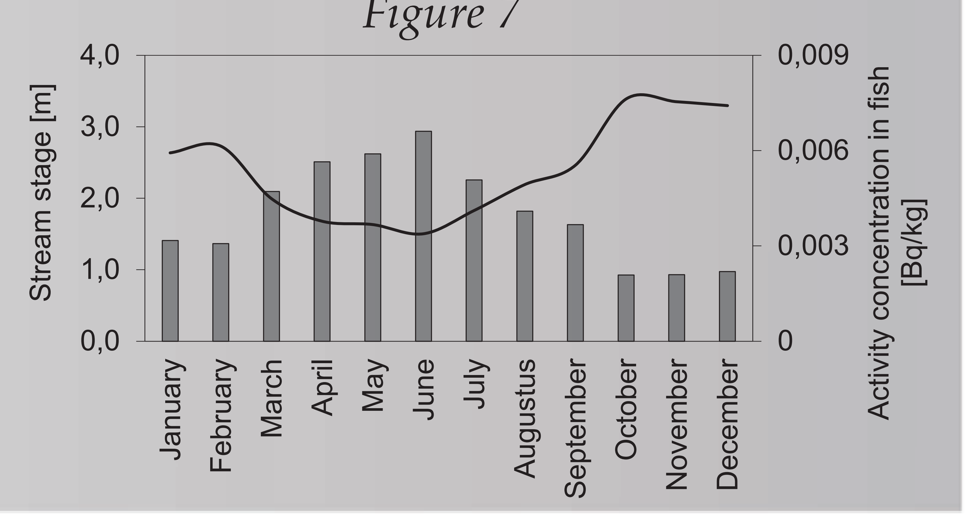


Figure 7

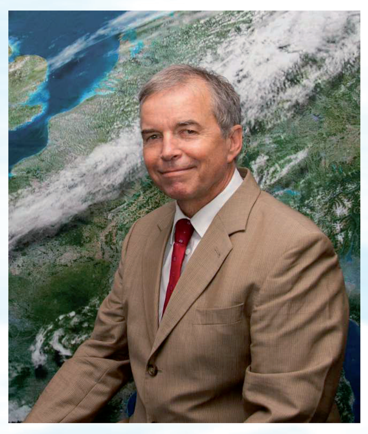


Conclusion

After an accidental radionuclide release, it is important to use the best-estimated site specific hydrological variables during a decision support modelling. Most of these parameters are derived from the daily measured stream stage. Studies were made to find connection between the stream stage, and the activity concentration in different media. The results show, that increase of the water level decreases the activity concentration in water, suspended sediment and in the fish. These results indicates that using a maximum, minimum or yearly averaged flow rate value for calculations can lead to incorrect estimations and decisions.

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Accidental Release of Radioactive Material - New Procedures of Radiation Protection for Crew and Passengers in Aircrafts



Dr. Thomas Steinkopff

Impact on aviation in case of the release of radioactive material

In case of an accidental release of radioactive material in the atmosphere crew and passengers of aircrafts may be exposed to higher radiation when entering contaminated air space (zones). As a consequence, information on the release and the distribution of radioactive material and the expected radiation exposure has to be provided to the aviation organization as fast as possible. The information has to be robust to non experts to define danger zones based on radiation protection principles.

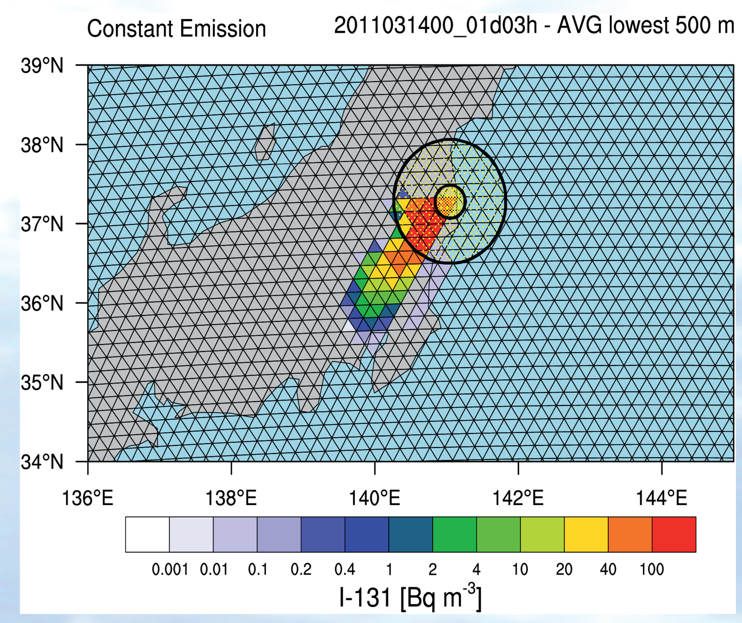


Fig. 1: Transport of radioactive material beyond the danger zone of 30 km

Initial Guide for aviation in case of the release of radioactive material

The International Civil Aviation Organization (ICAO), the International Atomic Agency (IAEA), and the World Meteorological Organization (WMO) recommend to provide a short information (SIGMET: Significant Meteorological Information) about the site of the release and a cylinder with a radius of up to 30 km defining it as a danger zone. This measure takes into account the recommendations of the International Radiation Protection Commission (ICRP) [1] and the derived procedures of IAEA to evacuate people if a dose of 100 mSv would be exceeded.

Atmosphere Transport Dispersion Model (ATDM)

Radioactive particles are quickly transported to areas beyond the defined danger zone (Figure 1). An ATDM will provide information about the dispersion of radionuclides, i.e. for example about the expected maximum concentration on the ground and respectively the distribution of the concentration with height (Figures 2 and 3). The outcome is uncertain because of poor knowledge about the source term. But with an assumed worst case scenario based on the source term of the NPP Chernobyl and NPP Fukushima the outcome of ATDMs would help to define the danger zone better. The results of the dispersion calculations are provided as activity concentrations.

Concept of Operation Intervention Level (OIL)

The relation between the activity concentration and the radiation exposure to the crew as well as to the passengers can be calculated based on the new developed "Operation Intervention Levels" (OILs) procedure. The OIL calculation is based on the approach recently described in an IAEA publication [2]. Basic idea behind this procedure is to establish generic criteria at which response actions should be implemented. The OILs for aviation purposes are based on a dose criterion of 1 mSv as recommended by the ICRP for exposure situations of members of the public [1].

Calculation of OILs

The OILs are calculated for all the radionuclide mixes expected to be released from a Light Water Reactor (LWR) or its spent fuel during a severe emergency which may be significant contributors to the dose of the public. In consequence 19 different release scenarios and their specific and relevant radionuclides (38) have been considered in the OIL procedure.

Applying the OIL with consideration of procedures, parameters, factors and constraints for flight conditions, the outcome are several curves representing the 19 different emission scenarios and the activity concentration for a specific radionuclide as a function of time. Figure 4 represents the marker radionuclide I-131.

From the graphs and curves it can be deduced, that if the activity concentration for I-131 is below 100 Bq/m³ (see red horizontal line in the respective figures) one can assume, that the level of radiation exposure regarding air shine and inhalation in total stays well below the dose criterion for the effective dose of 1 mSv as recommended by the ICRP for exposure situations of members of the public.

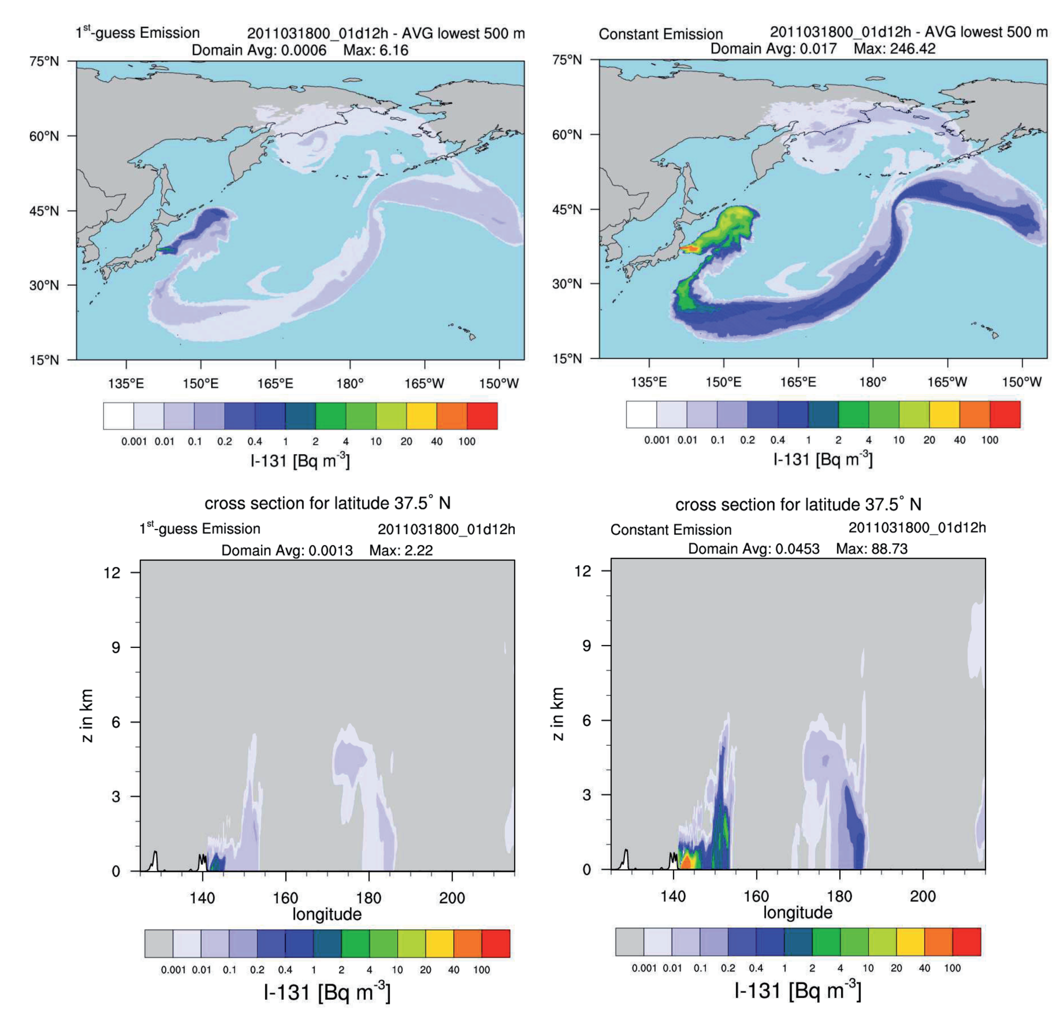


Fig. 2a,2b: ATDM for the ground, using a 1st guess (2a) and constant (10^{15} Bq/6h) "worst case" (2b) source term Fukushima

Fig. 3a,3b: Corresponding vertical cross sections for latitude 37.5° N

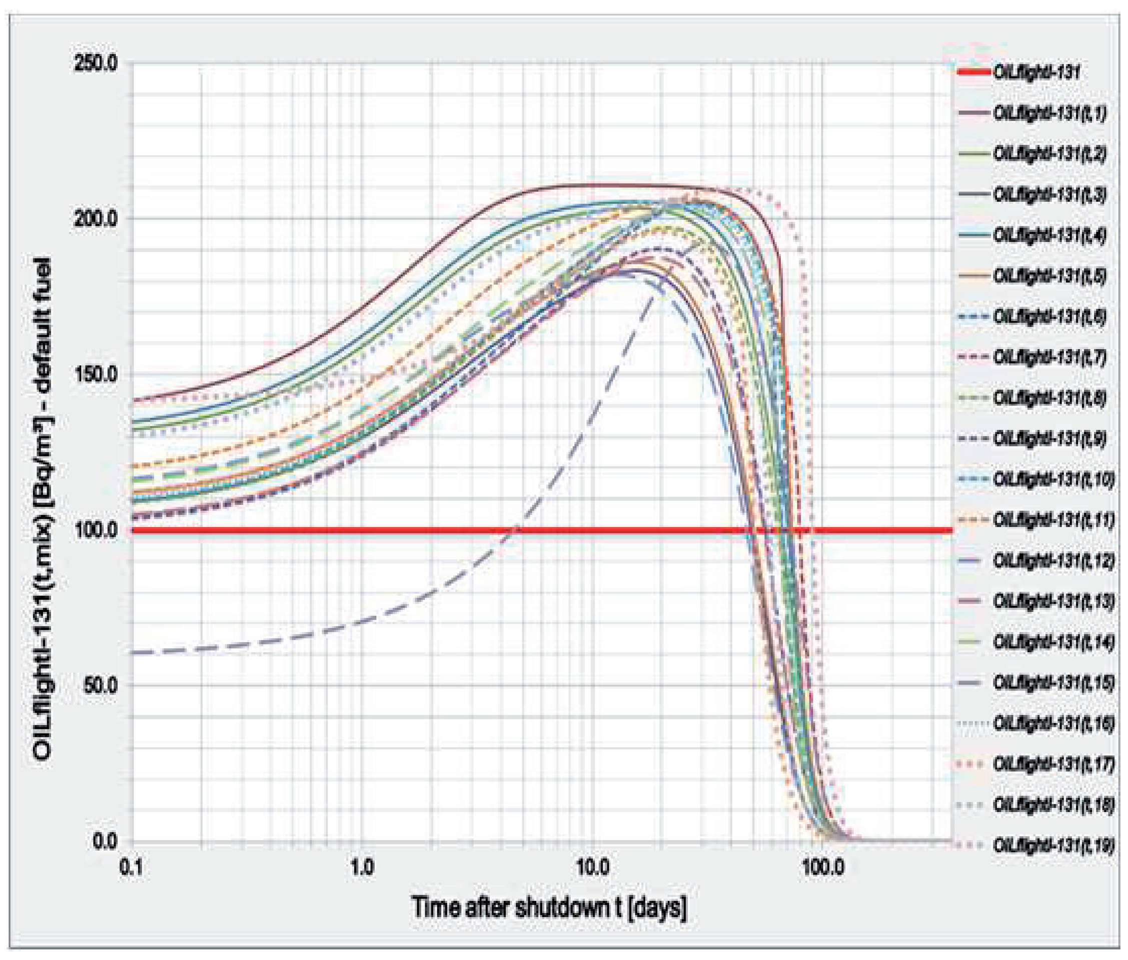


Fig. 4: OILflight I-131 for 19 nuclide mixes given in [2]. Default OIL is 100 Bq/m³ for I-131

References

[1] The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Elsevier, Oxford (2007).

[2] Operational Intervention Levels for Reactor Emergencies and Methodology for Their Derivation. EPRNPP-OILs 2017, March 2017, IAEA, Vienna, ISSN 2518–685X

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Added value of Poisons Centers in the response to radiological incidents

UMC Utrecht

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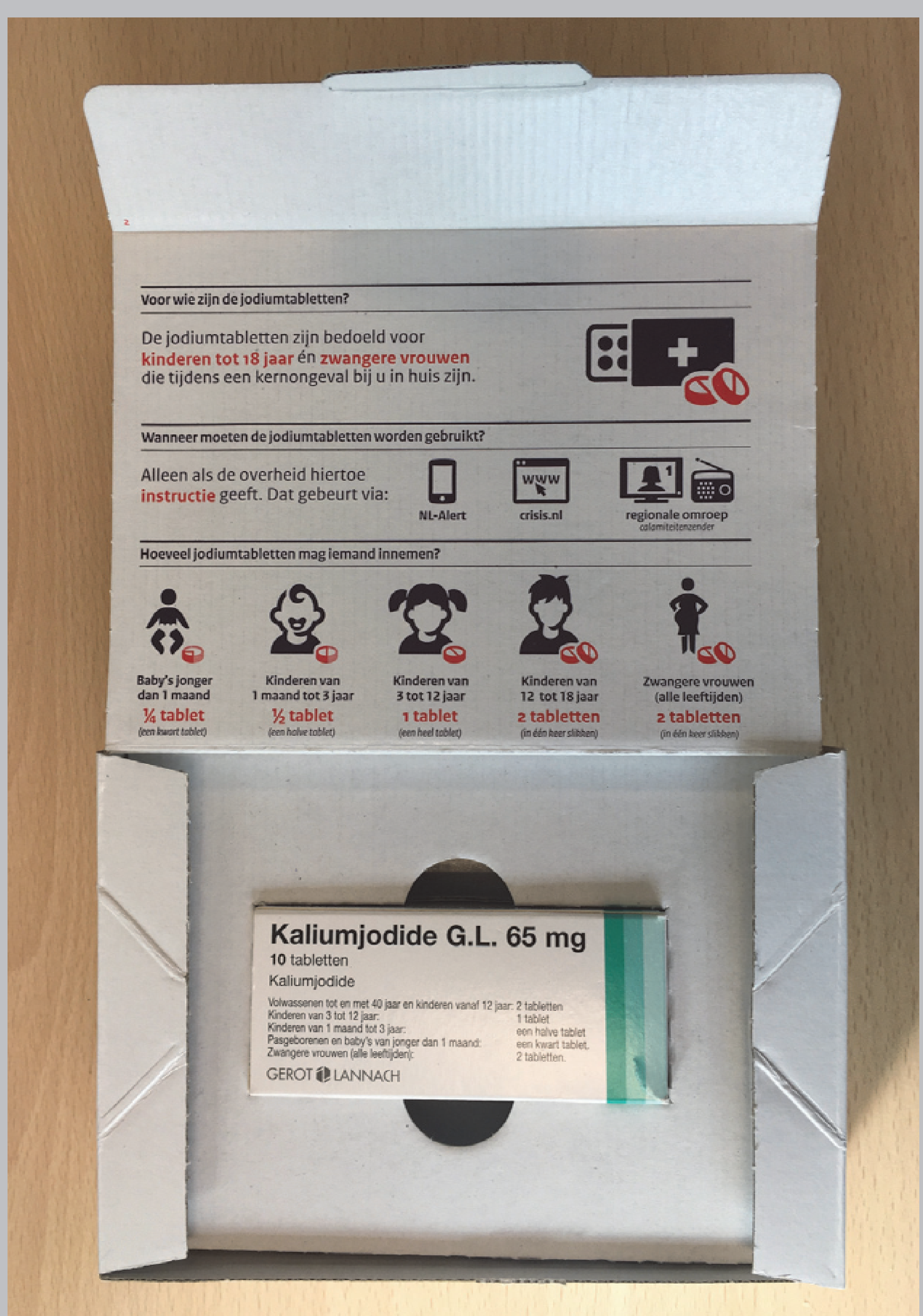
Introduction

The Fukushima nuclear power plant disaster (Japan, 2011) and growing terrorist threat during the last decade have increased awareness for incidents involving radioactive material. Poisons Centers (PCs) can play an important role in the preparation on and immediate medical response to radiological and nuclear incidents.

In the Netherlands, the PC is officially embedded in the response network for radiological and nuclear incidents. Radiation protection experts are available 24/7 to calculate radiation dose, perform risk assessment and provide health management advice after radionuclide exposure. The tasks PCs can perform are illustrated by recent involvement in exposure assessment and incident preparedness.

Results

In the past few years the Dutch PC was consulted about several suspected radionuclide exposure cases. Haematologists asked the PCs radiation experts to assess the relationship between unexplained aplastic anaemia and chronic exposure to dust from uranium-containing minerals. Calculation of possible bone marrow dose made such a relationship unlikely.



Another consultation concerned a second opinion on a pregnant patient with a pelvic tumour who had to undergo radiotherapy. Advice was asked whether or not this would be possible without harming the unborn child.

Another role of the PC is to advise authorities and healthcare professionals on management of radiological incidents in or outside the Netherlands in which Dutch citizens might be involved. After the Fukushima incident the PC radiation experts advised on the possible need for stable iodine for Dutch citizens in Japan.

After internal contamination with radionuclides, elimination can often be enhanced by administering antidotes. However the availability of these antidotes is limited.

On PC recommendation, the Ministry of Health built a stockpile of the chelators DTPA (for e.g. plutonium, americium and other actinides) and Prussian Blue (for cesium and thallium). Thereafter healthcare professionals and policy officers were trained on the recognition, risks and medical management of radiotoxicity.

In 2017 the Ministry of Health decided to distribute iodine tablets to 1,2 million households in the Netherlands. The radiation protection experts of the PC advised in the preparation of this distribution. PC employees wrote Q&A's for health care personnel and the public, gave interviews to the press and answered 51 telephone calls about iodine pills via the 24/7 telephone service. Even after accidental overdose in young children no health complaints were found.

Conclusion

In the last ten years the Dutch PC radiation experts have assessed individual radiological exposures, have trained healthcare professionals on radiotoxicity and have acted as experts in radiological incident response teams. In this way the radiological expertise of the PC, build upon toxicological knowledge, showed its added value to health care personnel and to the Dutch authorities.

5th European IRPA Congress 4-8 June 2018 in Hague

Assessment of effective dose from various exposure pathways for people living in Korea following a hypothetical nuclear accident

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Introduction

Following a nuclear accident, a large amount of radioactive materials are released to the environment. Released radionuclides are dispersed to the environment and resulting radioactive contaminations of environmental media (air, soil, water, or food stuff, etc). Radionuclide contaminated environmental media lead to human exposure through various pathways and consequentially affect human health.

Materials and Methods

Dose assessment code system has been developed to calculate radiation dose through various exposure pathways for people living in Korea following a nuclear accident. Exposure doses are calculated using radionuclide distribution concentration data in environmental media, which are estimated by atmospheric and aquatic dispersion models, etc. Exposure pathways considered in the code system are cloudshine, groundshine, inhalation, resuspension inhalation, and food ingestion. The code system includes a semi-dynamic food chain model [1] for estimating the radionuclide concentrations in agricultural and livestock products in the Korean agricultural environment and ingestion doses from the intake of radionuclide contaminated foods. Internal and external dose coefficients were taken from International Commission on Radiological Protection (ICRP) Publication 72 (ICRP, 1996) [2] and Federal Guidance Report No. 12 (FGR 12) [3], respectively.

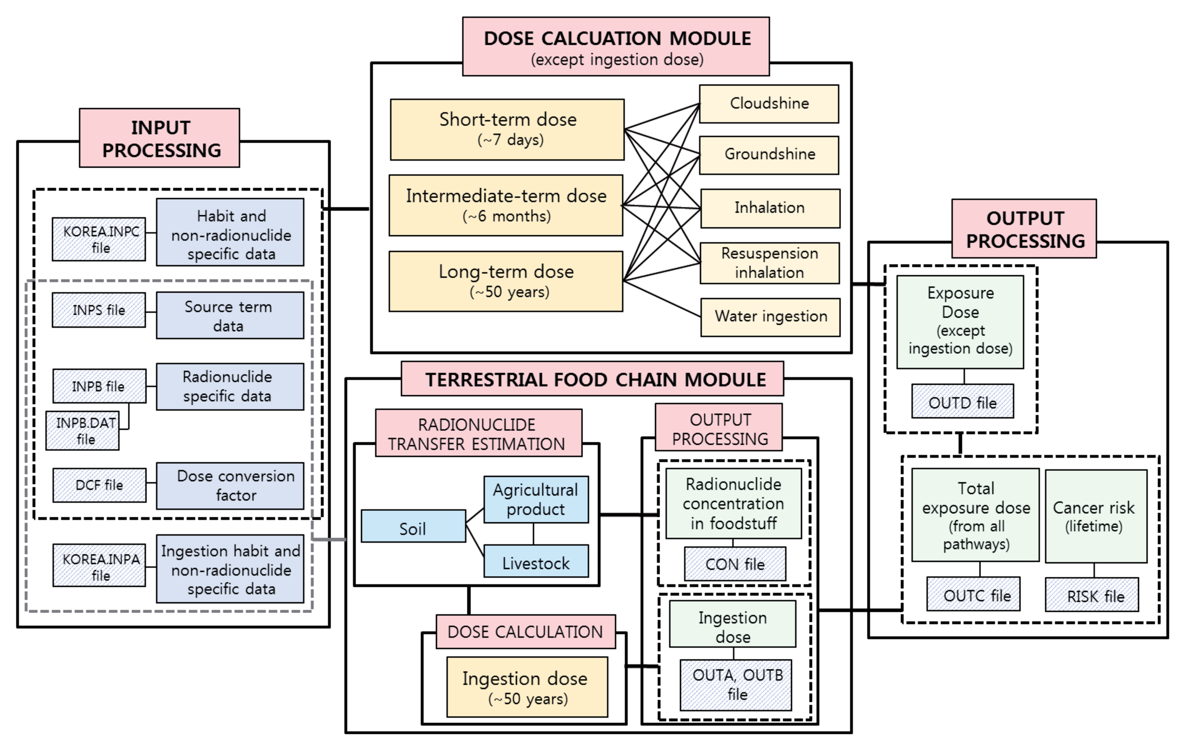

Fig 1. Outline of the developed dose assessment system.

Results and Discussion

The code estimates the effective dose and equivalent doses for short-term (within 7 days), intermediate-term (within 6 months), and long-term (1 to 50 years) phases. It was assumed that radioactive materials were accidentally released to the atmosphere from Hanbit Nuclear Power Plant in Korea. Assessment was performed for adult living in the regions of Korea and applied Korean-specific environmental and habit data. Dose assessment was performed on I-131, Cs-134 and Cs-137, which are main contributors to human exposure following the nuclear accident.

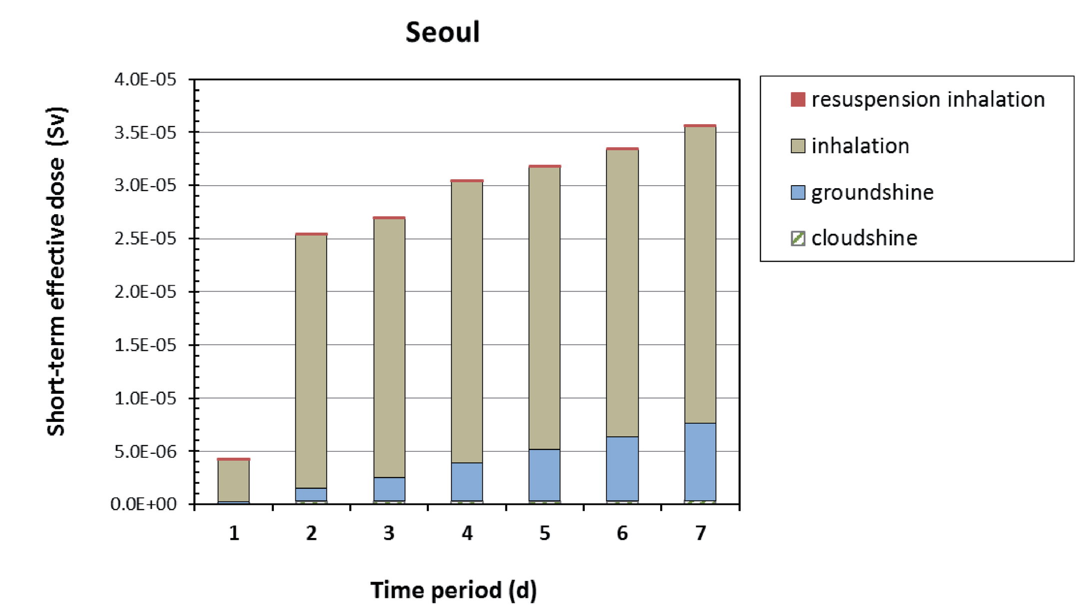

Fig 2. Short-term effective doses in Seoul after the accident

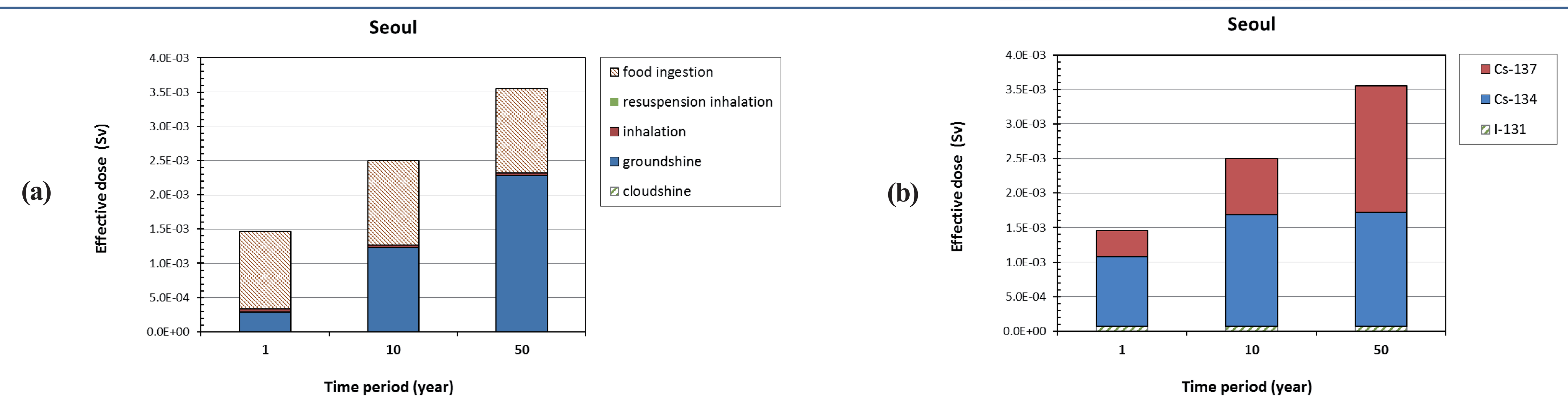

Fig 3. Long-term effective doses in Seoul for 1, 10, and 50 years after the hypothetical accident. Contributions of (a) each exposure pathway and (b) each radionuclide

Conclusions

From the results, we could identify which exposure pathways are significantly contributed to the effective dose for each time period after the accident. In the short-term (within 7 days), the pathways of external exposure to groundshine and internal exposure from inhalation were assessed as the main contributors to the effective doses. Otherwise, the results showed that external exposure to groundshine and ingestion of contaminated food stuff significantly contributed to the total effective dose in the long-term (1 to 50 years). The developed dose assessment model will be used as a tool to estimate exposure doses for residents in Korea for the nuclear accident.

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[2] International Commission on Radiological Protection (ICRP) (1996) Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5. Compilation of Ingestion and Inhalation Dose Coefficients. ICRP Publication 72. ICRP, Pergamon Press, Oxford.

[3] Environmental Protection Agency (EPA) (1993) External Exposure to radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12. EPA-402-R-93-081. Oak Ridge National Laboratory, Oak Ridge, TN; U.S. Environmental Protection Agency, Washington, D.C.

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

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Availability and reliability of meteorological data for atmospheric dispersion models

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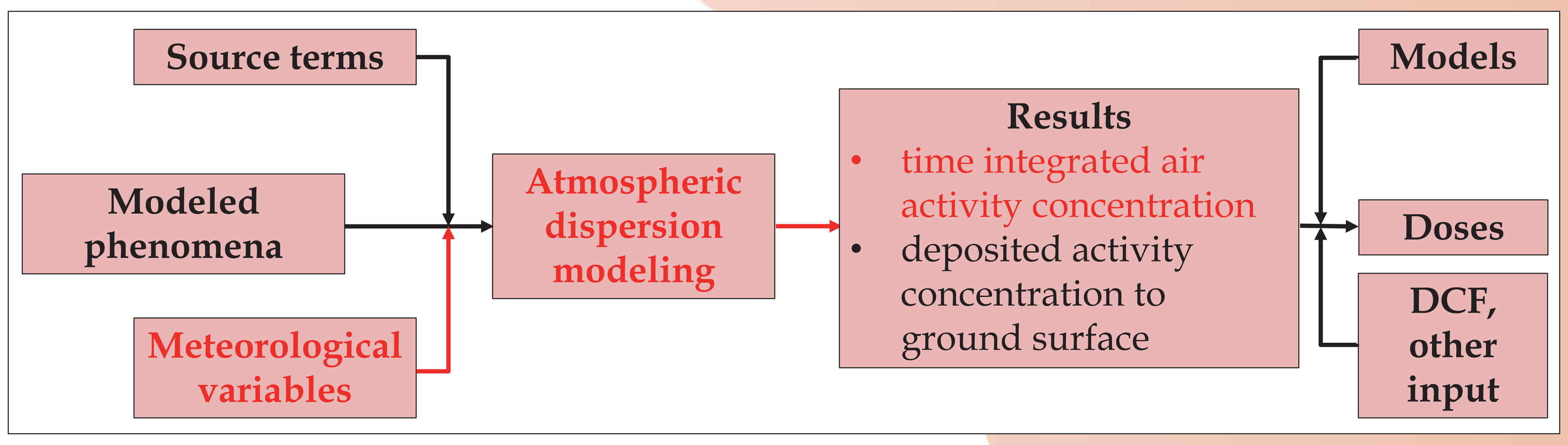
Introduction

Atmospheric dispersion calculations are widely used in the nuclear industry for certain assessments, such as environmental impact assessment of normal operation and safety analysis for DBC (design basis conditions) or DEC (design extension conditions), as well as for decision support systems for nuclear emergency response.



Required meteorological variables for activity dispersion calculations: **wind direction**, **wind speed**, **atmospheric stability**, **precipitation**, **height of the atmospheric boundary layer**.

Uncertainty in atmospheric dispersion model calculations is associated with:

- **model uncertainty**, resulting from the inadequate treatment and simplifications of the modelled processes, numerical approximations and misspecifications of the model structure;
- **parameter uncertainty**, arising from the uncertainties in the input data, the model parameters and initial and boundary conditions;
- **stochastic uncertainty**, arising from the natural variability and non-predictive capability of the atmosphere.

Availability and uncertainties of meteorological variables

Sources of meteorological data: **measurements and observations, numerical weather prediction (NWP) models** are summarized in *Table 1*.

Table 1: The availability and uncertainty requirements of meteorological parameters from measurements, observations and regional numerical weather prediction models (based on WMO requirements).

Measurements and observations				
Meteorological variable	**Availability**		**Uncertainties less than**	
	Resolution	**Time resolution**		
Wind direction	1°	2 and/or 10 min	± 5°	
Wind velocity	0.5 m/s	2 and/or 10 min	≤ 5 m/s > 5 m/s	± 0,5 m/s ± 10%
Precipitation intensity	0.1 mm/h	10 min	0.02 – 0.2 mm/h 0.2 – 2 mm/h > 2 mm/h	n.a. ± 1 mm/h ± 5%
Numerical weather prediction models (regional)				
Meteorological variable	**Availability**		**Uncertainties less than**	
	Spatial resolution	**Time resolution**		
Wind field	10 km (horizontal) 0.1 km (vertical)	1 h	troposphere stratosphere	± 2 m/s ± 3 m/s
Precipitation intensity	10 km (horizontal) 0.1 km (vertical)	1 h	± 0.1 mm/h	

Methods

Atmospheric dispersion modelling

To evaluate the effect of the used meteorological input data uncertainties on the results of atmospheric dispersion modeling, a sensitivity analysis of the Gaussian puff model in the SINAC decision support system *[1]* was conducted as an example.

The SINAC software calculates:

- Atmospheric dispersion
- Deposition (dry and wet)
- Doses (cloudshine, groundshine, inhalation, ingestion)
- Countermesures (sheltering, evacuation, iodine tablets)

The **Gaussian puff model** in SINAC considers:

- The same horizontal dispersion parameters ($\sigma_x = \sigma_y = \sigma_r$)
- Physical processes of advection, turbulent diffusion and deposition
- Atmospheric stability based on Pasquill stability classes
- Reflection from the ground and the atmospheric boundary layer

Sensitivity analyses

Aims:

- Identification of the meteorological parameter with the greatest importance on the output (time integrated **air activity concentration of ^{135}Xe, ^{137}Cs**) of the atmospheric dispersion modelling.
- Quantification of the impact of the changes in meteorological data between the typical uncertainty intervals on the dispersion calculation's results.

The evaluated meteorological parameters and the used default values and perturbations are summarized in *Table 2*.

Table 2: The summary of the default values and perturbations of the meteorological parameter for the sensitivity analysis.

Meteorological variable	Default value	Perturbation
Wind velocity [m/s]	3	-2, -1, +2, +5, +9
Wind direction [°]	180	+1, 3, 5, 7, 10
Pasquill stability category	D	A, B, C, E, F
Precipitation intensity [mm/h]	0	+1, 3, 5, 8, 12

Results

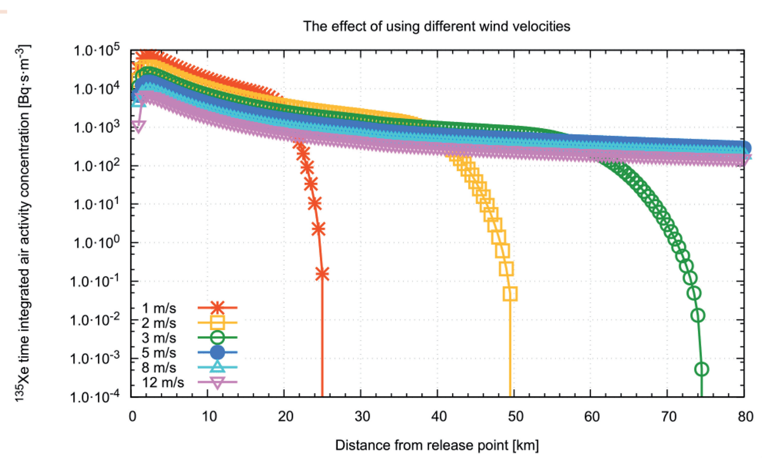


Figure 1: The time integrated air activity concentrations of ^{135}Xe for different wind velocities.

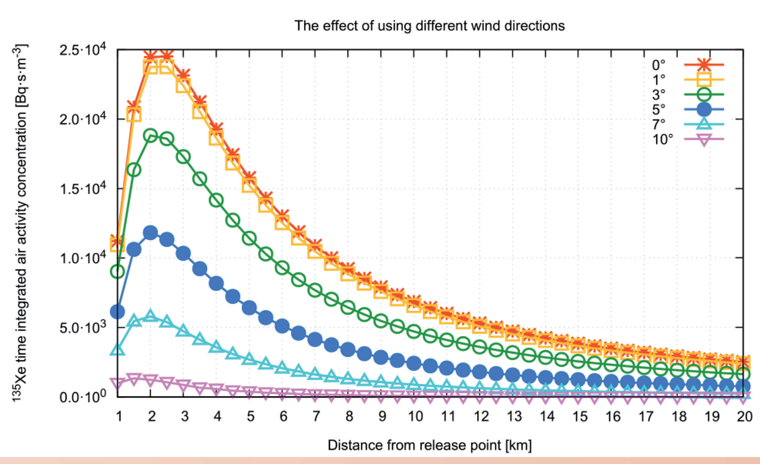


Figure 2: The time integrated air activity concentrations of ^{135}Xe for different wind directions.

The results of the sensitivity analysis show that the change of the **wind velocity** caused about one order of magnitude maximum difference in time integrated air activity concentration for a distance up to 20 km. Further than that, with the slower wind, the contaminants do not reach the receptor points by the end of the first 6 hours of the release so there is a cut off in the time integrated activity concentrations (*Figure 1*). When changing the **wind direction**, we find that the air activity concentration along the original plume centerline decreases (*Figure 2*).

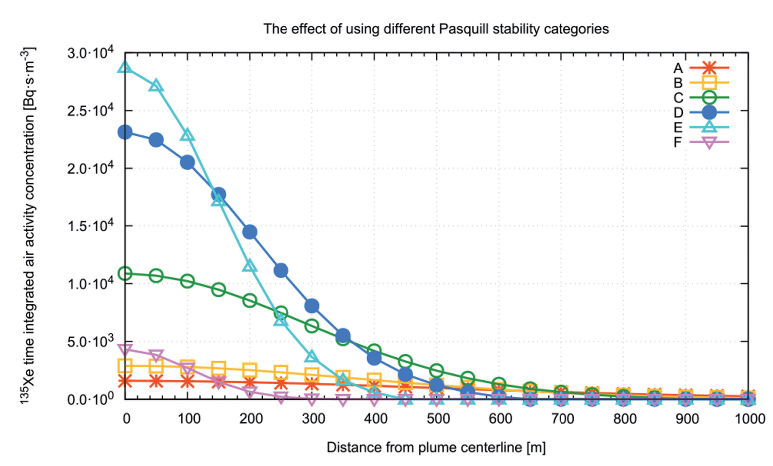


Figure 3: The time integrated air activity concentrations of ^{135}Xe for different Pasquill categories.

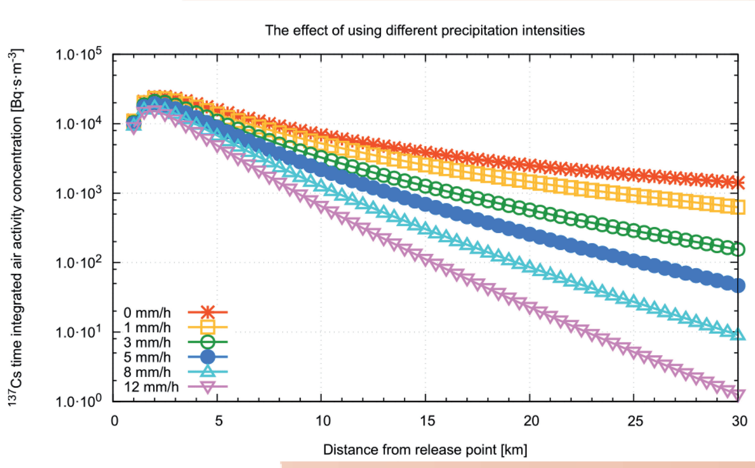


Figure 4: The time integrated air activity concentrations of ^{137}Cs for different precipitation intensities.

This is the result of the shift of the plume center with changing wind direction, thus the air activity concentration decreases based on a Gaussian function. *Figure 3* shows the spread of the plume perpendicular to the wind direction for different **atmospheric stability categories** at 3 km from the release point. For more stable atmosphere the plume is more dense with higher maximum air activity concentration values and for instable conditions the plume is more spread out and therefore, the maximum air activity concentration values are lower. Concerning the **precipitation intensity**, the calculation yields that the more intensive the rain is, the less the air activity concentration will be shown in *Figure 4*.

The maximum ratio of the results due to the different meteorological perturbations shown in *Table 3*, were combined with the uncertainties of the different meteorological dataset to describe **the overall uncertainties of the time integrated air activity concentration** results of the atmospheric dispersion modeling:

- **Wind velocity:**
  - Measurements and observations: 10%
  - NWP models: more than 50%
- **Wind direction:**
  - Measurements and observations: 50-80%
- **Pasquill stability category:**
  - One category change: 2 orders of magnitude (for stable atmosphere)
- **Precipitation intensity:**
  - Measurements and observations: 1-5%
  - NWP models: 1-5%

Table 3: The maximum ratio of the calculated air activity concentration at the original plume centerline due to the perturbation of meteorological parameters.

Difference of the evaluated meteorological parameters	**The maximum ratio of the air activity concentration in the original plume centerline for different perturbations**		
	Distance from the release point [km]		
	1-5	5-20	20-30
Wind velocity: 11 m/s	$9\cdot10^{-2}$	$1\cdot10^{-1}$	$3\cdot10^{3}$
Wind direction: 10°	$6\cdot10^{-2}$	$1\cdot10^{-3}$	n.a.
Pasquill category: 1 category	$1\cdot10^{-2}$	$4\cdot10^{0}$	$3\cdot10^{0}$
Precipitation intensity [mm/h]	$7\cdot10^{-1}$	$2\cdot10^{-2}$	$2\cdot10^{-3}$

Reference

[1] *Szántó, P., Deme, S., Láng, E., et al., 2012. SINAC – Simulator Software for Interactive Modelling of Environmental Consequences of Nuclear Accidents (2nd Generation), IRPA The 13th International Congress of the International Radiation Protection Association, 13-18 May 2012, Glasgow, Scotland*

Conceptual Design of Thyroid Dose Monitoring System using Gamma-ray spectrometers

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Thyroid Dose Monitor

Thyroid dose monitoring for a large number of people should be performed immediately after severe nuclear accident.

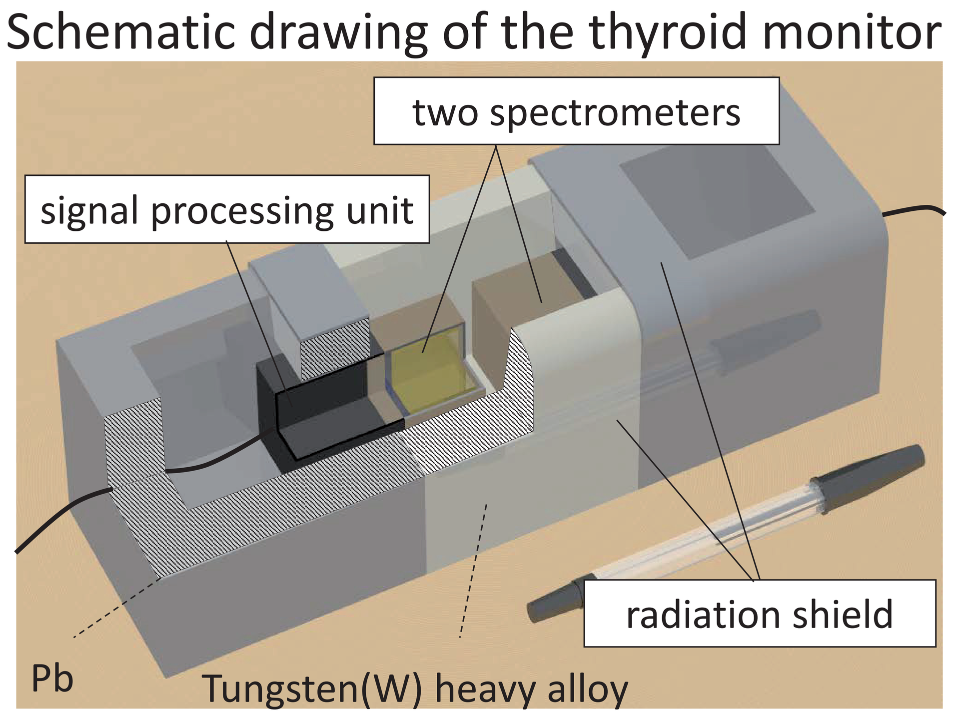
Conventional monitors

- fixed at laboratory
- large radiation shields

Proposed monitor

- portable and can be installed easily to evacuation centers and incident command post
- available under a high dose rate condition
- reliable estimation based on spectral information

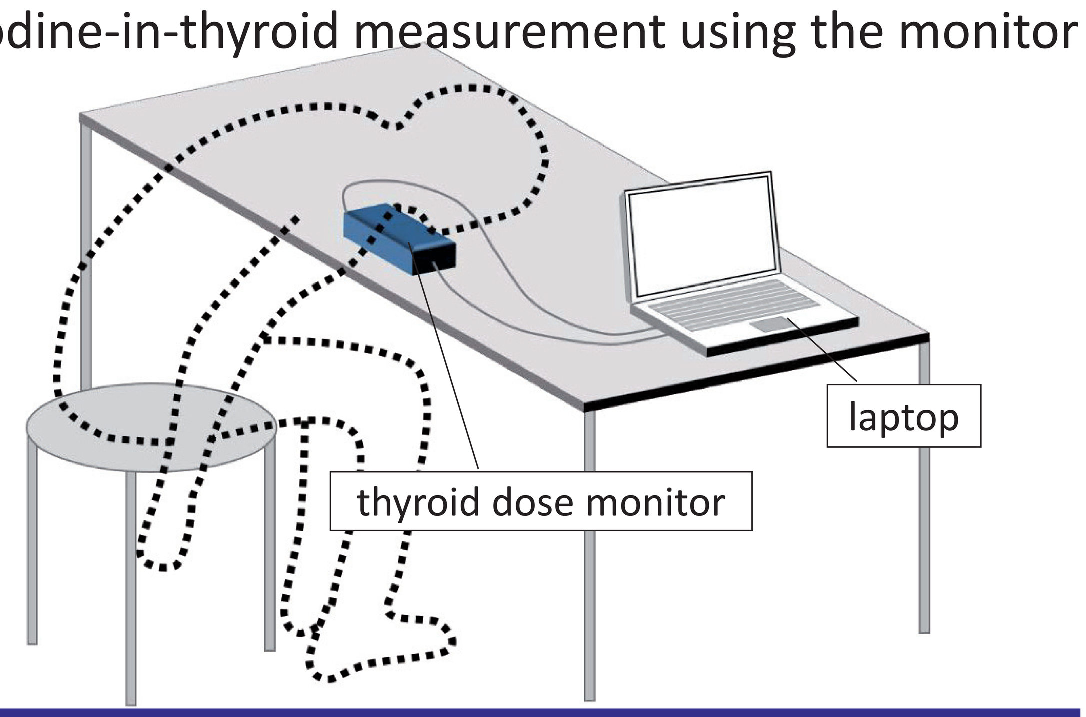
Schematic drawing of the thyroid monitor



Requirement for proposed thyroid monitor

	Requirement	Notes
Minimum assessable thyroid dose	< 10 mSv	when measured 3-5 days after intake
Acceptable background dose rate	several tenth µSv/h	evacuation centers, command posts in the radiologically affected area.
Measurement time	< 5 minutes / subject	>150 subjects / day/1system
Power supply	supplied via USB cable	operational with connecting to a laptop PC or a mobile battery

Iodine-in-thyroid measurement using the monitor



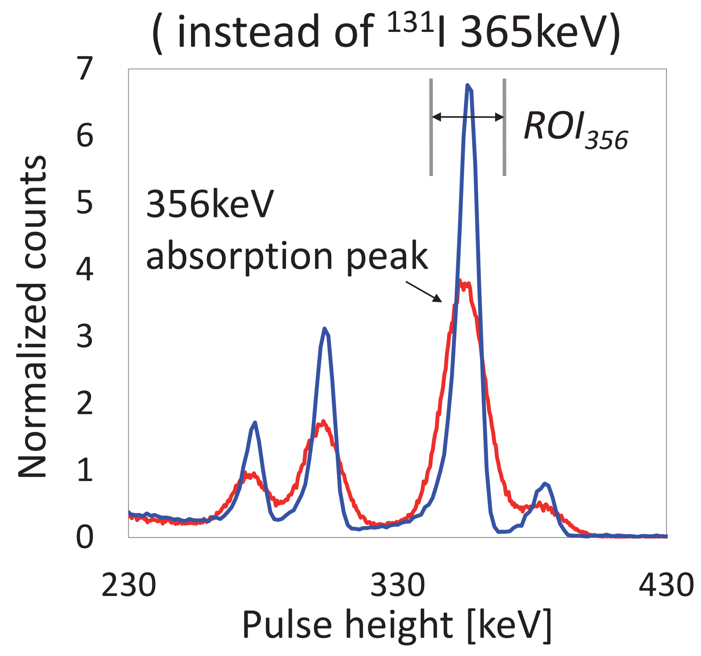
Experiments & Results

Spectrometers to be tested

CdZnTe: 1.5cm^3 LaBr$_3$(Ce): 16cm^3

	CdZnTe	LaBr$_3$(Ce)
ΔE/E	2.8%	5.3%
sensitivity	0.39 cm^2	1.9 cm^2

^{133}Ba 356keV spectrum (instead of ^{131}I 365keV)

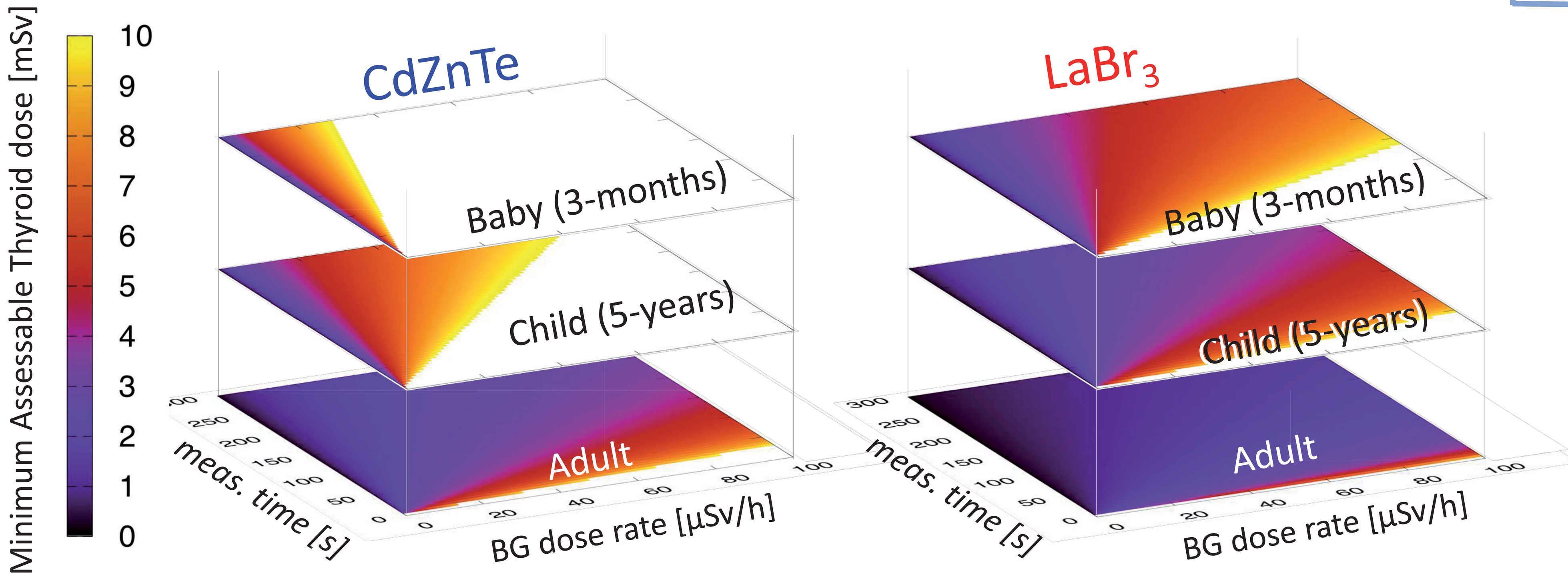


Minimum Assessable thyroid equivalent dose; $H_{thy,min}$

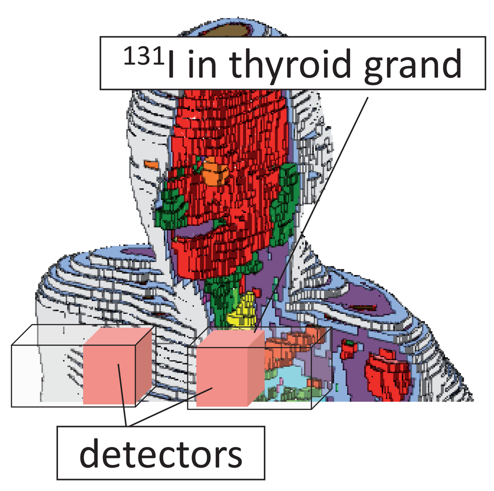
$$H_{thy,min} = \frac{k}{t\varepsilon_*}\left(k + 2\sqrt{2n_0}\right) \cdot \frac{CF_{thy}}{F}$$

k: (=1.65) gives 95% confidence level
t: measurement time [s]
ε_*: counting efficiency [s^{-1}/Bq]
n_0: BG counts within ROI$_{356}$
CF_{thy}: thyroid dose conversion factor [mSv/Bq]
F: retention fraction at the date of measurment

$H_{thy,min}$ as a function of measurement time [s] and BG dose rate [mSv/h]



Evaluation of counting efficiency



Fluence rate [s^{-1}cm^{-2}/Bq]at detector position is obtained by Monte-Calro calculation.

※Detector arraignment is optimized so as to minimize an influence of uncertainty due to positional displacement

divided by detector sensitivity [cm^2] given in experiment (see left).

⇒ ε_*: counting efficiency [s^{-1}/Bq]

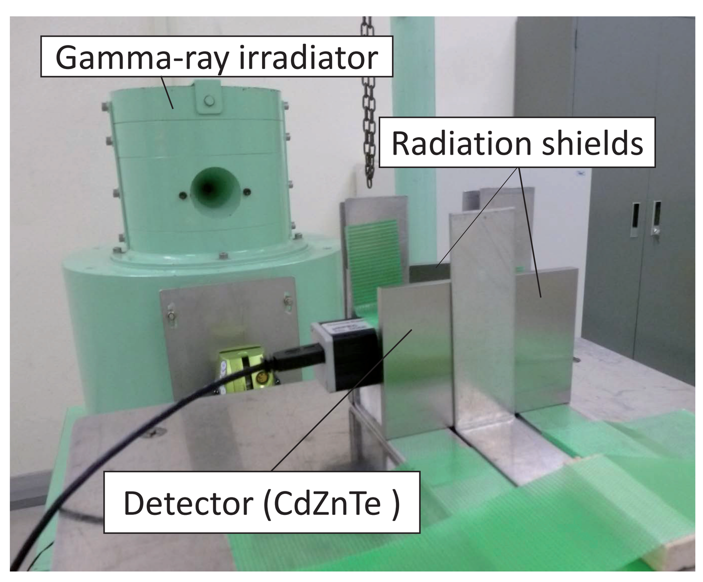
Rough estimation of BG counts

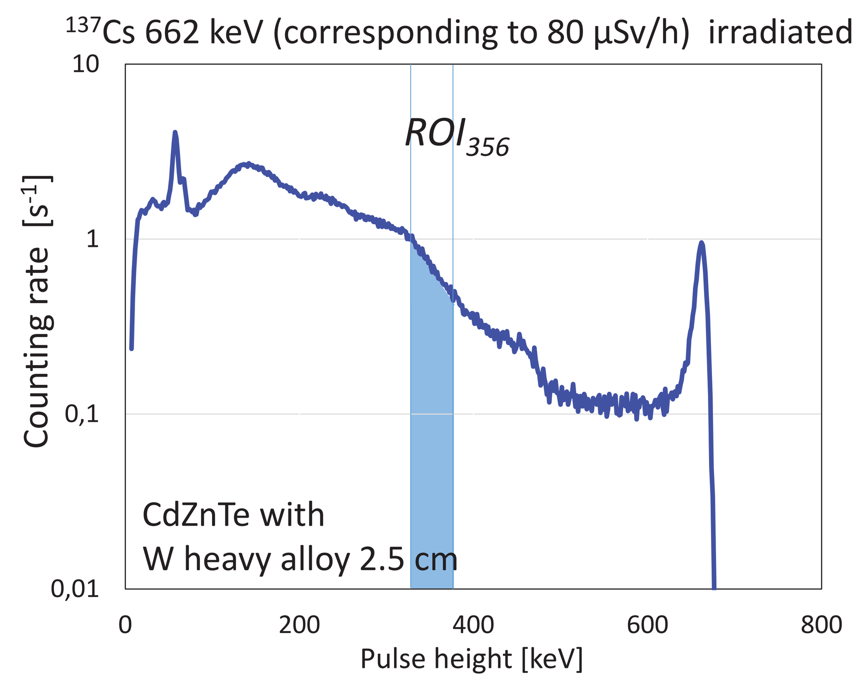
n_0: number of continuous-BG counts within evaluation area of 356 keV (ROI$_{356}$).

The gamma-ray reference field (^{137}Cs) in FRS/JAEA was used to simulate a high dose rate condition.

n_0 given with the detector shielded by W heavy alloy 2.5 cmt ※ was examined.

(※ optimized so as to be; thyroid ^{131}I 365keV rate >> BG ^{131}I 365keV rate)





Summary

Performance requirements can be satisfied by using CdZnTe or LaBr$_3$ detectors with W heavy alloy shield.

- For adult-radiation workers at a incident command post :
  High BG dose rate, small-number of subjects, various kinds of radionuclides ⇒ **CdZnTe** (higher energy resolution)
- For members of public at evacuation centers :
  Low BG dose rate, large-number of subjects, necessity of short-time measurement ⇒ **LaBr$_3$** (higher counting efficiency)

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CYTOGENETIC BIODOSIMETRY SMALL NETWORK AND ITS ADVANTAGE FOR RADIATION EMERGENCIES IN OCCUPATIONAL FIELD

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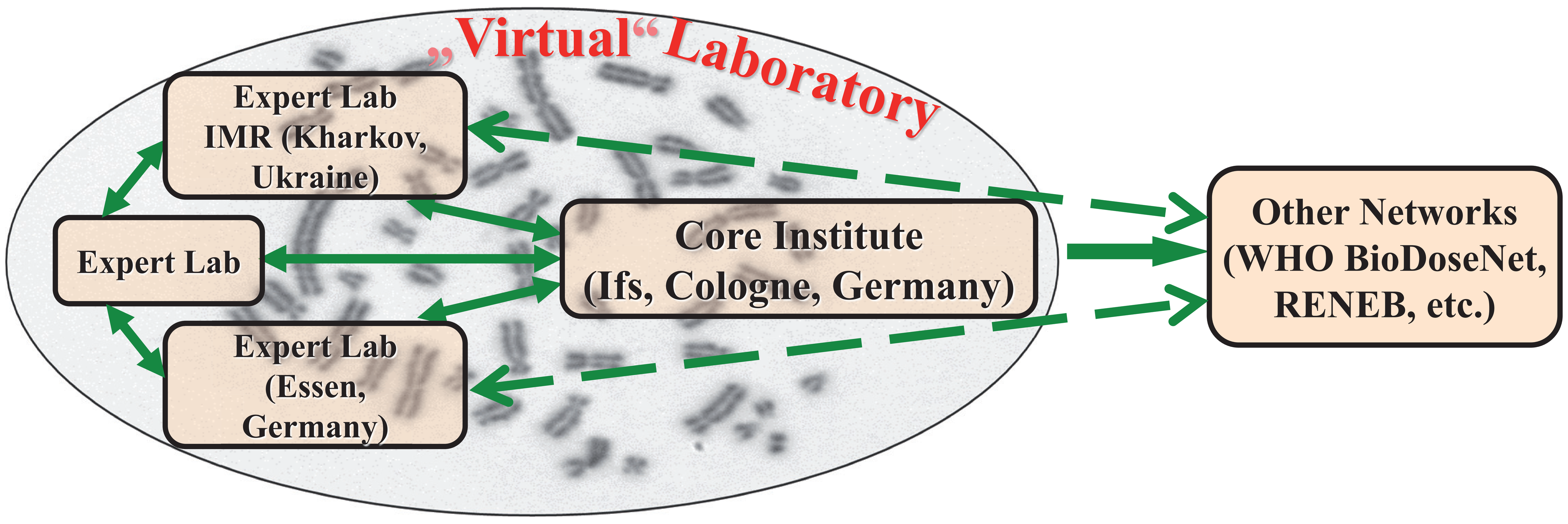
Cytogenetic biodosimetry has been a part of radiation accident countermeasures. As radiation accidents are rare, for radiation protection institutes with limited opportunity to keep running biodosimetry laboratory for emergency preparedness and response, international cooperation became an excellent choice. We have established a small network bringing together the expertise from radiation protection and cytogenetic biodisimetry fields



Important requirements, key points and advantages for virtual biodosimetry laboratory creation and development:

- The connections between member institutions have to be established prior to accidents.
- The core organization has to be either radiation protection institution or medical or governmental authority.
- The image capturing system is required and capturing software parameters have to be adjusted for different tasks.
- Applying of QA/QC procedures, including harmonization of scoring criteria.
- Working out the optimal ways of communication between experts from various fields, including data protection, data security matters and data exchange (secure web-server).
- Providing the inter-comparison studies with gradual complicacy in order to:

- assess inter-scorers' variability with an elaboration of the most possible equal way of scoring as a goal to achieve;
- gain an experience with various dose range and exposure scenarios, especially partial-body exposure.

- Flexibility for radiation protection institutions or other authorities in building up biological dosimetry service considering their needs.
- All the benefits of ready-to-use biological dosimetry service.

Inter-comparison studies in order to determine the best ways of communication, sample collection, sample processing, image and microscopy analysis, data distribution and data protection were conducted

Pilot study of microscope and image analysis intercomparison

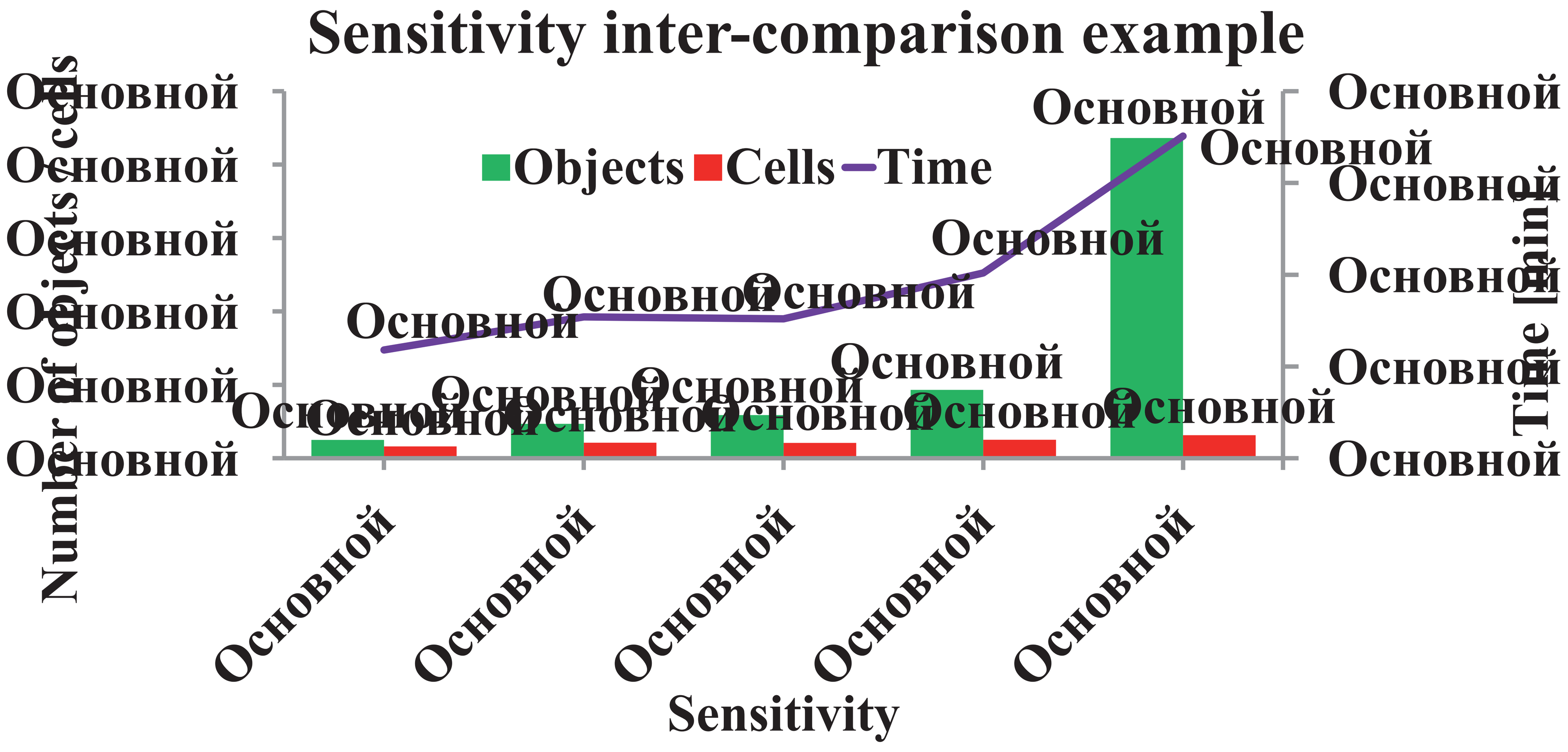
	German Professionals		Ukrainian Uranium Miners *)	
	chromosome type aberrations	Dicentrics	chromosome type aberrations	Dicentrics
Microscopy analysis	1,67%	0,48%	11,02%	6,47%
Image analysis	1,70%	0,47%	8,86%	5,06%

*) Some of donors undergone radiation therapy for cancer treatment

Dicentric yield in two studies of inter-scorers' variability

Coded Samples	Scorer 1	Scorer 2	Scorer 3	Scorer 4	Scorer 5
Non-Irradiated	0,00 %	0,36 %	0,70 %	0,00 %	0,00 %
Irradiated	43,71 %	42,35 %	34,08 %	50,28 %	45,45 %
"Mixed" telescore	114,00 %	108,00 %	106,00 %	112,00 %	112,00 %

Sensitivity inter-comparison example



Dose range inter-comparison exercise

Dose below 0,5 Gy				
Scorer	Images	Cells 2N	Ab. cells	DR fr
Scorer 1	1190	806	4,59 ± 0,76	1,36 ± 0,41
Scorer 2	1190	805	4,72 ± 0,77	1,12 ± 0,37
Scorer 3	238	195	3,39 ± 1,36	0,51 ± 0,51

Dose 0,5-2 Gy				
Scorer	Images	Cells 2N	Ab. cells	DR fr
Scorer 1	555	344	20,35 ± 2,44	14,53 ± 2,06
Scorer 2	522	328	20,12 ± 2,48	13,72 ± 2,05
Scorer 3	157	87	26,44 ±5,54	19,54 ± 4,77

Conclusion: Suggested way of creating small networks in biodosimetry field is of great advantage for radiation protection institutions and authorities with mandatory tasks in emergency preparedness and response.

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BG ETEM Energie Textil Elektro Medienerzeugnisse

Development of information systems for understanding environmental monitoring data on the Fukushima Daiichi Nuclear Power Plant accident

Japan Atomic Energy Agency

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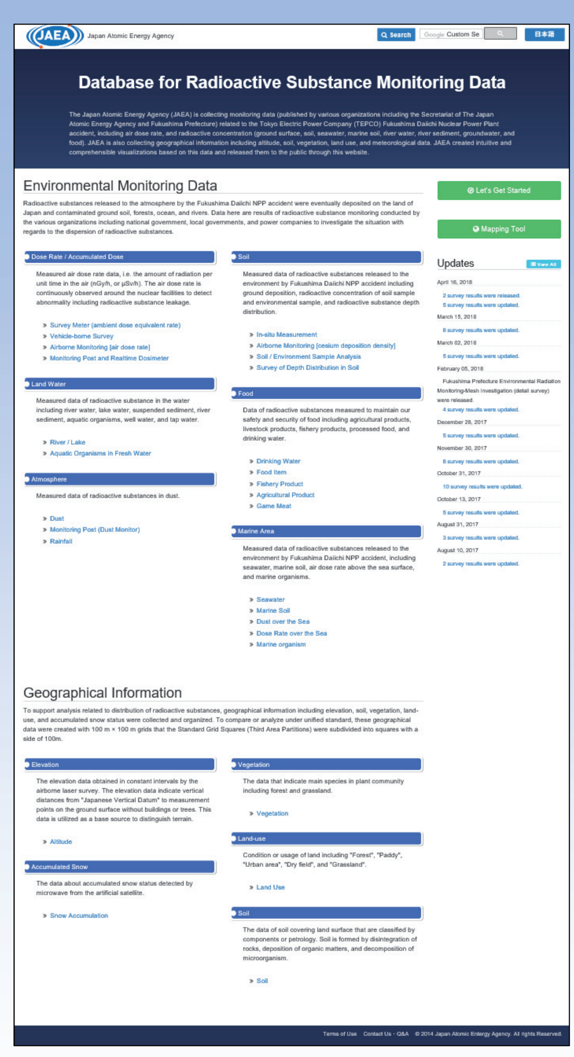
Introduction

Seven years had passed since the Fukushima Daiichi Nuclear Power Plant accident, and a lot of environmental monitoring had been carried out to understand radionuclide distribution, and to provide data for considering countermeasures. In monitoring immediately after the accident, it was important to conduct environmental monitoring in the wide area and to provide those data quickly and accurately. Therefore, we had developed information systems to support the collection of wide area data and to provide accurate data quickly. However, as seven years have elapsed, the needs of information systems handling monitoring data were changing. In addition to updating the existing systems, we developed new information systems to meet these needs.

Information systems for understanding environmental monitoring data

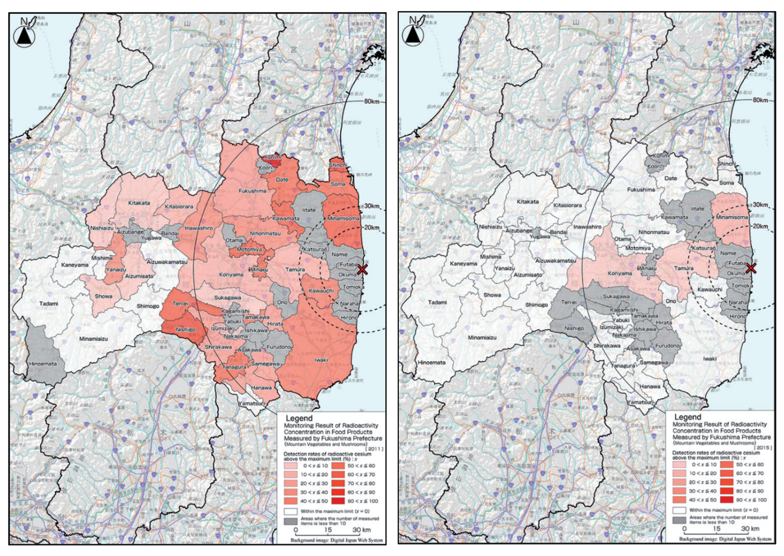
Environmental monitoring database

About 257 survey results (740M records) had been provided with static maps, clickable graphs, download files. Those information are summarized in the same format so that measurement results can be compared.



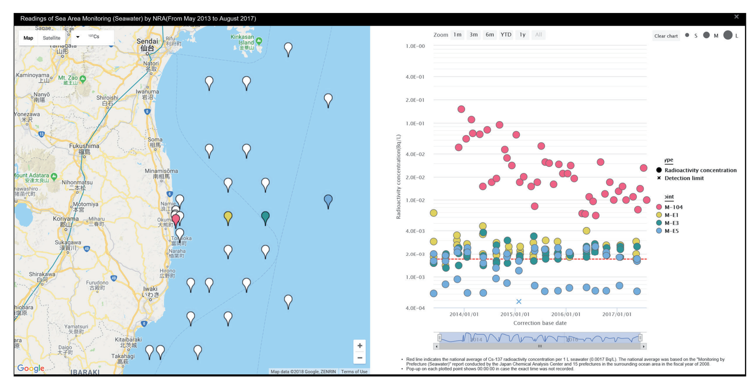
https://emdb.jaea.go.jp/emdb/en/

Ex.
Static map of radioactivity concentration in mountain vegetables and mushrooms (2011, 2015)



It can be confirmed that there are no foods exceeding the standard value in many areas, and it is understood that the radioactive substances contained in foods are decreasing as well as the trends indicated by other environmental monitoring data.

Ex.
Clickable graph of sea area monitoring (Seawater) (2013- 2017)

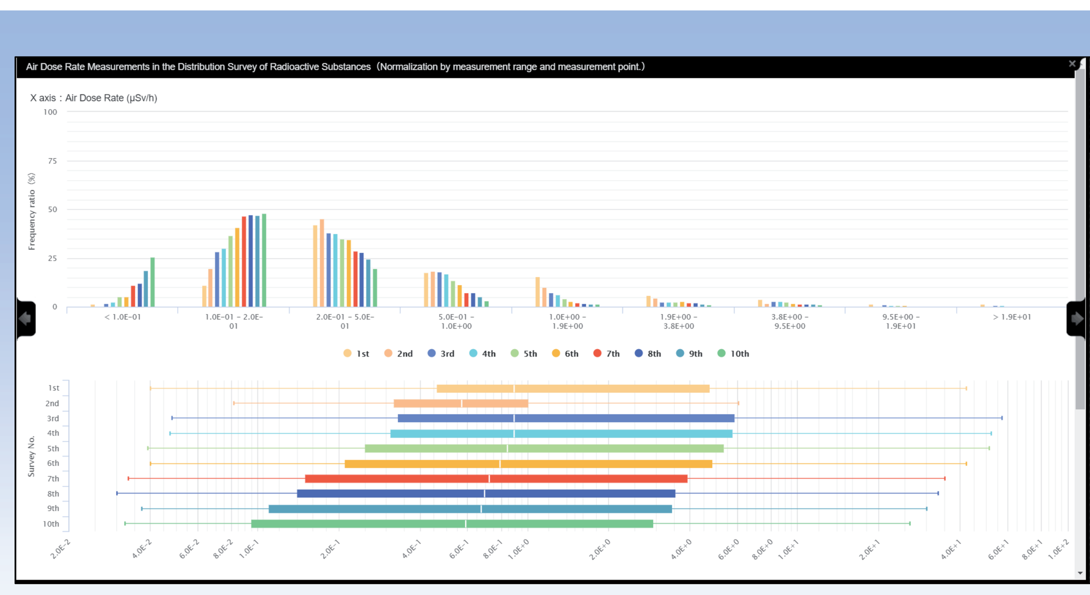


It is possible to display and compare multiple changes in dose rate and radioactivity concentrations corresponding to specific locations on the map.

Environmental Monitoring Data	Recorded number
Dose Rate / Accumulated Dose	
Survey Meter	318,751
Vehicle-borne Survey	6,060,512
Airborne Monitoring	23,008,421
Monitoring Post and Realtime Dosimeter	691,971,862
Soil	
In-situ Measurement	6,359
Airborne Monitoring	19,179,542
Soil / Environment Sample Analysis	6,703
Survey of Depth Distribution in Soil	988
Land Water	
River / Lake	15,999
Aquatic Organisms in Fresh Water	3,267
Atmosphere	
Dust	14,974
Monitoring Post (Dust Monitor)	826
Rainfall	369
Food	
Drinking Water	31,986
Food Item	220,097
Fishery Product	19,718
Agricultural Product	1,270
Game Meat	1,951
Marine Area	
Seawater	43,662
Marine Soil	7,251
Dust over the Sea	127
Dose Rate over the Sea	144
Marine organism	1,800
Total (8/May/2018)	**740,916,579**

Statistical infographics

Statistical infographics show histograms or box plots of measured results of air dose rate and radionuclide concentration which have been continuously measured. We created statistical infographics for large-scale measurement results that are being measured nine times or more since the accident.

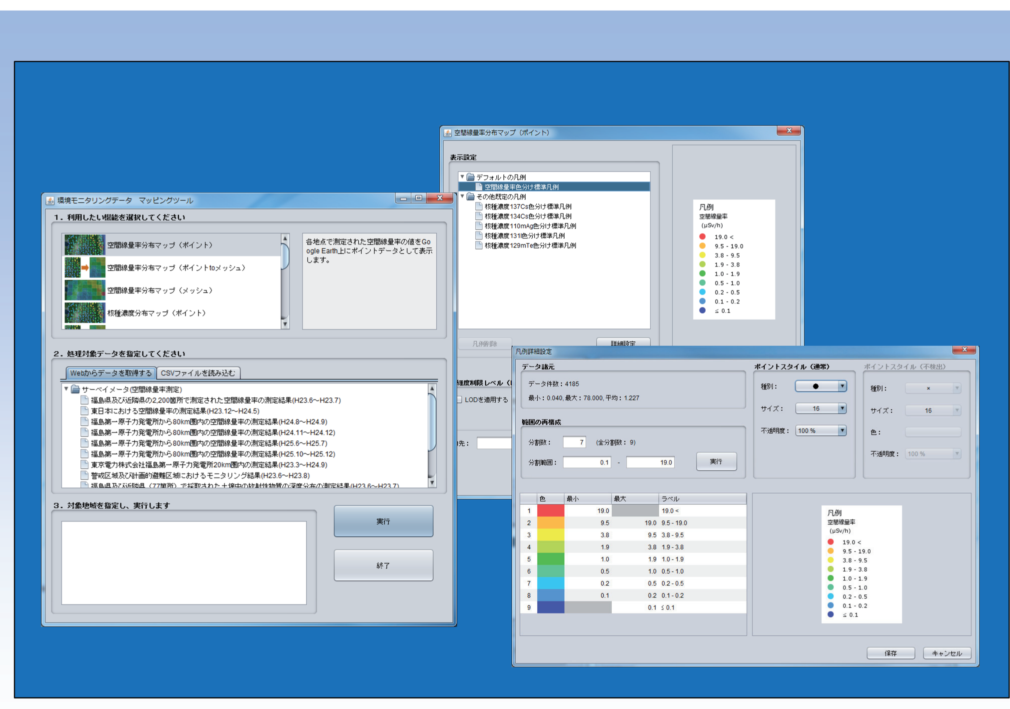


This series of data was created based on results of the air dose rates measured using NaI(Tl) scintillation survey meters and ionization chamber type survey meters from FY 2011 to FY 2015 in Map Project

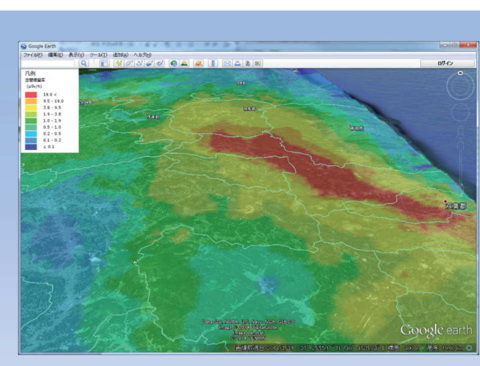
This analysis results show the depth distribution of radioactive cesium in soil. Soil samples at various depths were collected using scraper plate which is standard method to measure radioactive nuclides in soil profiles employed at IAEA.

Visualization support tool

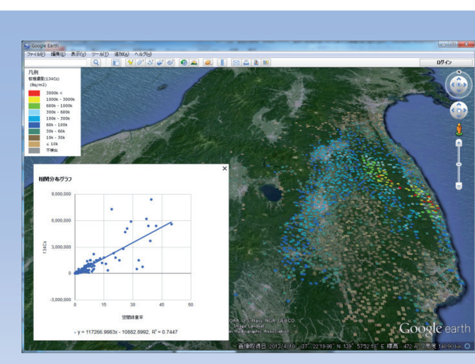
The visualization support tool can map and graph the monitoring results for the area the users want to see. Also, since the visualization support tool directly accesses the database and use the many measurement results, the users can use the latest registration data at any time.



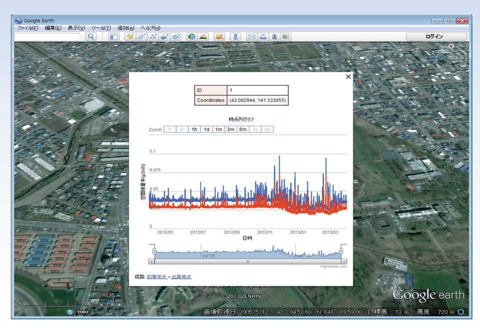
GUI of the visualization support tool



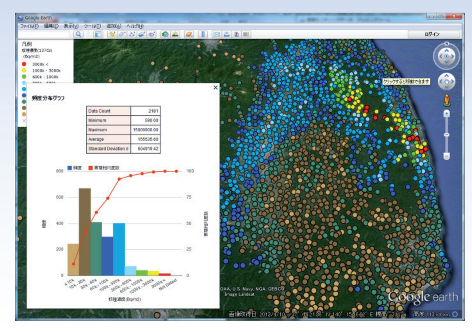
Interpolated map



Correlation graph



Time series graph



Histogram

Conclusion

We had developed information systems which supports providing a large amount of diverse monitoring data. It was found that the platform is effective in reducing the time needed to analyze the monitoring data. Reducing the cost and workload for analyzing the monitoring data is also important because monitoring should be continued over a few decades in the case of Fukushima accident. These systems are useful not only for providing information in the current Fukushima Daiichi Nuclear Power Plant accident but also for future nuclear accident cases.

EMERGENCY MEASUREMENTS OF THE POPULATION- A TASK FOR COMPETENT INCORPORATION MONITORING LABORATORIES

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Introduction

After releases of radioactive substances in the environment, incorporation monitoring of parts of the population is indispensable. In the competent incorporation monitoring body Jülich methods including direct measurements (whole body counter), indirect measurements with radiochemical testing methods of excretion samples and internal dose assessment are used.

Legal framework (Emergency response)

EU directive	Council directive 2013/59/Euratom 5 December 2013
Radiation protection act	Strahlenschutzgesetz 27 June 2017, BGBl. I S. 1966 and sublegal basic rules

Emergency measurements for the population

https://de.wikipedia.org/wiki/Open_Clip_Art_Library

Families with

- ✓ Young people
- ✓ Infants and children

- In-vivo / in-vitro measurements
- Qualified experts
- Internal dose assessment
- Competence and experience

Competent Incorporation Monitoring Body Jülich

In-vivo monitoring

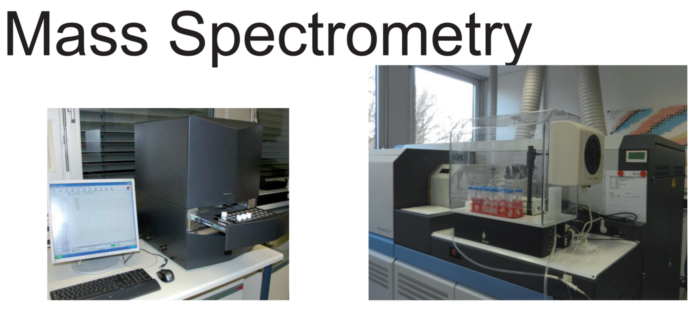
Testing method: γ-spectrometry
Detection: HPGe detectors, NaI detectors
Energy range: 20 to 2000 keV

Whole body measurement | **Thyroid measurement** | **Mobile in-vivo counting**

In-vitro monitoring

Testing methods

- ✓ Inductively Coupled Plasma Mass Spectrometry
- ✓ Liquid Scintillation Counting
- ✓ LL-β measurement
- ✓ α-spectrometry



Emergency measurements

Triage

Process of determining the priority:

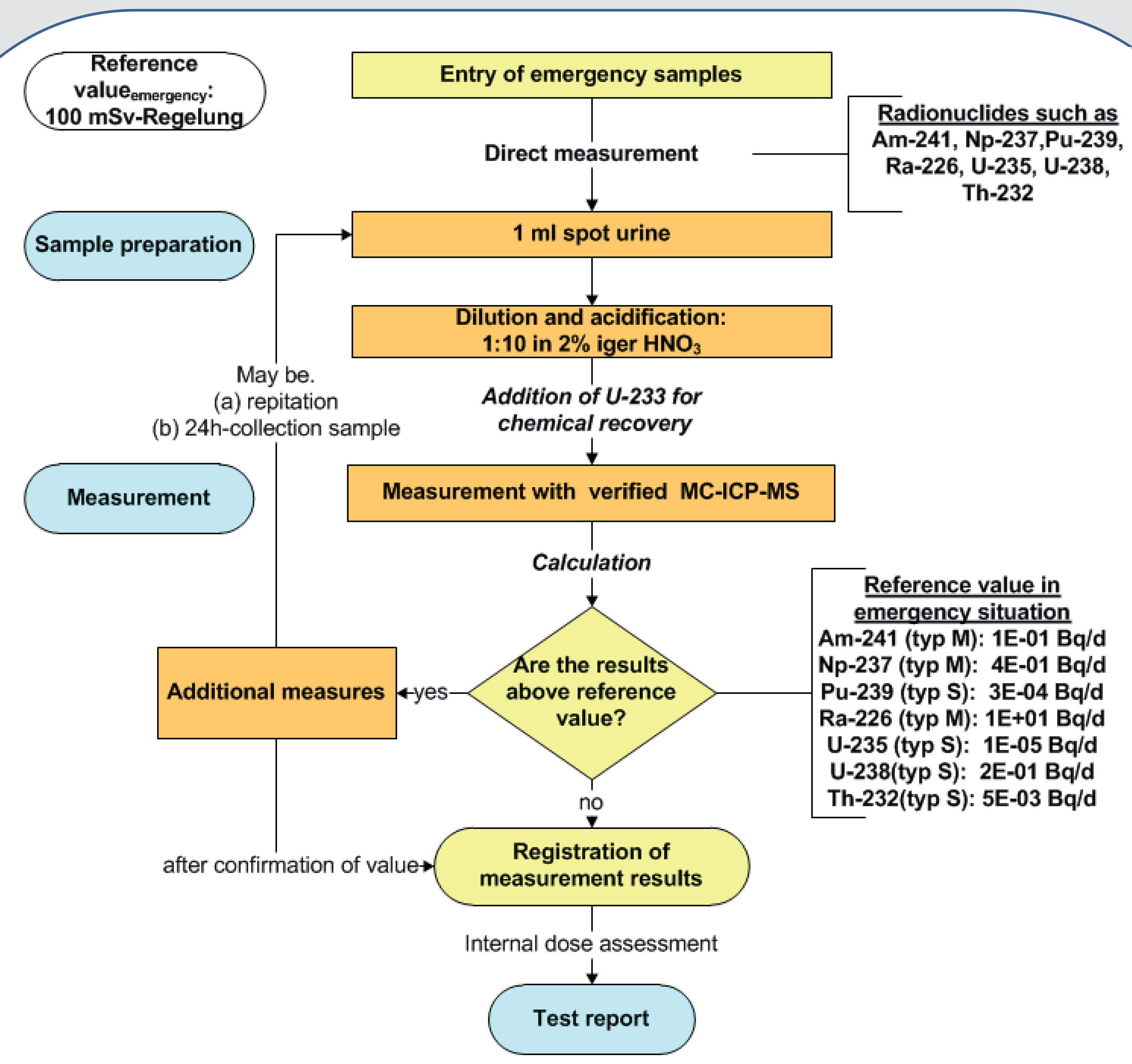
- ✓ is a medical treatment necessary?
- ✓ Selection of person for special incorporation monitoring

Acute incorporation

(a) Emergency situations after releases and/ or contamination
- ✓ In-vivo measurement (^{137}Cs, ^{131}I etc.)
- ✓ in-vitro measurement (^{90}Sr, ^{210}Po, actinides etc.)

(b) Existing exposure situations

Example of direct measurement with MC-ICP-MS



Radionuclides	abs. typ	path	Activity* Bq/1400 ml	Sample throughput in 2 days
Am-241	M	Inh	1E-01	100-150
Ra-226	-	Ingest	1E+01	100-150
Np-237	M	Inh	4E-01	100-150
U-238	S	Inh	2E-01	100-150
Th-232	S	Inh	5E-03	100-150
Pu-239	S	Inh	2E-03	100-150

assumption: emergency exposition
**activity to be reproved after 10 days*

Summary

In order to obtain quick informations about a possible intake, it is necessary to use modified routine test methods in the case of emergency measurements. Depending on released radioactive substances testing methods can be used, such as

- ✓ ICP-MS, Low-Level Beta measurements, LSC, Alpha spectrometry (for in-vitro monitoring),
- ✓ Mobile unit: thyroid measurements and mobile in-vivo-counting systems and
- ✓ additional whole-body counting (for in-vivo monitoring).

DTU Nutech
Center for Nuclear Technologies

Influence analysis of air kerma calculations, different environments, deposition scenarios and post deposition mobility of radiocontaminants on the external gamma exposure inside buildings as a part of risk assessment in radiological emergency preparedness

Y. Hinrichsen and K. G. Andersson

1. Introduction

After a release of radionuclides to urban environments the gamma radiation from deposited radioactive substances contributes to the radiation exposure of the population. For the evaluation of this exposure pathway, three main model requirements are needed: (i) the calculation of the air kerma per photon emitted per unit source area, based on Monte Carlo calculations; (ii) the deposition distribution of contaminants on the different urban surfaces; and (iii) their post-deposition migration.

2. Comparison of Monte Carlo calculations from the 1980s with new calculations using MCNP6

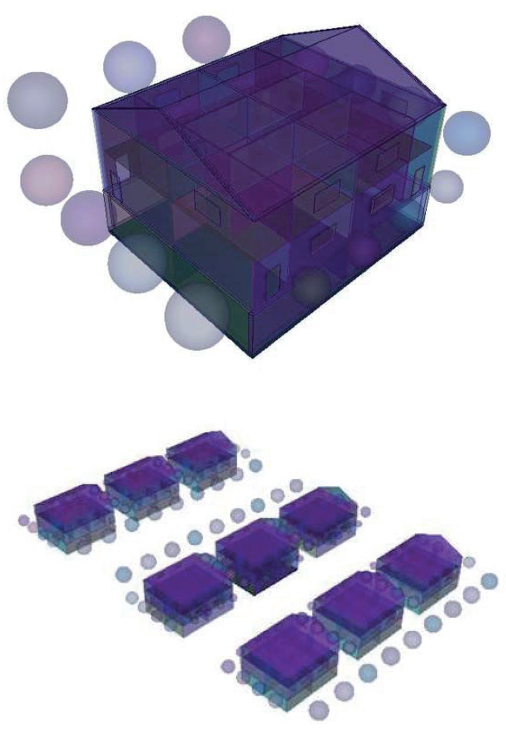


Figure 1: Birds-eye view of the semidetached house without (top) and with (bottom) neighbouring buildings. The spheres indicate the position of the trees.

Most of the air kerma for different types of buildings were calculated in the late eighties by Meckbach et al.. On the basis of the published data the model of a semi-detached house (Fig. 1) was calculated again using the transport code MCNP6.

The calculated air kerma values per photon emitted per unit source area were compared to those published by Meckbach et al.. The deviations were calculated for different source and detector areas and averaged over three different photon energies (Tab. 1).

From the results for the source areas on the house can be assumed that the highest differences of the shielding capability are the walls of the house. This effect can also be seen for the other source regions.

Source area	Detection area: Basement	Ground floor	First floor	Attic
On the house:				
Windows	11%	-59%	-22%	-32%
Walls and doors	-64%	-59%	-84%	-77%
Roof	1%	-18%	-8%	6%
Without neighbouring buildings:				
Ground	-49%	-63%	-73%	-19%
With neighbouring buildings:				
Ground	-58%	-64%	-87%	-87%
Neighbouring buildings	-65%	-78%	-65%	-47%
Trees	-62%	-72%	-94%	-76%

Table 1: Deviation of kerma calculations to previous ones according to source and detection area.

3. Comparison of experimental and calculated shielding factors

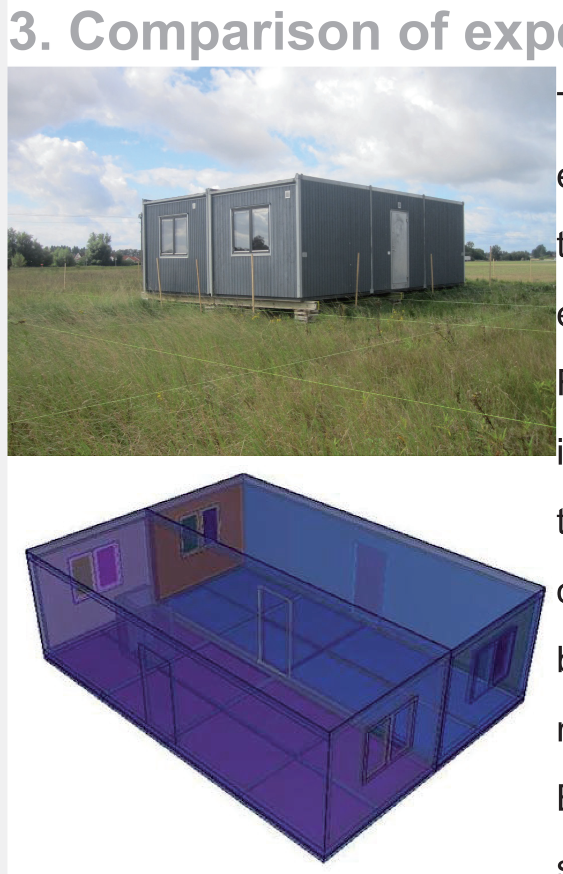


Figure 2: Birds-eye view of the experimental setup of the modular building (top) and the respective MCNP6 model (bottom).

To show the applicability of Monte Carlo simulations for a standard exposure scenario shielding factors for point sources of Cs^{137} on the ground around a modular building (Fig. 2) were determined experimentally and calculated theoretically employing MCNP6. Furthermore, a "inner room" of clay bricks was set up to investigate the impact of heavier building materials. Both shielding factors were determined for four different detector positions and compared with each other. The ratios were plotted in heat maps (Fig. 3) and the averaged ratio was determined to be 1.00 ± 0.01 showing the applicability of MCNP6 for radioactive fallout scenarios.

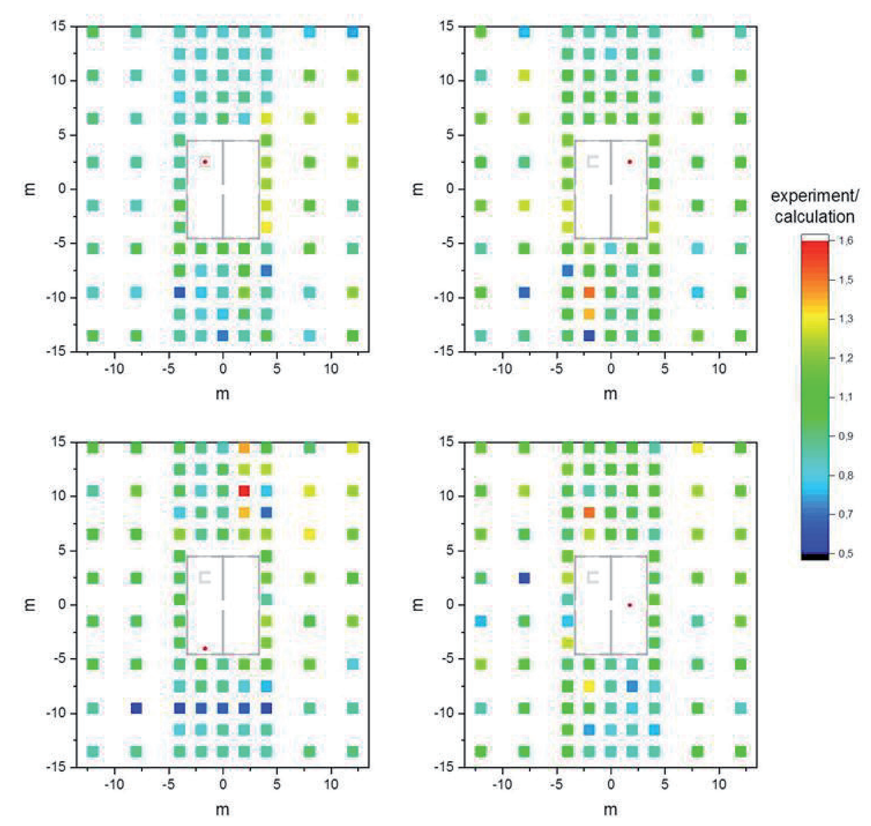


Figure 3: Ratio of experimentally determined to theoretically calculated shielding factors according to source region position around a modular building for four different detector regions inside the modules (red spot) for ^{137}Cs sources on the ground. The U-shape in the top-left corner represents a clay brick structure.

4. Distribution of contaminants on urban surfaces

The relative deposition of particles depends on different weather conditions, the types of surfaces and the characteristics of the contaminants. In combination with the determined air kerma from different surfaces for gamma energies of 0.662 MeV the initial air kerma after deposition was calculated for the different parts of a semi-detached house (Fig. 1) for different deposition conditions assuming once paved ground and once grassed ground. The respective values are presented in Figure 4 for the ground floor as for all other parts of the building air kerma is almost entirely caused by contamination on the roof. Thus, the air kerma inside the building decreases with distance to the roof. The bars show that particles with an activity median aerodynamic diameter (AMAD) >2 µm are causing the highest initial air kerma per unit area contamination, especially those of AMAD 2-5 µm. In general the air kerma caused by a grassed ground is higher compared to a paved ground and apart from wet deposition scenarios the roof is the surface that causes the largest fraction of initial air kerma.

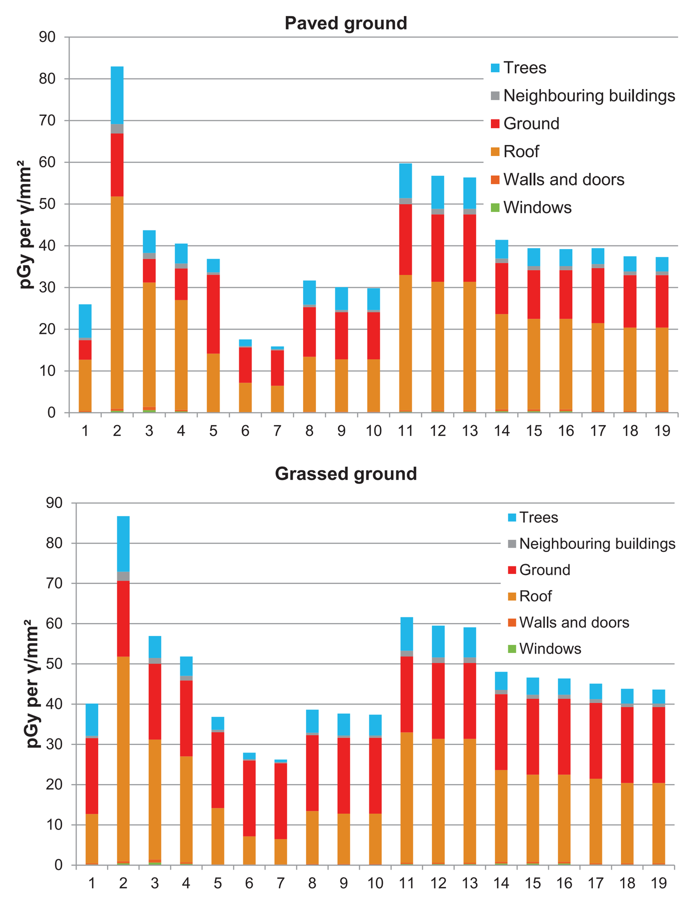


Figure 4: Initial air kerma after deposition in the ground floor of a semi-detached house distributed on different source areas assuming once paved ground (top) and once grassed ground (bottom). Bars 1-4 represent dry, bars 5-7 wet and bars 8-19 an equal amount of dry and wet deposition. Different particle sizes as AMAD are represented for <2 µm in bars 1 and 8-10, for 2-5 µm in bars 2 and 11-13, for 5-10 µm in bars 3 and 14-16 and for 10-20 µm in bars 4 and 17-19. The first run-off of rain water is represented in bars 6, 9, 12, 15, 18 for caesium cations and in bars 7, 10, 13, 16, 19 low solubility particles. The results are given in pGy per emitted photon of 0.662 MeV (^{137}Cs) on a grassed reference surface of 1 mm².

5. Migration of contaminants after deposition on urban surfaces

The migration of deposited particles depends on the types of surfaces and the characteristics of the contaminants and the retention of contamination is commonly described using a double exponential equation. In combination with the pervious results the development of air kerma per unit contamination at the initial deposition was calculated over different time scales for the ground floor assuming an equal amount of wet and dry deposition and particles in form of caesium cations with an AMAD of 2-5 µm as particles of this size shew the highest initial air kerma assuming once paved ground and once grassed ground.

The graphs show that the surfaces that contribute mostly to the air kerma are the roof, the ground, and the trees. After ca. 1 year the contribution of the trees becomes negligible caused by their annual cycle. The roof remains the surface with the highest fraction of air kerma over all time scales, but over time the ground reaches similar importance if it is grassed, whereas it becomes negligible after a few years when it is paved.

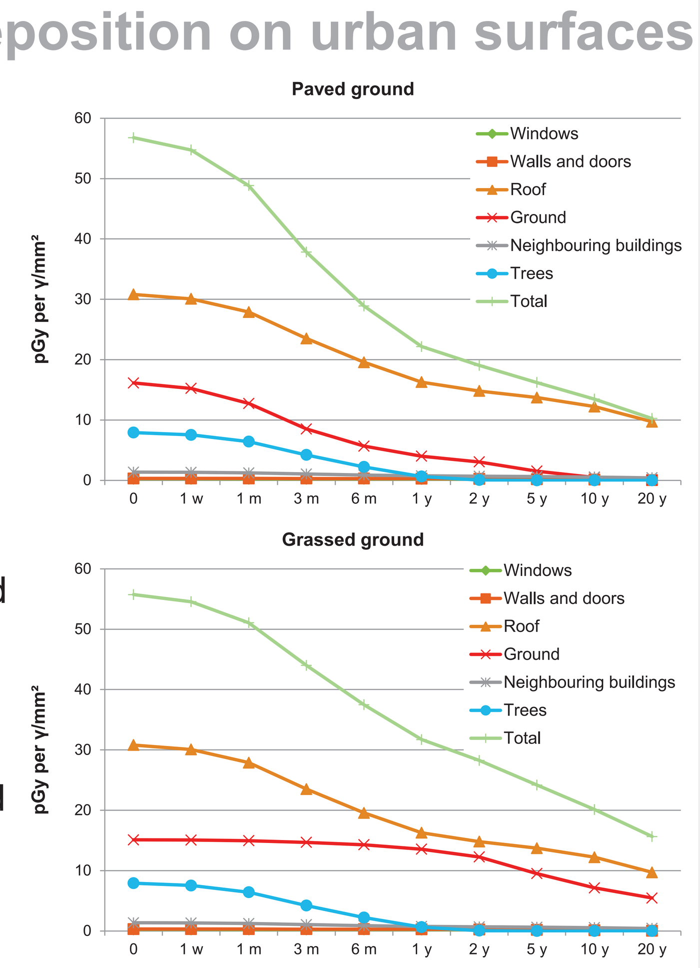


Figure 5: Air kerma development caused by different source areas over different time scales at the ground floor of a semi-detached house assuming once paved ground (top) and once grassed ground (bottom). The results are given in pGy per emitted photon of 0.662 MeV (^{137}Cs) on a grassed reference surface of 1 mm² at the time of initial deposition and the deposited particles are assumed to be ceasium cations with an AMAD of 2-5 µm.

6. Conclusions

The comparison of old and new Monte Carlo shew agreements and deviation within the order of magnitude. From comparing experimentally determined with theoretically calculated shielding factors can be concluded that MCNP6 is applicable for radioactive fallout scenarios. The combination of the calculated air kerma values with data on deposition distribution for contaminants shew the importance of the roof, the ground, and the trees for the intial air kerma inside a semi-detached house after deposition of the radiocontaminants, although over longer time scales only the roof and the grassed ground seem to be of major importance assuming post-deposition migration of the contaminants. Therefore, further radiological parameter studies on the behaviour of contaminants especially on different types of roofs as well as further Monte Carlo calculations are of major interest in urban dose estimation.

ORGANISATION OF THE ENVIRONMENTAL MONITORING: LESSONS LEARNT FROM FUKUSHIMA

Mélanie MAÎTRE, Pascal CROÜAIL and Thierry SCHNEIDER*

GENERAL INTRODUCTION

In post-accident situations, the implementation of the **environmental monitoring is essential**:

- To **characterize** the radiological situation of the environment;
- To help people to **become actors** of their own radiological protection.

Feedbacks from Chernobyl have shown that both institutional and non institutional actors come into play…

… and in Japan? What are the lessons learnt from Fukushima?

OBJECTIVES AND METHODOLOGY

1. Identify the official environmental monitoring strategy implemented in Japan following the Fukushima accident

2. Highlighting local initiatives developed in the affected territories

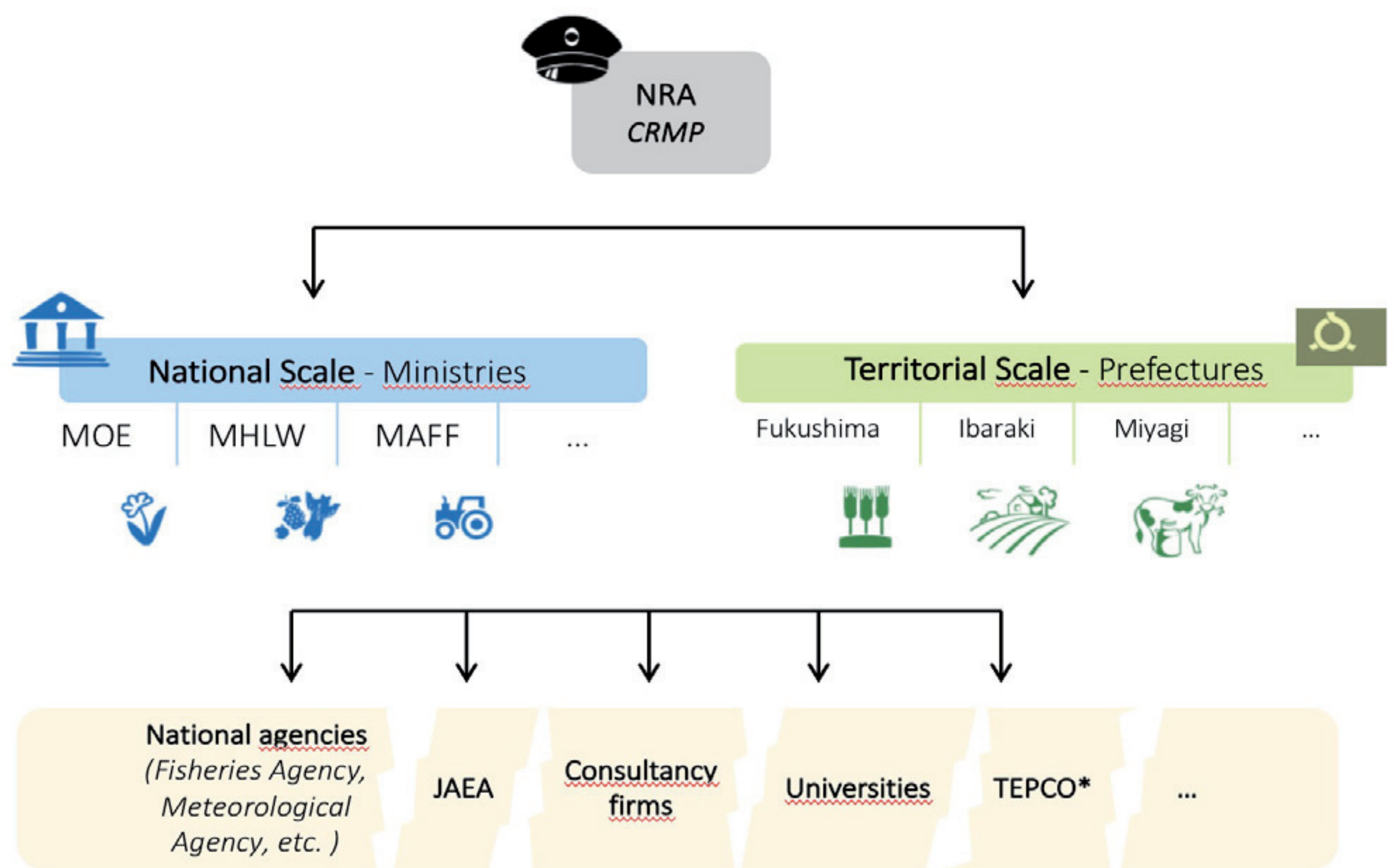
Document reviews, analysis of public environmental data bases, *etc.*

Interviews of both institutional and local actors involved in the environmental monitoring

THE OFFICIAL ENVIRONMENTAL MONITORING SET UP IN JAPAN

- Creation of the ***Comprehensive Radiation Monitoring Plan*** (CRMP) by the Japanese Government on **August 2, 2011** *(updated each year)*.
- Based on former environmental programmes, the CRMP aims to **characterise the radiological situation** of the whole Japan by monitoring all the environmental compartments.
- Coordinated by the Nuclear Regulatory Authority (NRA), the CRMP brings together **various actors from national to territorial scales**. Some of these actors are appointed by the NRA to supervise dedicated environmental surveys, the others support and realise directly the field work.
- Dissemination of the results in various public platforms.

Overall structure of the national environmental monitoring programme set up in Japan since the Fukushima accident.



LOCAL INITIATIVES TO MEASURE THE ENVIRONMENTAL QUALITY

In a context of **mistrust towards authorities and official institutions**, implementation of **various local initiatives.**

By municipalities and local communities

- ✓ Coordination of additional studies to check the results of the official monitoring;
- ✓ Provision of monitoring devices to local populations, with support of RP experts.

By NGOs and citizen networks

- ✓ Proposing various measurements (environmental sampling, foodstuff, WBC, *etc.*);
- ✓ Implementation of open and share environmental data bases (SAFECAST, Mina No Data Site networks, *etc.*).

Local community of Suetsugi village measuring garden products

https://blog.safecast.org/

http://en.minnanods.net/

MAIN LESSONS LEARNT & PERSPECTIVES

- The ***Comprehensive Radiation Monitoring Plan*** **embarks many actors** who publish their results on their own public platform without any interaction. This leads to the publication of **heterogeneous data** which can cause **confusion for the users**.
- The local initiatives produce a **large amount of data** of which the scientific robustness is questionable. However, these results have **all the confidence of local populations** and create a real opportunity for them to **regain control of their daily life**.
- Regarding the **multiplication of measurements and actors** from national to local scale, the current Japanese environmental monitoring seems **redundant**.
- There is a **lack of sharing results** between local initiatives, or even between local and national initiatives.
- **RP experts**, who are involved in both sides (national and local levels) **could play a role in sharing these results**, and try to **better coordinate institutional and non institutional initiatives to a common approach**.

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Radiation incident preparedness of Dutch hospitals

UMC Utrecht

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Introduction

The 2011 Fukushima nuclear incident and increasing terrorist threat underscore the necessity for hospitals to prepare for casualties of incidents involving radioactive material and/or ionizing radiation.

This is also recognised in the International Atomic Energy Agency (IAEA) Safety Standard 'Preparedness and Response for a Nuclear or Radiological Emergency ' (No. GS-R-2) that e.g. provides requirements for 'Managing the medical response'. Paragraph 4.78 requires arrangements for 'initial medical treatment of contaminated or highly exposed individuals in local medical facilities'.

To determine compliance with this requirement the Dutch Poisons Center (PC) assessed radiation incident preparedness of Dutch hospitals in 2015.

Methods

An online survey on resources and knowledge concerning management of casualties of radiation incidents was sent to all Dutch hospitals with a 24/7 available emergency department. Additionally, nine hospitals were visited for an in-depth interview.

Results

The response to the online survey was 67% (58/87 hospitals responded). We divided the hospitals in small (less than 500 beds), large and academic hospitals.

Most responding hospitals are prepared for the care of casualties of radiological incidents (86%). In small hospitals (n=31) the percentage is 77%. Large (n=19) and academic hospitals (n=8) almost all take into account radiation incidents.

About two third of responding small hospitals, three quarter of larger hospitals and all academic hospitals can decontaminate casualties contaminated with radioactive material (see figure 1).

The decontamination capacity is 1-5 persons/hour for most hospitals (83%) with increase in capacity with hospital size (maximum of 30 persons/hour for two larger/academic hospitals).

Most hospitals have indoor decontamination facilities (70%) and a minority has facilities outside (e.g. decontamination tents).
Of hospitals without decontamination facilities 75% have not made arrangements with other hospitals about referral of contaminated patients.

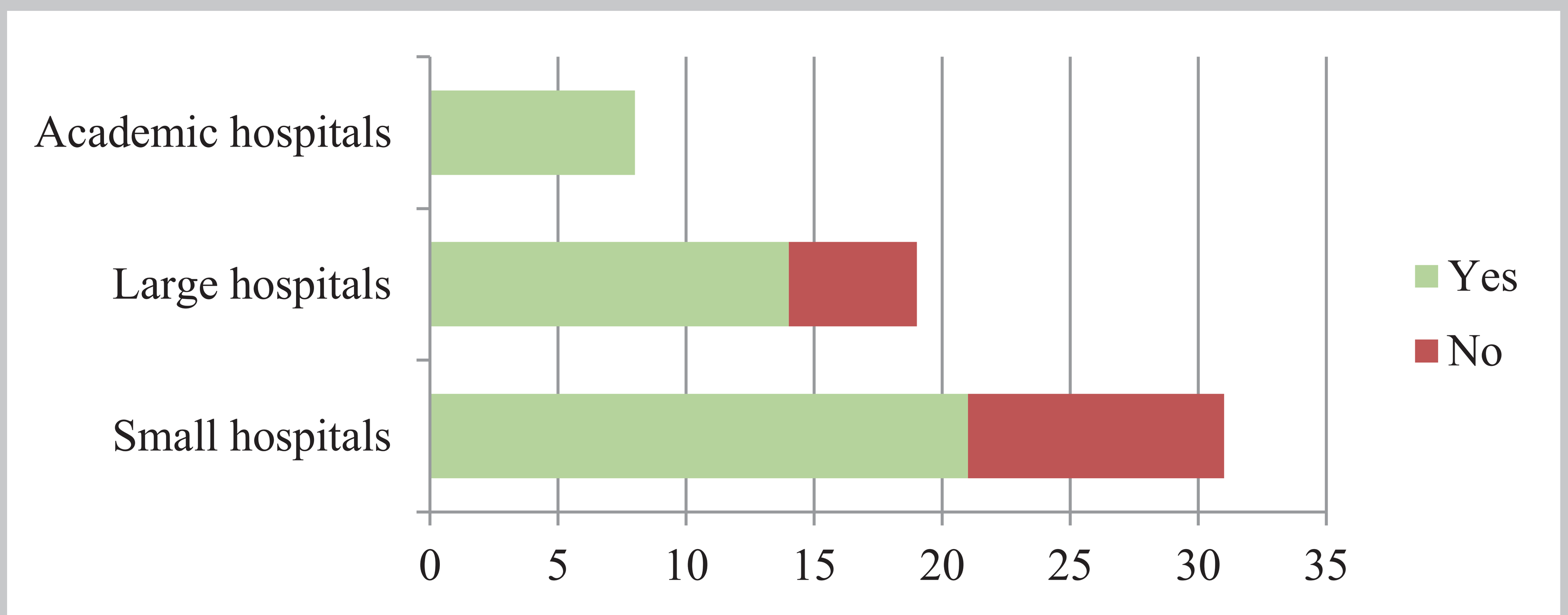

Figure 1: Is it possible to decontaminate casualties contaminated with radioactive materal in your hospital?

Disaster exercise of University Medical Center Utrecht and Major Incident Hospital

Results continued

70% of hospitals describe radiation incidents in a disaster relief plan. The others do have plans for chemical and biological incidents and some are preparing to include radiation incidents. Most hospitals do not specifically perform exercises with incidents in which radiation is involved.

Small hospitals are not able to treat casualties that are internally contaminated with radioactive material. Treatment is possible in over half the large hospitals (57%) and in all academic hospitals. Around half of all responding hospitals know that there is a National stockpile of Prussian Blue and DTPA to treat internal contamination

A majority of hospitals (81%) knows that the Dutch PC advises on patient management after radiation incidents.

The Dutch Poisons Center

In the Netherlands, the Poisons Center plays a significant role in both the preparation on and the immediate response to incidents with radioactive material and/or ionizing radiation.

The PC is officially embedded in the response network for radiation incidents. In case of emergencies with a nuclear power plant, the PC advises on 'Evacuation', 'Sheltering in place' and 'Iodine prophylaxis'.

The NVIC also provides information on decontamination, radionuclide specific treatments and patient management.
A team of radiation specialists is available 24/7 for medical advice in case of exposure to radioactive material or ionizing radiation.

Conclusion

We conclude that in general there is compliance with the IAEA 'initial medical treatment' requirement in Dutch hospitals.

The main recommendation from this study is that hospitals that are not yet prepared, either create decontamination facilities or make arrangements for referral of contaminated victims to a hospital in the region with these facilities.

Additionally, it is recommended for hospitals to make regional arrangements in advance about distribution of larger groups of casualties if their own capacity is limited.

Finally, it is important to include emergency response to radiation incidents in a disaster relief plan and perform exercises.

Restoration of Contaminated Areas in Sweden following an RN Accident

–How to Best Combine Long-term Measures in Order to Protect People in Urban Environments from Radiation while taking Economic and Social Factors into Account

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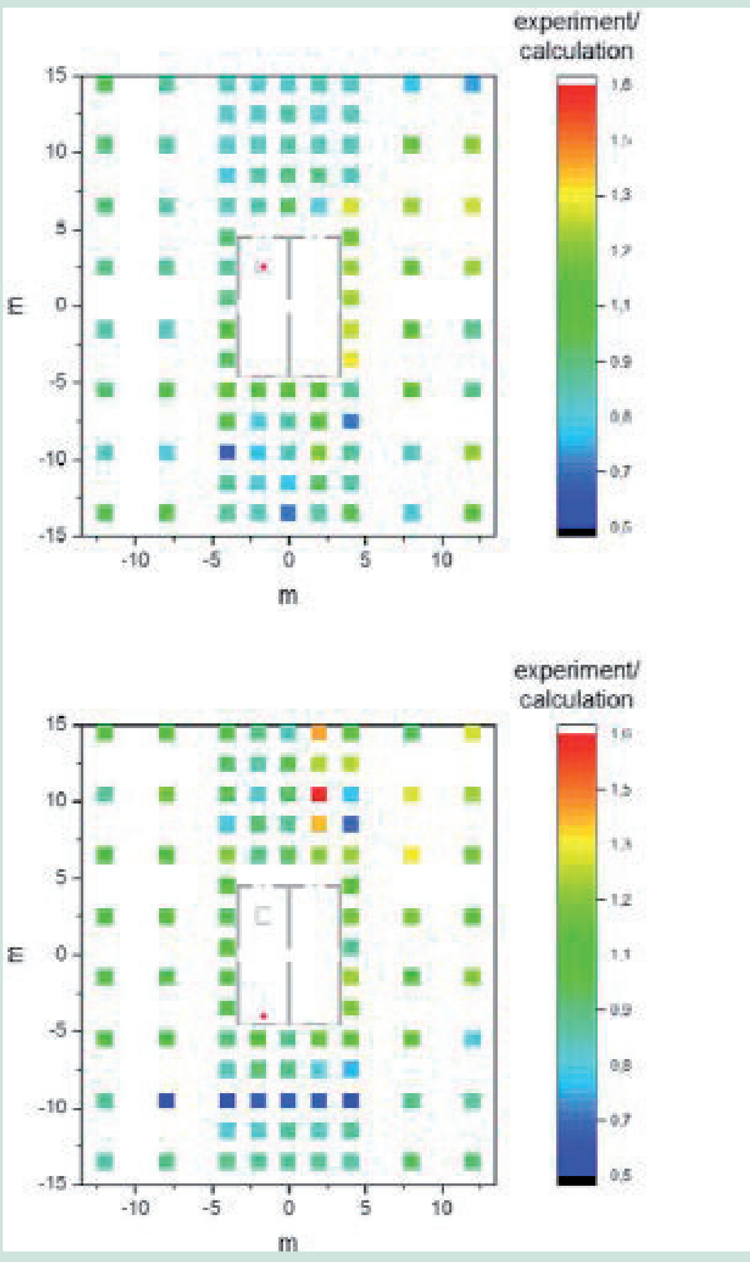

An intradisciplinary research project was started in 2017 with the goal of providing recommendations for decision making of urban environments in Sweden following a radiological or nuclear (RN) incident.

The project aims to provide a tool for easy comparisons between different remediation actions that also includes dynamic costs, specially design for typical Swedish living conditions. A new approach where expected reactions from the public will be taken into account and included in the recommendations of choosing counter measure methods.

MC-computed shielding factors and associated dose reduction by omitting nearby surfaces of uniform deposition of various gamma emitters on a simple modular building have been experimentally verified in a previous Swedish study (Hinrichsen et al., 2018). Continued studies show that the size of the area that would need to be decontaminated increases substantially when raising the dose reduction requirements. For example, to increase the dose reduction from 10 to 30 %, a ten times as large area would need to be decontaminated around a typical Northern European building.

Ongoing work:

- Continued MC-simulations of the shielding factor and dose reduction achieved by decontamination of surfaces on the buildings and the surroundings will be done using drawings from authentic Swedish houses and from a cluster of such buildings.
- Modelling of external and internal radiation doses to people following radioactive fallout
    - Mathematical calibration of a whole body counter with scanning bed geometry
    - Investigate other methods for estimation of whole body burden by measurements in the affected areas, e.g. by medical equipment for nuclear diagnostics
    - Develop a long term program for measurements of members of the public in the affected areas, regarding the extent of the measurements as well as the frequency of repetitive measurements
- Exploring the state of scientific knowledge concerning the nuclear post-disaster phase and risk- and crisis communication
- Analyzing governmental risk- and crisis communication models with affected citizens in the post-disaster phase
- Analyzing the role of mass media and social media content and functions in the post-disaster phase
- In order to be able to assess the costs of remedition actions correctly today (and prepare for them), they have to be put in their context - a process called discounting. We will refine this procedure with regard to a number of factors that relate to what the future looks like:
    - How rich are we in the future?
    - What does the preferences, technology and relative prices look like in the future?
    - How quickly do problems with radioactive substances ”fade"?

References: Hinrichsen, Y., Finck, R., Östlund, K., Rääf, C., Andersson, K.G. Comparison of experimental and calculated shielding factors for modular buildings in a radioactive fallout scenario. Journal of Environmental Radioactivity 189 (2018) 146–155

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SEED: A NUMERICAL SIMULATION TOOL FOR THE DEPLOYABLE EXPERT TEAM CReDO (OPERATIONAL DOSE RECONSTRUCTION CELL)

Service de santé des armées

SPRA

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École Doctorale PHENIICS Doctoral School

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

INTRODUCTION

In the context of a nuclear or radiological accident involving high doses of ionizing radiation, medical teams face two different situations: contaminated patients and irradiated patients. For these casualties, priority goes to the diagnosis because it is essential to know how the dose is distributed among the organs in order to sort the victims according to the severity of the exposure. The victims can consequently be lead to the most appropriate health structures.

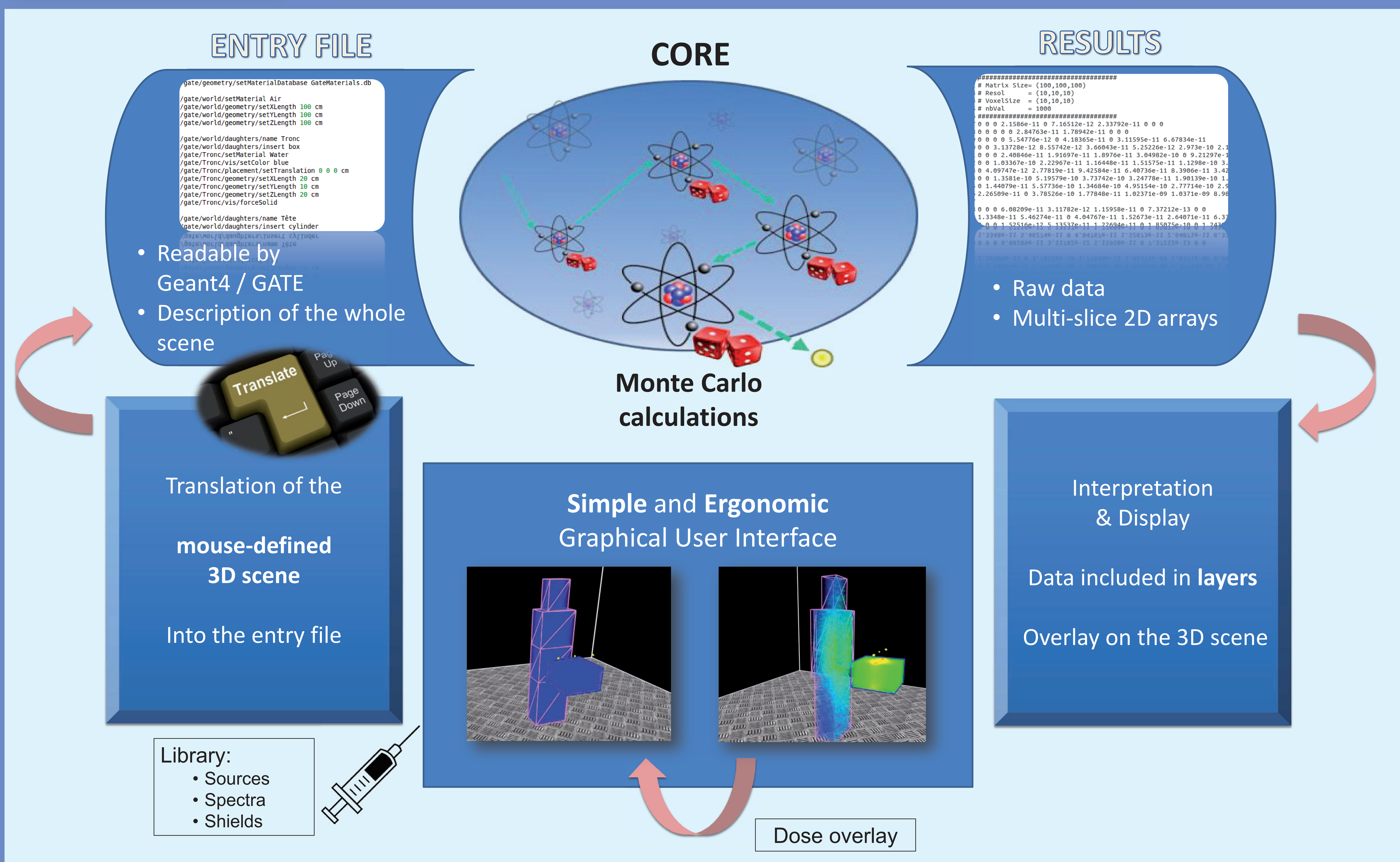
At present there is yet only very few operational techniques that are capable of rapidly characterizing an external radiation exposure[1] in case of an accident involving a large amount of victims. The proven dosimetric tripod (clinical, biological and physical dose assessment) can't be performed today by field teams since it requires expert laboratories (IRSN in France). This makes a space and time distance with the accident scene, that increases the human primary uncertainty. Nevertheless scientific, industrial and military applications as well as terrorist menace generate a significant probability of such an event.

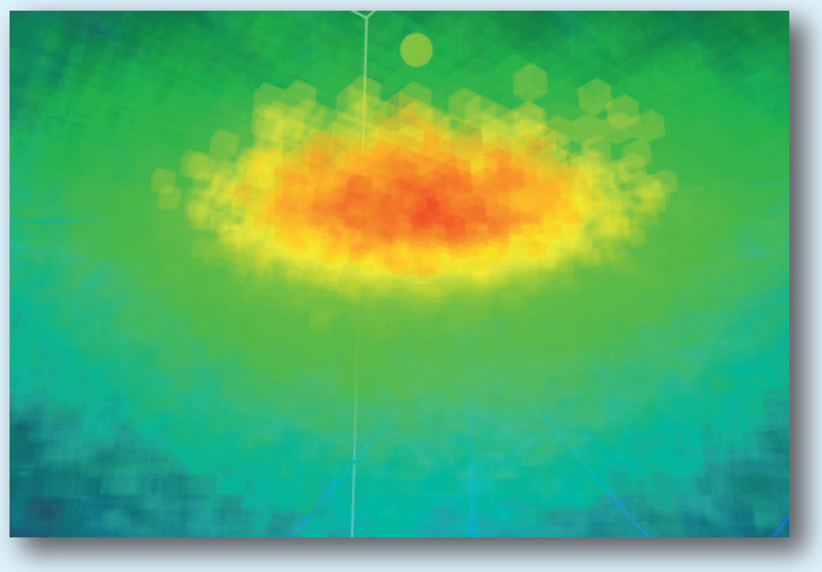
That's why an operational numerical simulation tool is currently developed within a collaboration between SPRA and IRSN. Its name is "SEED": Simulation of external exposures and dosimetry.

MATERIALS AND METHODS

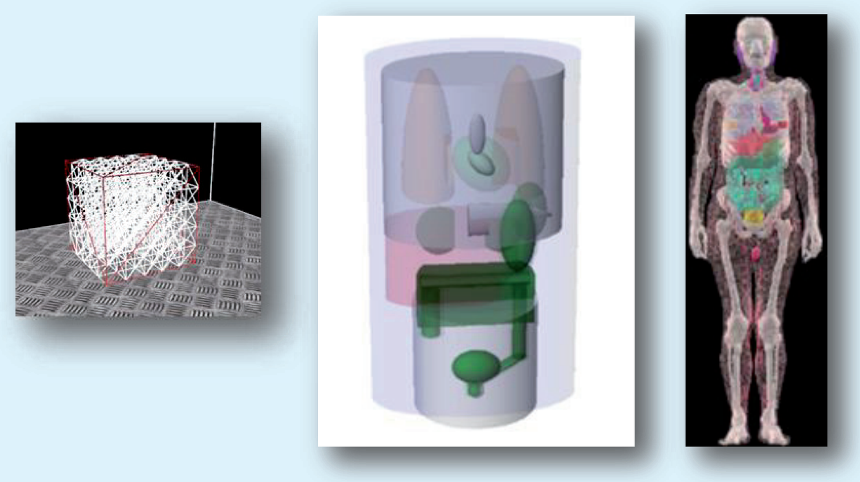
The dosimetric reconstruction tool currently under development uses the Geant4 and the GATE[2] Monte Carlo codes to provide dose maps in the area of an irradiation accident.

An important feature of the simulation device is to be able to operate in highly degraded situations. As it is integrated in a militarized and hardened case, it can be freed from any link to a remote computer cluster thanks to a powerful multicore calculator that allows performing dose simulations with total autonomy.





"Dose fog" is used to represent the dose deposit in the air or inside an object



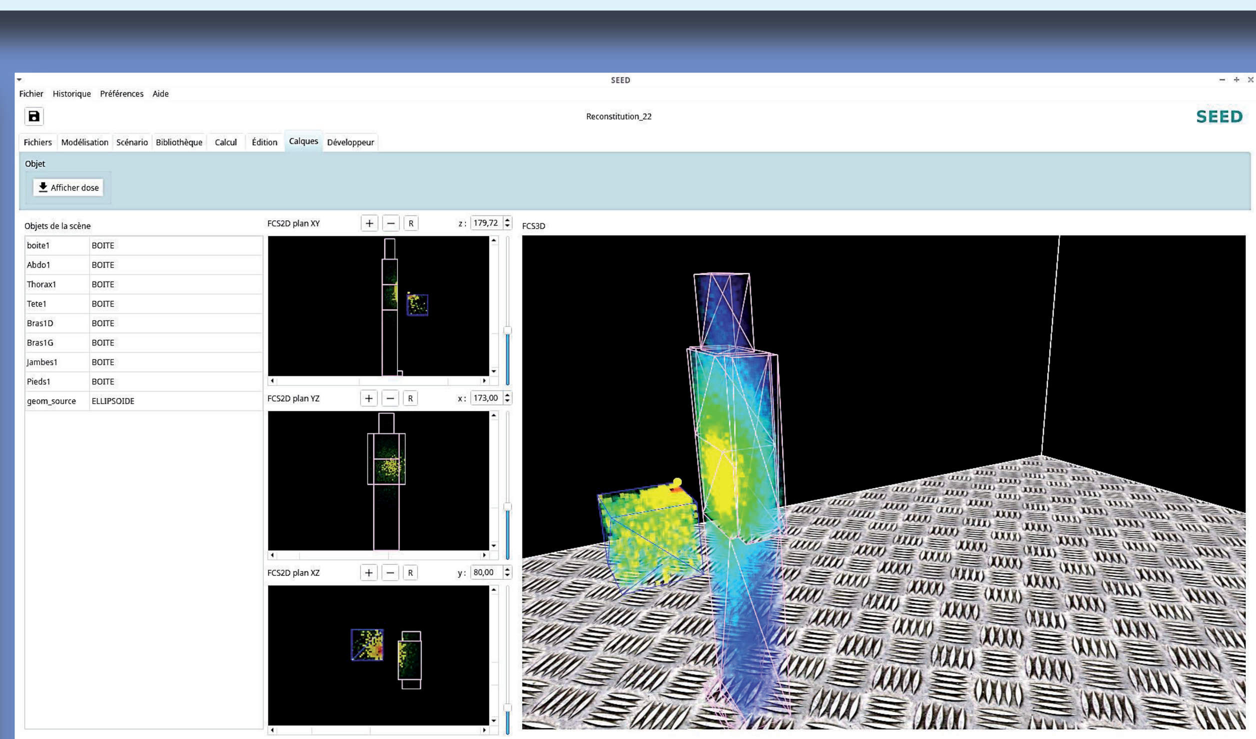
SEED must be compatible with several phantoms according to the objectives and the degree of emergency

RESULTS

Using an intuitive graphical user interface developed by SYMALGO Technologies, trained users will be able to quickly design the scene of the accident, navigating in a 3D virtual world with a first person camera.

This simulation tool is also compatible to work with libraries of sources, voxel phantoms and shielding materials that can be quickly integrated into the modeled scene of the radiation accident.

Numerical filters are currently under development to target the most exposed areas to help medical teams to guide victims through appropriate medical care management solutions.



SymAlgo Technologies

The first 24 hours are decisive for initiating growth factor therapy

DISCUSSION AND CONCLUSION

This numerical simulation tool based on modern technologies for dose calculation is aimed to strengthen the current diagnostic arsenal by meeting the need of on-field dosimetric triage for radiation-exposed victims.

Scientific validation is planned by a two steps procedure:

- Currently, a first validation phase is comparing the SEED results to those of usual Monte Carlo codes (MCNP)
- In 2019, a second validation phase based on standardized scenarios will evaluate the performance of this dosimetric solution for different types of possible external exposure situations

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Stockpile of antidotes for radiological incidents

UMC Utrecht

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Introduction

The Dutch Poisons Centre (PC) has a team of 5 radiation experts who advise on the medical treatment of casualties after incidents with radioactive material and/or ionizing radiation.

After internal contamination, timely administration of a specific antidote is important. The antidote will enhance radionuclide elimination from the body and consequently the radiation dose will be reduced. However, besides a stockpile for stable iodine tablets (to block uptake of radioactive iodine in the thyroid gland after exposure), antidotes to treat internal contamination with other radionuclides were not readily available in the Netherlands until 2011. The delivery time from an antidote producing pharmaceutical company is at least two working days.

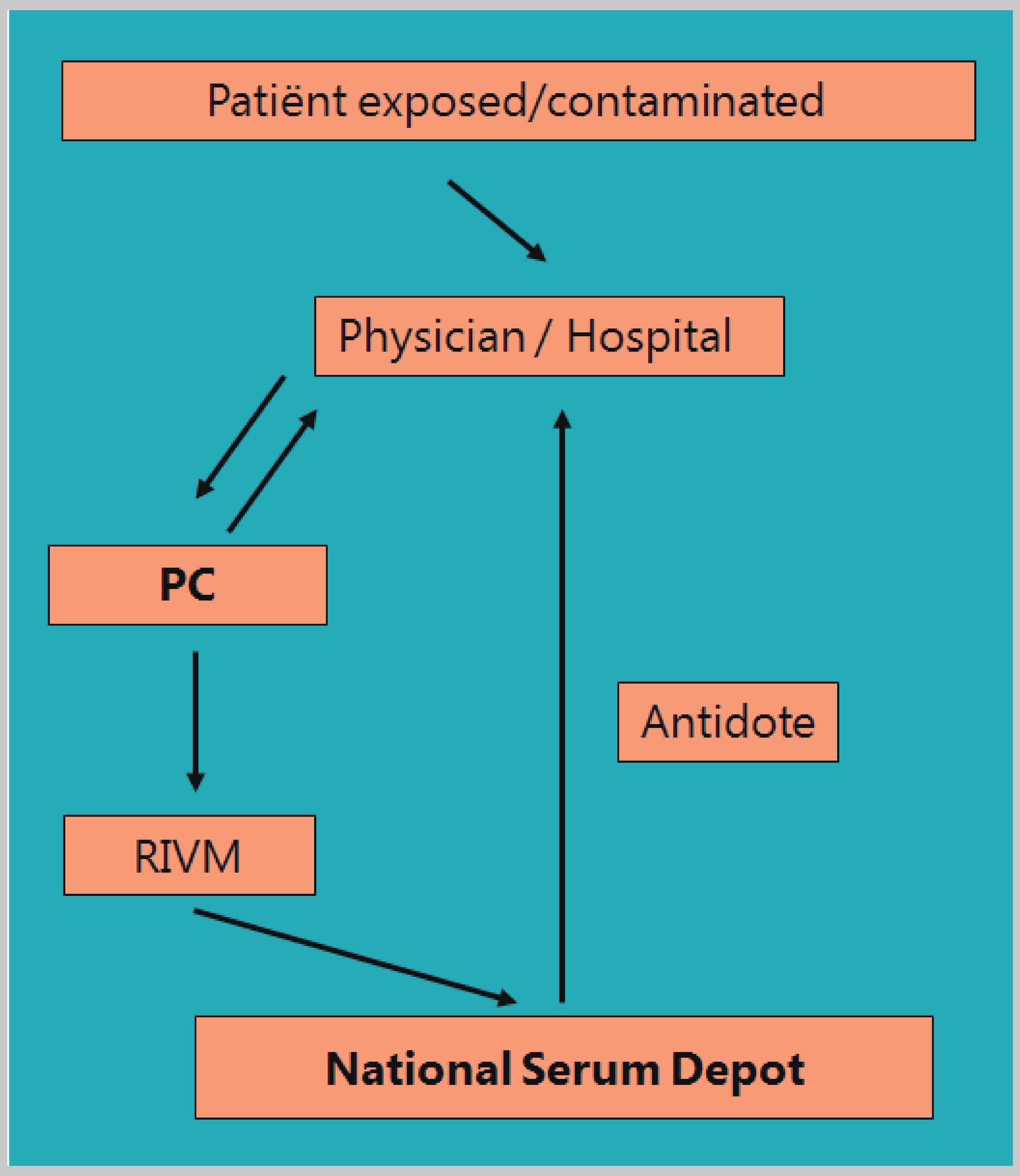
Strategy

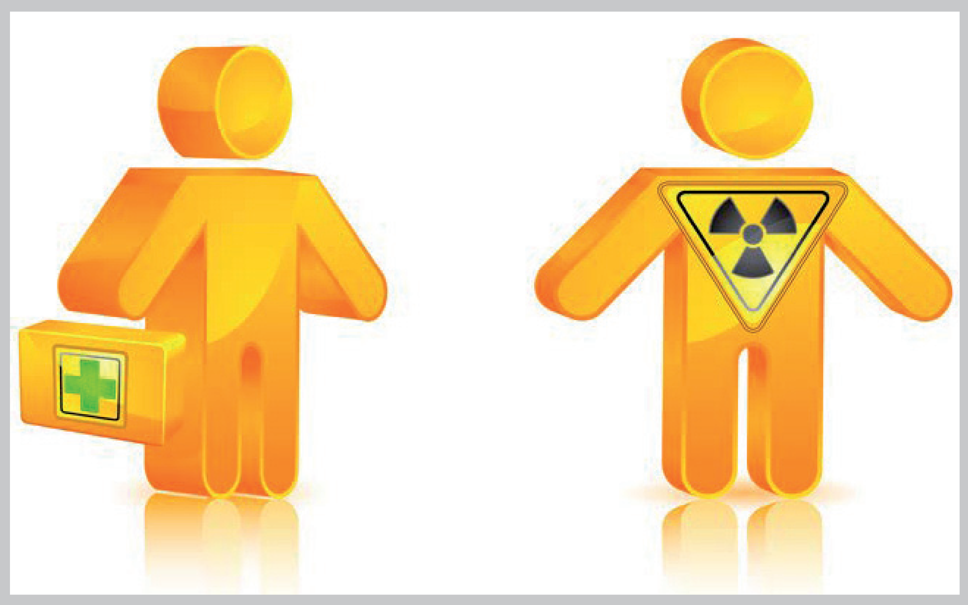
The antidotes considered most useful to have available were Prussian Blue (for cesium and thallium) and DTPA (for e.g. cesium, americium, curium, californium and plutonium). These antidotes cover a wide range of radionuclides, including those most likely used in a dirty bomb (that spreads radionuclides on detonation). For DTPA, the calcium salt (Ca-DTPA) is most effective in the early phase after exposure, while the zinc salt (Zn-DTPA) is recommended for prolonged treatment. A national stockpile of these three antidotes ensures early administration when necessary.

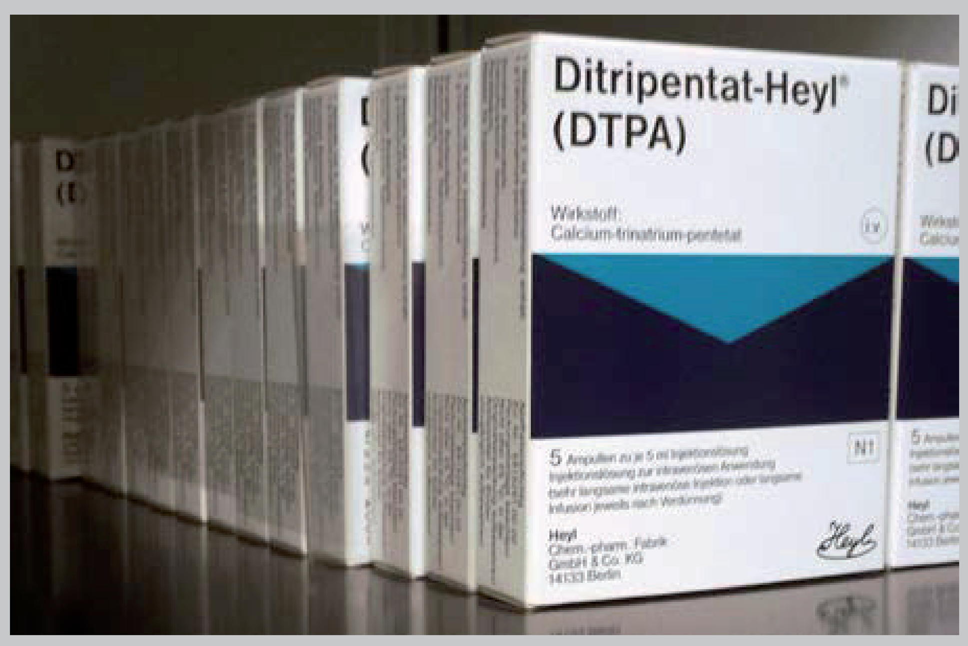
Stockpile

The size of the stockpile was chosen to be minimally sufficient to treat 50 persons during the first 10 days after exposure. This amount is based on a well-known, large incident with a dismantled radioactive cesium source in Goiânia (Brazil).
The Dutch PC advised the Ministry of Health to establish an antidote stockpile with Prussian Blue, Ca-DTPA and Zn-DTPA.
After approval the stockpile was set up at the centrally located National Institute for Public Health and the Environment (RIVM) in Bilthoven. This institute already has a stockpile of antidotes for animal bites and stings with a 24/7 infrastructure for nationwide delivery. There is also a pharmacist available for surveillance.

RIVM & PC







Internal contamination

Internal contamination occurs if radioactive material enters the body by contamination of an open wound, inhalation or ingestion (e.g. contact of contaminated fingers with mouth). This is a hazard after incidents spreading radionuclides in the environment, e.g. detonation of a dirty bomb.

The Dutch Poisons Center

In case of exposure, the treating physician contacts the PC and a PC radiation expert determines whether antidotal treatment is indicated.
The maintenance costs of the radionuclide antidote stock are around 3500 euro/year, taking into account the 5 year shelf life. This is low compared to the benefit such a stockpile can provide. The stockpile was renewed in 2016.

Conclusion

For the direct medical treatment of persons internally contaminated with radionuclides, it is advisable that every country has a stockpile and 24/7 delivery system for suitable antidotes such as Prussian Blue, Ca-DTPA and Zn-DTPA.

RIKILT
WAGENINGEN UR

UAVs in use as a sensor platform during disasters, crisis situations or investigations

Siebren van Tuinen, Sandra Munniks

Introduction

Unmanned Aerial Vehicles (UAVs) equipped with modern measuring instruments can be used to perform measurements at high altitudes in the event of a disaster. Tests have demonstrated that UAVs can be used to conduct measurements of smoke particulates, radioactivity, volatile organic compounds (VOCs) and gases as CO, SO_2 and NH_3 in the event of a chemical fire or environmental accidents.

One major advantage of using UAVs is that they reduce or even completely eliminate the need to send first responders to the area. As a result, first responders are not exposed to dangerous contaminant levels, while retaining the ability to perform measurements close to the source in the 'danger zone'.

Figure 1: Field experiments in Belgium (left) and the current sensors of the drone (right): (L:) In 2017 and 2018 field experiments were performed with several types of radiation detectors on NORM enhanced fields. (R:) Besides the sensors a microprocessor and data transfer devices are integrated in the design.

The setup of testing and results

Several tests with different radioactivity detectors were performed. The tests were performed with a Cs-137 source where the drone was flying over, registering the dose rate.

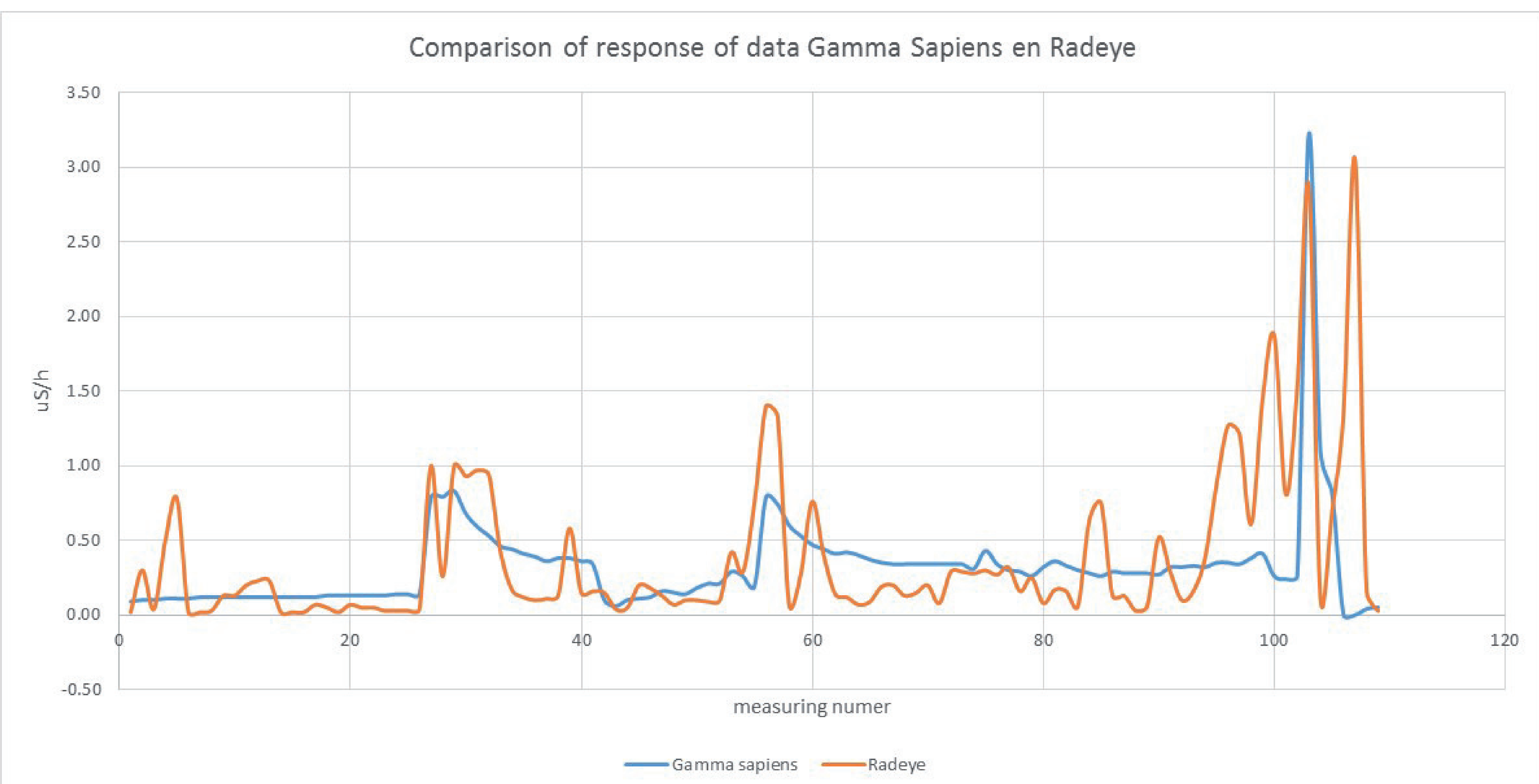


Figure 2: Test flight of the drone with different detectors

Collected data

Data obtained by the drone is transmitted wireless to allow real time processing and visualisation. The software is designed to calculate concentrations and to translate those numbers into a potential risk. The data can be projected on topographic maps to allow a faster and more accurate interpretation of a potentially hazardous situation.
The responses of the gas sensors are individually tested using different gasses in a controlled environment. Results show a correlation between concentration and the read-out of the sensors, resulting in a concentration calculation.
The dust sensor and radioactivity sensors are tested on laboratory scale and are ready to be used on the drone.

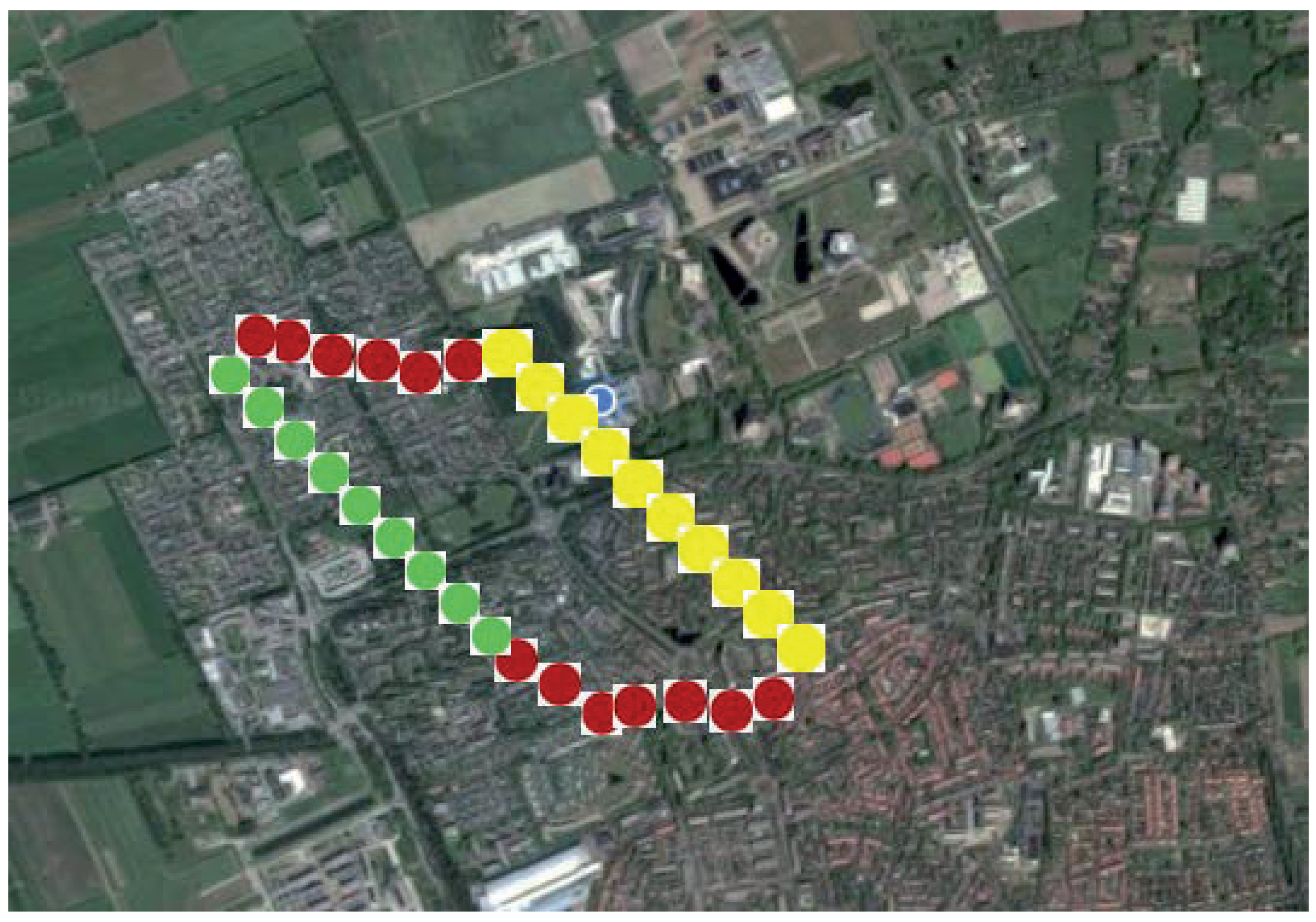


Figure 3: Results of test flights using the sensors. Data point are displayed real-time on a ground station in a graph that can be overlaid on a topographic map of the area to visualise the shape of the cloud. Green dots mean no direct risk for the environment, red dots mean a potential risk for the environment.

Future work

The next steps in the research is to add other sensors to the sensor array and to test more advanced sensors on laboratory scale with the smelly box. Furthermore the functionalities are expanded with an automatic sample intake system. These samples, taken in TEDLAR bags, can be analysed with special field equipment or with specialised analysis techniques (for instance LC, GC, ICP, NMR) at a laboratory.

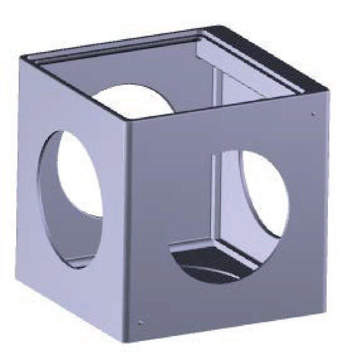


Figure 4: The TEDLAR bags and the smelly box for laboratory tests

Acknowledgments

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Variance and sensitivity analysis of food-chain models

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Introduction

Artificial radionuclides are produced by nuclear explosions and nuclear facilities, if released into the environment, may reach the human body through several transfer pathways is considered as one of the important routes through which radionuclides can enter the human body via food-chain. To minimize the radiological consequences from radioactive materials released into the environment, the reliable dose assessment is essential. All environmental assessment models, which can describe the transport of radionuclides from a source through the calculation of dose to the public, only simulate approximate real-world phenomena due to physically complex systems. Additionally the parameter values in models are inherently uncertain from improper parameter estimation, and stochastic effects due to random measurement and sampling errors or natural variation. Understanding of these uncertainties is required to effectively interpret model prediction. The sensitivity analysis involves the determination of the change in the response of a model to change in individual model parameter. Thus, it is a procedure for improving the reliability of model predictions and saving a major effort in the collection of relevant data by identifying the main contributors of input parameters to model predictions.

Materials and methods

The model is based on a compartmental approach from IAEA SRS 19. [1]. The uncertainty of the applied parameters influences the accuracy of the results, depending on the model, to a smaller extent, to determine it using by Partial Rank Correlation. It is necessary for the sensitivity analysis of input parameters to specify several items including the distribution of parameter values and the correlation coefficient between input parameters. The sensitivity indices calculated from rank-transformed values are more effective for representing a variety of relationships between parameter values (X) and model outputs (Y), and for minimizing the effects of extreme values than those calculated from actual values. Such a correlation coefficient is called the partial rank correlation coefficient (PRCC).

$$\rho_{12} = \frac{\sum (r_{x1i} - \frac{n+1}{2})(r_{x2i} - \frac{n+1}{2})}{\sqrt{\sum (r_{x1i} - \frac{n+1}{2})^2 \sum (r_{x2i} - \frac{n+1}{2})^2}}$$

The strength of a simple linear relationship in ranking r_x between variable X_1 and X_2 in usually measured with ρ, called Spearman's rho is expressed in Fig 1. PRCCs can be obtained from correlation matrix and inverse correlation matrix based on Fig 2. PRCCs were calculated with 300 different parameter sets yielding a distribution of 300 model outputs using Latine hypercube sampling (LHS) technique based on a Monte Carlo approach.

Fig 2.: Correlation amtrix and inverse correlation matrix.

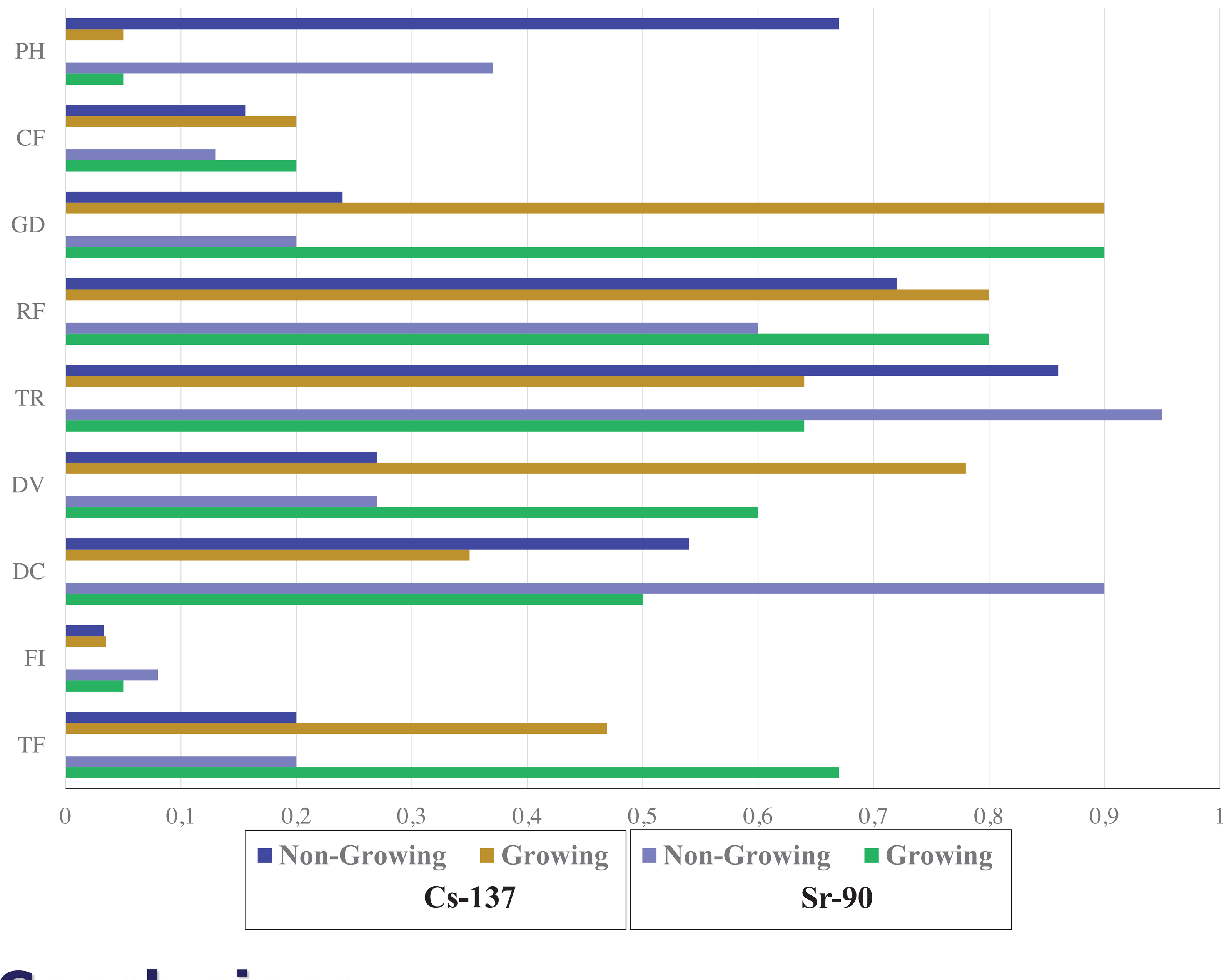
$$\begin{matrix} & X_1 & X_2 & & Y \end{matrix}$$

$$R = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1k} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2k} \\ \cdots & & & \\ \rho_{k1} & \rho_{k2} & \cdots & \rho_{kk} \end{bmatrix}$$

$$R^{-1} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1k} \\ b_{21} & b_{22} & \cdots & b_{2k} \\ \cdots & & & \\ b_{k1} & b_{k2} & \cdots & b_{kk} \end{bmatrix}$$

$$PRCC_{ij \cdot (allothers)} = -\frac{b_{ij}}{\sqrt{b_{ii} b_{jj}}}$$

Results and discussion



The sensitivity analysis of input parameters for food-chain models [1-2] was performed as a function of deposition coefficient and transfer factors for the long-lived radionuclides (Sr-90, Cs-137). The input parameters were used from different databases [2-3]. The influence of input parameters for short and long-term contaminations of the foodstuffs after a deposition was also investigated. In deposition during growing stage of agricultural plants, the parameters associated with contamination by foliar absorption were relatively influential in long-term contamination as well as short-term contamination. They were also influential in short-term contamination in case of deposition during non-growing stage.

In our calculations, we were the most conservative approach to the realistic (best estimate) modeling conditions, which in practice meant that the calculation results declined significantly, up to several orders of magnitude. The influence of parameters with different deposition times and contamination periods is primarily caused by growth characteristics of agricultural plants, behavior characteristics of radionuclides in the environment, and breeding practices and metabolism of cattle.

Conclusions

PRCCs were strongly dependent on the contamination period of foodstuffs as well as the deposition time of radionuclides.
The results of this study may be serve as a useful information for improving the reliability of predictive results and saving a major effort in the collection of relevant data by identifying the main contributor of input parameters to model results.

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Security

A THIRD LIMB OF INFLUENCE TO IMPROVE THE ADOPTION OF RADIOACTIVE SOURCE SECURITY AT THE GLOBAL LEVEL

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Summary

- Currently, processes to define standards take place **without direct participation of operational stakeholders.**
- The resulting **effectiveness**. of radiological security is **not progressing** as expected.
- The challenge: **how to reach and recruit the operators** to exercise **ownership** of the security **principles** that have been given **international priority?**
- There is a need for **closer interaction** among all **stakeholders** involved in operations and processes of for radiological security; i.e. **operators**, **manufacturers** and **associated professionals** as a **third limb** of the radiological security foundation.
- **New initiatives are required** to mobilize operators, manufacturers and manufacturers in **support** of **improved radioactive source security** at the **global** level.
- It is **time to add a new, "bottom up" approach** in which **operators, manufacturers and associated professionals** are invited to contribute **directly** to the international framework for radiological security.
- **A pre-requisite**: **industrial standards for security** measures for radioactive sources that could be **adopted directly** by practitioners.

The solution?

The **missing limb** in establishing effective radiological security is a **ground-level involvement of operators, manufacturers and associated professionals** in wider **dissemination**.

This can be achieved in two steps:

- **Development of appropriate international industry standards** for radiological security, for radioactive sources used in the civil sector, and by
- proactive **enhanced engagement with the wider professional communities** with the aim to engender **deeper understanding** and **competence at the practitioner level**.

This could work **complementary to the regulatory body** and other competent authorities.

Promoting the establishment of **international industry standards**, consistent with international legal undertakings and national regulations, is not only a **pre-requisite to wider dissemination** but has the **collateral benefit** of increasing **practitioner level engagement**.

The drivers

Security of radioactive materials has been **high priority** since the threat-landscape changed on **11 September 2001**.

Radioactive sources became **recognized** as potential tools for terrorists to **cause death and disruption.**

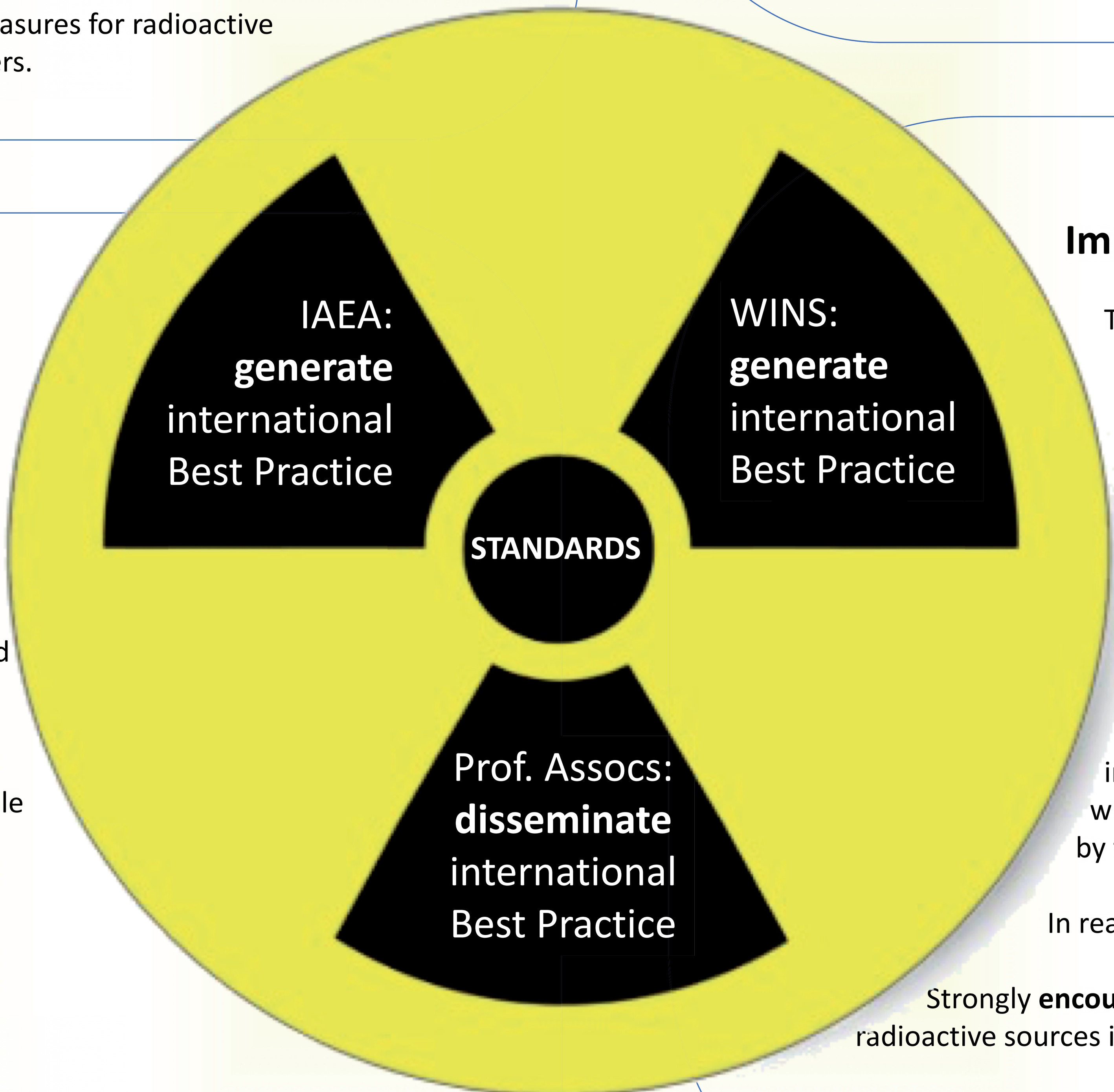
Since then, the **international community** has invested In **strengthening security of radioactive sources**, to keep them out of the hands of **terrorists.**

These investments are of various forms. A considerable body of work has been undertaken in various for a.

Examples include:

- **Legally binding undertakings**:
  - **International Convention on the Suppression of Acts of Nuclear Terrorism** (2007)
  - **Amendment to Convention on the Physical Protection of Nuclear Material** (2016),
- Non-binding instrument:
  - **Code of Conduct on the Safety and Security of Radioactive Sources** .
- The **IAEA's comprehensive** suite of nuclear **security guidance**, and
- Programmes of **bilateral assistance** to both **strengthen human resource development** and **upgrade** physical protection of radioactive sources
- Four **Nuclear Security Summits**, (2010 to 2016) - Heads of States and international organizations addressed threat of radiological terrorism and **agreed on measures** to **strengthen security** implementation.

Despite this, 17 years after the "9/11", the level of radiological security implemented in a **globally** is still variable, and **within states**, levels of **knowledge** and **engagement** remains **highly variable**.



Implementation

This engagement could be mediated via **new forums** of **consultation** and **professional development**, using the **professional associations**.

Industrial standards on radiological security would approaches, set a level of **in-device protection** and **project** the security arrangements within which the devices are to be used.

The **special challenges** associated with security in the civil sector, e.g. **productivity** in medical treatments, a friendly **safe environment** that allows people to move and in which **medical emergencies** must be responded to without delay, could be much **more efficient** when supported by those that have **direct responsibility** for its effectiveness.

In real terms, this means:

Strongly **encouraging development** of **meaningful security standards** for radioactive sources in **use, transport** and at **end of life**, and

providing **development material directly** to **IRPA** Associate Societies, **security professional association**s, **manufacturers federations** and other **similar** groups.

The challenge

Involve more the **operators, manufacturers and associated professionals** in the building of global, effective**, radiological security**.

Still to be crystallised:

- An **international, industrial standard on radiological security**.
  - a **prerequisite** to **consistency** of **delivery** and **outcomes**.
- More resource and proactivity injected by, **relevant professionals**.
- **Development of effectiveness** of the relatively limited knowledge dissemination mechanisms
  - (IAEA, WINS and others),
- **Additional hubs for education** and training through **long-term investments**

Conclusions

- Recognizing the **considerable efforts** expended **internationally** and **nationally** in support of the radiological security foundation, it **is disappointing** that more **progress at ground level** has **not been achieved.**
- Something else is clearly required: it is **time** to initiate an **additional approach**
- Across the groups of **operators, manufacturers and associated professionals,** there is a **considerable resource** that is **currently untapped.**
- The current **major influencers (IAEA, WINS)** could **harness** this resource in **two ways:**
  - Firstly as a **resource to develop meaningful security standards** for the protection of radioactive sources, but also
  - As a **conduit for dissemination** of the considerable **existing body of knowledge** at **operational** level.
- The **aspiration** is that **effective radiological security** could be implemented **wherever radioactive sources** are used or stored, in **all states**, even without a statutory system of regulation. **IRPA Associate Societies would be one important mechanism to achieve this**.

Analysis by Monte Carlo of Thermal Neutron Flux from a $^{241}Am/^{9}Be$ Source for an Explosive Detection System

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IRPA 2018

POLITÉCNICA

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Abstract

A thermal neutron irradiation system has been designed, based on an $^{241}Am/^{9}Be$ source with cylindrical polyethylene moderators. The system has an irradiation cavity, allowing to take advantage of backscattered neutrons; with a source having a nominal emission rate of $6.4\times10^{6}\cdot s^{-1}$, thermal fluence rates up to 530 $cm^{-2}\cdot s^{-1}$ are obtained. Using Monte Carlo techniques (MCNP6 code) three different configurations were simulated using polyethylene cylinders. Once the geometric configuration of the system has been optimized, the model has been replicated experimentally in the neutron measurements hall of the Energy Engineering Department of Universidad Politécnica de Madrid (UPM), performing several measurements with a miniature BF_3 detector and using gold foil-cadmium.

The aim of this work has been the design of the system and its geometry, maximizing the thermal neutron flux for the intended purpose of using it for explosives detection applying the PGNAA (Prompt Gamma Neutron Activation Analysis) method.

Materials and Methods

- An $^{241}Am/^{9}Be$ neutron source, high-density polyethylene (HDPE) cylinders of 4 different sizes and a miniature BF_3 neutron detector (NC-202) have been used to produce, moderate, and detect the neutrons **(figure 1).** The BF_3 detector is practical since the ^{10}B capture cross-section for thermal neutrons is 3.837 barns and the released energy of over 2 MeV is transferred as kinetic energy to charged particles (α + ^{7}Li) that are fairly easy to detect [5].
- The experiment was simulated with the MCNP6 code, including the source`s cladding, its support, and the irradiation bench **(figure 2)**, taking advantage of previous extensive calculations [6]. The total neutron fluence rate was obtained by using the Monte Carlo spectra multiplied by the source strength.
- The neutron spectra produced by a 111 Gbq $^{241}Am/^{9}Be$ source were measured at 10, 20, 30, 40 and 50 cm, in order to obtain as many neutrons as possible. The 3 HDPE cylinders with different diameters fit one out of the other, and a last one was added as shadow cylinder; the fluxes and the distance were measured from the source center.
- To complement measurements, the thermal fluence rate at a distance Z=27cm was measured by activating ^{197}Au foil without and with cadmium cover, counting the delayed activation gamma-rays of 0.4118 MeV with a NaI(Tl) detector **(figure 3).**

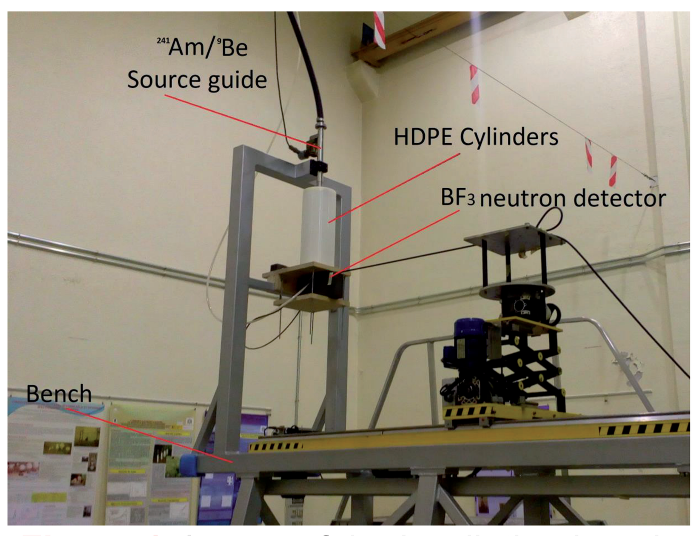


Figure 1. Image of the irradiation bench with the HDPE cylinders and the BF_3 neutron detector.

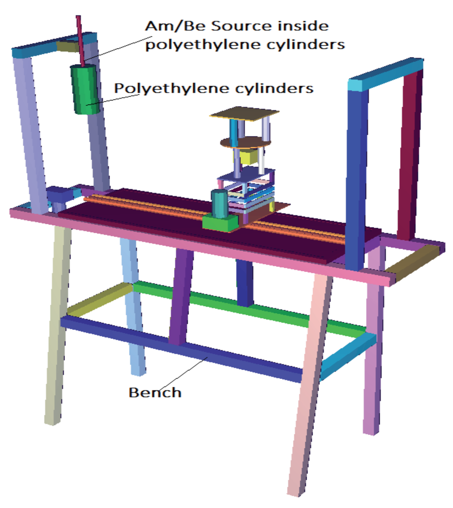


Figure 2. Scheme of the MCNP6 model of the irradiation bench with the source and HDPE cylinders.

Figure 3. Experimental arrangement to activate and measure the Au foils.

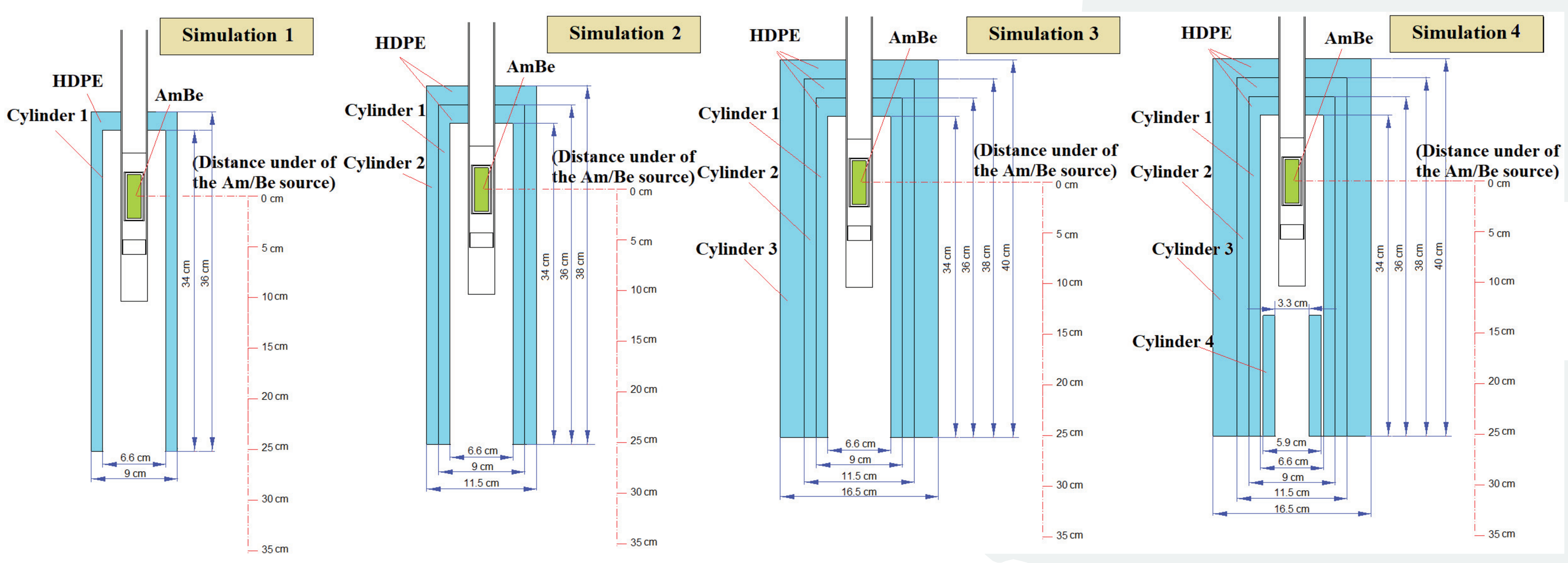


Figure 4. Scheme of the configurations of the system showing the HDPE cylinders used for each experiment and in the four simulations.

Introduction

PGNAA is a non-destructive analysis technique which provides both qualitative and quantitative information about the studied sample material [1]. The constituent elements of the sample absorb neutrons and the excited nuclei emit prompt gamma rays when returning to an equilibrium state which are measured with a gamma ray spectrometer [2]. The energies of the gamma rays identify the elements, while the peak intensities are proportional to their concentrations.

Moderator materials are required to reduce neutron energies to the thermal range in order to increase interaction between neutrons and sample atoms. Polyethylene shows an excellent attenuation behaviour thermalizing fast neutrons [3]; it is also a very effective neutron shielding material. To detect substances by non-intrusive or non-destructive methods, it is necessary to have low energy neutrons flux above 10^{3} $cm^{-2}.s^{-1}$. When the source intensity is low, the neutron flux can be increased by using the backscattered neutrons, through collisions in the walls of a cavity [4].

Results

- The thermal neutron fluence rate was measured at points along the main axis at distances Z = 29, 30, 31, 32, 33, 34, 35, 36, and 37 cm, for each configuration, as indicated in **Figure 4.** Note that for configuration 4, the fourth cylinder is inside the first one.
- Calculation results are shown in **Table 1**. Experimental measured values with the BF_3 neutron detector are shown in **Table 2.** The most efficient is configuration 3.
- A comparison of calculated versus measured values for configuration 3 is shown in **Figure 5.** Fluence rates obtained with MCNP6 for E<0.4 eV are compared against the experimental values at the selected distances obtaining a good agreement.
- With the technique of ^{197}Au foil-cadmium at distance Z=27 cm the obtained thermal neutron flux was of only 317 $cm^{-2}\cdot s^{-1}$, due to the wood layer used. This indicates that the experimental arrangement should be improved.

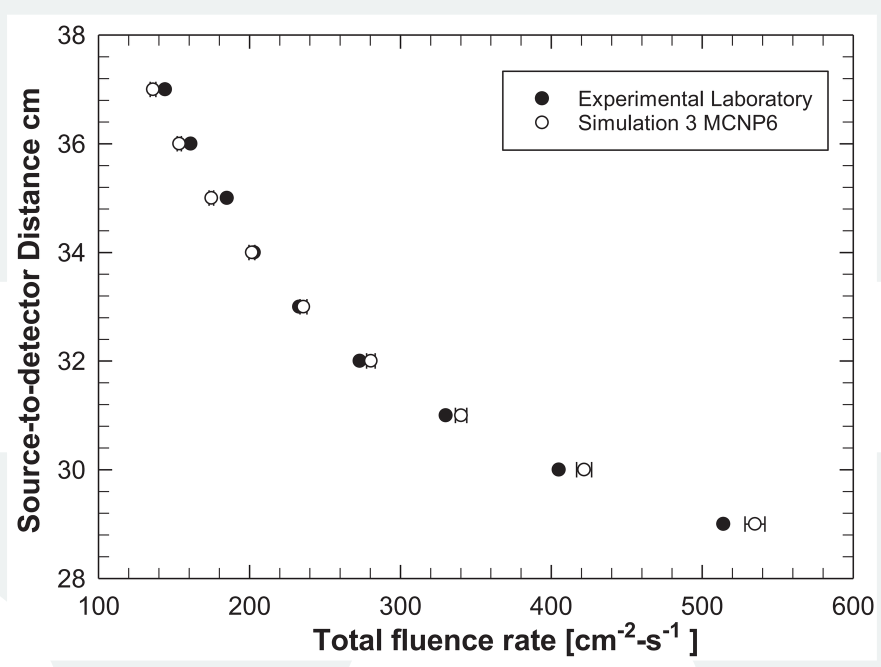
Table 1. Results of MCNP6 calculations for the four simulations, values of thermal fluence rate (E < 0.4 eV) at the center of different irradiation planes

	Simulation 1		Simulation 2		Simulation 3		Simulation 4	
	Cylinder 1	Uncertainty	Cylinder 2	Uncertainty	Cylinder 3	Uncertainty	Cylinder 4 (shadow)	Uncertainty
	Values low energy neutrons (E < 0.4 eV)							
Distance cm	$[cm^{-2}. s^{-1}]$	$\pm [cm^{-2}. s^{-1}]$	$[cm^{-2}. s^{-1}]$	$\pm [cm^{-2}. s^{-1}]$	$[cm^{-2}. s^{-1}]$	$\pm [cm^{-2}. s^{-1}]$	$[cm^{-2}. s^{-1}]$	$\pm [cm^{-2}. s^{-1}]$
29	6.87E+01	2.25E+00	2.42E+02	4.48E+00	5.35E+02	6.63E+00	1.32E+02	1.34E+01
30	5.58E+01	1.66E+00	1.92E+02	3.29E+00	4.22E+02	4.94E+00	9.81E+01	8.30E+00
31	4.63E+01	1.26E+00	1.56E+02	2.46E+00	3.40E+02	3.74E+00	7.68E+01	5.77E+00
32	3.92E+01	1.00E+00	1.29E+02	1.95E+00	2.80E+02	2.88E+00	6.25E+01	4.24E+00
33	3.38E+01	7.70E-01	1.10E+02	1.62E+00	2.36E+02	2.28E+00	5.21E+01	3.28E+00
34	2.96E+01	6.29E-01	9.44E+01	1.21E+00	2.02E+02	1.91E+00	4.44E+01	2.59E+00
35	2.63E+01	5.56E-01	8.25E+01	9.99E-01	1.75E+02	1.53E+00	3.85E+01	2.11E+00
36	2.37E+01	4.41E-01	7.29E+01	8.43E-01	1.53E+02	1.35E+00	3.38E+01	2.02E+00
37	2.15E+01	3.76E-01	6.51E+01	7.29E-01	1.36E+02	1.87E+00	3.01E+01	1.58E+00

Table 2. Measured values of thermal fluence rate (E < 0.4 eV) at nine points along the main axis for configuration 3 (measuring time: 600 seconds at each point)

Values obtained in the bench		
Thickness HDPE cylinder 9.9cm		
Distance	Flux	Uncertainty
cm	$[cm^{-2}. s^{-1}]$	$\pm [cm^{-2}. s^{-1}]$
29	5.14E+02	6.87E+00
30	4.05E+02	6.09E+00
31	3.30E+02	5.50E+00
32	2.73E+02	5.00E+00
33	2.33E+02	4.62E+00
34	2.03E+02	4.32E+00
35	1.85E+02	4.12E+00
36	1.61E+02	3.85E+00
37	1.44E+02	3.64E+00

Figure 4. Comparison of calculated vs. measured values of thermal fluence rate for configuration 3



Conclusions

The neutron characterization of a new thermal neutron irradiation device was presented; it is composed of polyethylene moderator cylinders with about 16.5 cm diameter, 9.9 cm thickness and 40 cm height, and a irradiation cavity with 6.6 cm diameter and 34 cm height.

The experimental device for irradiation with thermal neutrons developed in the bench of UPM was used to compare the results obtained with the MCNP6 code. The calculations and results offer similar values of thermal neutron fluence rates. The simple geometry design makes this device an interesting tool to characterize elemental composition of several samples by PGNAA.

Acknowledgements

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Legislation and Communication as Part of a Security Theater in the Case of Asse II

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Introduction

The Asse Mine is a former salt mine. From 1967 to 1978 the mine was used for disposal of radioactive waste „for research purpose“.

In February 2013 the German Bundestag amended the Atomic Law and stipulated that all embedded waste has to be retrieved.

The political communication

- Retrieval of all waste is declared to be necessary due to legal requirements concerning long-term safety (benchmark 0.3 mSv/a).
- All involved decision-makers emphasize „safety“ as first and key target of their doing.
- The site of the “Intermediate Storage Facility” is explained to be necessarily close to the mine due to the optimization principle.

The radiation protection facts

- In the Asse Mine exists a chamber with ILW that was declared as not justified for retrieval because it does not cause a long-term risk. In 2017 the preferred retrieval of this waste was declared to be in the planning.
- Retrieval of ILW from the mine poses a risk of doses above 100 mSv for persons of the public.
- In connection with the decision that all waste has to be retrieved the political decision makers explicitly denied the optimization principle of radiation protection as an applicable criterion.

Security Theater: “the practice of investing in countermeasures intended to provide the feeling of improved security while doing little or nothing to achieve it.” (Wikipedia)

- Legislation and communication on Asse Mine demonstrate: the term „Safety“ is used in the political context to hide enhanced radiation risks from the public.
- There are many groups of interested parties (including NGOs and media) that loudly discuss the (low) radiation risks in case of flooding the mine – but never address the much higher risks by retrieval of not justified ILW.
- Communication about radwaste and final disposal is part of a „Security Theater“ and should be termed so by independent experts.

Nordic EXercise for Unmanned Systems NEXUS

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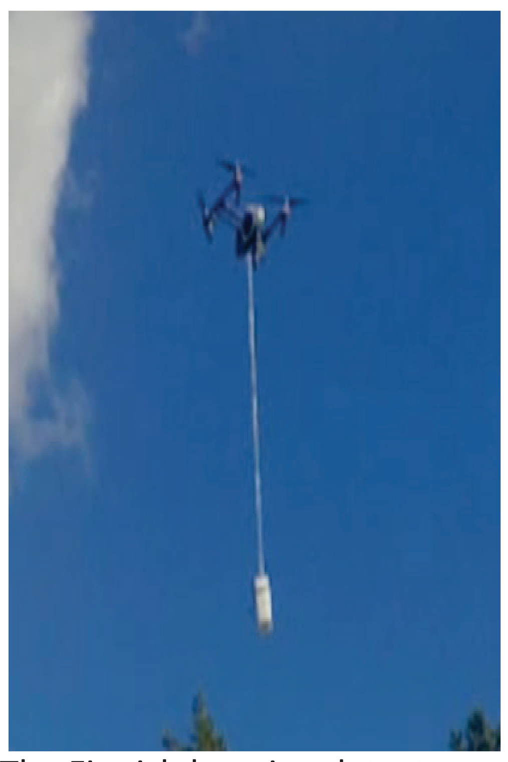
Abstract

The NEXUS exercise offered challenges in urban environments, contaminated fields and scenarios for fixed wing systems.
The use of fixed wing platforms was tested and demonstrated briefly.
Unmanned measurements in urban environments was tested and demonstrated in two scenarios, the street market and the 2-storey building. In particular the scenario around the 2-storey building demonstrated the 3D survey advantages with rotary wing systems. Survey of contaminated areas was tested and demonstrated in a scenario with dispersed activity in a pattern.
The exercise demonstrated that the capacities in the Nordic countries are in ongoing development. Exercise in an area where the teams can see each other's approach and solutions is most inspiring for the exchange and growth of knowledge.

The Swedish rotary wing

The Norwegian rotary wing system



The Finnish hanging detector

Swedish fixed wing after safe landing. Photo: Marie Carlsson

The Nordic community

The Nordic countries have a **growing competence** in radiation measurements utilizing unmanned aircraft systems. During three activities in recent years, one team from Sweden, one from Norway, three from Finland and one from Denmark have participated.

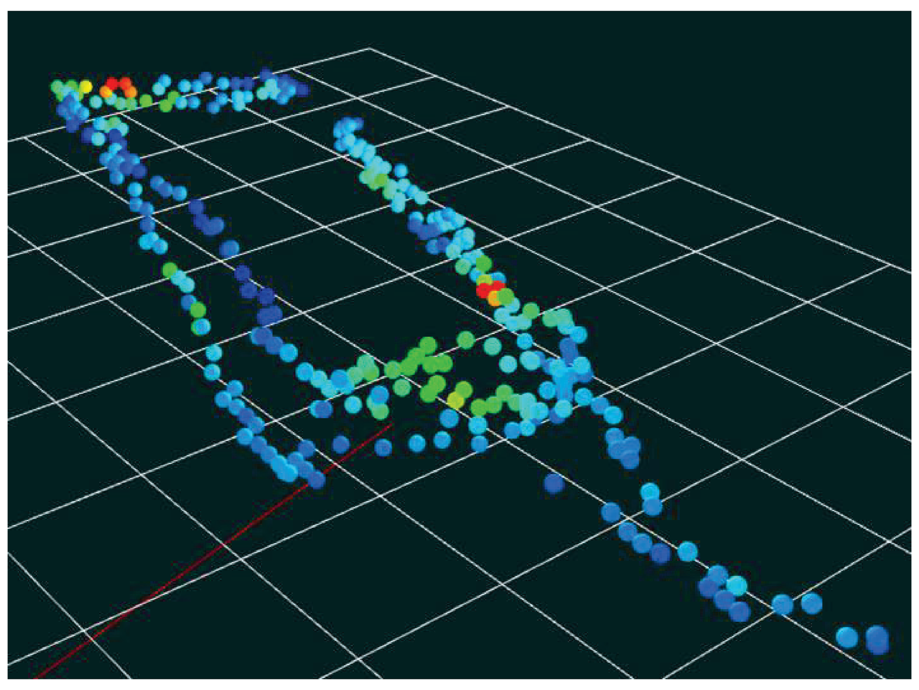
The NKS-B activity **SemUnaRS** – Seminar on Unmanned Radiometric Systems, was held in 2014 in Linköping, Sweden. The seminar was the start-up and an inventory of the capacities for unmanned measurements in the Nordic countries (Gårdestig et al 2015)

The NKS-B activity **NORDUM** - Intercomparison of Nordic unmanned aerial monitoring platforms, was in Norway 2016. NORDUM had eager participation of measurement teams from Denmark, Finland, Sweden and Norway (Tazmini et al 2016)

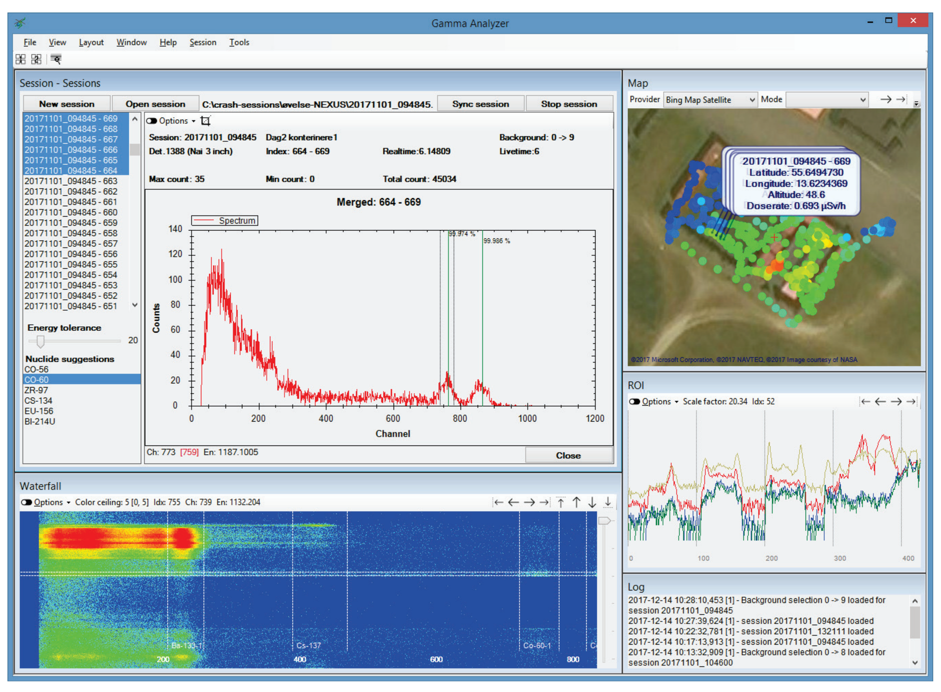
The **NEXUS** exercise in 2017 further expanded the challenges to **urban** environments, contaminated **fields** and scenarios for **fixed** wing systems. The exercise was held at an open, joint exercise area where the teams could observe each other's systems and techniques directly. (Gårdestig et al 2018)

Acknowledgement

The NEXUS activity was funded by Nordic Nuclear Safety Research



The Norwegian 3D plot of the 2-storey building.



The Norwegian Ground control station.

The Finnish view of the street market. Different ROIs in different colors.

Conclusions

The use of fixed wing platforms was tested and demonstrated briefly. The Swedish team had their fixed wing designed for carrying a detector system in the air. The use of **fixed wing UAS platforms could fill a gap** between rotary wing UAS and full scale fixed wing systems in surveying larger areas.

The use of unmanned measurements in urban environments was tested and demonstrated in two scenarios. In particular the scenario around the 2-storey building demonstrated the **3D survey advantages** with rotary wing systems.

Survey of contaminated areas in contrast to separate point sources was tested and demonstrated in the scenario with the contaminated area with dispersed activity in a pattern.

The aim to have team's report to reach back failed, presumably due to lack of time and preparations. This is something to develop since the end result should be decision support.

The capacities in the Nordic countries are still in development.

Exercise in an area where the **teams can see** each other's approach and solutions is most inspiring for the exchange and growth of knowledge.

LINKÖPING UNIVERSITY

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Securing the high-activity sealed source life cycle

From cradle to grave

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Introduction

Sealed sources that are used in Radiotherapy are usually sources with a relative longer half-value-time compared with open sources used in the department of Nuclear Medicine. Sealed sources hardly have any contamination issues however security of High-Activity Sealed Sources (HASS) does pose security challenges [1]. For healthprotection of patients, public and healthcare providers administering therapy as well as environmental protection security measures must be taken to counteract theft, abuse or sabotage of HASS. The risk of criminal or intentional unauthorized use of radioactive material creates a threat to international security.

Transport

Transport of Category 1&2 sources remains challenging. Transport of radioactive material can be seen as an interim mobile state between two stationary areas. The potential consequences are identical and therefore the level of security needs to be at least comparable to the security level of the hospital. These shipments are mainly achieved by air or by road transport and therefore constuctional security is limited. In order to maintain the same security regime as in stationary areas, operators have to rely on organizational and electronic measures.

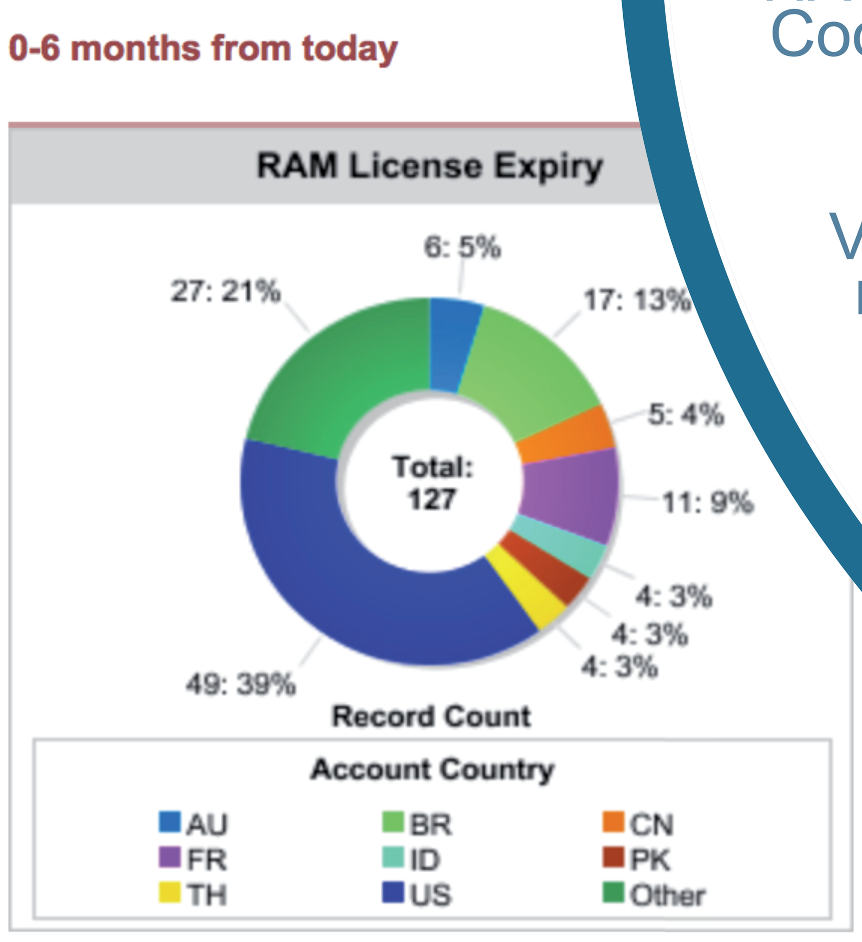
Example of 'storage room' full with transport containers including HASS

CONCLUSION

IAEA gives a clear indication that HASS are a high-risk target.[2] In order to prevent any unauthorized access, the occurrance of orphan sources should be prevented. Pre-sales assessment for any economic sanctions or embargoes must be executed in an early stage. The legal manufacturer should refrain from sending new souces if the combined activity of the stationary sources exceeds the amount of activity stated in the permit of the hospital. Regular checks whether the hospital has a valid, relevant RAM-license is mandatory and a financial guarantee for repatriation must be put in place.

The main goal is to reach an equilibrium between securing the HASS and using the sources safely by authorized staff. Cooperation with the medical staff and annual security awareness training is essential.

Vital transport information of consignments containing radioactive material and the security measures applied to the transport should be restricted to the minimum number of staff required. Tracking consignments carrying HASS using Global Positioning System (GPS)-navigation to transmit their position is recommended. Although enhancing organisational security measures are preferable, as GPS navigation and computers may be exposed to respectively spoofing and hacking.



Radioactive Material Holder-User License

Example of a dashboard from Customer Logistics Management (CLM) database of RAM licenses expiry tracking six months in advance.

RAM-license

The legal manufacturer carries out vital checks prior to shipment (e.g. RAM license checks of recipient hospitals). Despite controlling in-appropriate storage of depleted sources is in fact a governmental task, it is in the interest of manufacturers to ensure the maximum activity limits of recipient hospitals is not exceeded. To keep track of radioactive sources which are no longer in possession nor property of the legal manufacturer, the legal manufacturer is forced to make extra time and money investments.

Electronic measures

To keep track of consigments carrying radioactive material an 'enhanced security level' with tracking devices is recommended in the IAEA Nuclear Security Series no.9. It is preffered to use an on-line tracking system in conjunction with a communication system in the conveyance. These on-line tracking devices are using Global Positioning System (GPS) navigation to transmit position. As soon as a transport diverts from preset routes an alarm is sent out and immediate action can be taken.

Orphan sources

Due to unclear division of tasks source return shipments remain on the hospital premises longer than strictly necessary. In some hospitals obsolete sources are gathered in unequipped or in-appropriately equipped storage rooms. Combined with a lack of awareness of potential health and security risks, a stagnating source return process or a downright refusal of hospital management to carry the transportation costs, these sources pose a serious hazard of becoming “loss of control” sources.

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Physics, Chemistry & Biology

Baicalein attenuates radiation enteropathy by regulating pro-inflammatory cytokine IL-33

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Introduction

The gastrointestinal tract is a radiation-sensitive organ, and is occurred a clinical problem, called acute radiation enteritis, which involves diarrhea, inflammation, edema, sepsis by radiotherapy for cancer treatment or accidental radiation exposure. Baicalein is a major flavonoid compound isolated from Scutellariae radix, an important herb used in traditional medicine. Its safety has been clinically proven, and it possesses anti-allergic, antioxidant, and anti-inflammatory properties. IL-33 as epithelial-derived pro-inflammatory cytokine, induces a rapid release on inflammatory mediators such as IL-1β, IL-6, and TNF-α and chemokines by a variety of innate immune cells including neutrophils, eosinophils, and macrophages.

Here, we investigated that whether baicalein improved acute radiation enteropathy by downregulating IL-33.

Methods

Whole abdomen of male C57BL/6 mice was single irradiated with total dose of 13.5 Gy (2 Gy/min). The irradiated mice (IR) were treated with baicalein (10 mg/kg, intraperitoneal injection) for 6 days. To evaluate the effects of baicalein in IR–induced intestinal barrier dysfunction, bacterial translocation, FITC-Dextran assay and claudin 3 expression were assayed using the mesenteric lymphnode and ileum tissue. Also, Histological analysis performed in the ileum of baicalein-treated IR mice. The levels of inflammatory cytokines and chemokines were evaluated in the ileum tissue using ELISA and Real-Time RT-PCR.

Results

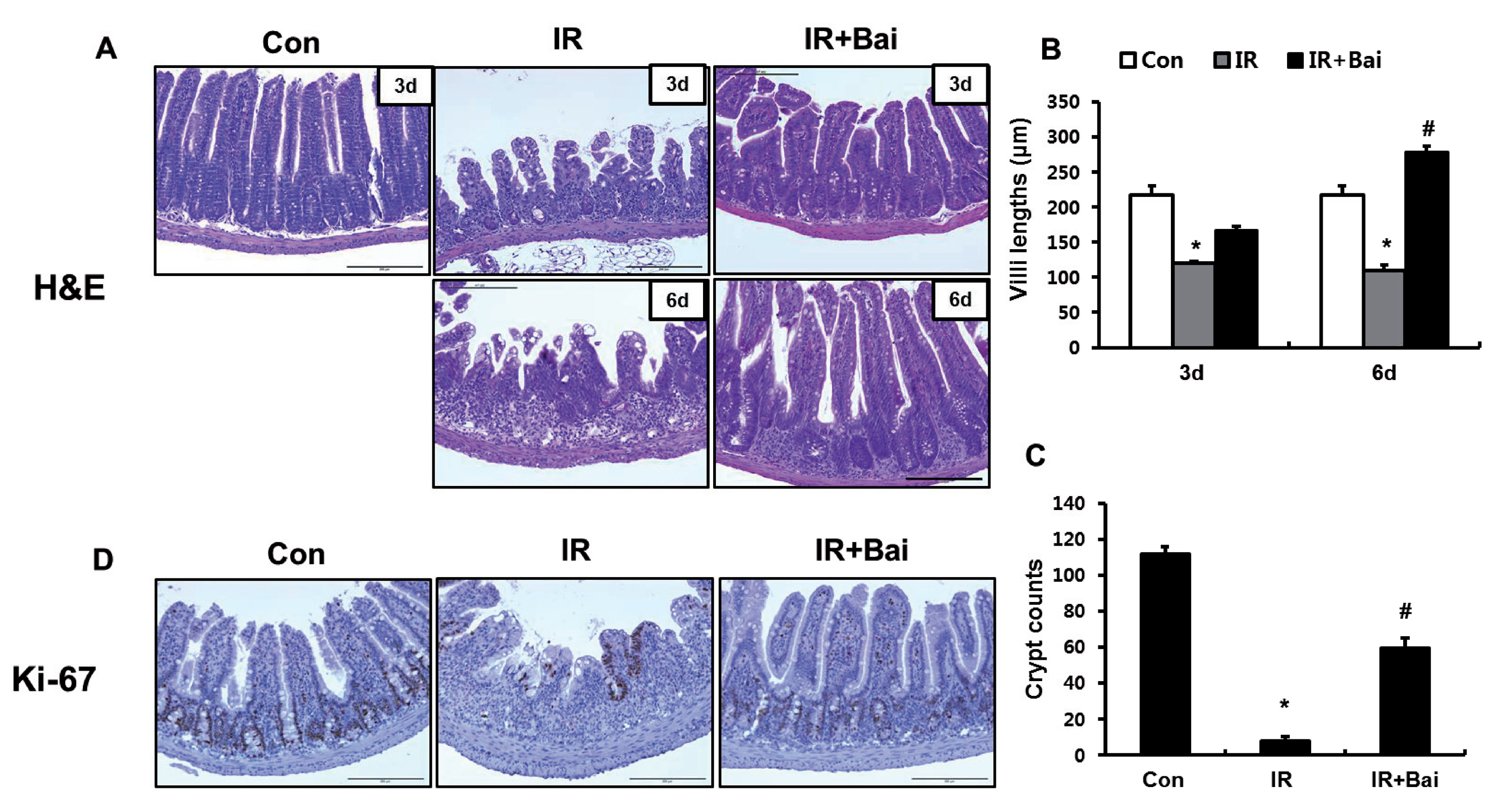


Fig 1. Baicalein improves radiation-induced enteritis. (A) H&E, (B) villi length, (C) crypt counts, and (D) Ki-67, a marker of proliferation in the small intestine of control, irradiation (IR), and baicalein treated IR (IR+Bai) groups. *$p < 0.05$ vs. control group; #$p < 0.05$ vs. IR group

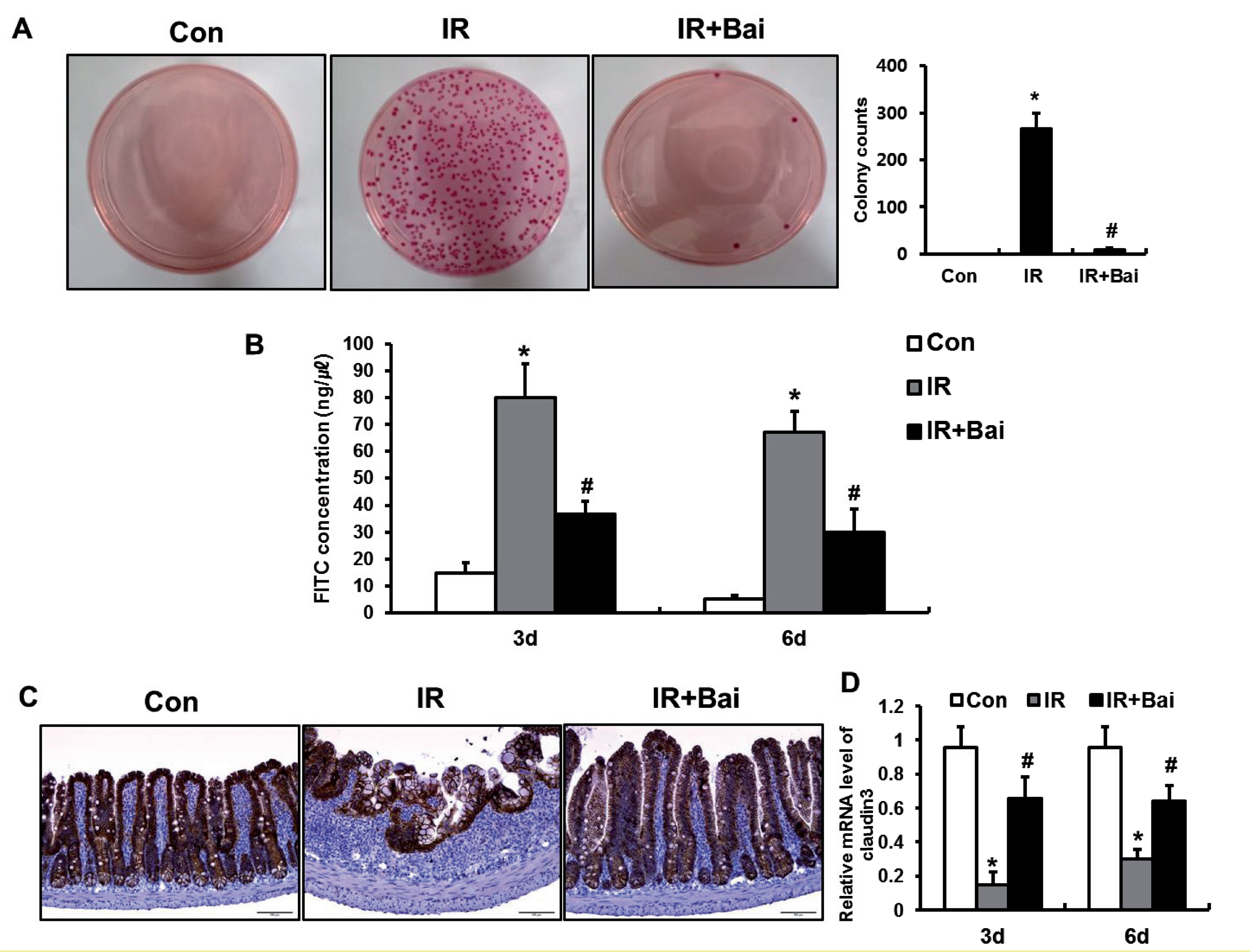


Fig 2. Baicalein recoveries intestinal barrier dysfunction of radiation-induced enteritis. (A) the number of colonies in mesenteric lymphnode (Bacterial translocation to lymphnode), (B) FITC-dextran assay (measurement of intestinal permeability), (C) immunohistochemistry of Claudin 3, a marker of tight junction and (D) mRNA level of Claudin 3 in control, irradiation (IR), and baicalein treated IR (IR+Bai) groups. *$p < 0.05$ vs. control group; #$p < 0.05$ vs. IR group

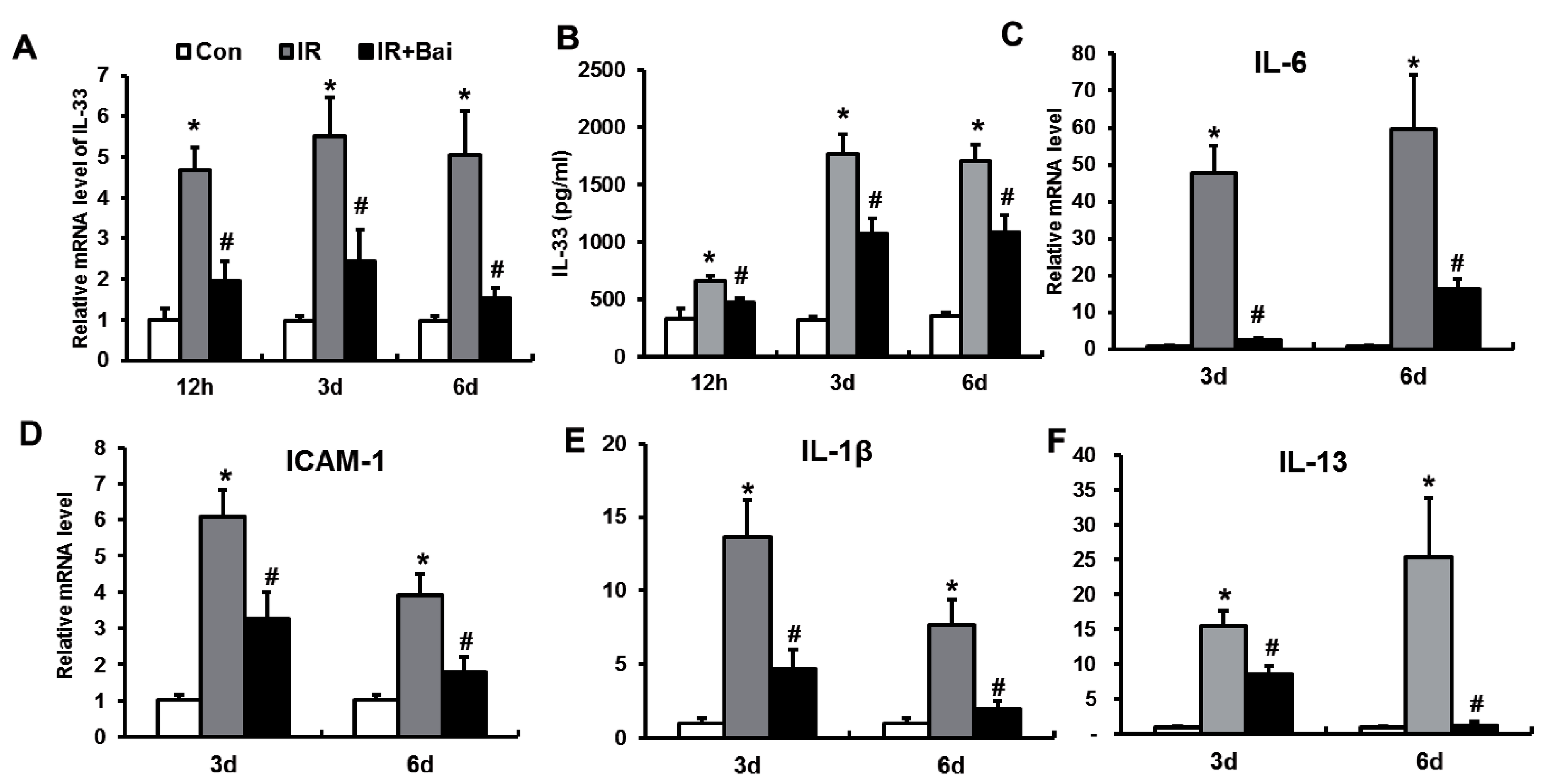


Fig 3. Baicalein inhibits (pro-)inflammation mediators of radiation-induced enteritis. (A) mRNA and (B) protein levels of IL-33, mRNA levels of (C) IL-6, (D) intercellular adhesion molecule 1 (ICAM-1), (E) IL-1β, and (F) IL-13 in the small intestine of control, irradiation (IR), and baicalein treated IR (IR+Bai) groups. *$p < 0.05$ vs. control group; #$p < 0.05$ vs. IR group

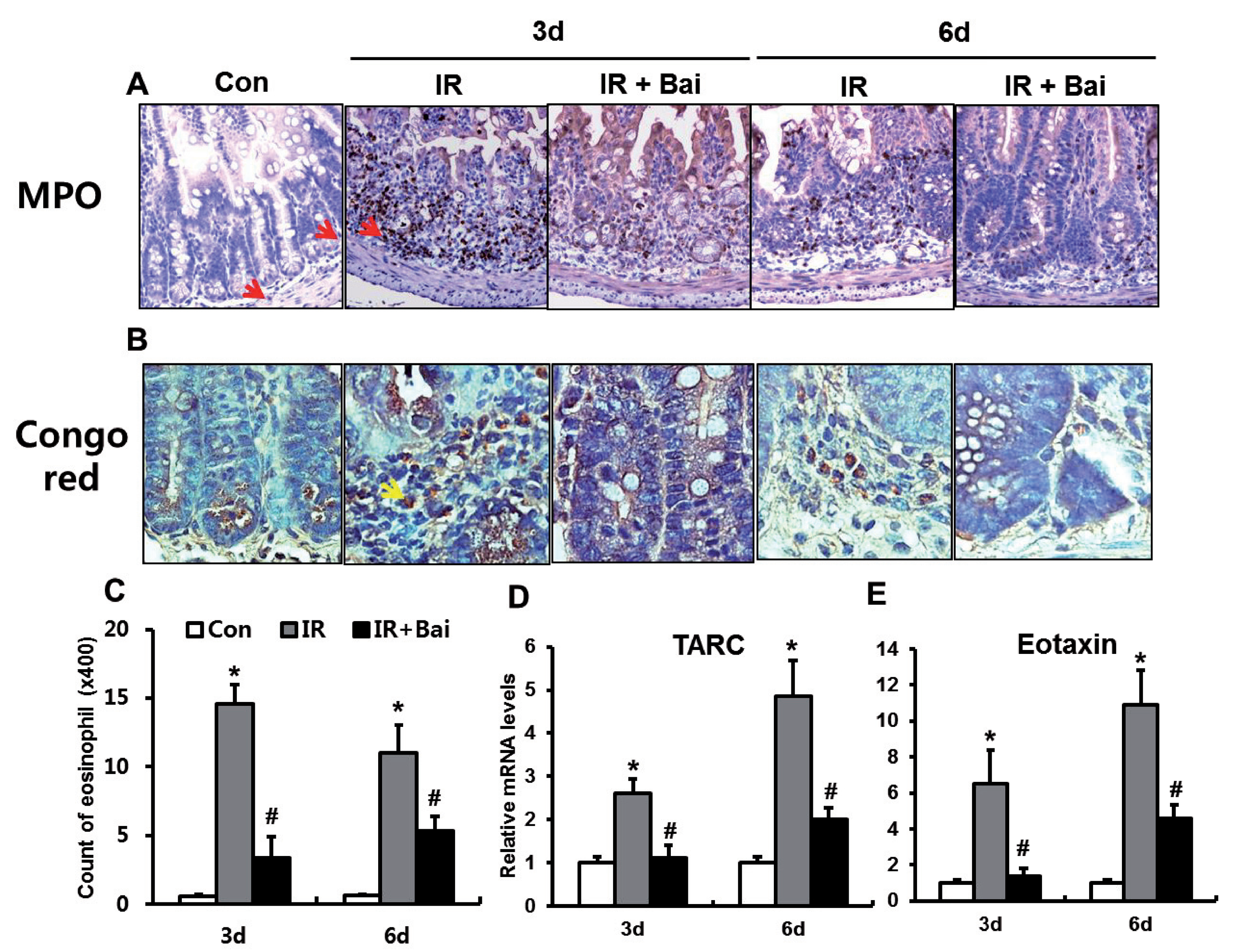


Fig 4. Baicalein attenuates inflammatory response in the radiation enteropathy. (A) Neutrophil, (B) eosinophil infiltration, and (C) the counts of eosinophils in the small intestine of baicalein treated IR mice at 3 and 6 days. mRNA levels of (D) TARC (chemotaxis of T cell), (E) Eotaxin (chemotaxis of eosinophil) in control, irradiation (IR), and baicalein treated IR (IR+Bai) groups. *$p < 0.05$ vs. control group; #$p < 0.05$ vs. IR group

Conclusion

Baicalein improves the effect of anti-inflammation and damaged intestinal barrier function by reducing IL-33 in radiation enteropathy. Baicalein may provide a new therapeutic agent to manage radiation enteropathy.

KOREA INSTITUTE OF RADIOLOGICAL & MEDICAL SCIENCES
NATIONAL RADIATION EMERGENCY MEDICAL CENTER

Public Health England

Protecting and improving the nation's health

Biota dose rate calculations in PC-CREAM 08®

Tracey Anderson, Justin Smith, Iain Brown

Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, OX11 0RQ, UK

INTRODUCTION

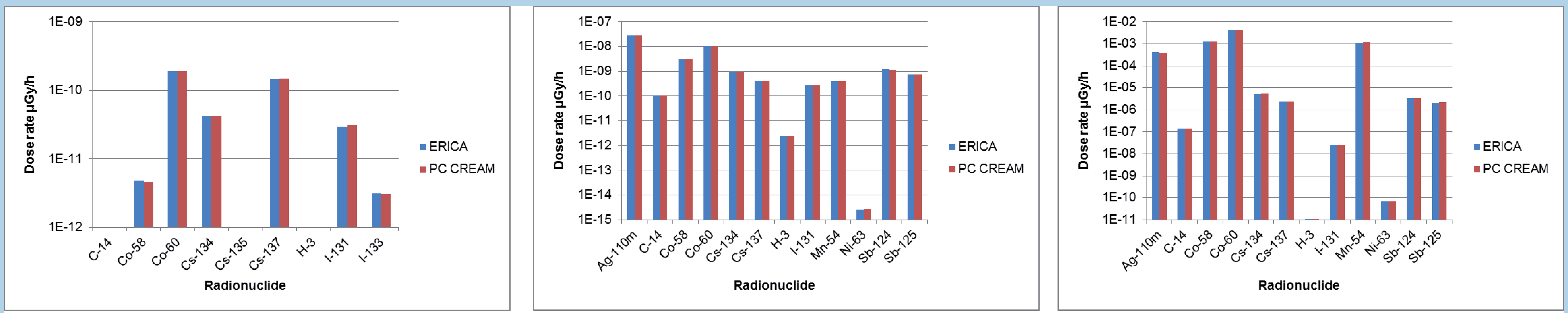
PC-CREAM 08® (Smith and Simmonds, 2009) is a suite of models and data intended to be used to assess the radiological impact of continuous and constant releases of radioactive effluents to atmosphere, rivers and marine waters arising as a result of normal operations. Until now, PC-CREAM only assessed radiological impact to humans; work is currently under way to implement the calculation of dose rates to non-human biota using the system recommended by the International Commission on Radiological Protection (ICRP). The system includes a set of Reference Animals and Plants (RAPs) considered typical of different environments and defines dose conversion factors (DCFs) for estimating the internal dose rate from the biota's activity concentration and external dose rate from activity concentration in the surrounding media (ICRP, 2008). ICRP also define a set of concentration ratios (CRs) to estimate an organism's internal activity concentration from the activity concentration in the surrounding media (ICRP, 2009). Below we present dose rates to a variety of RAPs calculated using this methodology and compare the results with output from the ERICA tool (Brown et al, 2008; Brown et al, 2016) for assessing the radiological risks to biota.

METHOD

A hypothetical pressurised water reactor (PWR) was assumed to discharge radioactive effluents to atmosphere, to a river and to the sea. Activity concentrations for typical PWR discharges were derived for environmental media: in air, on soil, in soil, in freshwater, in marine water and in seabed sediment. A RAP was selected for each of the terrestrial, freshwater and marine habitats and, for simplicity, the selection was limited to those RAPs that spend their entire time in a single environment. For the terrestrial habitat, reference Pine tree was selected (known as Tree in ERICA); for the freshwater habitat, reference Trout (known as Pelagic fish in ERICA); and for the marine habitat, reference Flatfish was selected (known as Benthic fish in ERICA). A Tier 2 assessment was created in ERICA version 1.2.1 (Brown et al, 2016) for each selected organism using the activity concentrations in media derived as described above and ERICA default values of concentration ratios and dose conversion factors were used. An assessment was created in a prototype of PC-CREAM that implements the proposed methodology and uses the values for concentration ratios and dose conversion coefficients recommended by ICRP (ICRP, 2008; ICRP 2009).

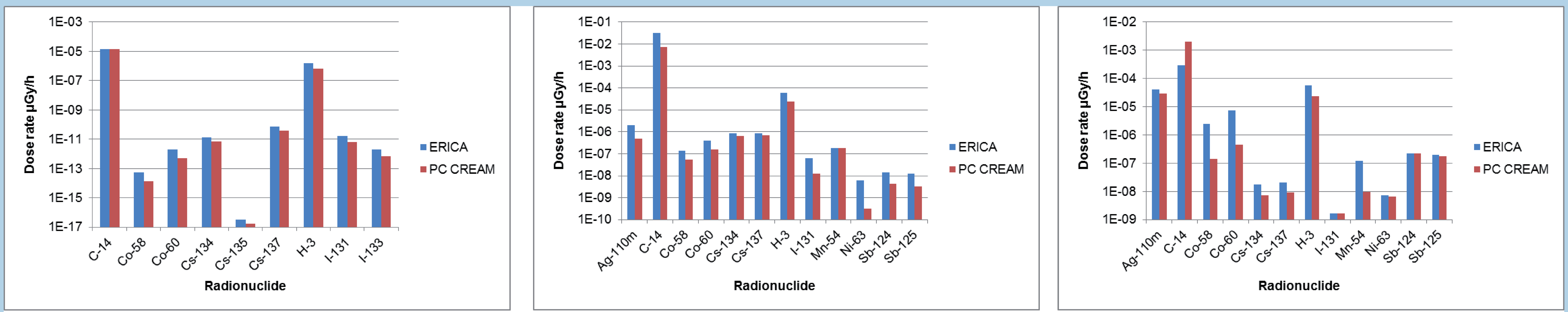
RESULTS

Figure 1 illustrates the external dose rates calculated by PC-CREAM and the ERICA tool and Figure 2 illustrates the internal dose rates. It can be seen that the values of external dose rates agree well. Conversely, there is more variation in internal dose rates, in some cases by more than an order of magnitude. The differences are partly caused by the application of radiation weighting factors in ERICA, and partly because the ICRP-recommended concentration ratios were derived from the Wildlife Transfer Database (WTD) in 2011, whereas the ERICA values were derived from the WTD in 2013, by which time the WTD was a richer data resource (Brown et al, 2016).



(a) Terrestrial: reference Pine tree (b) Freshwater: reference Trout (c) Marine: reference Flatfish

Figure 1. Comparison of external dose rates calculated by ERICA and PC-CREAM



(a) Terrestrial: pine tree (b) Freshwater: reference Trout (c) Marine: reference Flatfish

Figure 2. Comparison of internal dose rates calculated by ERICA and PC-CREAM

DISCUSSION AND CONCLUSION

The external dose rates calculated by the proposed PC-CREAM methodology agree well with those calculated by the ERICA tool for the same media activity concentrations. This result was anticipated since the ERICA dose conversion coefficients closely match the ICRP recommended dose conversion factors, varying by a few per cent at the most.

The internal dose rates calculated by PC CREAM agree less well with those calculated by the ERICA tool than the external dose rates. In general the PC CREAM dose rates are lower than those calculated by ERICA but are within an order of magnitude; exceptionally, the difference is greater than an order of magnitude (e.g. trout, 63Ni; flatfish, 54Mn). This can be explained by (i) the application of radiation weighting factors in the ERICA tool, and (ii) concentration ratios in the current version of the ERICA tools were generated from the Wildlife Transfer Database more recently than the ICRP recommended values.

In conclusion, the proposed methodology provides acceptable results and will be incorporated into future releases of PC-CREAM.

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Brown JE, Alfonso B, Avila R, Beresford NA, Copplestone D and Hosseini A (2016). A new version of the ERICA tool to facilitate impact assessments of radioactivity on wild plants and animals. *J Environ Radioact* **153**, 141-148.

ICRP (2008). Environmental Protection: the Concept and Use of Reference Animals and Plants. ICRP Publication 108. *Ann ICRP* **38**(4–6), 19-39.

ICRP (2009). Environmental protection: transfer parameters for reference animals and plants. ICRP Publication 114. *Ann ICRP* **39**(6), 1-111.

Smith JG and Simmonds JR (2009). *The methodology for assessing the radiological consequences of routine releases of radionuclides to the environment used in PC-CREAM 08.* HPA, Chilton, HPA-RPD-058.

O02

Blocking hemichannels protects against radiation-induced endothelial cell damage

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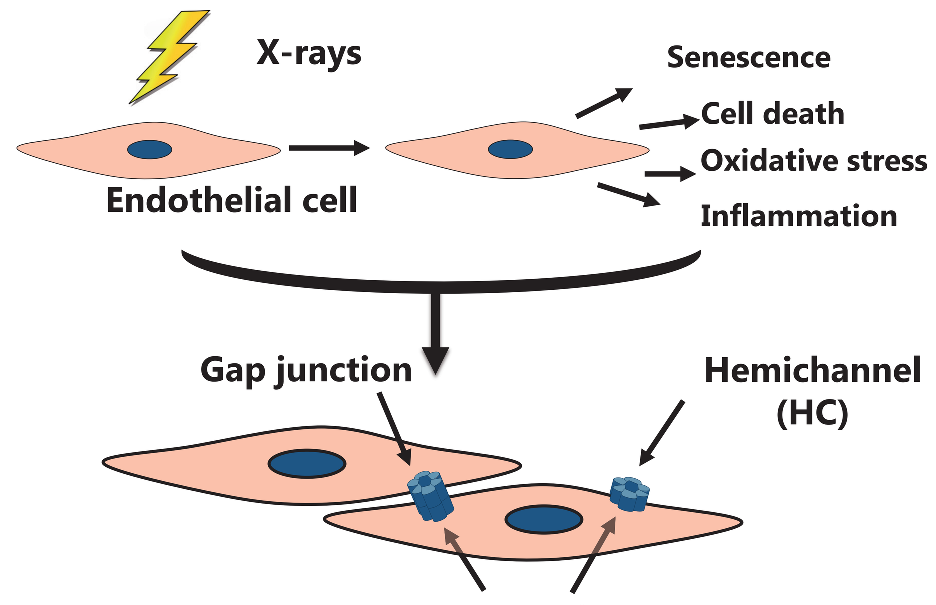
Background

- Epidemiological evidence suggest that **ionizing radiation (IR)** exposure, e.g. from radiotherapy, is a **risk factor** for the development of **atherosclerosis,** driven by endothelial dysfunction.
- **Intercellular communication** through channels composed of **connexin (Cx)** proteins (i.e. gap junctions and hemichannels) may play a role in **radiation-induced endothelial cell dysfunction.**
- However, the role of Cxs and their channels in radiation-induced endothelial cell dysfunction has **never been described**.



Objectives

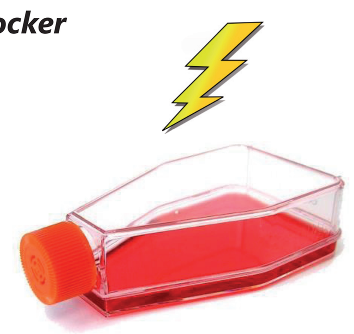
1. Investigate whether **Cxs and their channels** plays a role in radiation-induced endothelial cell response.
2. Validate whether **blocking** Cx43 hemichannels protects endothelial cells from radiation damage.

Material and methods

Irradiation

With or without Cx43 hemichannel blocker

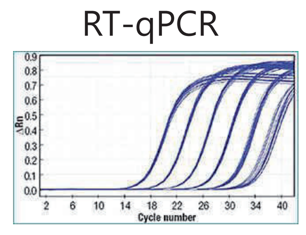
X-ray exposure
0.1 Gy
0.5 Gy
5 Gy



TICAE: Telomerase immortalized human **Coronary Artery** Endothelial cells
TIME: Telomerase immortalized human **Microvascular** Endothelial cells

A Cx gene expression

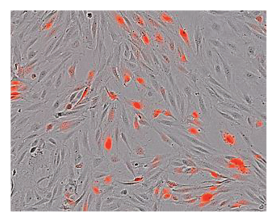
RT-qPCR



Cx protein level

Western blot

B Hemichannel function (HC)



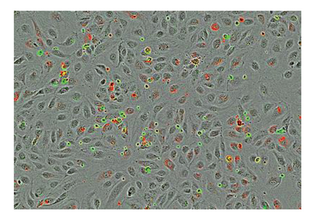
Propidium iodide and Dextran fluorescein dye uptake

Gap junction communication

Scrape loading and dye transfer assay

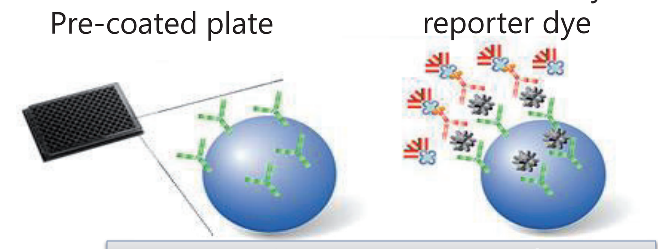
C Cell death detection

AnnexinV- Caspase 3/7
Life cell imaging



Cytokine detection

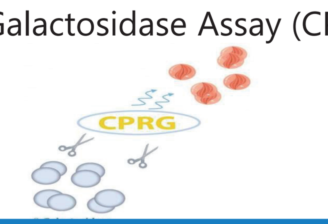
(1) Cytokine-specific antibodies Pre-coated plate
(2) Add supernatant, detection antibody and reporter dye



(3) Luminex MAGPIX Analyzer

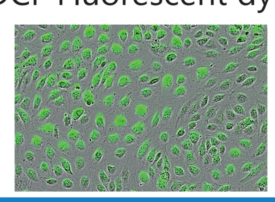
Senescence detection

SA-β-Galactosidase Assay (CPRG)



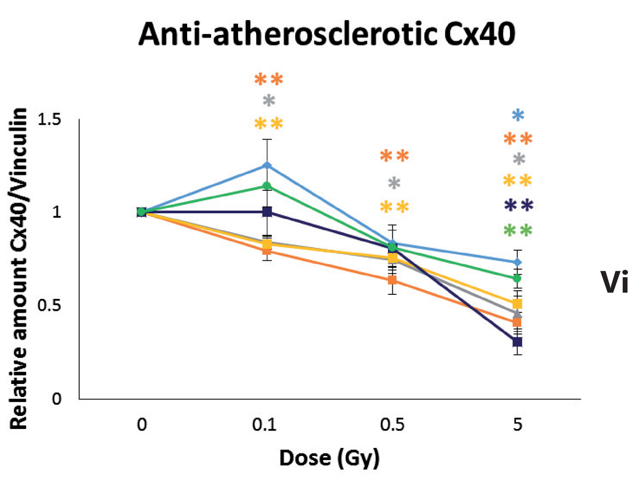
Oxaditive stress detection

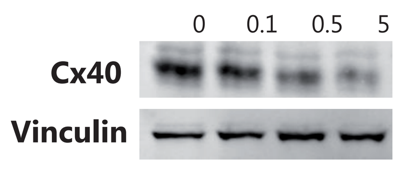
DCF Fluorescent dye

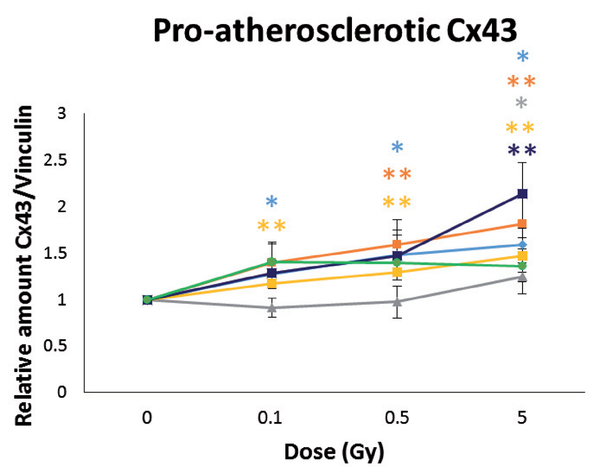


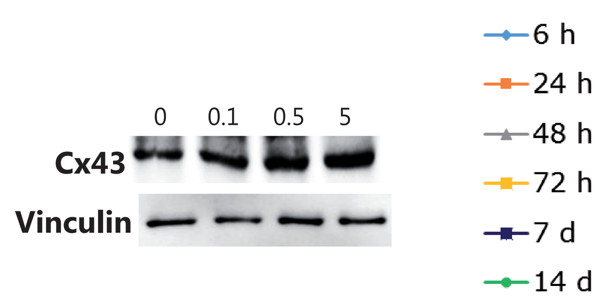
Results

A Alterations in Cx gene expression and protein level after X-ray exposure





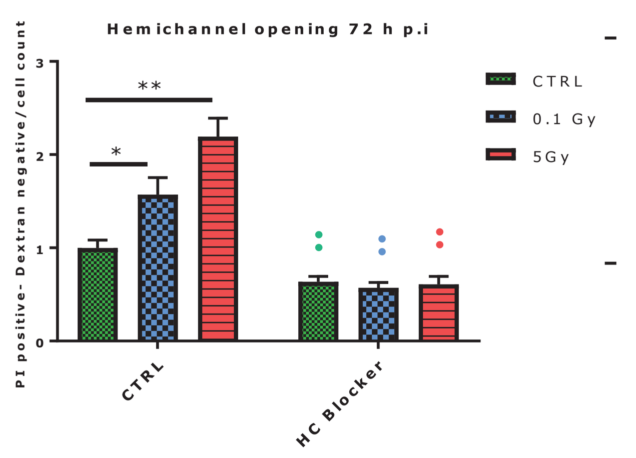




- A radiation-induced dose-dependent **downregulation** of **anti-atherosclerotic** Cx40 was observed.
- A radiation-induced dose-dependent **upregulation** in **pro-atherosclerotic** Cx43 was observed.
- The effect was acute and persistent in both TICAE and TIME cells.

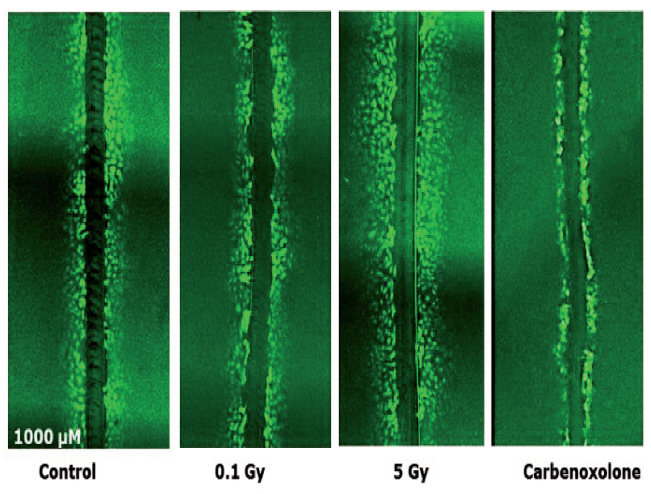
* P<0.05; ** P<0.01; *** P<0.001

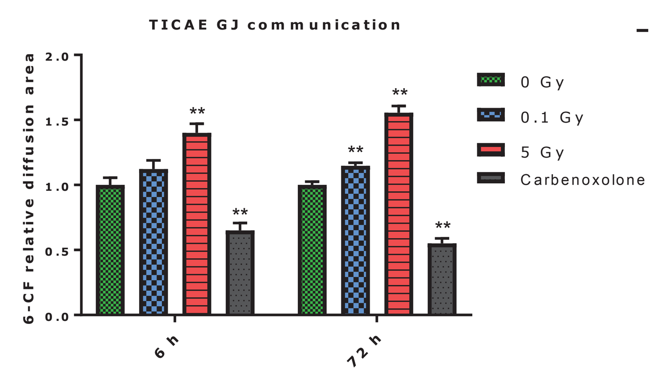
B Radiation-induced hemichannel opening



- **Acute and chronic** dose-dependent **increase** in **hemichannel opening** was observed 1 h, 6 h and 72 h after IR exposure in TICAE and TIME cells.
- **HC blocker protects** the irradiated endothelial cells form **hemichannel opening .**

Radiation-induced increase in gap junction communication

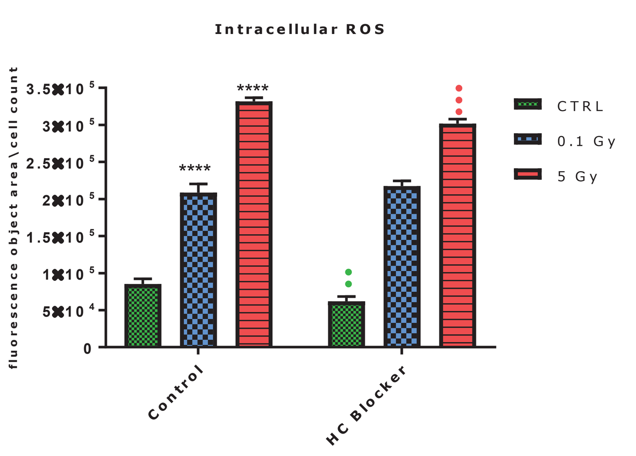


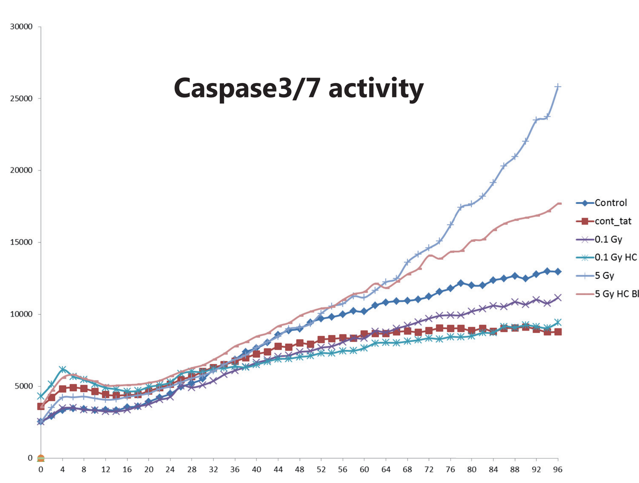


- **Acute and chronic** dose-dependent **increase** in 6-carboxyfluorescein (6-CF) **diffusion area** was observed 6 h and 72 h after IR exposure in TICAE cells.

*/• P<0.05; •: Statistical difference compared to the respective radiation dose of the control condition

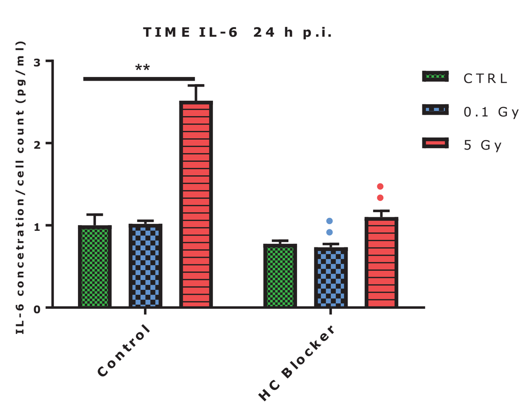
C Blocking hemichannel protects form radiation-induced oxidative stress and cell death

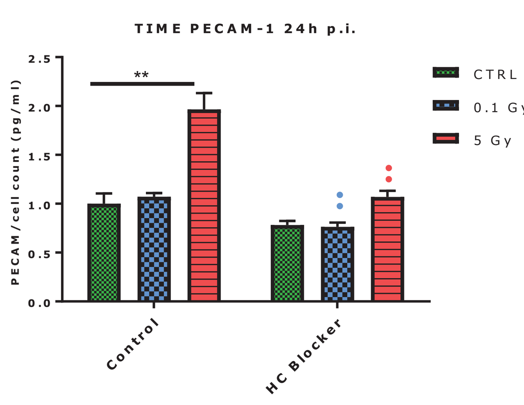


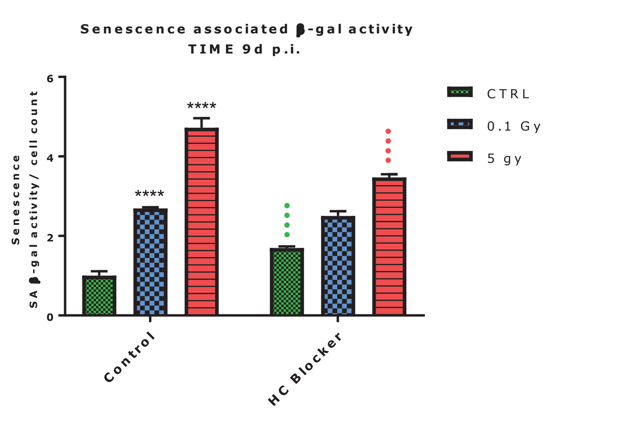


- An **increase** in **oxidative stress** and **cell death** was observed after IR exposure.
- **HC blocker** significantly **reduced oxidative stress** and **cell death** in the irradiated endothelial cells.

Blocking hemichannel protects from radiation-induced inflammation and premature senescence







- An **increase** in **atherosclerosis inflammatory markers** and premature **senescence** was observed after IR exposure.
- **HC blocker** significantly **reduced** this effect in t he irradiated endothelial cells.

Discussion and conclusion

- **IR-induced endothelial dysfunction** (increased cell death, oxidative stress, senescence and inflammation) is accompanied by **changes in gene expression and protein levels of endothelial Cxs** and an **increase in intercellular communication**.
  → **Similar alterations** in **Cx37, Cx40 and Cx43** protein levels have been reported in the literature **in endothelial cells covering atherosclerotic plaques**.
  → Therefore, our results suggest that **IR may contribute to the development of atherosclerosis** by modulating the intercellular transfer of IR damaging signals.
- **Inhibiting** the IR-induced opening of Cx43 hemichannels **reduces the IR-induced cell death and cytokine release**.
  → This holds a potential **promising radioprotectant** in the future.

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Contribution of macro and micro-dosimetry in alphatherapy

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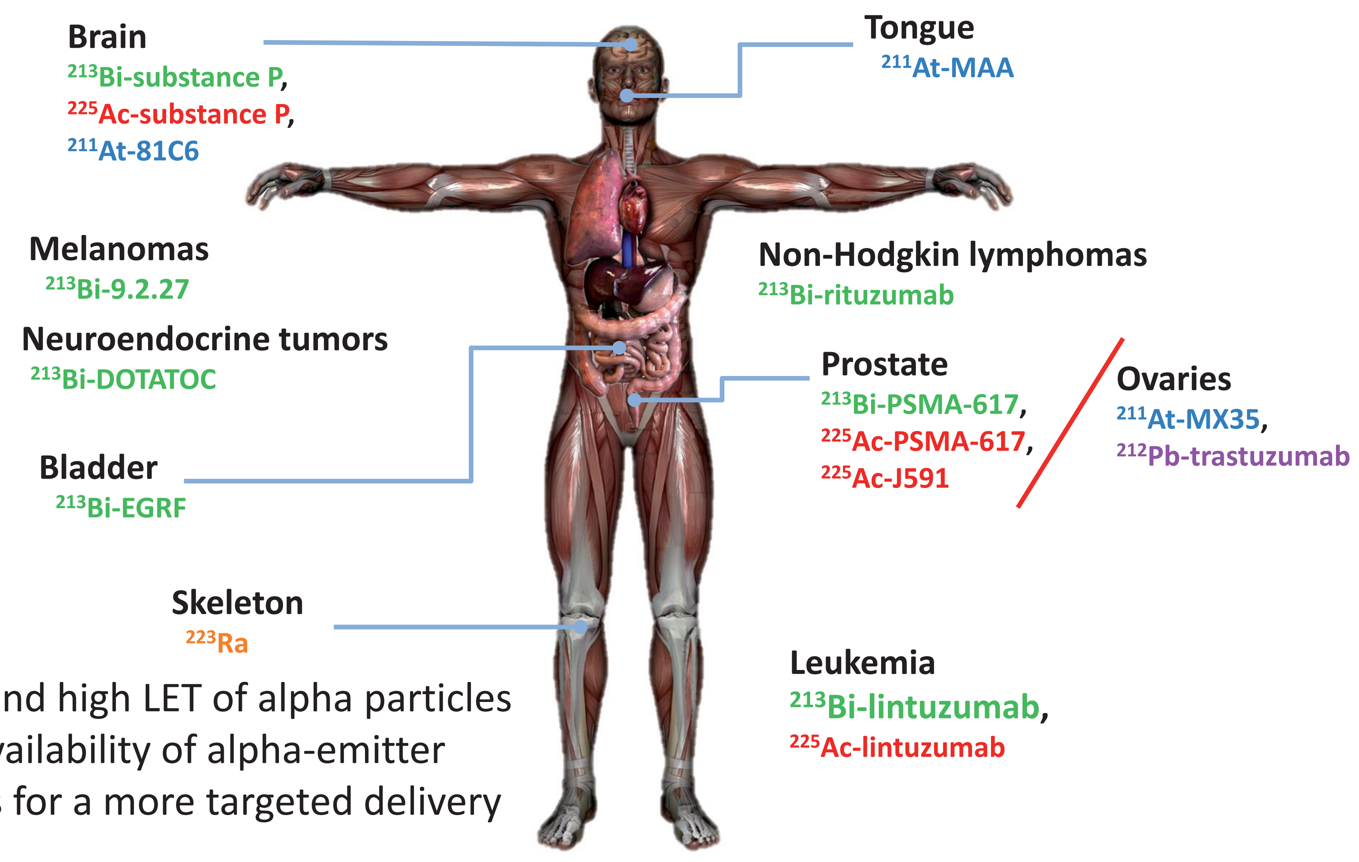
Context and Challenge

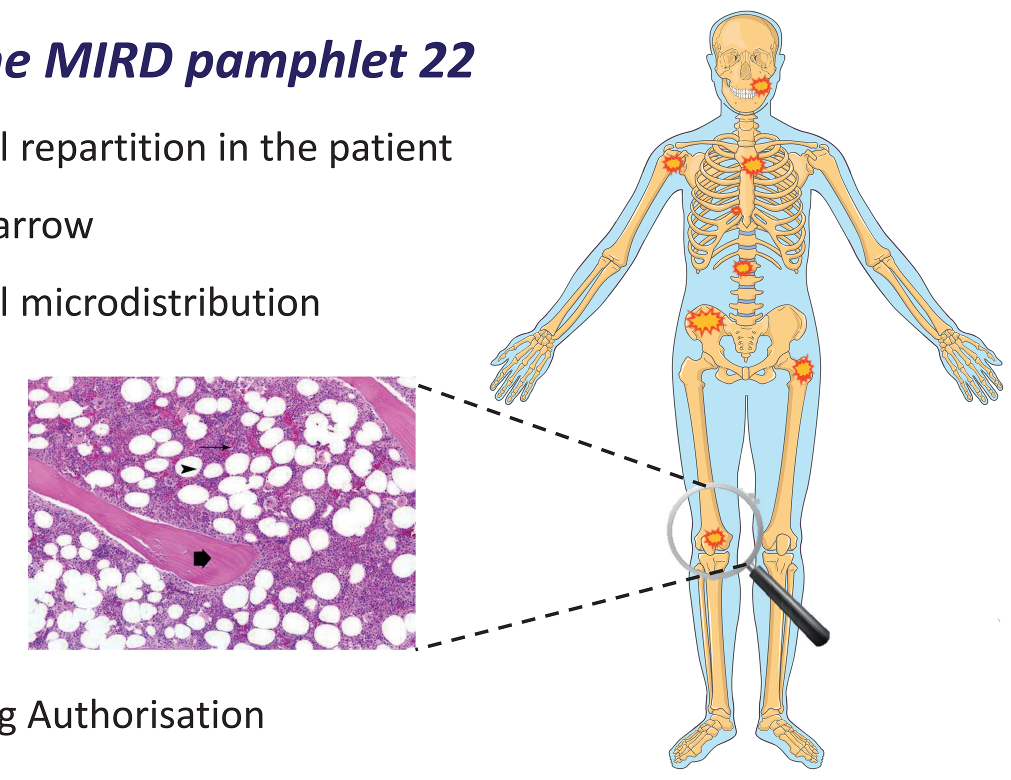
Emergence of alphatherapy



- Short path and high LET of alpha particles
- Increased availability of alpha-emitter
- New vectors for a more targeted delivery

3 dosimetric stakes based on the MIRD pamphlet 22

1. Determine the radiopharmaceutical repartition in the patient
2. Determine the dose to the bone marrow
3. Determine the radiopharmaceutical microdistribution

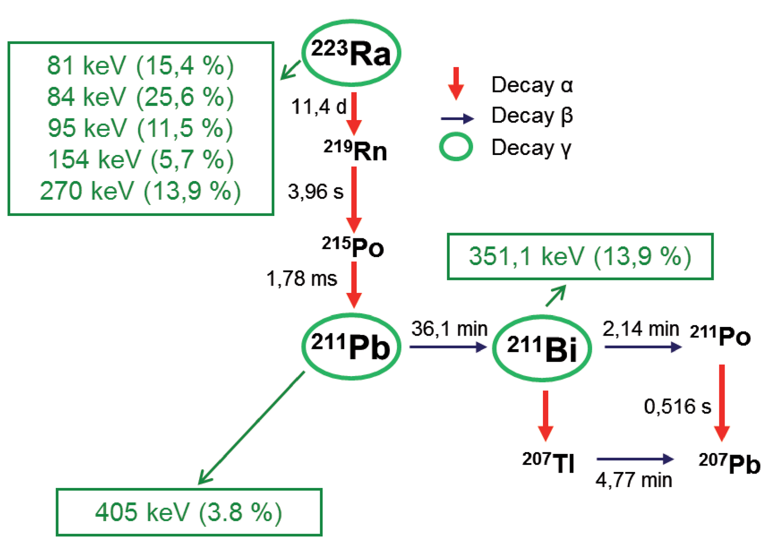


Xofigo® ($^{223}RaCl_2$)

- **First α emitter** to obtain Marketing Authorisation
- Bone metastatic prostate cancer
- Bone metastatic renal cancer (new clinical trial)
- Treatment: 6 injections of 55 kBq/kg every 4 weeks

1 Acquisition of Quantitative ^{223}Ra Images

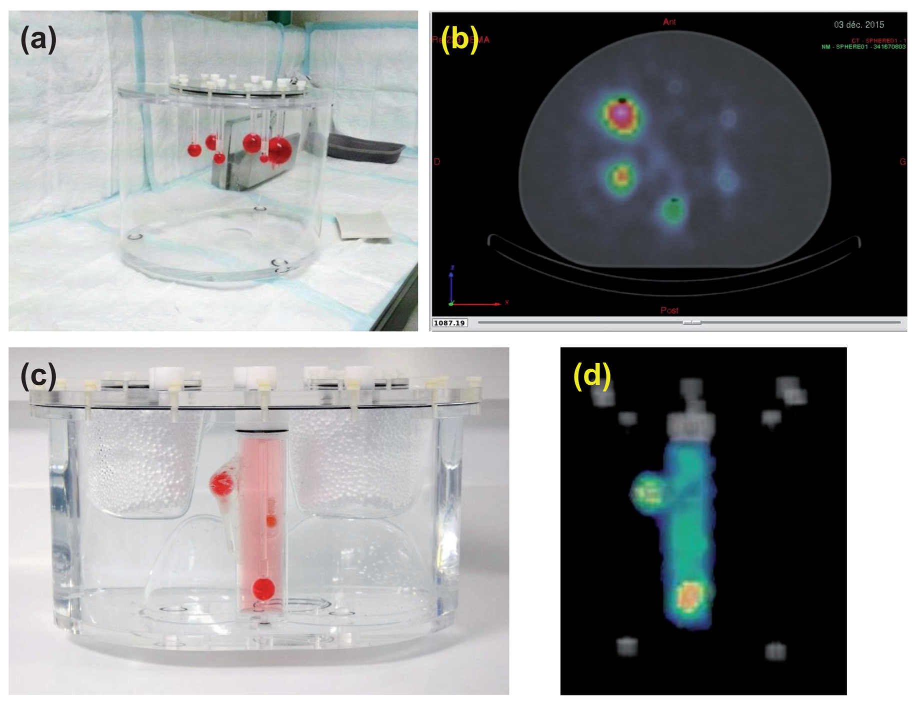
Goal: Establish a quantitative tomographic ^{223}Ra imaging protocol with clinically achievable conditions and investigate its limitations.



Materiel and Methods:

- ***NEMA Phantom :*** 6 spheres between 0.5 and 26.5 mL
- ***TORSO Phantom :*** cylindrical insert of 156 mL and 3 spheres : 2 of 5.6 mL and 1 of 0.5 mL

Results:

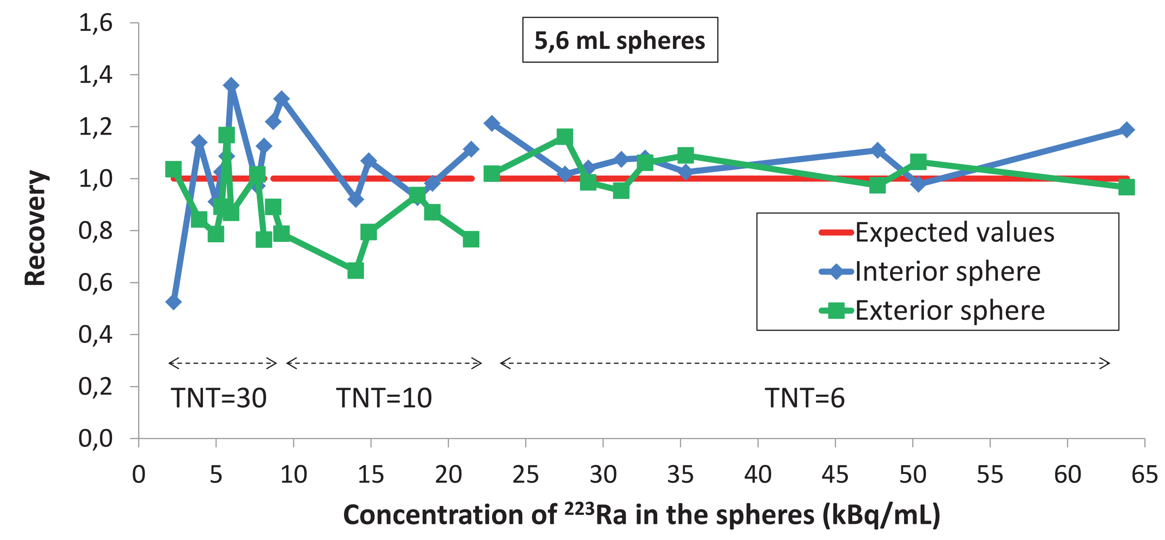


Example of results. NEMA phantom (a): each sphere filled with 22.8 kBq/mL of ^{223}Ra. Transaxial section of the reconstructed SPECT images merged with the CT (b). TORSO phantom (c): each sphere filled with 64 kBq/mL of ^{223}Ra and the cylindrical insert filled with ^{223}Ra in order to have a TNT ratio equal to 6. 3D view of reconstructed SPECT/CT images of the TORSO phantom (d).

Validation and limitations: Calculation of the activity recovery (defined as the ratio of activity estimated from the image to the true activity):

$$A_{estimated} = \frac{C_{measured}}{CF \times t}$$ *(MIRD pamphlet 23)*

where CF is the calibration factor determined thanks to the NEMA acquisitions and is dependent of each sphere size.



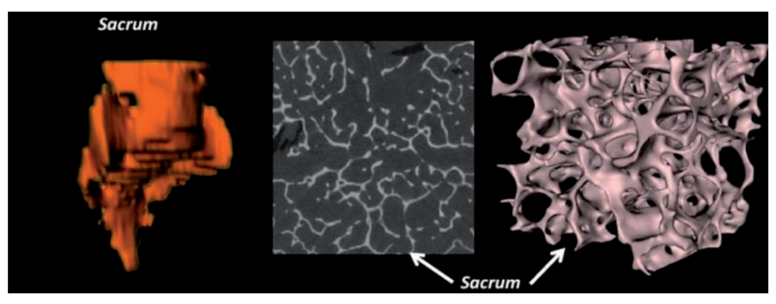
Activity could be quantified to within an error < 20% for each TNT ratio in a 5.6 mL lesion for ^{223}Ra concentrations higher than 8 kBq/mL.

2 Bone Marrow Dosimetry

Goal: Optimize dosimetry to the bone marrow in order to avoid any toxicity by taking into account the complex geometry of the bone and the presence of tissue inhomogeneities.

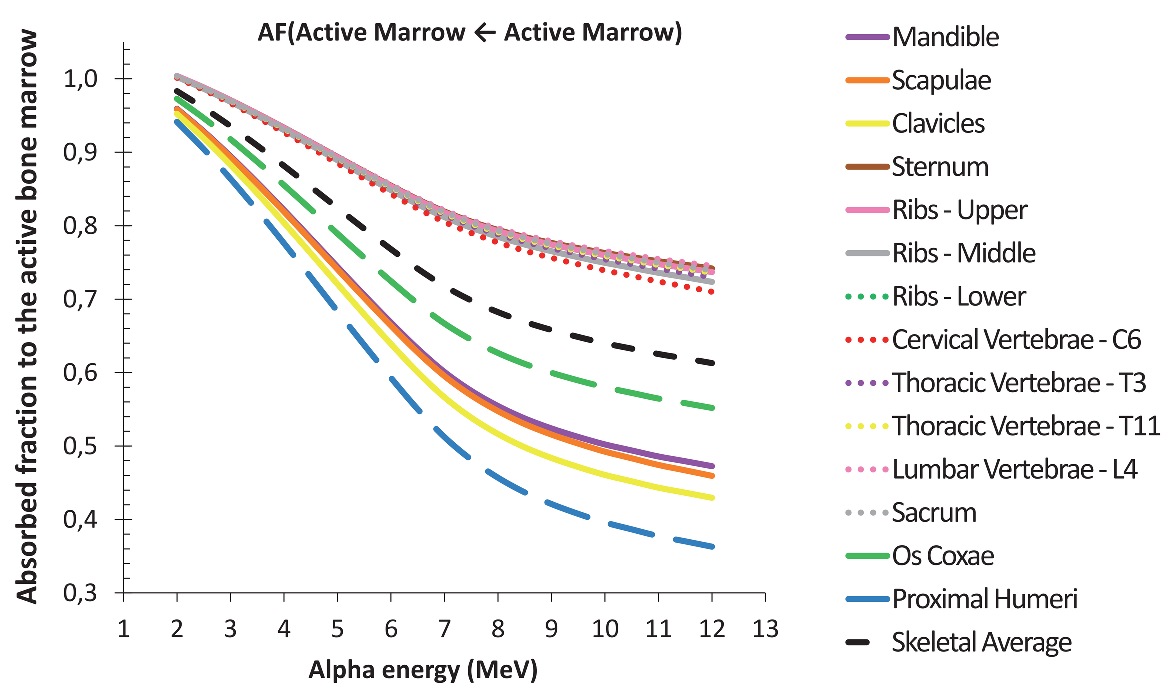
Materiel and Methods:

- Most realistic voxelized phantom of each bone site, developed in collaboration with the University of Florida



- MCNP6 Monte Carlo code with an energy range from 2 to 12 MeV

Results:



Dose to the bone marrow and to the endosteum:

- Patient of 70 kg
- 6 injections of 55 kBq/kg
- Biokinetic model from ICRP 67

	Dose to the bone marrow (Gy)	Dose to the endosteum (Gy)
ICRP 30	1,6	17,0
Our Study	0,8	6,0

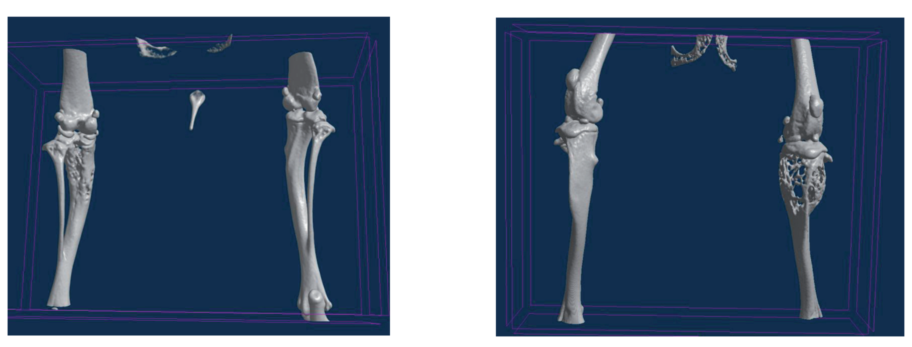
These results show the very important impact of taking into account realistic bone models and may explain the absence of hematological toxicity observed in patients.

3 Microlocalisation of ^{223}Ra

Goal: Characterize the distribution of ^{223}Ra at the microscopic level in order to better assess the relationship between dose and biological effects.

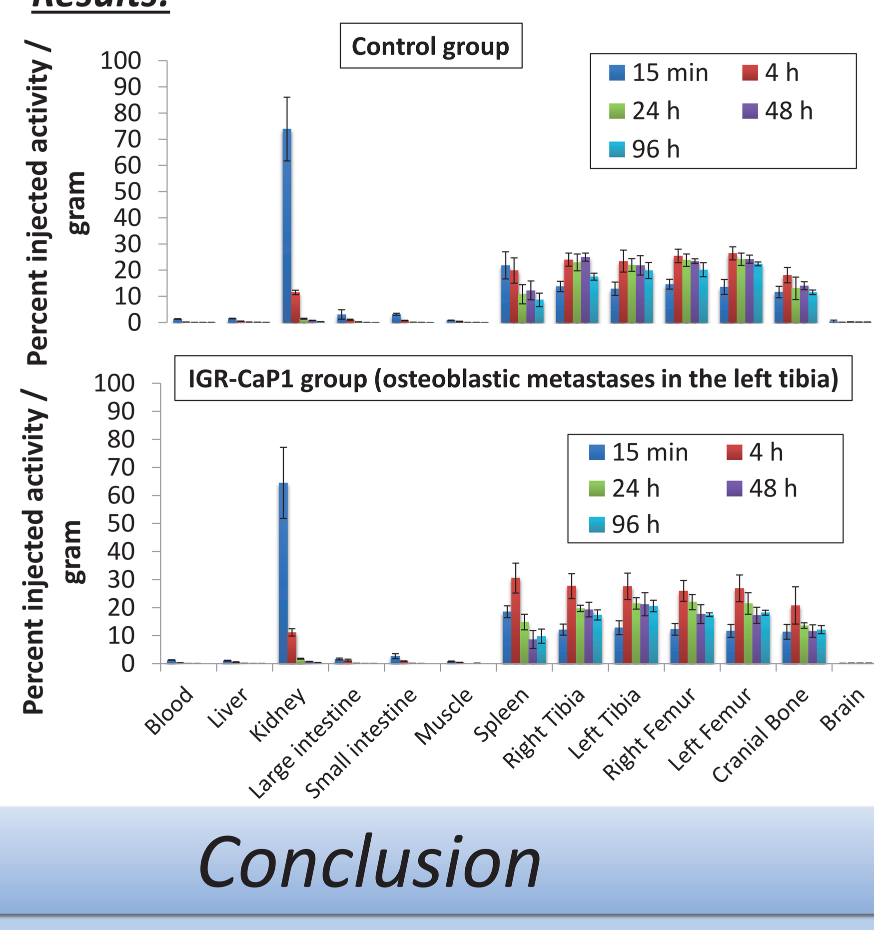
Materiel and Methods:

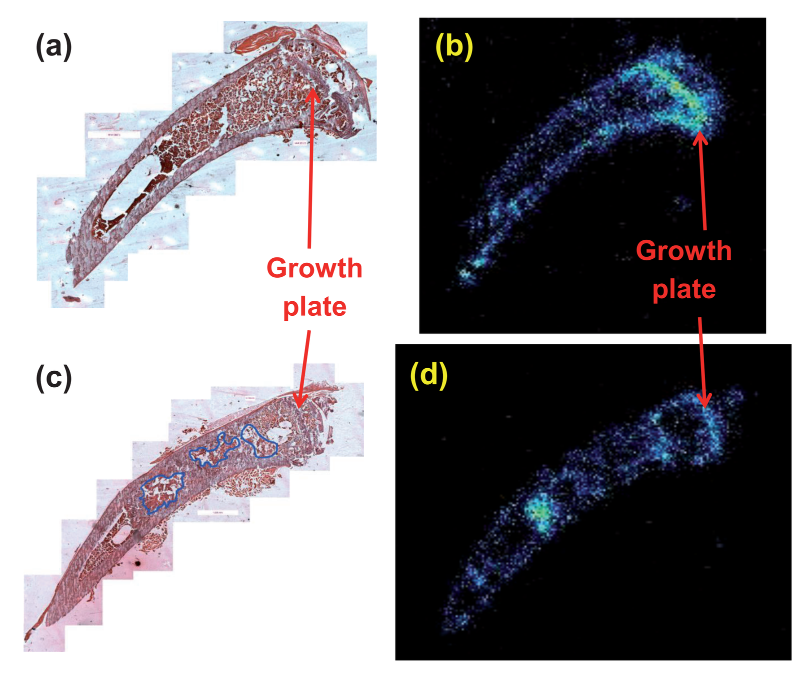
- 3 animal models: a control model with healthy mice, a diseased model with osteoblastic/osteolytic metastasis (IGRCaP 1 cells) and a diseased model with osteolytic metastasis (786-O cells)
- Tissue activity assayed in several organs by gamma counting
- Microdistribution of ^{223}Ra determined using autoradiographies on fresh frozen, undecalcified tissue sections and H&E stains



Osteoblastic/osteolytic metastasis — Osteolytic metastasis

Results:





Mouse inoculated with osteoblastic metastasis due to prostate cancer and euthanized at 48 hours: (a) H&E stain of the healthy tibia, (b) autoradiography of the healthy tibia, (c) H&E stain of the diseased tibia with tumors circled in blue, and (d) autoradiography of the diseased tibia.

Conclusion

- Gain more insight into the various aspects of the ^{223}Ra dosimetry: from the macro- to the microscopic scale
- Clinical trial on going: optimization and personalization of the patient dosimetry
- Emergence of new alpha-emitter radiopharmaceuticals, very promising but still few dosimetric studies → Methodology useful for these new radiopharmaceuticals
- Some aspects to improve: optimization of the reconstruction of SPECT images using MC calculations (GATE), adaptation of the microscopic distribution found on mice in a dosimetric model for patient.

Development of the new radiation monitoring system using DNA molecules as a radiation sensor

OSAKA UNIVERSITY

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UNIVERSITY of Fukui

Background

◆ A biological dosimeter that directly reflects cellular responses to ionizing radiation in living organisms would be useful for protecting human health against exposure.

◆We are developing a novel dosimetric system using DNA molecules as a radiation sensor. DNA molecules are irradiated and the resulting DNA damage is quantified by a real-time polymerase chain reaction (quantitative PCR, qPCR).

◆In order to know which damage was effective for block of DNA polymerase reaction, we also examined the amount of oxidative damage in the DNA which were produced by gamma-ray and ion particle.

Materials and Methods

◆Samples

The DNA fragment for the dosimetry system was formed using the PCR technique (amplification of 804 base pairs of *URA3* gene DNA fragment of yeast). The amplified DNA fragments were dissolved in a TE buffer (Tris-HCl 10 mM, EDTA 1 mM, pH7.4).

◆Irradiation Methods

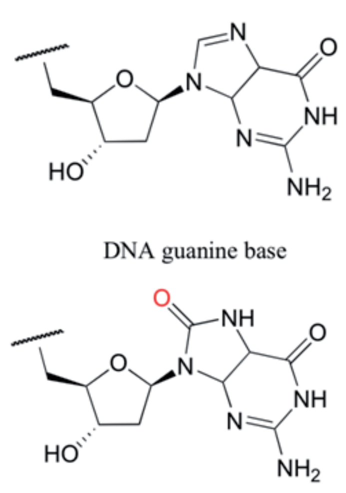
- Gamma-ray (From ^{60}Co, LET 0.2 keV/μm);
  by Chiyoda Technol Corp., Japan and Osaka univ.
- Carbon ion beams (290 MeV/u, LET 50 keV/μm and 220 MeV/u, LET 107 keV/μm);
  by HIMAC (NIRS, Japan) and TIARA (JAEA, Japan).
- Neon ion beams (260 MeV/u, LET 428 keV/μm);
  by HIMAC (NIRS, Japan).

◆Real-Time PCR

The real-time PCR was used to amplify a 200 bp region of the *URA3* gene. We used EcoTM Real-TimePCR System (illumina®). The template amount is 0.1ng (1μl: 0.1μg/ml). The amplification leads to an increase in fluorescence intensity which allows measurement of DNA concentrations.

◆8-oxoG assay

8-oxoG is one of the main mutagenic modifications induced in DNA by oxidative stress.
The amount of 8-oxoG in the model is estimated by 8-oxoG Check ELISA kit. Absorbance in 450nm was measured using iMark microtiter tray leader (BIO-RAD, Japan), and quantity of 8-oxoG was evaluated. Calf thymus DNA (SIGMA, Japan) was used as Model DNA.



DNA guanine base

damaged 8-oxoguanine base

Essential point

◆Quantitative PCR (Real-time PC) is used to amplify and quantify a radiation irradiated DNA molecules.

◆The DNA molecules irradiated with ionizing radiation suffer damages such as strand brakes and oxidation of base, and this Real-time PCR method is based on the fact that such DNA lesions caused by ionizing radiation block DNA synthesis by DNA polymerase, resulting in a decrease in the amplification of a damaged DNA template compared with that of non-damaged DNA templates.

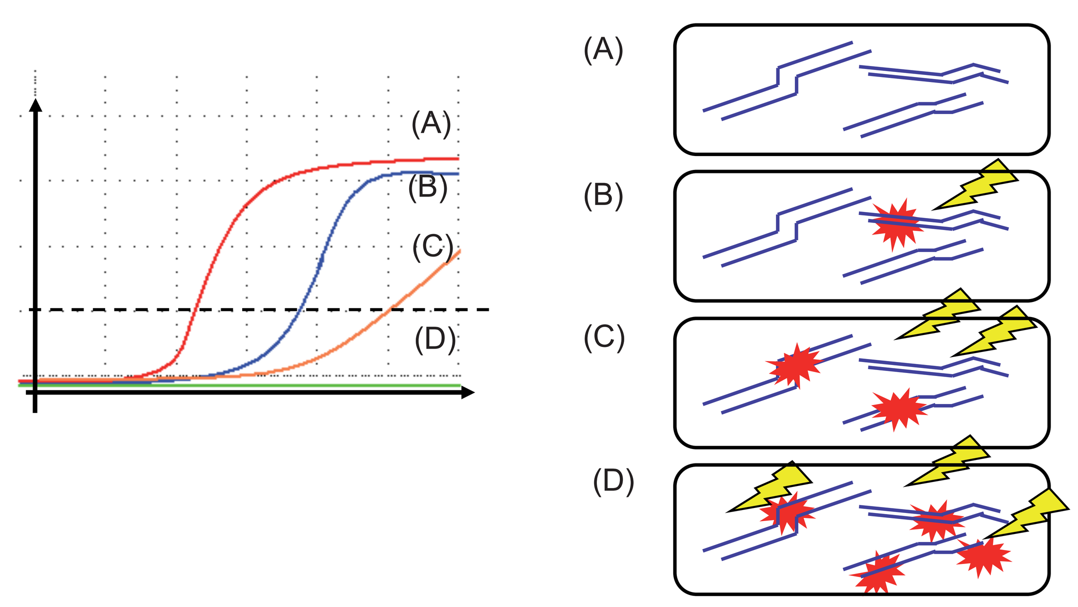


Fig. 1 Schematic model of qPCR method

What is qPCR Method?

●Polymerase Chain Reaction (PCR) was used to amplify specific DNA fragments.

●DNA polymerase synthesizes a new DNA strands from primers using single-strand DNA as a template from 5' to 3' direction.

● Real-time PCR is a laboratory technique based on the PCR, which is used to quantify the amount of DNA molecules .

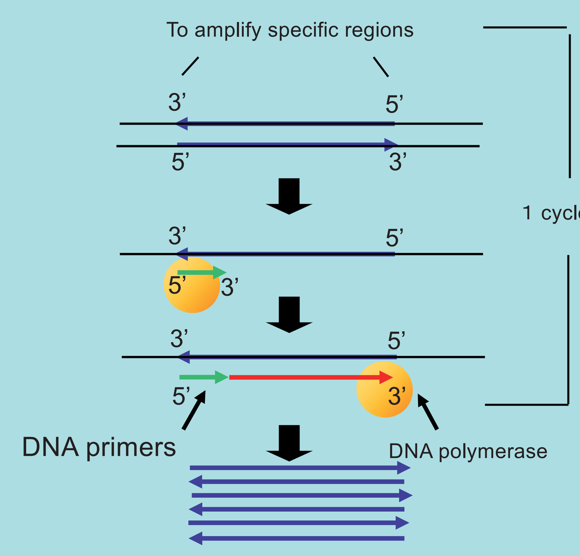


Figure 2 Schematic drawing of the PCR cycle.

▲At each extension step, the amount of DNA is doubled, leading to exponential amplification of products.

Results and Discussion

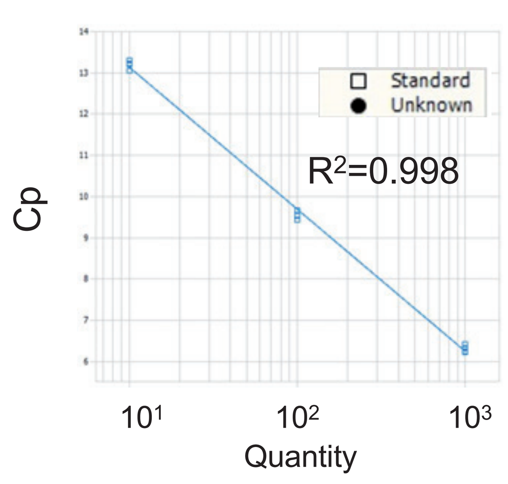


Figure 3 plotting of standard

The Cp (crossing point-PCR-cycle) value is the cycle at which fluorescence achieves a defined threshold.

We obtained the result that amplifiable template by the polymerase chain reaction decreased in proportion to gamma-ray irradiation.
This means that DNA lesions such as strand breaks caused by ionising radiation inhibit the DNA polymerase reaction using irradiated DNA fragments.

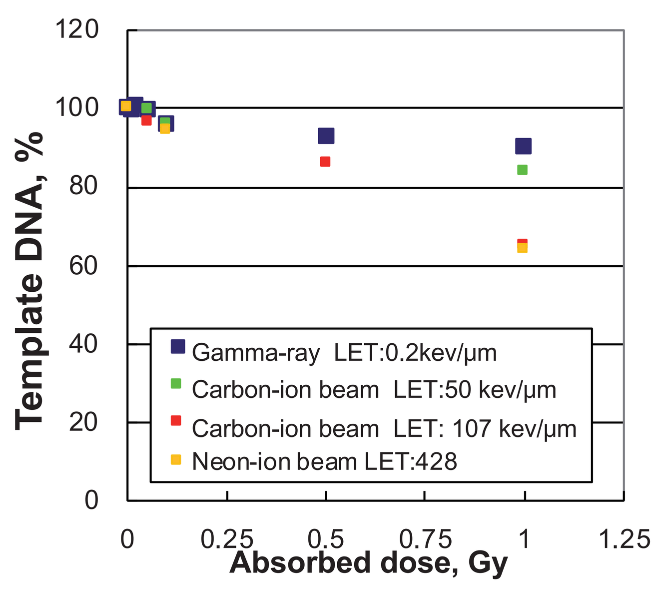


Figure 4 DNA deactivation rate by the Real-Time PCR.

It was shown that the efficiency of DNA synthesis decreased corresponding to increasing LET.

It means that DNA lesions, in particularly double-strand breaks, affect the rate of DNA synthesis.

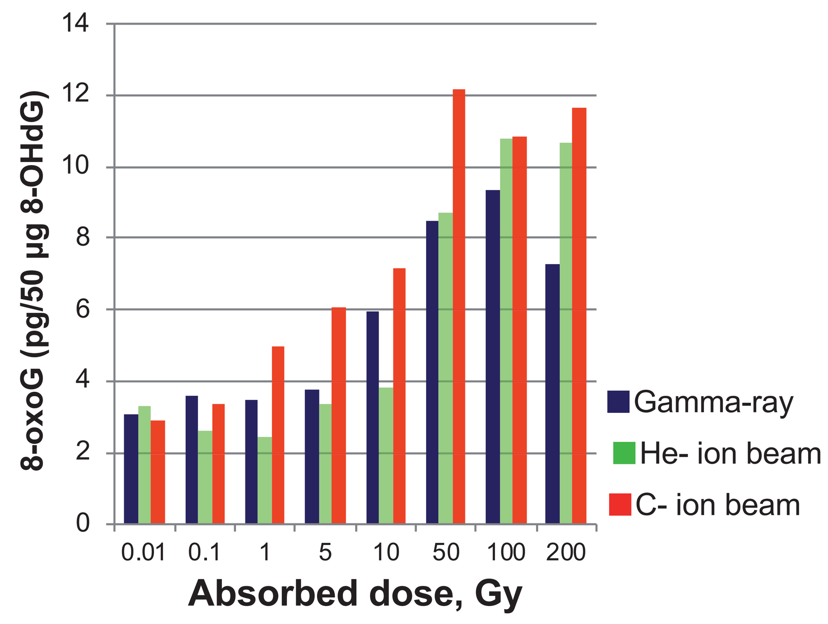
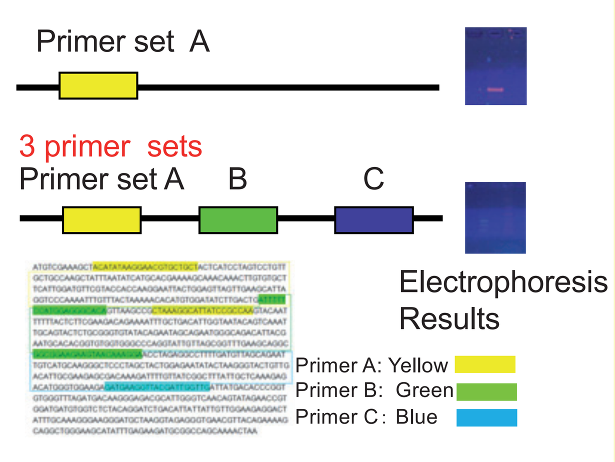


Figure 5 8-oxoG formation after irradiation with ionizing radiations

While ionizing radiation elicits not only DNA strand breaks but 8-hydroxy-2'-deoxyguanosine (8-OHdG) production, the levels of 8-OHdG produced by high- and low-LET gamma irradiation were similar, demonstrating that 8-OHdG production was not affected by the magnitude of LET.



The only 1 primer set is used in the conventional real-time PCR. In the DNA synthesis process, we used three sets of primers. it is thought that detectability becomes higher as the evaluable regions increase.

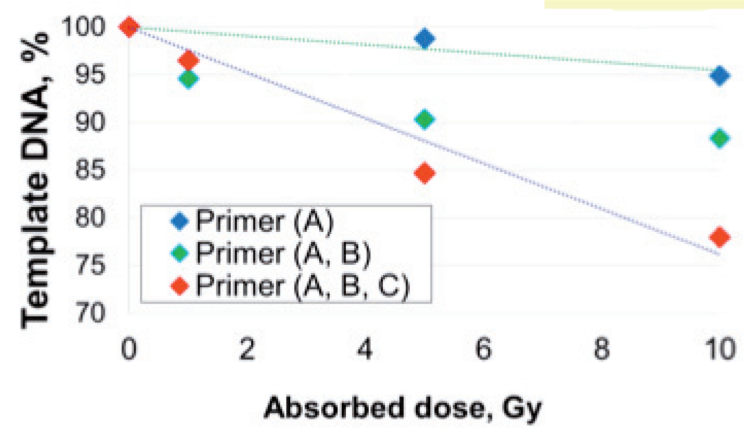


Figure 6 The results of the Real-Time PCR using three sets of primers.

It was shown that detection sensitivity for DNA lesions was improved, by using 2 and 3 primer sets. The detection sensitivity for DNA lesions will improve by enlarging a region performing DNA synthesis. We will perform optimization to evaluate the minute DNA lesion in the low dosage range.

Conclusion

(1)The real-time PCR assay for the irradiated DNA is useful to measure the irradiated dose.

(2) The detection sensitivity for DNA lesions will improve by enlarging a region performing DNA synthesis.

Effect of acute whole-body gamma irradiation on circulating microparticles levels in rats.

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OBJECTIVES

Damage to cellular membrane and disruption of the cytoskeleton is a well recognized complication of the irradiation. The disorganization of the cytoskeleton leads to form membrane blebs, which is called microparticles (MP). Our objective was to determine the gamma-irradiation effect on the circulating MP as biomarker of cellular membrane damage in blood of rats.

METHODS

The Wistar rats were divided into six groups: a control group and 5 groups of rats receiving a different dose of irradiation (0.5, 1, 2, 4 and 8 Gy) for different times (24h, 72h and 1 week). MP in blood of rats were counted by flow cytometer after 24h, 72 h and one week post-irradiation.

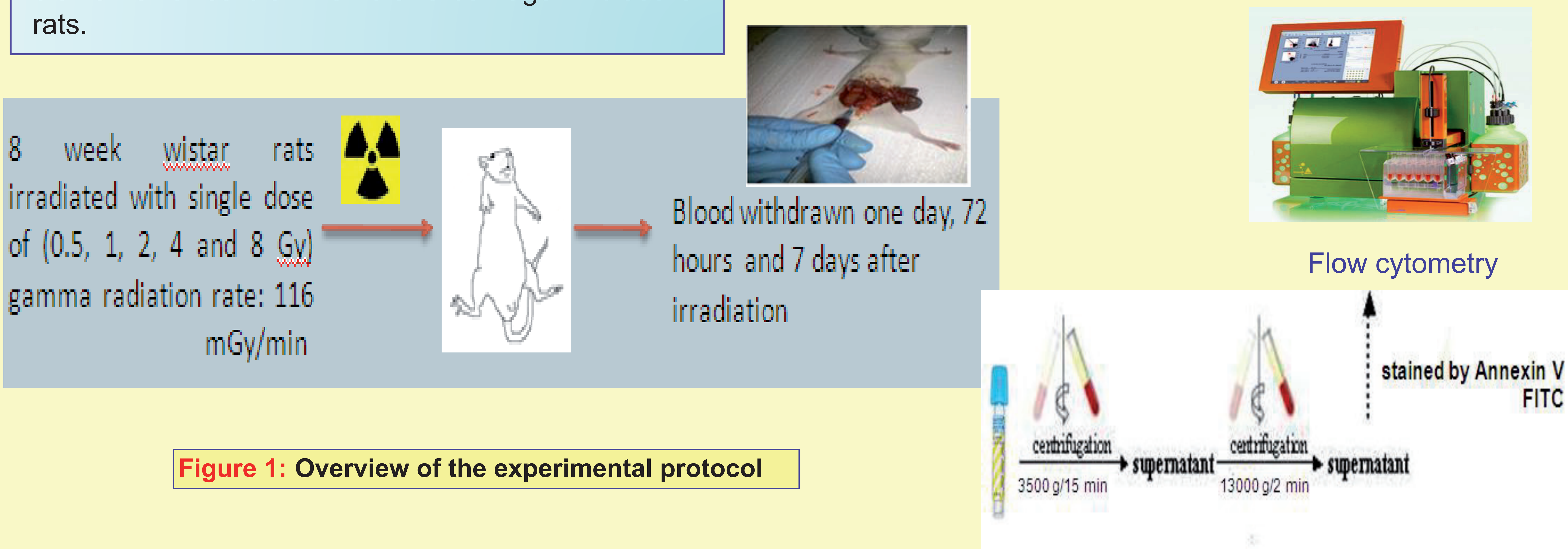

Figure 1: Overview of the experimental protocol

RESULTS

Quantified MP showed that there was increased in MP count in irradiated rats compared to control group, ($p<0.05$) at all the time points and in a non-dose dependant manner, Whereas at one week post-irradiation the increase in MP levels is clearly less pronounced with lethal dose (8 Gy, $p=0.09$). After one day of irradiation, the levels of MP in rats irradiated with 4-8 Gy was significantly lower than those in rats irradiated with doses of 1-2 Gy, without reaching their values in controls.
However, we observed a significant decrease in the number of MP (72h and one week) post irradiation at all doses except for 0.05 Gy compared to those found 24h after irradiation. It seem that there a partial restoration in MP levels with time elapsed from the exposure to gamma irradiation.

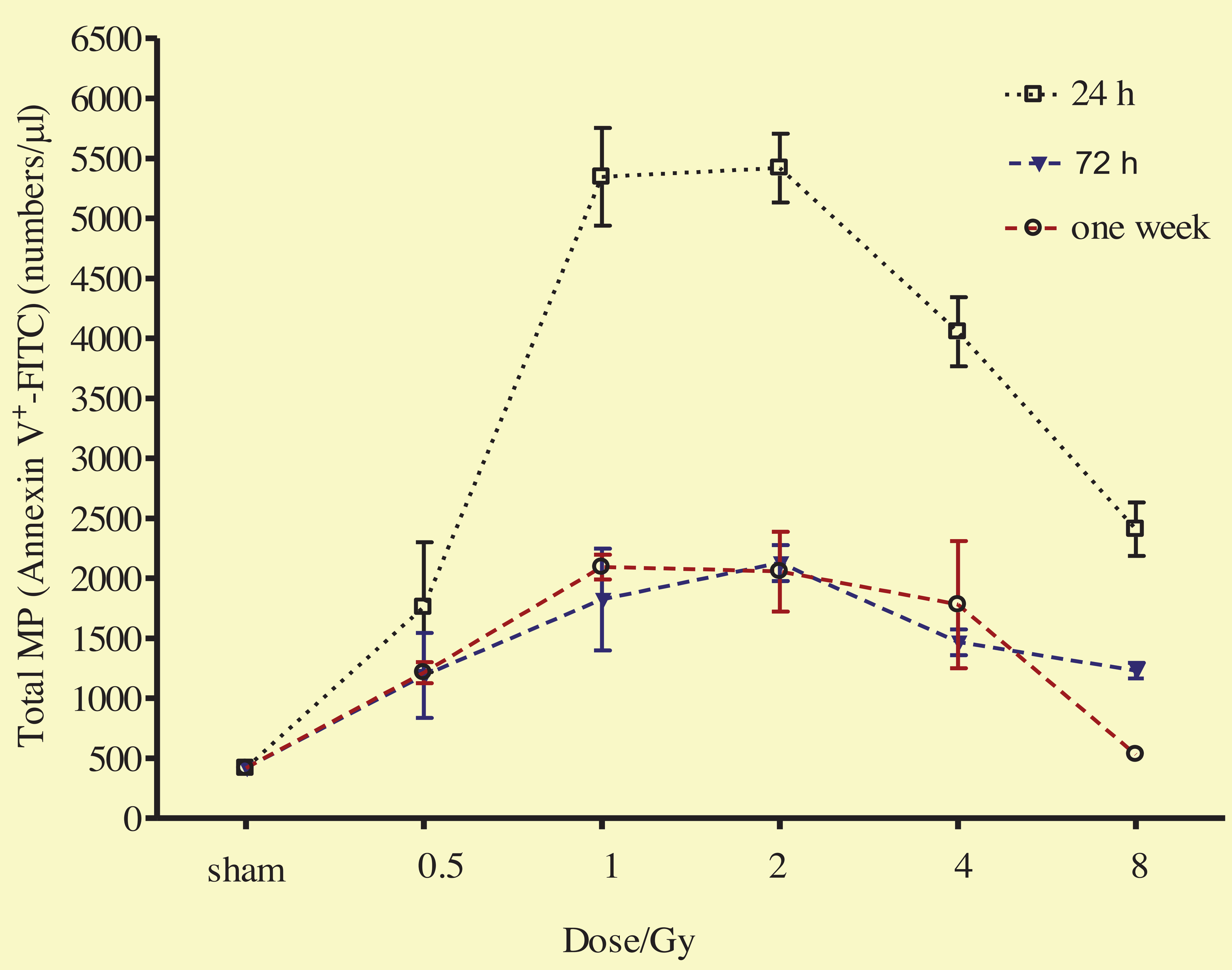

Figure 2: Dose-related changes in total MP count in the rats after whole-body irradiation.
MP numbers were scored one day (dotted black), 3 days (dotted bleu) and one week (dotted red) after acute irradiation. Each point represents the mean total MP count in six rats. Error bars are standard error of the mean (SEM) for n=6 independent experiments.

CONCLUSIONS

The number of MP in rats exposed to whole-body gamma irradiation was increased in a dose-dependent manner and it partly recovered during the 72h interval after irradiation. We suggest that MP count may be an early indicator of the membrane damage induced by ionizing radiation.

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY
Norwegian Institute for Water Research
Stockholm University
Nordic nuclear safety research
Statens strålevern
Norwegian Radiation Protection Authority

Investigating ecosystems effects of ionizing radiation: A Microcosm study

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Background

Ecosystem response to **gamma radiation** exposure depends on the different **species sensitivities** and the multitude of **direct and indirect pathways** by which individual organisms can be affected, including the potential for complex **interactions** across multiple **trophic levels**.

The approach in this study was to sample a wide range of endpoints, from molecular to ecosystem-level, spanning both structural and functional components.

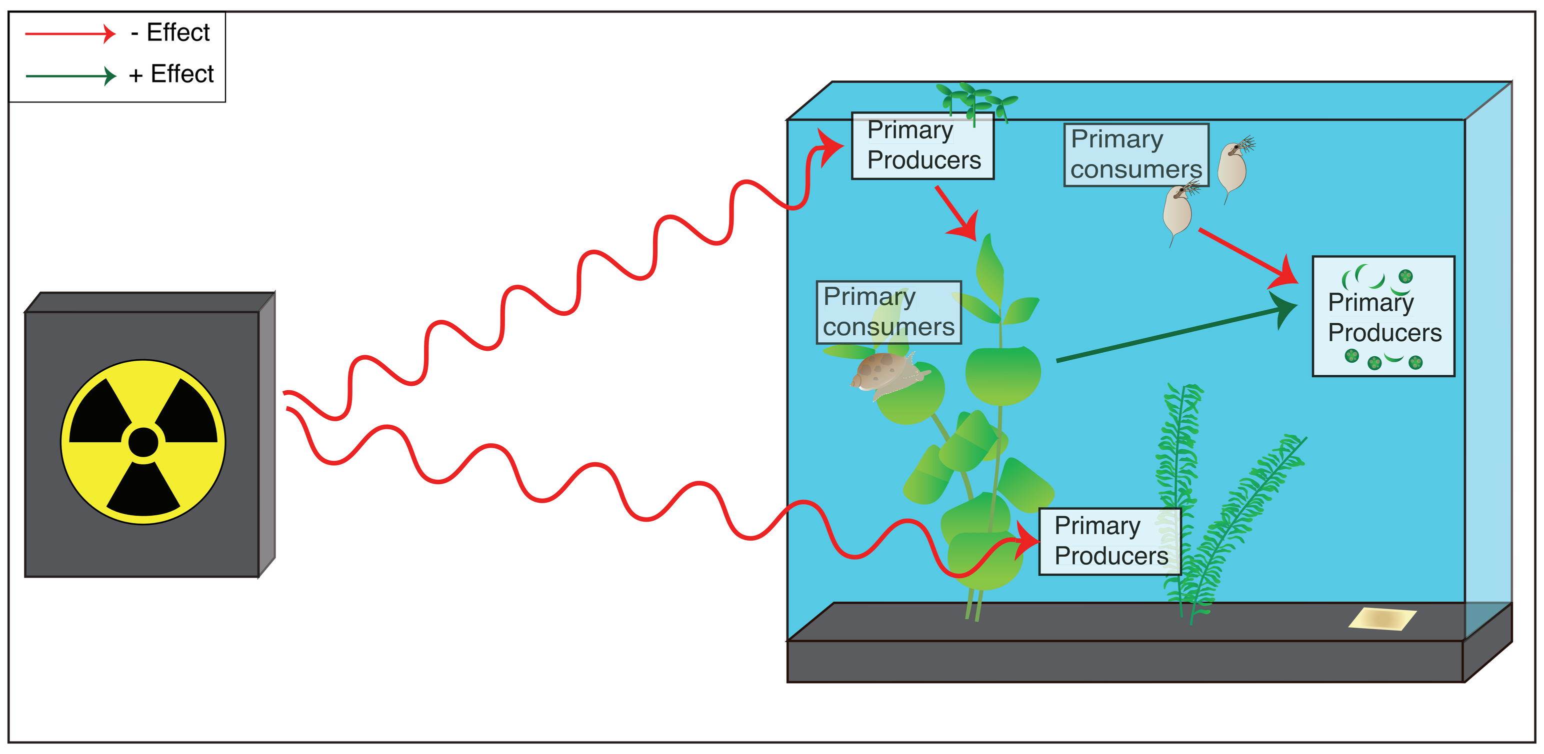


Figure 1: Graphical abstract of experiment.

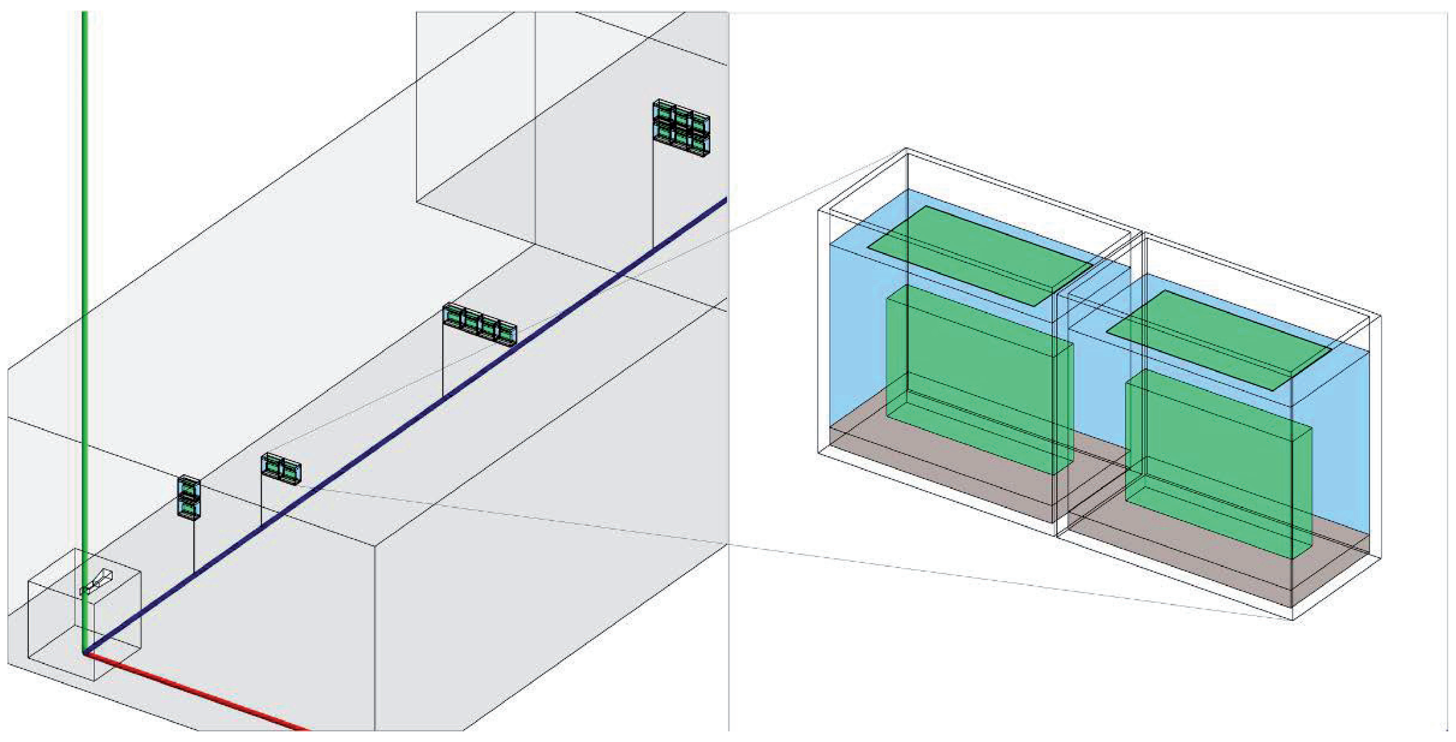


Figure 2: Dosimetry in climate chamber (FIGARO) the source is located in the lower left corner and microcosms are arranged over four dose levels at increasing distances to the (Hansen et al, in press).

Methods

1. **Freshwater species in semi-standardized 4L microcosms with primary producers and primary consumers (Fig.1)**
2. **22 days exposure to Cobalt-60 gamma source (FIGAR0 facility NMBU)**
3. **Four dose rates in the range from 0.72 to 19 mGy/h (Fig.2)**
4. **Endpoints measured; oxygen rates, grazing rates, population counts, reproduction rates, growth rates, photosynthetic parameters, primary production, lipid peroxidation and more.**
5. **Analysed endpoints via traditional regressions and Structural Equation Modelling (SEM).**

Results

- Large range of parameters measured gave us an overview of the ecological systems
- Significant stress response of plants at the molecular level that was not so apparent at individual or population level.
- Different effects in D. magna and L. minor to those seen in previous single species radiation studies
- Significant dose-dependent effects on primary producers (Fig. 3)
- Significant indirect effects measured through SEM analyses (Fig. 4)

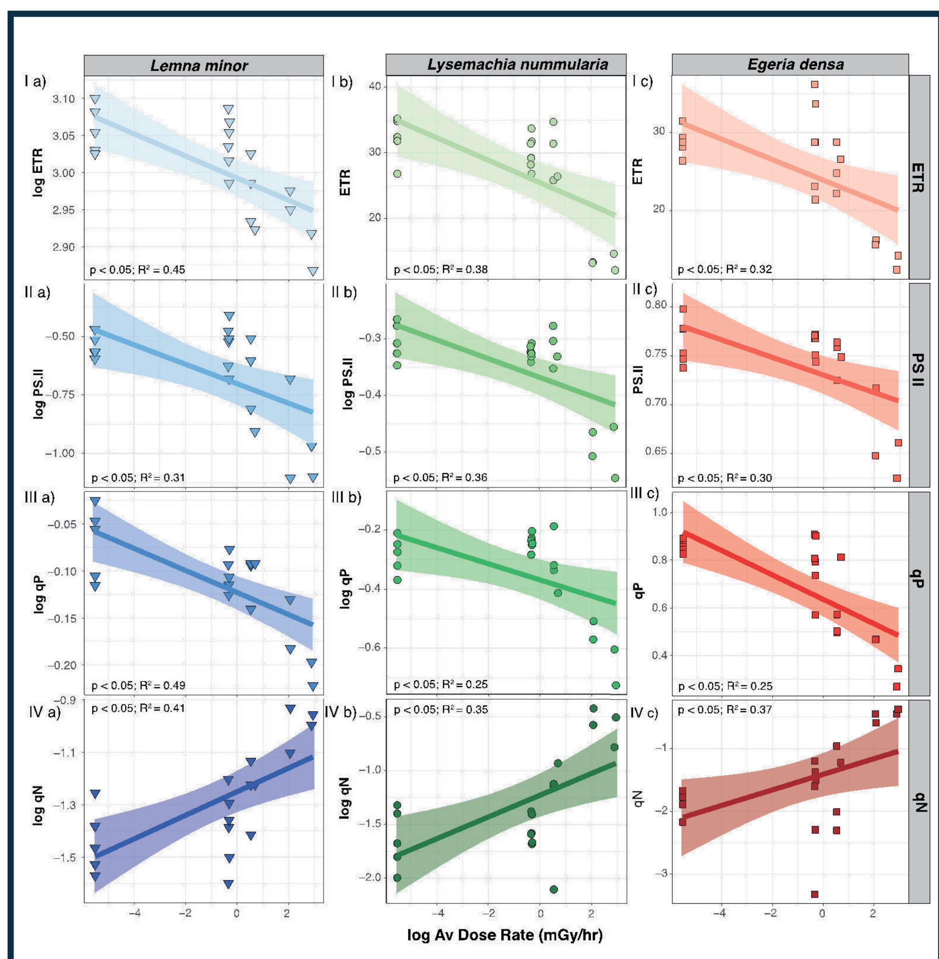


Figure 3: Response of chlorophyll florescence emission measurements in plants in increasing dose rates I) ETR, II) ΦPS II, and photochemical quenching coefficients (III and IV).

Conclusions

- Few direct effects of radiation; ecological pathways and consequences of these effects can be more important.
- Lack of correspondence between individual and population level responses support the hypothesis that effects at one level cannot always be used to infer effects at another level.
- Microcosms, with their multi-species approach, have different interactions, processes and mechanisms that single species tests fail to encompass
- Microcosms allowed us to isolate specific relationships between interacting species in an ecosystem and test the effects of radiation on them, both direct and indirect.

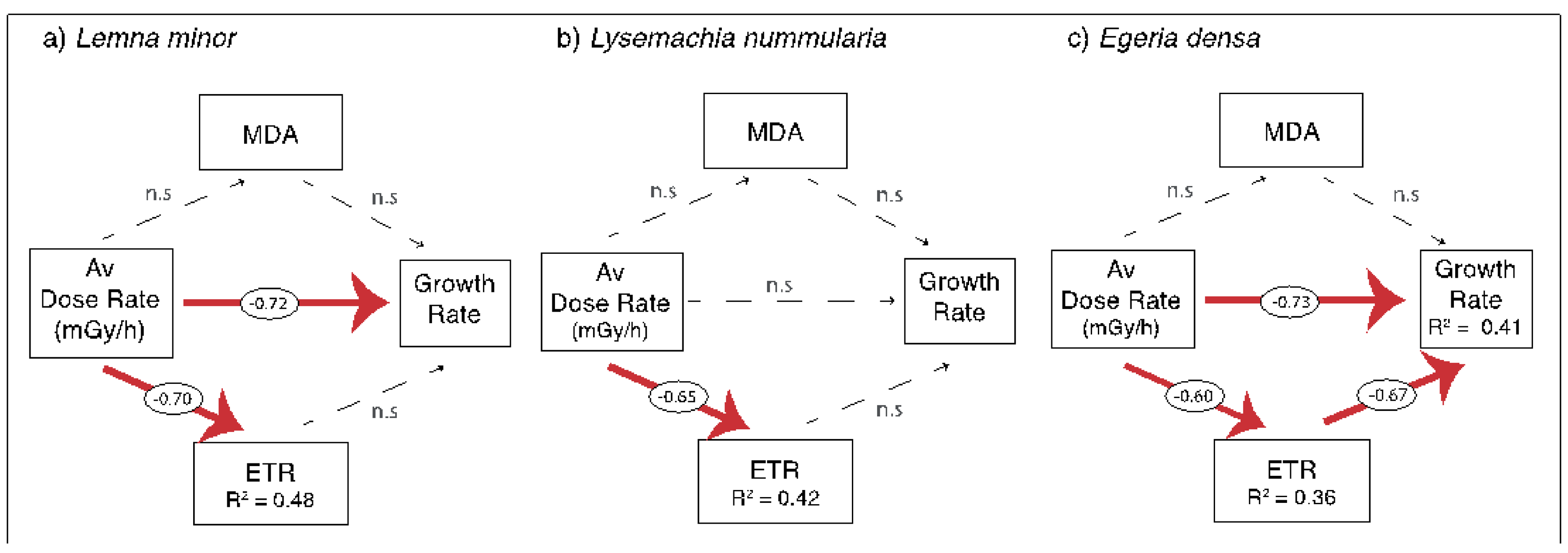
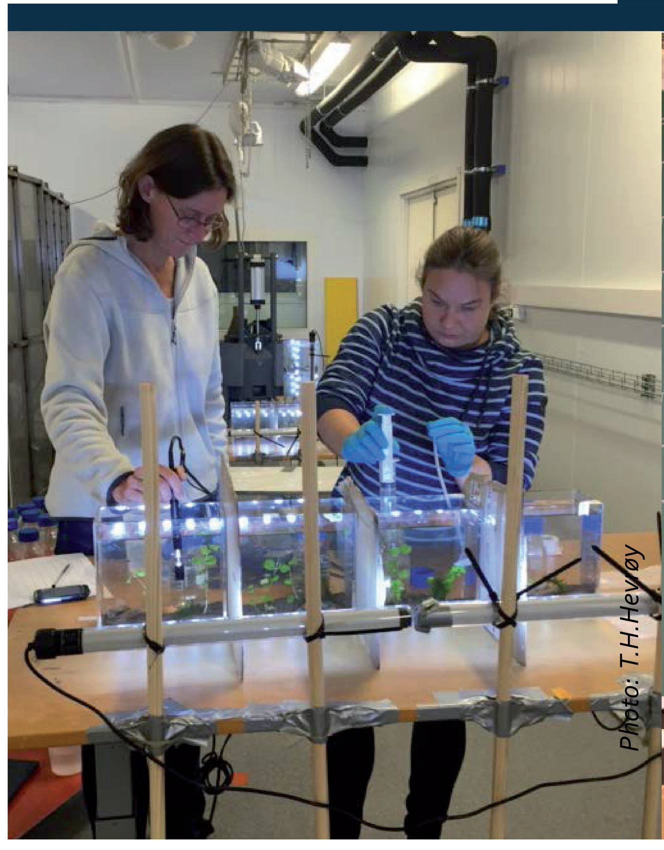


Figure 4: Piecewise structural equation modeling (SEM) of average dose rate MDA and ETR as predictors of plant growth rates. Solid red arrows represent negative paths ($p < 0.05$) and dashed grey lines represent non-significant paths.



Microbiological analysis of the cooling waters of a nuclear research reactor

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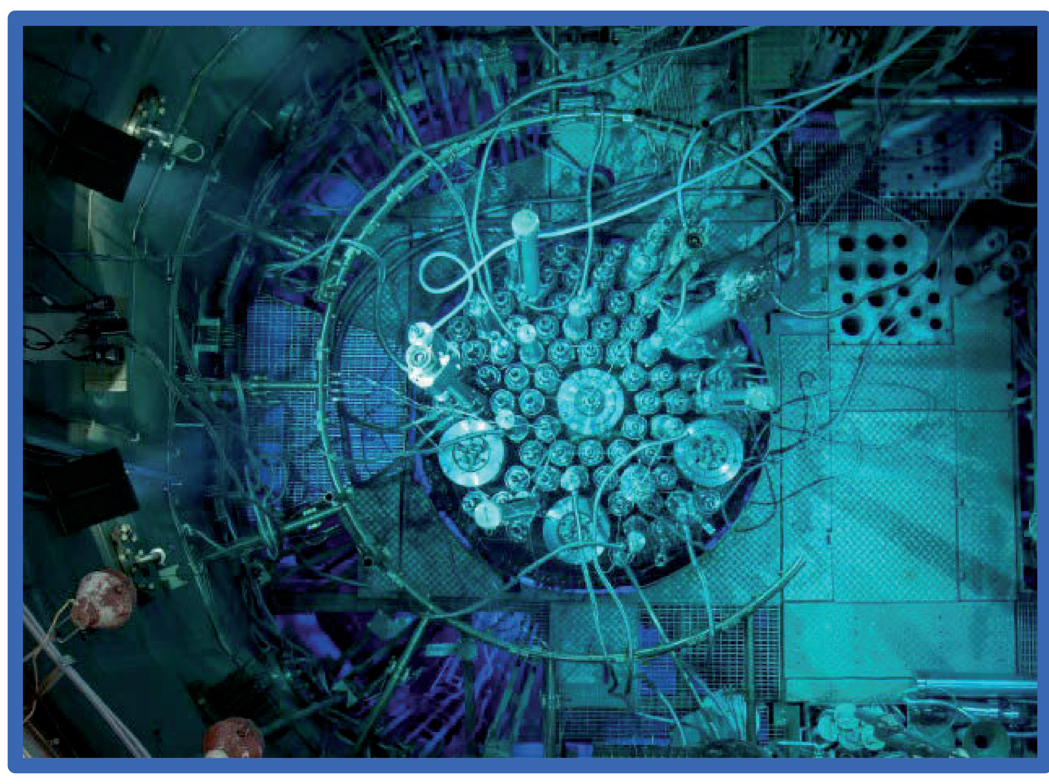
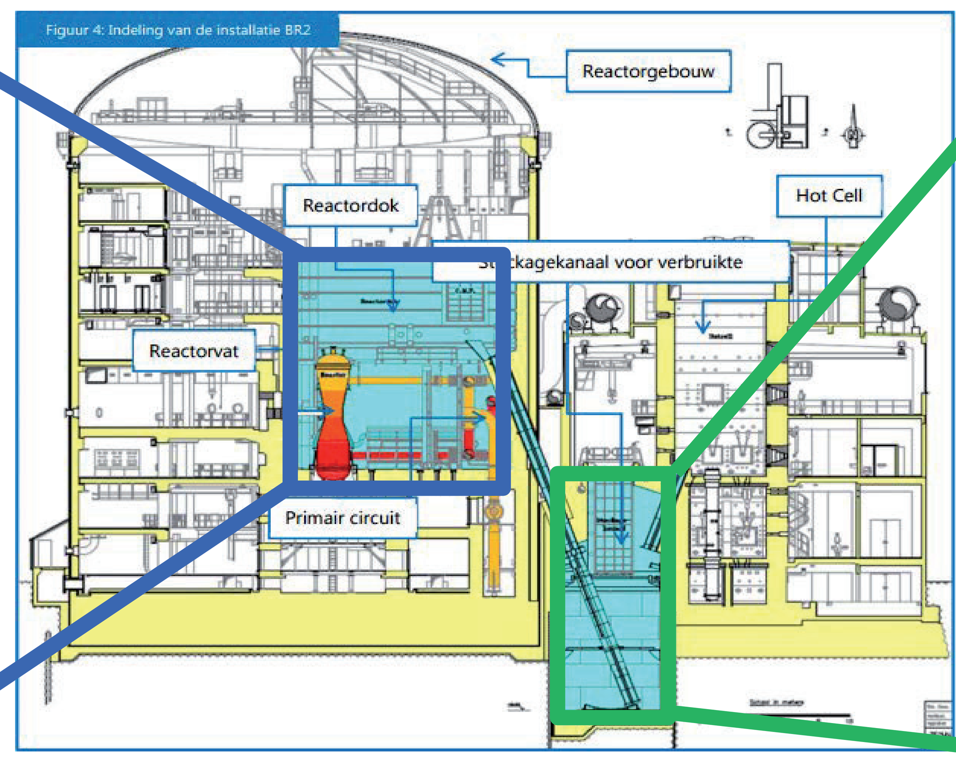
Introduction

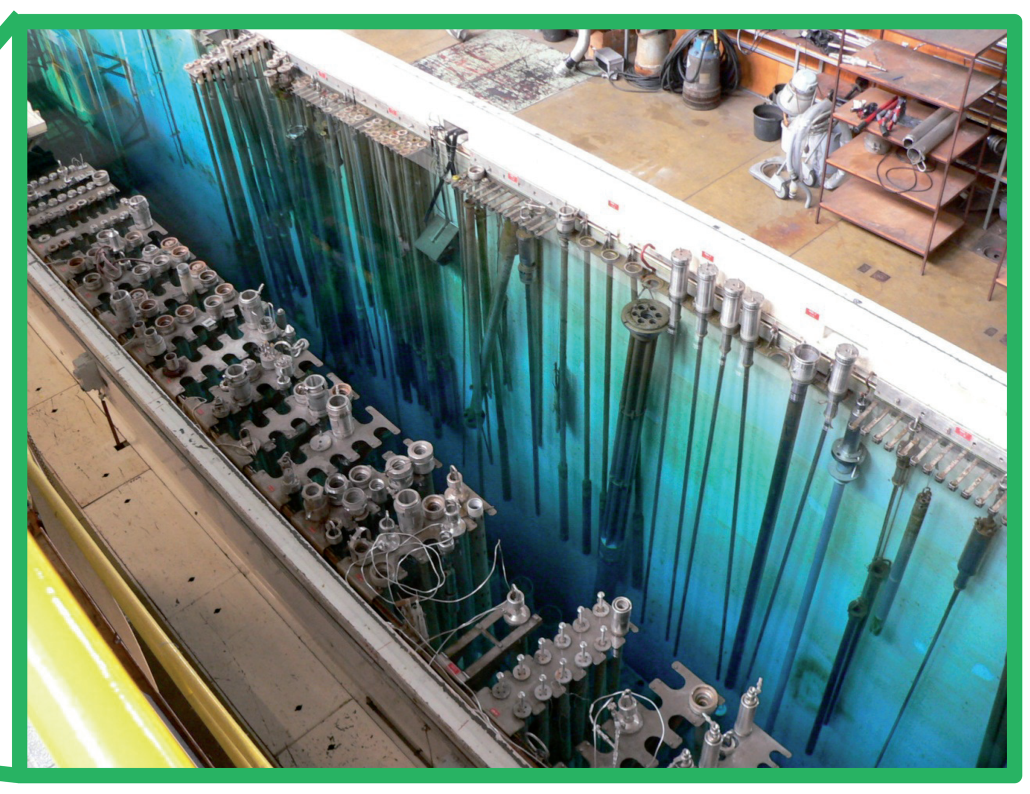
The BR2 nuclear research reactor's main activity is the production of medical isotopes. It comprises different watery environments: the primary cooling circuit consists of a closed loop containing water that cools down the fuel rods in the reactor core. An open basin surrounds the reactor vessel and spent nuclear fuel is stored in the contiguous spent nuclear fuel pool (SNFP) in order to cool down before being safely disposed. Although this ultrapure water is intermittently subjected to significant doses of ionizing radiation, several microbes appear to be able to survive and thrive in such conditions. Microorganisms identified in those environments thus provide a unique opportunity to acquire new insights into survival strategies and radiation-resistance mechanisms.



Top view of the BR reactor vessel submerged in an open basin



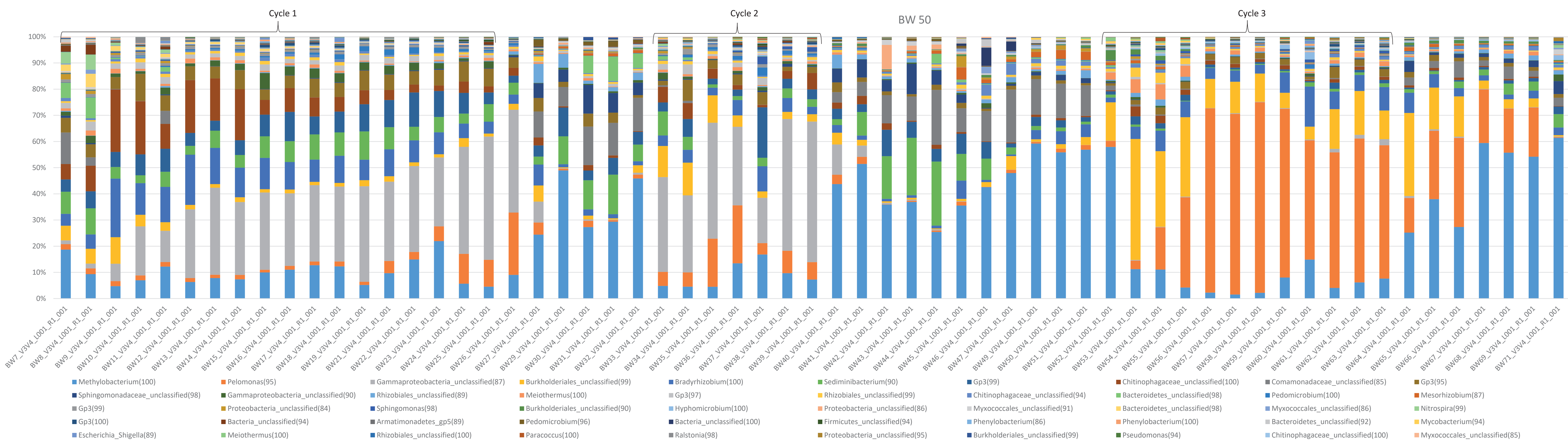
BR2 reactor configuration



Spent nuclear fuel pool

Follow-up of basin community

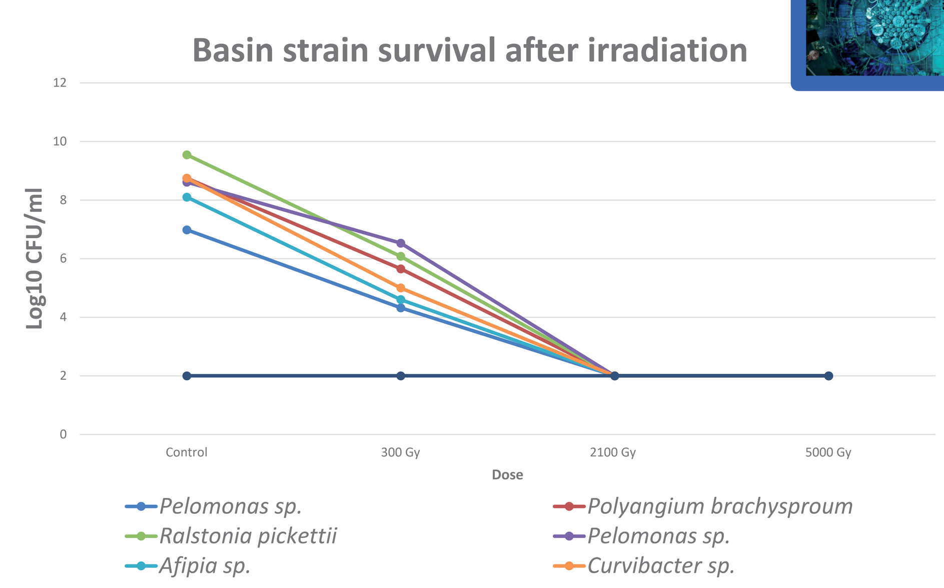
The bacterial community in the basin water was monitored over time during and outside isotope production cycles. Samples were taken at different time points and 16S rRNA amplicon sequencing was subsequently performed. Results were analyzed via an in-house developed data analysis pipeline.



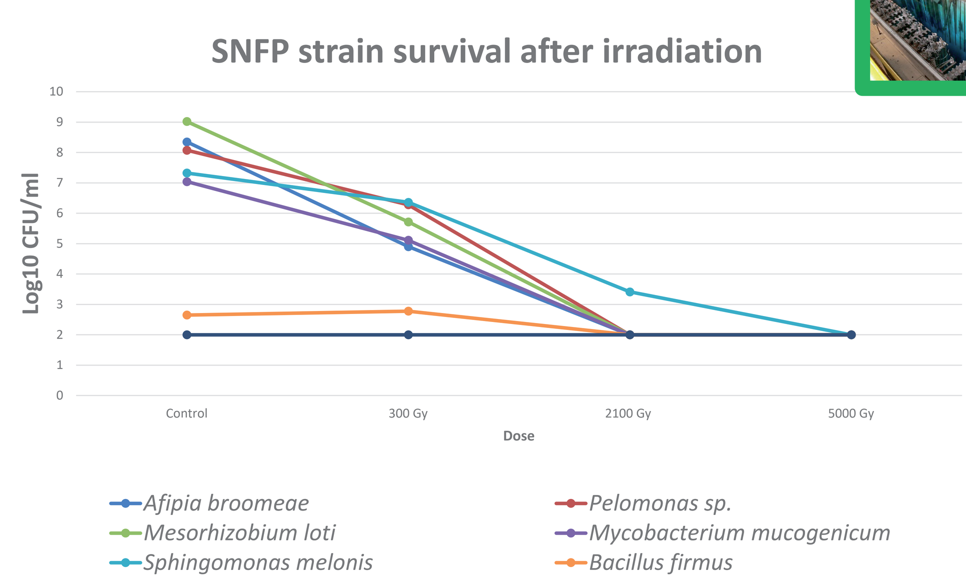
Bacterial community profile obtained from 16S rRNA amplicon sequencing for the basin water. Only the 50 must abundant OTUs are shown. A clear shift in the community is apparent during and outside reactor cycles. This can be correlated to changes in physico-chemical parameters of this environment (e.g. temperature, conductivity, radiation)

Phenotypic characterization of isolates

Water samples were taken from the basin and the SNFP and bacterial strains were subsequently cultured. The radiation resistance of the isolated strains was tested using the RITA gamma irradiation facility at BR2.



Basin strain survival after irradiation at a dose of 300 Gy, 2100 Gy and 5000 Gy.



SNFP strain survival after irradiation at a dose of 300 Gy, 2100 Gy and 5000 Gy.

Conclusion

The BR2 waters are home to a diverse microbial population. The phenotypic characterization of the isolates showed a large variability in radiation resistance between different strains, and as such not necessarily a high radiation tolerance to survive in these environments. The 16S rRNA amplicon sequencing follow-up illustrated a clear shift of the bacterial community across different reactor cycles.

Acknowledgements: Valérie Van Eesbeeck has been supported by a SCK•CEN PhD fellowship

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Radiation resistance in the cyanobacterium *Arthrospira*

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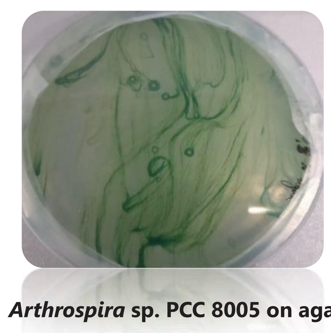
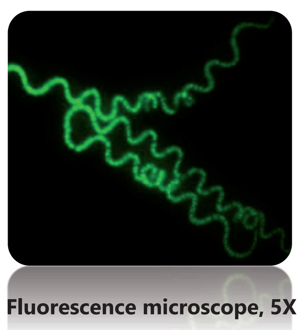
KNOWLEDGE IN ACTION

Introduction

- *Arthrospira* are filamentous, multicellular cyanobacteria that typically reside in alkaline lakes. They are blue-green in colour with cylindrical cells organised in helicoidal trichomes.
- As photosynthetic organisms, *Arthrospira* are able to convert solar energy into chemical energy by oxidising water while they produce O_2 and fix CO_2. They have a high protein content and are rich in minerals, vitamins, carbohydrates, and essential fatty acids and hence *Arthrospira* are globally used for their added-value products or as feed- and food stock.
- Original PCC 8005 is curly in morphology (P6) but a new mutant straight morphotype of PCC 8005 was found in lab (P2), having interesting properties.
- *Arthrospira* was found to be highly resistant to gamma radiation (Badri et al. 2015).



Arthrospira sp. PCC 8005 on agar



Fluorescence microscope, 5X

Objective

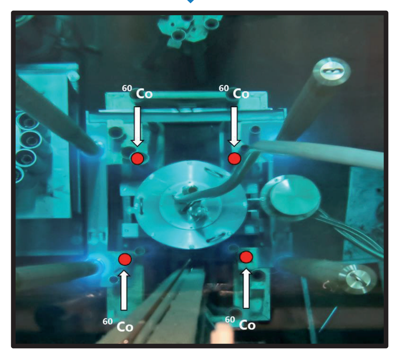
The immediate aim of this study is to elucidate the radiation resistance mechanisms of *Arthrospira sp.* PCC 8005, on the cellular and molecular level.

Materials and methods

Pre-culture

- 2 morphotypes of *sp.* PCC 8005
- Zarrouk growth medium
- Rotatory shaker, speed 120 rpm
- 30°C temperature

Radiation



- RITA facility at SCK•CEN
- ^{60}Co gamma rays
- Dose rate: ca. 600 Gy/h
- Temperature: RT
- Dark

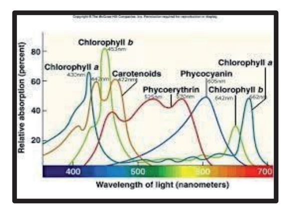
Cell level analysis

Growth: OD at 750 nm, every 3rd day for one month

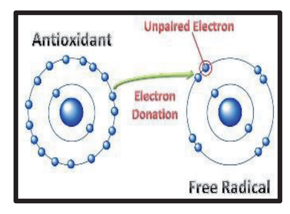
Structure: Transmission Electron Microscopy (TEM)

Molecular level analysis

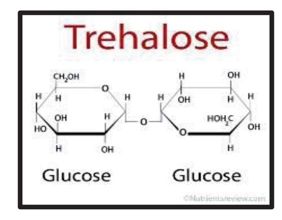
Pigments: APC, PC, Carotenoids, Chlorophyll



Antioxidants



Trehalose



Results

A. Growth

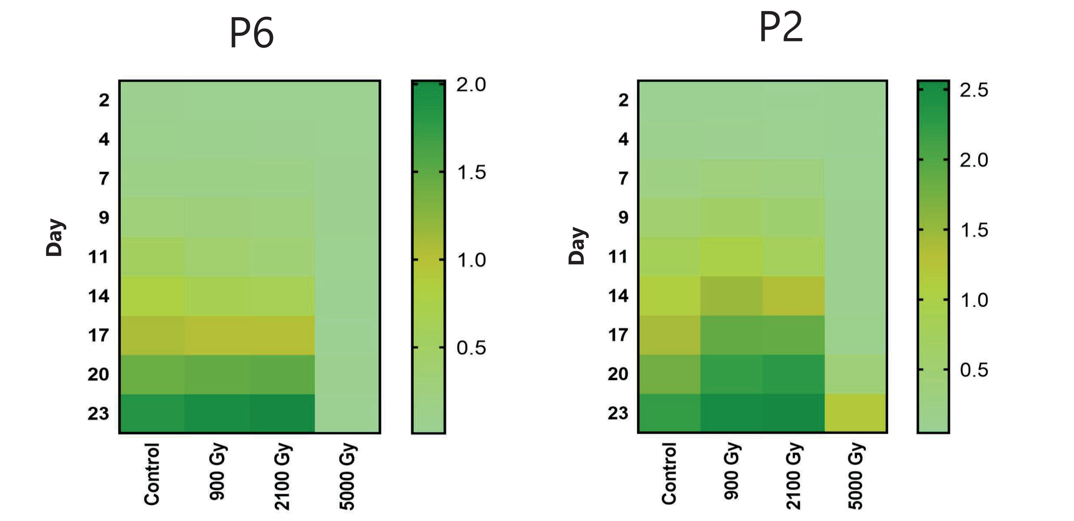


Fig 1: Morphotypes exposed to different doses of ^{60}Co radiation (C- curly (P6) and S- Straight (P2) morphology) showed a significant difference in radiation sensitivity.

B. TEM

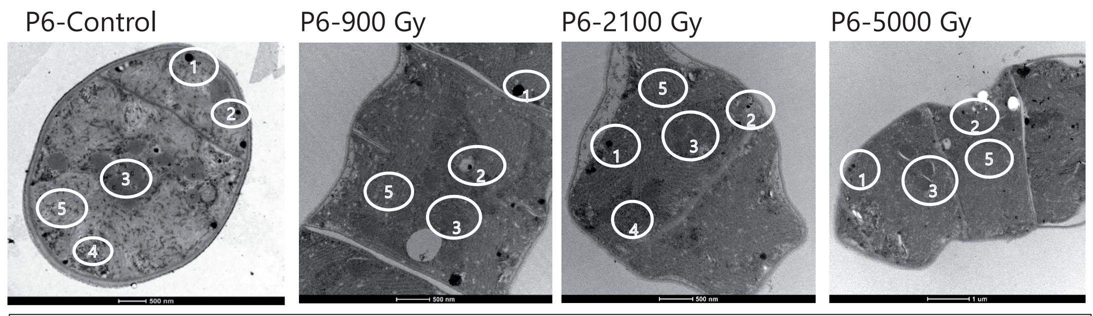


Fig 2: TEM images (by courtesy of K. Waleron, Medical University of Gdansk): 1: Polyphosphate granule, 2: Lipid inclusion, 3: Carboxysomes, 4: Glycogen granule, 5: Thylakoid

C. Trehalose

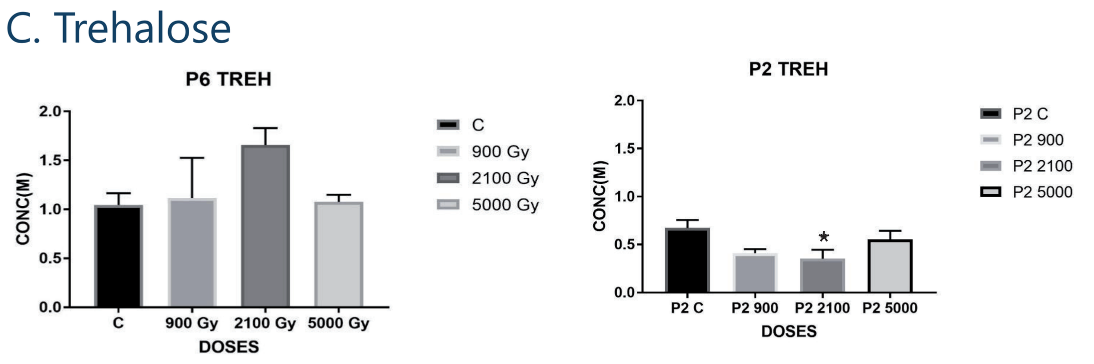


Fig 3: Trehalose concentration (a) in strain P6 and P2 at different IR doses. Significant difference between control and 2100 Gy in strain P2

D. Total antioxidant proteins

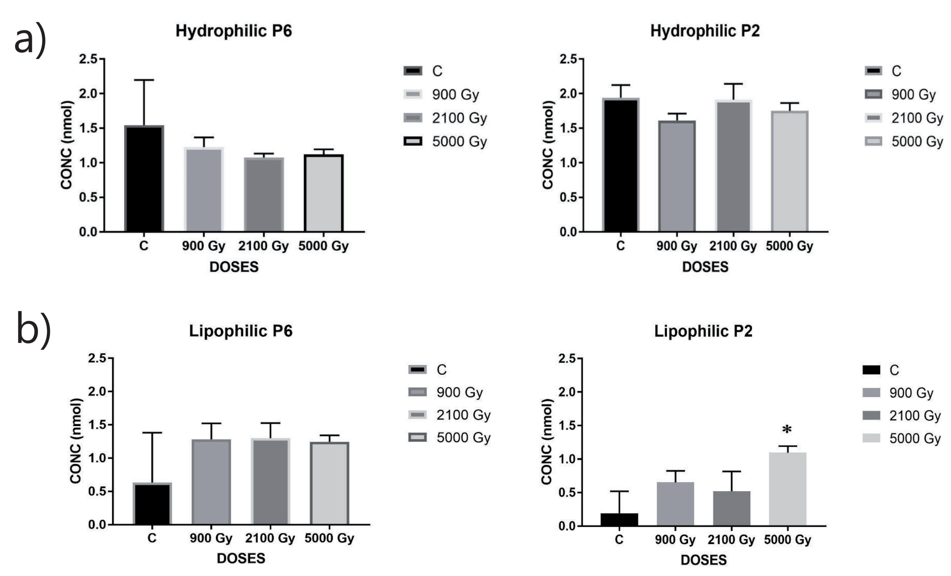


Fig 4: Total antioxidants concentration in the cells at different IR doses in P6 and P2; a) Hydrophilic proteins, b) Lipophilic proteins, showing a significant difference between control and 5000 Gy in the P2 strain

E. Glutathione

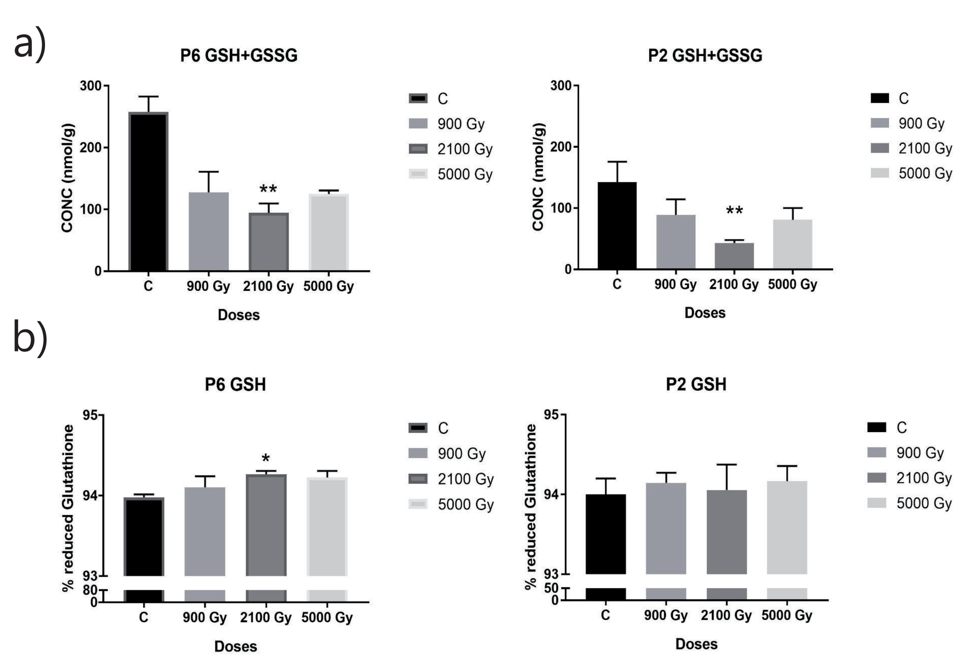


Fig 5: Glutathione concentration in cells at different IR doses in P6 and P2; a) Total glutathione concentration, showing significant difference between control and 2100 Gy in both morphotypes, b) % of reduced glutathione out of total glutathione, showing a significant difference between control and 2100 Gy in the P6 strain

F. Pigments

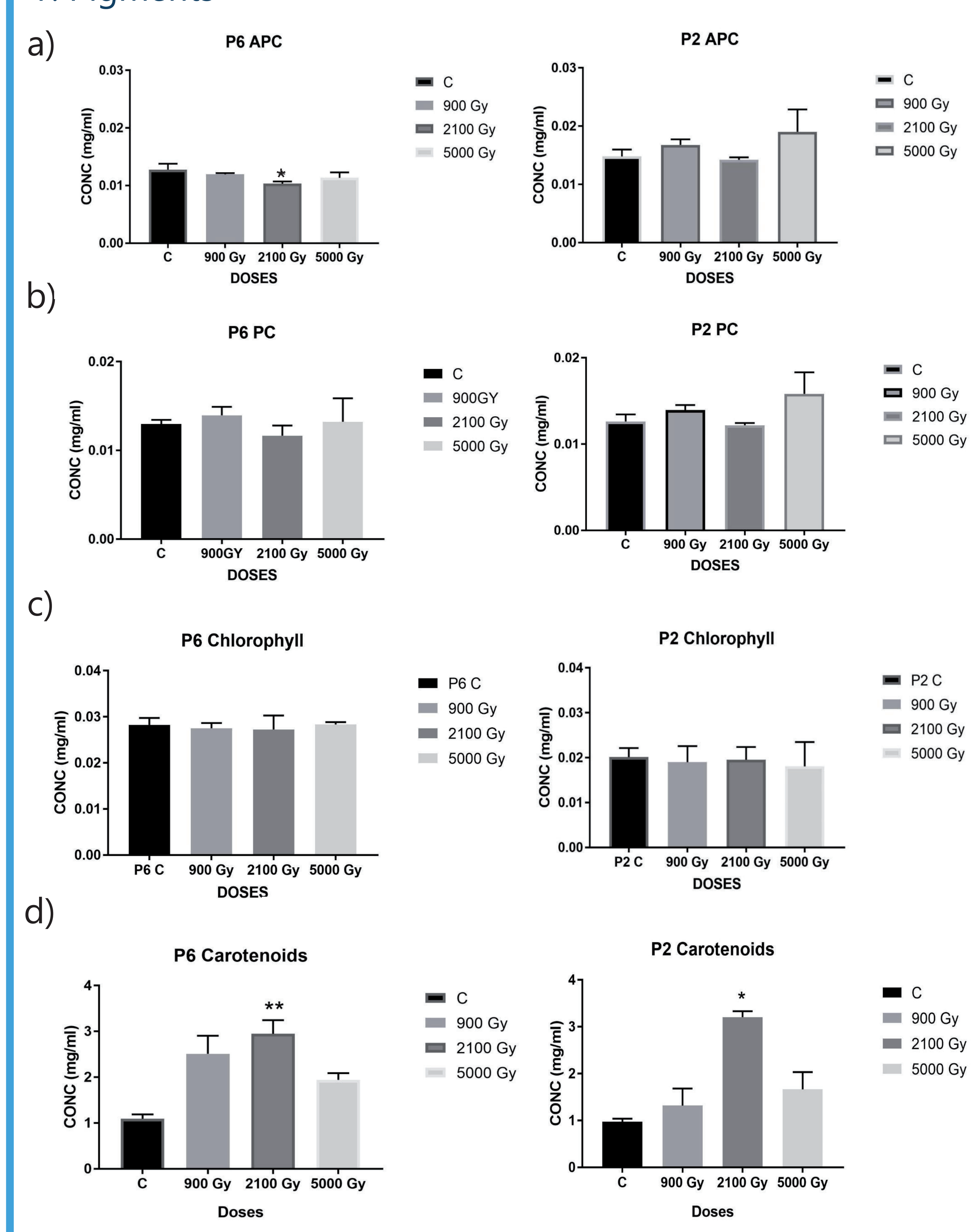


Fig 6: Pigment concentration in cells at different IR doses in P6-P2 strain ; a) Allophycocyanin (APC) concentration, showing a significant difference between control and 2100 Gy in the P6 strain (less IR resistant), b) Phycocyanin (PC) concentration, c) Chlorophyll concentration, d) Total carotenoids concentration, showing significant difference between control and 2100 Gy in both morphotypes

Discussions

- We observed a difference in IR resistance between the two morphotypes of *Arthrospira sp.* PCC 8005 i.e. P2 (straight trichomes) and P6 (spiral trichomes), the former being more resistant (Fig. 1).
- The original morphotype (P6) didn't display any structural damage (Fig. 2), not even after 5000 Gy which did have a growth impact.
- The trehalose concentration in morphotype P2 (straight; more IR resistant) decreases significantly at 2100 Gy as compared to non-irradiated control (Fig. 3).
- The amount of lipophilic proteins (e.g. vitamin E, carotenoids, chlorophyll) increases significantly at 5000 Gy in morphotype P2 (straight; more IR resistant) (Fig. 4 (b)).
- The total glutathione concentration decreases significantly in both morphotypes as a result of radiation (Fig. 5(a)), out of which the percentage of reduced glutathione is significantly increasing in P6 (curly; less IR resistant) at 2100 Gy (Fig. 5(b)).
- The amount of allophycocyanin pigment decreases significantly at 2100 Gy in P6 (curly; less IR resistant) (Fig. 6(a)). Also, the total carotenoid content is significantly increasing in both morphotypes at 2100 Gy (Fig. 6(b)), while the concentration of other pigments remain unchanged.

Conclusions

- Being more resistant to IR, the P2 cells display a lower trehalose content which further decreases at 2100 Gy, suggesting an improved metabolic use of trehalose and possible rerouting of cellular energy.
- The consistently higher cellular content of hydrophilic and lipophilic proteins in P2 (more IR resistant) at high IR doses up to 5000 Gy suggest a role in protection against IR by antioxidants. This is also suggested by sudden increase in carotenoids and more usage of glutathione at 2100 Gy.
- The amount of APC is higher in P2 than in P6, (significantly higher at 5000 Gy) suggesting a more light-harvesting capacity in P2 but the negligible difference in other pigments implies that the photosynthetic capacity is not (or only in a very limited way) affected by ionizing radiation.

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Reanalysis of the epidemiological data of the Hanford site considering the dose rate

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1. Introduction

◆We attempted the **reanalysis of cancer mortality using publically available epidemiological data from the viewpoint of the dose rate (dose-rate window.**

◆The ERR for cancers excluding leukaemia was reanalysed by varying the **cut-point of the dose rate** from 2 to 40 mSv/y.

2. Material and Methods

◆ Epidemiological data

Comprehensive Epidemiological Data Resources (CEDR)

◆ Definition of cohort

Among the 36,927 monitored workers,

- Length of employment was less than 6 months were excluded
- The first year of the monitoring was determined by considering the doses received off-site in addition to on-site dose.
- The date of entry was defined as the later of the date of starting employment plus 6 months and the date of the first monitoring.
- Whose year of entry and last year of vital status were the same were excluded from the analysis.
- Who may have received a higher dose rate (more than 250 mSv in a year) were excluded.

Consequently, 32,988 subjects were selected in this study. (Table 1)

◆ Statistical methods

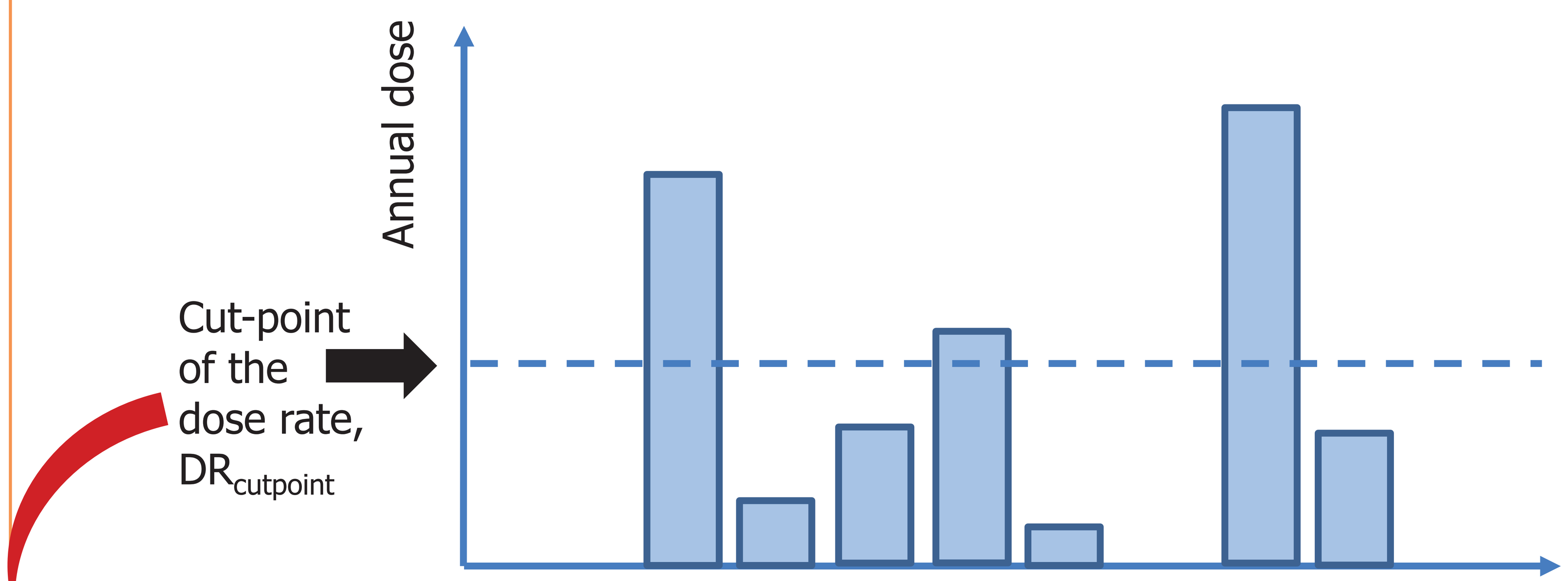
The ERR was estimated by Poisson regression analysis, where a linear model of the form: $\lambda = \lambda_0(1+\beta d)$ …(1)

By contrast, to perform analysis based on the dose rate obtained from the annual dose recorded using a personal dosimeter, the following model was considered: $\lambda = \lambda_0(1+\beta_L d_L + \beta_H d_H)$ …(2)

Here, d_L is the cumulative dose of the dose rate, which is lower than the specified cut-point of the dose-rate windows ($DR_{cutpoint}$), and d_H is the cumulative dose of the dose rate, which is higher than the specified cut-point of the dose-rate windows (Fig. 1).

Table 1. Definition of cohort and ERRs for the simple linear model (Eq. (1))

	Present study	Cardis et al. (1995)	Gilbert et al. (1993)
Number of workers	**32,988**	32,595	32,643
Men	**24,930**	24,628	24,672
Women	**8,058**	7,967	7,971
Number of deaths	**6,541**	6,445	6,200
Number of cancer deaths	**1,478**	1,452	1,466
Leukaemia excluding CLL	**48**	47	44
Mean dose (mSv)	**30.3**	-	26
ERR			
All cancers excluding leukaemia	**-0.23 (-0.9, 0.6)**	-0.22 (<0, 0.6)	-0.0 (<0, 1.0)
Leukaemia excluding CLL	**-0.85 (<0, 2.9)**	-0.90 (<0, 2.9)	-1.1 (<0, 1.9)



	1	2	3	4	5	6	7	8	9	Total
Annual dose (mSv)	0	10	2	4	6	1	0	11	4	38
Cumulative dose, d_L	0	0	2	6	6	7	7	7	11	11
Cumulative dose, d_H	0	10	10	10	16	16	16	27	27	27

Fig. 1. Example of the trend of the annual dose and cumulative doses of d_L and d_H considering cut-point of the dose rate.

3. Results and Discussion

◆ (Fig .2) β_L varies considerably ($DR_{cutpoint}$ < 6mSv/y), although they did not differ from β_H significantly.

ICRP states that "*Chronic exposures at a dose rate of a few mGy per year mean that every cell in the body is hit by a track of radiation every few months. This elimination theory lowers the linear term.*" in its Publ. 131. The difference between β_L and β_H might reflects the difference of these effects, hence, it should be carefully examined whether biological phenomena eventually produce a consequence of large difference in mortality.

◆ β_L and β_H were similar and appeared to be stable without any noticeable tendency ($DR_{cutpoint}$:6-20mSv/y).

◆ The variation in β_L became more stable while that in β_H and its CI became wider ($DR_{cutpoint}$ > 30mSv/y).

Number of person-years corresponding to such higher dose rates decreasing suddenly above the annual dose limit for workers, increasing the statistical uncertainty.

◆ **On the basis of the results, β_L and β_H for all cancers excluding leukaemia did not differ significantly at the dose rate that radiation workers are normally exposed to under normal operation.**

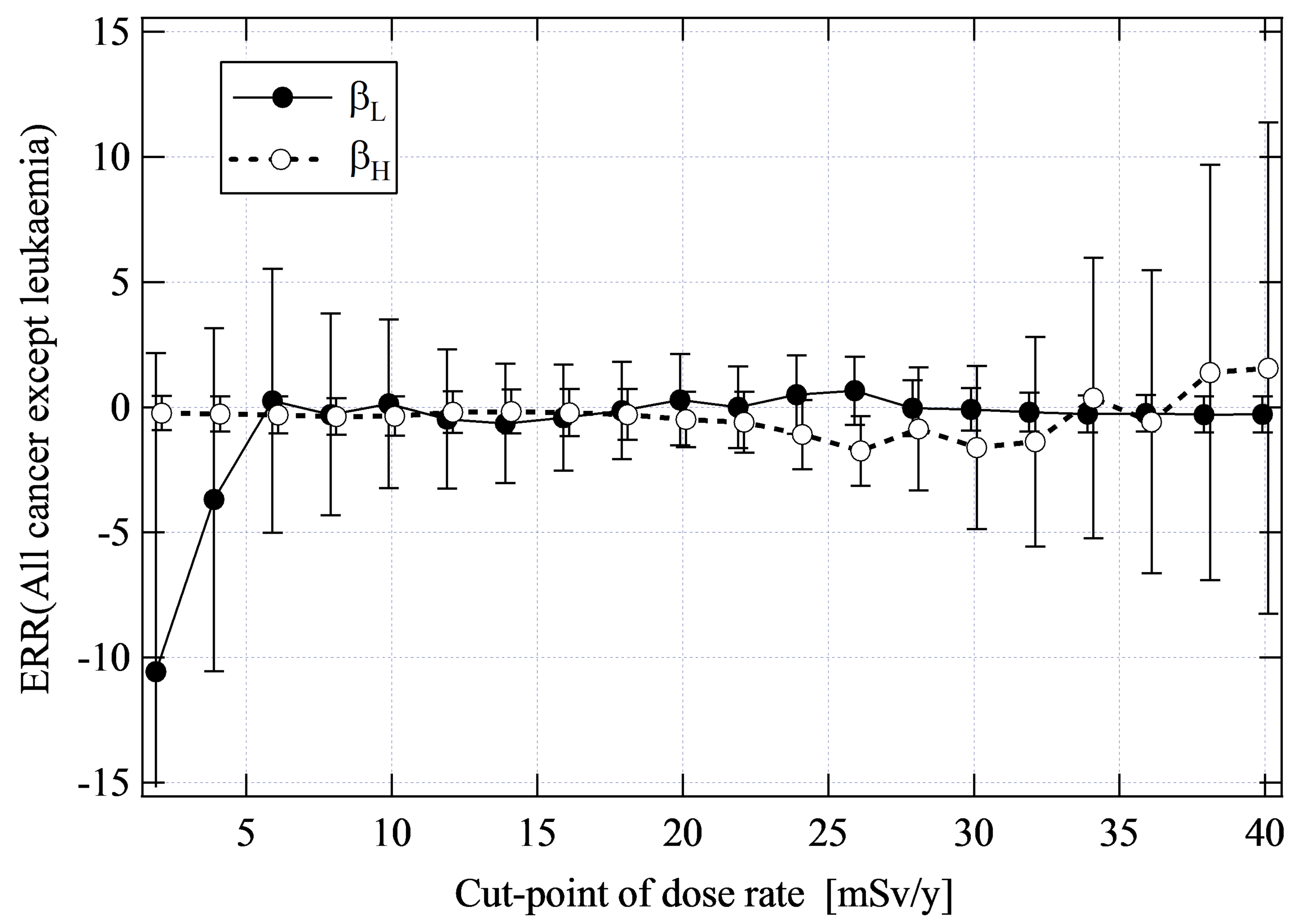


Fig.2 ERRs (β_L and β_H) in Eq. (2) for all cancers excluding leukaemia

4. Conclusions

◆Fluctuations in the excess relative risk were upon varying the cut-point of the dose rate; but there was no statistically significant difference .The conclusive reason of differences between β_L and β_H which shown under 6 mSv is unclear at this time.

◆To explore the present results in detail, and to investigate the effect of the dose-rate for other diseases, we will continue to analyse on site-specific cancer, as well as non-cancer, such as circulatory disease, considering the possibility of pooled analysis by combining other available datasets.

Acknowledgements
We wish to thank the US Department of Energy (DOE) for providing publically available datasets at the Comprehensive Epidemiologic Data Resource. We also express our gratitude to Dr Fumiyoshi Kasagi and Mr Masami Ikai of the Radiation Effects Association (REA) and Dr Toshiyasu Iwasaki of the Radiation Safety Research Center of the Central Research Institute of Electric Power Industry (CRIEPI) for their valuable comments. This work was partly funded by the Nuclear Regulation Authority (NRA), Japan. The views of the authors do not necessarily reflect those of DOE, REA, CRIEPI, and NRA.

The use of ionizing radiation in experimental animals, a sustainable combination

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university of groningen

Background

Working with ionizing radiation and working with experimental animals have at least one thing in common: the need to *justify the use*. In medical research, ionizing radiation in combination with experimental animals provide essential tools for gaining knowledge of disease origin, progression and intervention strategies.

This poster presents work of the UMCG and RUG combined

Justification

Pros

- Longitudinal studies using same animal
- High resolution imaging
- Preclinical research

Cons

- Hazardous for worker
- Experimental Animal use
- Specialized equipment necessary

Riskanalysis for worker

Mouse injected with human tumorcells
10 Mbq of Zr89 per mouse for imaging
12 animals

Dose on body during experiment: 1,5µSv
Injection incident: 3 mSv

Safety:

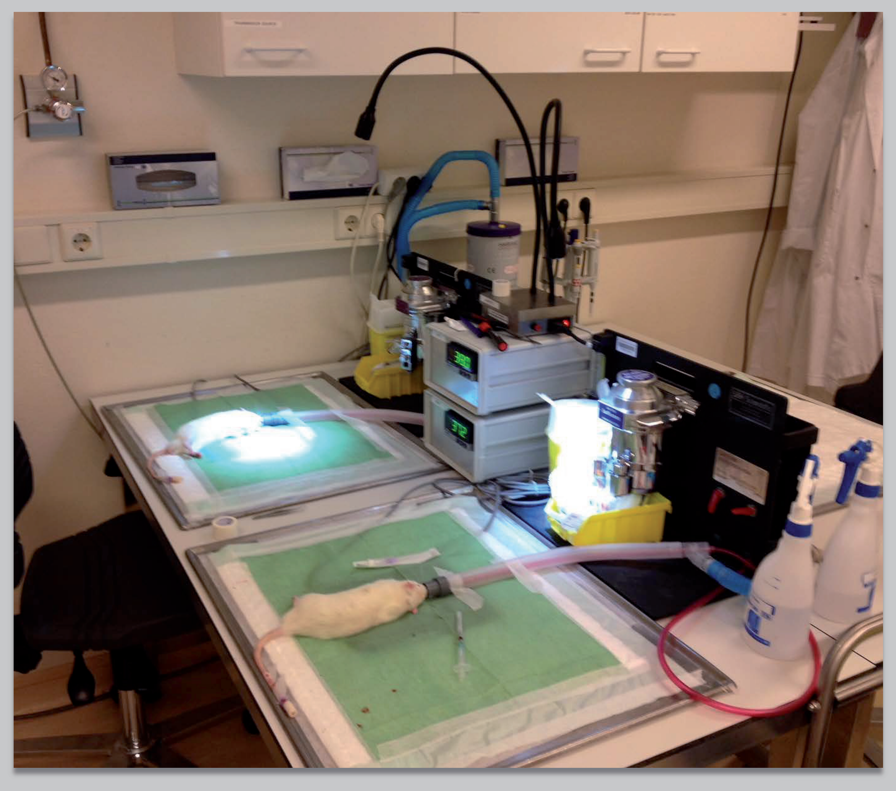
- Minimize risk by using pre-place cannulas for injection
- Experienced workers
- Distance – Shielding - Time

Typical amounts per animal

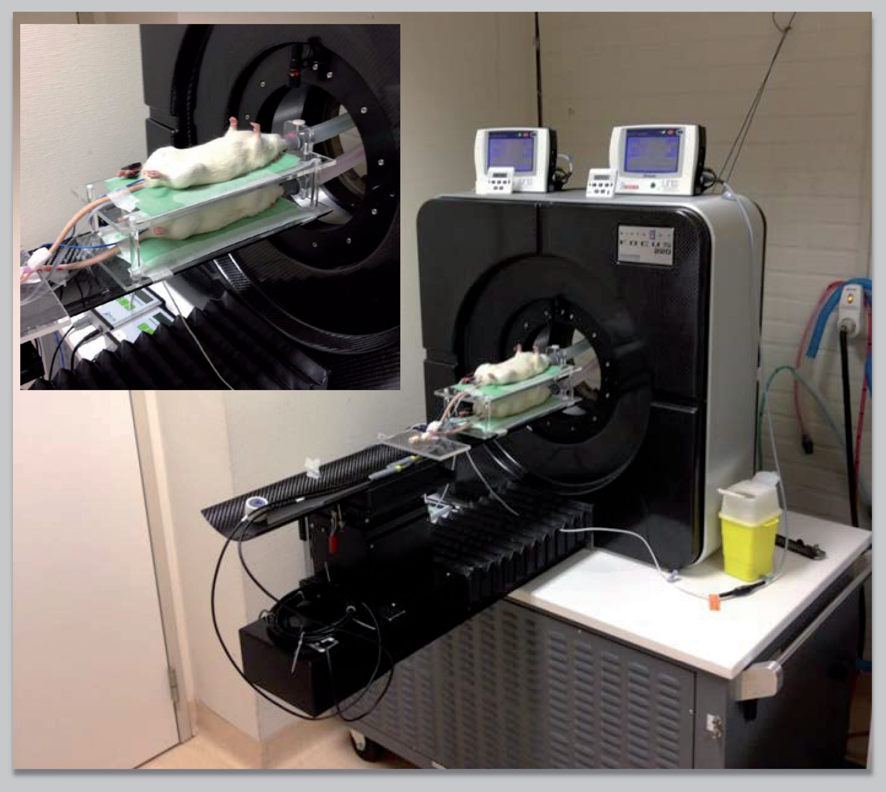
C11	50-100 MBq
F18	50-100 MBq
Zr89	5-10 MBq
In111	1 MBq
Tc99m	15-60 MBq

Around 600-700 animals annually

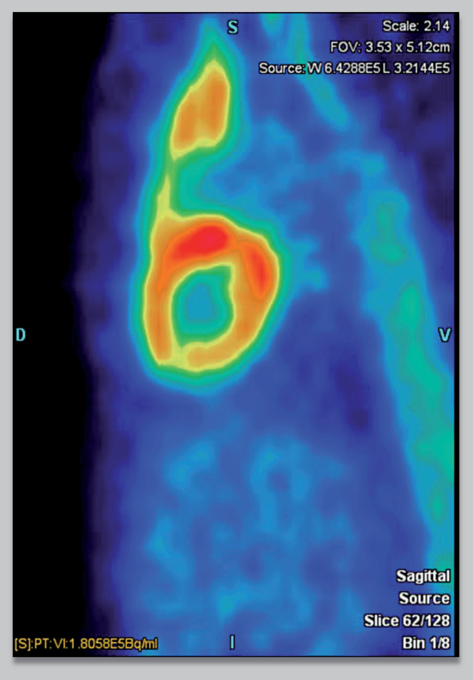
The ALARA principle is applicable to ionizing radiation as well as animal use



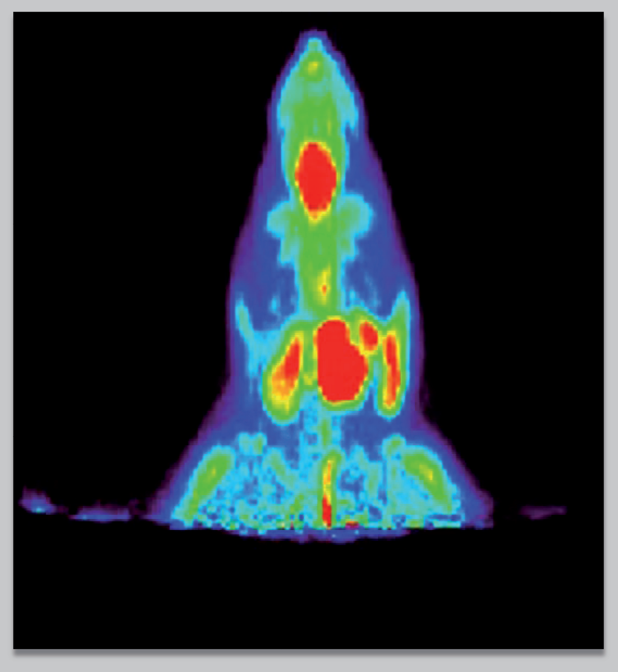
Preparation of animals



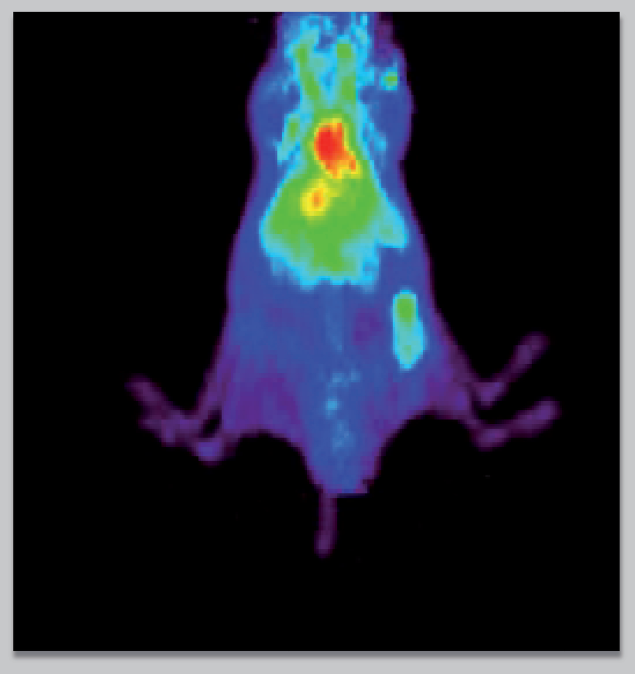
PET scan, two animals can be scanned simultaneously, note the animal monitoring systems on top of the scanner



PET scan of Heart (F-18), research on perfusion of the heart (rat)[1]

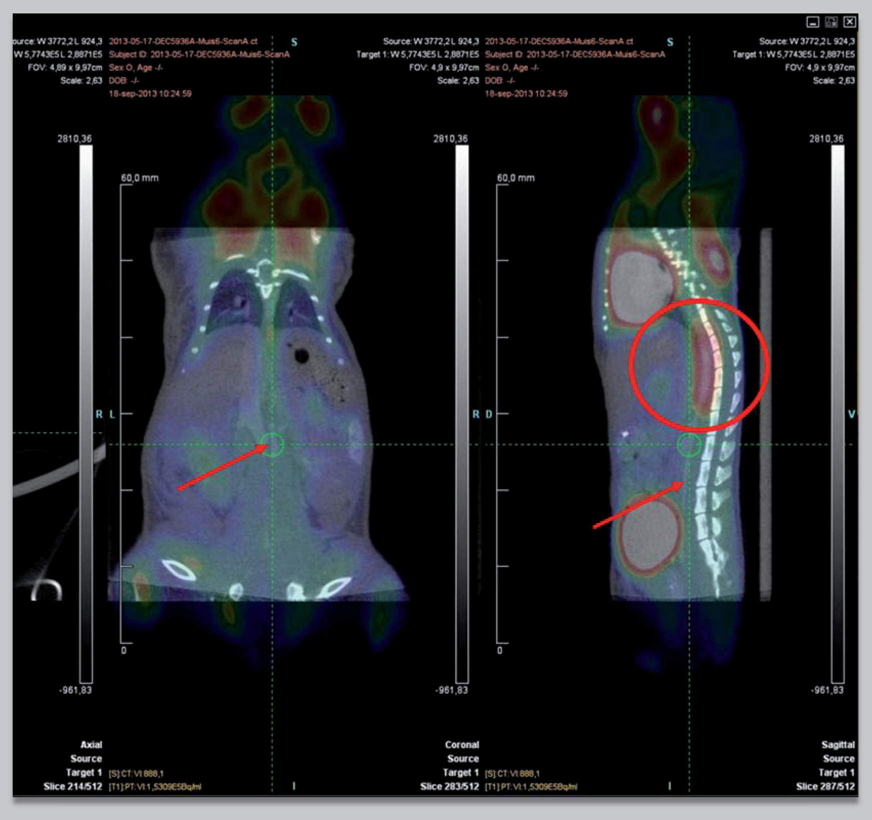


PET scan of Brain (C-11), research on brain inflammation (rat)[1]

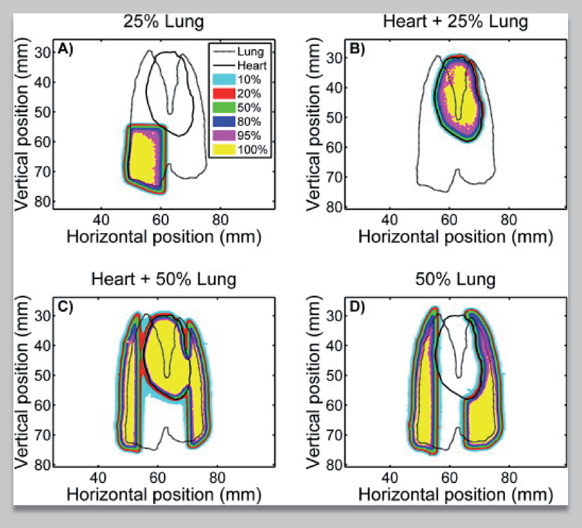


PET scan of tumor (Zr-89), note two animals (mouse)[1]

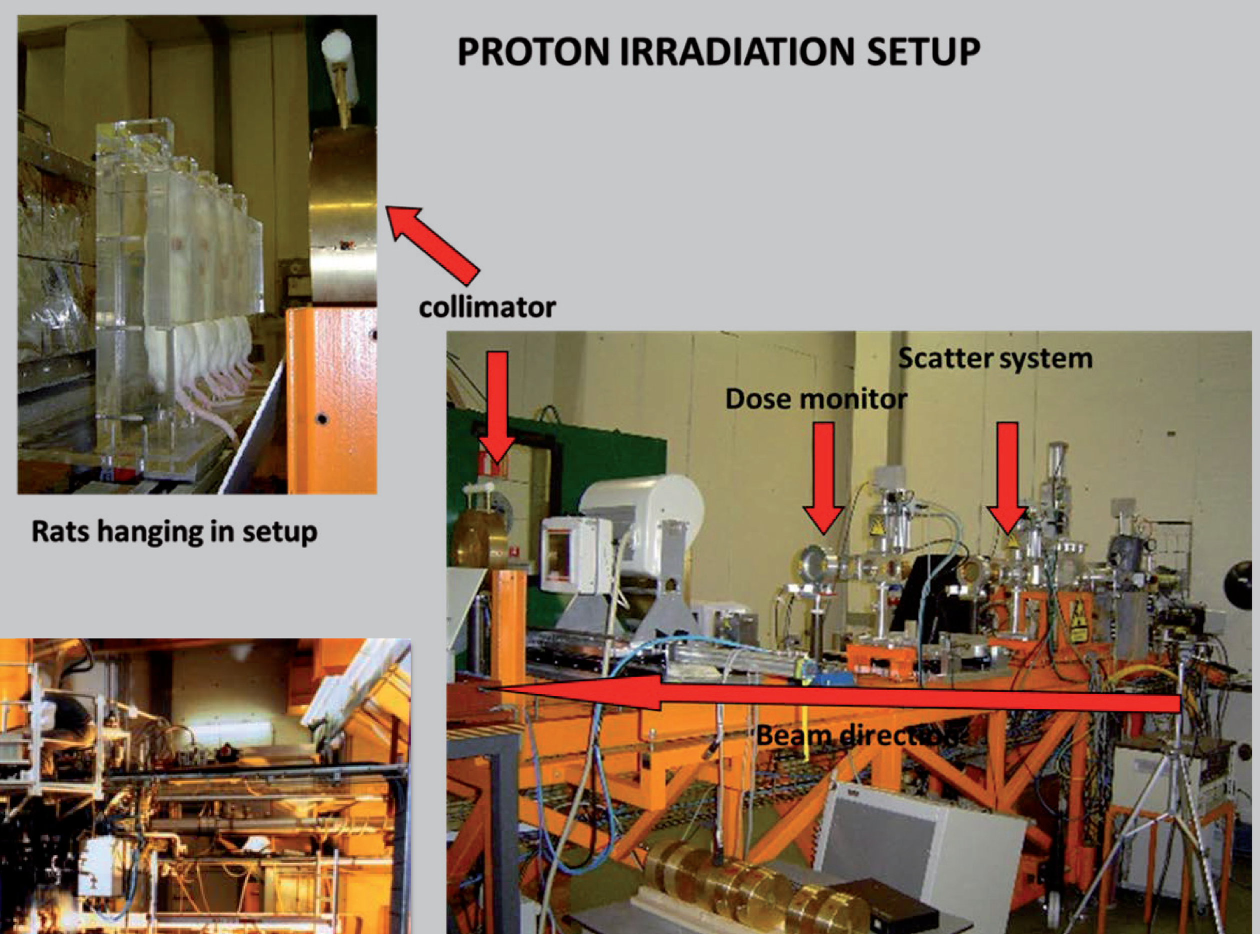
CT scanner



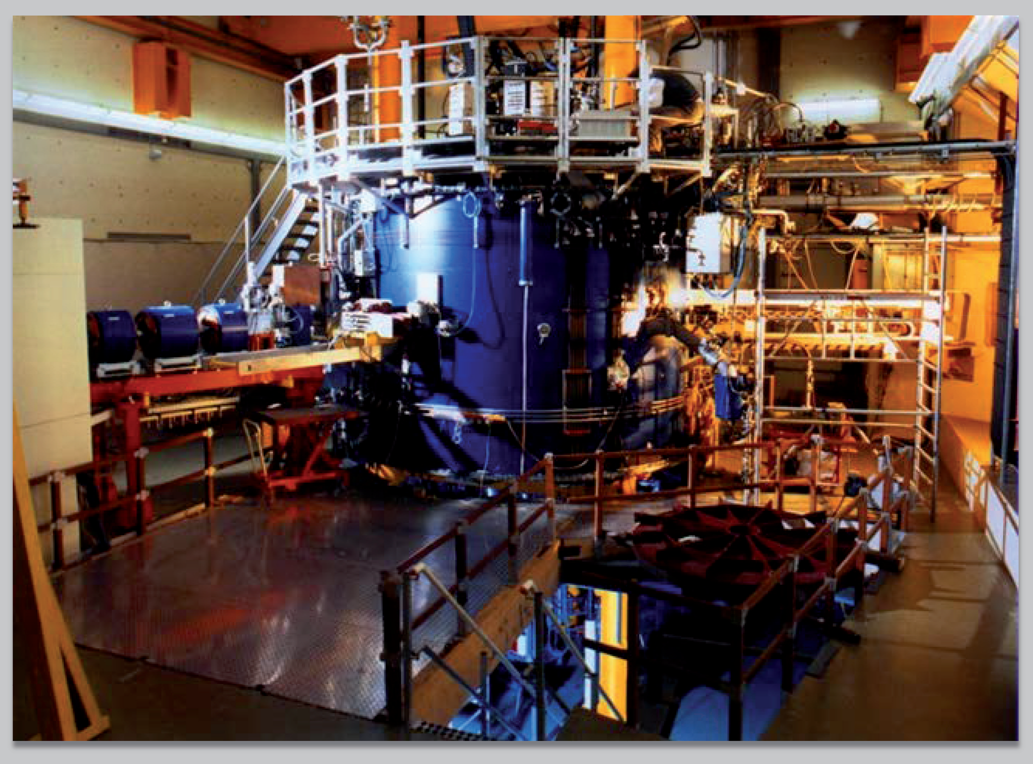
PET/CT scan of abdomen (F-18), arteriosclerosis research. Note the plaque development in the circle[1]



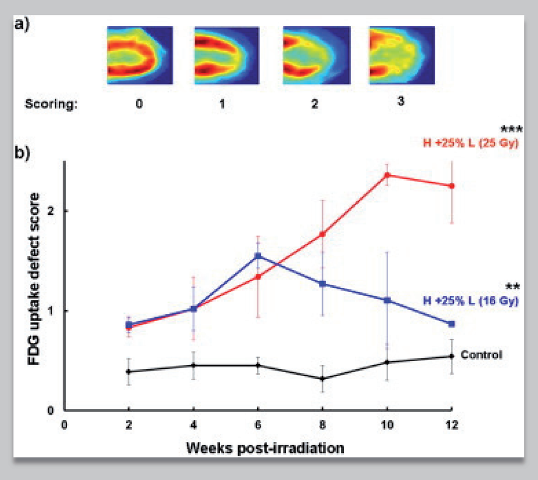
Isodose contours and anatomy[2]



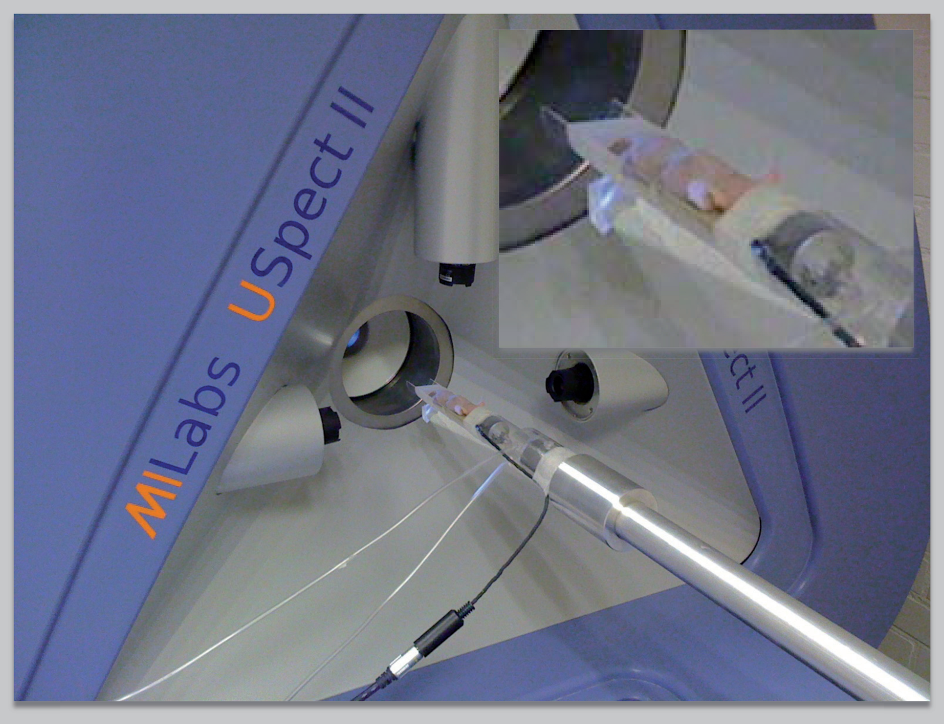
Irradiation of rats with protons



KVI-CART: Cyclotron 600MeV
Rats irradiated with 16-25 Gy (protons)
Study on interaction between lung and heart in thoracis irradiation[2]



Cardiac metabolic changes after heart irradiation based on F-18 uptake[2]



microSPECT using Tc99m for bone scan in a mouse[1]

By using ionizing radiation for imaging techniques, animal don't have to be sacrificed at different time point but can be followed longitudinal. This reduces the amount of animals needed and justifies the use of ionizing radiation resulting in sustainable use of laboratory animals as well as radioactivity.

References

1 Sijbesma, personal communication
2 Ghobadi et. Al., Int J Radiation Oncol Biol Phys, Vol. 84, No. 5, pp. E639-e646, 2012

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