Universidad Politécnica de Madrid
Escuela Técnica Superior de Ingenieros Industriales

16th EURADOS SCHOOL

Contribution of dosimetry in the field of nuclear emergency preparedness and radiological accident management

Thursday, 15th June 2023

Dosimetry needs in support of nuclear and radiological emergency preparedness

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- The need to protect the population in case of nuclear or radiological accidents was recognized very early…

Kyshtym, 1957

- About 10,000 inhabitants evacuated after 7 days until 1960.
- Decontamination: Buildings, belongings, livestock and agricultural production destroyed, burned and buried.
- Environmental impact on biota

Windscale, 1957

- Milk destroyed in an area of 500 km^2
- No evacuation
- Significant concern on the potential health effects

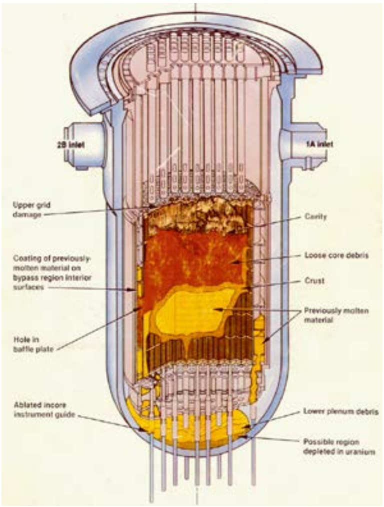
Introduction. Historical perspective

➢ The need to protect the population in case of nuclear or radiological accidents was recognized very early…

SL-1, 1961

- Prompt criticality accident
- 3 operators died; bodies heavily contaminated
- Offsite: small release of I-131. Monitoring of the area

TMI-2, 1979



- Large damage to the reactor core
- There were no evacuation plans…
- Chaotic response: miscommunication, contradicting orders: Stay inside, or evacuate children and pregnant women… finally about 40% of the population within 15 miles evacuated by themselves

Introduction. Historical perspective

- The need to protect the population in case of nuclear or radiological accidents was recognized very early… and applied

Chernobyl, 1986

- Total destruction of the reactor
- Approx. 135,000 evacuees
- 600,000 emergency workers (“liquidators”)
- Strong increase in thyroid cancers between those that were children at the time of the accident (11,000 cases in 2016)

Goiania, 1987

- 1 source of Cs-137, 51 TBq
- 21 with ARS; 4 deaths
- 249 contaminated
- 112,000 radiologically checked
- Characterization – decontamination – 3,000 m^3 radioactive waste generated

Introduction. Historical perspective

➢ The need to protect the population in case of nuclear or radiological accidents was recognized very early… and applied

Tokaimura, 1999

- Prompt criticality accident
- 2 died
- 161 evacuated
- 300,000 confined
- 10,000 medical check-ups – 667 received radiation

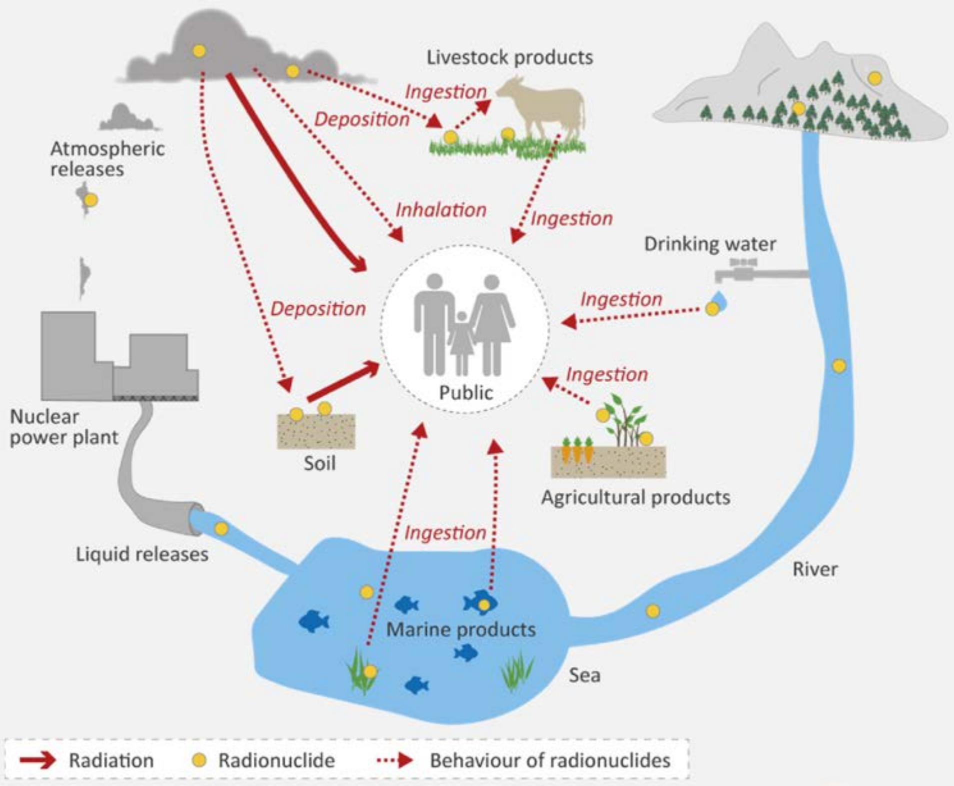
Fukushima, 2011

- Fukushima-Daiichi – 3 reactors with very large core damage – very large radioactive releases
- 78,000 evacuees + 10,000 later + 58,000 confined in the emergency zones
- About 24,000 have not returned

- The need to protect the population in case of nuclear or radiological accidents was recognized very early… and applied
- Nuclear and radiological accidents involving significant releases of radioactivity are **very complex situations**
- A good radiological characterization of the situation is fundamental for taking decisions on the implementation of protective actions for the population and the emergency responders
- **Dosimetry issues are very important in all phases of an accident**

Accidental releases and exposure pathways

- In the event of an accident, the radioactive material released can affect the human being and the environment through different exposure pathways that must be well characterized and monitored

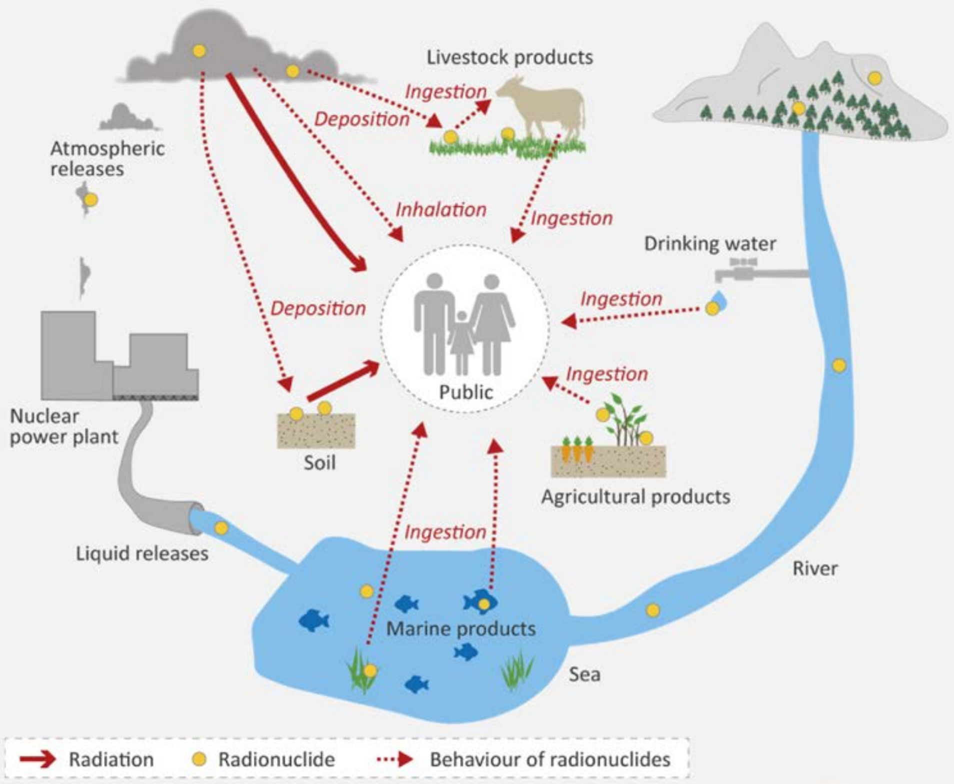


Credit: IAEA, 2015

- External exposure:
  - airborne radioactive material
  - radioactive material deposited:
    - Ground
    - Buildings
    - clothing and skin.
- Internal exposure:
  - inhalation of radioactive material from the plume
  - Inhalation of re-suspended material from contaminated surfaces,
  - Ingestion of contaminated food and water
  - Inadvertent ingestion of radionuclides on the ground or objects

Accidental releases and exposure pathways

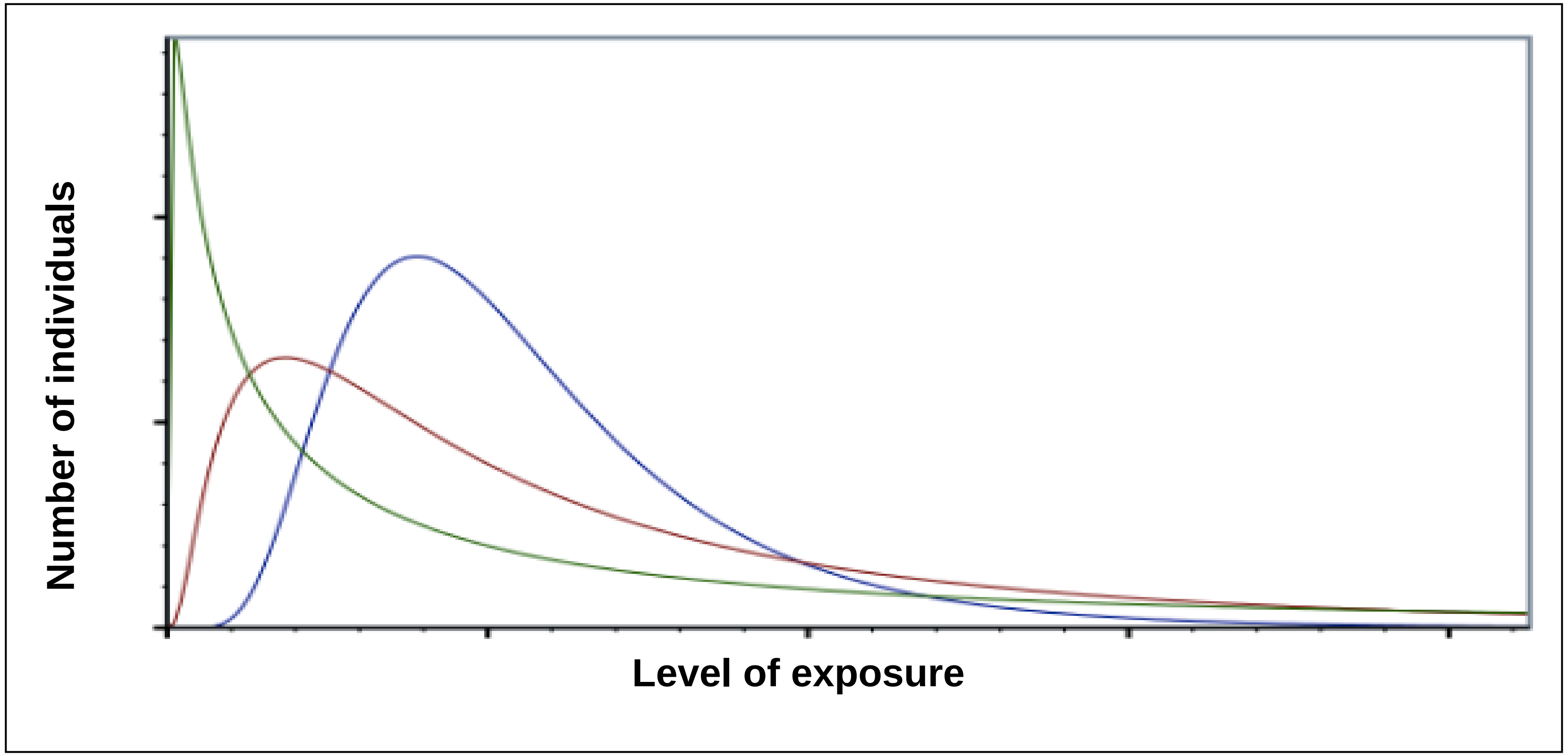
- In the event of an accident, the radioactive material released can affect the human being and the environment through different exposure pathways that must be well characterized and monitored



Credit: IAEA, 2015

- Activity measurements (continuous or by sampling)
  - Air
  - Ground and buildings
  - Water (including groundwater)
  - Soil
  - Food
  - People
  - Flora and fauna
- Dose rate monitoring
  - Ambient dose equivalent H*(10)

- After a radiological or nuclear accident, it is necessary to have a good knowledge of the individual doses (actual and future)



Exposure situations (ICRP 103)

- "The processes causing human exposures from natural and man-made sources."

Sources → **Pathways** → **Human Exposures**

- "Protection can be achieved by taking action at the source, or at points in the exposure pathways, and occasionally by modifying the location or characteristics of the exposed individuals." ICRP103, § 169

The types of exposure situations (ICRP-103)

- **Planned exposure situations :** when exposures result from the **deliberate introduction and operation of sources.** Exposures can be anticipated and fully controlled but may be significantly higher than expected in case of incidents and accidents
- **Existing exposure situations :** when exposures result from **sources that already exist when decisions to control them are taken**. Characterization of exposures is a prerequisite to their control

  Remark: ICRP considers long term exposures resulting from a nuclear accident or a malicious act as an existing exposure situation

- **Emergency exposure situations :** when exposures result from the **loss of control of a source**. These situations require urgent and timely actions in order to mitigate exposures

  Remark: ICRP considers exposures resulting from a malicious act as an emergency exposure situation

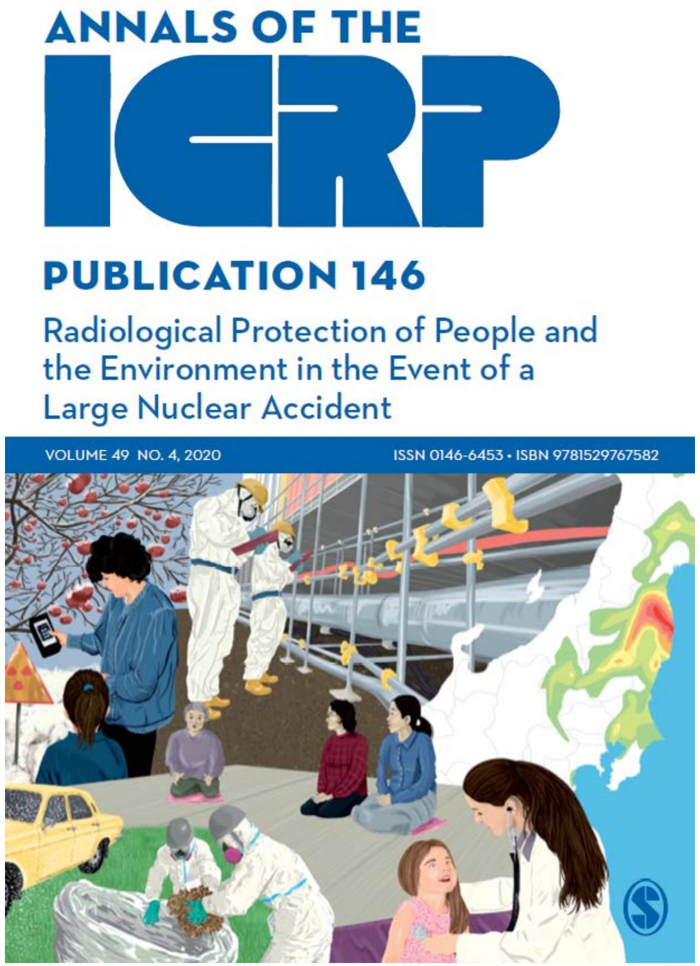
The Radiological Protection System (ICRP 103 & ICRP 146)

- **OBJECTIVES** of radiation protection in emergency exposure situations:

    - to prevent the occurrence of **tissue reactions (deterministic health effects)** among emergency workers, members of off-site assistance services, and in the public

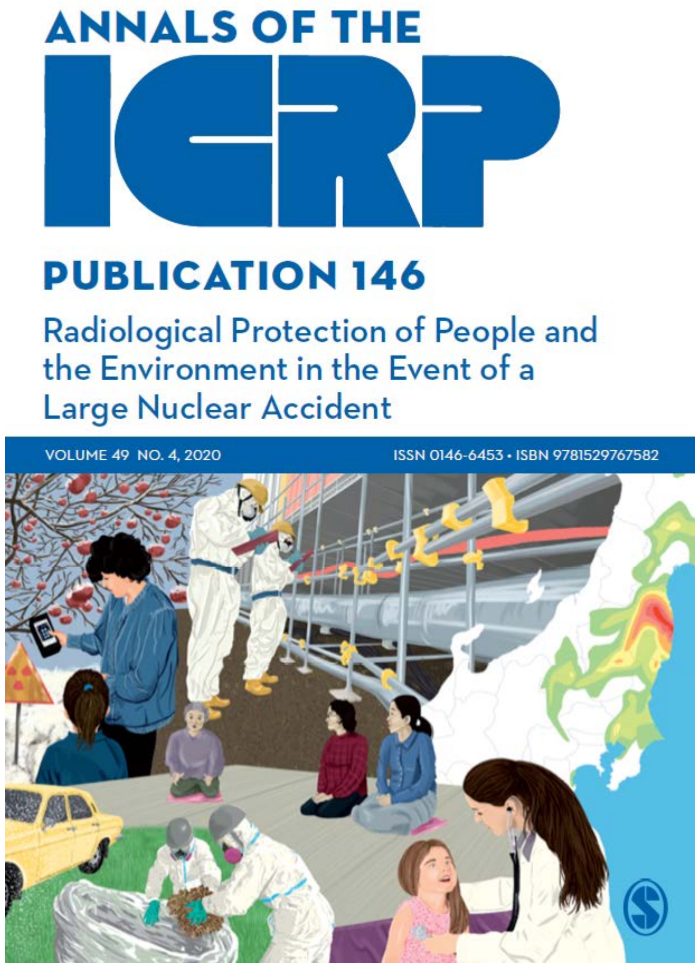
    - to avoid, to the extent practicable, **increased individual risks** of incurring stochastic health effects (cancer and heritable diseases).

- **PRINCIPLES** of radiation protection: **justification** and **optimisation** are to be applied in emergency exposure situations.



The Radiological Protection System (ICRP 146)

- **Main Points:**
  - The **objective** of radiological protection is to mitigate radiological consequences for people and the environment whilst, at the same time, ensuring sustainable living conditions for the affected people, suitable working conditions for the responders, and maintaining the quality of the environment.
  - Characterisation of the radiological situation **on-site and off-site** is essential to guide protective actions, and should be conducted as quickly as possible.



Dose criteria in ICRP 103

- **For preventing tissue reactions**
  - **Dose limits** to organs

- **For keeping the risk of stochastic effects at tolerable levels**
  - Source related restrictions associated with the optimisation principle:
    - **Reference levels** for existing and emergency exposure situations
    - **Dose constraints** for planned exposure situations
  - Individual related restrictions:
    - **Dose limits** applying only to planned situations other than medical exposure

The recommendations (ICRP Pub. 103) propose a similar system regardless of the Exposure Situations:

Optimization with Dose Constraints or with Reference Levels

Exposure in Planned Situations

Dose Limits

Dose Restrictions

ALARA optimization

Exposure in emergencies and existing situations

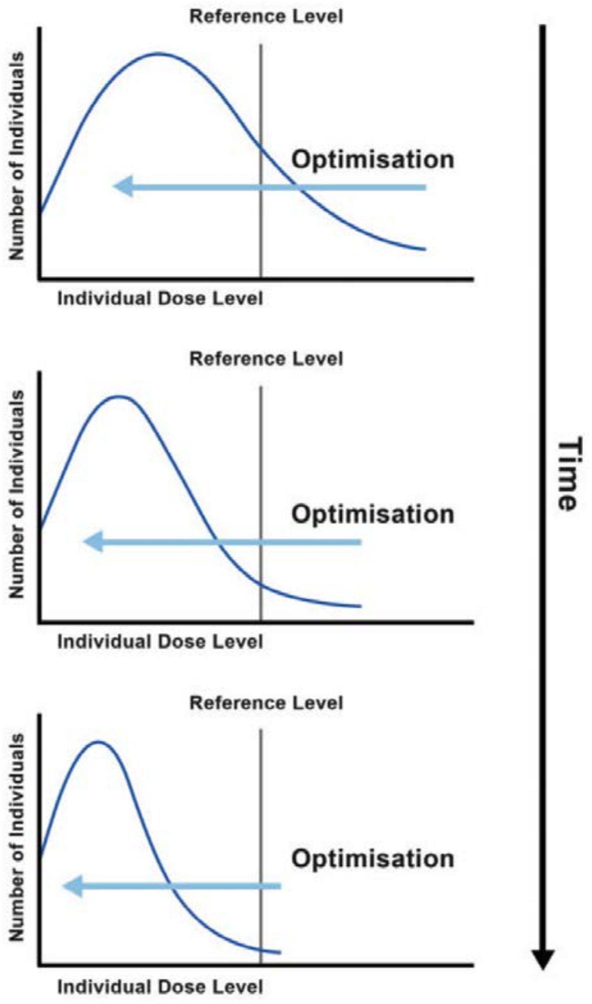
Reference Levels

ALARA optimization

Reference dose level

- **In emergencies, or in situations of existing controllable exposure**
- It represents the level of dose or risk, above which it is judged inappropriate to allow exposures to take place, and below which optimization of protection should be implemented.
- The value chosen for a reference level will depend on the prevailing circumstances of the exposure under consideration.

Reference levels in emergency and existing exposure situations (ICRP 103 & ICRP 146)



- Implementing the **optimisation** process with a reference level,
- to restrict inequity in individual dose distributions and to focus attention on the higher levels of exposure
- **ALL EXPOSURE PATHWAYS** and all relevant protection options have to be considered when deciding on the optimum course of action to be taken
- The full **PROTECTION STRATEGY** must be justified –resulting in more good than harm– and optimised

Reference dose levels for guiding the optimisation of protection of responders and members of the public during the successive phases of a nuclear accident
(ICRP Pub. 146, 2020)

	Early Phase	Intermediate phase	Long-term Phase
Responders **On site**	**100 mSv** or below* Could be exceeded in exceptional circumstances†	**100 mSv** or below* May evolve with circumstances*†♣	**20 mSv per year** or below
Off-site	**100 mSv** or below* Could be exceeded in exceptional circumstances†	**20 mSv per year** or below♣ May evolve with circumstances	**20 mSv per year** or below in restricted areas not open to the public **Lower half of the 1 to 20 mSv/y band** in all other areas♠
Public	**100 mSv or below for the entire duration of both the early and intermediate phases** §		**Lower half of the 1 to 20 mSv/y band**♠ with the objective to progressively reduce exposure to levels towards the lower end of the band, or below if possible

* Previously, the Commission recommended selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendations recognise that the most appropriate reference levels may be lower than this band under some circumstances.

† The Commission recognises that higher levels in the range of a few hundred millisieverts may be permitted to responders to save lives or to prevent further degradation at the facility leading to catastrophic conditions.

♣ As some responders may be involved in both the early and intermediate phases, the management of exposures should be guided by the objective to keep the total exposure during these phases below 100 mSv.

§ Previously, the Commission recommended the selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendation recognises that, in some circumstances, the most appropriate reference level may be below 20 mSv.

♠ This clarifies the expression 'lower part' as used in Publication 111.

Time phases of a nuclear or radiological accident (ICRP, Pub. 146)

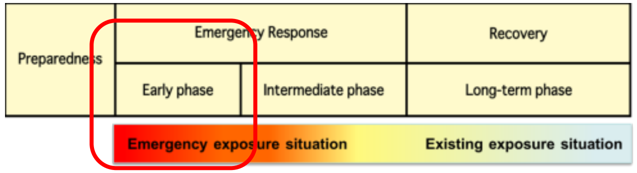
Prior to the accident	emergency response		Recovery
preparation phase	**Initial or early phase**	**intermediate phase**	**long term phase**

	Emergency exposure situation	**Existing exposure situation**

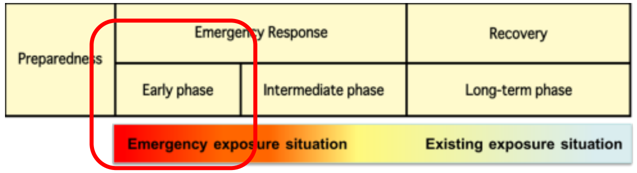
The management of the response may need to deal simultaneously with different phases affecting different geographic areas

Dosimetry challenges in the Early Phase of an emergency (Workers and emergency responders)

- Unusual situation. Urgent interventions necessary to control the source and to avoid worsening of the situation.
- The main concern is to avoid the possibility that workers and first responders receive doses above thresholds of **tissue reactions**
- Important:
  - Individual active dosimeters with alarm
  - Protective clothing and masks
  - whole body counting
  - in vitro measurements of biological samples and other methods as necessary

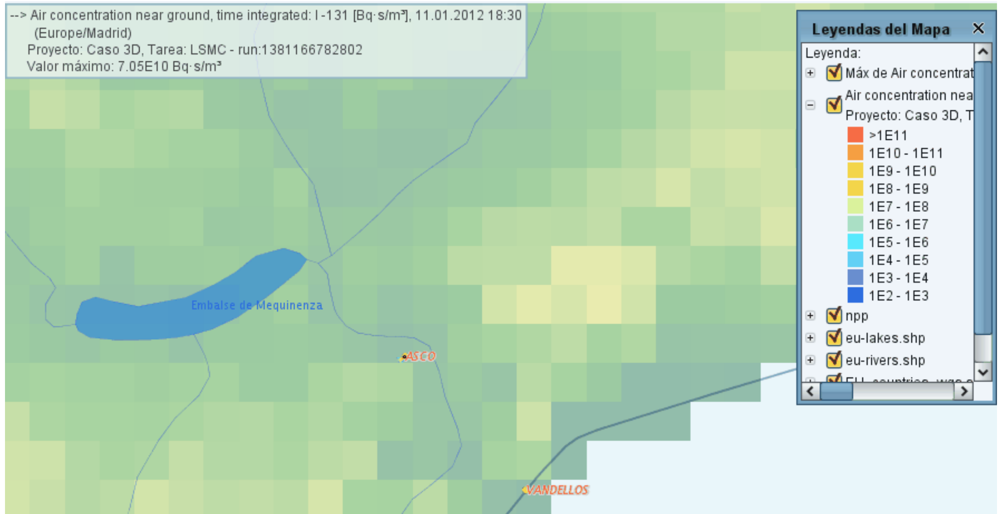


Dosimetry challenges in the Early Phase of an emergency (Population Off-site)

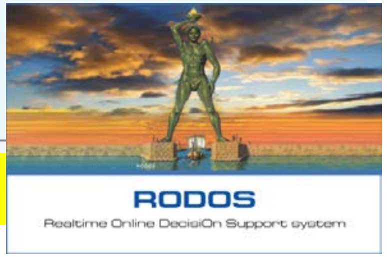


- The main concern is to decide <u>under uncertainty</u> whether an **evacuation**, **sheltering** or **iodine thyroid prophylaxis** are required to protect the population.

- It is necessary to have a reliable dose prognosis using **state-of-the art models for atmospheric dispersion and dose assessment**
  - **Decision-Support Systems** can also integrate data from environmental monitoring



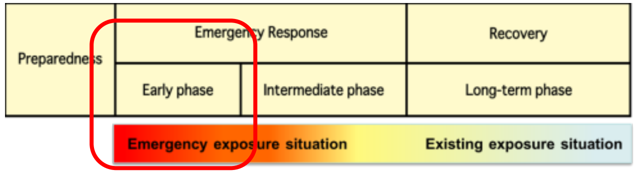
https://resy5.iket.kit.edu/JRODOS/



CHALLENGES:

- Improve predictability reducing uncertainties! (recent projects, like EU-**CONFIDENCE**, looking for using Ensemble predictions)
- Better assimilation of monitoring data to reduce uncertainties in the calculations
- Benchmarking of dose assessment models

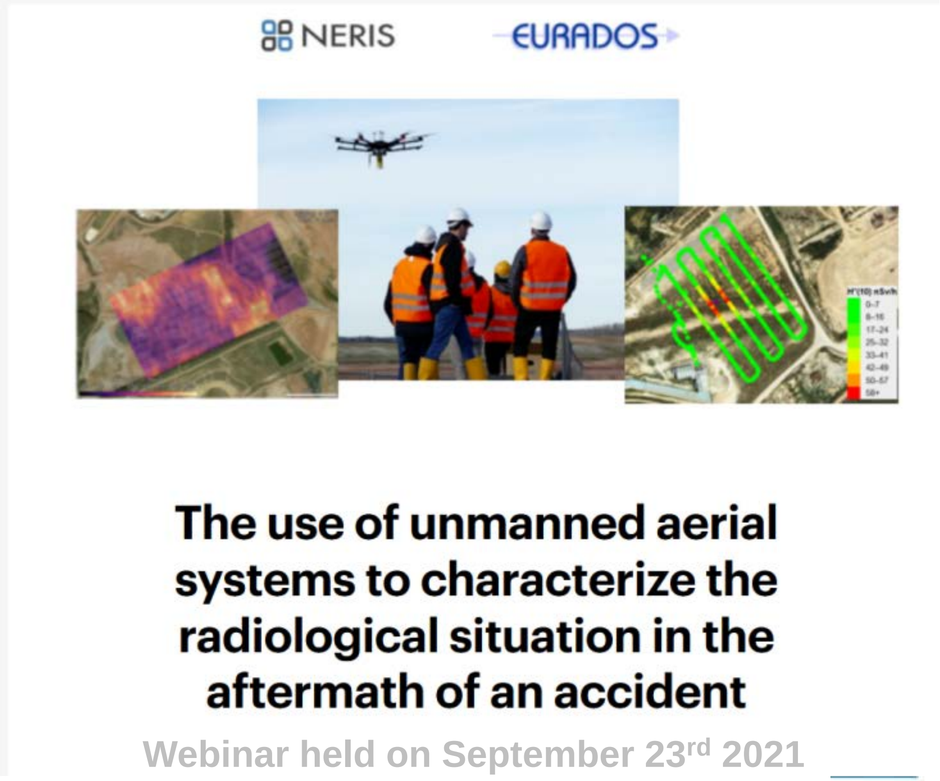
Dosimetry challenges in the Early Phase of an emergency (Population Off-site)



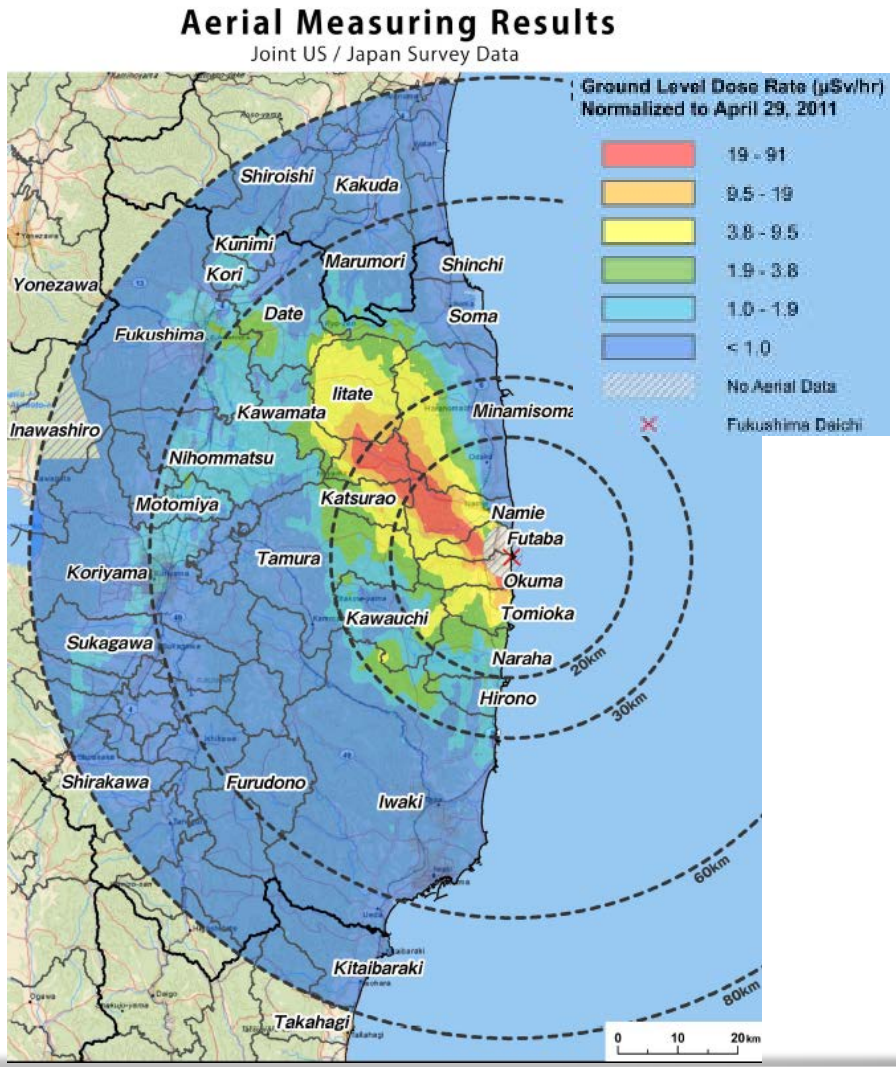
- Real time data from
  - On-site fixed radiation monitoring systems
  - Off-site surveillance networks
  - Mobile units, both terrestrial and airborne

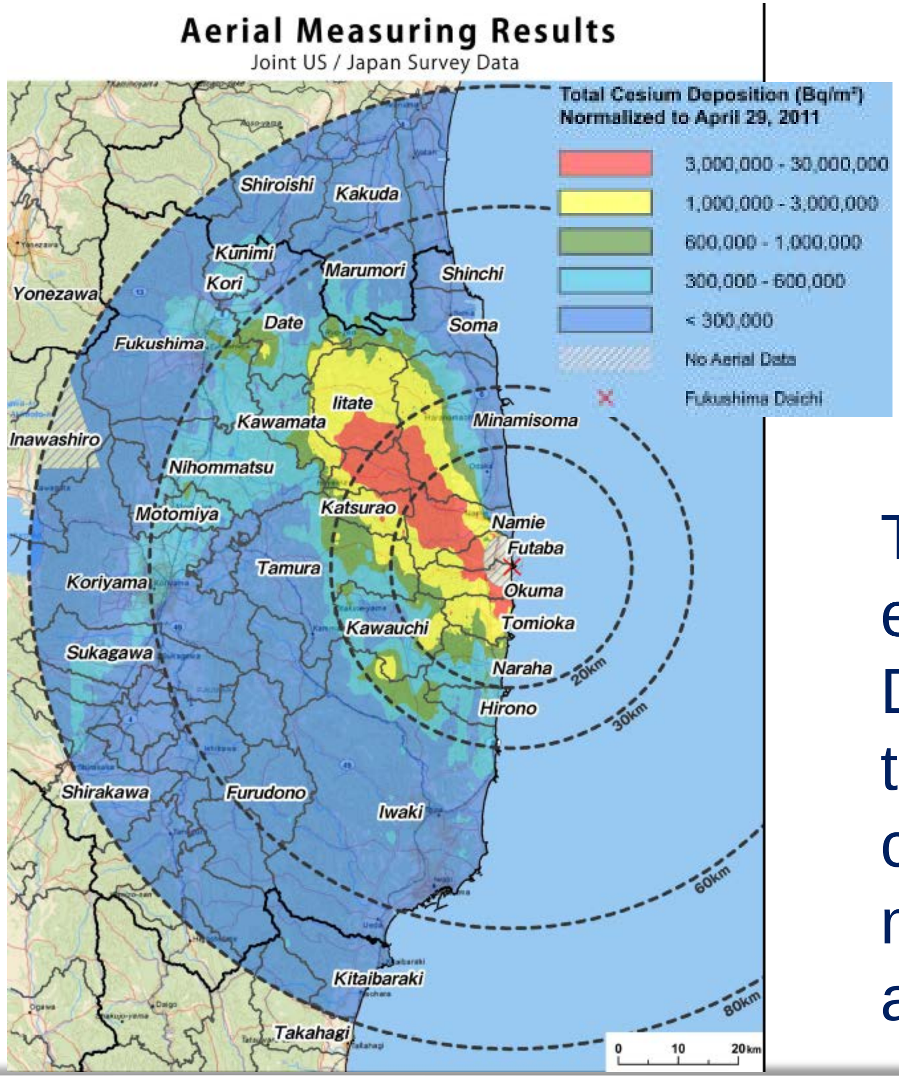
CHALLENGES:

- Obtaining significant data using new technologies like UAV (drone) – **EURADOS WG3** and **EMPIR Preparedness** project
- Quick assessment of the degree and extent of the environmental contamination [days], avoiding unnecessary exposure of those workers measuring



Post-Fukushima experience

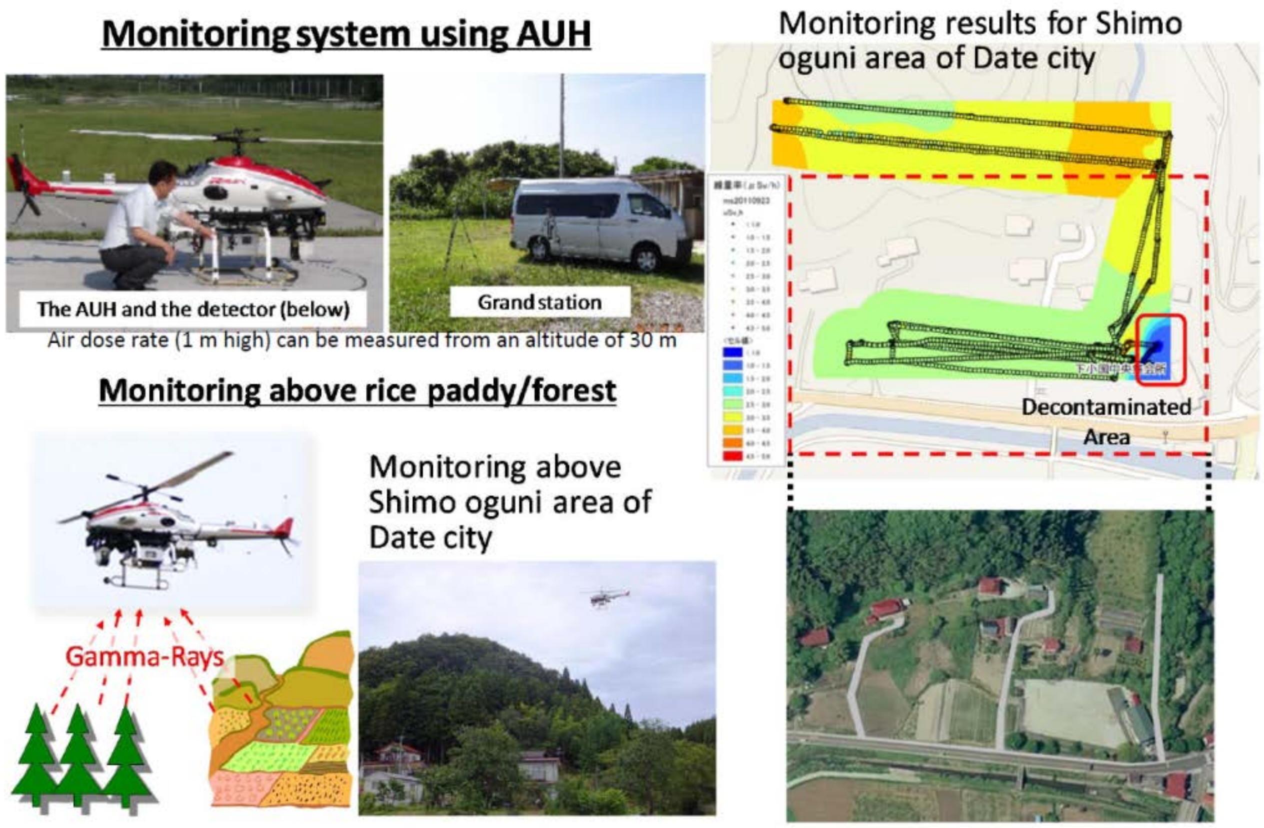




Thanks to a joint effort between US DoE and Japan, the first map was completed 1.5 months after the accident!

3. R&D on ENVIRONMENTAL RESTORATION

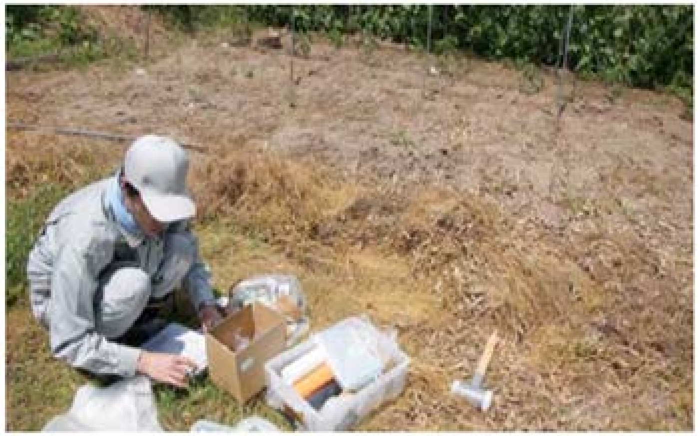
Autonomous Unmanned Helicopter (AUH) Monitoring System



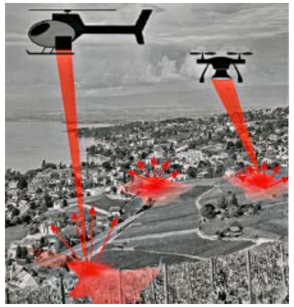
Souce: JAEA

In Japan, AUH were used in the intermediate phase as pilot projects

Hand survey was important to better characterize deposited activity and locate hot spots



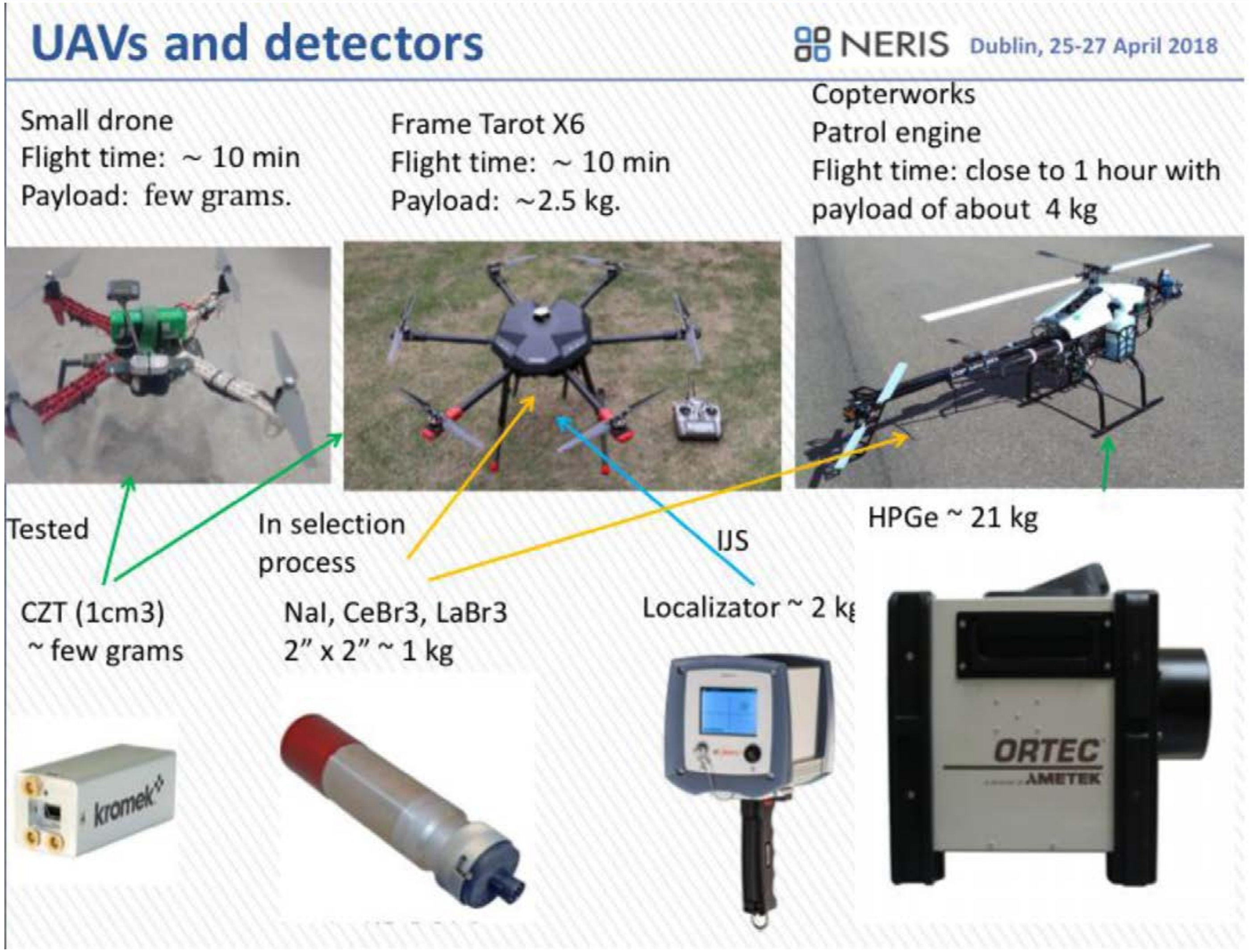
Recent projects (examples)



RemoteALPHA project

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States



Recent projects (examples)

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Now Available: New Drone Technology for Radiological Monitoring in Emergency Situations

Aleksandra Peeva, IAEA Department of Nuclear Sciences and Applications

FEB
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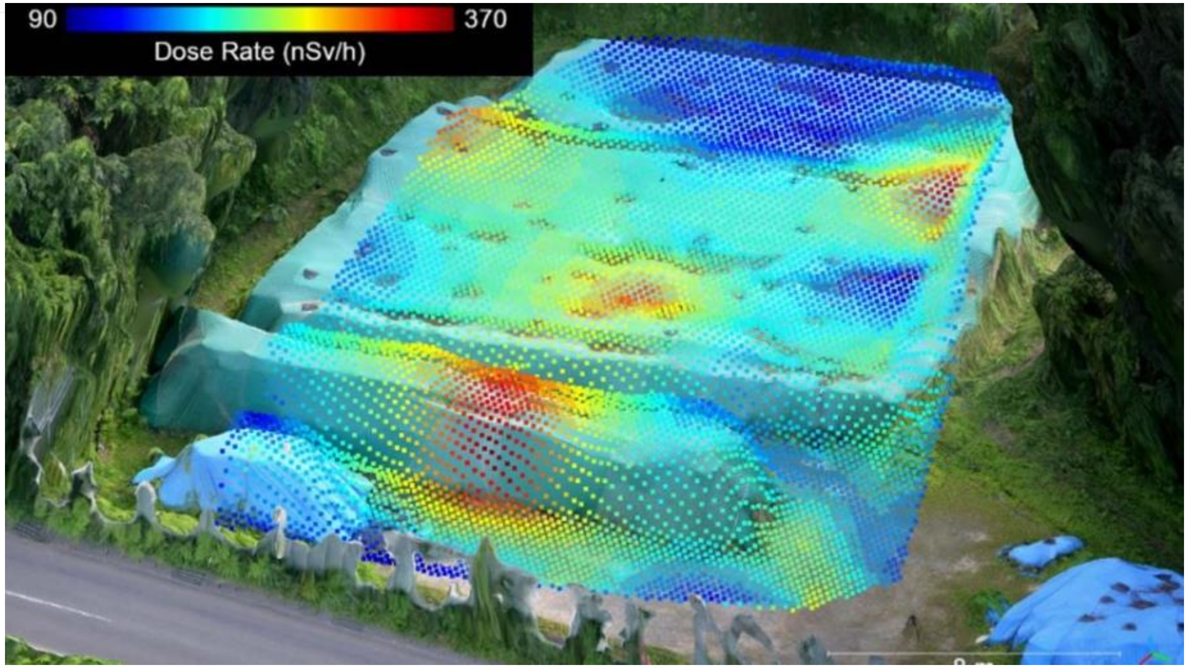
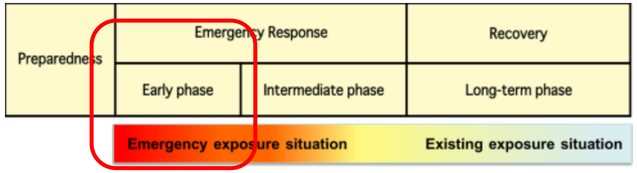
2021

A new technology using drones, developed by the IAEA for use by the authorities of Fukushima Prefecture in Japan, allows for radiological measurements in contaminated areas. (Photo: Fukushima Prefecture)



Dosimetry challenges in the Early Phase of an emergency (Population Off-site)

- In complex scenarios, with significant releases and **persons potentially irradiated**, decisions on their treatment would require
  - initial screening (triage)
  - decontamination if needed
  - followed by a more detailed dose evaluation using
    - **biological dosimetry**,
    - **whole body counting**, also for babies and children [BABYSCAN]
    - **in vitro measurements** of biological samples and other methods.



J. Radiol. Prot. **34** (2014) 645 R S Hayano *et al*

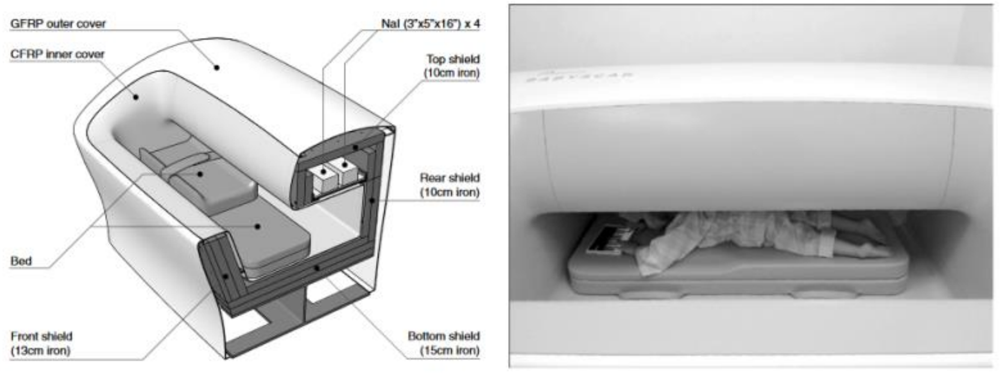


Figure 1. Left: a cutaway view of the BABYSCAN. Right: a 4-year-old child lying on front, playing with a tablet computer, during a 4 min measurement in the BABYSCAN.

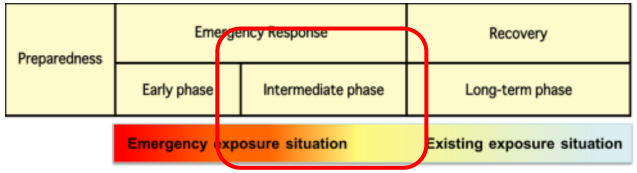
Dosimetry challenges in the Early Phase of an emergency (Population Off-site)

Preparedness	Emergency Response		Recovery
	Early phase	Intermediate phase	Long-term phase
	Emergency exposure situation		Existing exposure situation

- Particular attention is necessary to **thyroid dose monitoring**, especially for children and pregnant women [**CATHYMARA** project]

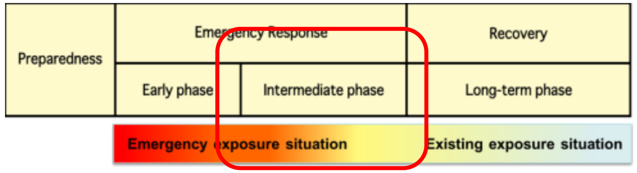
- **CHALLENGE:**
  - All these techniques require adequate laboratories and equipment available in advance and to keep them ready → **sustainability is a challenge!**

Dosimetry challenges in the Intermediate Phase of an emergency (Off-site)



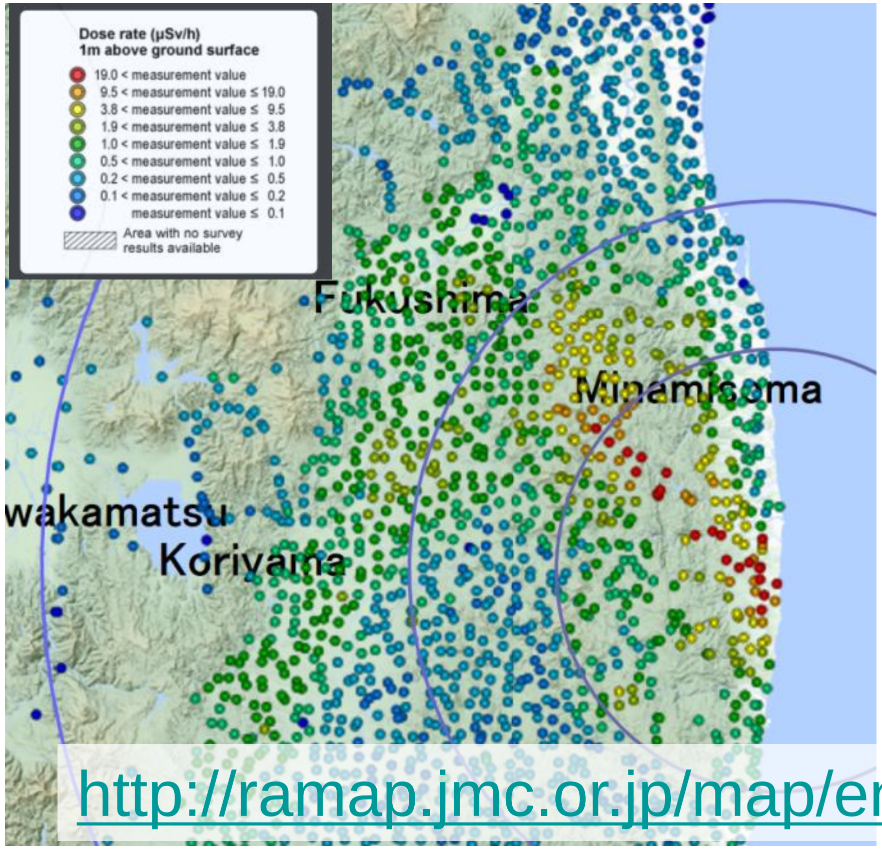
- An emergency exposure situation may be of very short duration (hours or days), or may continue for an extended period of time (weeks or months) in the event of a large nuclear accident.
- During the intermediate phase, the release is progressively brought under control.
- The intermediate phase implies the **change from an emergency exposure situation to an existing exposure situation**.
- Offsite, there is still uncertainty about exposures and the future for the affected areas. Therefore, the intermediate phase generally lasts longer off-site than on-site.
- Important decisions:
  - Termination of the urgent protective actions adopted during the early phase (mainly evacuation!)
  - Adoption of new countermeasures:
    - **food bans**,
    - **decontamination** of areas
    - **relocation** of people from the hottest zones

Dosimetry challenges in the Intermediate Phase of an emergency (Off-site)



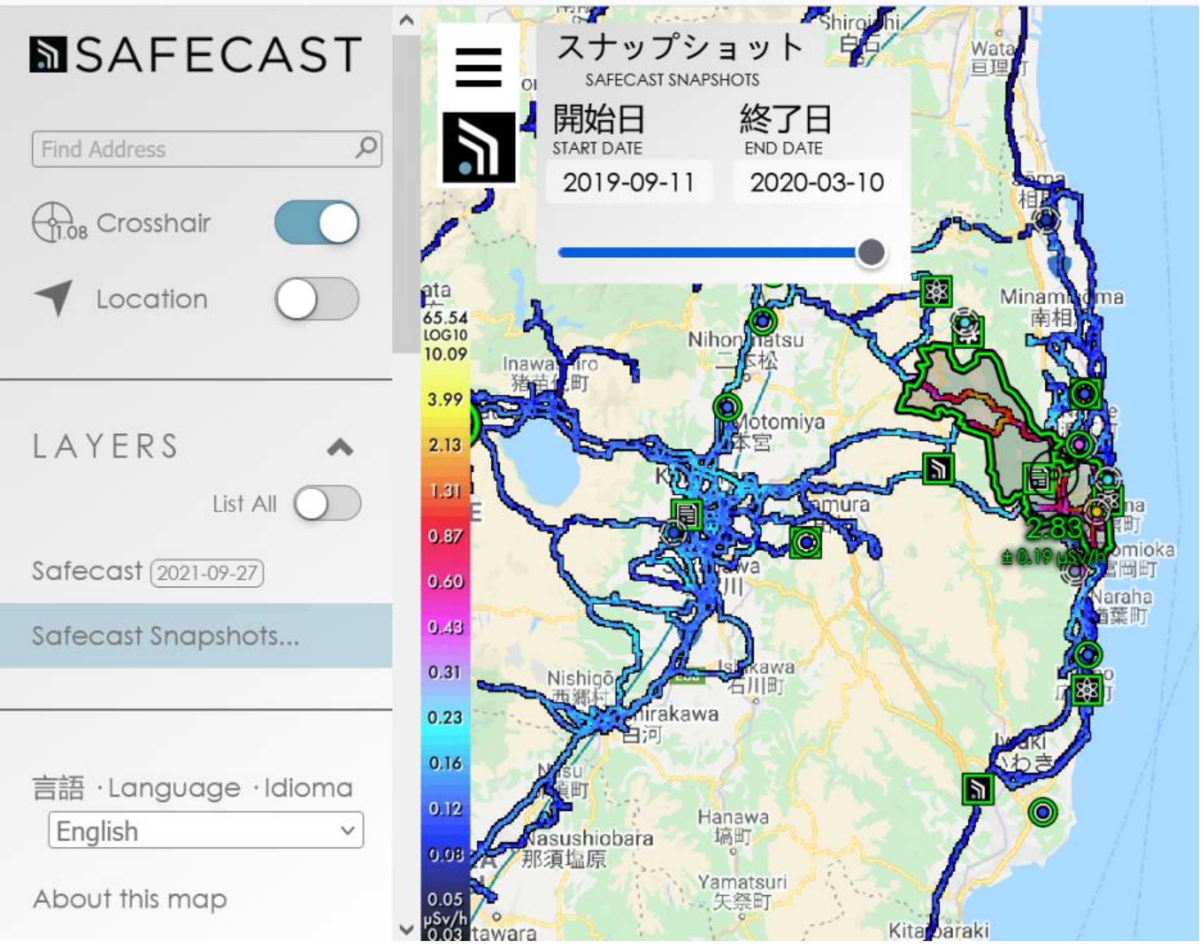
Key information for the radiological characterization:

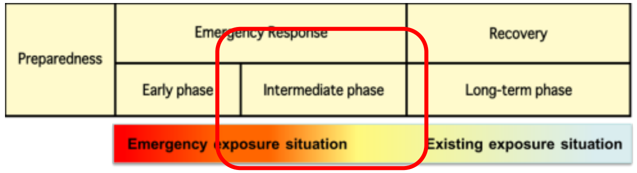
- Detailed characterization of the contamination levels of potentially large areas:
  - heterogeneity - **hot spots**!
- Radioactivity controls in air, food and water



http://ramap.jmc.or.jp/map/eng/

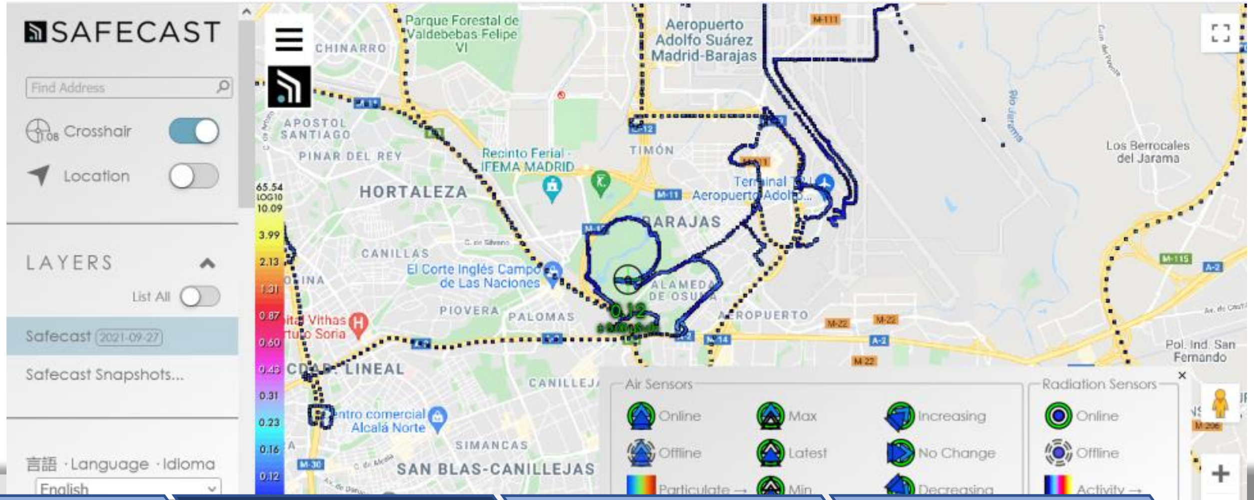
Dosimetry challenges in the Intermediate Phase of an emergency (Off-site)





CHALLENGE:

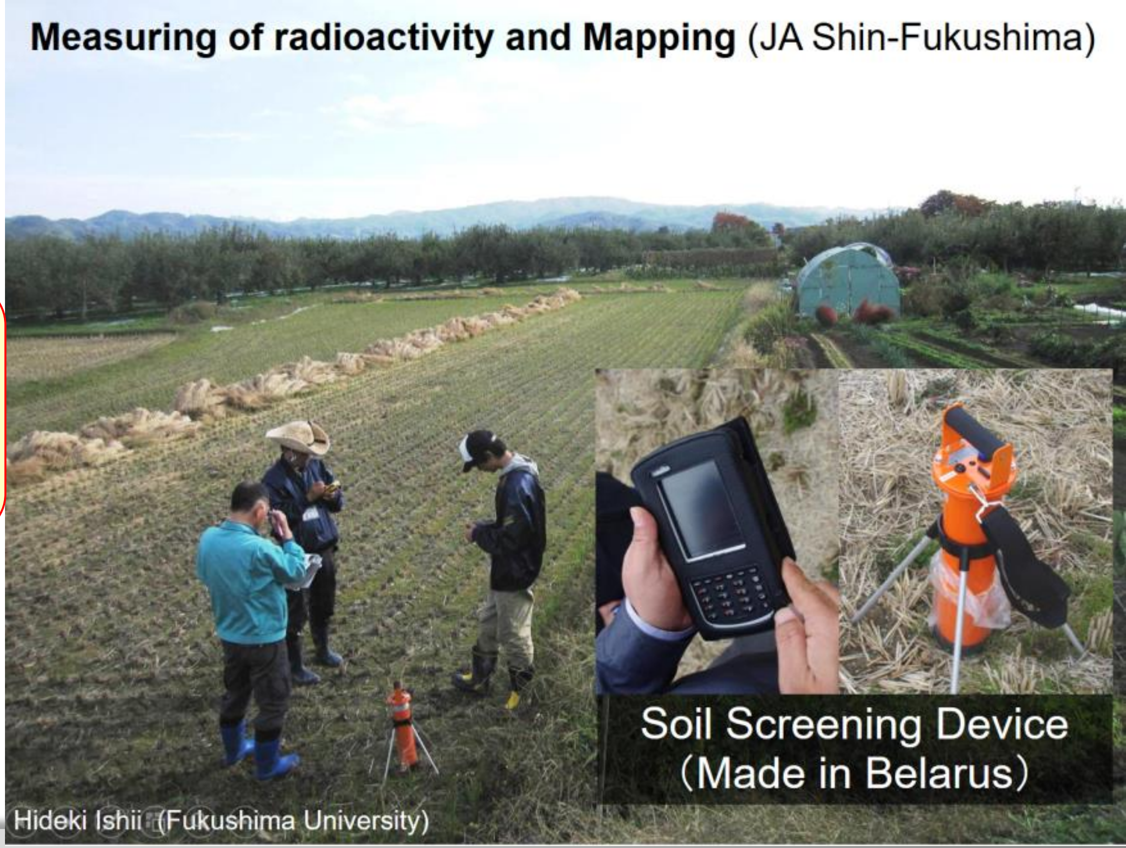
- Data collection by lay people and how to integrate this into operational approaches. [Examples: SAFECAST; Open Radiation]
- Communication of risk!



Dosimetry challenges in the Long-term phase – Recovery

Preparedness	Emergency Response		Recovery
	Early phase	Intermediate phase	Long-term phase
	Emergency exposure situation		Existing exposure situation

- Adoption of new countermeasures:
  - **food bans**,
  - **decontamination** of areas
  - **relocation** of people from the hottest zones
- **Reference dose levels** for the <u>existing exposure situation</u> in the long-term are set in terms of residual dose
- **<u>Realistic dose projection models</u>** should be employed together with monitoring data to produce a good assessment in which to base such transcendental decisions.
- Besides the official experts, other actors like affected citizens or local institutions may collect radiological data.
  - Protocols should be prepared to assist in such data collection by stakeholders and to integrate them.

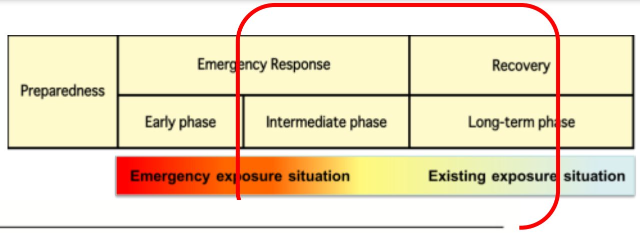


Dosimetry challenges in the Intermediate and Long-term phases

CHALLENGES:

- **Realistic dose projection models** should be employed together with monitoring data to produce a good assessment in which to base such transcendental decisions.

- **Suitable individual dosimetry systems** for the public should be made available to allow people knowing their radiation exposure, including where, when and how they are exposed



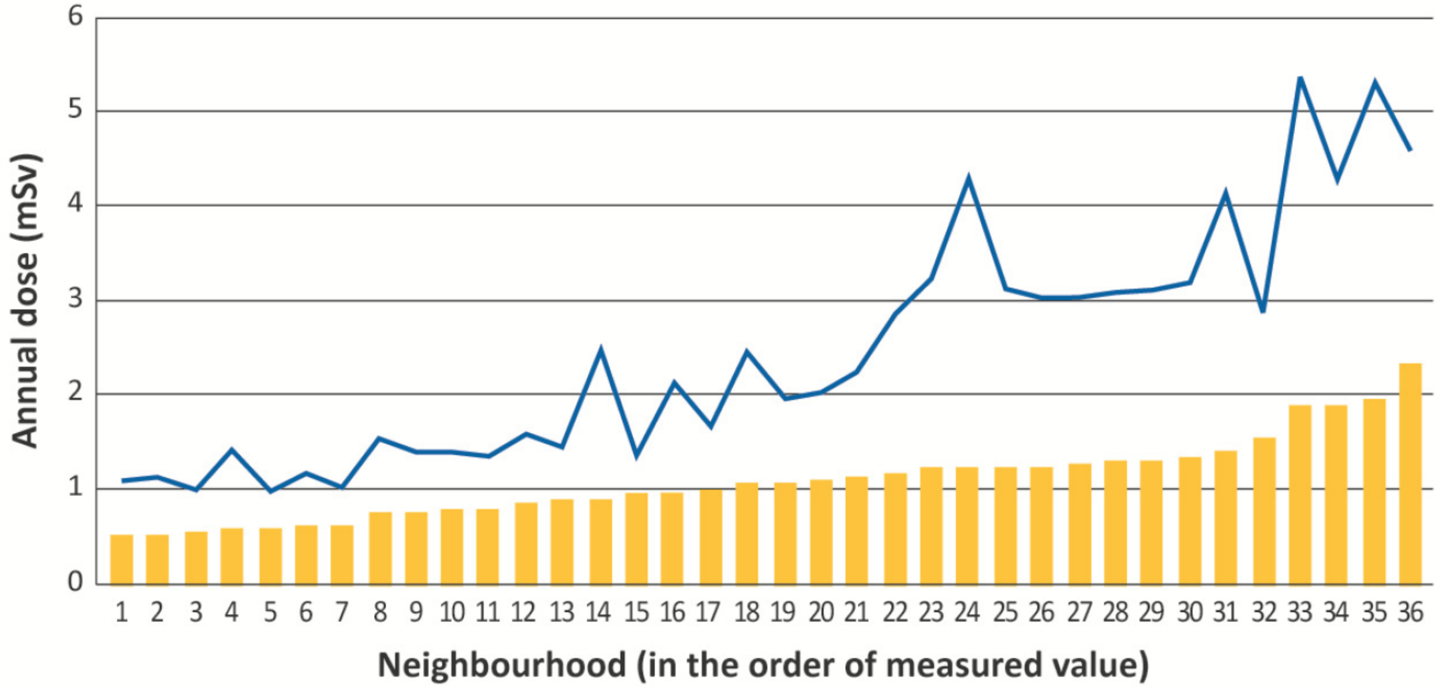


FIG. 4.8. Comparison of external individual dose estimates with measurements for a representative affected city between July 2012 and June 2013. The effective doses are assessed by estimation (line), assuming indoor occupancy and shielding for 16 h, outdoors for 8 h, and by personal monitoring (bar) of personal dose equivalent, in various neighbourhoods of the city (numerated) [209].

Credit: IAEA, 2015

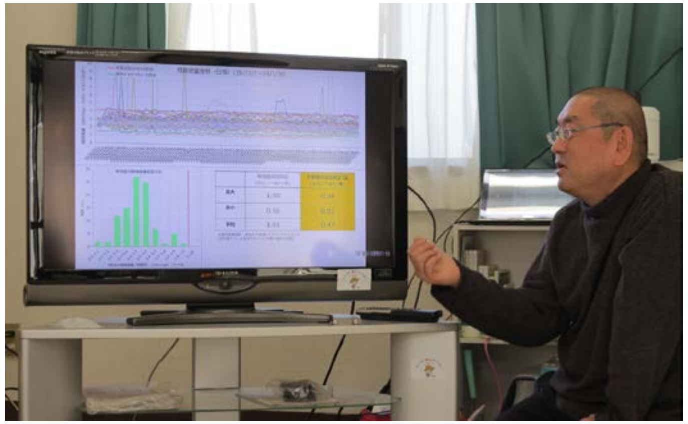
Dosimetry challenges in the Long-term phase – Recovery

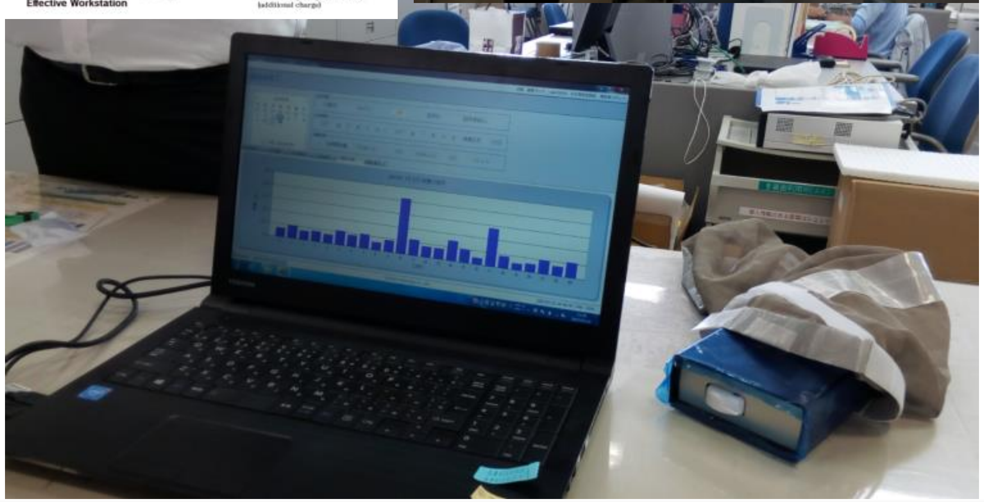
Preparedness	Emergency Response		Recovery
	Early phase	Intermediate phase	Long-term phase
	Emergency exposure situation		Existing exposure situation

CHALLENGES:

- Qualified personnel and suitable individual dosimetry systems for the public should be made available to allow people knowing their radiation exposure, including **where**, **when** and **how** they are exposed

  [Example:D-Shuttle]





Control of radioactivity in food (Fukushima pref.)

A 30kg bag of whole rice is loaded onto a conveyor belt and a 15 second test of radioactivity is conducted.

This machine can measure radioactivity of over 25Bq/kg or more.

All the rice produced in Fukushima Pref. is examined for radioactivity.

Dosimetry challenges in the Long-term phase – Recovery

Preparedness	Emergency Response		Recovery
	Early phase	Intermediate phase	Long-term phase
	Emergency exposure situation		Existing exposure situation

CHALLENGES:

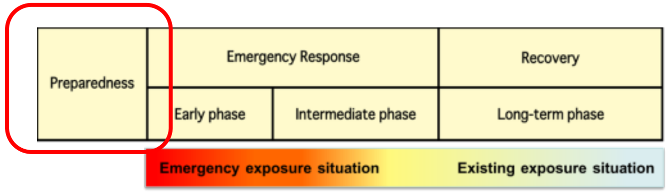
- Measurements of concentrations of radionuclides in foodstuffs and in the environment locally.

- Sustainability in the long-term together with support to understand the relevance of such data, so that **people can make their own protection decisions**.

0.23 µSv/h

CONCLUSION: Dosimetry challenges in the Preparedness phase

➢ We are now in the Preparedness phase!



➢ The great challenge for improving emergency preparedness and response is the participation, motivation and commitment of the interested organizations and the population.

➢ It's time to …

- address all the challenges identified,
- develop representative accident scenarios – training and testing of protocols,
- work together to increase the **radiation protection culture** of the different, stakeholders and the population in general, for example, through periodic exercises and analysis of realistic accident scenarios,
- favour interaction and cooperation between experts and stakeholders through open networks.

16th EURADOS SCHOOL

Contribution of dosimetry in the field of nuclear emergency preparedness and radiological accident management

EURADOS

Thursday, 15th June 2023

Many thanks for your attention.

Questions?