Challenges for Fukushima environmental recovery - JAEA's perspective on radiocaesium distribution and behaviour in the environment

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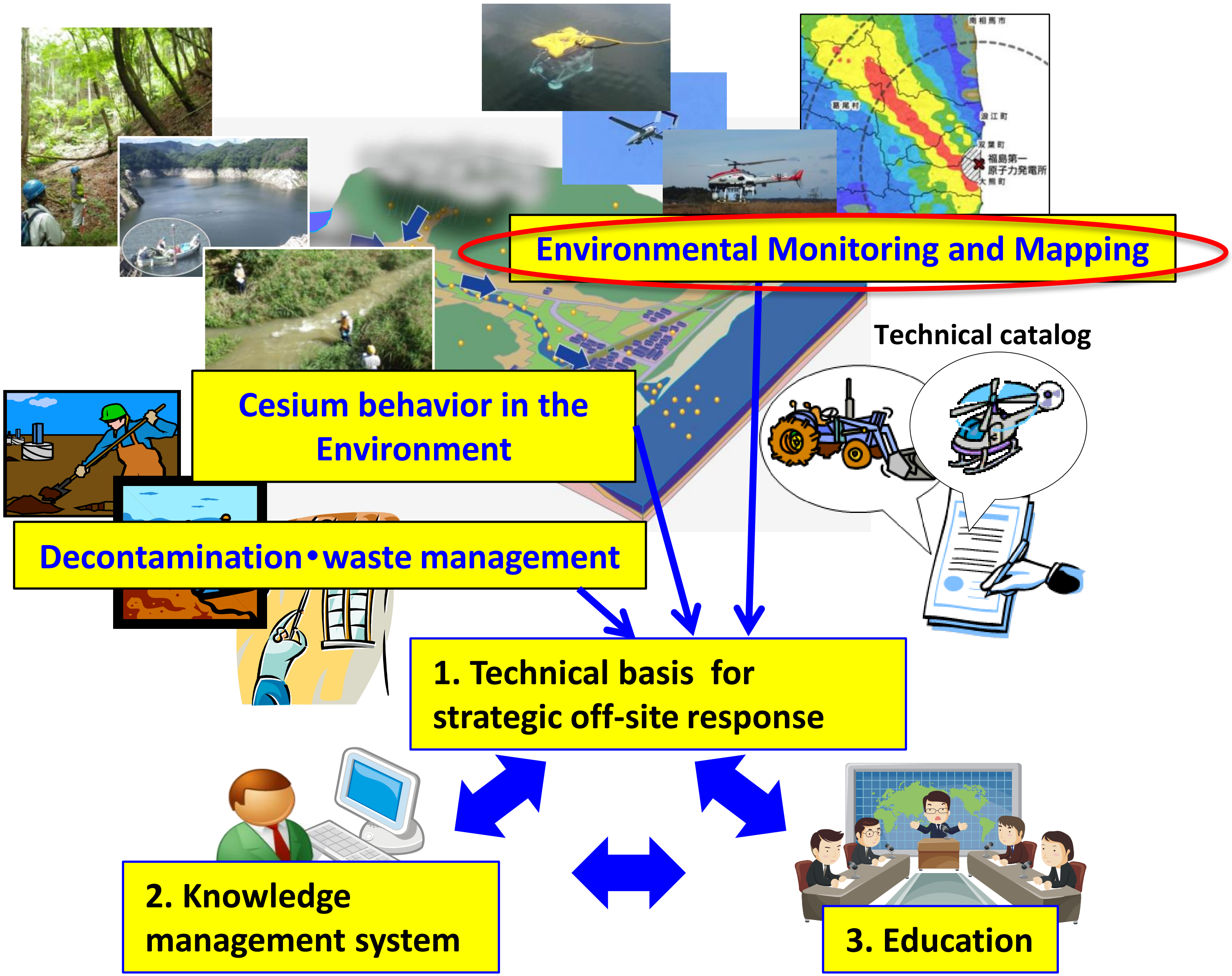
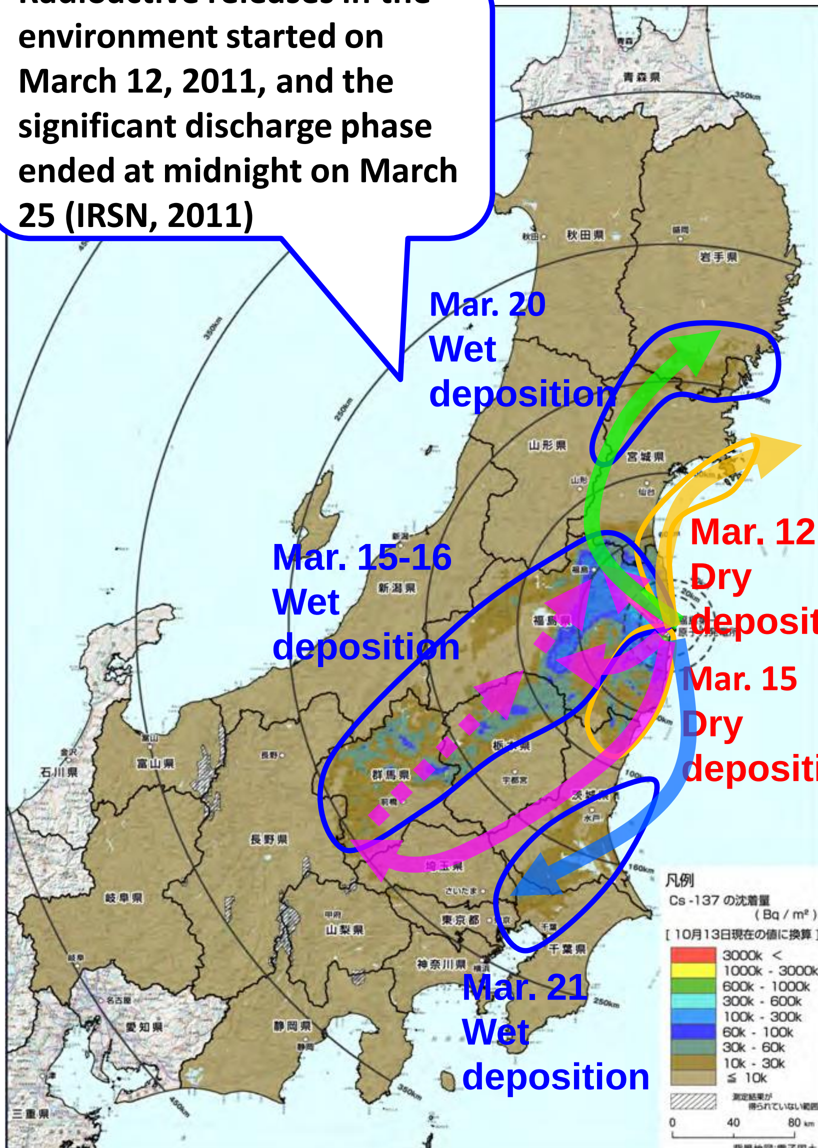
The Society for Remediation of Radioactive Contamination in Environment

Development of a technical basis for strategic off-site response



Understanding off-site release

Radioactive releases in the environment started on March 12, 2011, and the significant discharge phase ended at midnight on March 25 (IRSN, 2011)

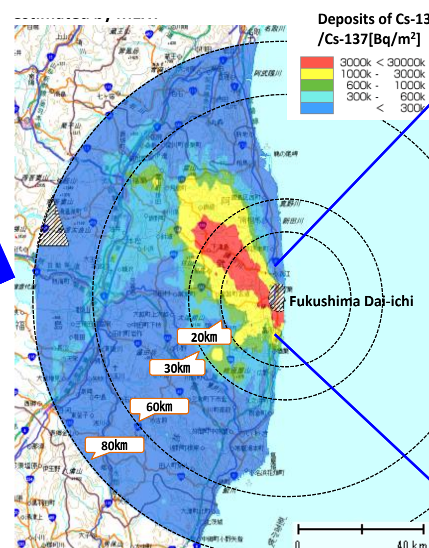


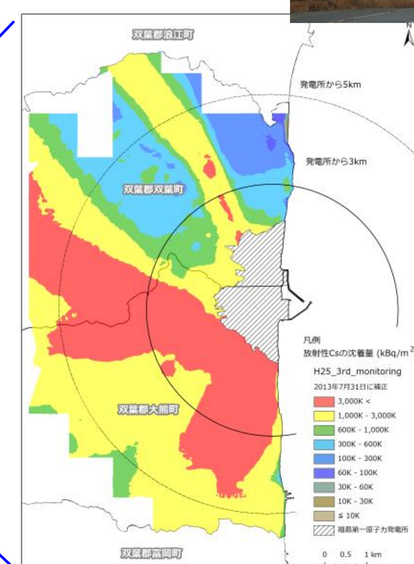
Nagai *et al.* (2012)

Start of reactor core damage (orange) | Hydrogen explosion (reactor building) (green)

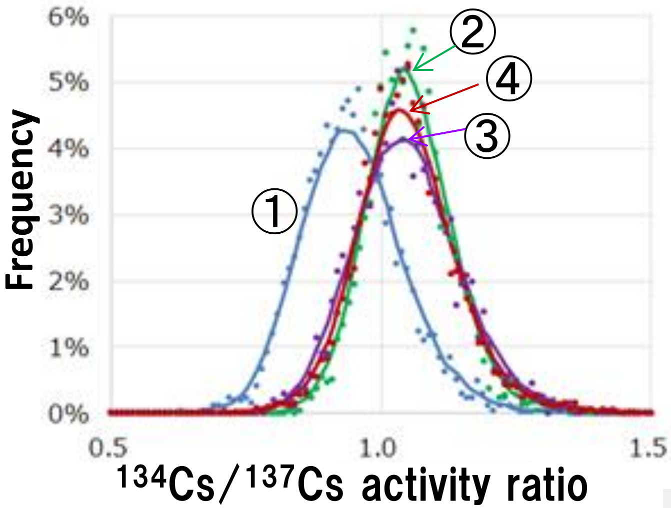
	Unit 1	Unit 2	Unit 3	Unit 4
3.11	2:46 pm Earthquake			
	3:37 pm Tsunami (peak of waves)			
	~6:50 pm			
3.12	3:36 pm			
3.13			~10:40 am	
3.14			11:01 am	
		~7:20 pm		
3.15		~6:00 am Damage to suppression chamber		~6:00 am

NAIIC (2012)

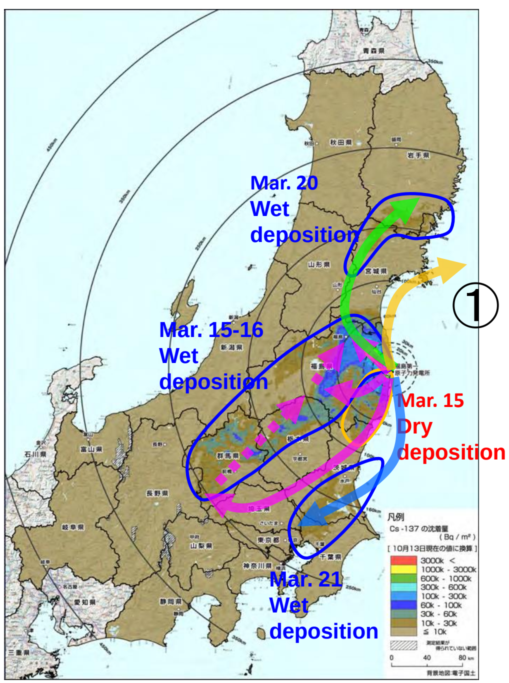




Understanding off-site release

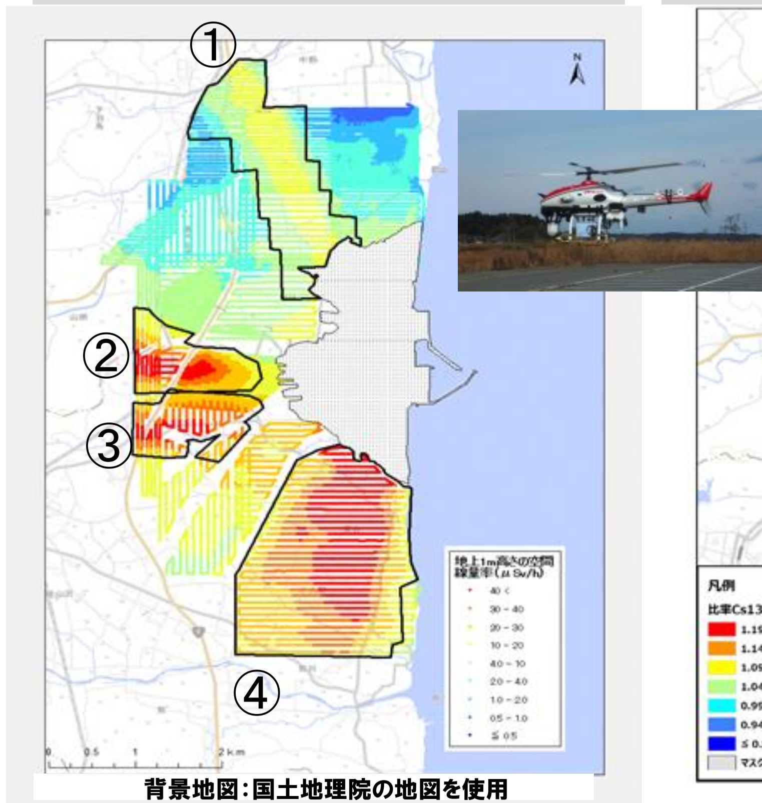


Deposition due to the plume from the unit 1 can be distinguished by comparison of the $^{134}Cs/^{137}Cs$ activity ratios

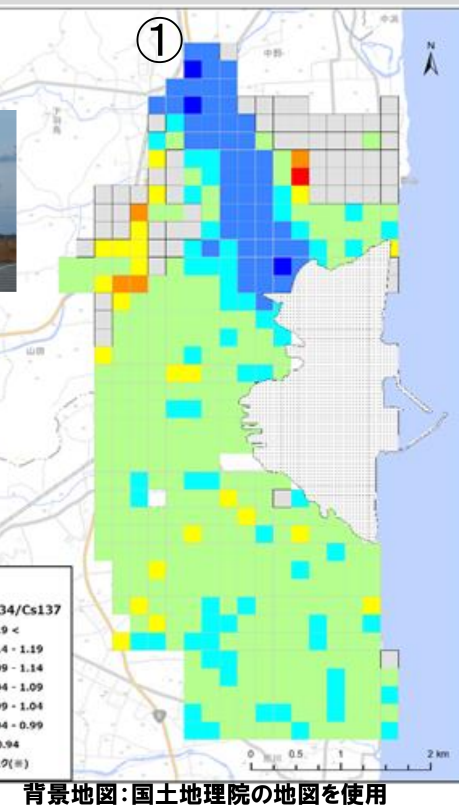


Nagai *et al.* (2012)

Air dose rate（1m height）

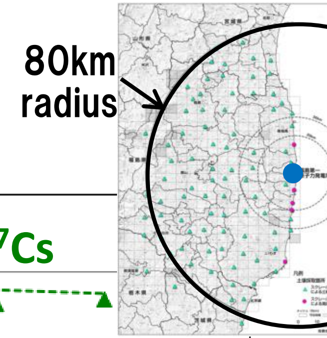


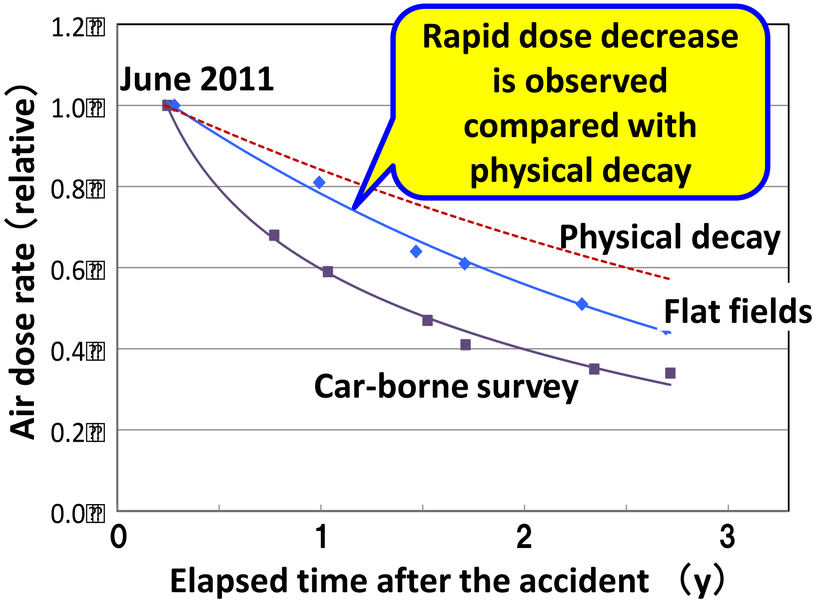
$^{134}Cs/^{137}Cs$ activity ratio

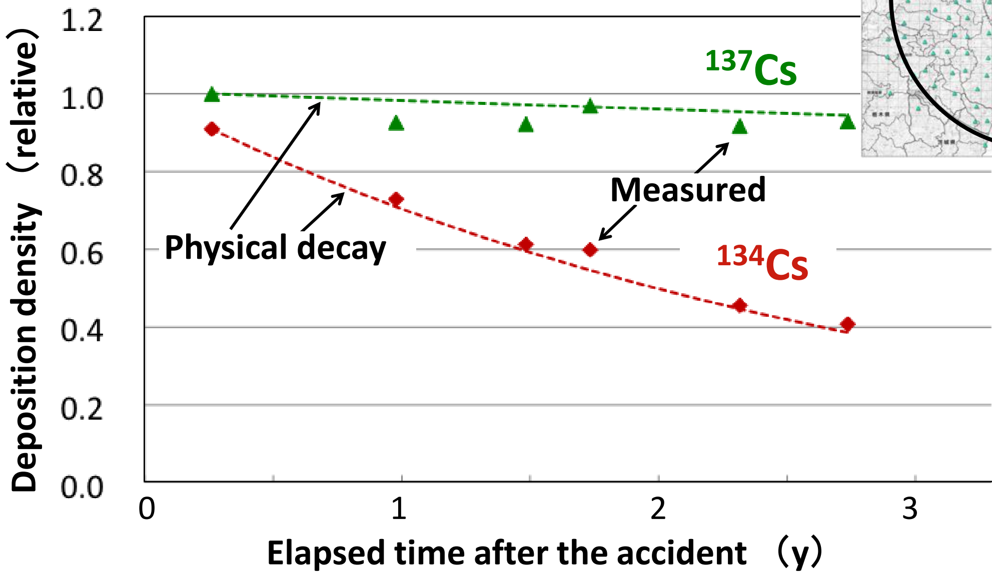


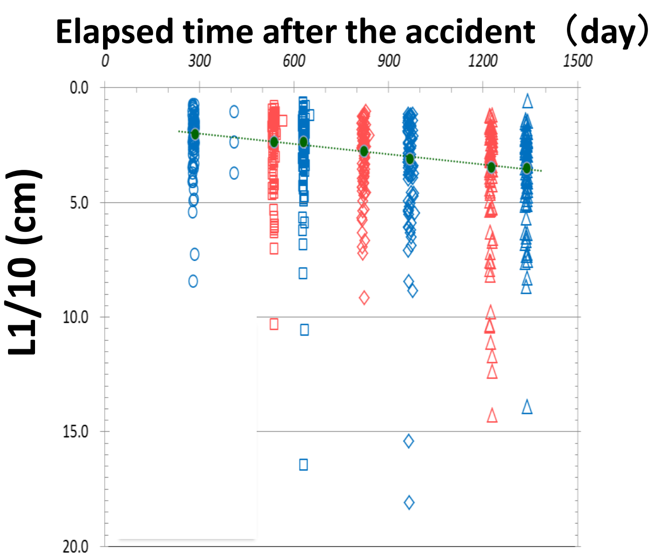
Flat fields

（Within 80km radius from 1F except decontaminated areas）

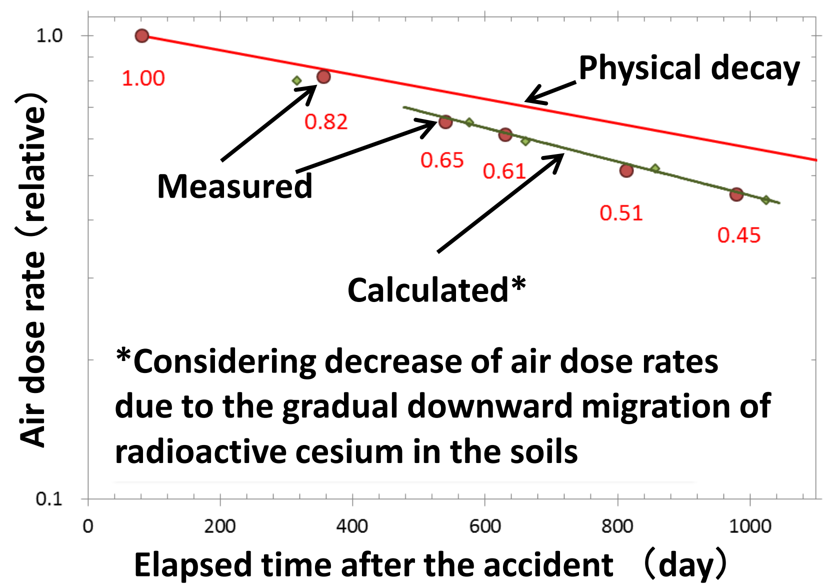




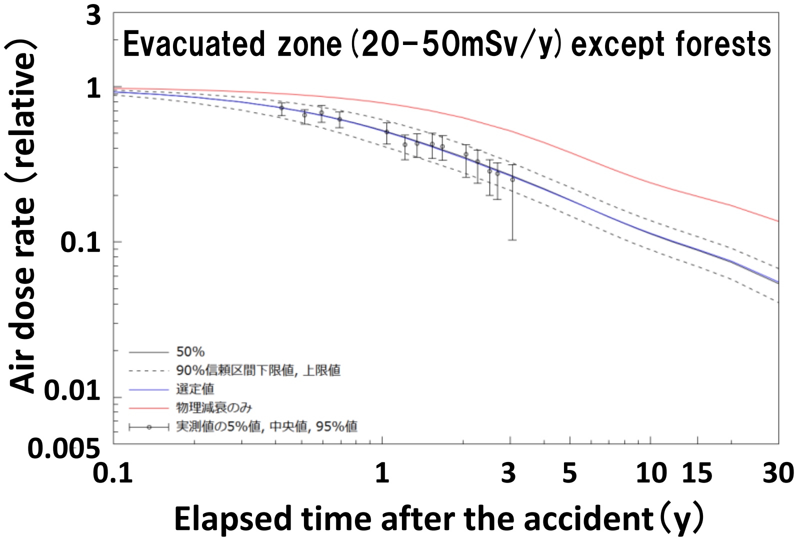


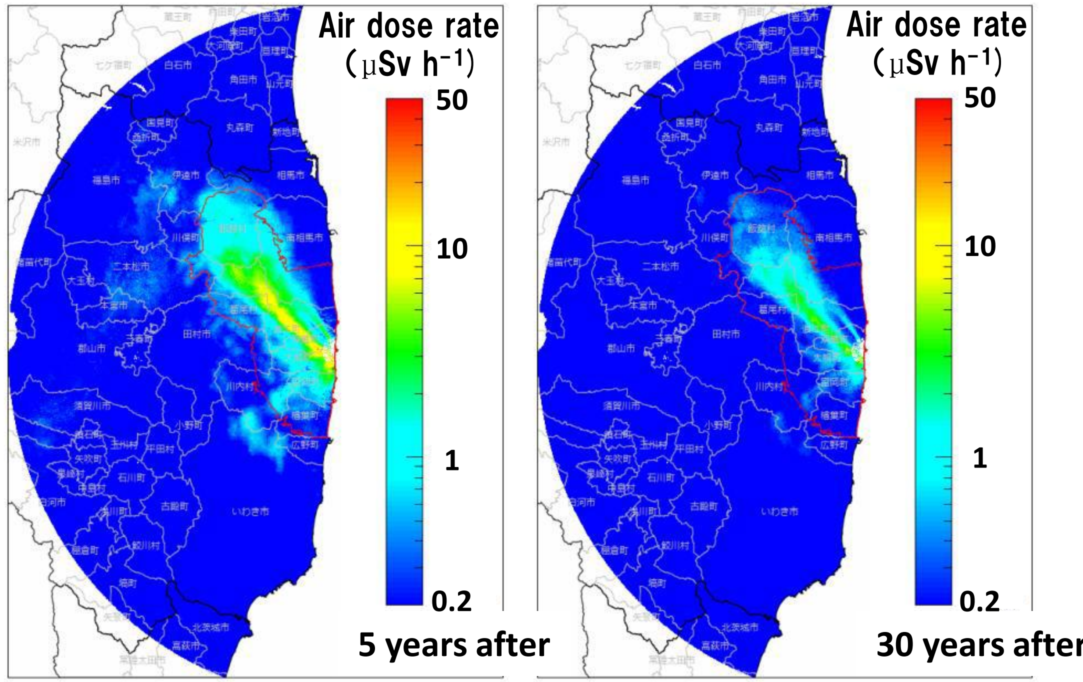


1/10 depth at which the soil contains 90% of the inventory



Development of a predictive model





- An empirical approach to allow prediction of the dose rate distribution based on statistically analysed results of the environmental monitoring data accumulated in the projects
- The time-dependent decrease of air dose rate in any specific setting can be approximated by a combination of two exponential functions, representing “fast” and “slow” reduction rates
- Analysis linked to geostatistical data shows that the environmental half-life clearly depends on land use

＊空間線量率の予測図は、原子力機構が平成26年度原子力規制庁の委託業務を実施する中で得た知見をもとに作成したものである。当該図は、50%値の予測。

Estimation of individual dose

The current simple model approach

「Air dose rates measured by radiation monitoring (e.g. aerial survey)（μSv/h）」×
「(people spend 8 hours a day outdoors and 16 hours a day indoors）× a shielding factor of 0.4 for indoors」
× 365days ÷ 1000 ＝ Individual dose（mSv/y)

A flexible model approach tailored to specific lifestyles and locations (Takahara, 2013)

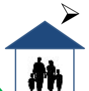
「Location-specific air dose rates（μSv/h）」×
「Amounts of time spending indoors or outdoors depending on occupation」×「Dose reduction coefficient」
× 365days ÷ 1000 ×「The ratio of personal dose rates to air dose rates」 ＝ Individual dose（mSv/y)

Difference of lifestyle

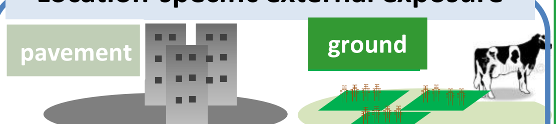
- Amount of time spent indoors or outdoors depending on occupation
- Variations in does rates depending on the type and location of work

Dose reduction coefficient

- Shielding effect and filtering effect depending on construction type and time spent indoors
  - Differences in dose reduction depending on lifestyle and type of accommodation

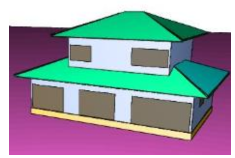


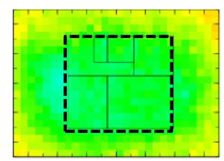
Location-specific external exposure

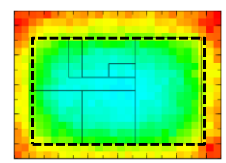


- Distribution of radiocaesium deposition on the surface (ground, pavement etc.)
- Weathering effects

Wooden house

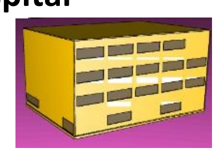


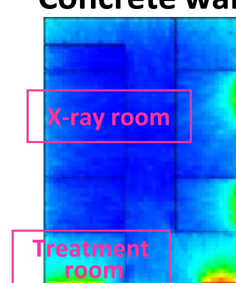


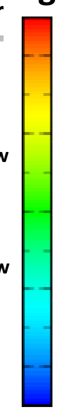


Reduction factor; 0.42 at center in the 1st floor

Hospital

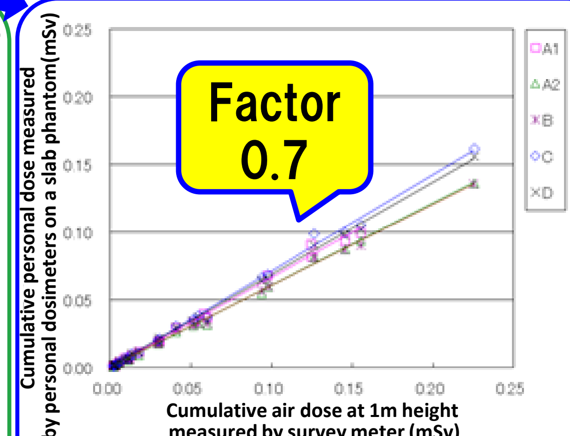






Reduction factor; 0.10（Treatment room）
0.02（X-ray room）

Takahashi (JAEA, 2013)

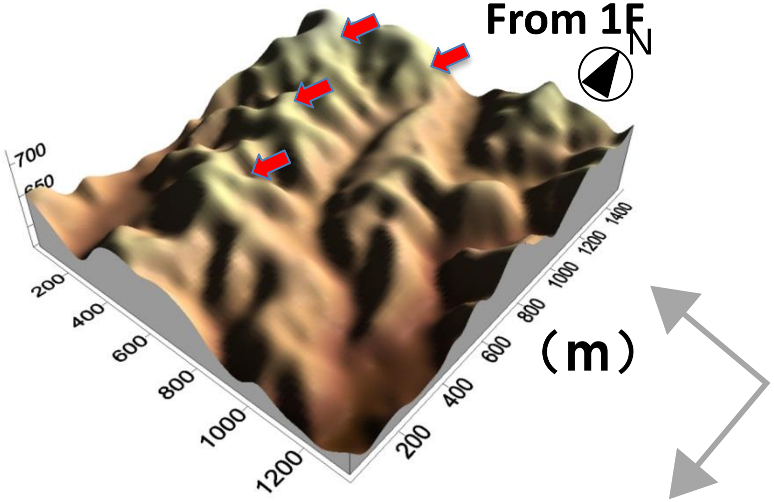


Takada (JAEA, 2014)

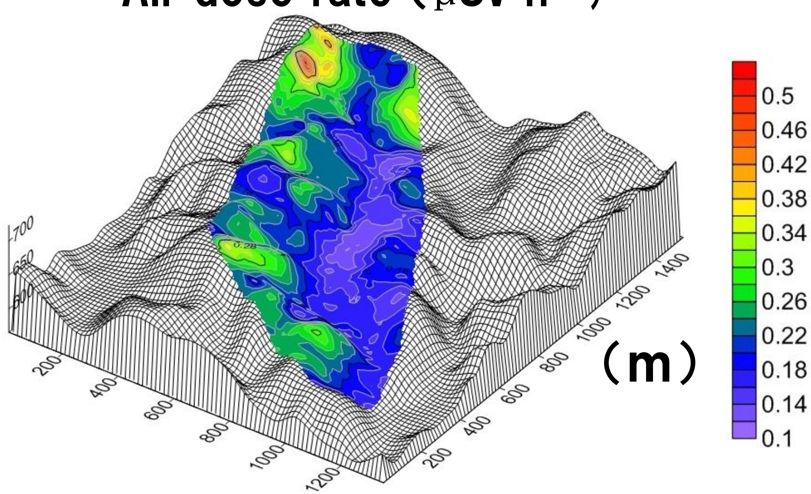
Radiocesium deposition in mountainous forests

-understanding a relationship between radiocesium deposition and topography -

Lighting pattern in the 3D surface map



Air dose rate (μSv h^{-1})

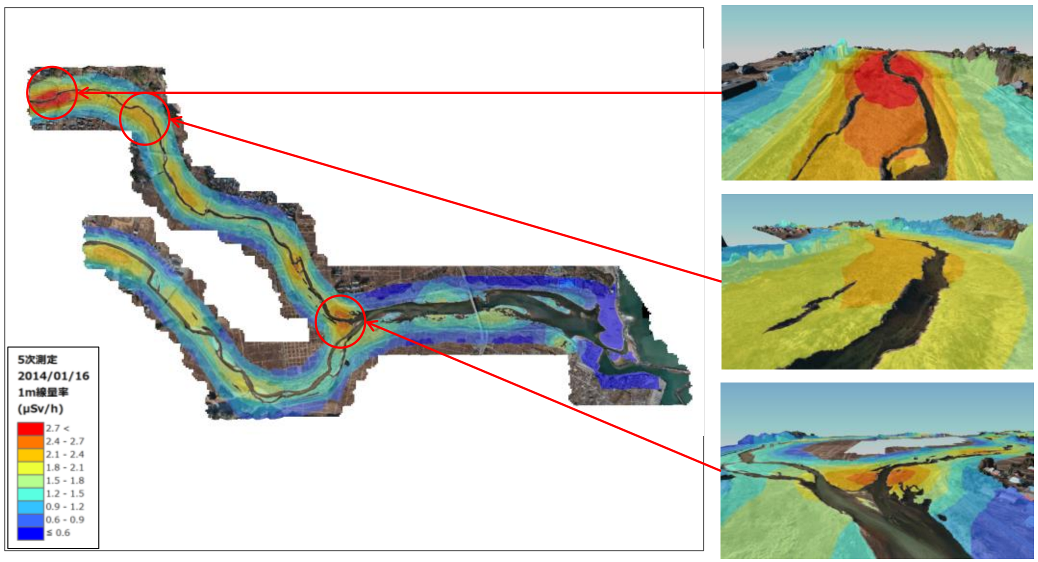


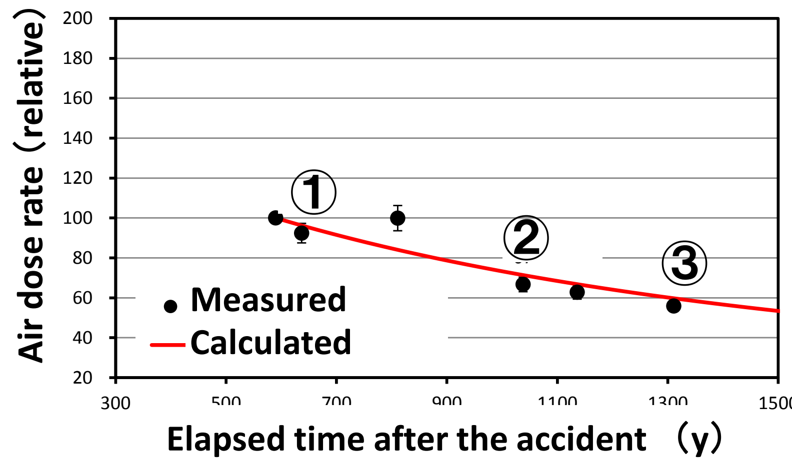
Andoh et al. (2015)

- **Radiocesium deposition is strongly affected by an east wind in this catchment (shadow effect)**
- **Proportional relationship between the air dose rate and elevation on the east-facing slope**
- **Aerosol interception by mountainous forests is greater for dry deposition than for wet deposition**

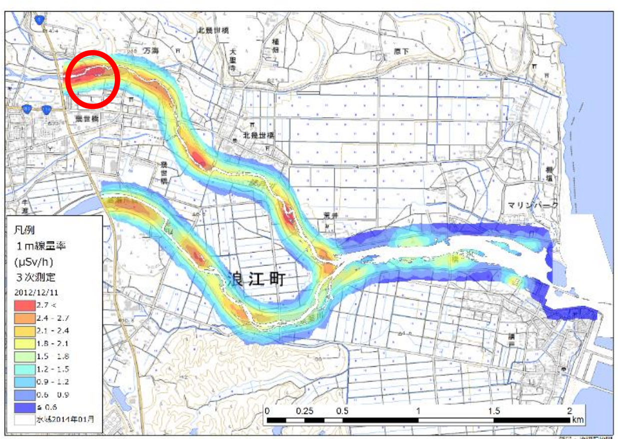
More investigations on the distribution of air dose rates on a catchment scale are necessary under varying deposition conditions to understand the general relationship between air dose rate and topography (elevation/slope) for appropriate forest managements

The time-dependent decrease of air dose rates along a river system
Aerial survey results along Ukedo river

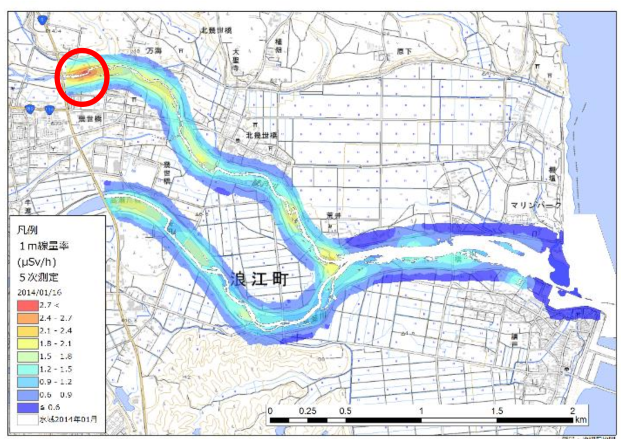




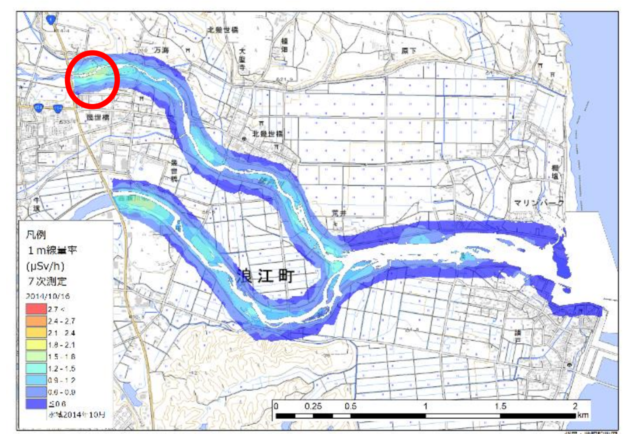
① Dec.11, 2012



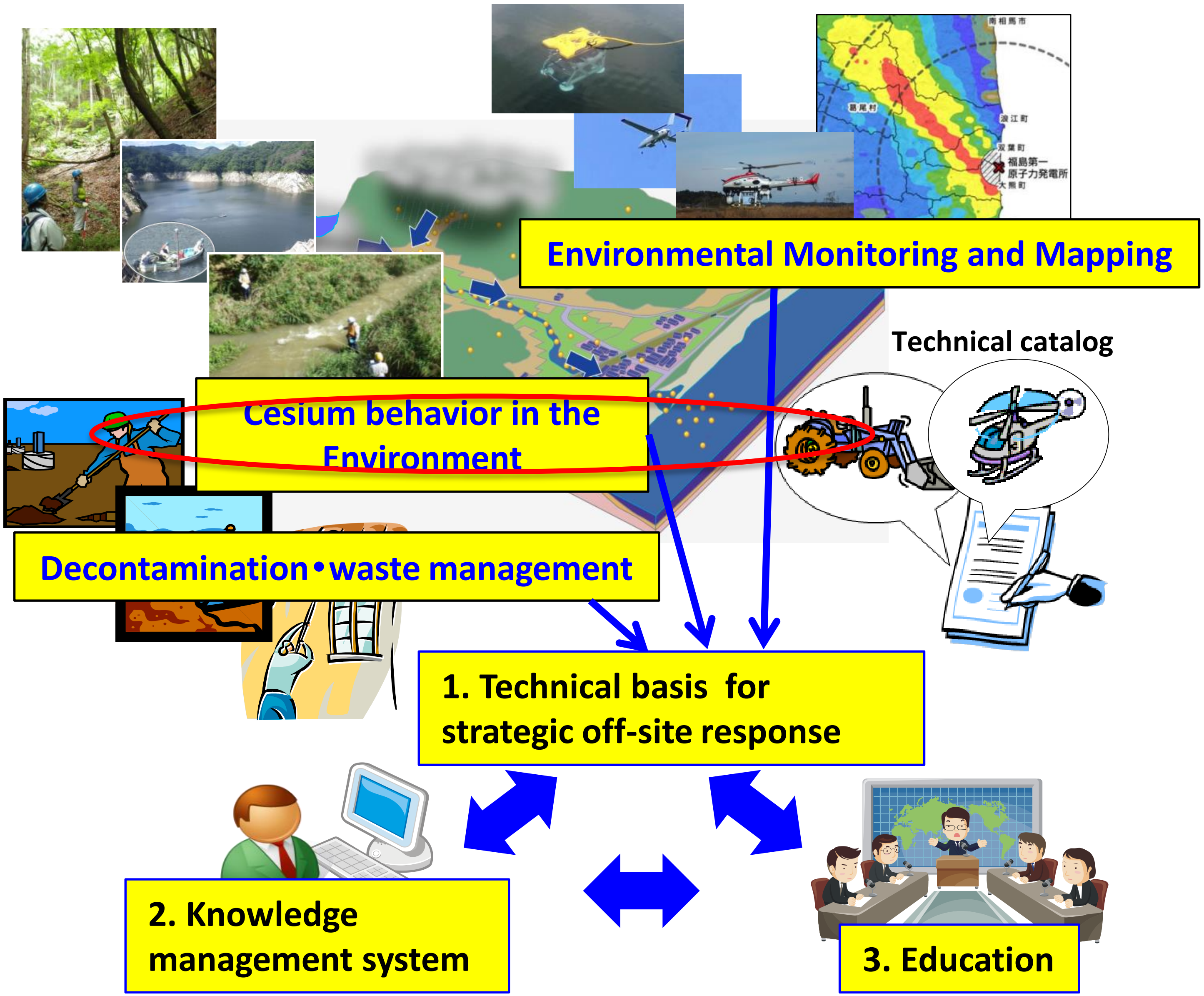
② Jan.16, 2014



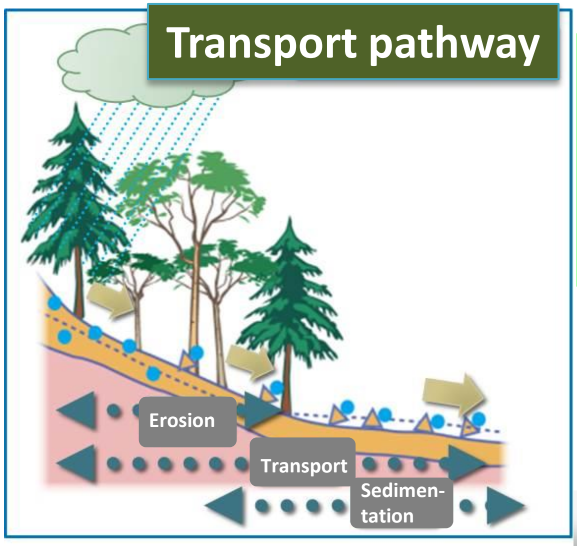
③ Oct.16, 2014



Development of a technical basis for strategic off-site response



Key transport behavior of radiocaesium (F-TRACE)



In forests

➔ evaluate external irradiation of forestry workers in the forest

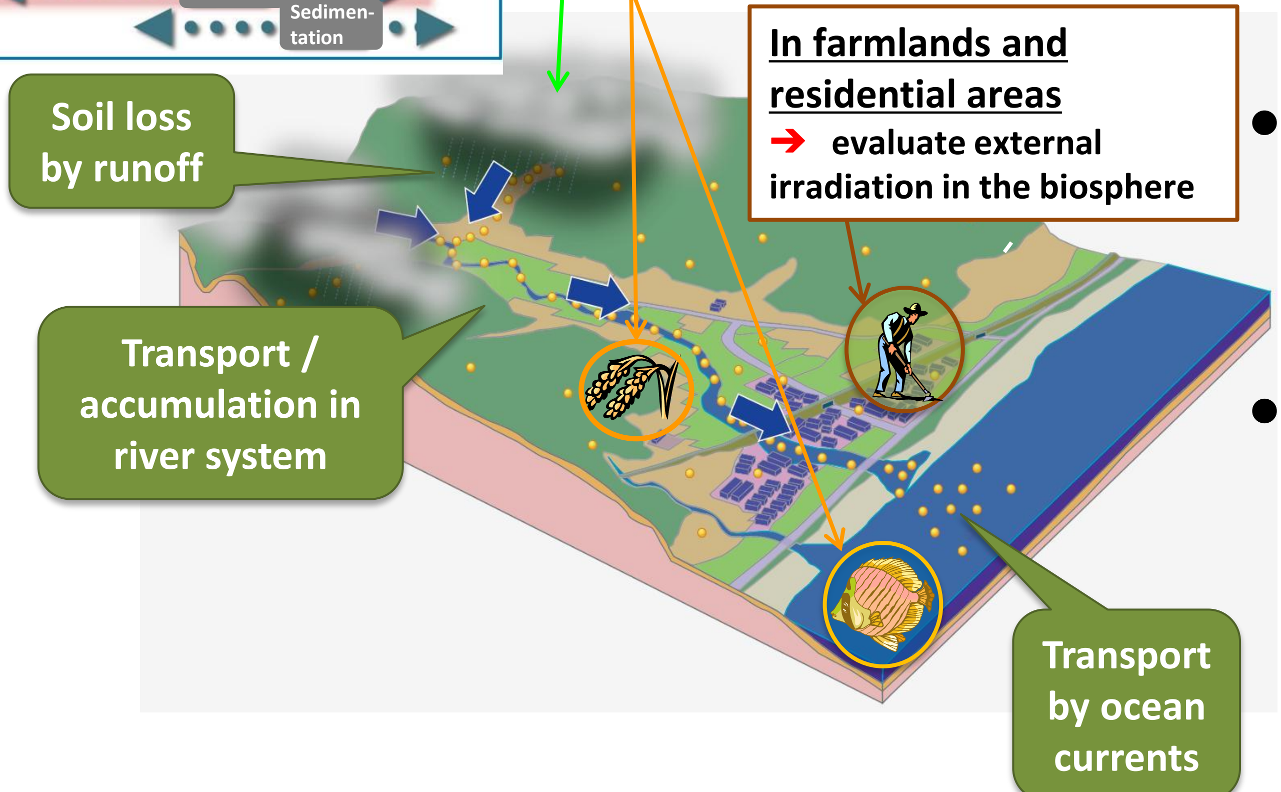
➔ apply to evaluate cycle of Cs in forest ecosystem

In water system

➔ apply to evaluate Cs uptake by vegetation / fish

In farmlands and residential areas

➔ evaluate external irradiation in the biosphere



- Deposited Cs tends to bind strongly to soils, especially clays
- Annual discharge of radiocaesium from the topsoil of the mountainous forest by runoff erosion was estimated to be 0.1% of the total inventory in the topsoil
- Accumulation of radiocaesium in the river system was found on flood plain and in dam / lake sediments
- Limited amounts of fine particles such as clay could be discharged from dams to downstream rivers

Cs behavior in the environment;
- mountainous forest, dams / lakes, river system -

Annual discharge by runoff : **~ 0.1 %** of Cs in the topsoil (observed in the plot)

Rainfall in the forest : **~ 2 Bq/L**

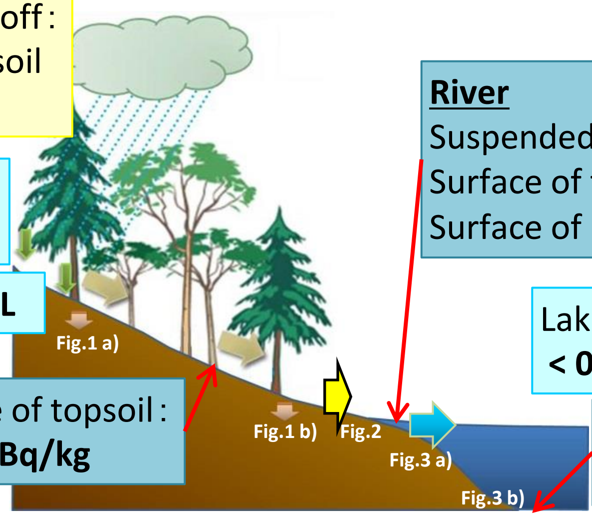
Stem flow : **~ 20 Bq/L**

Forest Surface of topsoil : **~ 30 kBq/kg**

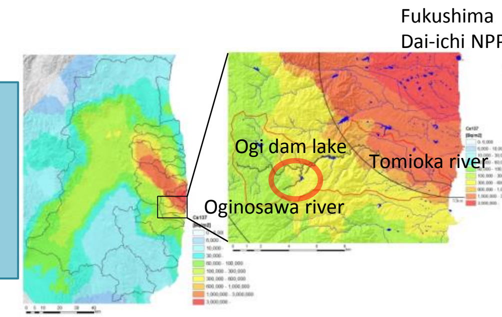
River
Suspended solids (SS): **10 – 50 kBq/kg**
Surface of floodplain: **10 – 30 kBq/kg**
Surface of river bed : **~ 1 kBq/kg**

Lake water : **< 0.01 Bq/L** (soluble)

Lake Surface sediment : **~ 10 kBq/kg**



Overview of ^{137}Cs behaviors in Oginosawa river basin after ~ 2.5 y since the accident



The location of investigated areas in Oginosawa river basin

Cs concentration in dam lake water is extremely low

Most Cs exists within 5 cm from the ground surface

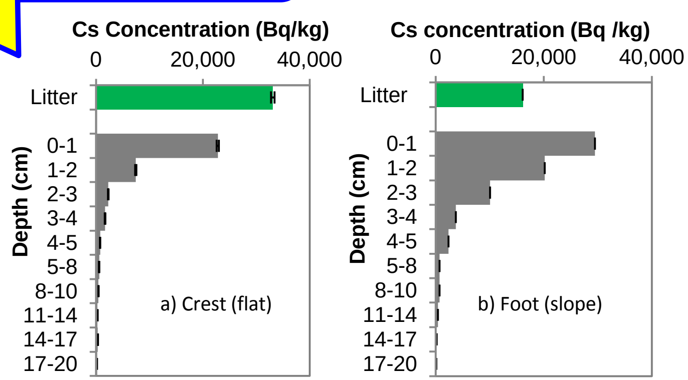


Fig. 1 Depth profiles of ^{137}Cs in the topsoil of Japanese cedar forest beside the Ogi dam lake on Jan. 2013

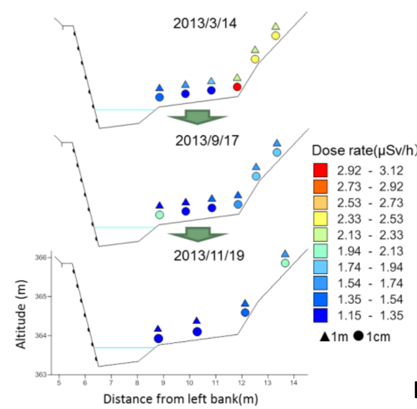


Fig. 2 Evolution of distribution of dose rate on the floodplain of the Oginosawa-river.

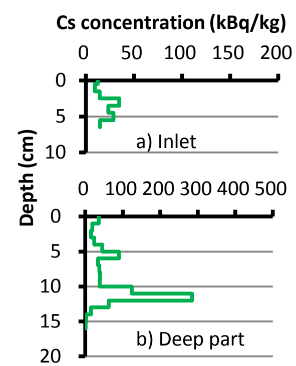


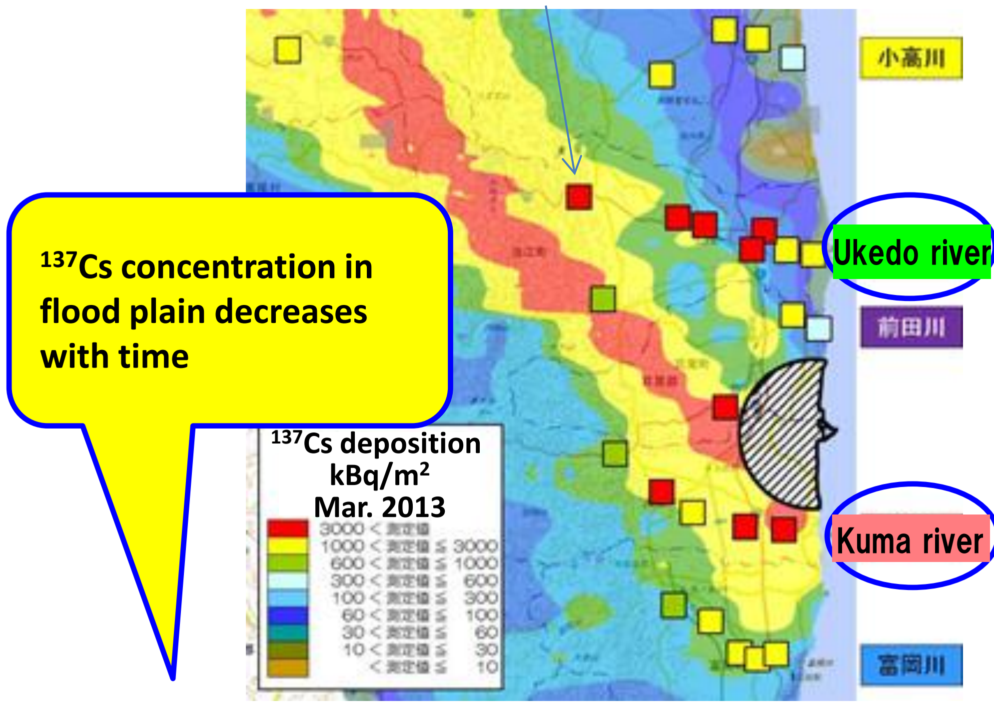
Fig. 3 Examples of depth profiles of ^{137}Cs in the bottom sediment of the Ogi dam lake on Jan. 2013

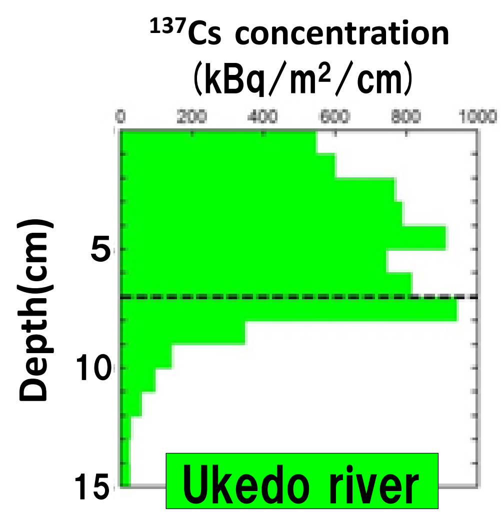
Aquatic ecosystems (1)

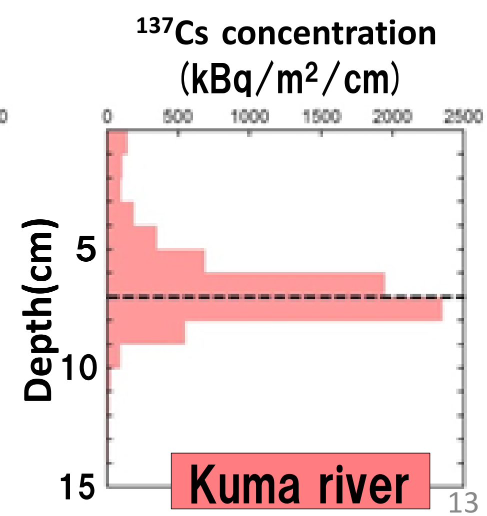
Guidelines

- **Implement decontamination focused on the living environment of residents (riverbanks and ponds)**
- **For riverbanks utilized as parks or playgrounds, decontamination needs are assessed based on comparison of ambient doses with those in surrounding environment; if ambient doses significantly increase due to a heavy rain, the situation is reassesed**
- **For relevant ponds, when ambient doses significantly increase due to drying out, assessment of whether decontamination is needed or not**
- **Long-term planning based on a perspective of attenuation of radiation in aquatic ecosystems, continuous monitoring of radiation doses; this is supported by investigations of radio-Cs behavior in the environment**
- **Promote risk communication with residents and other stakeholders**

^{137}Cs deposition in flood plain



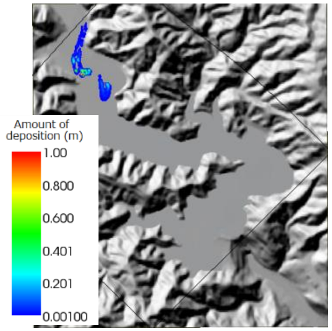




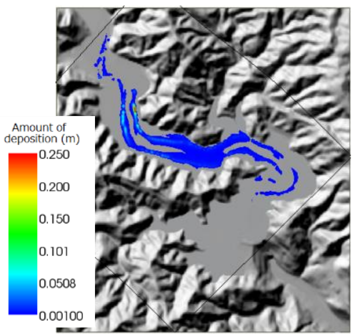
Aquatic ecosystems (2)

Simulation of Sediment inflow due to a flood event (Deposition of sand, silt, and clay 120 hr after the event)

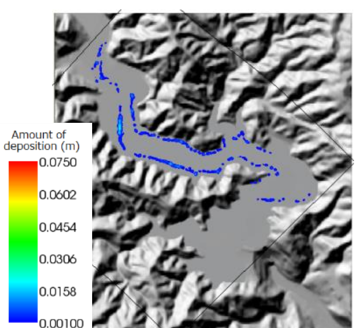
Sand



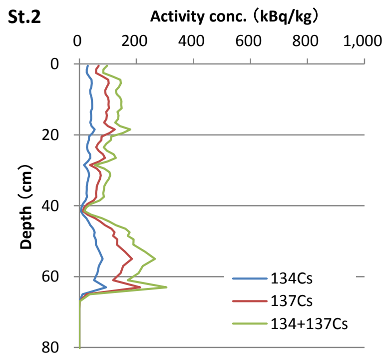
Silt

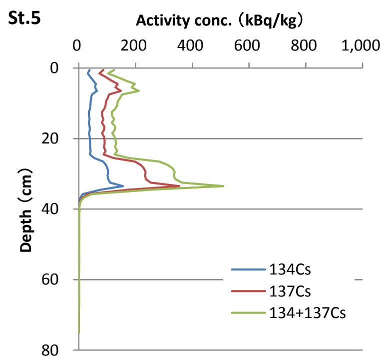


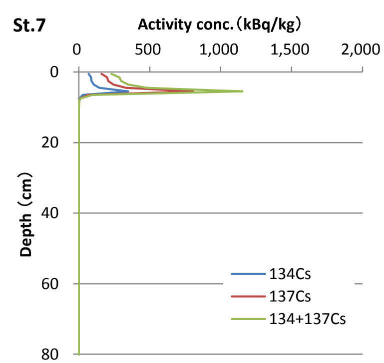
Clay

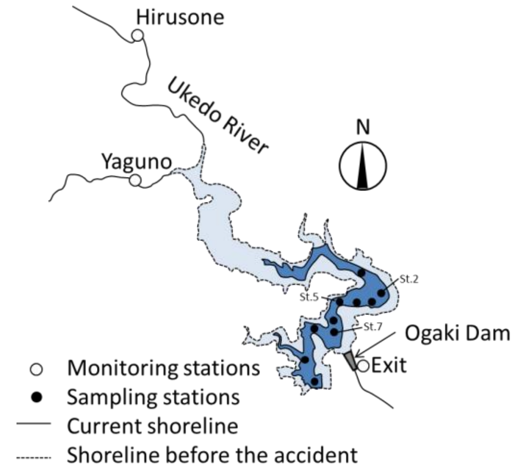


Observed Cs concentration in the sediment of dam lake

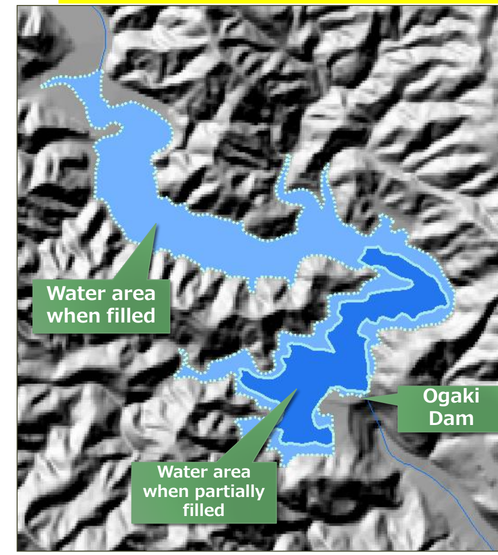








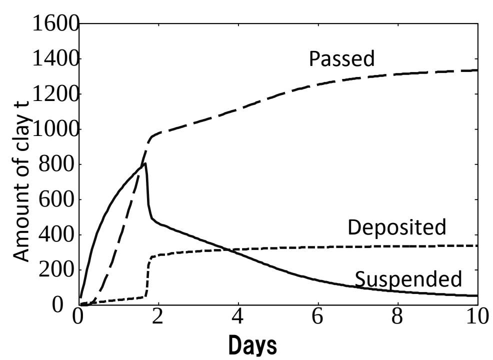
An example of water level management for dam lake to mitigate Cs transport to the downstream (Ogaki dam case)



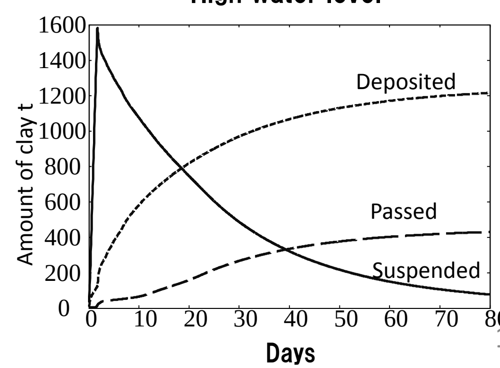
Simulating Ogaki Dam Reservoir for two different water level conditions

Clay behavior in low & high water level

Low water level



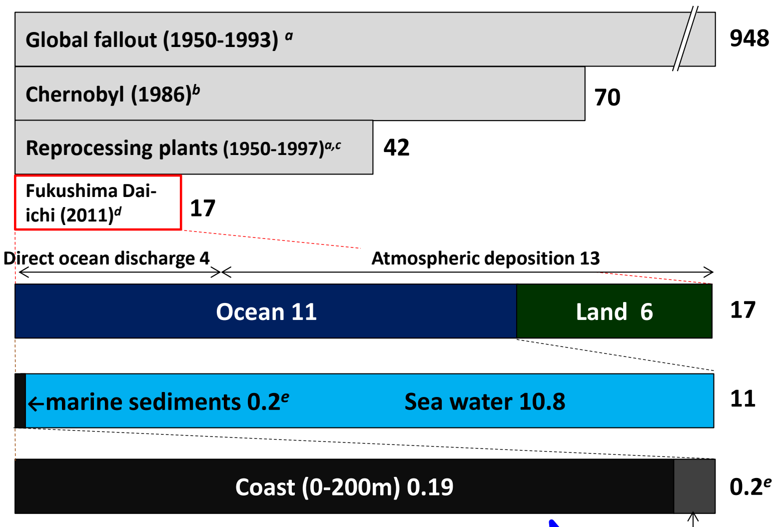
High water level



Radiocaesium accumulation in seafloor sediments (1)

^{137}Cs sources to the environment

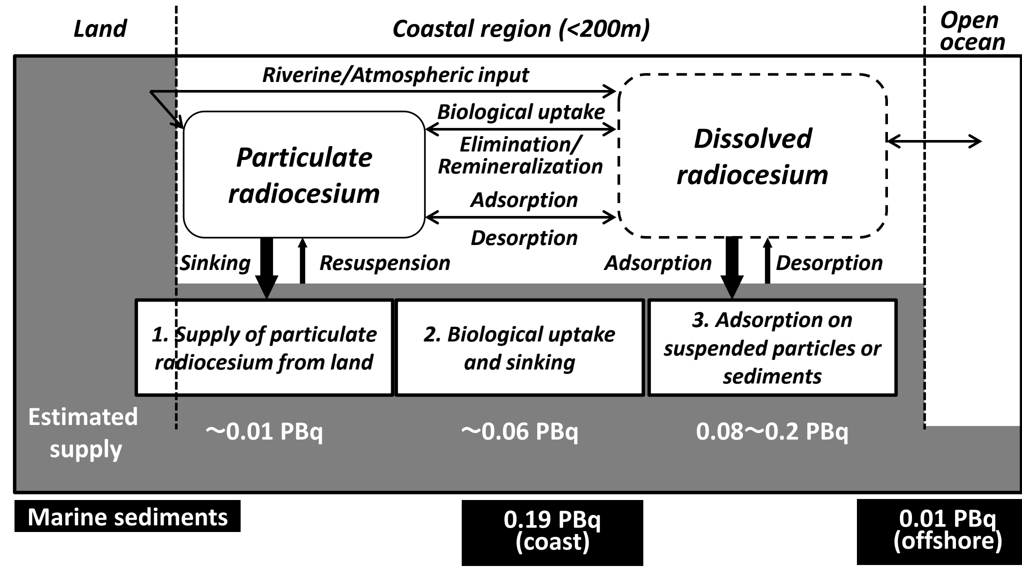
PBq (10^{15} Bq)



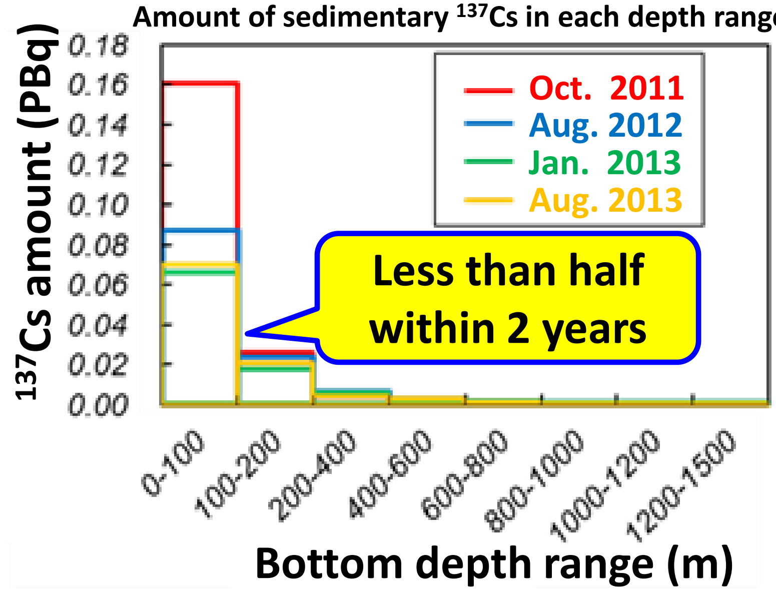
a UNSCEAR (2000)
b UNSCEAR (1993)
c Smith et al. (1993) J. Environ. Radioact. 68, 193-214.
d Kobayashi et al. (2013) J. Nucl. Sci. Technol. 50, 255-264
e Otosaka and Kato (2014) Environ. Sci.: Proc. Impacts 16, 945-1156

^{137}Cs inventory in coastal marine sediments is ~1% of the total released amount

Expected accumulation processes of radiocaesium in the coastal region

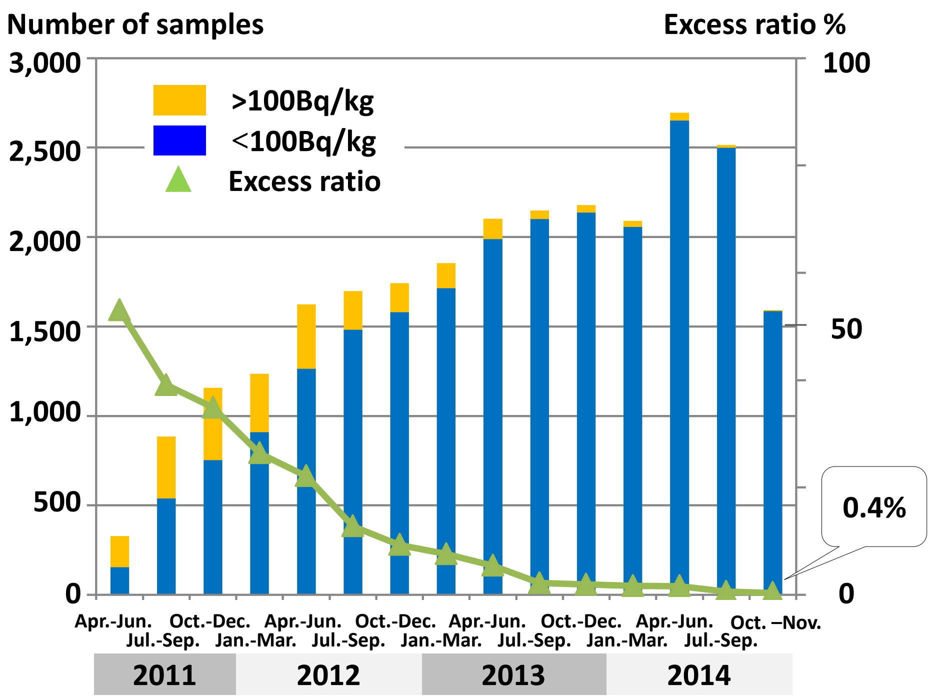


Amount of sedimentary ^{137}Cs in each depth range

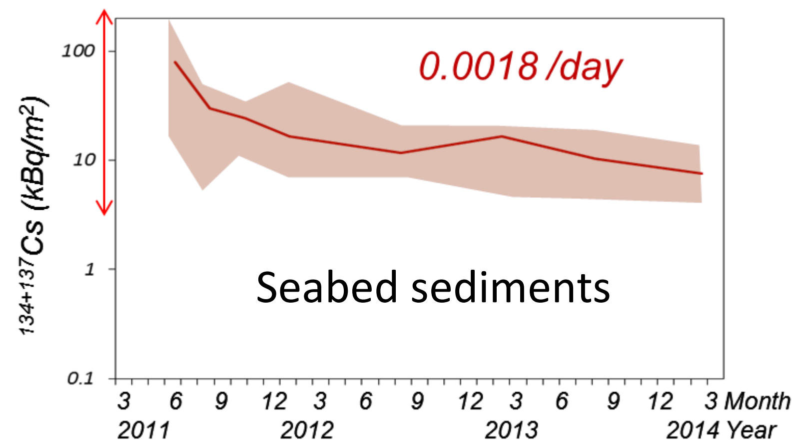


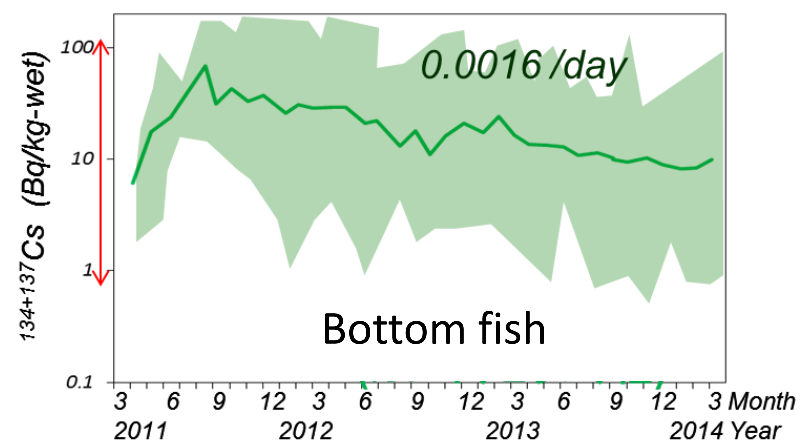
Otosaka (2014)

Radiocaesium accumulation in seafloor sediments (2)



Fisheries Agency of Japan (2014)



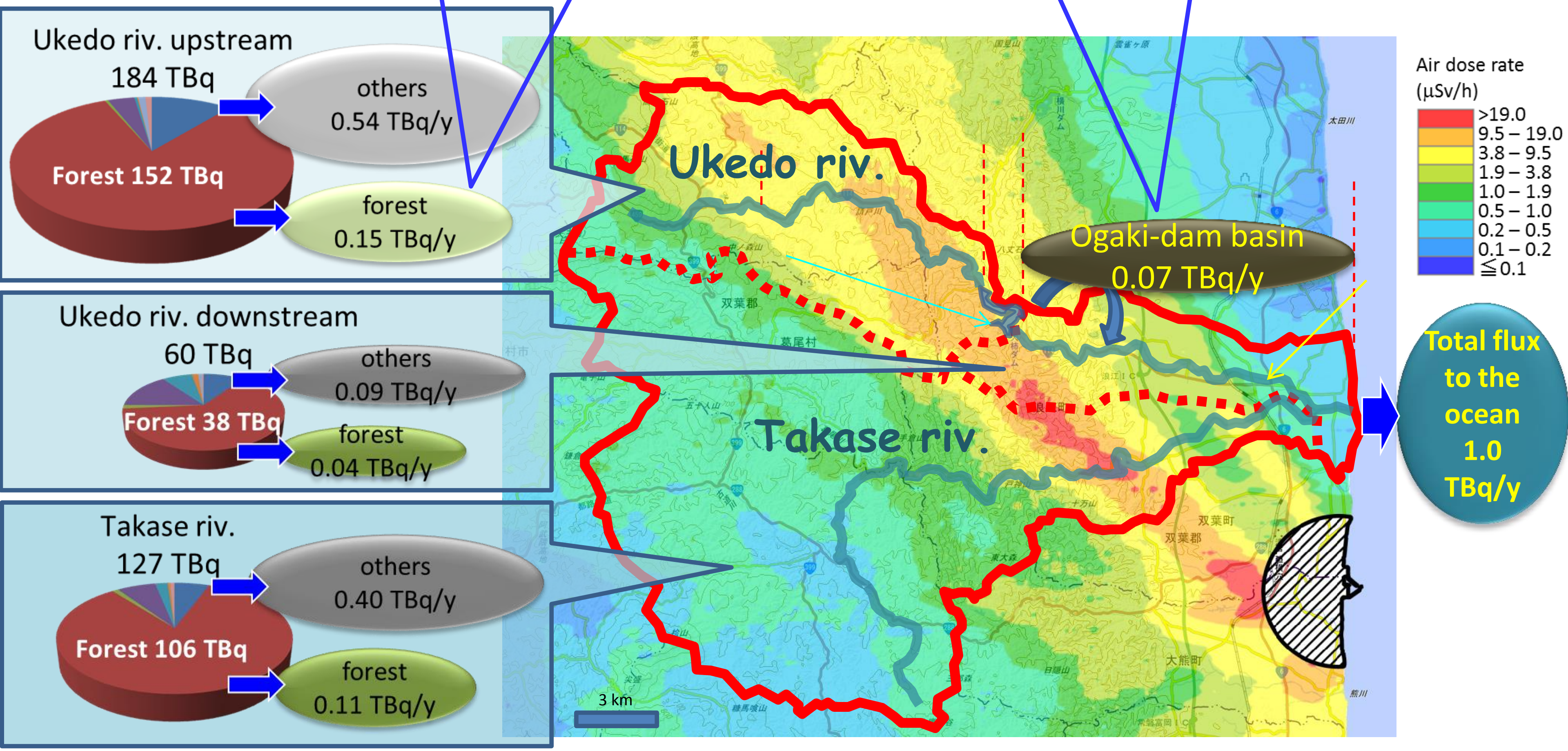


Otsaka(JAEA, 2013)

Overview of ^{137}Cs flux from each catchment of Ukedo River basin

Annual erosion rate of ^{137}Cs of the forest topsoil is around 0.1%

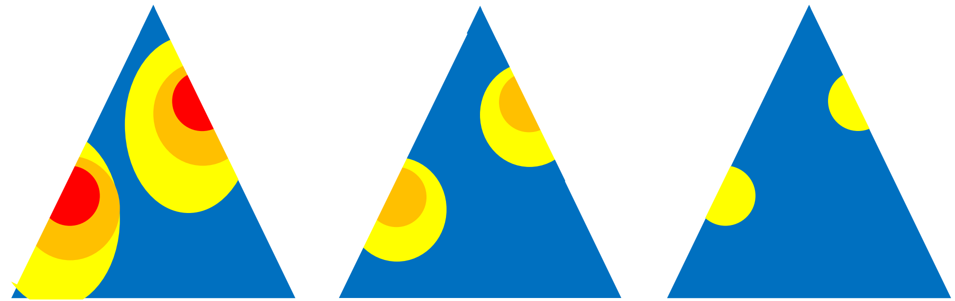
More than 90% of radiocaesium flowing into the Ogaki dam lake was sedimented in the lake



Forest management strategy

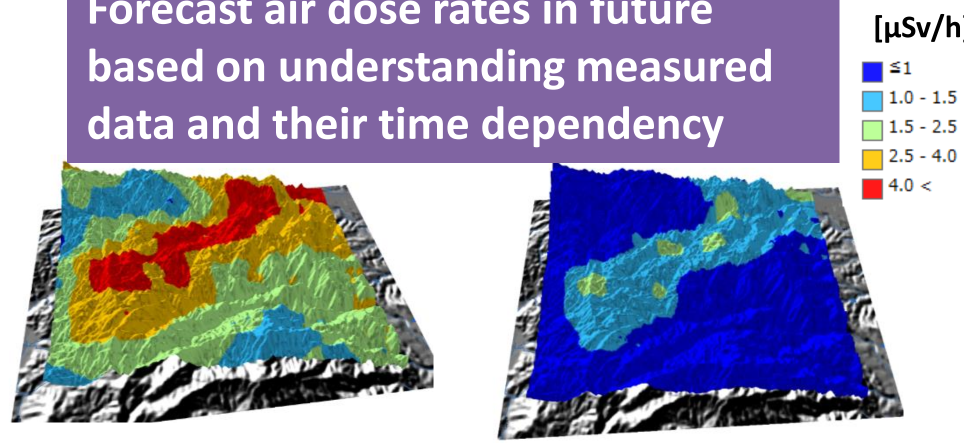
- Zoning for selecting appropriate countermeasures against heterogeneously contaminated mountanous forests
  - Efficient measurements of air dose rates in higher resolution using low altitude aerial survey
  - Forecast when restriction on the use of forest products can be lifted

An image of zoning



present | 10 years after | 30 years after

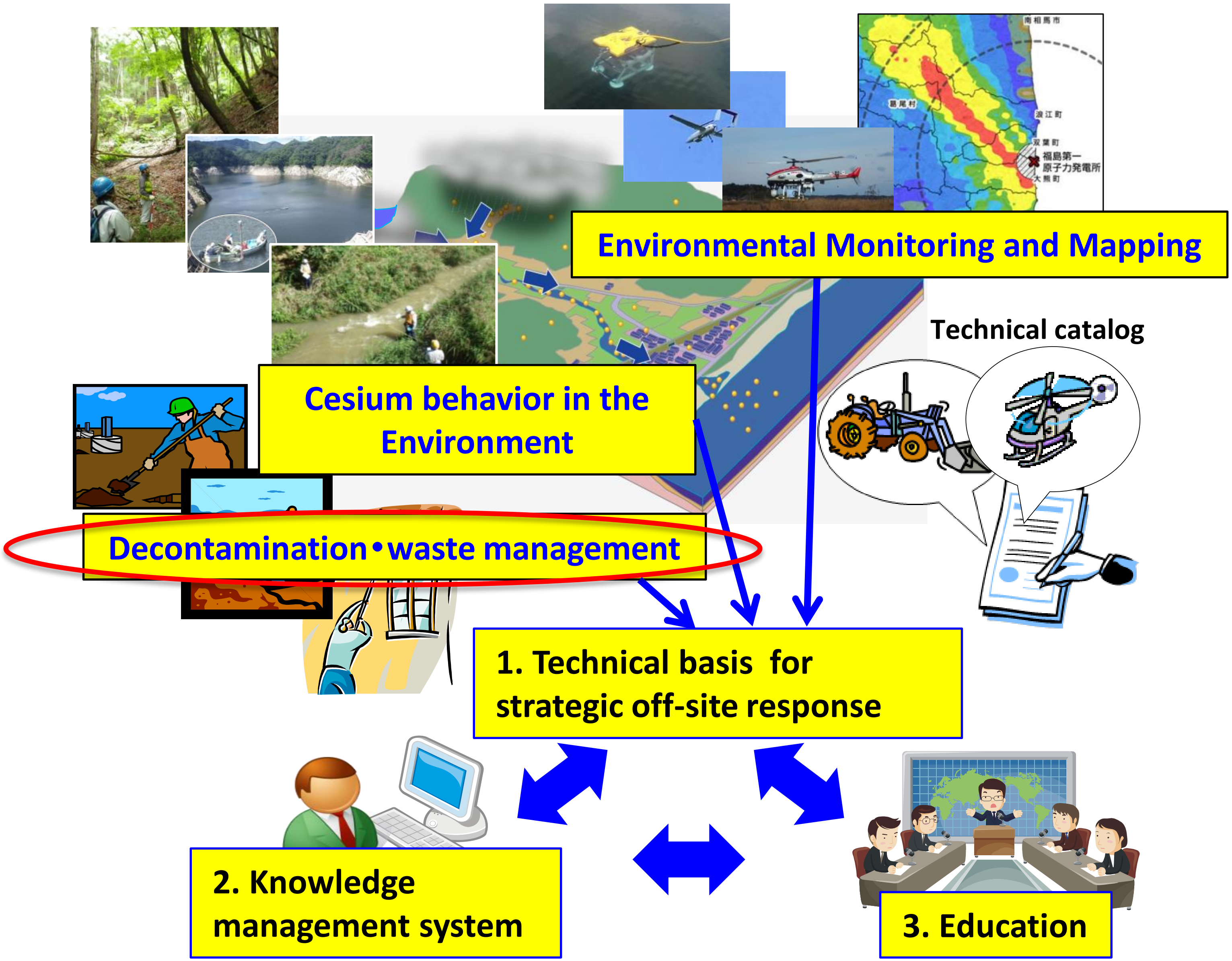
Forecast air dose rates in future based on understanding measured data and their time dependency



Nov. 2011

March 2016
（5 years after the 1F accidents）

Development of a technical basis for strategic off-site response



Waste management challenges

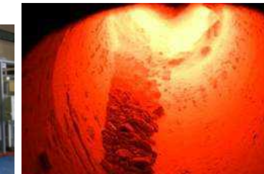
Soils & wastes

- Cs removed or reduced materials → Reuse
- Volume Reduction
- Cs accumulated materials → Final disposal

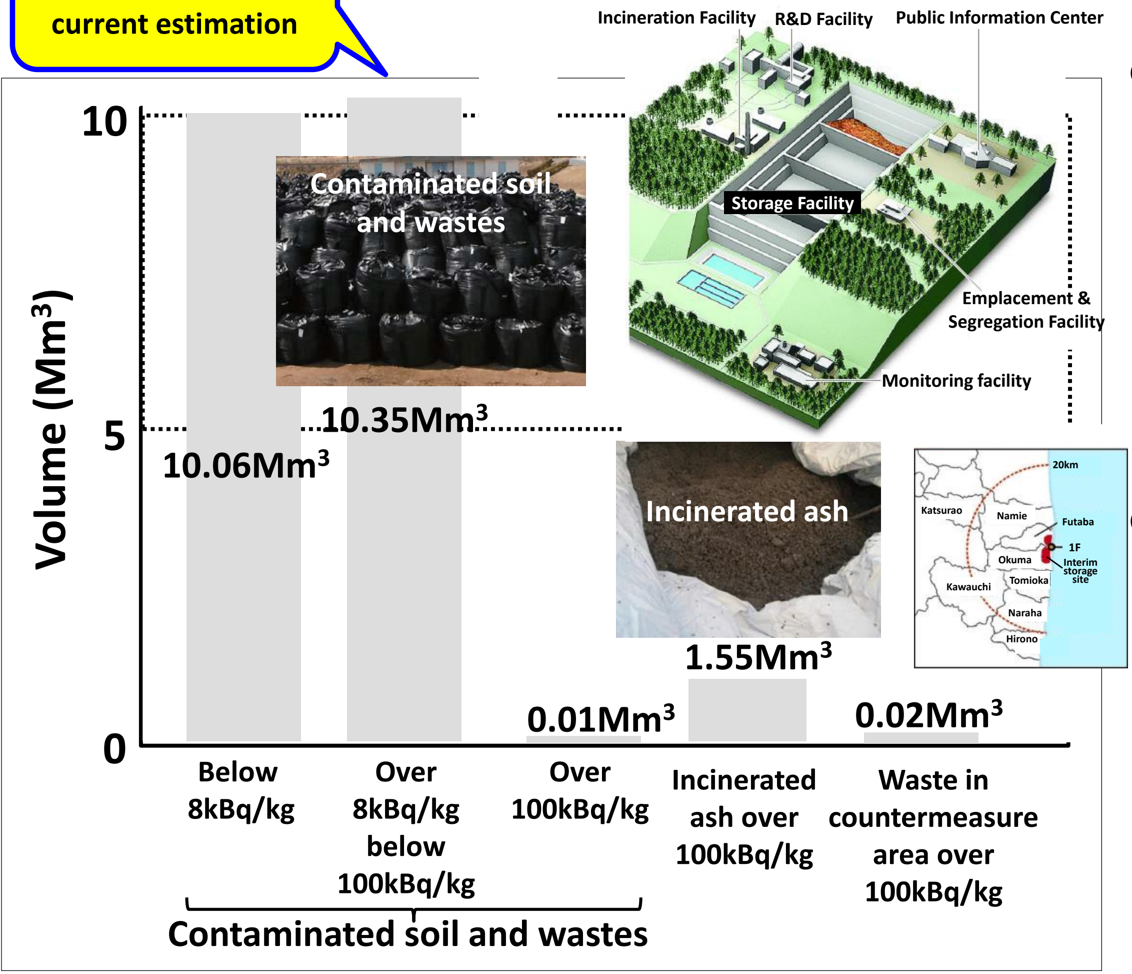
16~22Mm³
current estimation

Wet particle-size separation

Chemical treatment

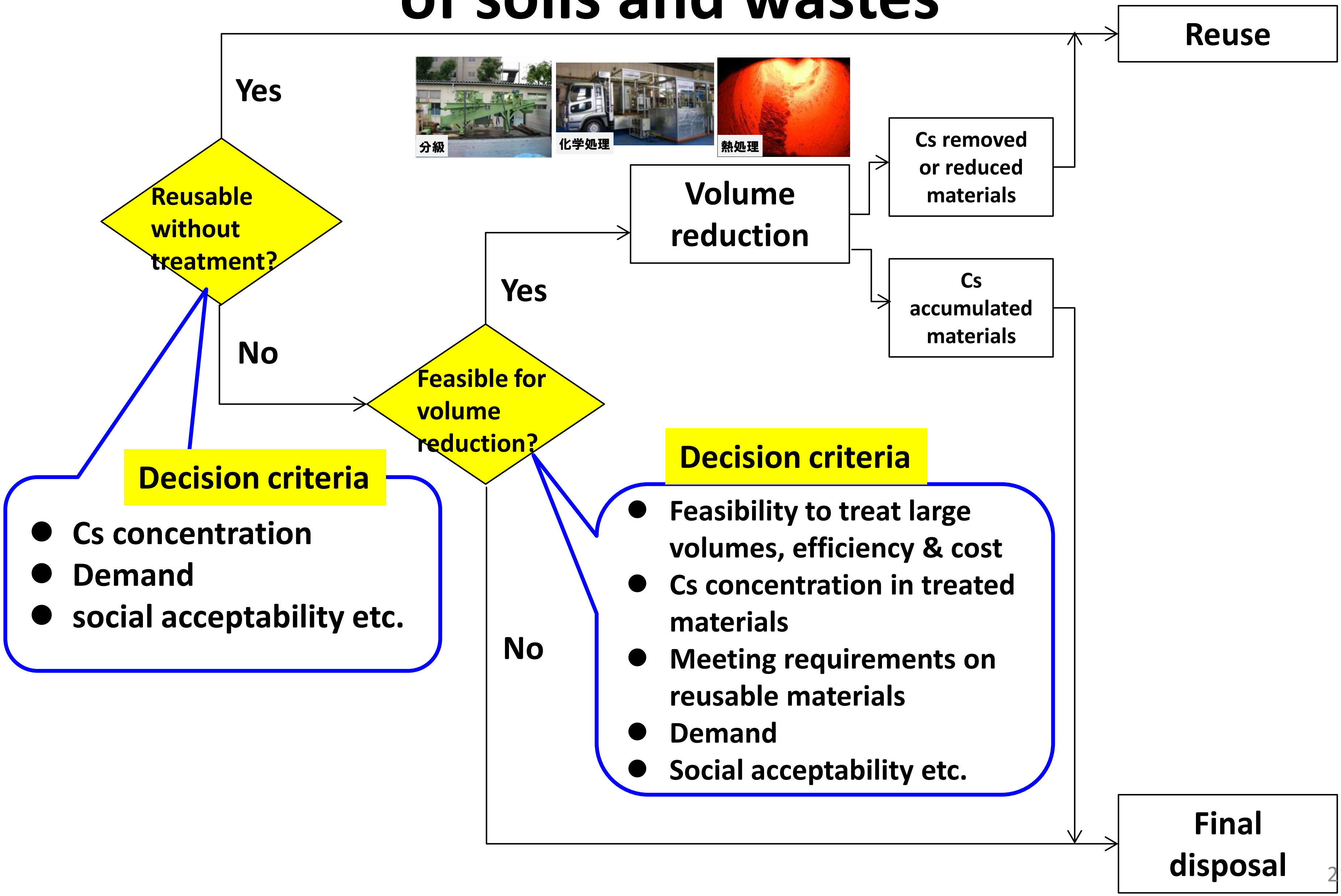


Heat treatment

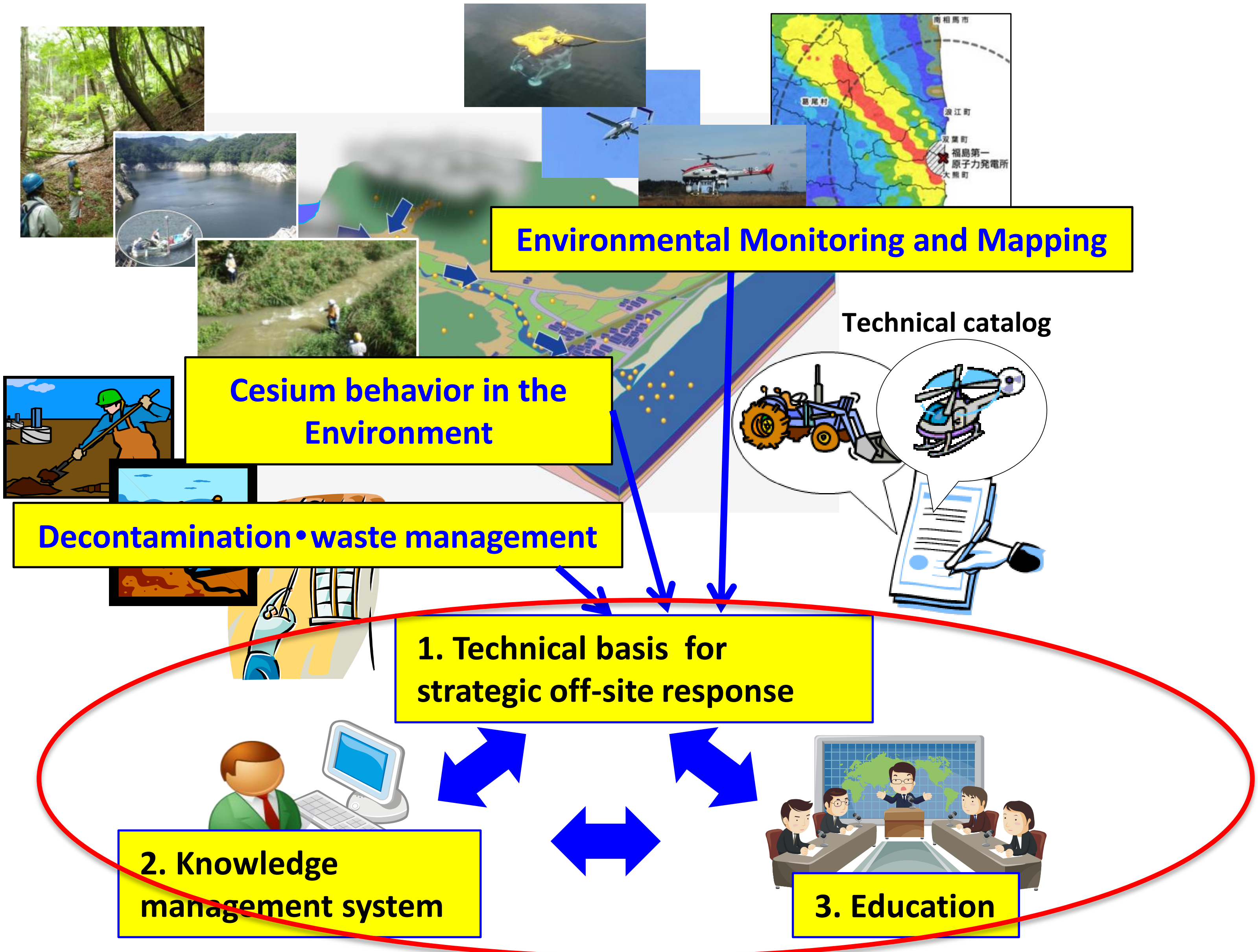


- Clean-up efforts are generating huge volumes of contaminated soil and waste, which must be managed in a safe and cost-effective manner, wherever possible implementing waste volume reduction
- Future reuse of soil for construction purposes is an important option, if constraints in terms of allowable organic and clay content can be managed

Decision tree for volume reduction and reuse of soils and wastes

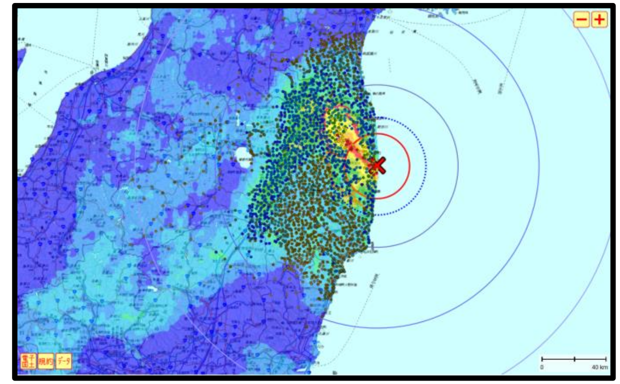


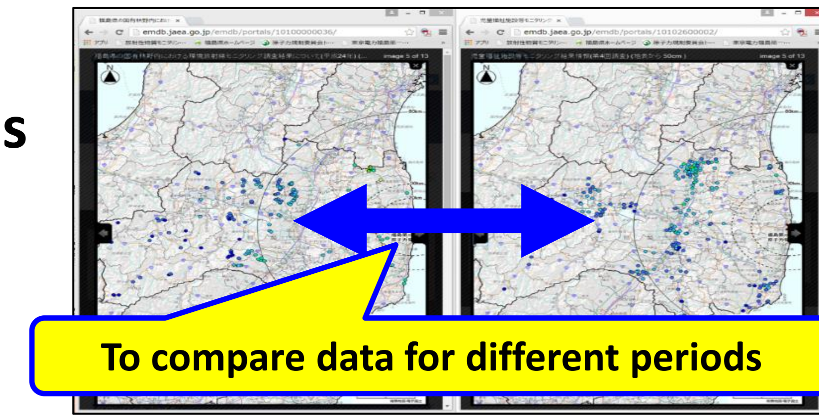
Development of a technical basis for strategic off-site response

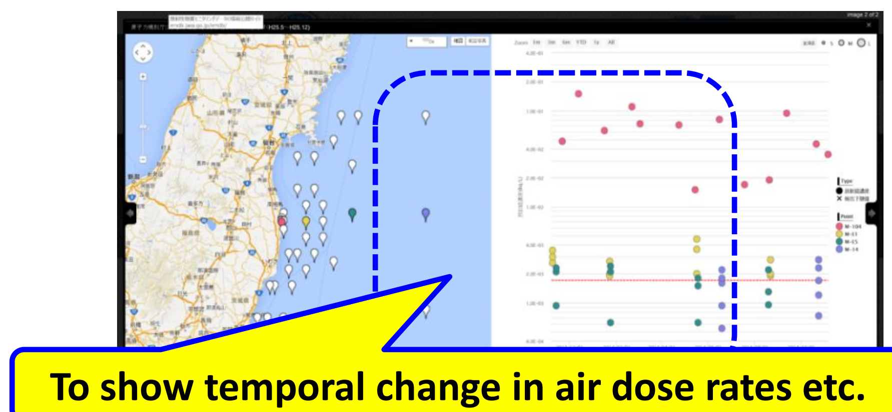


Publishing of Databases

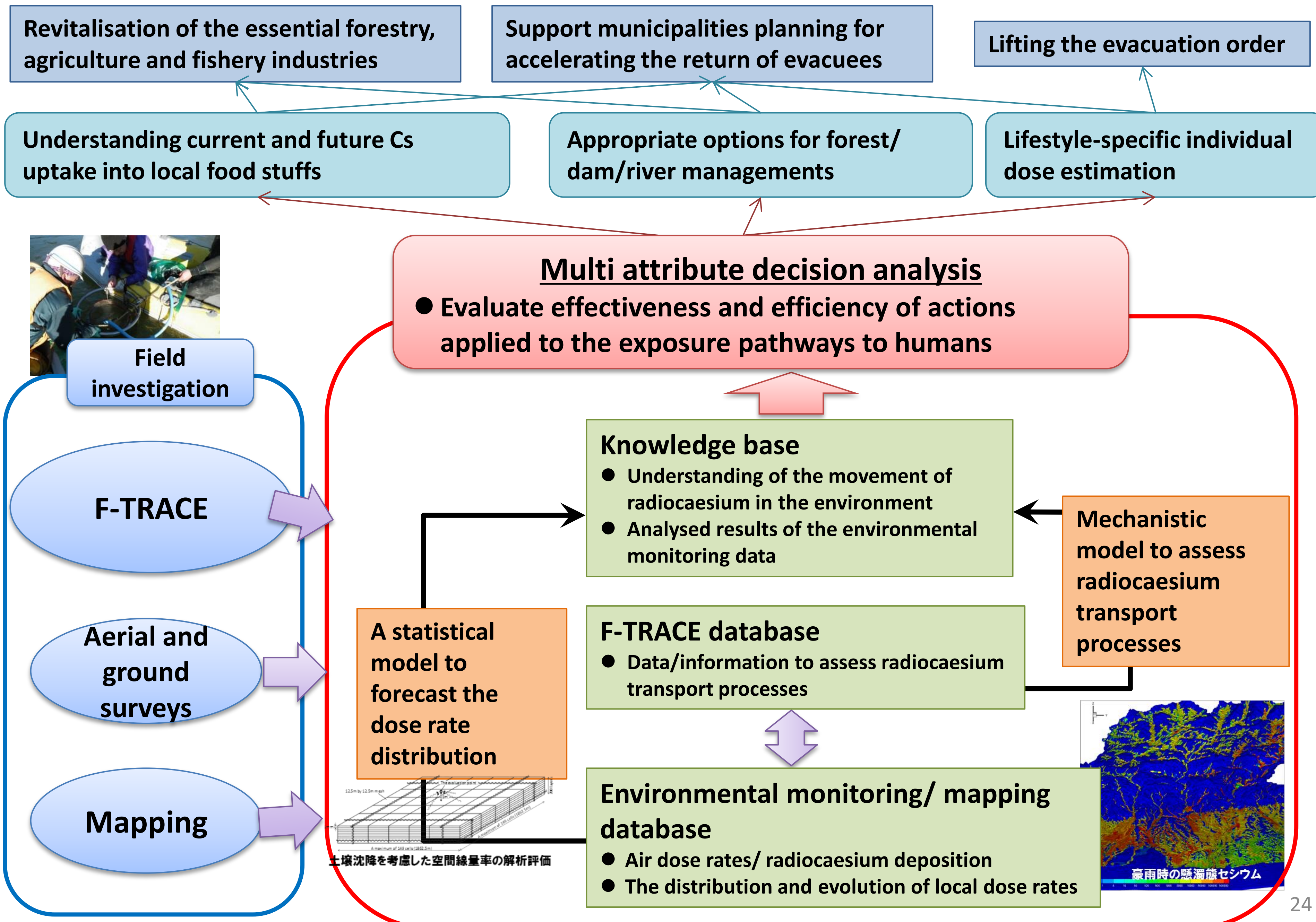
- **Distribution Map of Radiation Dose**
  http://ramap.jaea.go.jp
- **Database of Radioactive Materials Distribution**
  http://radioactivity.nsr.go.jp/ja/index.html
- **User-friendly tools for data analysis and visualisation**
  http://emdb.jaea.go.jp/emdb/







Integrated decision support system for appropriate remediation and management options



Development of a technical basis for strategic off-site response

Use of knowledge and experience gained from the Fukushima Daiichi accident to establish the technical basis for strategic off-site response

English report is available here

http://dx.doi.org/10.11484/jaea-review-2015-001