

# Science facing nuclear legacy

Towards an international approach for a scientific basis for decommissioning, waste management and decontamination

B. Grambow

SUBATECH – IMT Atlantique – University of Nantes, CNRS/IN2P3, France

# A planetary challenge

## Time

- Nuclear legacy sites since 70 yr (Hanford...), problem will not fade away in the next 70 yr
  - contaminated territories
  - decommissioning sites
  - waste storage...

## Complexity

- Unprecedented problems of handling high radioactivity at difficult accessible localities
- Strong coupling of large scale contamination, climate + natural bio-geochemical cycle, ...
- Science involved in all steps, but missing overall road map and long term vision and too little account for international and transdisciplinary dimension

## Planet

- Many ten-thousands of square km concerned: contaminated area, waste disposal sites..
- Environmental impact and extremely difficult remediation

## Prosperity

- Astronomic costs, opportunities for innovation
  - Loss of agricultural and fishing markets in Japan
  - waste management as bottle neck of nuclear industry

## People

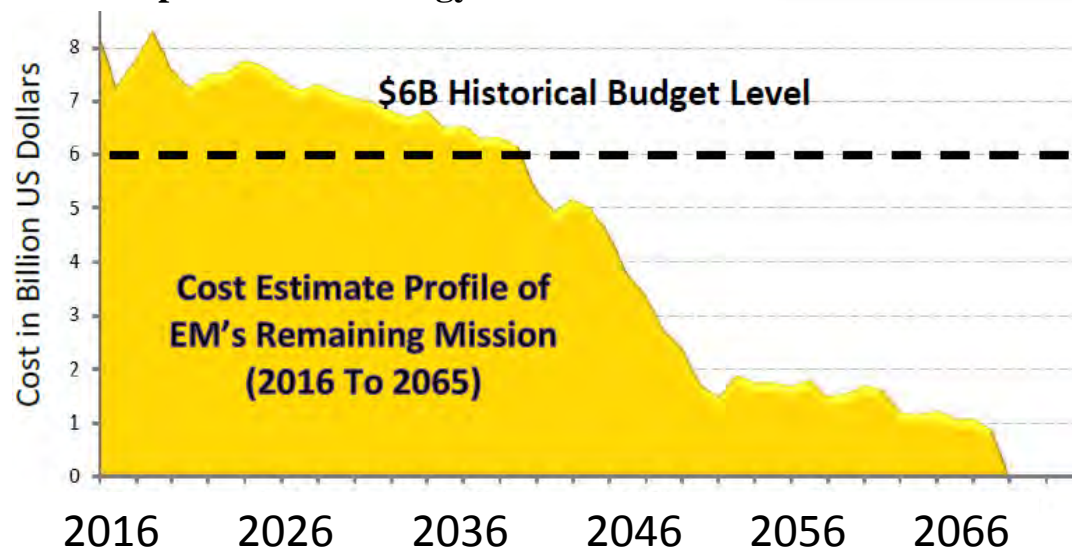
- 100000 evacuations due to radioprotection and health precautions
- Large concern and distrust, including in remediation strategies and measurements
- Business loss

The costs will be astronomical ... unless ways are found to do the job faster, cheaper, and better through technology.

- increase the budget used for science:
  - High impact technology development
  - Transdisciplinary science approach

Need for a « systems approach on nuclear legacy cleanup »

### SEAB Task Force Recommendations on **USA** Technology Development for Environmental Management to the US department of Energy



### **Japan Fukushima**

Financial Times March 6, 2016:  
**Annual costs since 5 yr**

#### **Cleanup:**

Decontamination: \$6,1B

Decommissioning: \$4,0 B

#### **Other costs:**

Compensation: \$11,0 B

Loss equity value \$23,4 B



# Example: Rocky Flats Cleanup and Closure Challenges seemed insurmountable 1995

- 21 tons of weapons-grade nuclear material; much of it improperly stored
- 30,000 liters of Pu and eU solutions in aging tanks and pipes, some leaking
- 15,000 m<sup>3</sup> of transuranic/transuranic mixed waste
- 100 tons of Pu residues with no treatment/disposal path
- The “the most dangerous building in the America”
- **1995 BEMR cleanup estimate, \$36B and 70 years to complete**
- **With scientific characterisation of particle transport (synchrotron) cleanup and closure was finished more than 60 years earlier and \$29 billion less than DOE’s 1995 estimates**



Slide from D. Clark, modified

A seminar in Nov. 2015 :

# THE CERN MODEL, UNITED NATIONS AND GLOBAL PUBLIC GOODS: addressing global challenges

- The United Nations Model and Sustainable Development
- The CERN model and climate related issues
- Presence of
  - Former french prime minister
  - Prof. Carlo Rubbia,
  - ICSU...



**UNOG**  
UNITED NATIONS OFFICE AT GENEVA



European Organization for Nuclear Research  
*Organisation européenne pour la recherche nucléaire*

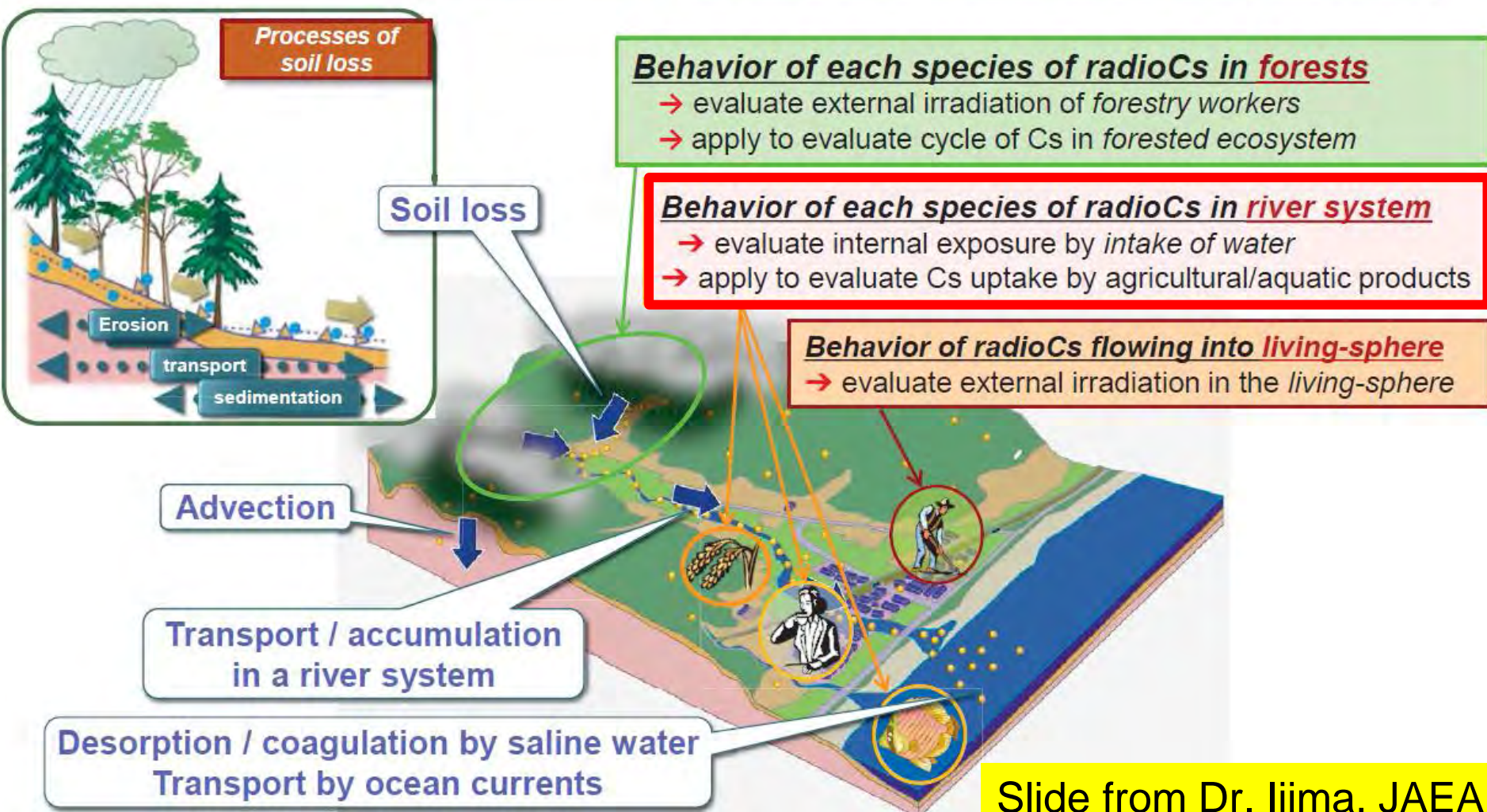


# Strongly coupled transfer processes: example

*Develop phenomenological models to describe quantitatively transport of radioisotopes(especially radioactive Cs) along water systems*

**Transport pathways & processes**

**Transport behavior of Cs to be modeled**



# Missing link between assessment of contamination and health

In Fukushima, whole body counters show 10 times lower Cs in humans than expected from equal soil contamination in chernobyl

## Nuclear medicine

*Empirical data: urines, blood...*

*Dynamic models:*

Bio-kinetic/ physiological based pharmacokinetic models (see ICRP100)

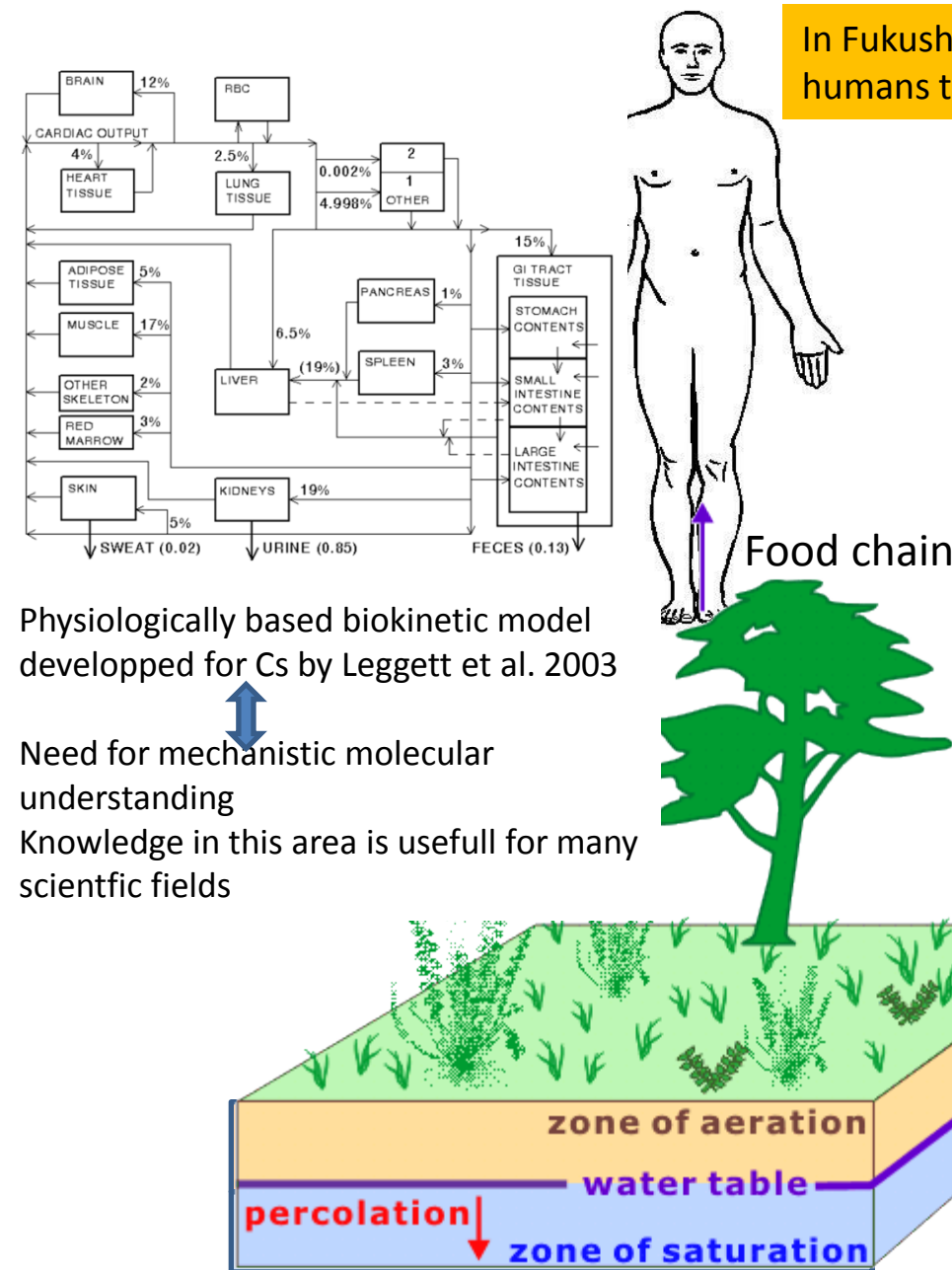
Too little interaction missing is a joint large scale studies including epidemiological perspectives

## Agricultural and Environmental radiochemistry

Distribution and fluxes of radionuclides between soils and water and food stuff in the environment

Molecular and large scale geochemical and transport models

Multiscale molecular metabolic flux "Soil/Plant model" i.e. linking K and Cs cycle,





## Systematic addressing local contaminant heterogeneity

## Quantify the fluxes in all types of matrices (ICP-LA)

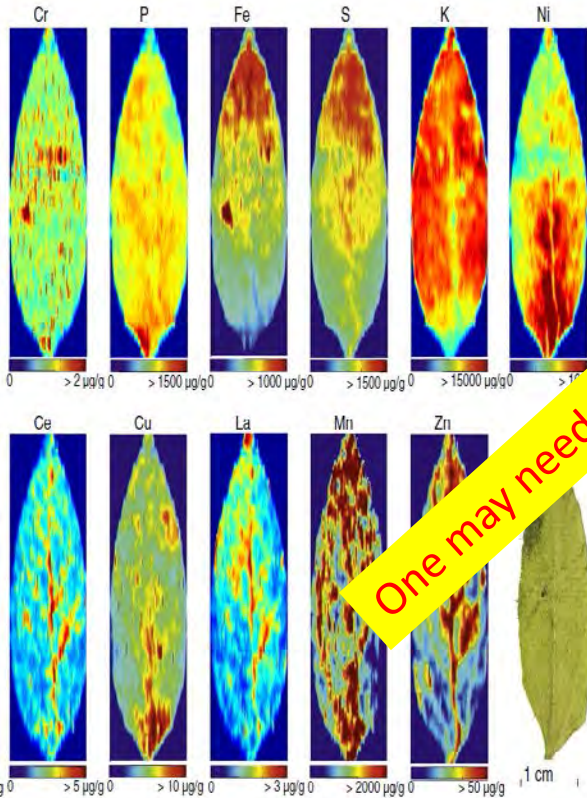
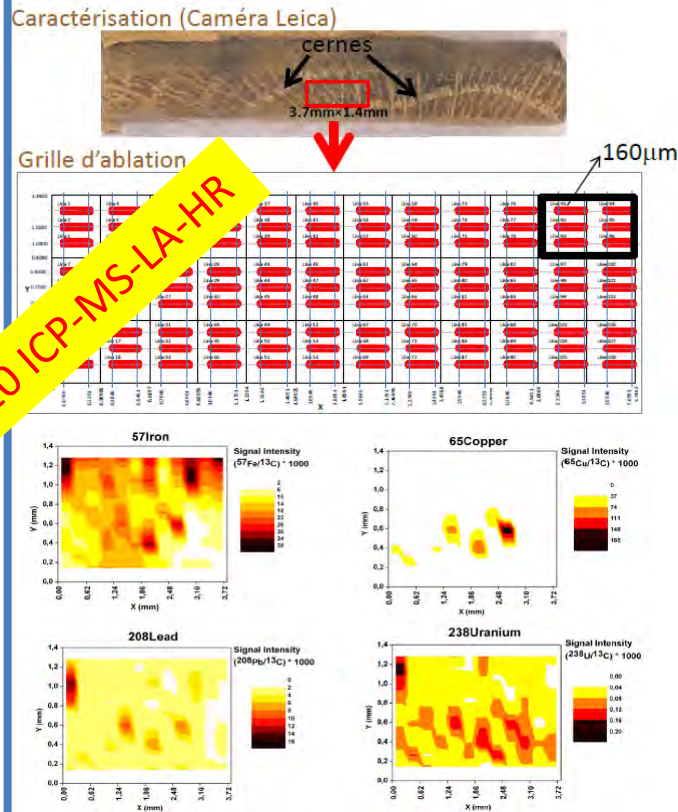


Fig. 2. Spatially resolved mapping of nutrients and toxic elements in the leaves of sunflower (*Helianthus annuus*).

Sunflower leaves, From: A. Kötschau et al., Microchemical Journal 110, 783 (2013).

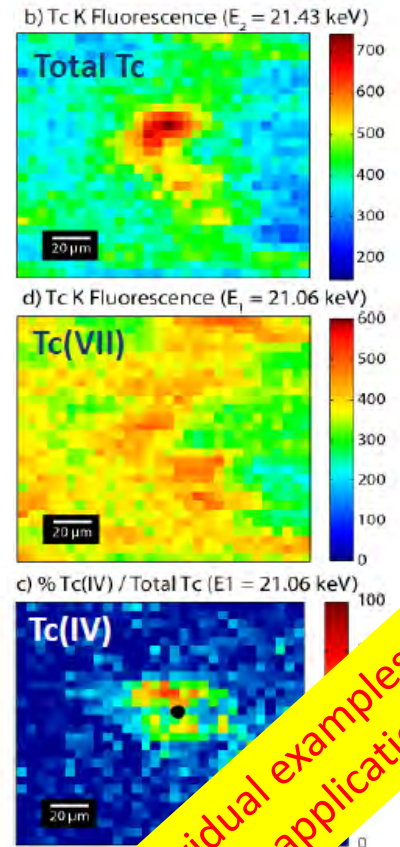
## The historical record of contamination (ICP-LA-HR)



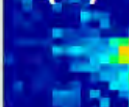
# Tree ring analyses of U from K. David, SUBATECH

Redox state distribution of contaminants ( $\mu$ -XRF, synchrotron)

(Tc(VII)=soluble, Tc(IV)= insoluble)



C. Corkin, *Journal of Experimental Psychology: Applied*, 2004  
conflict of interest statement (10/10/2015)



From individual examples  
systematic application

Cork  
epnet  
(5/10/2015)



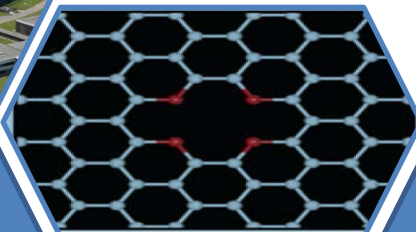
# Proposition for an integrated programming of cleanup research

- Cleanup is national, the underpinning science and observatory program is universal
  - Create a **scientific toolbox and observatories** to help national programs
- A shared **transdisciplinary research agenda** from molecular level to territory, from physics, geosciences to agriculture, health, economics
- Under the auspices of ICSU
- Internationally accessible research sites in one or more associated centers for the science of nuclear legacy cleanup (in Japan? others...)
  - Collaborative International Laboratories for Advanced Decommissioning (and decontamination?) Science (JAEA...)
  - Virtual institutes
  - Characterization and decontamination techniques at central and local places
  - Organizing simple access to students... (including financing exchange schemes)
- An observatory mission
  - Evolution/prediction of degree of contamination/risks
  - Links to GEO, WHO...?
- Accessibility of trusted large quantity high quality analytical data (CODATA, WDS...)
  - Big data enabled discovery
- A central place for education and capacity building
  - Attractive to the brightest students
- May include a citizens science approach to cover a 10-100 km scale territory
- Spin-off for other fields of transdisciplinary knowledge: resources, energy, climate, food security...

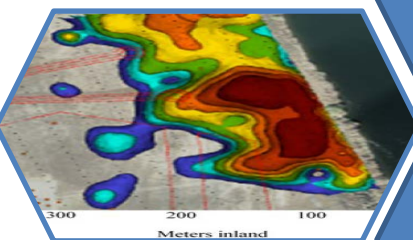
# Basic research needs



New methods for **mapping of radionuclide distribution** and effectiveness of remediation in selected contaminated territories from molecular scales to macroscopic heterogeneity.

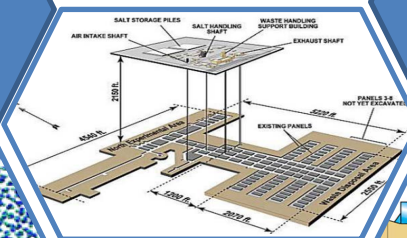
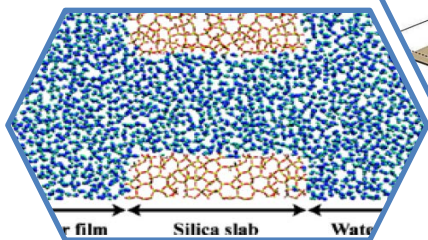


Analyses of **chemical speciation** of actinides and other radionuclides and bio-geochemical mechanism governing distribution e.g. considering large scale oxidation state mapping.

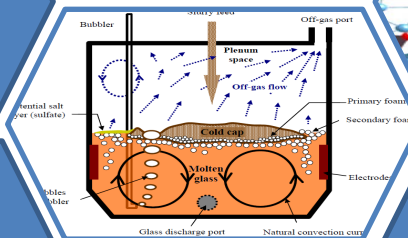


Improve predictive physical chemical **site evolution models**, considering erosion, multi phase transport and deposition of radionuclides along heterogeneous soil and water pathways to and among living systems

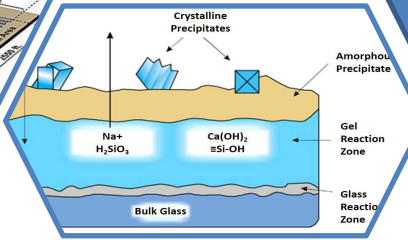
Scientific base for effective **remediation strategies** for multiple contaminants, considering the complex relationship between biological, chemical, hydrologic, and geologic effects.



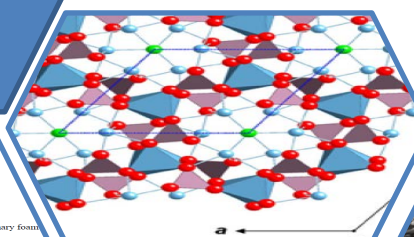
"**Big data**"-enabled scientific discovery, correlating disparate datasets to span broad temporal and spatial, far from equilibrium regimes and develop strategies passing from short term lab tests to long term massive real systems



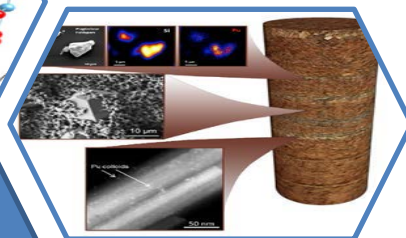
Integrated theoretical and experimental approach to new **waste forms**, considering pro-cessing schemes, radiation, composition, hierarchical structure (atomistic, mesoscale, grain boundaries, continuum...) and long term performance.



Extensive employment of ICPMS-HR-LA, neutron sources, X-ray light sources, electron microscopy centers, radiological user facilities, **high-performance computing, and nanoscience facilities**

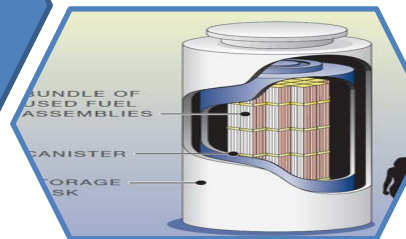


New generation of extremely selective **separation materials** with specific supramolecular architectures to yield materials with tailored pores with high performance lifetimes in extreme environments (radiation...) and recyclability



New methods characterizing **fuel debris** and developing **decommissioning strategies** by combined analyses of various indicators, experimental simulation and advance accident codes

Scientific base for **waste management**, from remediation to waste treatment and final disposal considering safety functions, margins, uncertainties and demonstrability



# Science in a collective process of learning from disaster



Adapted from: S. Cornel et al; « Opening up knowledge systems for better responses to global environmental change », Environmental science & policy 28 (2013) 60 – 70



### Coordination/exchange

- Conferences
- Meetings
- Governance



### Global Strategic research agenda

- Scientific bottle necks
- Priorities
- Research planning



### Outreach

- Policy briefs
- Research articles, reports...
- News papers



### Capacity building

- Ability to ask the right question
- Ability to interpret
- Ability to react



### Collective problem framing

- Civil society
- Business
- Science funders

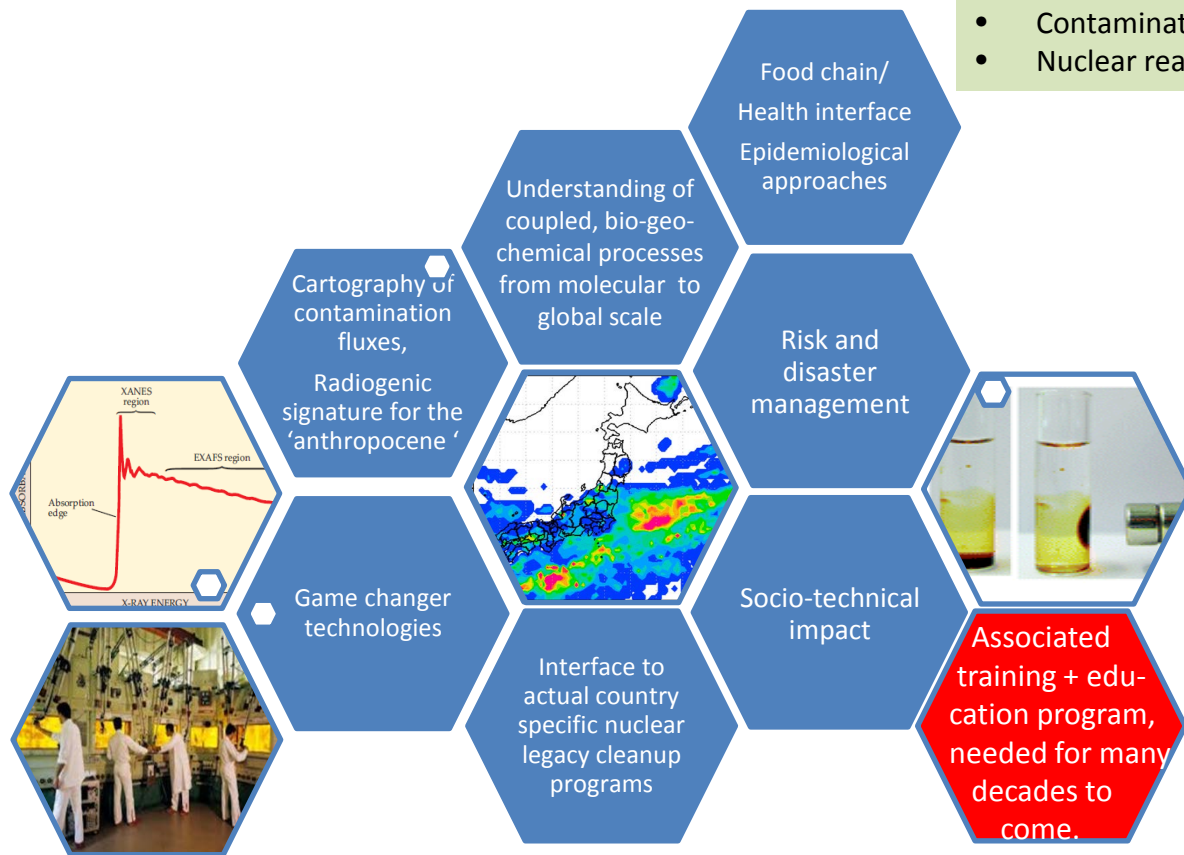


### Intl. Conference on radionuclide migration

# Science facing nuclear legacy cleanup

## Perimeter:

- Decommissioning
- Nuclear waste management
- Contaminated territories
- Nuclear reactor debris



## Countries

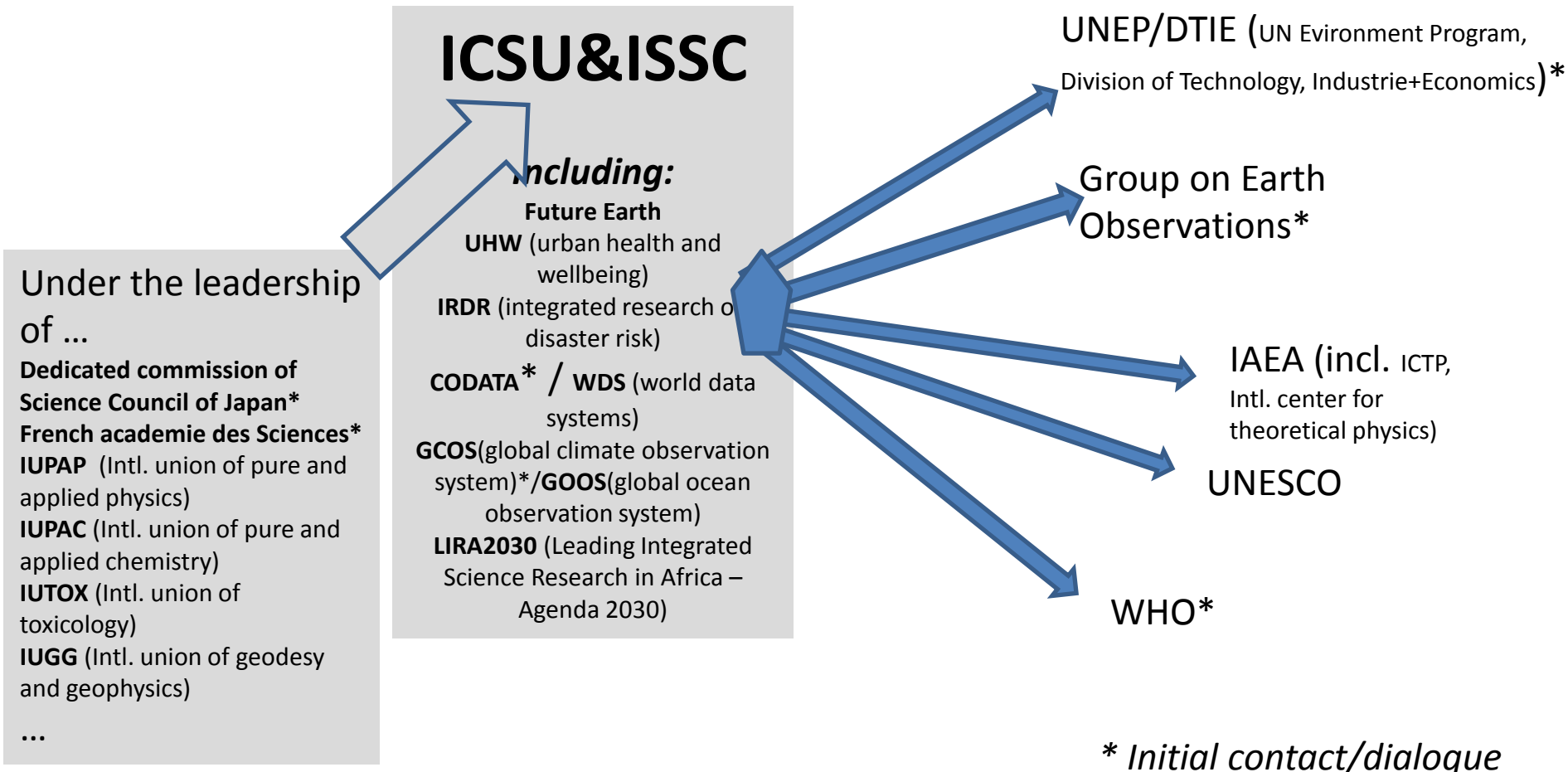
	Japan	Germany	US	France	Belgique	EU
Attention: red items not confirmed yet	<ul style="list-style-type: none"> <li>• Future Earth?</li> <li>• JAEA</li> <li>• Science Council</li> </ul>	<ul style="list-style-type: none"> <li>• DFG?</li> <li>• Helmholtz association: NUSAFE</li> </ul>	<ul style="list-style-type: none"> <li>• DOE-OS</li> <li>• NAS</li> <li>• Mc Arthur fundation?</li> </ul>	<ul style="list-style-type: none"> <li>• Académie des Sciences</li> <li>• CNRS</li> <li>• CEA</li> <li>• IMT</li> </ul>	<ul style="list-style-type: none"> <li>• SCK-CEN</li> </ul>	<ul style="list-style-type: none"> <li>• JRC</li> </ul>
	<ul style="list-style-type: none"> <li>• Collaborative International Laboratories for Advanced Decommissioning (and decontamination) Science</li> </ul>	<ul style="list-style-type: none"> <li>• nuclear laboratories, hot cells, advanced spectroscopies</li> </ul>	<ul style="list-style-type: none"> <li>• Advanced light sources</li> <li>• ...</li> </ul>	<ul style="list-style-type: none"> <li>• Hot laboratories</li> <li>• Modelling</li> <li>• Light sources</li> </ul>		<ul style="list-style-type: none"> <li>• Hot laboratories</li> <li>• Minor actinide lab</li> </ul>
	<ul style="list-style-type: none"> <li>• Fukushima debris and territory</li> </ul>	<ul style="list-style-type: none"> <li>• Nuclear Waste legacy, disposal</li> <li>• Reactor decommissioning</li> </ul>	<ul style="list-style-type: none"> <li>• Hanford, SRL, Idaho...</li> </ul>	<ul style="list-style-type: none"> <li>• Ancien uranium mines</li> <li>• Nuclear Waste Legacy</li> <li>• UP1 cleanup</li> </ul>		<ul style="list-style-type: none"> <li>• JRC sites</li> <li>• Sellafield</li> </ul>



# Why to build the project at international level?

- International bodies have little capacity to finance
- Many international or bilateral collaborations exists and there shall be no competition with the proposed initiative, but synergies
- The interest for involving international institutions is
  - Acknowledge that this is one of the worlds larges problems to solve, equally in importance to climate research
  - Acknowledgement that solutions will take 50 yr or more on a world wide level
  - Collaboration on common scientific questions
  - Create complex systems understanding of high international visibility of large impact in other fields of knowledge
    - Transparent to external users
    - Databases
    - Models and their couplings
  - Credibility and trust building,
  - Increase attractiveness for brightest students to assist in a world leading edge initiative
  - Well established and financed structure for exchange of students, professors...
  - Well established and financed structure to organise abundant access to the worlds most advanced analytical techniques
    - MC-ICP-MS, AMS, light sources...

# Towards a Global Partnership on Cleanup Science (“CleanuPartnership”)



# Some steps forward:

- US: PNNL engagement by the IDREAM (Interfacial Dynamics in Radiation Environments and Materials) , an Energy Frontier Research Program recently funded by the US DOE
  - support of our initiative by IDREAM director Prof. Sue Clark
  - <https://science.energy.gov/bes/efrc/centers/idream/>
- Europe: JRC: inclusion in programming for next years
- Germany: inclusion in HGF program NUSAFE
- France:
  - January 5<sup>th</sup>, 2017: Letter of support by the high commissioner on nuclear energy
  - January 12<sup>th</sup>, 2017, Positive position of the governing office of the French Academy of Science:
    - Question of Academy: should this be an IAEA activity or an ICSU activity:
    - One will probably ask ICSU to evaluate the possibility to include it in the next activity plan under discussion
- ICSU EB January 17<sup>th</sup> 2017: invitation to make a proposition for a joint program, including a budget, the proposition can be formulated by the consortium of all interested parties
  - **Possible contribution in program formulation by SCJ?**
  - B. Grambow will make a presentation in front of ICSU the 24<sup>th</sup> and 25<sup>th</sup> of April
  - Financing may cover operation of an international network, but certainly not of research
- February 9-10: french/japanese REIMEI workshop with discussion on setup of cleanup programme
- Financing of research by national calls or other national foundations?

**Towards an international approach for a  
scientific basis for nuclear legacy cleanup  
proposal for CleanuPartnership**