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Environment-2013
Ecology and Sustainable Development
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EURO ASIA ECONOMIC FORUM

Long-term effects and remediation after a major nuclear accident

Rolf Sjöblom

Luleå University of Technology /
/ Tekedo AB

TEKEDO

LULEÅ UNIVERSITY OF TECHNOLOGY

Current strategy for safe and sustainable nuclear power

- Safe operation of nuclear power plants
- Responsible waste management
- Robust financing for nuclear liabilities
- Emergency preparedness (in case an accident might occur nonetheless)

- BUT:
  - what about after the emergency stage?
  - Are there time and planning constraints?

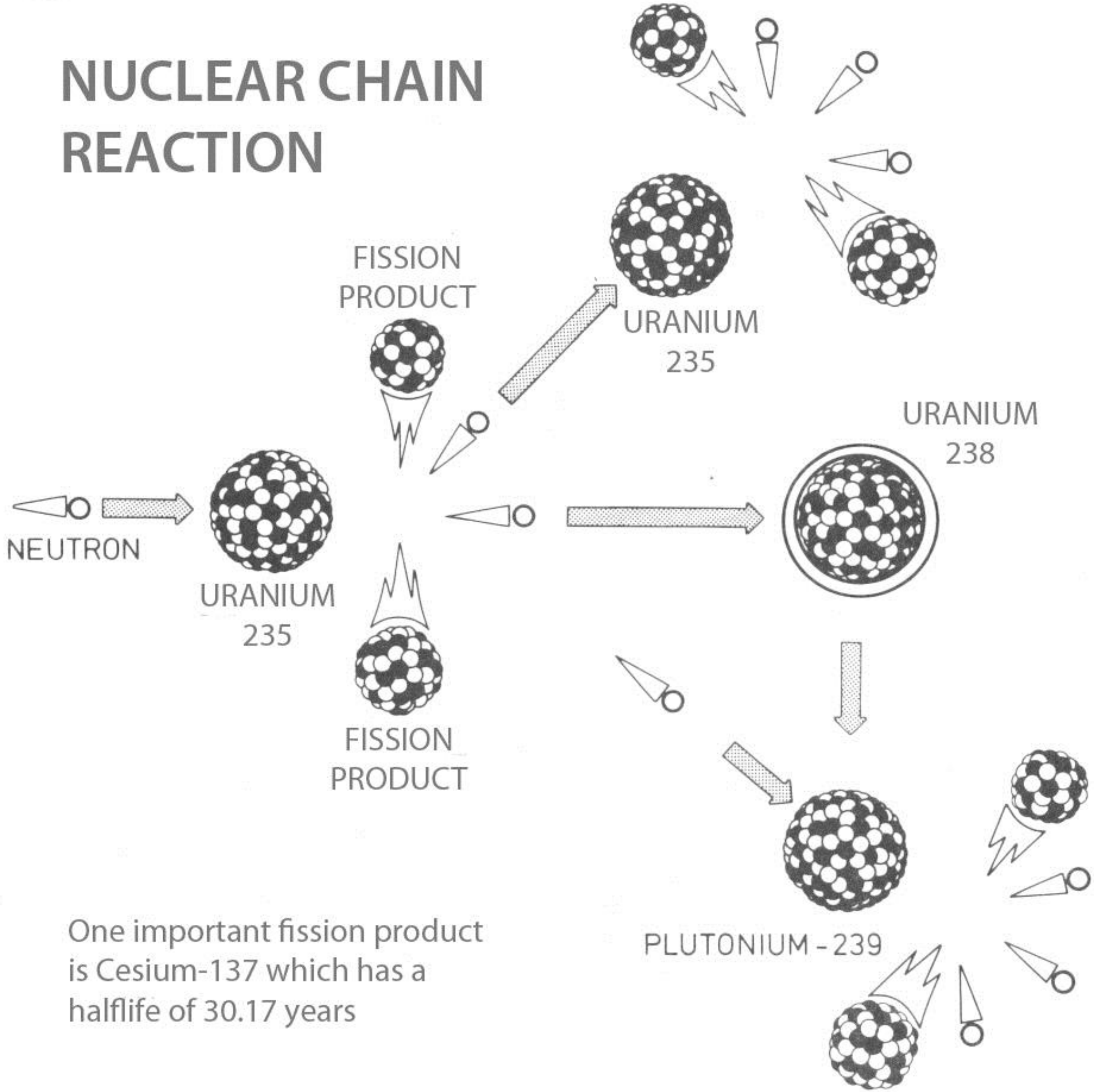
Issues that may warrant special attention

- Old disasters and early lessons learned
- Geographically and culturally remote experiences
- Experiences from other areas of science and technolgy
- The issue of chemical reactions that take place over long times (e g longer than it normally takes to do a doctoral study)

Purpose & objective

- To briefly describe
  - The Fukushima accident
  - The environmental impact & work towards remediation
- To share experiences on clean-up of contaminated reactor systems
- To analyse – based on previous experiences – the following options for contaminated soil
  - Encapsulation
  - Stabilization

NUCLEAR CHAIN REACTION



One important fission product is Cesium-137 which has a halflife of 30.17 years

Modified after a figure in the AKA public investigation SOU 1976:30-31

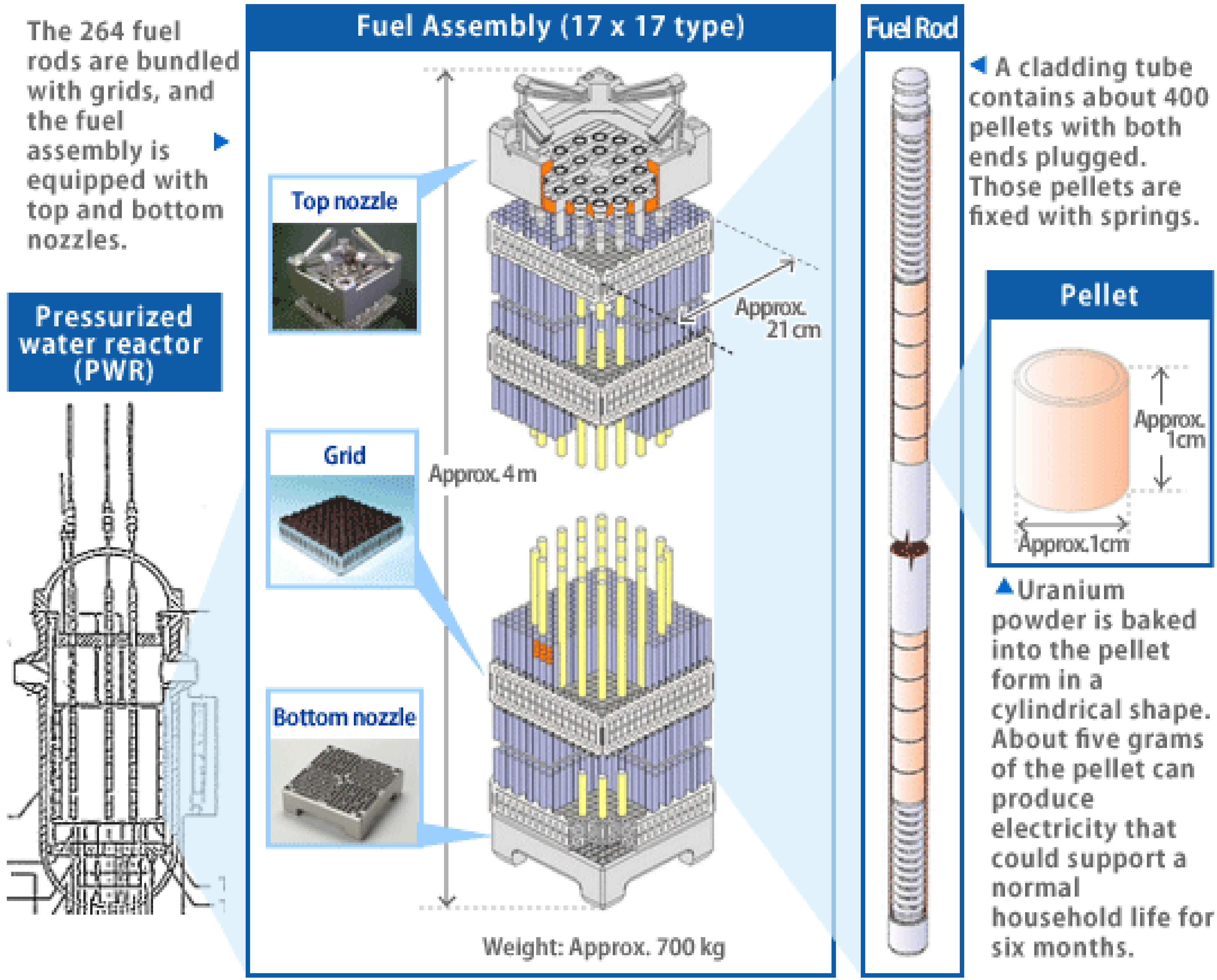
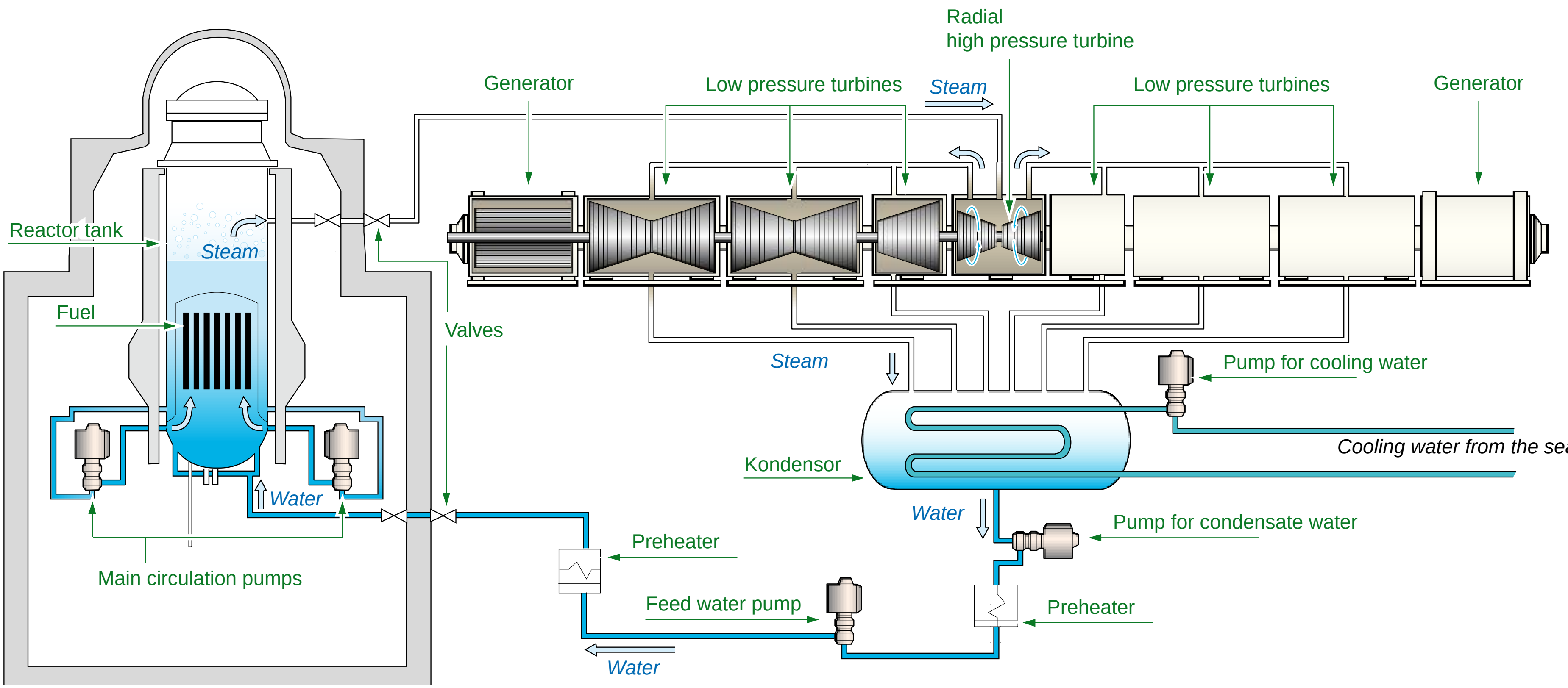


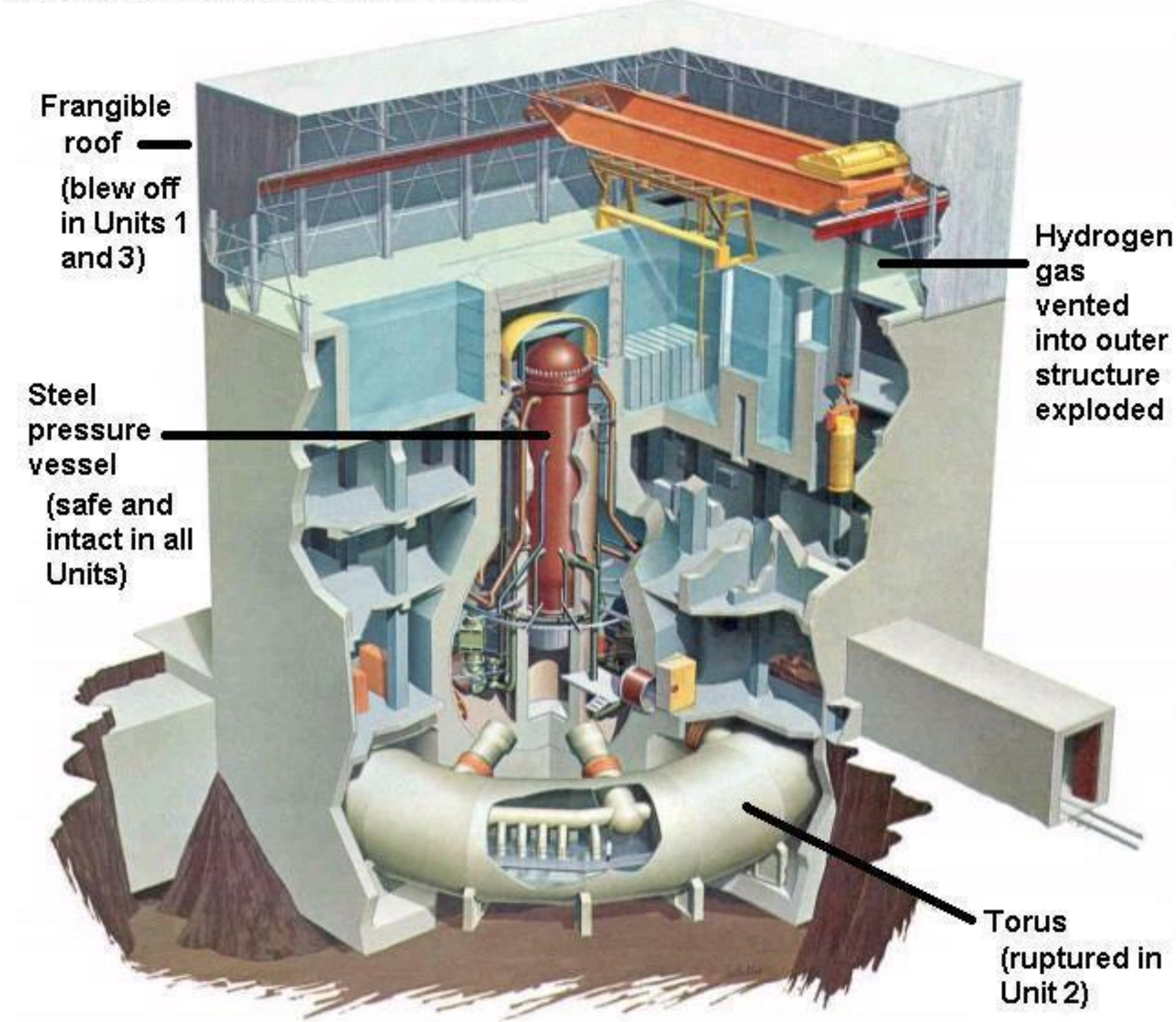
Image from Nuclear Fuel Industries, LTd.



Operating principle of a Boiling Water Reactor (BWR)

image modified after a drawing at the webbsite of OKG AB

Anatomy of Fukushima Daiichi blasts



- Unit 1: Roof blown off by hydrogen gas explosion on 12 March
- Unit 2: Torus under reactor exploded on 15 March
- Unit 3: Roof blown off by hydrogen gas explosion on 14 March
- Unit 4: Two-hour fire at the spent fuel storage pond on 15 March and another fire on 16 March

Image taken from http://glasstone.blogspot.se/2011/03/explosion-on-12-march-2011-of-outer.html

Fukushima before and after March 11, 2011

(Photos can be found at http://cryptome.org/eyeball/daiichi-npp/daiichi-photos.htm)

Gas explosion in a reactor building

Reactor building after gas explosion

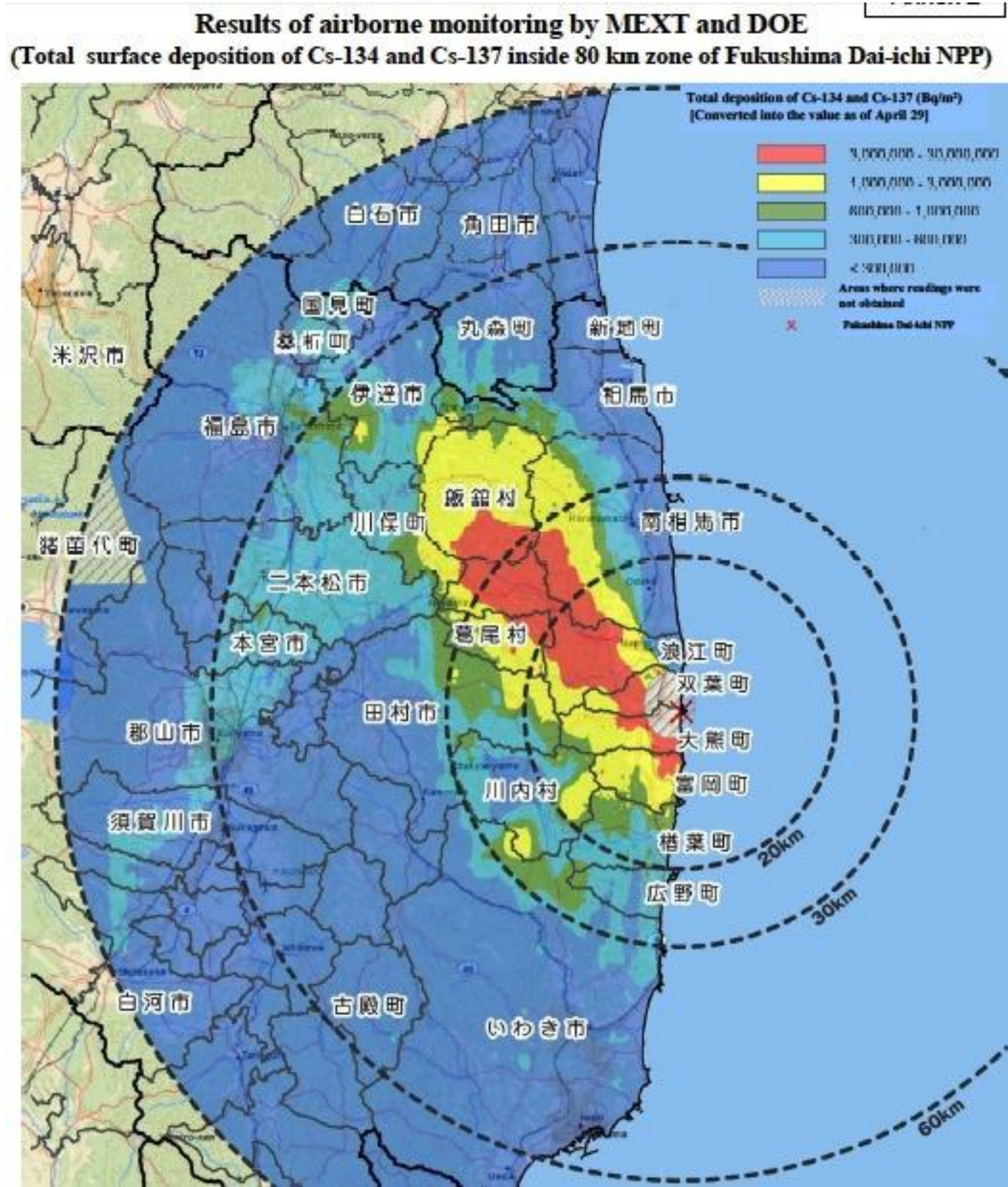
What happened?

- Earth quake and scram (rapid stopping) of the reactors in operation
- Electricity outage => emergency power generators started
- Tsunami 50 minutes after earth quake
- => Batteries instead of generators for cooling water
- As batteries went out, water boiled and evaporated in reactors and fuel pools due to heat from decay of fission products

What happened, continued?

- => hot fuel reacted with water vapour to form hydrogen gas
- Hydrogen mixed with air and caused explosions
- => fuel very hot and releases to the environment
  - – Not just cesium-137 which is relatively volatile under existing conditions
  - – But also transuranium elements
- => large scale contamination

Surface deposition of cesium-134 (halflife 2,07 y) and cesium-137 (halflife 30,17 y)



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Technical Note

Overview of rehabilitation schemes for farmlands contaminated with radioactive cesium released from Fukushima power plant

Masashi Nakano [a,*], Raymond N. Yong [b,1]

[a] The University of Tokyo, Japan
[b] McGill University, Canada

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ABSTRACT

Schemes for rehabilitation of farmlands contaminated with radioactive cesium are discussed based on the various pieces of information obtained to date from a series of validation trials in Fukushima, Japan. Decontamination of affected farmlands is to be achieved by scraper-removal of the very highly contaminated shallow top soil layer. In areas with very low contamination, the plans are to implement in-situ burial of the scraper-removed contaminated topsoil at depths greater than 2 m — meaning that the affected areas will be the burial sites. For disposal of the contaminated top-soils removed in the very highly contaminated areas, there will be a two-step procedure: (a) volume reduction and decontamination of the contaminated soil, and (b) disposal in a mulch barrier landfill system with encapsulating clay liners at selected sites. Volume reduction and decontamination of the contaminated soils will involve removal of the finer soil fractions through washing with water. For implementation of the schemes for rehabilitation, science-based verification of safety and public acceptance of the schemes are required.

International meeting to support remediation work in Japan

Radiological protection

ISTC/STCU Symposium and Seminar:

The Experience and Technology of Russia, Ukraine and Other Commonwealth of Independent States (CIS) Countries on Remediation and Restoration of Environments

On 3-4 February 2012, the Japanese government hosted a two-day symposium and seminar on *The Experience and Technology of Russia, Ukraine and Other CIS Countries on Remediation and Restoration of Environments*. Organised by the International Science and Technology Center (ISTC) and the Science and Technology Center in Ukraine (STCU), this meeting was an opportunity for experts from zones most affected by the Chernobyl accident (Ukraine, Russia and Belarus) to share best practices in managing contaminated land. The meeting was co-organised by the Japanese government, the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). Participants discussed ISTC and STCU land decontamination projects relevant to conditions following the Fukushima Daiichi nuclear accident and stakeholder engagement activities based on proposals made by the NEA.

Symposium on the application and R&D of the technologies of decontamination, remediation and restoration of environments

Tokyo, Japan
3 February 2012

Organisers

The Institute of Applied Energy, Japan
ISTC (International Science and Technology Center)
STCU (Science and Technology Center in Ukraine)

Remediation in progress

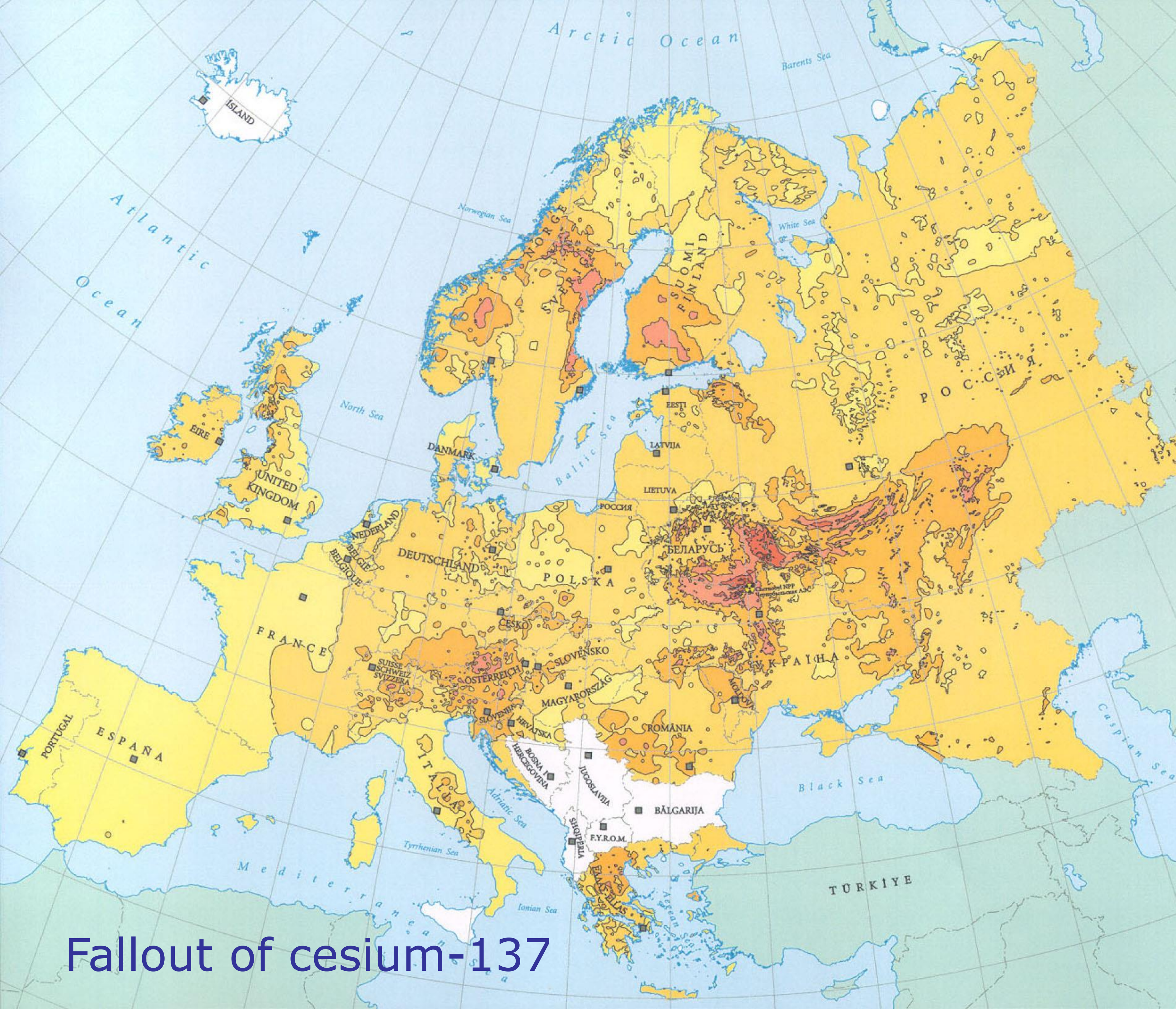
Ongoing work

- Washing of houses and streets (using various techniques)
- Collection of leaves e t c on the ground
- Removal of top 5 cm of soil
- Temporary storage of material

Plans

- Washing of soil to
  - Mechanically remove fines high in Cs-137
  - Chemically remove part of the remaining Cs-137
- Incineration of organic material
- Disposal in concrete structures (similar to other near surface LLW disposal facilities)


Tjernobyl, april 1986



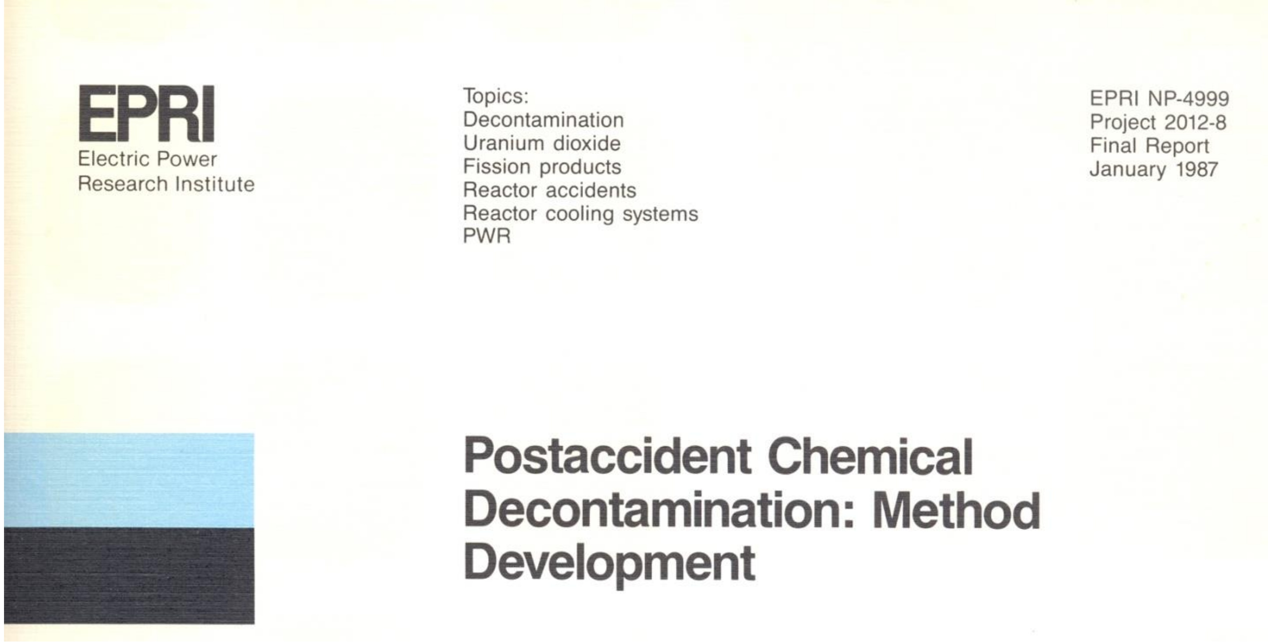
Fallout of cesium-137

- 185 – 1480 kBq/m²
- 40 – 185 kBq/m² (Gävle)
- 10 – 40 kBq/m²
- 2 – 10 kBq/m² (Syd-sverige)
- 0 - 2 kBq/m²

Swedish perspective

- Swedish scientists discovered Tjernobyl accident before admitted by the USSR
- Champion in the world with 6.4 MWh/capita & year of nuclear electricity
- Champion in Europe with ≈ 40 % energy from renewable sources
- Fallout from Tjernobyl concentrated in the bioash
- Also participation in Three Mile Island work

Three Mile Island 2, PWR



EPRI
Electric Power
Research Institute

Topics:
Decontamination
Uranium dioxide
Fission products
Reactor accidents
Reactor cooling systems
PWR

EPRI NP-4999
Project 2012-8
Final Report
January 1987

Postaccident Chemical Decontamination: Method Development

- Accident March 28, 1979
- Initially, plans to restart the reactor after decontamination of the primary system
- Systems decontamination well established already then (selective dissolution of oxide)
- But identified ”fuel debris” in primary system

TMI-2, continued

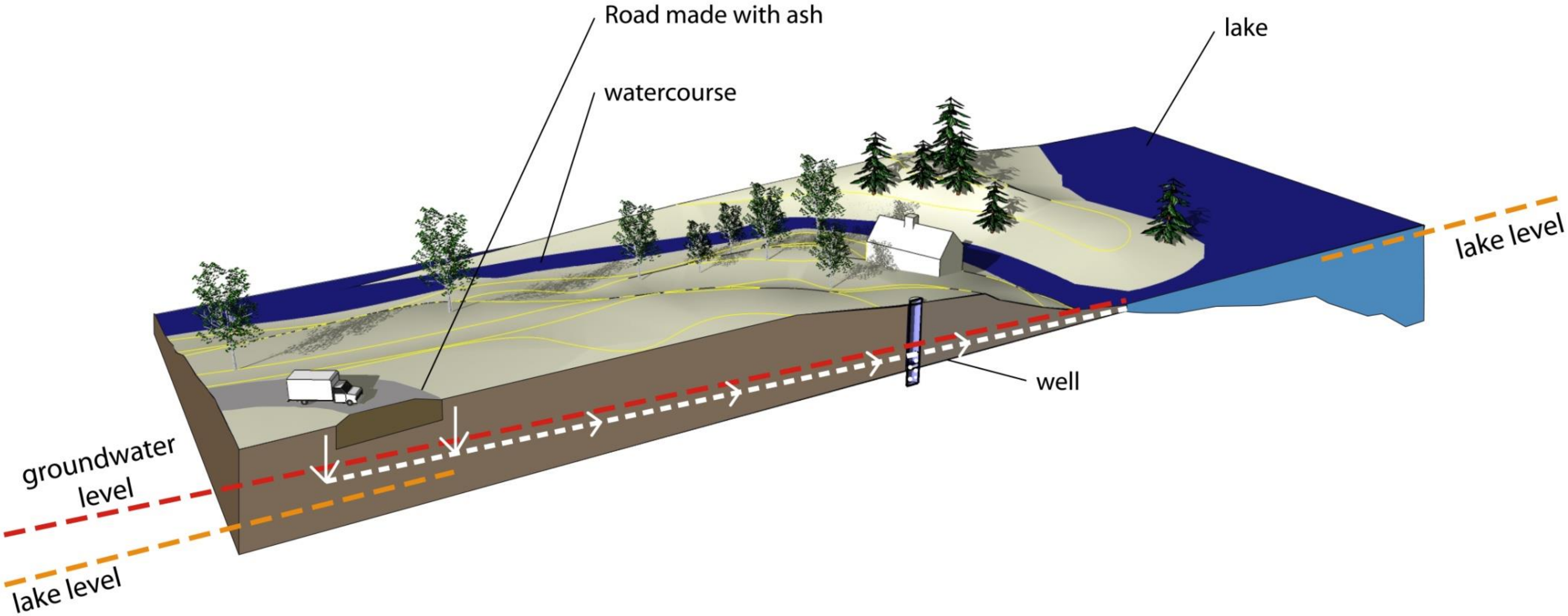
- Development of chemistry to rapidly dissolve ”fuel debris”
  - Worked excellently on fuel not irradiated
  - Failed on real ”fuel debris” – tests during 1985 ⬄ <u>six years after the accident</u>!
- Reason: Not ”fuel debris” but ”corium” = a solidified melt of uranium oxide, zincalloy and stainless steal
- Actually, 90 % of the cladding had failed and 50 % of the fuel had molten

TMI-2, continued

- => TMI-2 never to be restarted
- Now mothballed until time for TMI-1
- Removal of activity essential for continued work
- But this may not be so easy to do chemically for the corium involved
- This issue will be relevant for Fukushima later on

Chernobyl fallout in Sweden

- Initially problems with Cs-137 levels in reindeer meat
- Studies at the Radiation Protection Authority indicated concentration of Cs-137 in ash & associated dose problems
  - External radiation from the ground
  - Oral intake from water and fish
- => regulation in the year 2005 – <u>19 years after the accident</u> (& after a significant decay of the Cs)



Spreading of cesium-137
from a road built with ash
to a well for drinking water
and a small lake with fish

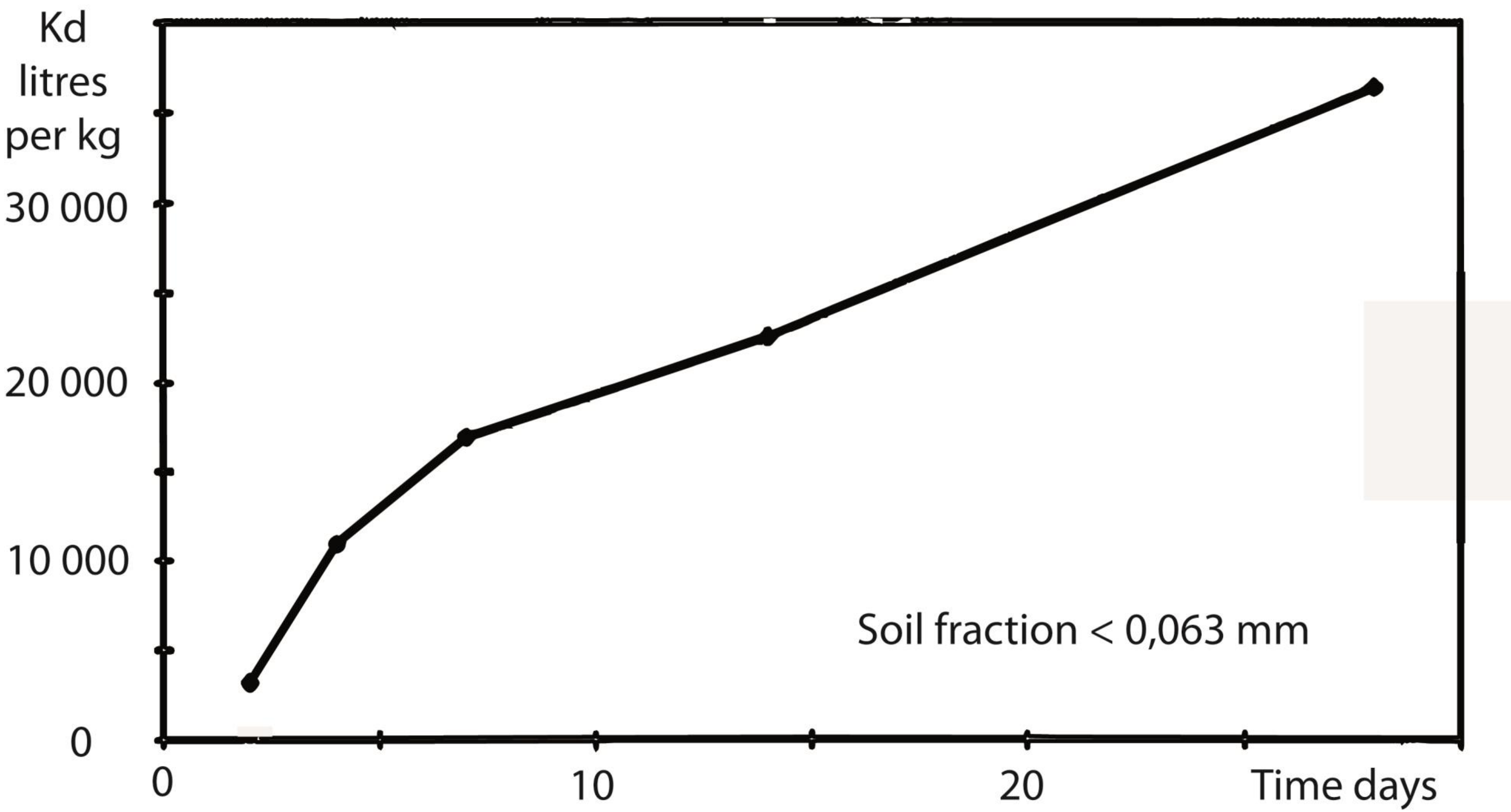
What distribution coefficient (Kd) should be used??

Distribution coefficients from the literature in litres per kilogram

Cation exchange capacity (CEC) in meq / 100 g	< 3	3 - 10	10 – 50
Clay content in weight %	< 4	4 - 20	20 – 60
Median Kd in litres per kg	**200**	**500**	**1500**
Lowest Kd in litres per kg	**10**	**30**	**80**
Highest Kd in litres per kg	**3 500**	**9 000**	**26 700**

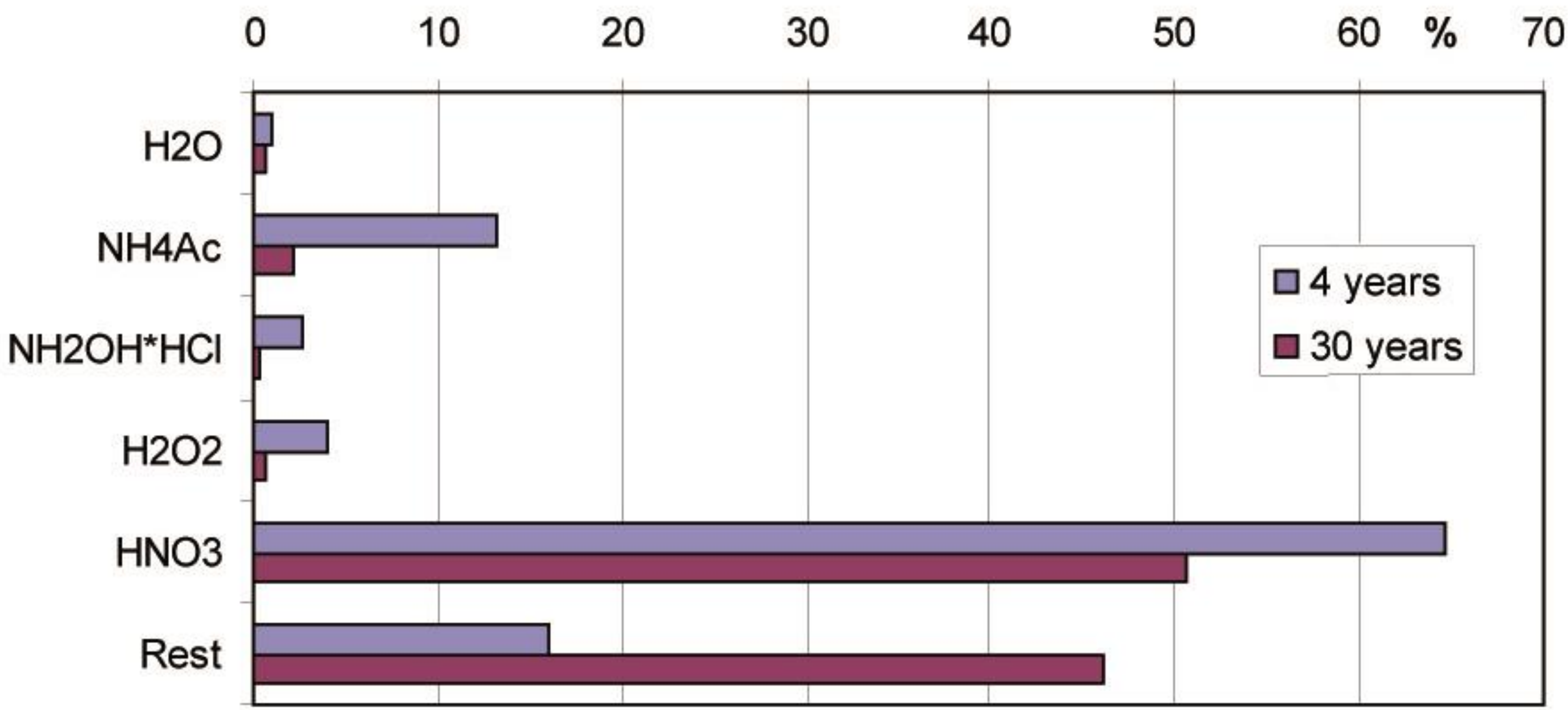
Availability of cesium-137 as a function of time

Modified from Funebo T*. Cesium sorption / Desorption behaviour on soil.* Diploma thesis for the degree of Master of science in Chemical Engineering. Department of Nuclear Chemistry, Chalmers University of technology, Göteborg 1995.



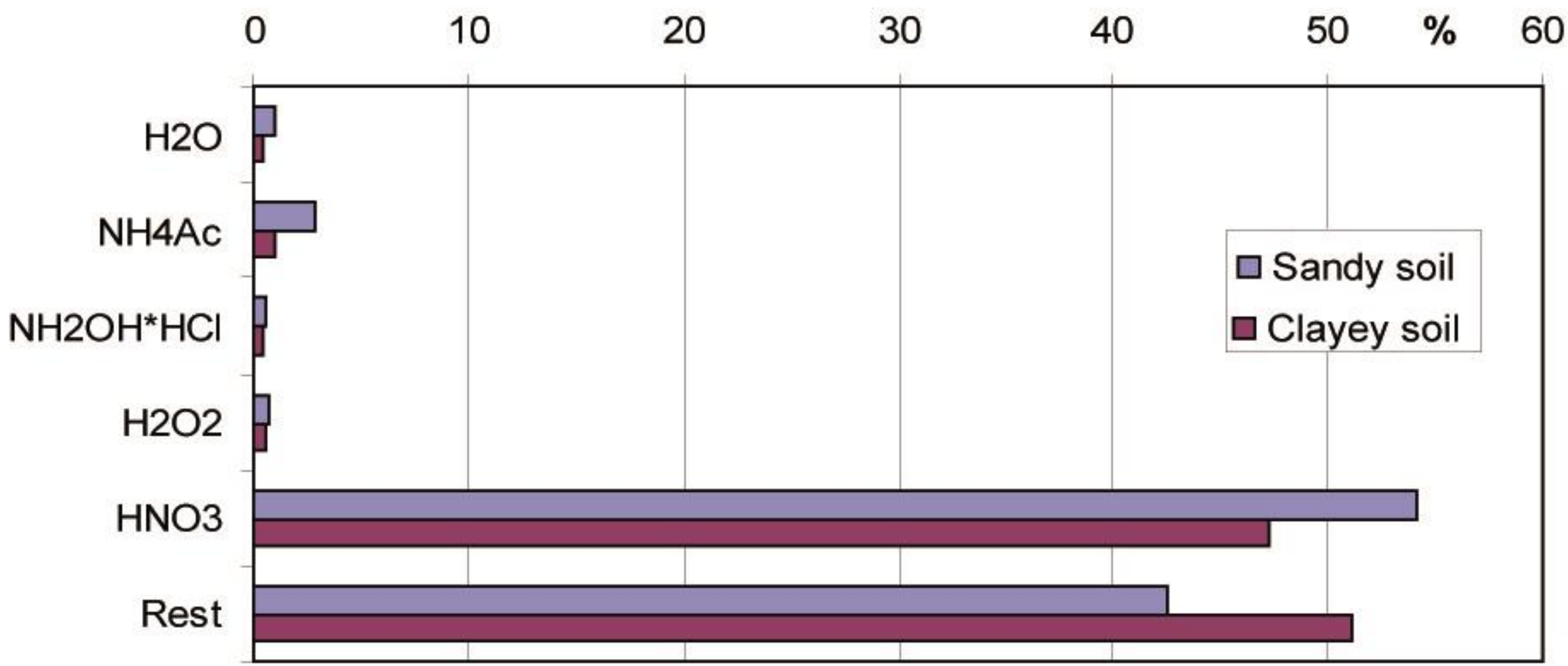
Cesium in soil after 4 and 30 years, respectively

Data from Forsberg S. *Behaviour of 137Cs and 90Sr in agricultural soils*.
Doctoral thesis. The Swedish University of Agricultural Sciences, Agraris 212, 1999.

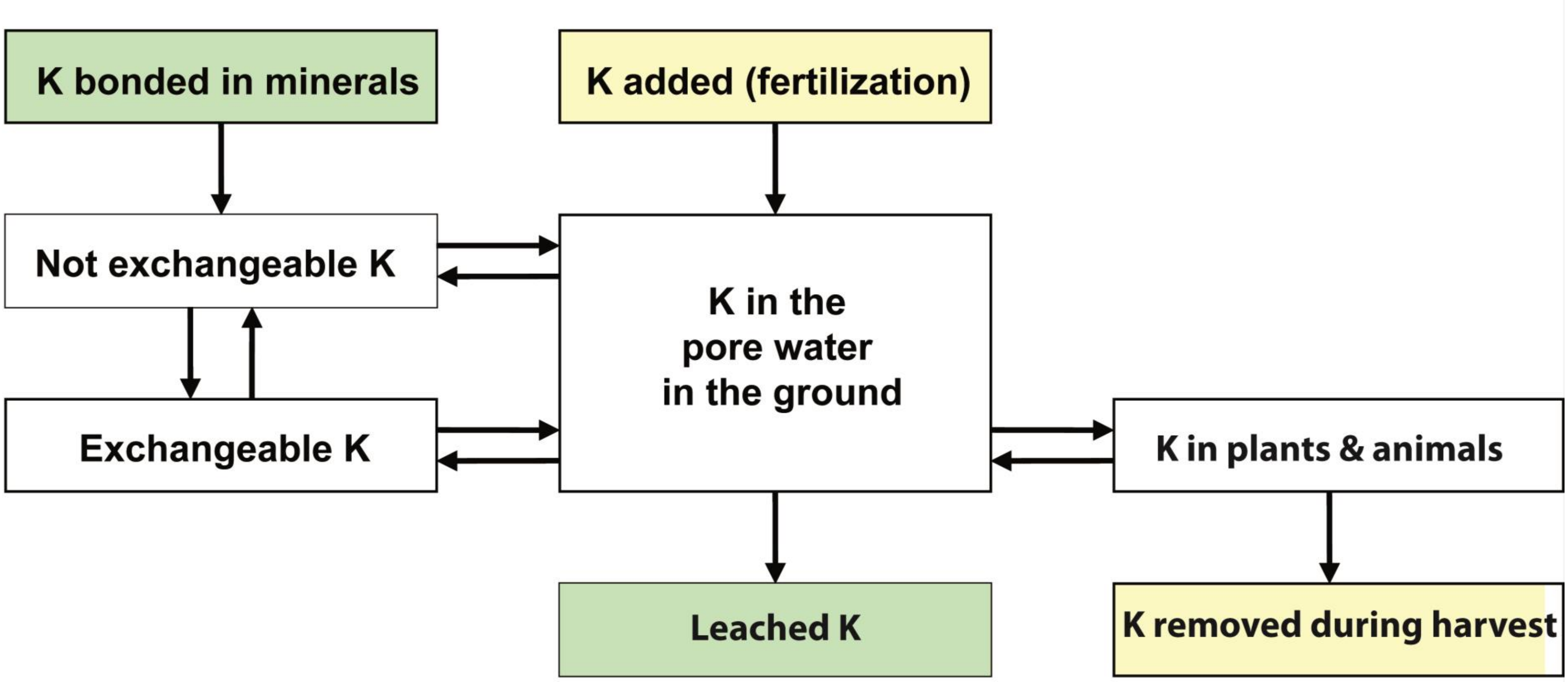


Cesium in sandy and clayey soil after 30 years

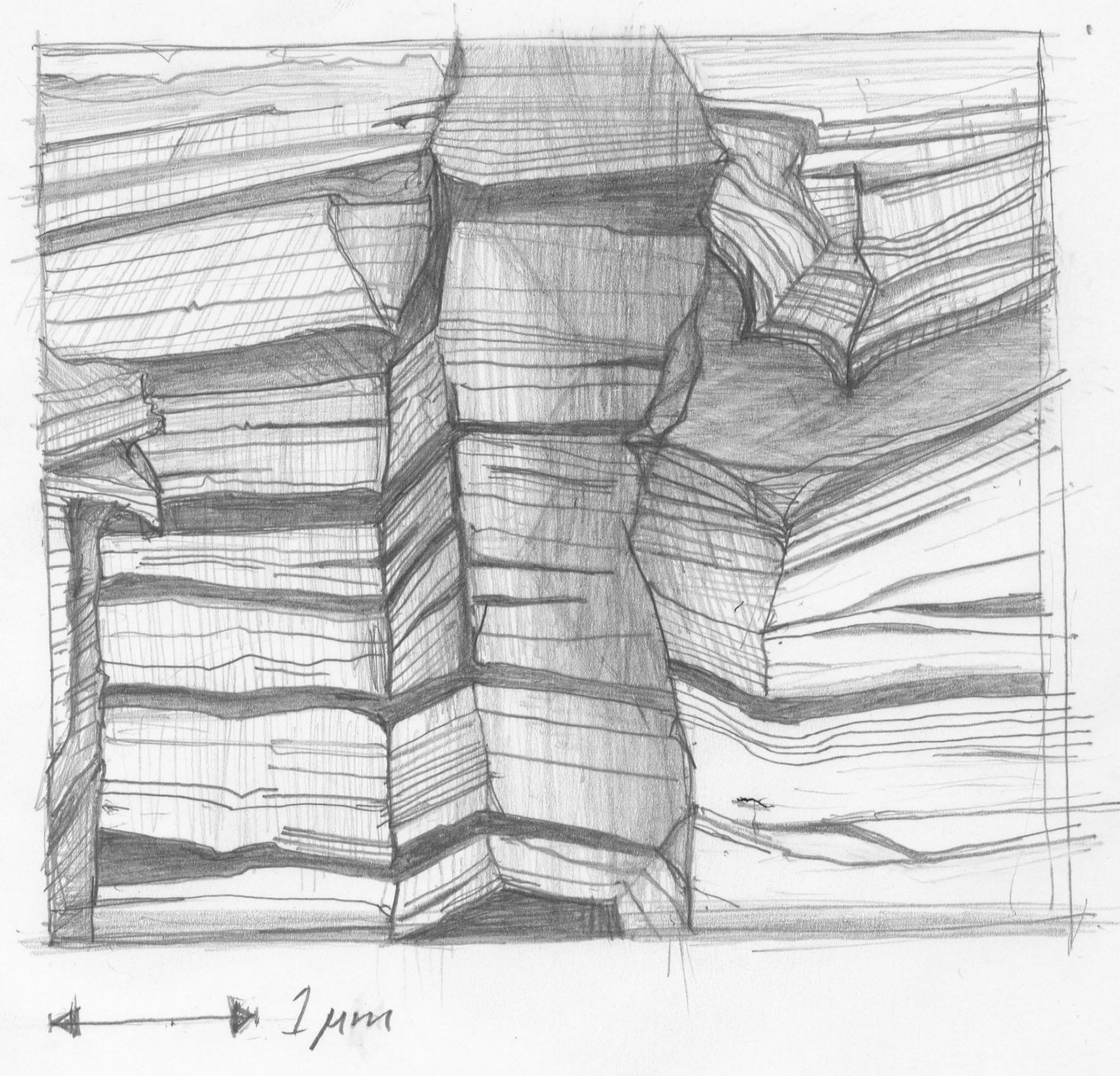
Rate of migration after 30 years = 1 mm per year



Similarity with potassium in soil From agricultural literature

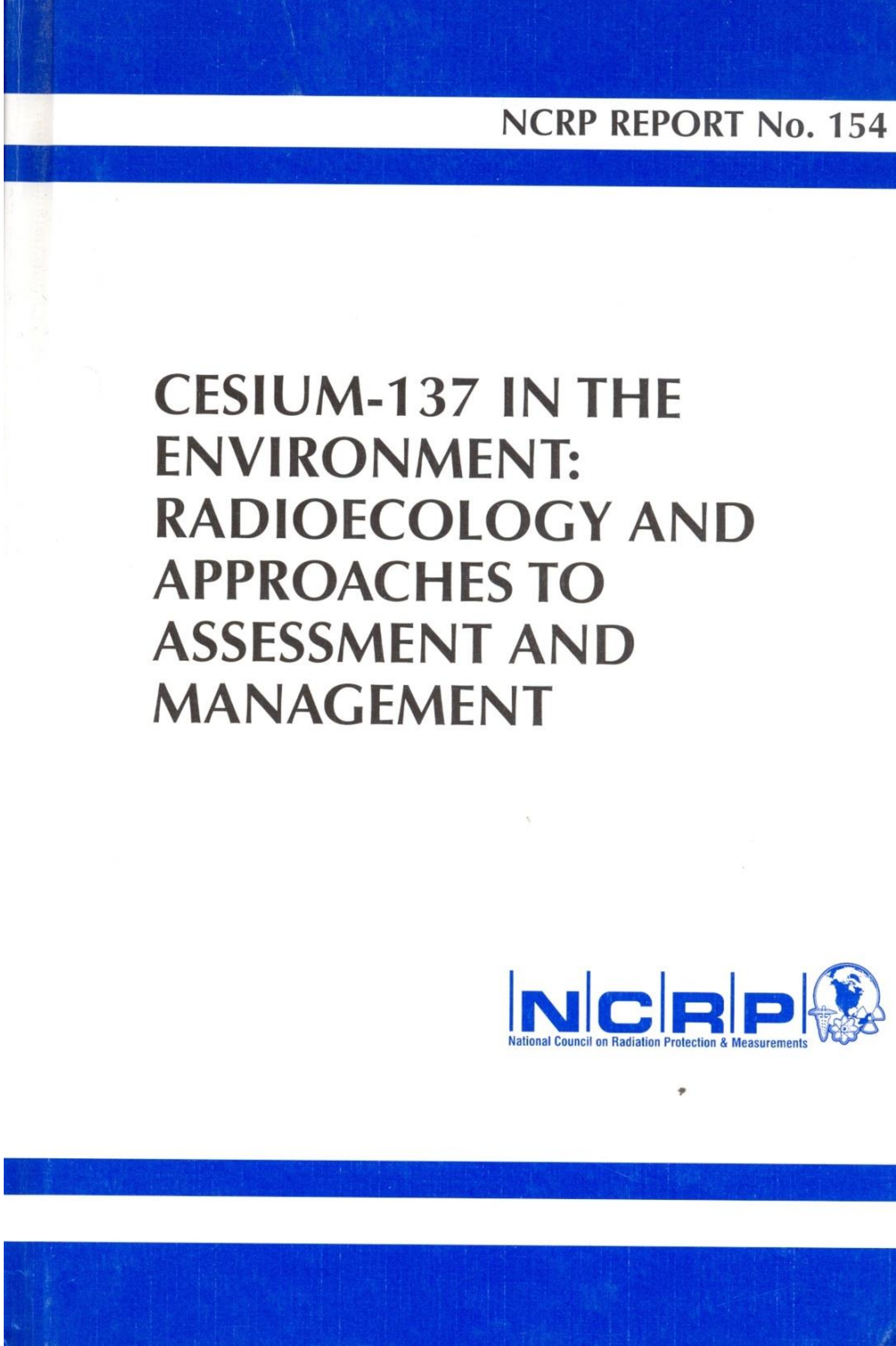


Mica
(e g biotite)
binds K
between
the sheets
near the
partially
weathered
surface



US experience from the 1940’s

- Cs-137 essentially immobile in suitable soils
- Micas and illites offer permanent positions for cesium-137 in their structures



Soils in Japan and near Fukushima

- Complex geology with e g
  - Old metamorphic rock
  - Vulcanic ash
- Both can transform to suitable clays in soils
- Recent studies on Cs on soils in Japan:
  - Strong binding also in soil low in micas
  - Stronger binding at low concentrations (such as for fallout)
- Anticipated soil washing may not be so easy

Stabilization versus containment

- Current planning directed towards containment
- Experience indicates that stabilization feasible
- Suitable minerals can be added if missing
- External radiation can be shilded by ploughing (half thickness ≈ 3 cm)
- Relative merits depend on level of contamination

Conclusions

- It takes time after a major accident before the situation can be evaluated and long-term plans made
- Important to plan also for the long-term since e g tests may require calendar time
- Different options need to be evaluated
- Knowledge & support for decisions can be found from
  - Different geographic locations
  - Long time ago
  - Other areas of science & technology

A final comment

- A similar discussion can be held on disposal, with regard to utilizing experience from contaminated soil & ash
- This will be dealt with in a supplementary presentation that will include landfilling
- It will be made at
  WASTE MANAGEMENT 2014
  7th International Conference on Waste Management and the Environment,
  12 - 14 May, 2014, Ancona, Italy

Acknowledgements

- Three Mile Island cleanup related work:
  - Electric Power Research Institute (EPRI), USA
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  - Thermal Engineering Research Institute (Värmeforsk), Sweden
  - Svenska Energiaskor AB (which translates to: "Swedish Energy Ashes Inc.")
  - ENA Energi AB, Enköping, Sweden
  - Ångpanneföreningen's Foundation for Research and Development (Åforsk), Sweden