Contamination of forests with radiocaesium - lessons from the Chernobyl accident

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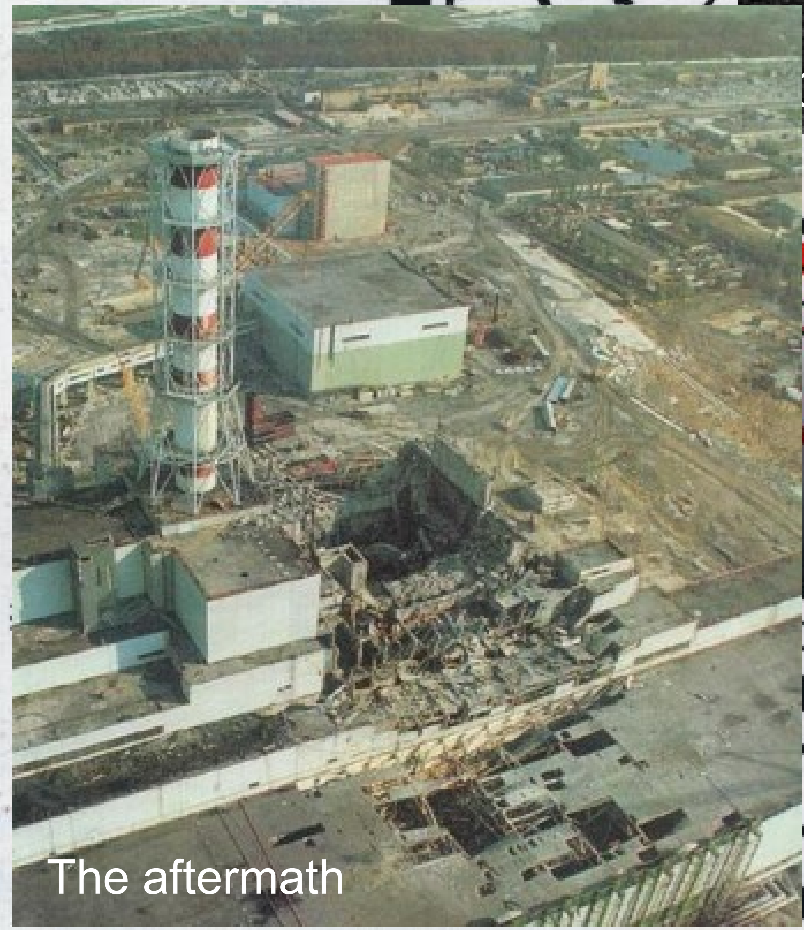
2nd International Symposium on Remediation of Contamination Site Caused by Fukushima Accident, June 2013

The University of Nottingham

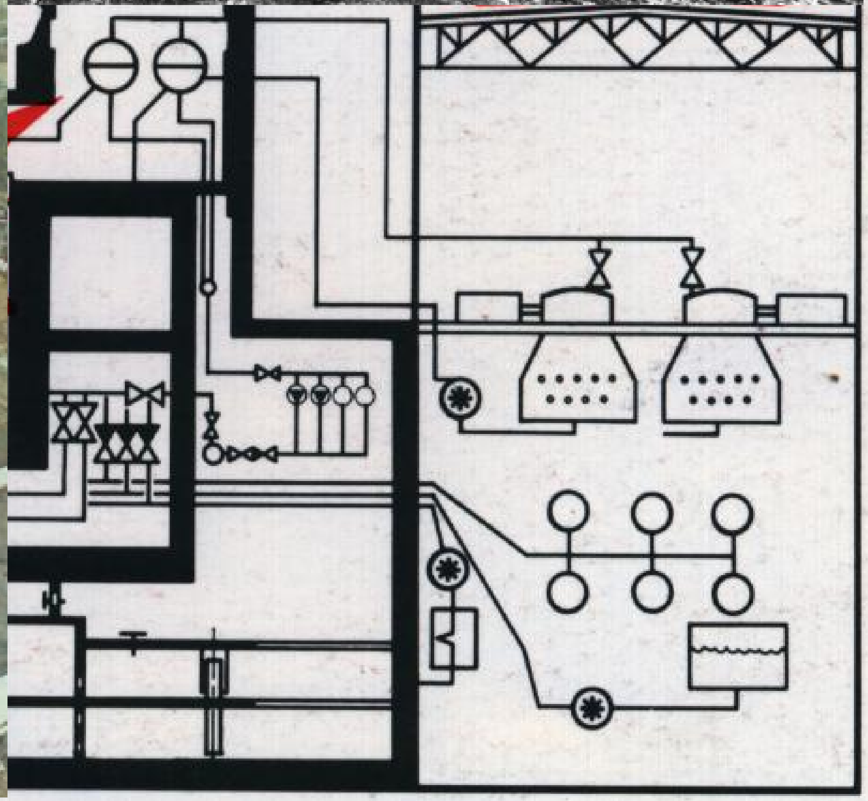
Outline of talk …

- The Chernobyl accident and its impact on Europe
- Research programmes – EU, IAEA
- Forest research in the Chernobyl exclusion zone
- Forest research across the European continent
- Modelling time dependent transfers of ^{137}Cs in forests
- Cost-benefit modelling of remediation options for forests
- Summary – what did we learn?

Clearing debris from roof of Reactor 3

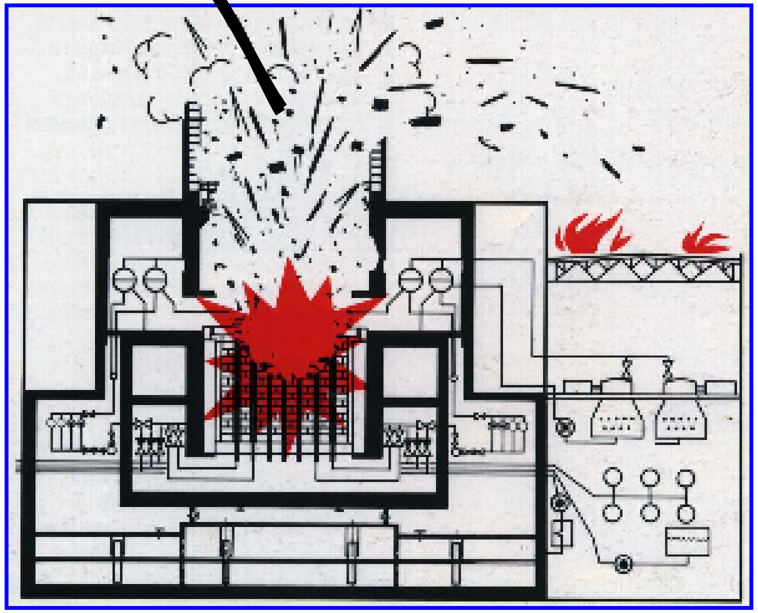


The aftermath



2^{nd} - 3^{rd} May 1986 (UK)

26^{th} April 1986

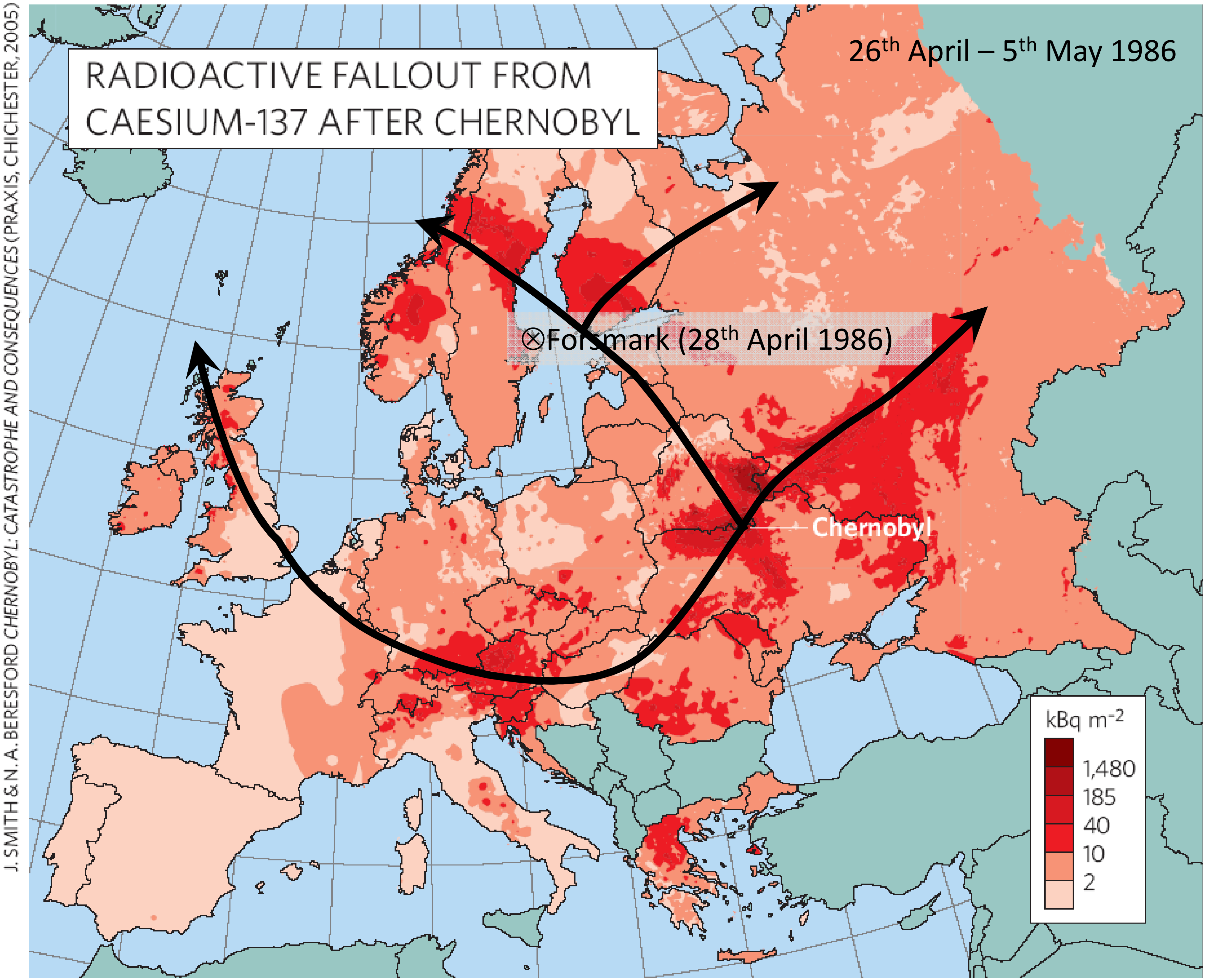


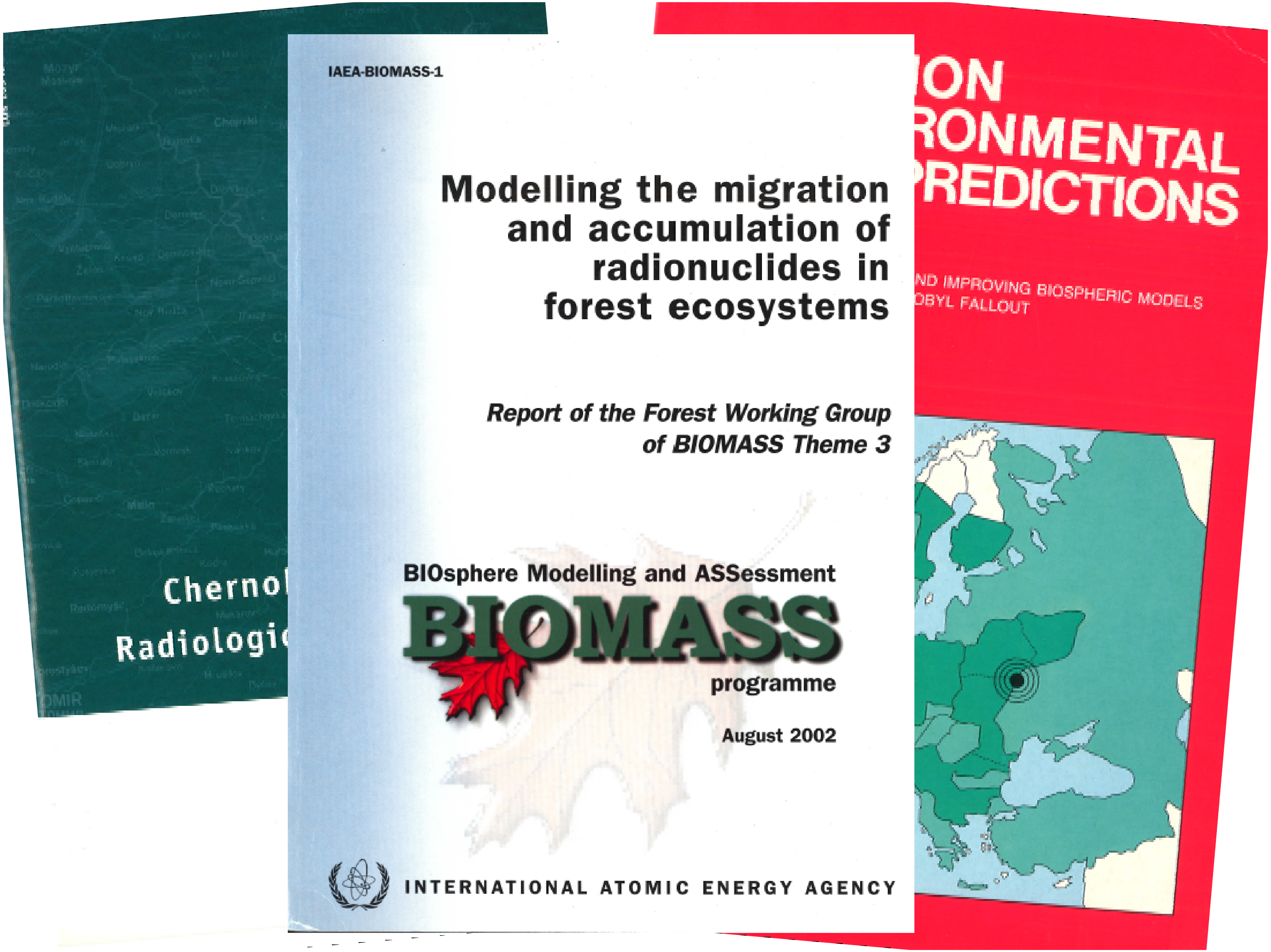
Small (~1 μm) particles containing ^{131}I, $^{103/106}$Ru and $^{134/137}$Cs subject to slow deposition except where rainfall was encountered.

Atmospheric transport over distances in excess of 2000 km.

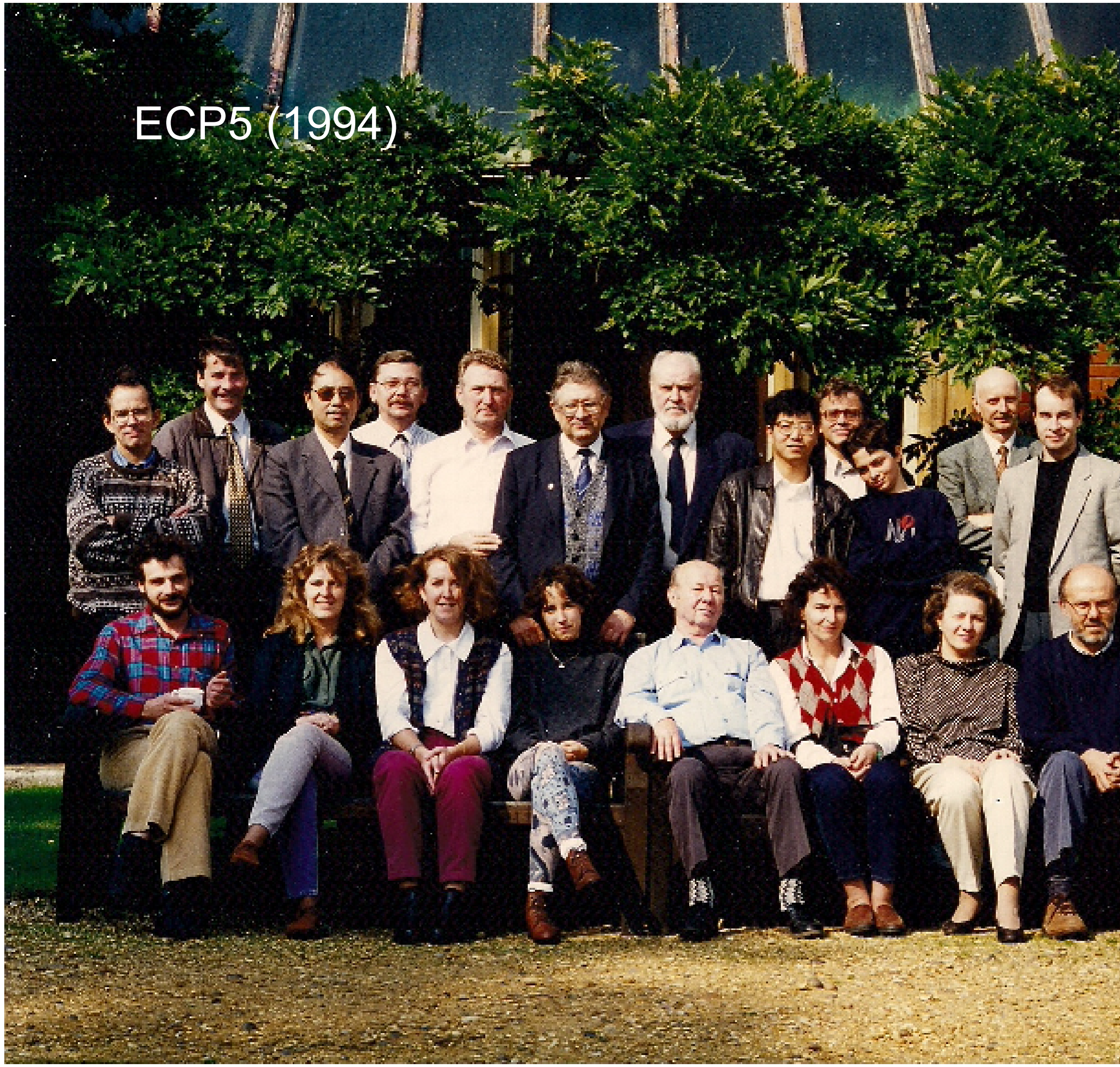
Large (10 to 100μm) 'hot particles' consisting of UO_x plus fission and activation products subject to rapid sedimentation.

Atmospheric transport up to ~50 km.

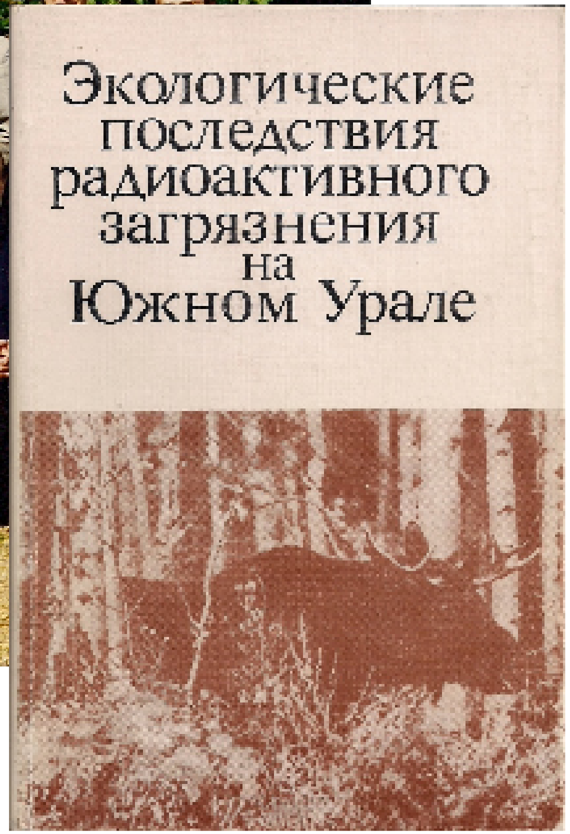

RADIOACTIVE FALLOUT FROM CAESIUM-137 AFTER CHERNOBYL
26th April – 5th May 1986
⊗Forsmark (28th April 1986)
Chernobyl
kBq m-2
1,480
185
40
10
2
J. SMITH & N. A. BERESFORD CHERNOBYL: CATASTROPHE AND CONSEQUENCES (PRAXIS, CHICHESTER, 2005)


IAEA-BIOMASS-1
Modelling the migration and accumulation of radionuclides in forest ecosystems
Report of the Forest Working Group of BIOMASS Theme 3
BIOsphere Modelling and ASSessment
BIOMASS
programme
August 2002
INTERNATIONAL ATOMIC ENERGY AGENCY
PREDICTIONS

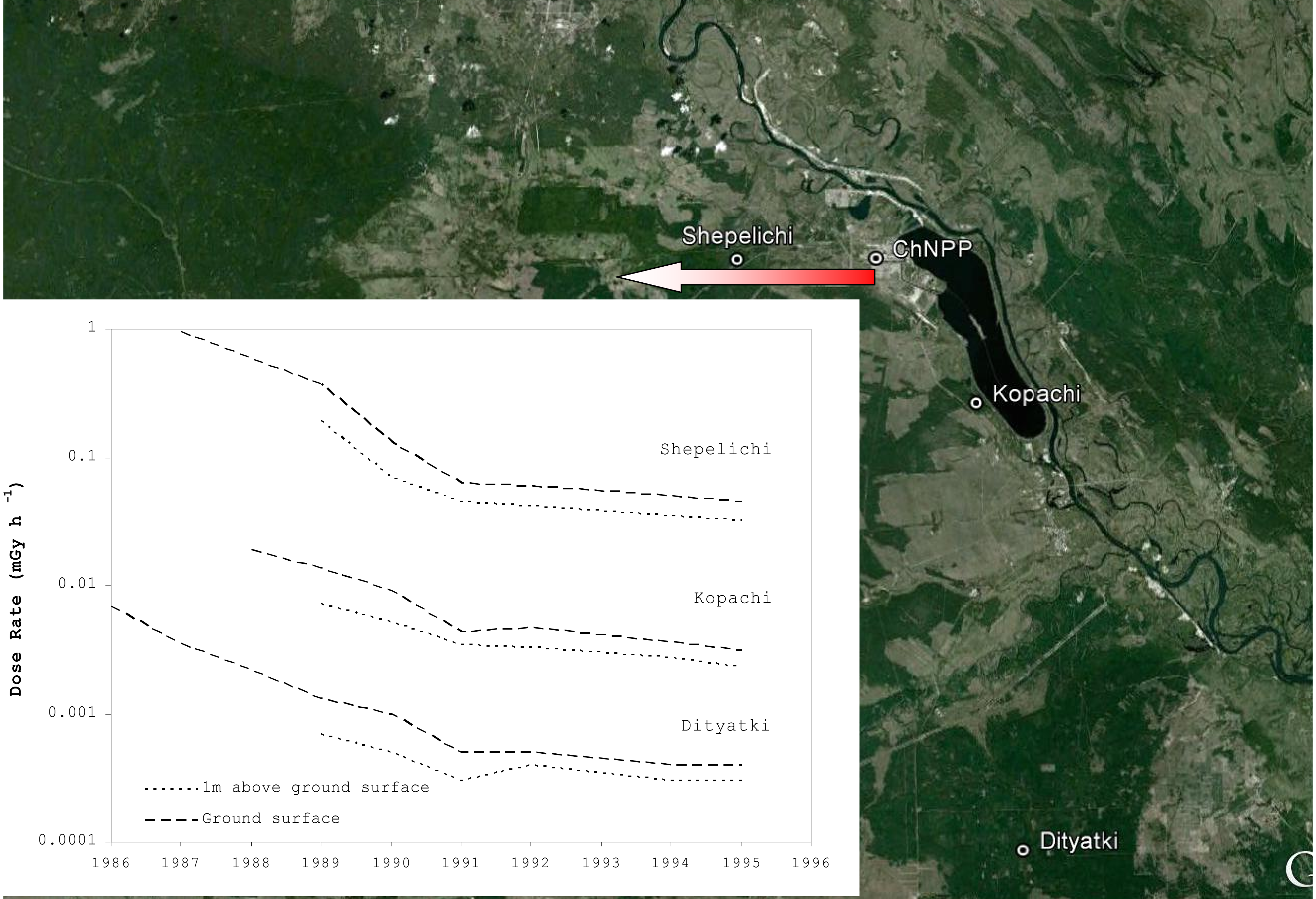
EU-CIS Collaborative Projects - Radionuclides in natural and semi-natural ecosystems



Ecological after-effects of radioactive contamination in the southern Urals ▶

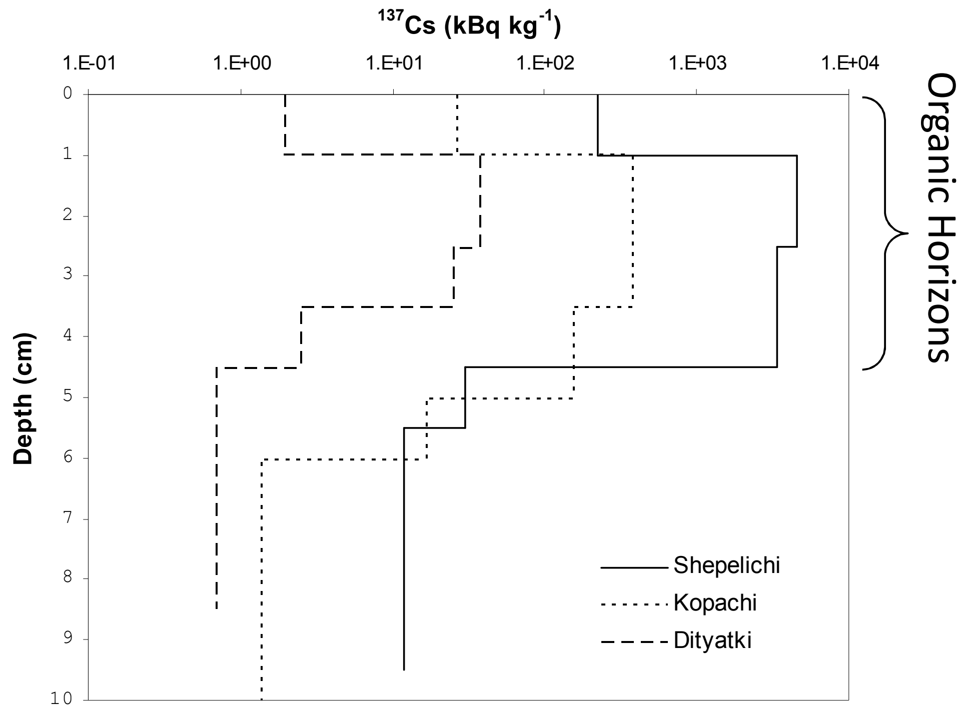


Moscow State University study sites in the Chernobyl 30 km exclusion zone

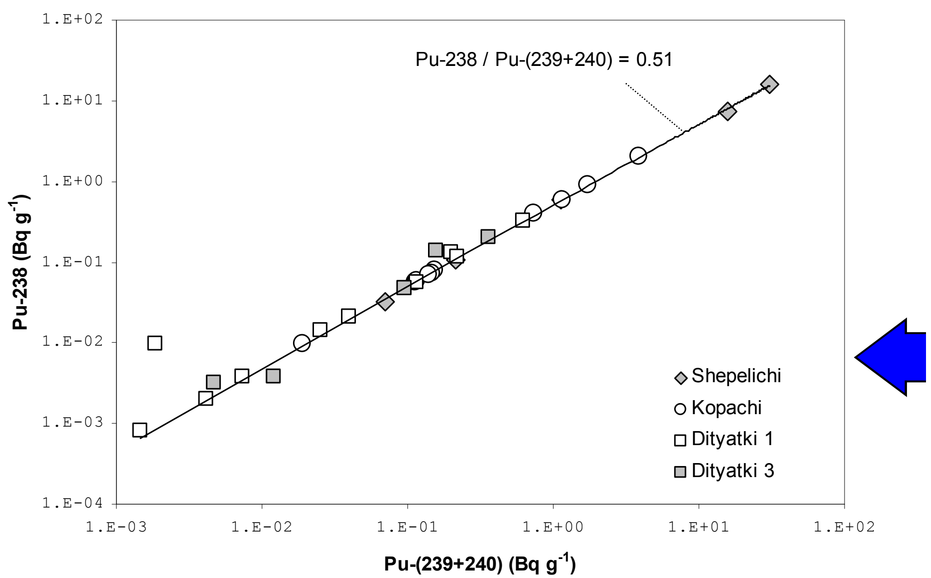


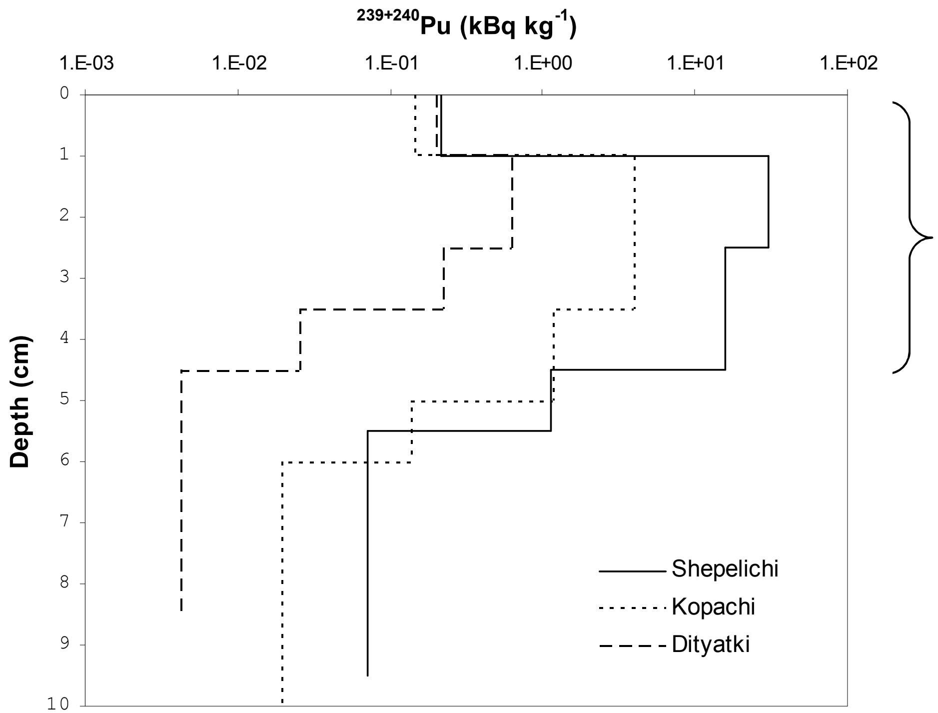
Deposited activities and dose rates from Shcheglov et al. (2001)


Pripyat, experimental plot
Shepelichi
ChNPP
Radiation damage to
Shepelichi 1994 (~75 μSv h-1)
lat 51.307868° lon 30.009607° elev 135 m



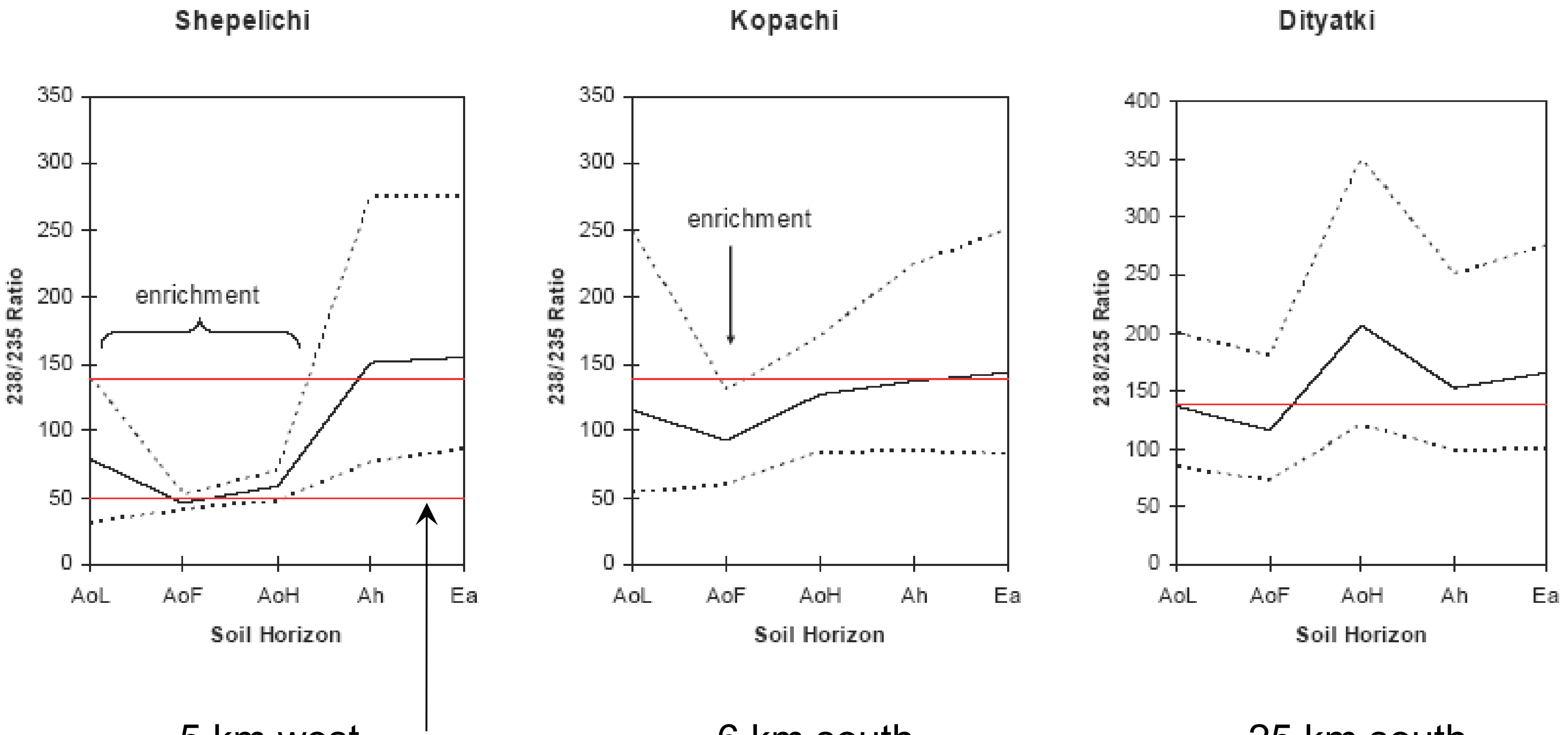
Depth profiles of ^{137}Cs and $^{239+240}$Pu in 'soddy podzol' soils (1993-94) underlying coniferous forest in the 30 km zone





Shaw and Wang (1996)

$^{238}U/^{235}U$ ratios in forest soils at MGU Chernobyl study sites



5 km west

2% enriched
RBMK reactor fuel

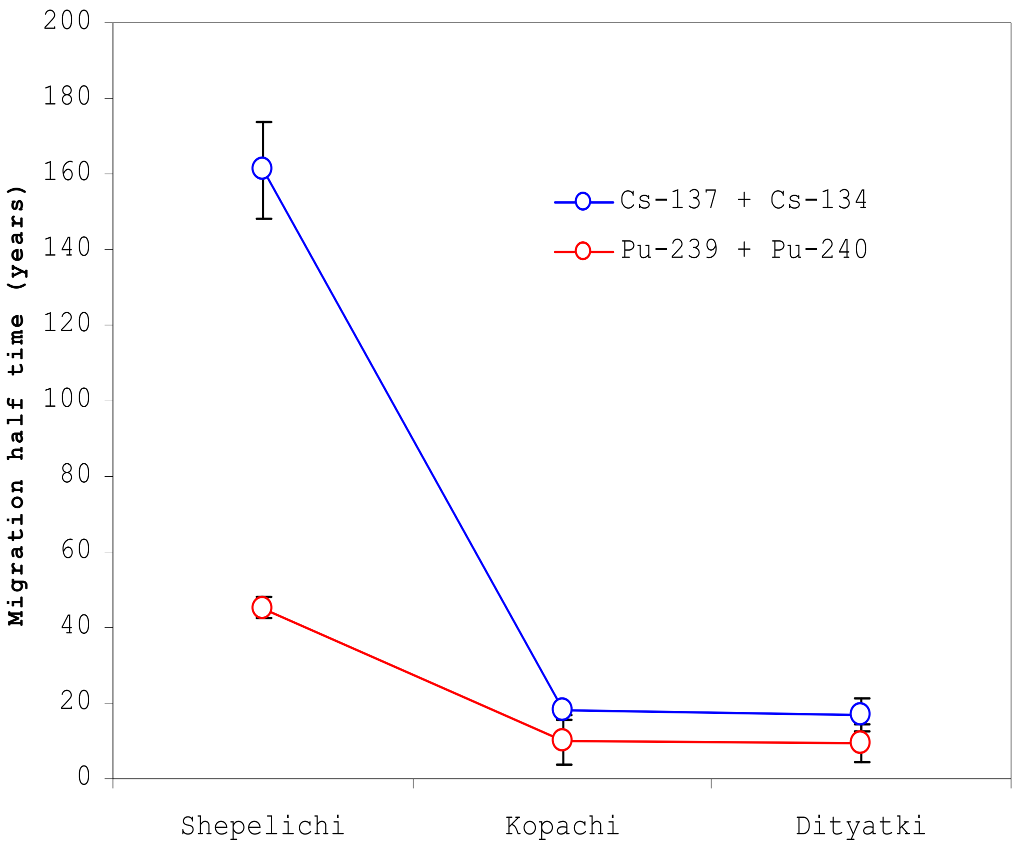
6 km south

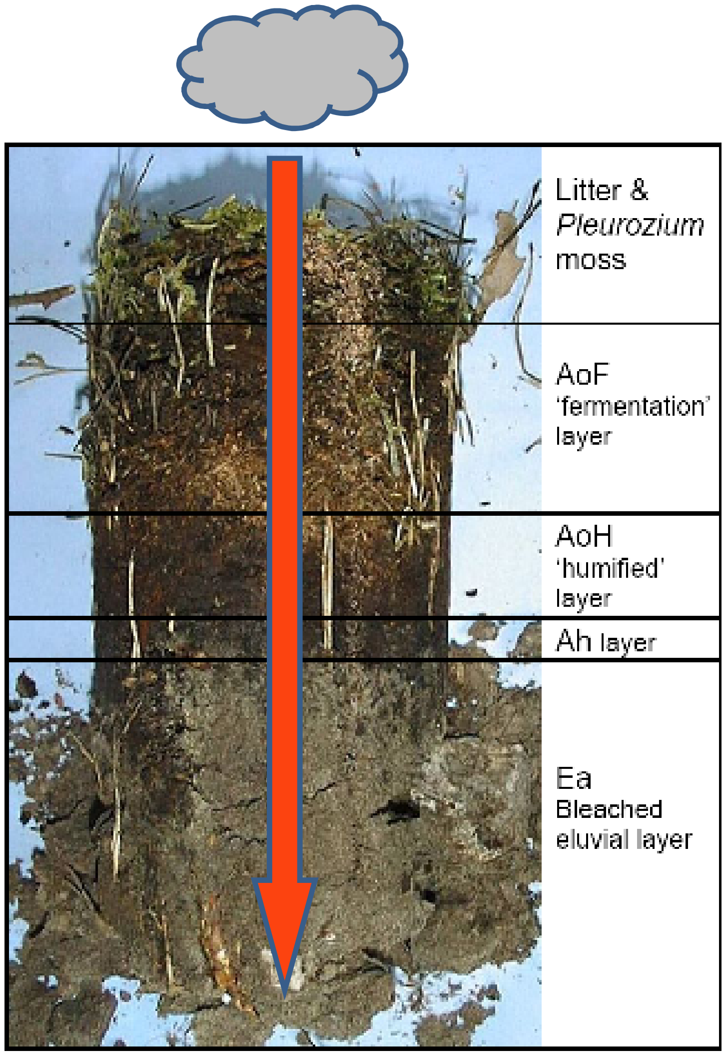
25 km south

'hot particles'

Shaw and Wang (1996)

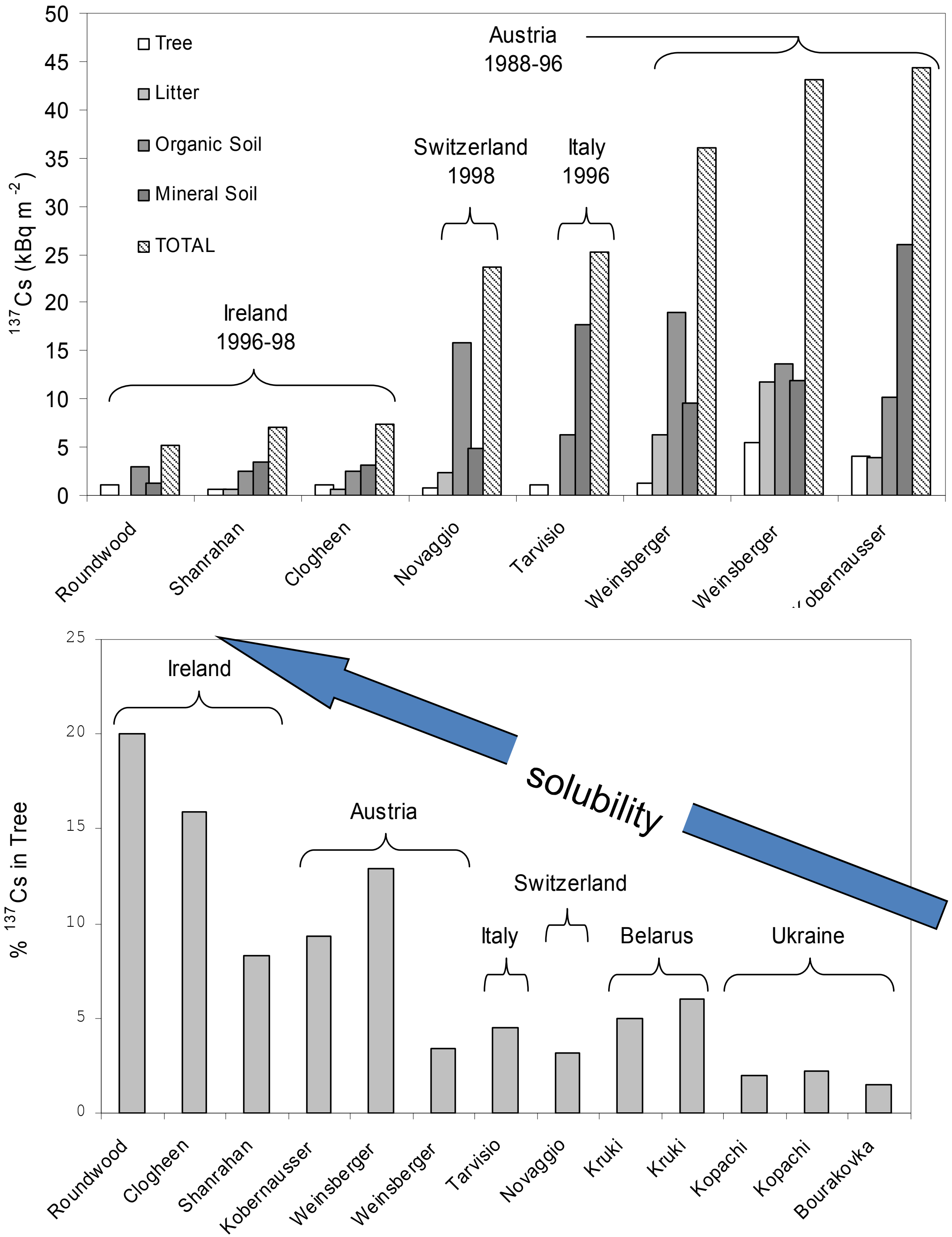
Migration half times (in years) of Cs and Pu isotopes in AoH horizons at Chernobyl 30 km zone sampling sites





Shaw and Wang (1996)


SEMINAT Forest Sites
Lady Wood (Sellafield)
Shanrahan
Roundwood
Chernobyl
~3,000 km
Weinsberger
Kobernausser
Tarvisio
Novaggio
© 2013 Cnes/Spot Image
Image © 2013 TerraMetrics
Image IBCAO
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Tour Guide
56°37'44.09" N 8°25'21.83" E elev -1 m eye alt 2807.12 km

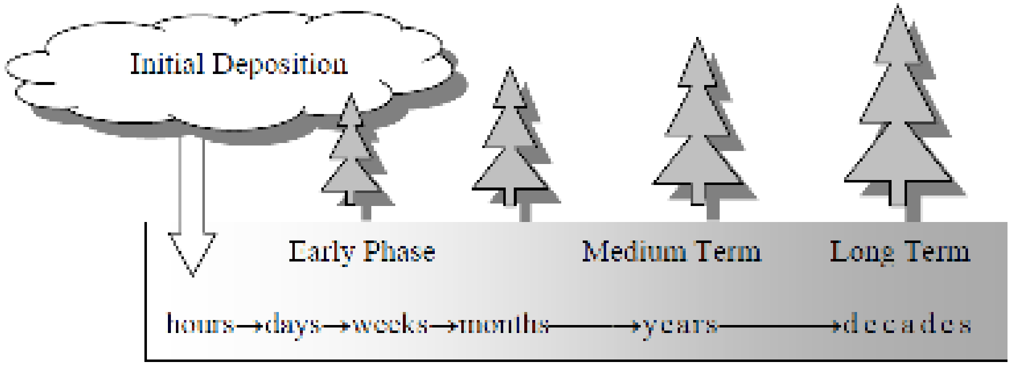


Assimilation of ^{137}Cs by trees (as an indicator of biological availability) over a 3,000 km distance (west) from the Chernobyl Power Plant.

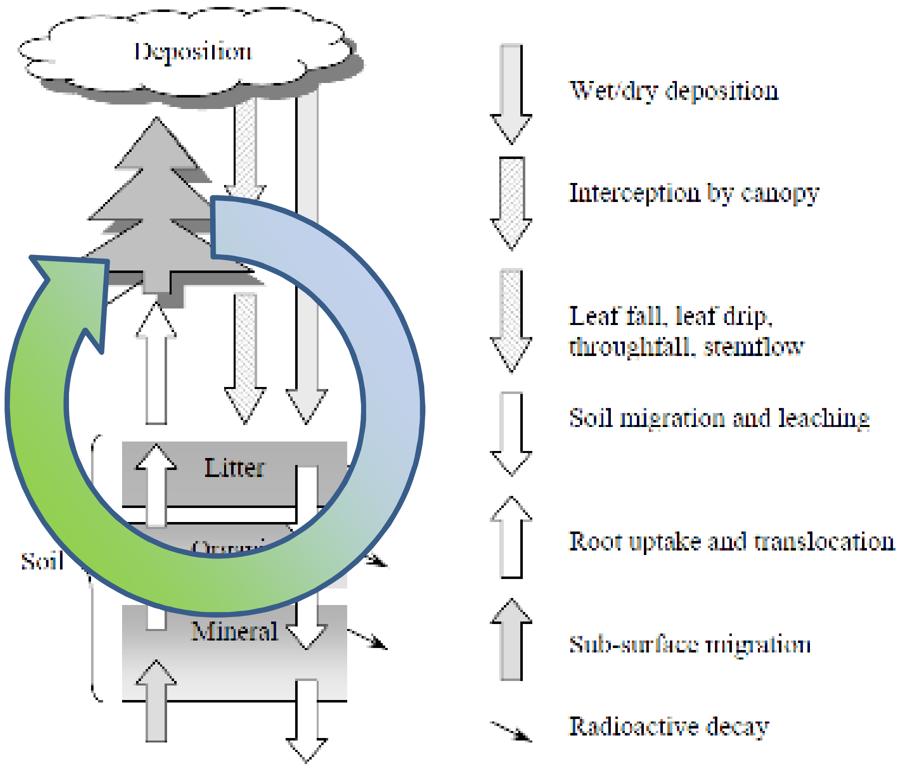
The increasing 'bioavailability' of ^{137}Cs with distance indicates increasing solubility of aerosol particles at the time of deposition.

Data obtained by the EC-funded 'SEMINAT' project (Belli et al., 2000)

Radionuclide dynamics in forest ecosystems

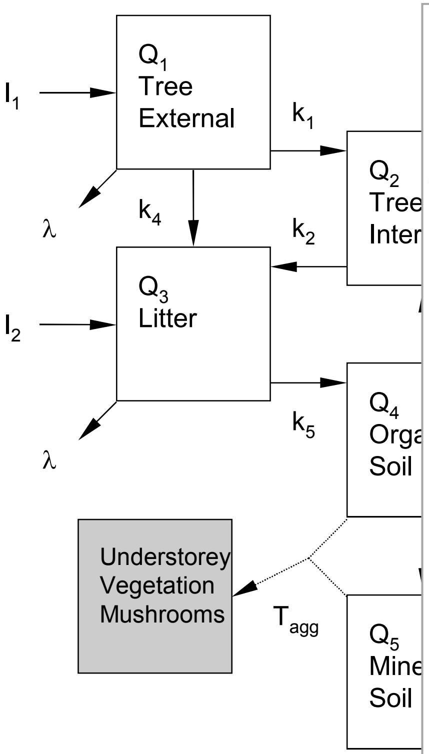


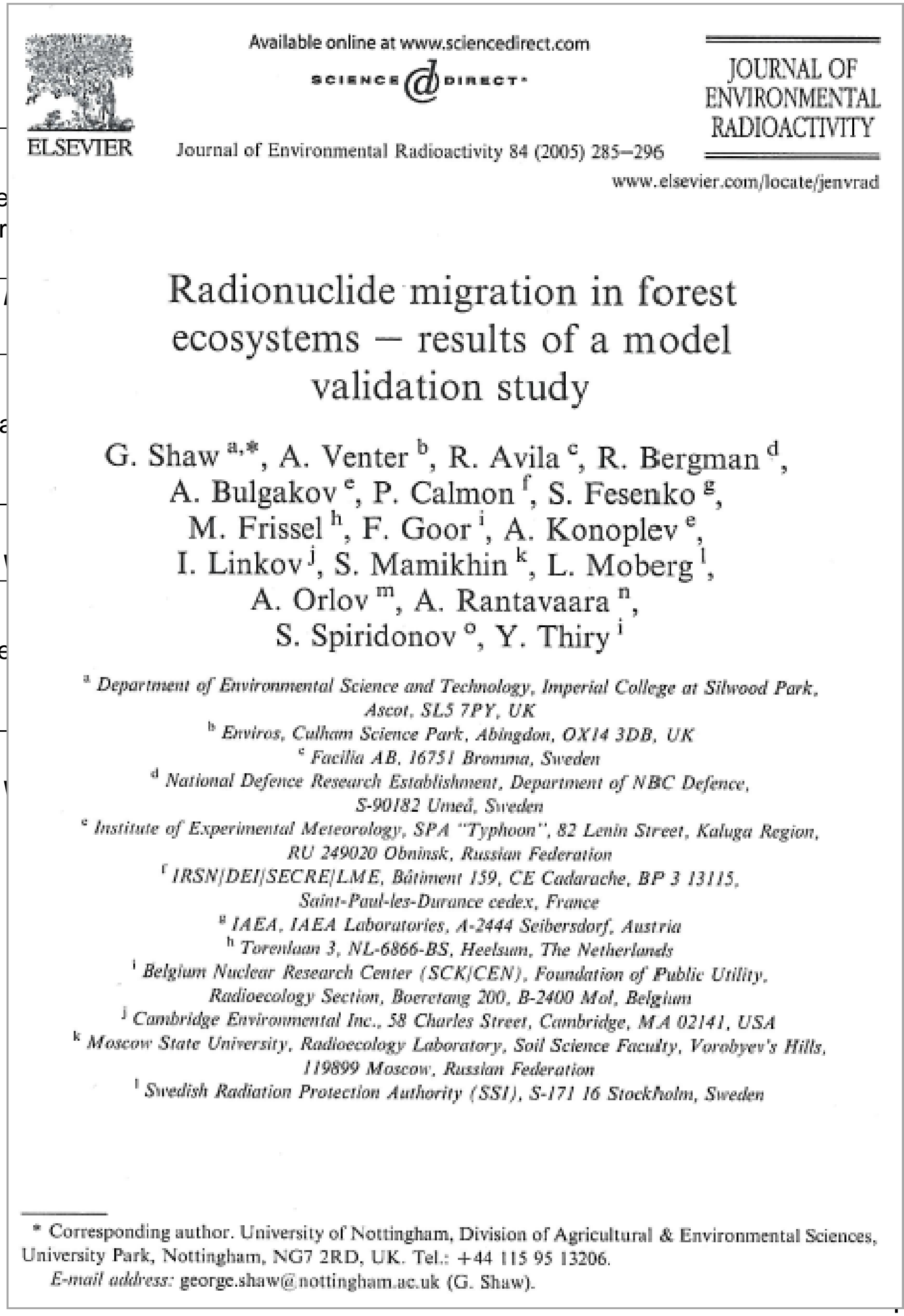
Ecological cycling of materials within forests lead to long-term re-circulation of radionuclides



in Forest Ecosystems

al model
surements of
ine, Belarus and





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Radionuclide migration in forest ecosystems – results of a model validation study

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[k] Moscow State University, Radioecology Laboratory, Soil Science Faculty, Vorobyev's Hills, 119899 Moscow, Russian Federation
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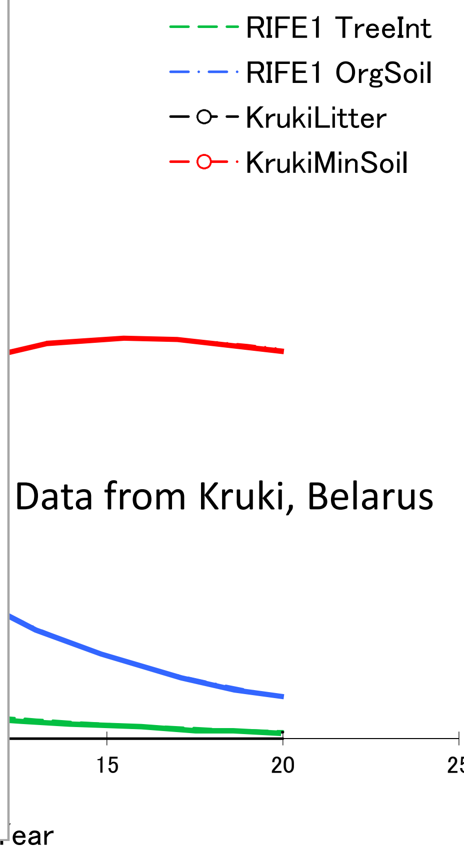
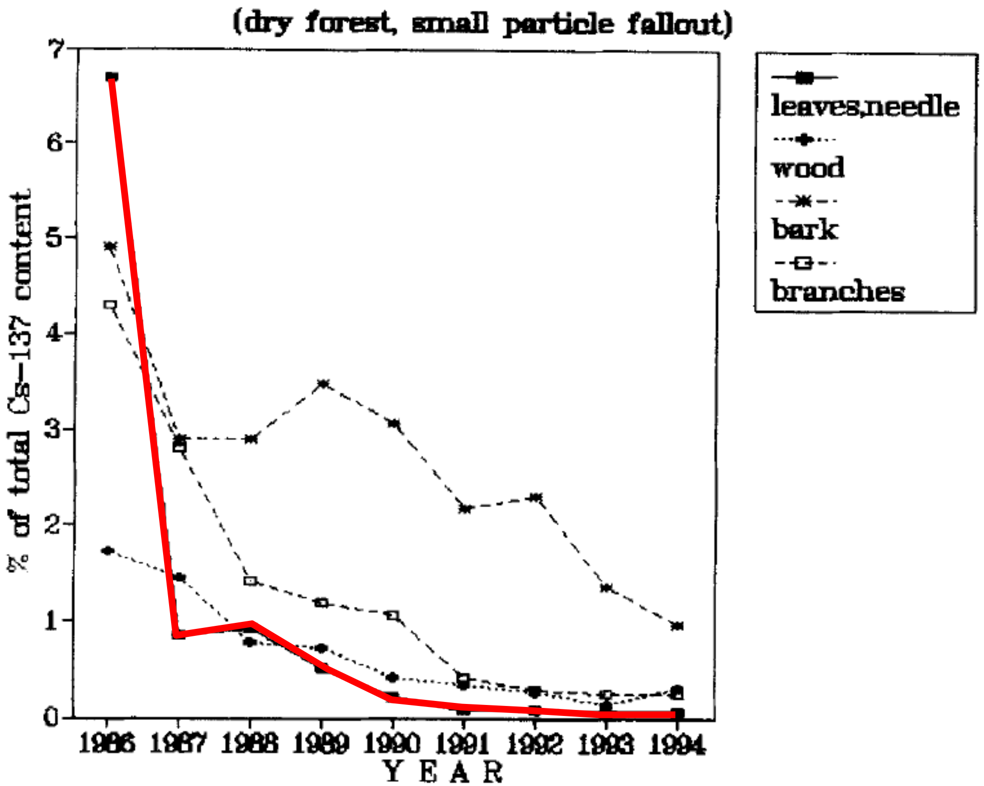
E-mail address: george.shaw@nottingham.ac.uk (G. Shaw).

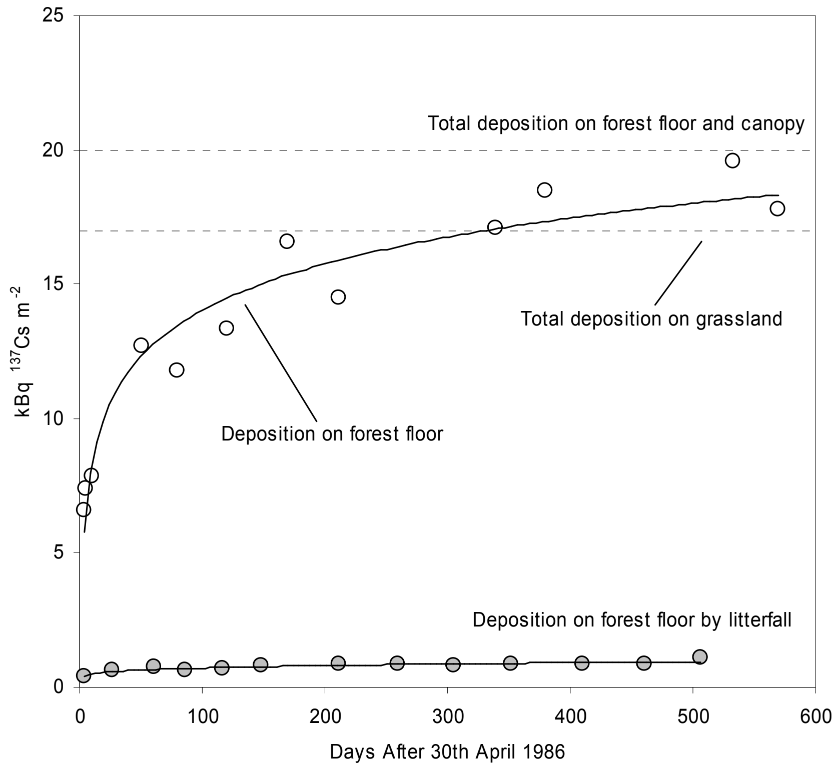


Small airborne radioactive particles are efficiently captured by the forest canopy:

- exposure of trees to β and γ radiation
- gradual transfer of radioactive particles from canopy to forest floor



Dityatki, Chernobyl (Mamikhin et al., 1997)

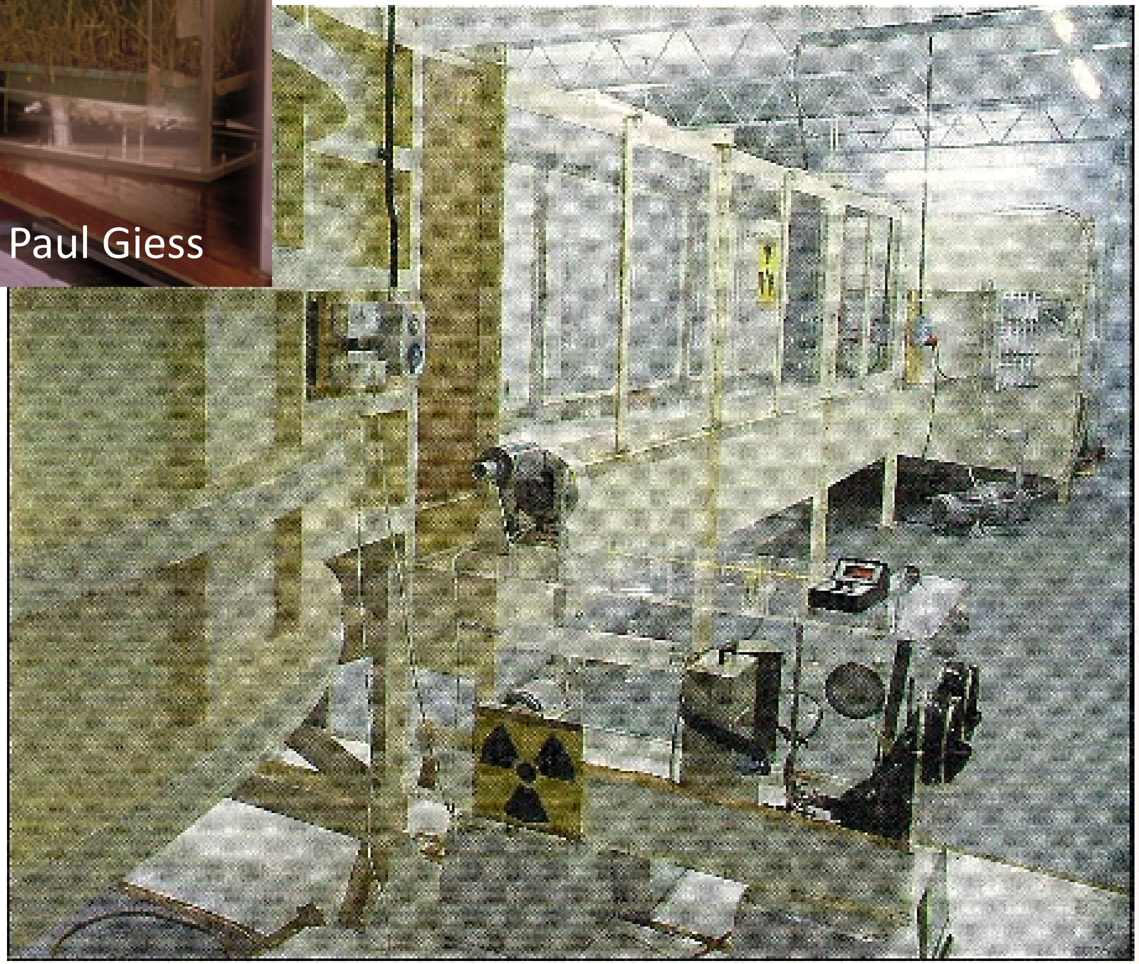


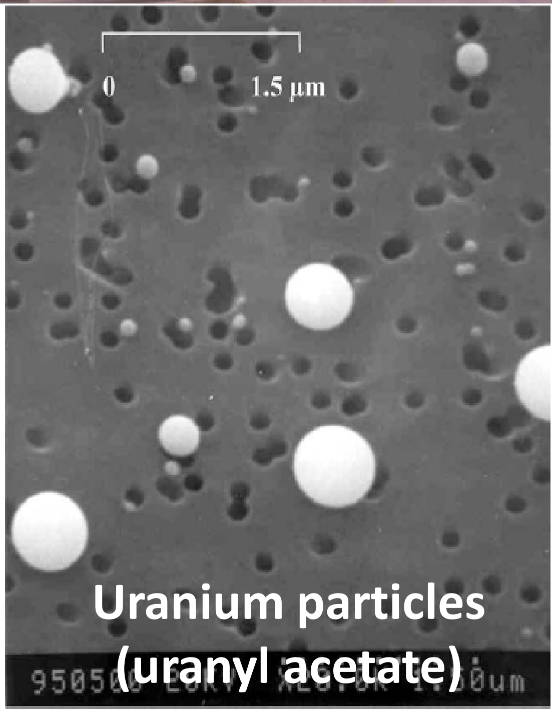
Bavaria (Bunzl et al., 1989)

MAFF / Imperial College
Wind Tunnel, Silwood Park

Paul Giess

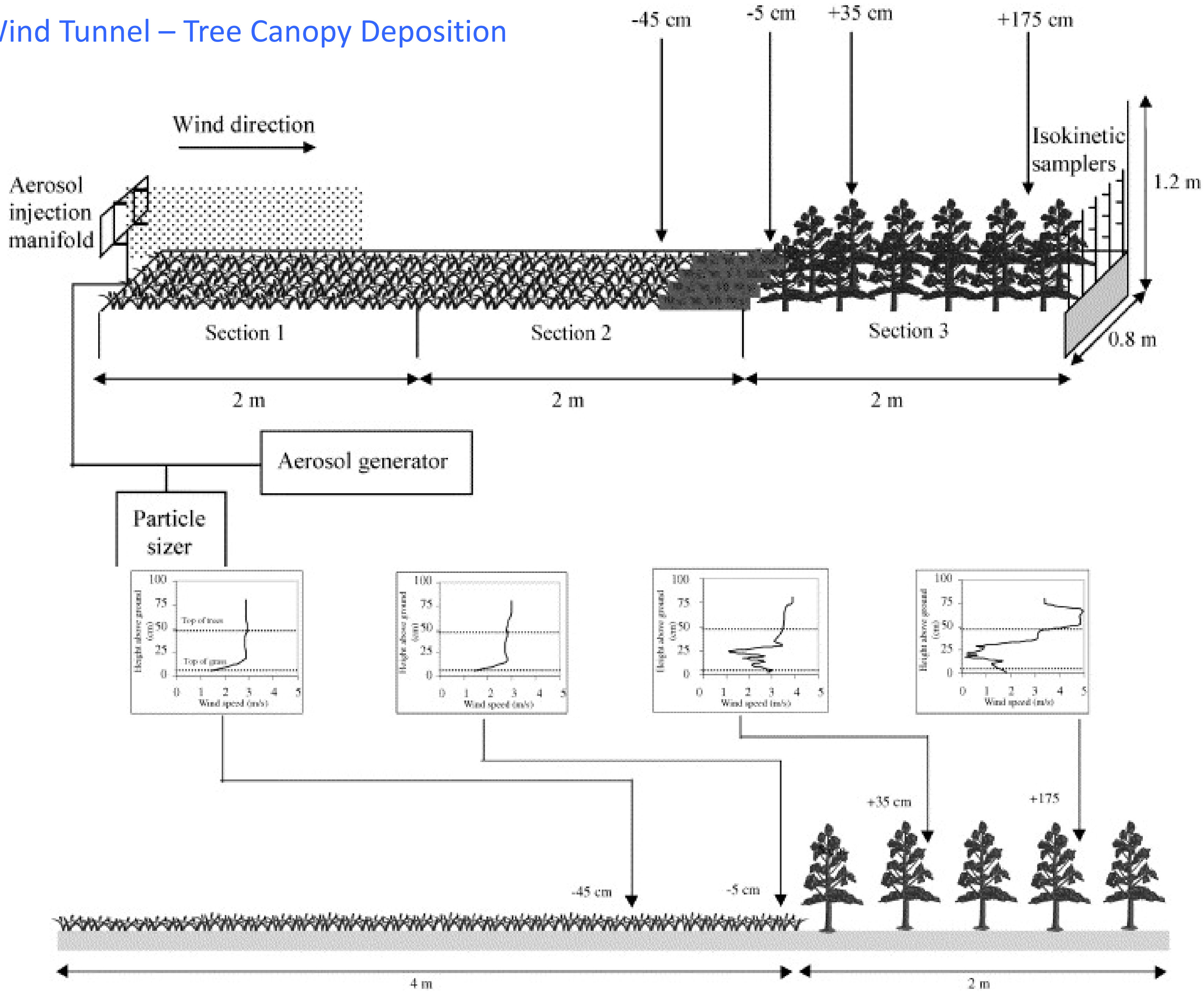
Rob Kinnersley & Zitouni Ould-Dada





Uranium particles
(uranyl acetate)

Wind Tunnel – Tree Canopy Deposition



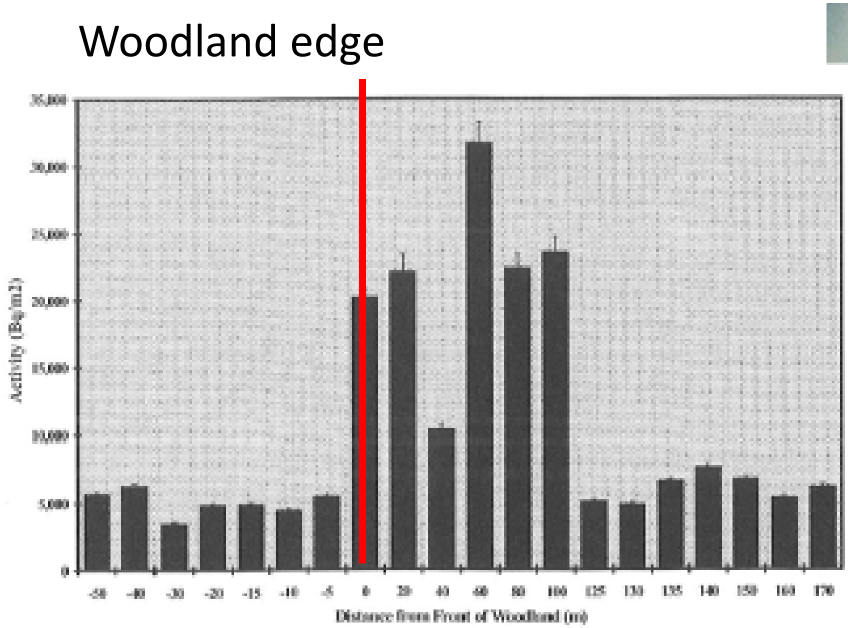
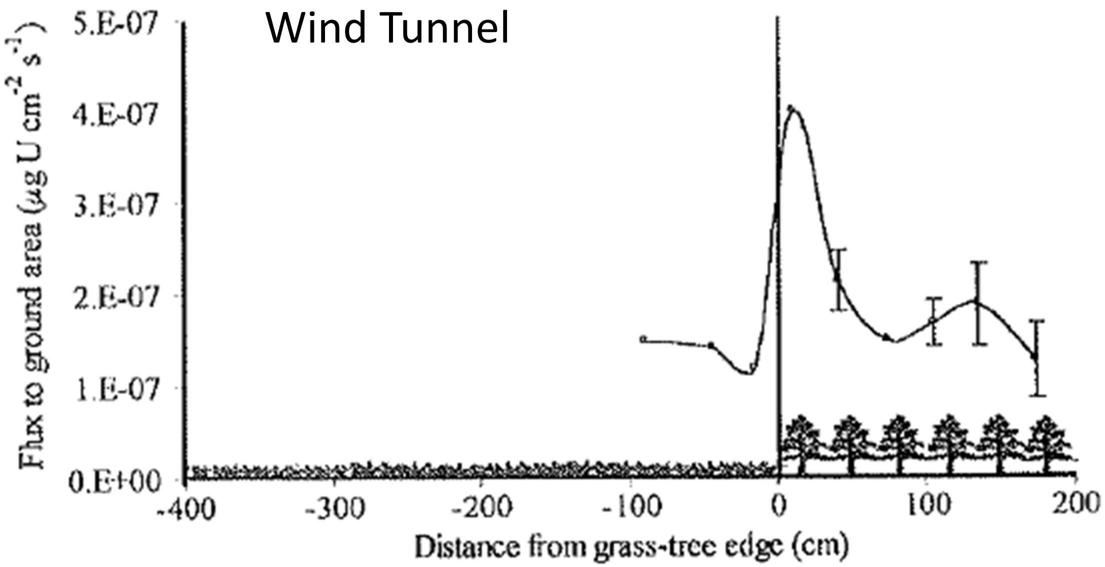
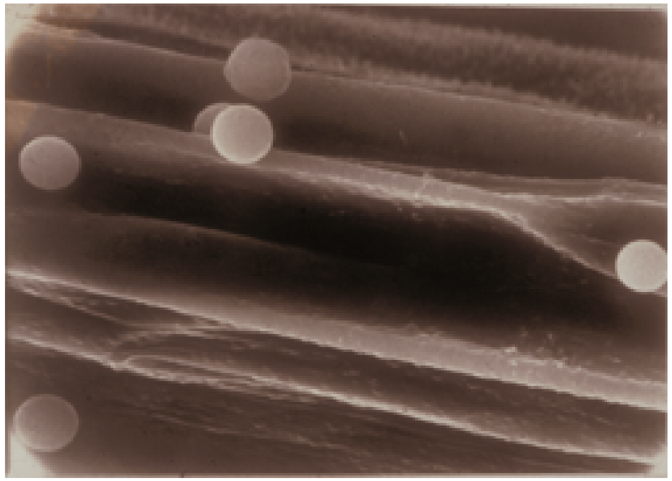


Fig. 8. ^{137}Cs (Bq m^{-2}) deposition in front of, through and behind Lady Wood. Transect 1.





Zitouni Ould-Dada & David Copplestone

Management and remediation options for contaminated forests

- Exposures can occur *in situ* or *ex situ*
- Countermeasure defined as a 'protective action to reduce the dose commitment to human populations' either:
  - Living in forest areas
  - Working in forest-based industries
  - Consuming forest products
- Countermeasures should provide <u>net benefit</u>, taking into account
  - Radiation dose
  - Economic consequences
  - Social impacts
  - Ecological impacts

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Decontamination methods for reducing radiation doses arising from radioactive contamination of forest ecosystems — a summary of available countermeasures

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Cost-benefit analysis of management and remediation options for forests

- Calculate radionuclide distribution within forest compartments
- Calculate radiation doses received via relevant pathways
- Calculate effects of management / remediation options on doses
- Benefits of dose 'averted' ($US / km^2)

  compared with …

- Costs of implementing countermeasure ($US / km^2)
- Probabilistic analysis of:
  - Frequency of 'least cost' option (%)
  - Total detriment of normal operation and least cost management option ($US / km^2)

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A cost–benefit analysis of long-term management options for forests following contamination with ^{137}Cs

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Abstract

This paper provides a description of a cost–benefit analysis applied to determine the cost effectiveness, or otherwise, of nine management strategies potentially applicable to forests contaminated with ^{137}Cs. The management strategies were considered singly and in a number of likely combinations. A management strategy was considered to be cost-effective if it resulted in a lower overall monetary detriment than was incurred if use of the contaminated forest was continued on a 'business as usual' basis. Only the banning of mushroom collection and restriction of public access proved to be cost-effective management strategies on the basis of this definition. However, even these strategies only proved cost-effective at high levels of ^{137}Cs contamination, at which net savings in detriment in the form of public dose were achieved. Cost-effective savings of doses to forest workers were never achieved at any of the contamination levels considered in this study. It is suggested that novel alternative uses of contaminated forests are required which could provide added value to the standing crop in return for small increases in public and worker doses. One such use might be biofuel production. © 2001 Published by Elsevier Science Ltd.

Keywords: Cost–benefit analysis; Remediation; Radioactivity; Forests; ^{137}Cs

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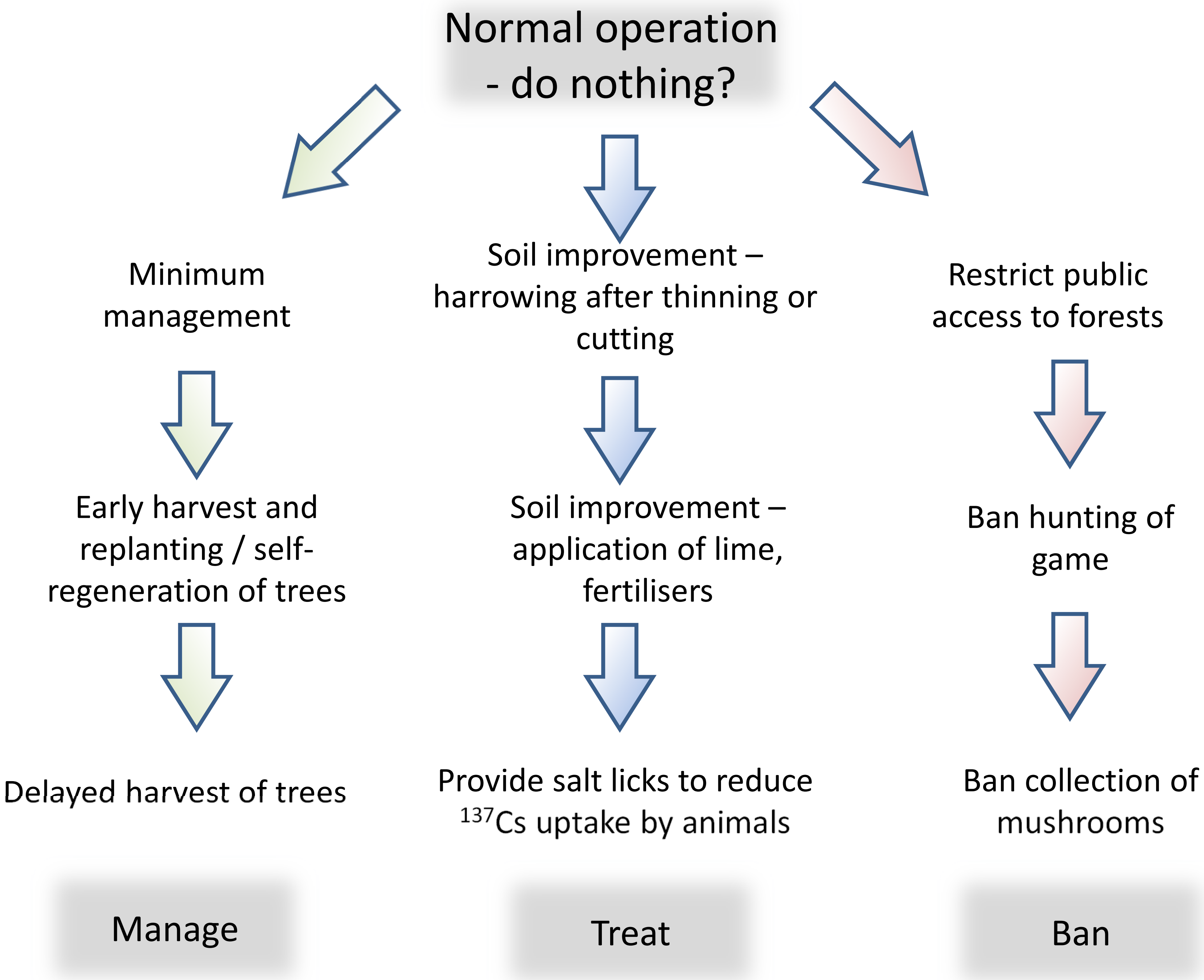

Normal operation - do nothing?
Minimum management
Early harvest and replanting / self-regeneration of trees
Delayed harvest of trees
Soil improvement – harrowing after thinning or cutting
Soil improvement – application of lime, fertilisers
Provide salt licks to reduce ^{137}Cs uptake by animals
Restrict public access to forests
Ban hunting of game
Ban collection of mushrooms
Manage
Treat
Ban

Combined Treatments

Minimum management

Soil improvement – harrowing after thinning or cutting

Restrict public access to forests

Early harvest and replanting / self-regeneration of trees

Soil improvement – application of lime, fertilisers

Ban hunting of game

Delayed harvest of trees

Provide salt licks to reduce ^{137}Cs uptake by animals

Ban collection of mushrooms

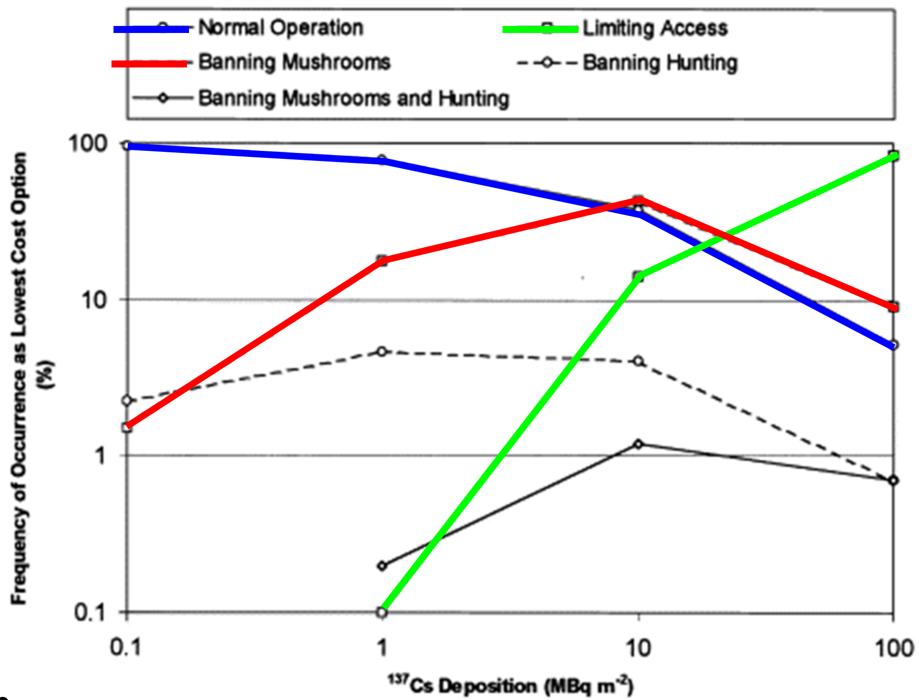
Manage

Treat

Ban

Countermeasures in contaminated forests: cost-benefit analysis

- Do nothing ('minimum management')
- Early or delayed harvest of timber
- Application of soil treatments (lime, fertilisers)
- Provide salt licks for animals (to reduce ^{137}Cs uptake by game)
- Ban hunting of game
- Exclude humans from forested areas
- Ban collection of mushrooms

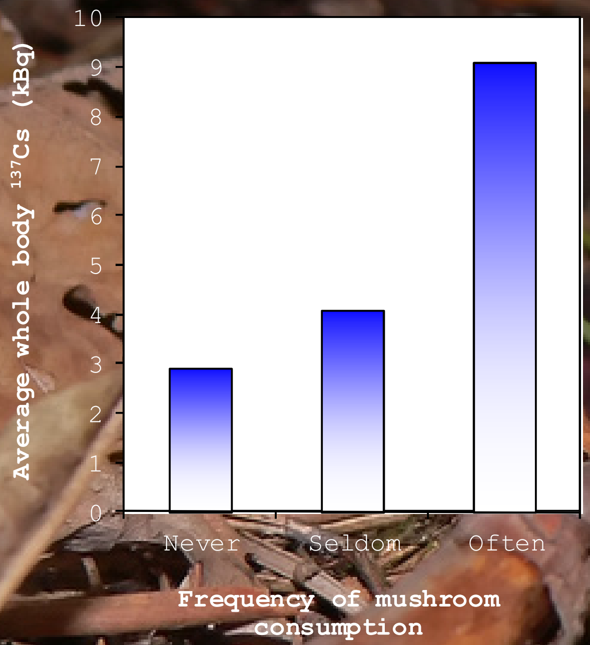


Malcolm Crick, Carol Robinson, Martin Frissel, Elis Holm

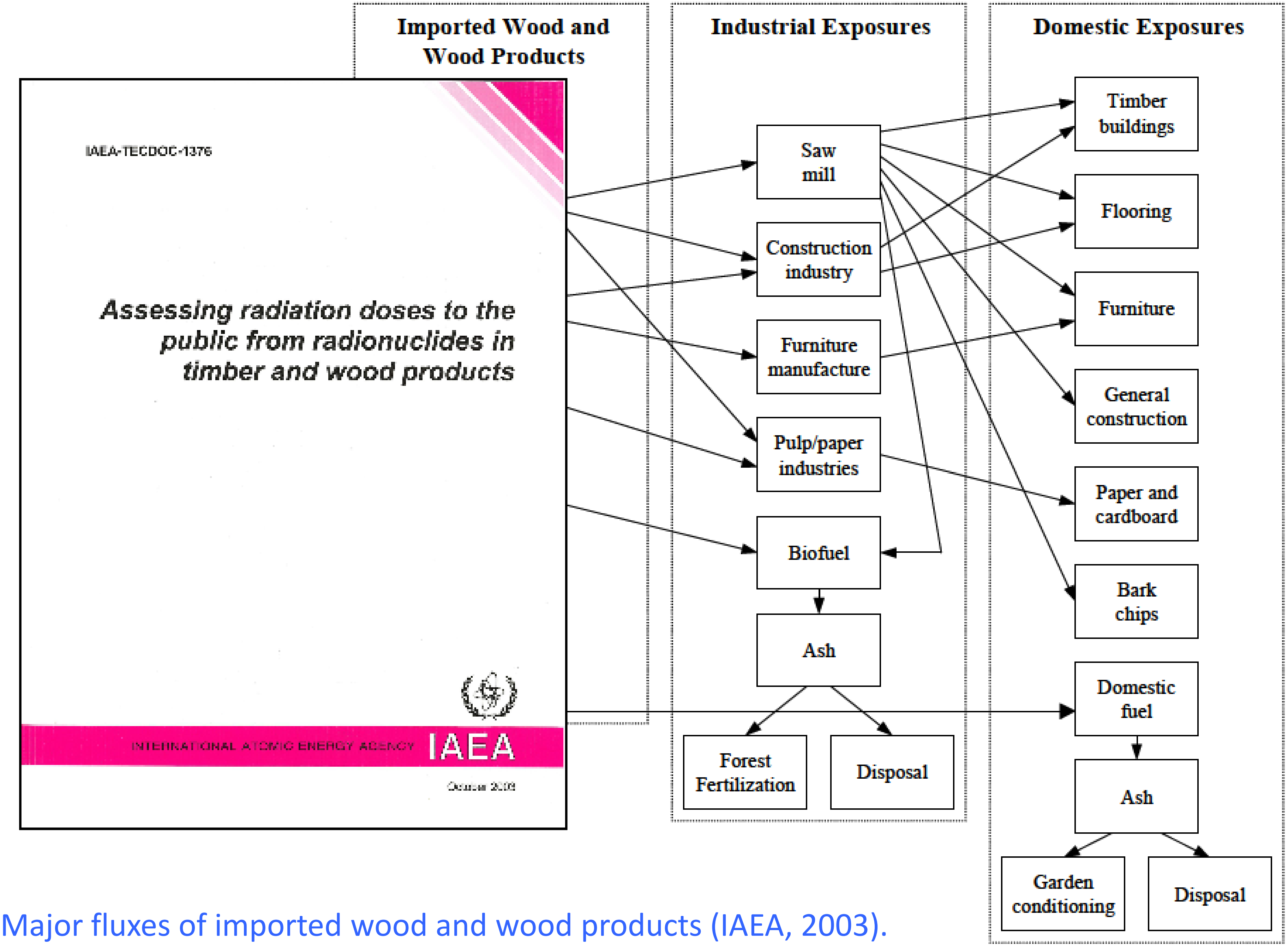
Edible Fungi – a major dietary source of radionuclides

Xerocomus badius Concentration Ratio = 0.2 – 7
Bilberry spp. Concentration Ratio = 0.002 – 0.2
Cereals Concentration Ratio = 0.001 – 0.83

Results of EU survey in Klincy, Russia (Strand et al., 1996)



Xerocomus badius (Bay Bolete)



Major fluxes of imported wood and wood products (IAEA, 2003).

Summary – what did we learn?

- Forests are susceptible to contamination because their canopies efficiently scavenge radioactive particles from the atmosphere
- Seasonal, meteorological and edge effects can lead to a heterogeneous mosaic of radiocaesium deposition
- Natural recirculation mechanisms and low net export of radiocaesium from forests result in long residence times – radioactive decay dictates lifetime of contamination
- Understanding the long-term recirculation of radiocaesium in forests is fundamental to management and (possibly) remediation
- Generic cost-benefit analysis of remediation options suggests that only simple management strategies are likely to be effective, both radiologically and economically
- Site-specific cost-benefit or decision-making analyses are needed to help design specific remediation strategies
- Long-term monitoring of contaminated forests and exported materials is needed

Thank you for your attention

George Shaw
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2nd International Symposium on Remediation of Contamination Site Caused by Fukushima Accident, June 2013

The University of Nottingham