Radiocaesium in terrestrial and aquatic environments: analogues for Fukushima

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Introduction

- The damage to Fukushima Dai-ichi by the Great Tohoku earthquake and tsunami resulted in considerable contamination: After decay of shorter-lived isotopes, off-site concerns mainly involve radiocaesium isotopes (-134 & -137)
- Here there is a huge international knowledge base on the environmental behaviour of radiocaesium accumulated as a result of releases over the last half century
- The SUERC / MCM team have worked in every relevant aspect of this topic, accumulating international, state-of-the-art experience over more than 3 decades

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Relevant international "analogues"

Although not widely recognised, there are many situations worldwide that provide valuable experience which can contribute towards planning and implementing Fukushima remediation

- Major reactor incidents
- Problematic spent fuel ponds
- Other major releases of radioactivity
- Contamination from past radioactive waste disposal activities
  - Releases to land and groundwater
  - Releases to coastal marine environments

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Previous reactor incidents

Reactor	Date	Immediate deaths	Environmental effect	Follow-up action
NRX, Canada (experimental, 40 MWt)	1952	Nil	Nil	Repaired (new core), closed 1992
Windscale-1, UK (military plutonium-producing pile)	1957	Nil	Widespread contamination. Farms affected (ca. 1.5×10^{15} Bq released)	Entombed (filled with concrete); being demolished.
SL-1, USA (experimental, military, 3 MWt)	1961	Three operators	Very minor radioactive release	Decommissioned
Fermi-1 USA (experimental breeder, 66 MWe)	1966	Nil	Nil	Repaired and restarted, then closed in 1972
Saint Laurent-A1, France (commercial, 480 MWe)	1969	Nil	Minor radiation release ?	Repaired (decomm. 1992)
Lucens, Switzerland (experimental, 7.5 MWe)	1969	Nil	Very minor radioactive release	Decommissioned
Three Mile Island-2, USA (commercial, 880 MWe)	1979	Nil	Minor short-term radiation dose (within ICRP limits) to public, delayed release of 2×10^{14} Bq of Kr-85	Clean-up programme complete, in monitored storage stage of decommissioning
Saint Laurent-A2, France (commercial, 450 MWe)	1980	Nil	Minor radiation release (8×10^{10} Bq)	Repaired (decomm. 1992)
Chernobyl-4, Ukraine (commercial, 950 MWe)	1986	47 staff and firefighters (32 immediate)	Major radiation release across E. Europe and Scandinavia (11×10^{18} Bq)	Entombed
Fukushima 1-3, Japan (commercial, 1959 MWe)	2011	Nil	Local contamination, extensive on site	Decommissioning / clean-up being planned

(modified from http://www.world-nuclear.org/info/inf06app.html)

Major activity releases from reactors

- Chernobyl
  - Criticality excursion during tests
  - Explosive release of core contents
  - Long-term releases during / after responses to control fire / criticality
- Windscale
  - Core fire during graphite annealing
  - Extensive releases of volatile components & water used for fire-fighting
- Fukushima
  - Core melt and fuel pond damage after loss of power following tsunami
  - Responses ongoing

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Chernobyl (1986): numbers

- Total release about 14 EBq: about 50% of this noble gases
- I-131 about 1.8 EBq
- Cs-137 about 85 PBq: widely distributed throughout Europe resulting in about 200,000 km^2 with fallout levels > 40 kBq / m^2
- Sr-90 about 10 PBq, Pu isotopes about 3 PBq: most distributed within 100 km of the reactor (due to association with larger particles)
- Residual activity contained within the sarcophagus about 500 PBq

1 GBq = 10^9 Bq, 1 TBq = 10^{12} Bq, 1 PBq = 10^{15} Bq, 1 EBq = 10^{18} Bq

1 Ci = 3.7 x 10^{10} Bq ~ 1 g Ra-226

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The exclusion zone - containing dispersed core

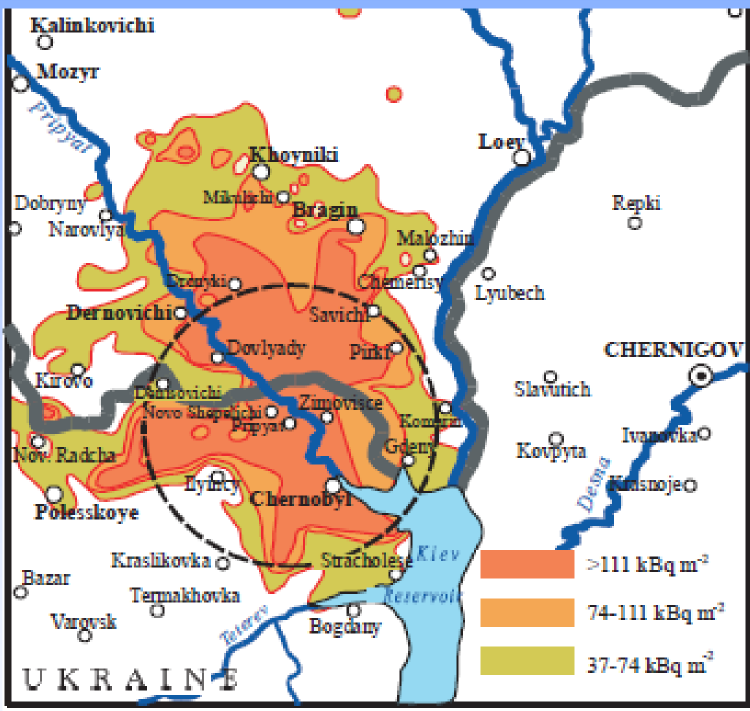


FIG. 3.8. Surface ground deposition of ^{90}Sr [3.4].

FIG. 3.9. Areas (orange) where the surface ground deposition of ^{239,240}Pu exceeds 3.7 kBq/m^2 [3.4].

CEZ - Chernobyl exclusion zone

CEZ not related to Cs levels

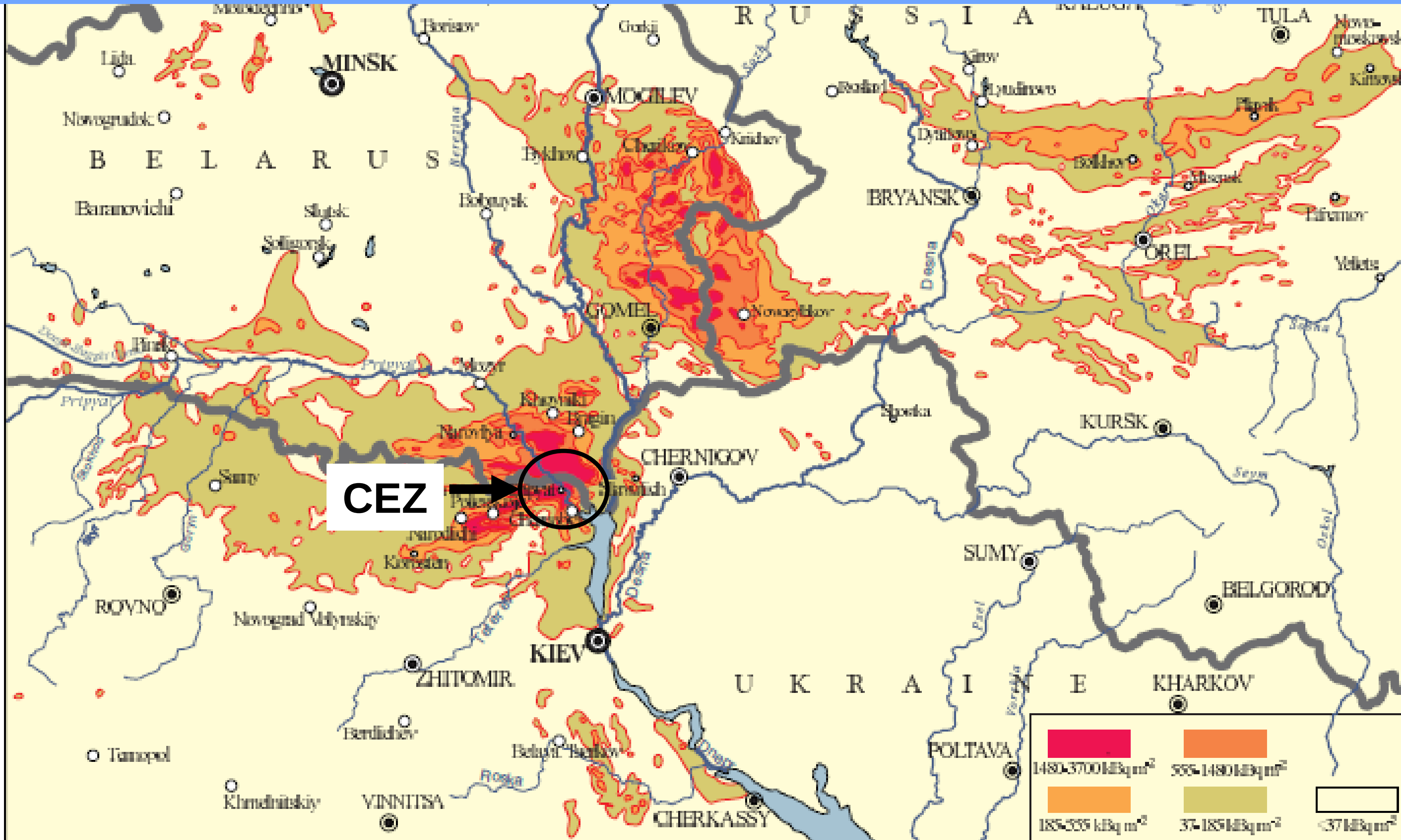
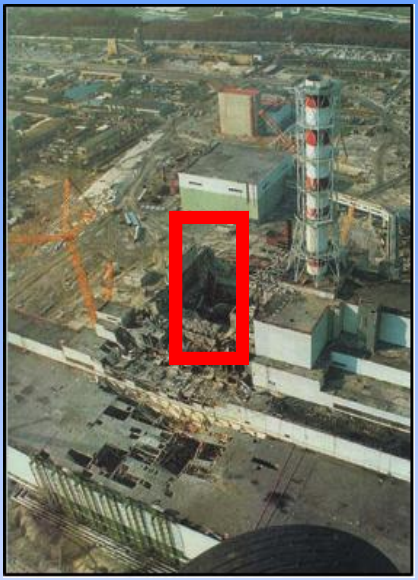


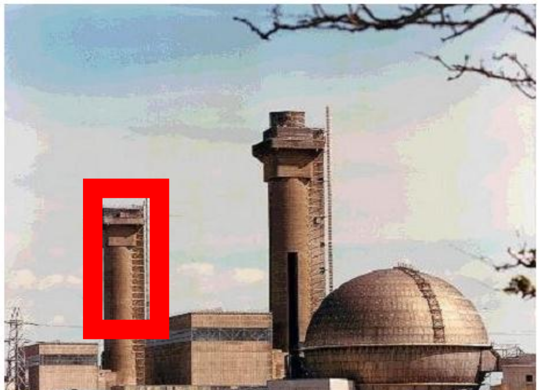
FIG. 3.6. Surface ground deposition of ^{137}Cs in areas of Belarus, the Russian Federation and Ukraine near the accident site [3.4].

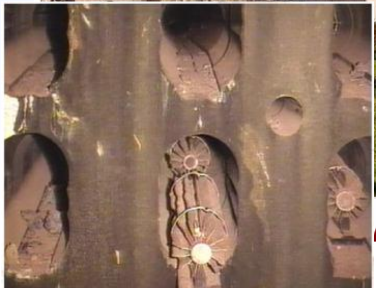
Fukushima releases in context

- Reactors scrammed days before first venting of RN: greatly reduces shorter-lived radioactivity
- Predominantly gases / volatiles released, only minor concentrations of less labile RN: wind blowing mainly towards the sea
- Hydrogen explosions gave only local distribution of slightly contaminated material
- Local populations evacuated and iodine tablets issued
- Although melt-through not precluded, core / corium contained within reactor buildings

Fallout in Evacuated Zone has no similarity to Chernobyl: if anything more like that from Windscale reactor fire of 1957

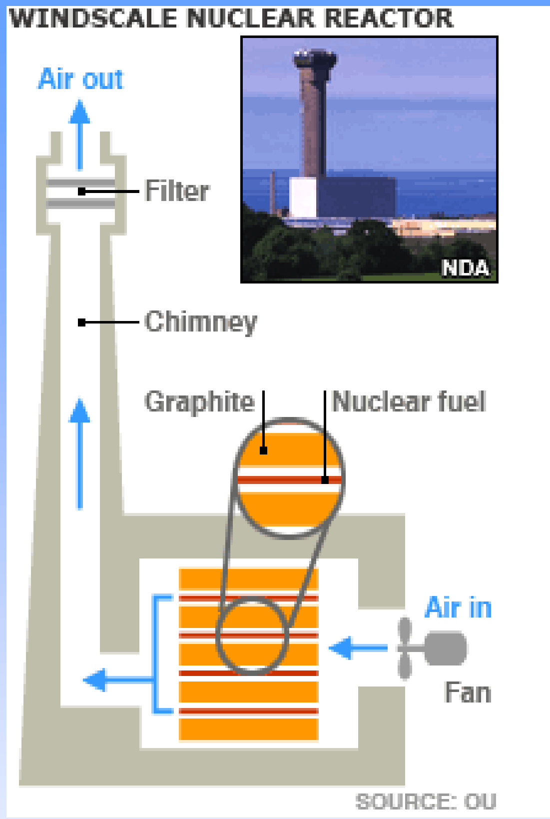


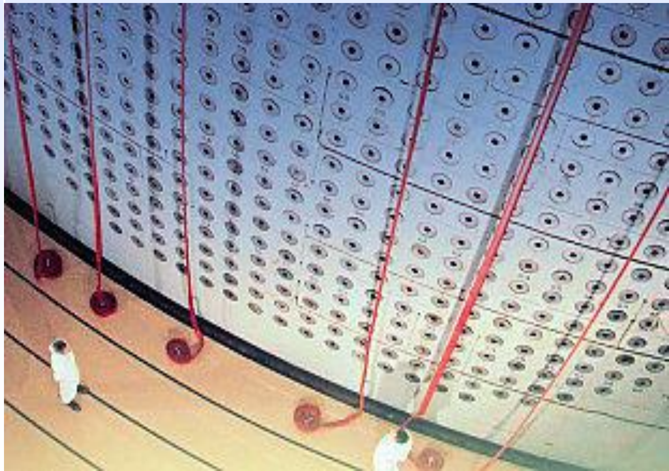




Windscale (1957)

- Activity releases lower (about 20 TBq Cs-137) but maybe more radiologically hazardous than Fukushima (Po-210)
- Initial attempt to conceal accident – no evacuation of highest-exposed local populations during maximum I releases and complete secrecy regarding Po-210 (probable main hazard: possibly resulting thyroid cancers)
- Poor records of operator doses, especially during fire-fighting actions
- Attempts to flood core resulted in large volumes of contaminated water – initially discharged directly into local river
- INES rating of 5 in terms of both immediate and long-term environmental impact debatable due to Po releases – but certainly very much less long-distance impact than Chernobyl (INES 7)





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Windscale: recovery

- Remediation focused on site – no evacuation zone or external clean-up. Releases considerably reduced by filters.
- Off-site activities focused on restriction of dose – e.g. restriction of consumption of contaminated milk over an area of 500 km^2 (especially until decay of short-lived radio-iodine)
- Main concern initially capture and treatment of water used to cool core
- Once stabilised, reactor core entombed; decommissioning not planned until 2037 (80 years after accident).
- Accident effectively forgotten: main area contaminated is major tourist attraction (Lake District).

Other incidents and atmospheric discharges

- A major global source of radioactivity fallout was atmospheric nuclear bomb testing (1945-1980), which released in the order of 2 EBq of long-lived radionuclides. Regional fallout was also important around major test sites (e.g. Nevada Test Site, where over 1000 explosions took place)
- The "Kyshtym" explosion of a high-level liquid waste tank at the secret Mayak site (1957) distributed between 70 - 1900 PBq of radioactivity, leading to long-term contamination of an area of around 800 km^2 (mainly with Cs-137 and Sr-90)
- Wind distribution of contaminated sediment from Lake Karachay (also Mayak site, 1967) spread about 200 TBq of long-lived radioactivity over several thousand km^2
- Hanford releases from reactors / separation plant before filters installed (1944-1947), including around 30 PBq of I-131 and many TBq of longer-lived fission products (Ru-103/106, Ce-144, Sr-90, Pu-239/240)

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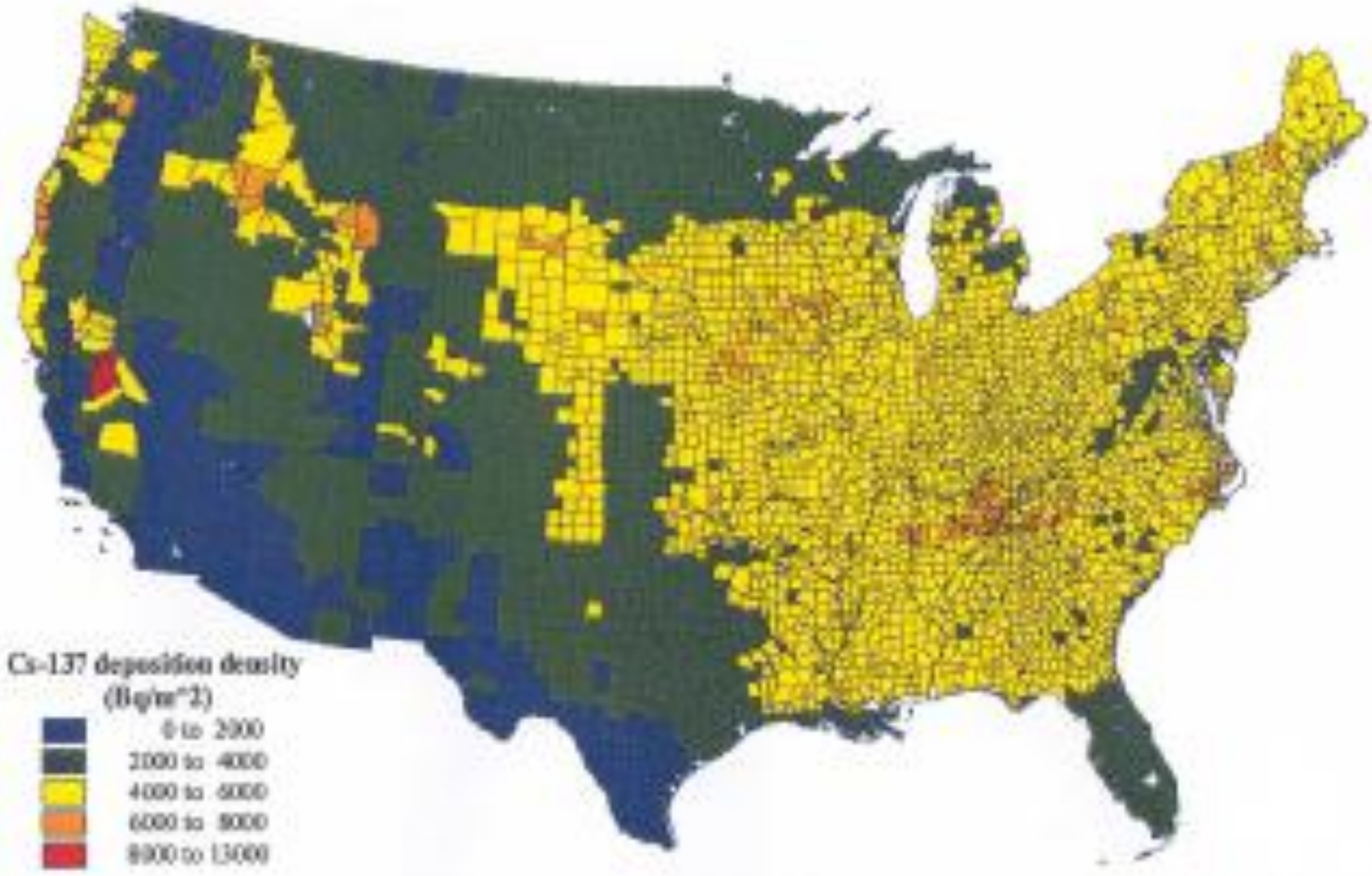
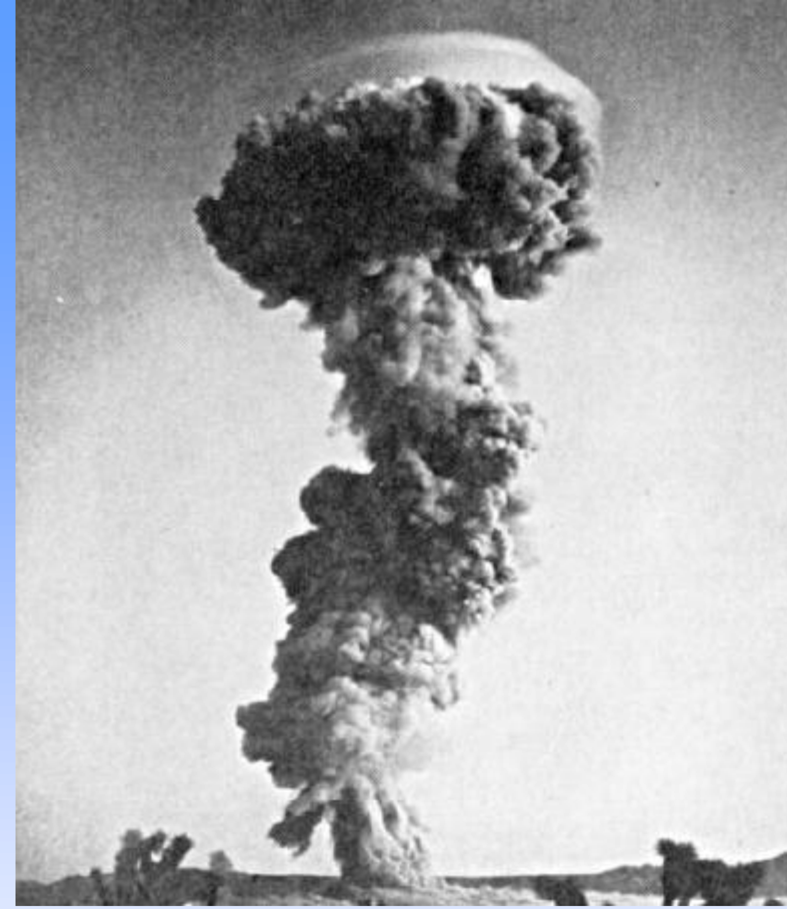
Global fallout



ATOMIC TEST EFFECTS
IN THE
NEVADA
TEST SITE REGION

UNITED STATES
ATOMIC ENERGY COMMISSION
JANUARY 1955



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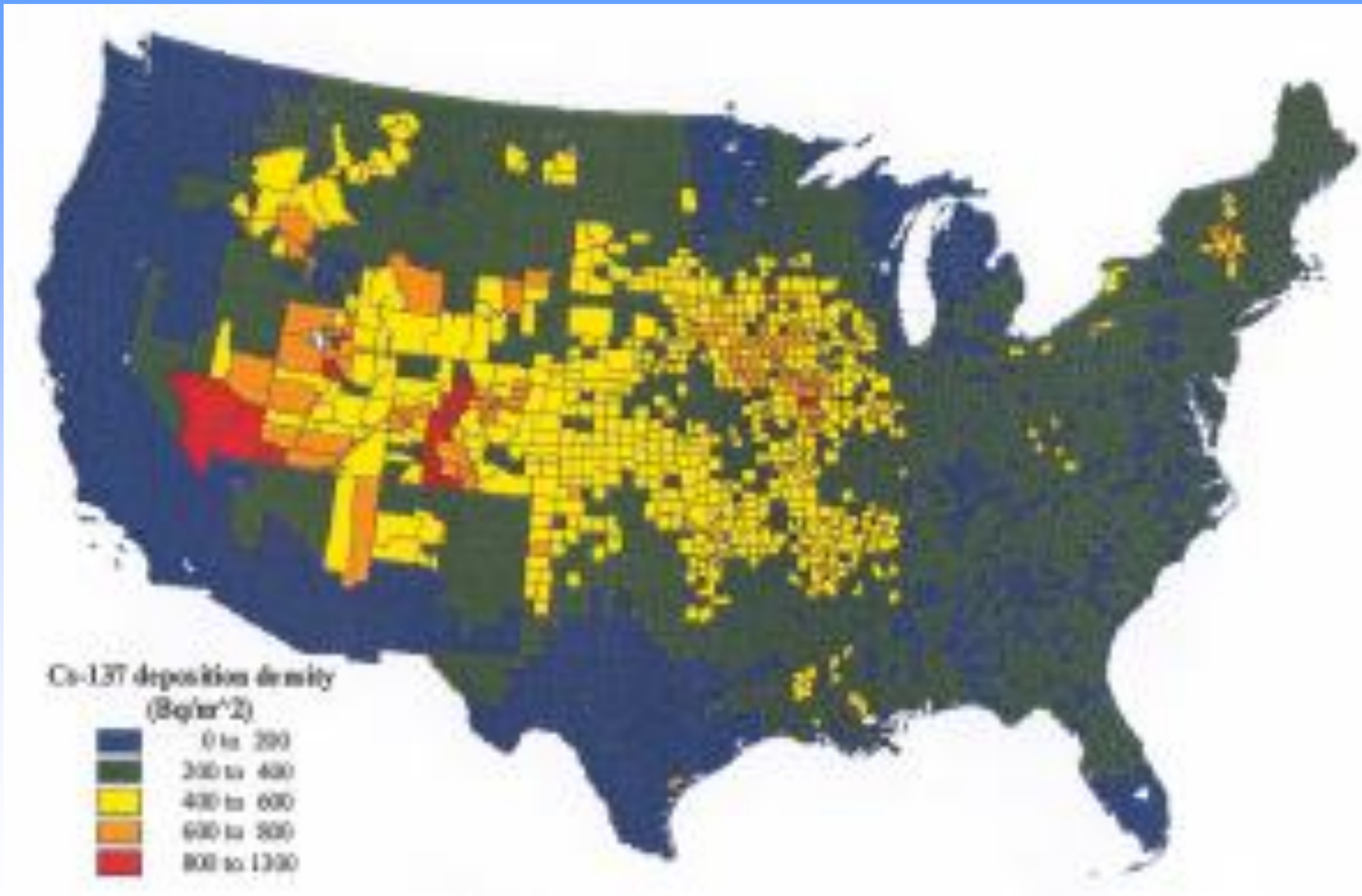
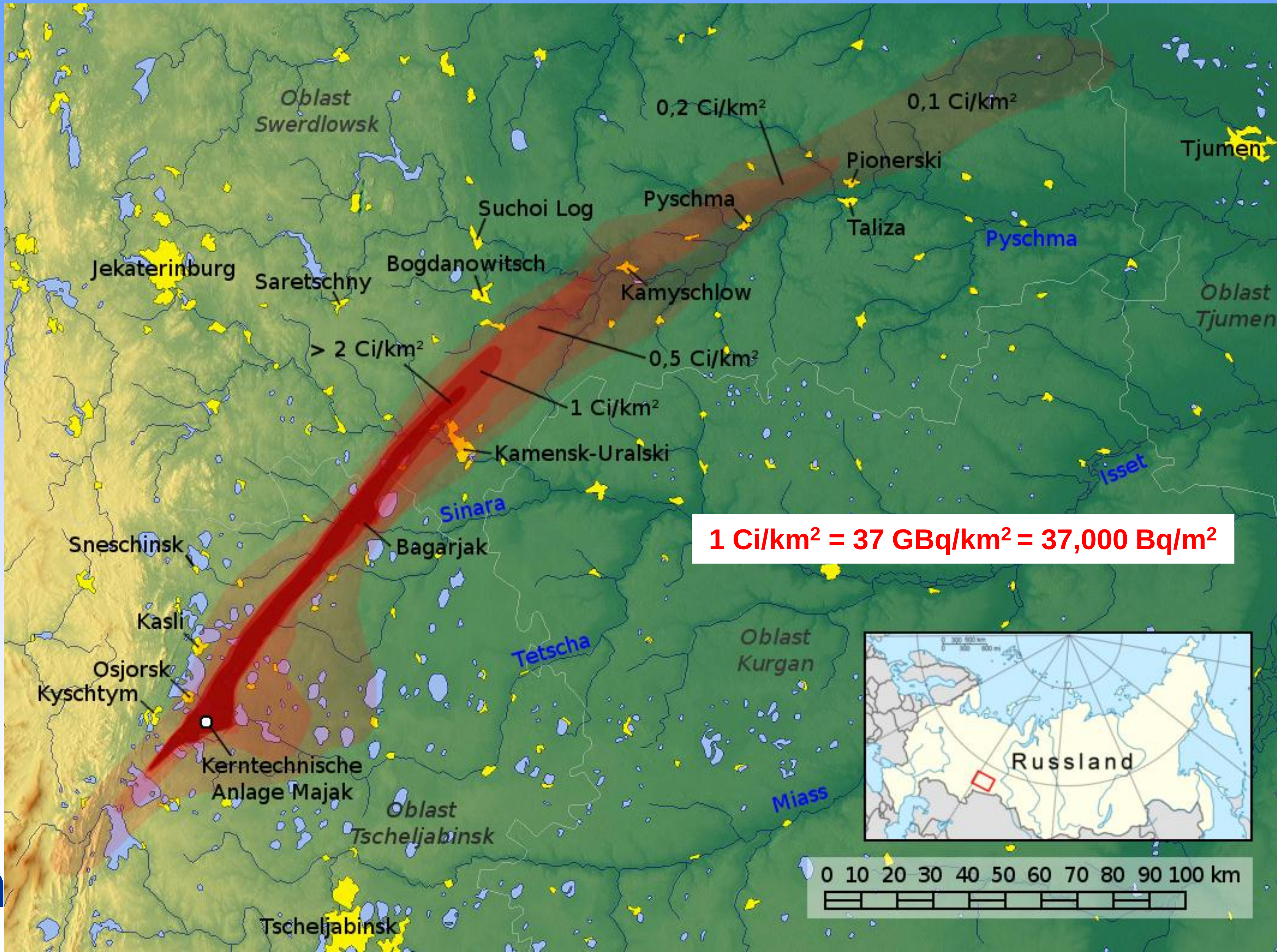
NTS fallout


Cs-137 deposition density
(Bq/m^2)
0 to 200
200 to 400
400 to 600
600 to 800
800 to 1300

Kyshtym plume



Analogue team support?

SUERC / MCM experience (1)

- Measurement of Cs-134/-137 in the environment (from bomb fallout, Windscale, nuclear submarines, Chernobyl...)
- Airborne and surface gamma surveys in contaminated regions and around nuclear facilities: equipment development, intercalibration, use for emergency response
- Long-baseline studies of trace element mobilisation in the environment (analogues, ka timescale)
- Modelling of RN (Cs) movement in water, sediment / soil, rock and the biosphere
- Laboratory measurement of Cs interaction with soils, rocks, microbes, colloids,...
- In-situ (URL) testing of migration models / databases

SUERC / MCM experience (2)

- Literature study and review of past radiocaesium contamination incidents
- Direct involvement in Fukushima contamination assessment and remediation planning
- Multi-decade involvement in the Japanese nuclear programme and close interaction with PNC / JNC / JAEA
- Supporting infrastucture for analysis of all other potentially required stable and radioactive isotopes
- Lead role in development and application of the JAEA advanced Knowledge Management System
- Communication of technical results to key stakeholders and teaching /training at all levels

Why so much experience in Scotland?

Radio-Cs in Scotland: mid ‘70s

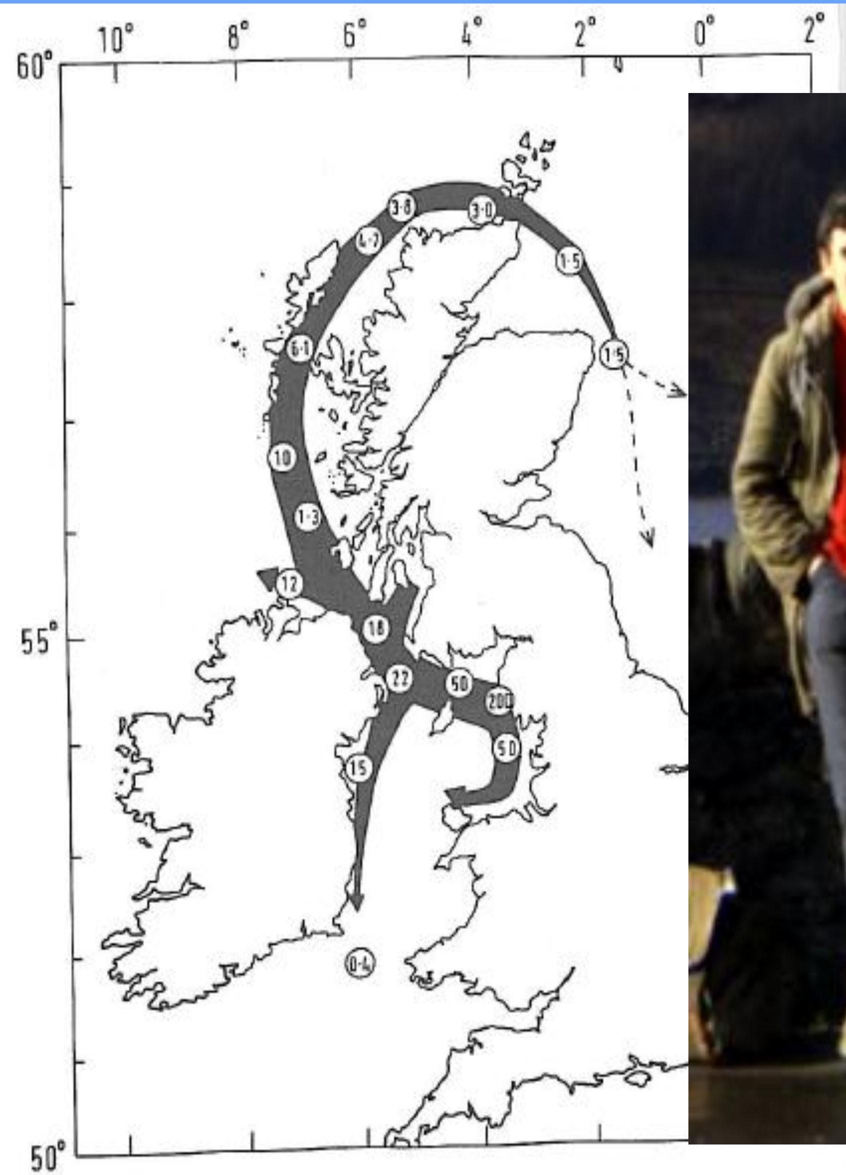
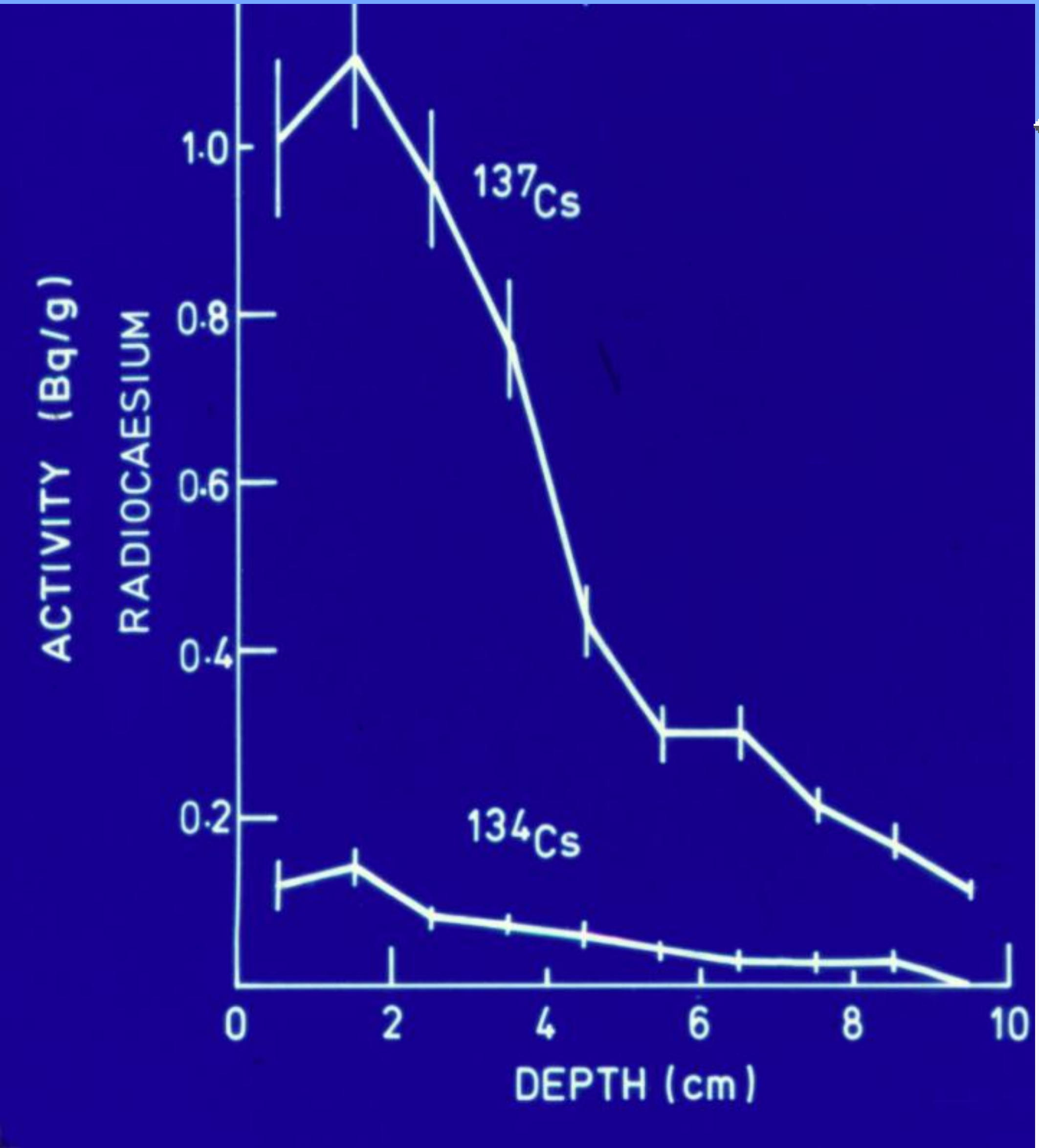


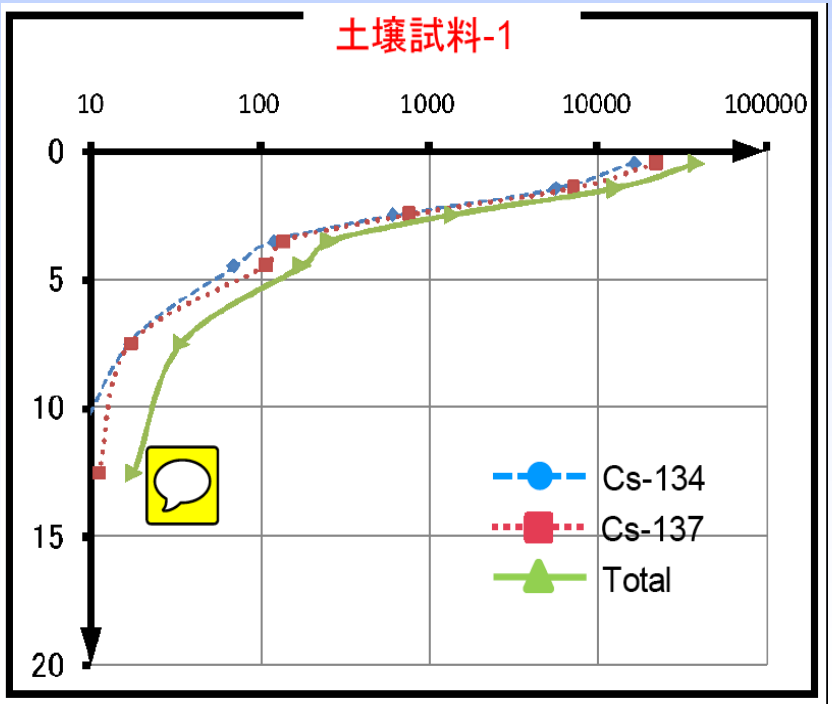
Fig. 1 Concentration of ^{137}Cs (pCi $l.^{-1}$) in UK coastal waters, May/July 1972 (from Jefferies *et al.*, 1973).

- Annual Cs releases to sea from the Windscale reprocessing plant similar to total releases from Fukushima Dai-ichi
- Exciting area for young researchers
- Glasgow University / SURRC (SUERC) internationally recognised in this area

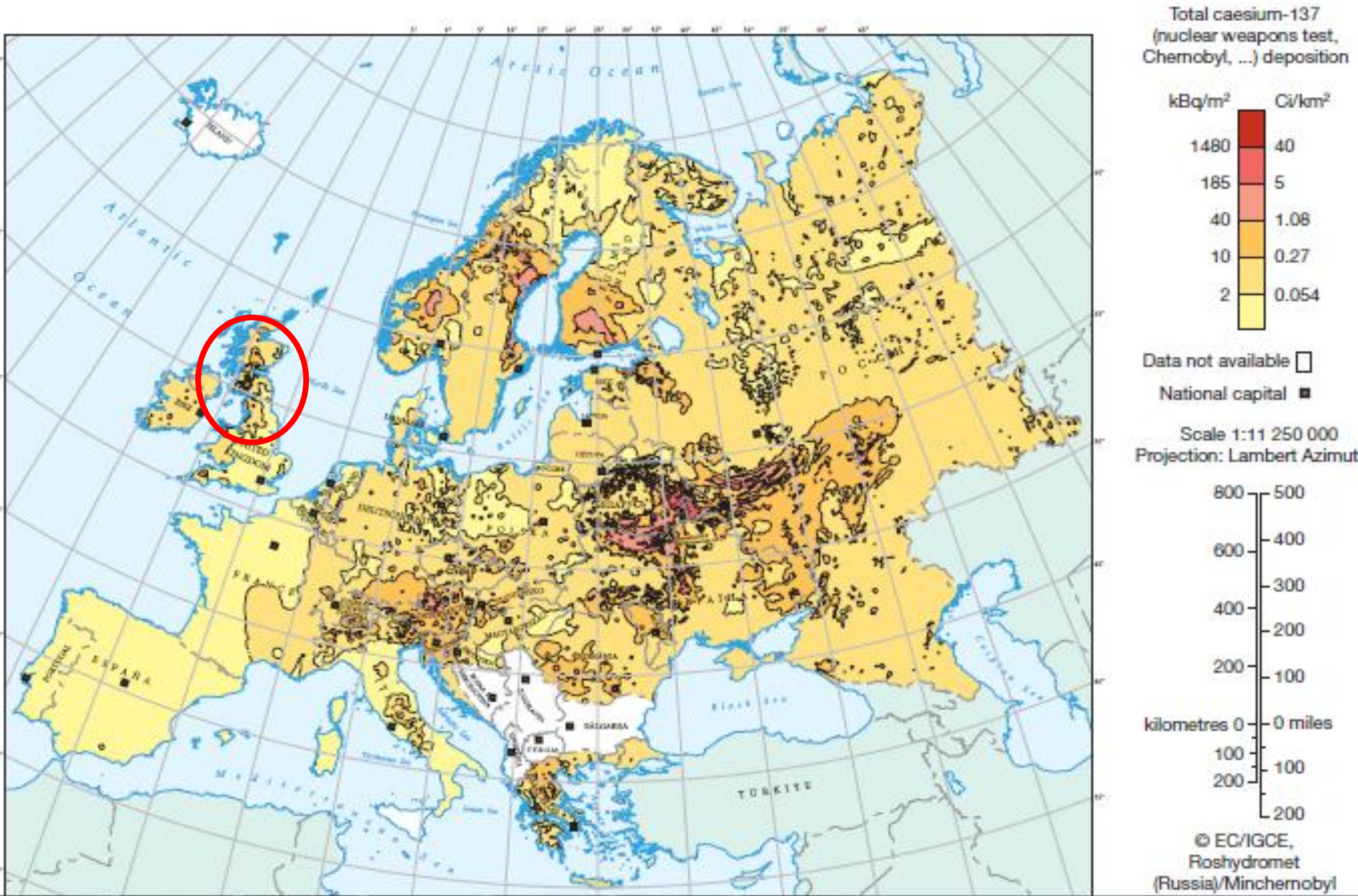
Radio-Cs in Scotland: mid '70s



- Radiocaesium profile in marine sediments very similar to Fukushima soil!
- Models developed to simulate transfer from Windscale to the water and sediment of the Clyde Sea Area (analogue / digital)

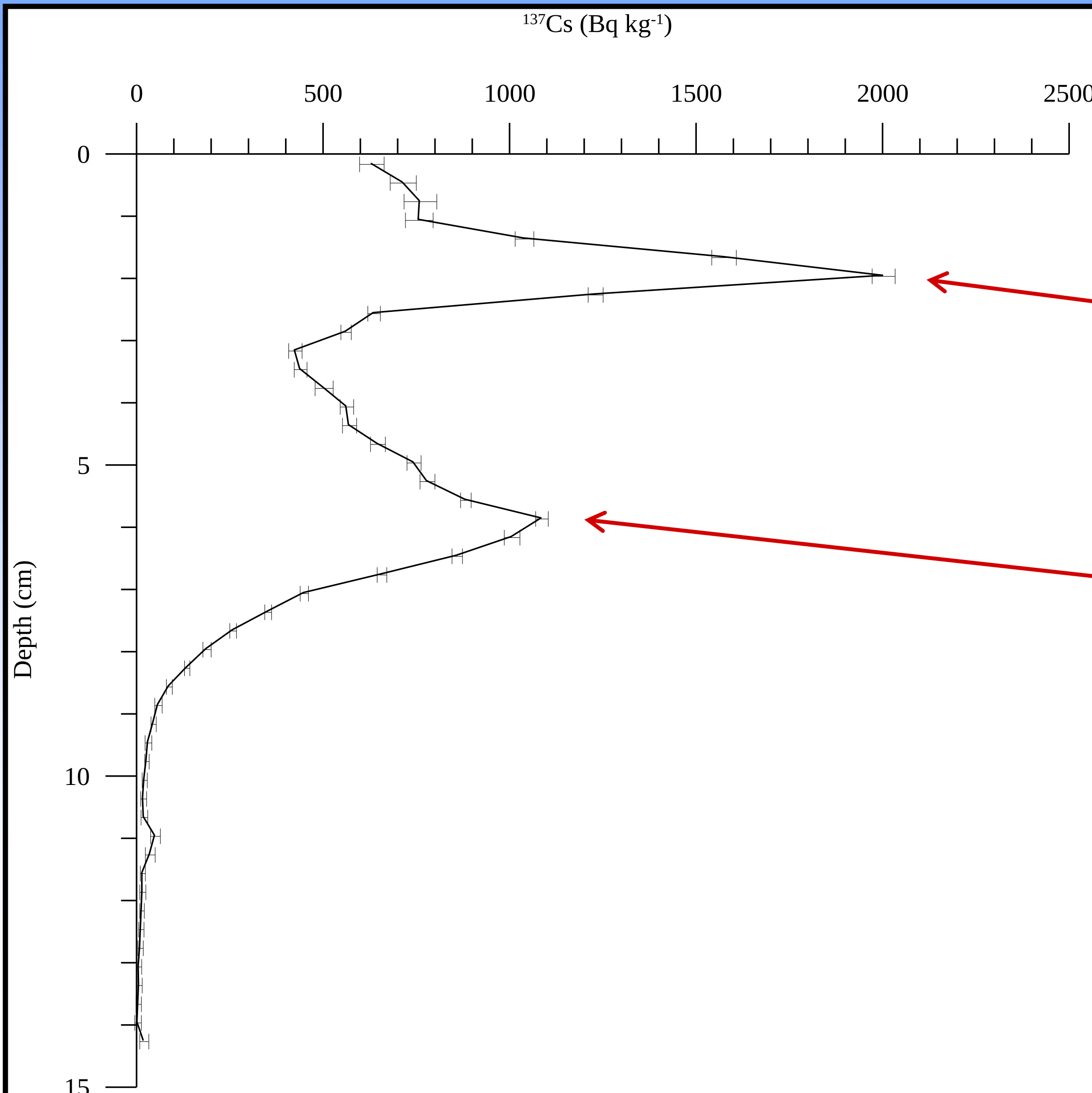


Large scale Cs-137 distribution



Radio-Cs in Scotland: now

Freshwater sediment profile (Loch Lomond)

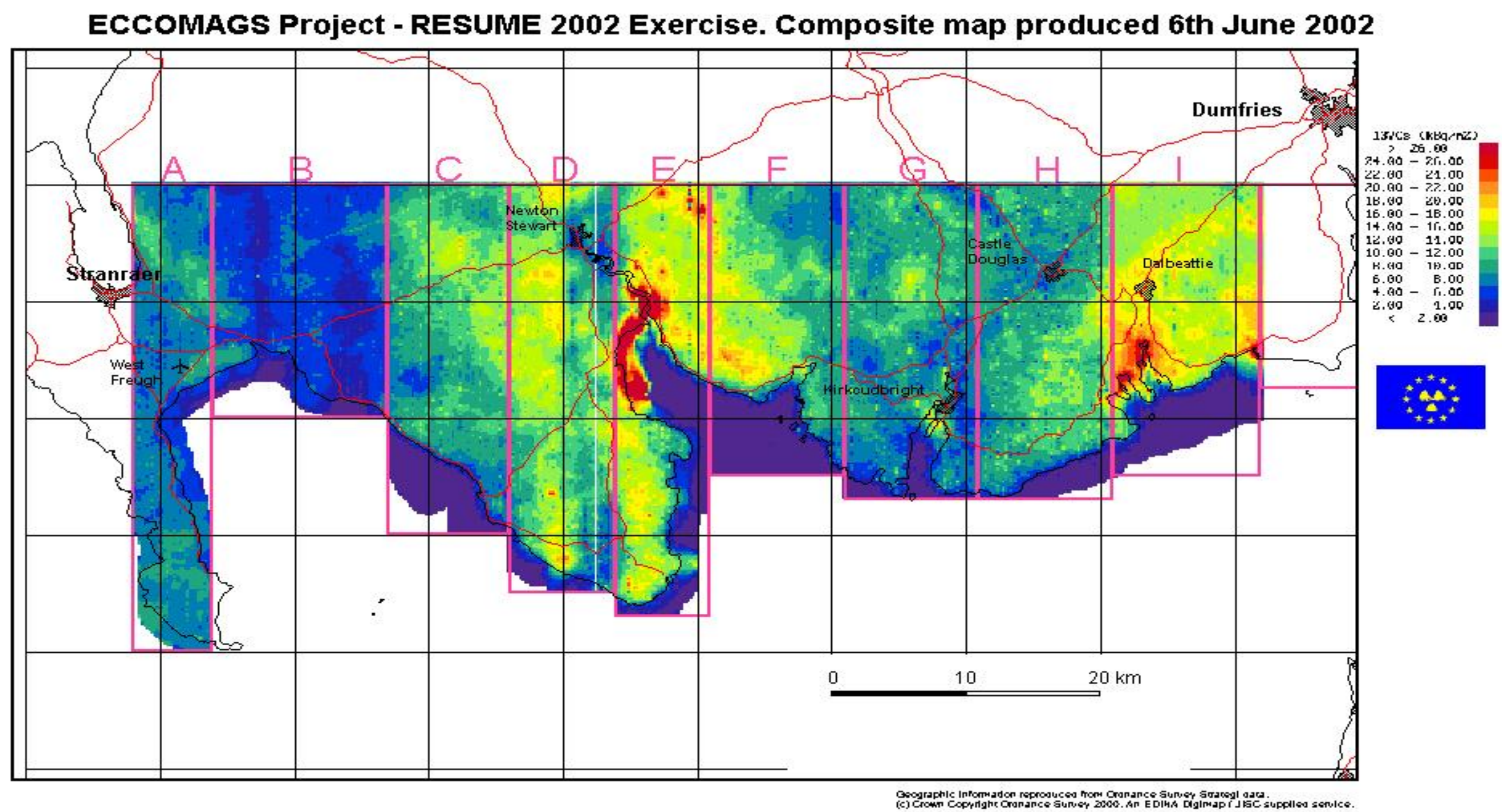


Chernobyl 1986

Bomb fallout peak 1963

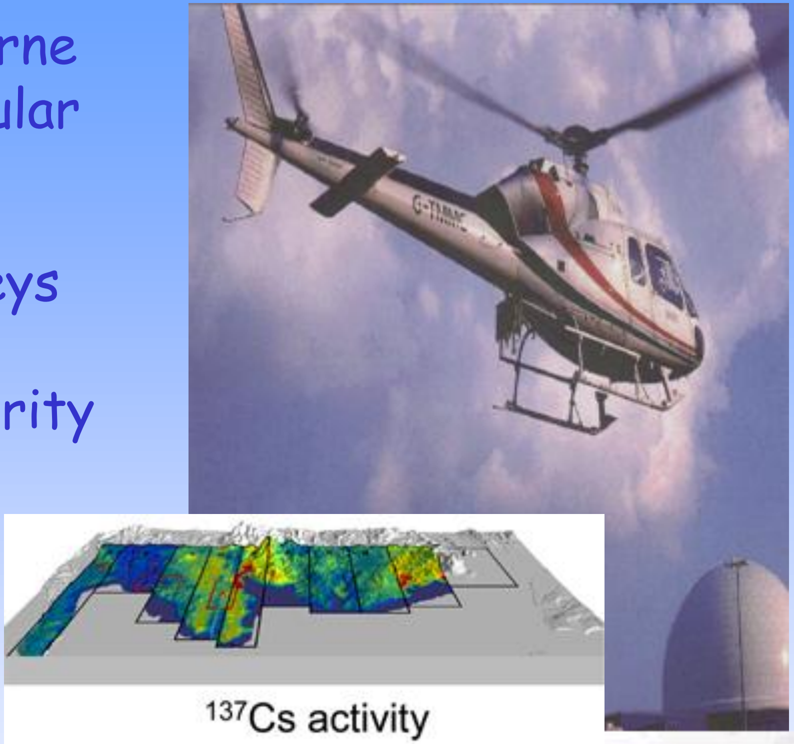
Radio-Cs in Scotland: now

- *Gamma-survey international intercalibration exercise in Scotland*



Aerial and Vehicular Gamma Survey

- Unique capability for conducting airborne gamma spectrometry (AGS) and vehicular radiometric surveys
- More than twenty environmental surveys have been completed in the UK and overseas including studies of the majority of UK nuclear sites
- Research techniques and calibration procedures including Monte Carlo simulation (20+ years)
- SUERC has been at the forefront of establishing European co-operation and co-ordinating method development at international level
- Gamma-ray spectrometer calibration pads



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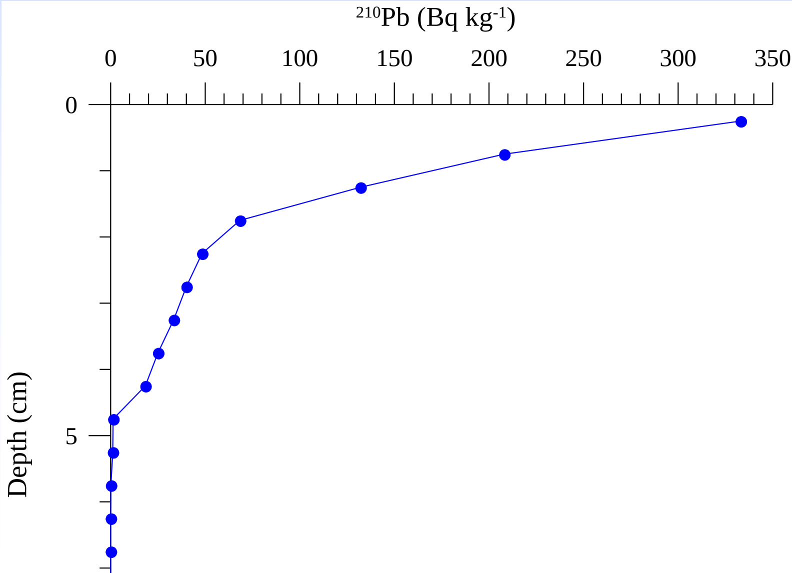
Sampling methods / analysis

- Experience in all aspects of environmental sampling, including concentration methods for low concentrations in solution and coring in terrestrial and underwater settings.
- Analytical capacity to determine key supporting information such as sedimentation rates



Communication!

- There is little doubt that fear of radiation will probably cause more health effects than the radiation itself: this is a real effect and must be addressed via improved communication
- There has been a massive loss in trust and credibility: this must be regained by government, government agencies and all involved technical groups before meaningful dialogue can be established
- Recovery is possible only when communities understand the future cleanup of the environment – both natural and via remediation: communication should be a focus for all work carried out

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Collaboration options

- How can we best support recovery of the Fukushima region?

...Hanami in Scotland?