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Remote sensing technology in use in the Fukushima area

David Sanderson

Meeting Challenges for Fukushima Recovery

Unix Building Fukushima, Japan
6th-9th October 2014

Remote sensing technology in use in the Fukushima area

- Roles for Radiometrics based on remote sensing
  - Some of the challenges
- Remote Sensing Technology already used in the Fukushima area
  - AGS (manned and unmanned) CGS, portable systems
  - Examining urban areas and forests
  - Interpretation of forest Cs evolution
- Needs for integration, intercalibration
- Plans for future actions
  - Access to remote sensing output
- Ideas for future development to meet Fukushima challenges

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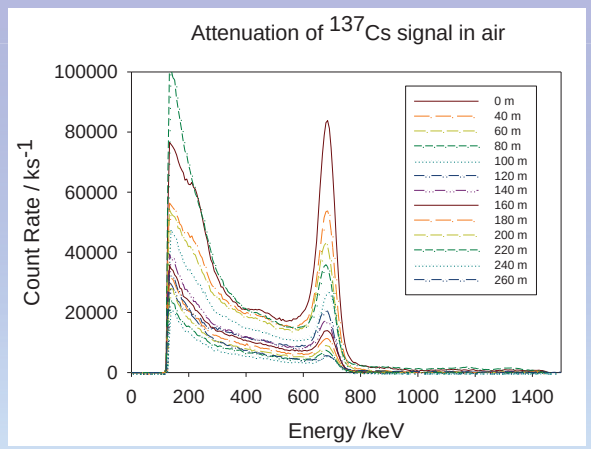
Remote detection of radioactivity and radioactive sources

- **Radiological safety of personnel and public**
  - In natural and built environments
  - In emergency response
    - Nuclear Reactor accident response
    - Nuclear Weapons accidents
  - Early/Intermediate and Recovery phases of event response
  - Security applications

- **Passive detection using gamma rays**
  - Range, energy, air attenuation, field of view
  - **Static and mobile options**
    - *Fixed detector : dynamic source* (eg portal monitors, static networks)
    - *Mobile detector : static source* (airborne, vehicular, portable)
    - *Mobile/Mobile* ; dynamic sensor networks and big data.....



Airborne (50-100m agl) MDL 10^5-10^6 Bq (10^3 Bq m-2)

- 10^3 readings hr^{-1}
- 10^7-10^8 m^2 hr^{-1} survey rate

Carborne (2-3 m agl) MDL 10^4-10^5 Bq; (10^2-10^3 Bq m-2)

- 10^2-10^3 readings hr^{-1}
- 10^4-10^6 m^2 hr^{-1} survey rate

Portable systems MDL <10^4 Bq; (10^2-10^3 Bq m-2)

- 10-10^2 readings hr^{-1}
- 10^3-10^4 m^2 hr^{-1}

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Roles for Radiometrics on the pathway to recovery

Emergency | Recovery | Normality

Pre-accident | early | transitionary | late

Maintenance of competence and preparedness

Emergency exercises

Activities to promote trust and respond to societal needs

Baseline studies dissemination and educational activities

Urgent actions to understand contain and mitigate the situation

Countermeasure decisions, based on available information (Iodine prophylaxis, shelter, relocation)

Breakdown of consensus

Radiometric data needed to define contaminated areas, to characterise radionuclides, to justify and modify countermeasure decisions, and to provide an evidence base to inform the recovery, and for public information

Revision of countermeasures, initial restoration activities

Many actions reactive, using available systems, and driven by events

Analytical approaches undergo rapid development, adaption and extension. Innovative techniques emerge. Lack of validation,standardisation coordination

Limited predictive modelling, available models inadequately constrained by data

Radiometric data urgently needed to define and assess remedial actions and to help improved public understanding and knowledge

Transition towards planned, proactive measures, supported by evidence and backed by consensus

Modelling supported by dense validated data, structured on fundamental knowledge; increasing capability for predictive output

Radiometric data needed to inform models, to register change, to revise remedial actions, to justify relaxation of interventions to contribute to restoring public confidence

Activities to ensure that lesson learned are not lost

Maintenance of competence

Activities to promote trust

Baseline studies and dissemination

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Some of the challenges

Pre-accident | Emergency | Recovery (early | transitionary | late) | Normality

- Data are needed at spatial scales ranging from national (>1500 km), regional (100 km), local (0.1-10 km), domestic (1-100m) and sampling scales (0.02-0.1 m), down to microscopic scales
  - Radionuclide behaviour may be determined at submicroscopic scales
- On time series which are appropriate to the dynamics of radionuclide decay and redistributional processes
- Diverse systems used, which need to be integrated
- Traceable calibrations are needed between methods and between different institutional and community groups
- Data should be accessible, and available for interpretation and assimilation together with realistic estimates of uncertainties
- Better models are needed to describe radionuclide distribution and behaviour, and to accomodate complex topography and nuclide fluxes

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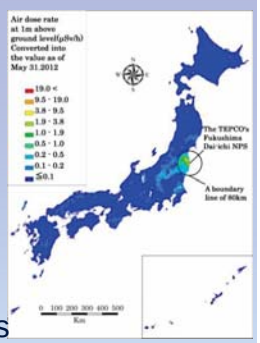
Remote Sensing Technology already used in the Fukushima area - AGS from manned aircraft

National & Regional Scales (100-1000 km)

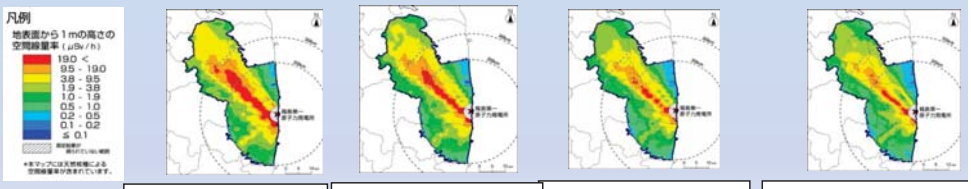
Spatial resolution on ~ 0.1-5km scale

Initial Japanese & US delivered dose rate maps with deposition estimates on contrained isotope ratio.



High volume NaI Spectrometers mainly used. Elsewhere CsI and combined scintillation and high resolution systems have been used

Cross validation and harmonisation needs



After 7 months (2011.11.05)	After 15 months (2012.06.28)	After 20 months (2012.11.16)	After 30 months (2013.09.28)

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Acknowledgement : Dr. T. Torii, Dr. Y. Sanada (JAEA)

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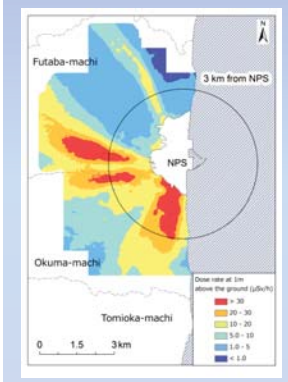
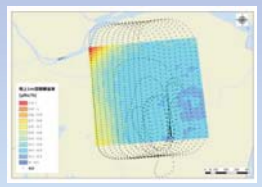
AGS from unmanned aircraft





Well suited to highly contaminated & evacuated zones, and plume tracking

Local scales (50m—5 km)

Low volume detectors (eg plastic scintillator, LaBr3, CZT)

Both spectrometric and dose rate – depending on detector type

Several systems developed or used, with different payload and operational parameters. EU emergency systems explored since 90's; rapid development since the 2011 accident.

Need for systematisation, integration and cross validation

Work needed in Japan and internationally to harmonise operating rules and to define protocols for safe operation in inhabited areas

Acknowledgements : Dr. T. Torii, Dr. Y. Sanada (JAEA), Prof. R. Kaiser (IAEA), Dr. T. Scott (Bristol)

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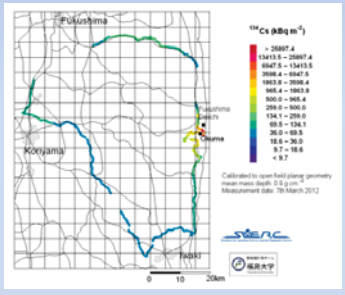
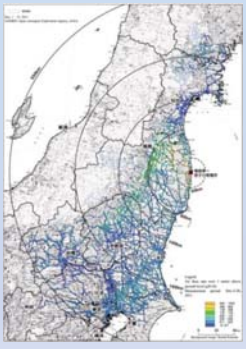
Vehicular systems





Highly effective platform for both dosimetric and spectrometric systems – powerful technique for rapid data capture

Japanese Kurama system widely used including on public transport networks

EU systems cross compared in Nordic countries (Resume exercises) and at EU level (ECCOMAGS and recent urban source search exercises)

Resume 99 (NKS) compared CGS and AGS in Swedish forests. Issues identified with topography, variable backgrounds and heterogeneous road response. ECCOMAGS data cover varied terrain with ground and airborne control.

Complex spatial fields of view and relationships between road and surroundings, which need to be taken account of in quantitative data interpretation

Work needed to improve response modelling for complex urban zones, and to establish traceable cross validation to open field ground based and airborne methods

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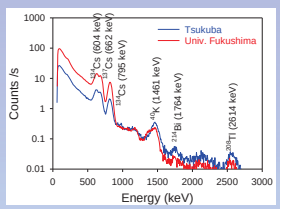
Backpack and portable systems

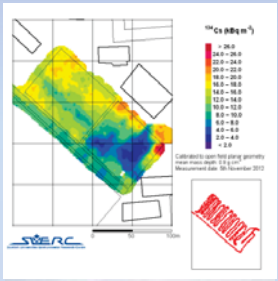
Capable of making measurements to < 1m resolution.

Both spectrometric and non spectrometric systems developed

Early spectrometric systems developed in Sweden in 1990's



Modern systems have real time spectral analysis and reduction capabilities, moving maps, intelligent alarms and automated data communication streams suited to direct transfer to emergency and spatial information systems



Strengths include the abilities to register a wide range of environments on spatial scales associated with exposure pathways to citizens

Complex and urban environments can be visualised

Spectrometric systems allow nuclide specific mapping, and apportionment of dose rate contributions

Quantitative analyses can be performed to determine inventories and to define changes with tme or in response to remediation

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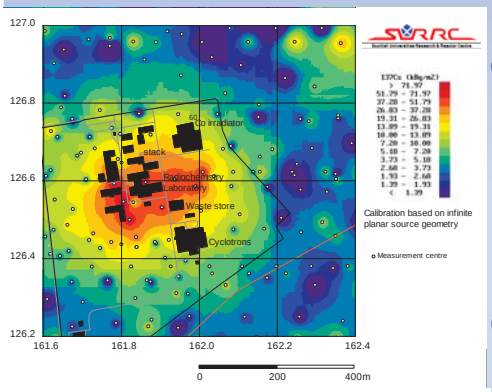
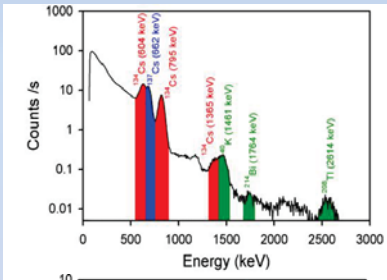
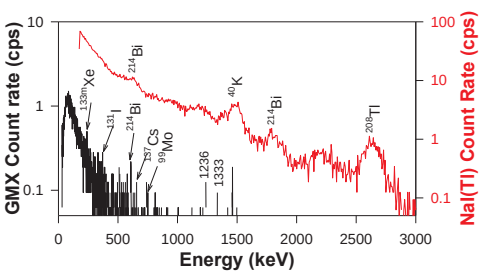
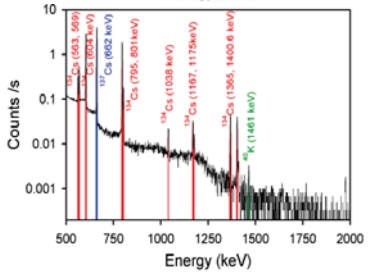
Sensor choices for AGS and CGS mapping

- Low Resolution (eg High Volume Scintillation spectrometers)
  - Excellent sensitivity (well suited to AGS and rapid portal work)
  - Lower resolution
  - Robust technology
  - Used in many systems worldwide
- High resolution (eg cryogenically cooled Ge detectors)
  - Excellent energy discrimination
  - Lower detection efficiency
  - More fragile and sensitive to microphonics
  - Not yet approved for AGS use in Japan
- New generation IDM systems
  - Ruggedised Stirling cycle cooling and integrated digitial spectrometry with low frequency rejection system
  - Tested at SUERC 2014
  - Evaluation for possible use in Japan
  - Application high precision isotope ratio measurement in different areas in Japan





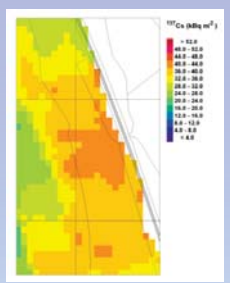


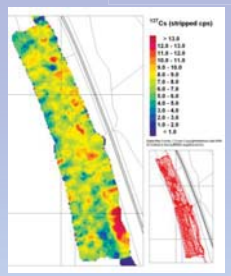


Backpack Systems

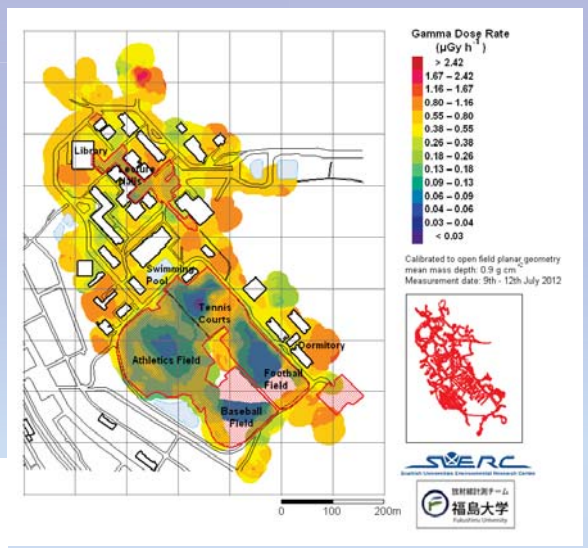
High resolution survey of Irish Sea beach in 2010

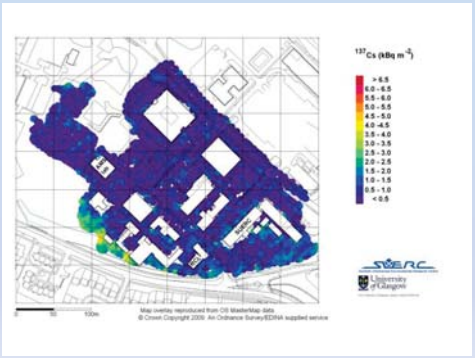
March 2000 AGS **June 2010 Backpack**





A.J. Cresswell , D.C.W. Sanderson, Science of the Total Environment 437 (2012) 285–296, Evaluating airborne and ground based gamma spectrometry methods for detecting particulate radioactivity in the environment: A case study of Irish Sea beaches





Sanderson, D., Cresswell, A., Seitz, B., Yamaguchi, K., Takase, T.,Kawatsu, K., Suzuki, C., and Sasaki, M. (2013) Validated Radiometric Mapping in 2012 of Areas in Japan Affected by the Fukushima-Daiichi Nuclear Accident. University of Glasgow. ISBN 9780852619377

http://eprints.gla.ac.uk/86365/1/86365.pdf

A.J. Cresswell , D.C.W. Sanderson, M. Harrold, B. Kirley , C. Mitchell , A. Weir,2013, Demonstration of lightweight gamma spectrometry systems in urban environments, Journal of Environmental Radioactivity 124 (2013) 22-28

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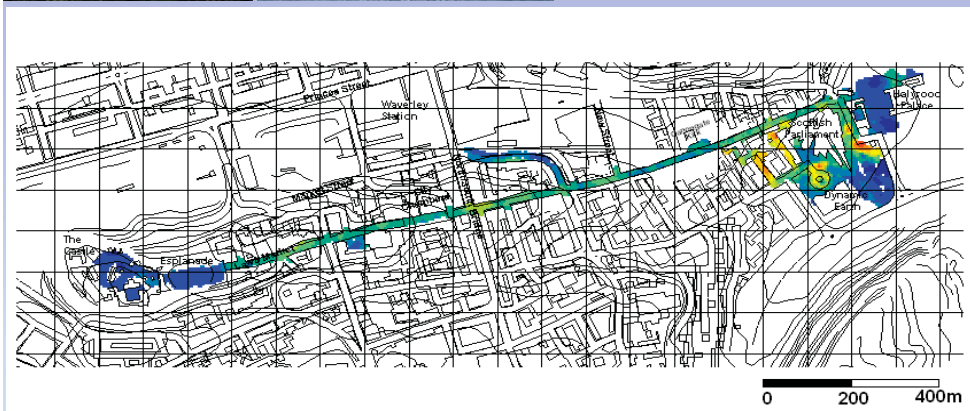
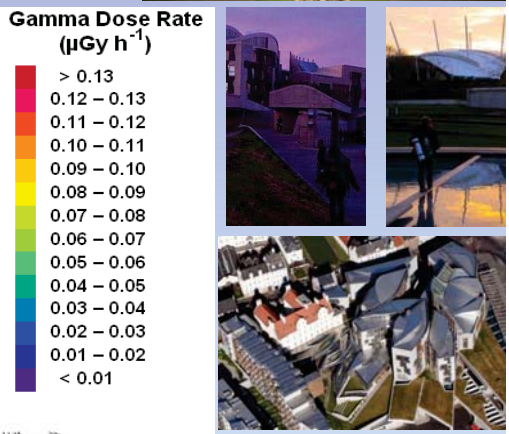
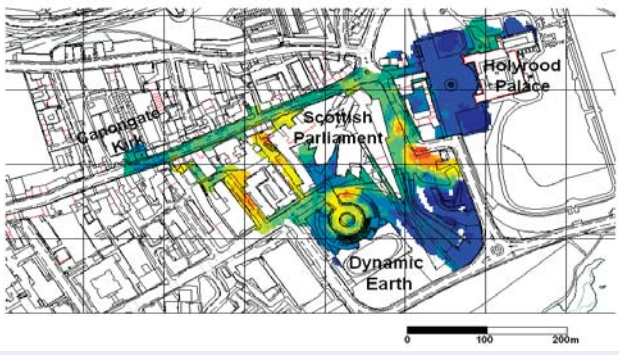
Visualising Urban Environments – Student projects in the Royal Mile Edinburgh, and Aberdeen





Laura MacIntosh and Heather Fraser studied the World Heritage Site in the Historic Old Town of Edinburgh. Here the radiation environment is controlled by building materials with prominent features around the Scottish Parliament and the Dynamic Earth centre.



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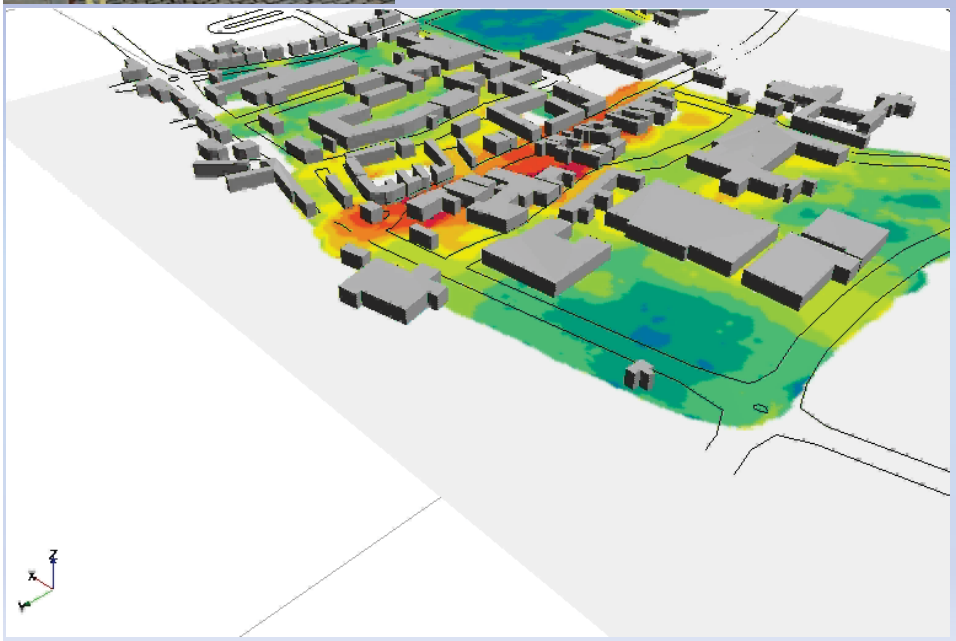

Calum Neilson and Neil Moffat studied the environment of Old Aberdeen and the University of Aberdeen. Once again the radiometric maps show significant variability, with granite architecture dominating the background levels Methods for 3D visualisation in digital model landscapes were explored

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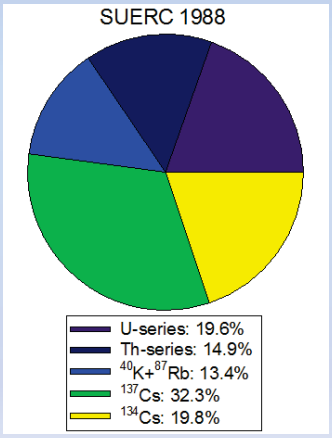
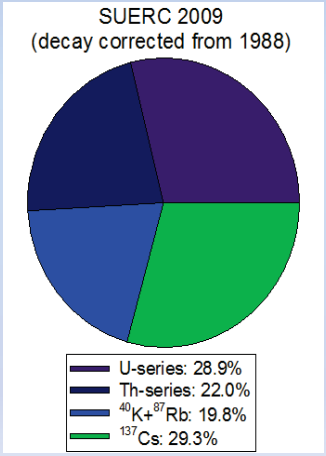
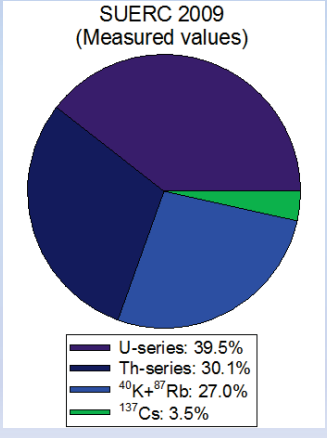
Apportionment of dose rate

The charts show the relative proportions of dose rates due to individual nuclides. Potentially useful for setting and evaluating remediation targets, for observing long term changes, or for sensitivity analysis of dose reduction by adaptive habit change

Here are data from SUERC, where Chernobyl deposition in 1986 left approximately 20kBq m-2 of ^{137}Cs and 10 kBq m-2 of ^{134}Cs. This contributed c. 52% of outside dose rates in 1988, but had declined to only 3.5% by 2009. Physical decay removed the ^{134}Cs component rapidly, but the major reduction in 137Cs dose contributions comes from redistribution on decadal timescales (ie self-remediation).







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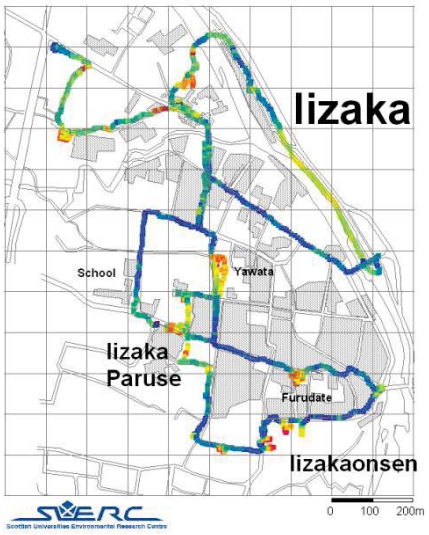
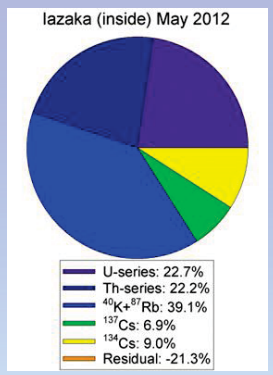
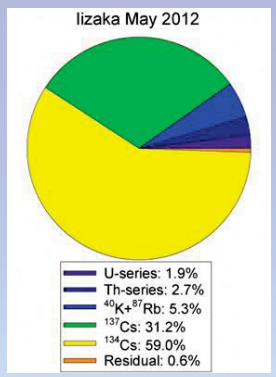
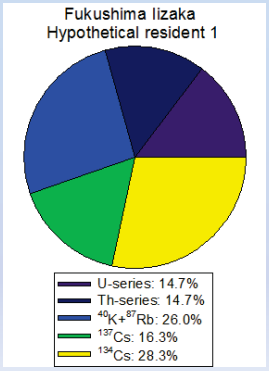
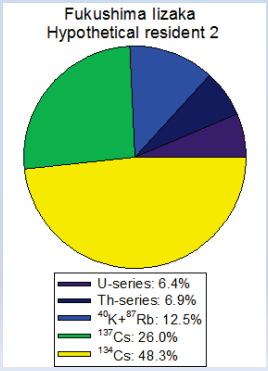
Dose Rate and Dose Apportionment – observations and models for 2012 data











Dose experienced by individuals depends on their occupancy habits, and will change with time as well

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Quantitative analysis of change on decadal timescales

1988 MAFF Survey West Cumbria 45 km^2

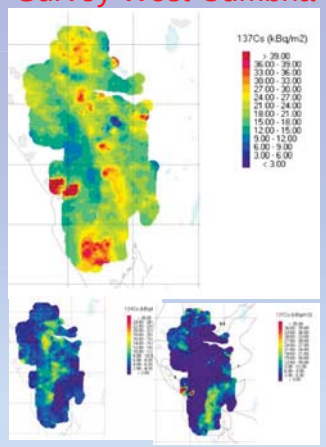
28th April Chernobyl

UK fallout arrives early May 1986

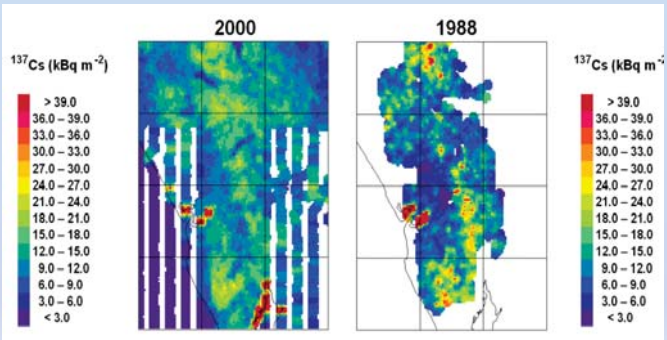
Initial deposition estimates based on limited ground sampling and meteorological modelling

Early SURRC surveys – SW Scotland, Western Isles, West Cumbria, North Wales

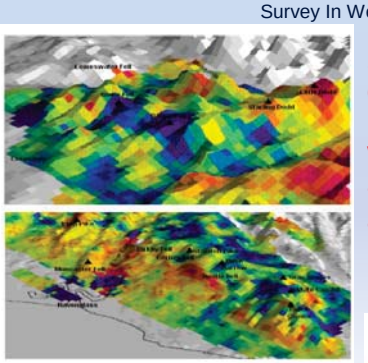
Later repeat surveys show long term migration of radionuclides



Sanderson D.C.W., Cresswell A.J., White, D.C., Murphy, S., McLeod J. 2001, Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. DETR Report DETR/RAS/01.001.



Sanderson D.C.W., Scott E.M.,1989, Aerial Radiometric Survey In West Cumbria In 1988, MAFF Report N611 120



2001 DETR study shows decadal downslope movement of radiocaesium in Upland areas of West Cumbria

- blue/green areas = loss of activity

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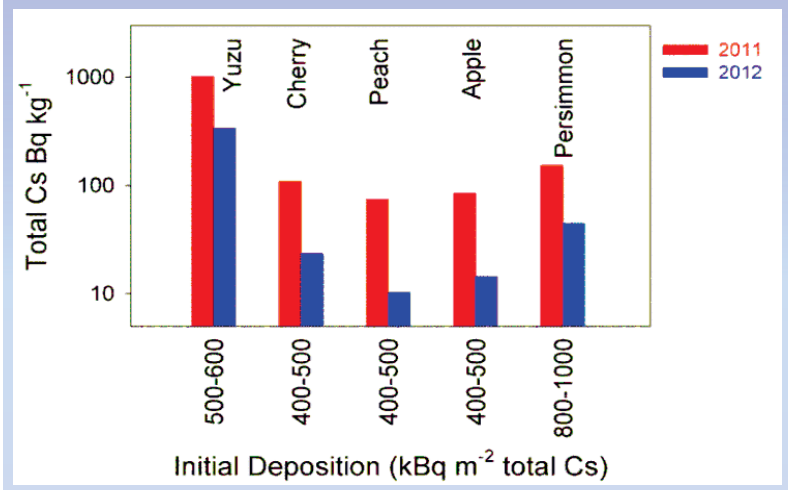
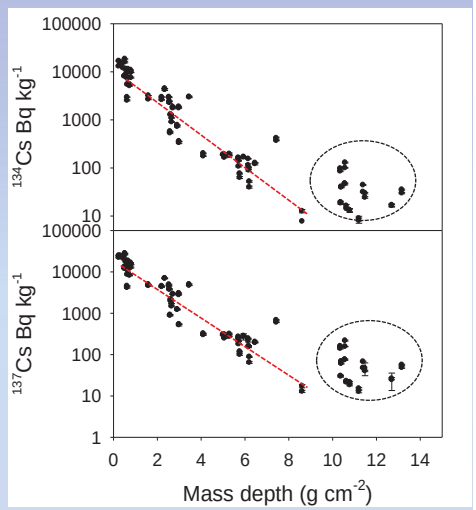
Interpretation of forest and orchard Cs evolution

Standard models for forests and orchards emphasise interception and translocation as dominant early processes, later supplemented root uptake and recycling





How well do these models apply in Japan?
Is behaviour in orchards and cultivated forests similar to natural woodland?
Can long term analogue studies using UK examples assist with development of robust models?

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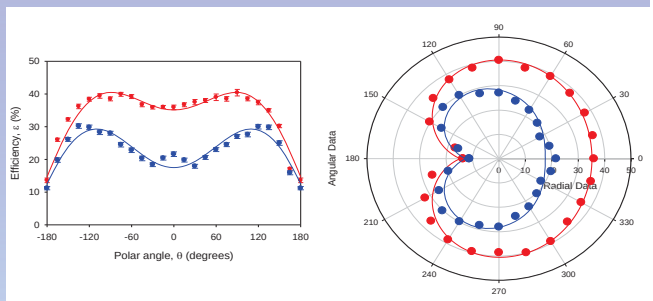
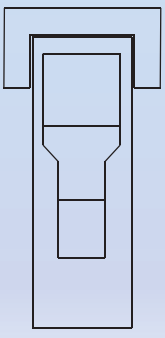
FCO prosperity funded investigation into the potential for synergistic biomass energy harvesting and phytoremediation.



Fieldwork conducted with the Iwaki “Friends of the forest NGO” to map contamination before and after community resourced forest litter removal. A novel collimated system was used to assess distribution of activity. Remapping following litter removal provided a 5 m resolution record of change



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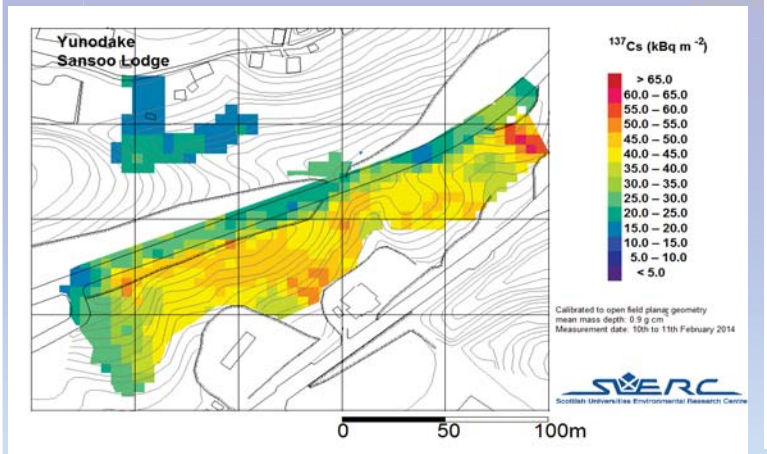
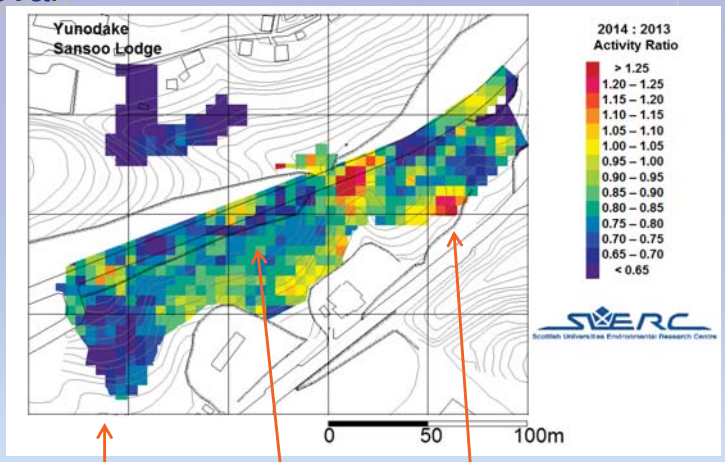
Iwaki forest activity in 2014 and changes due to redistribution and litter removal





Data corrected for snow attenuation using natural ^{40}K, and regridded, using inverse distance weighting, prior to spatial inventory analysis[1,2].

Litter removal

Loss by natural process

Increase by natural process

Results show effects of litter removal and redistribution

1. Sanderson D.C.W., Cresswell A.J., White, D.C., Murphy, S., McLeod J. 2001, Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. DETR Report DETR/RAS/01.001.

2. Sanderson, D. C. W., Cresswell, A. J. and White, D. C. (2007), 'The effect of flight line spacing on radioactivity inventory and spatial feature characteristics of airborne gamma-ray spectrometry data', International Journal of Remote Sensing, 29:1, 31 – 46, DOI: 10.1080/01431160701268970

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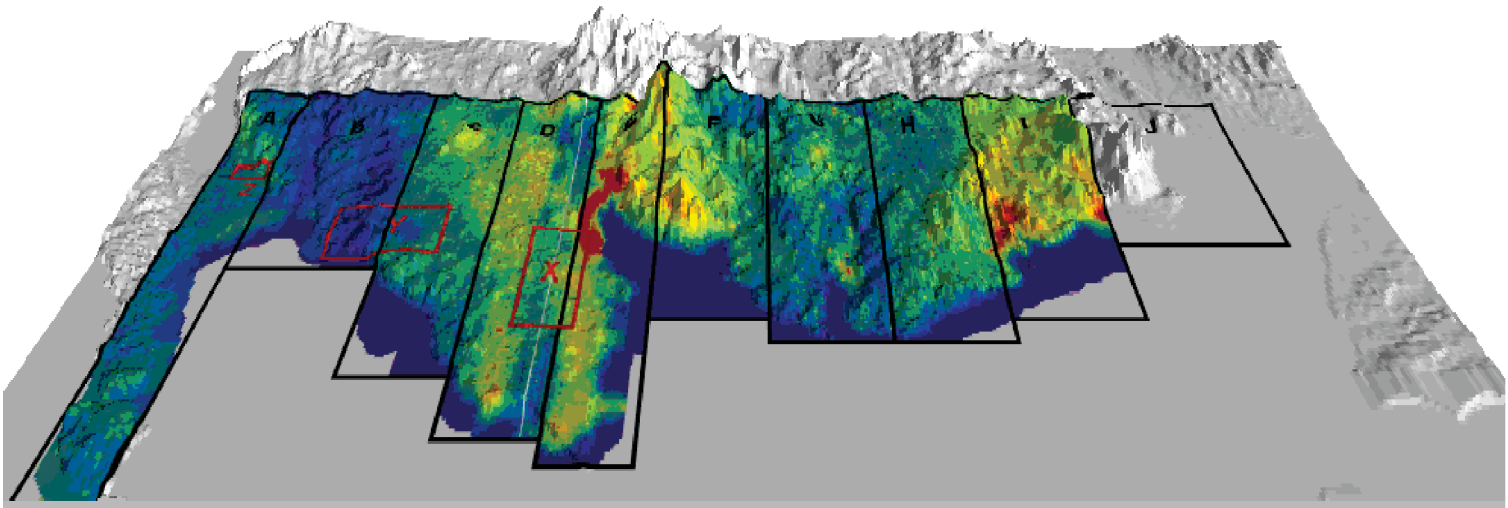
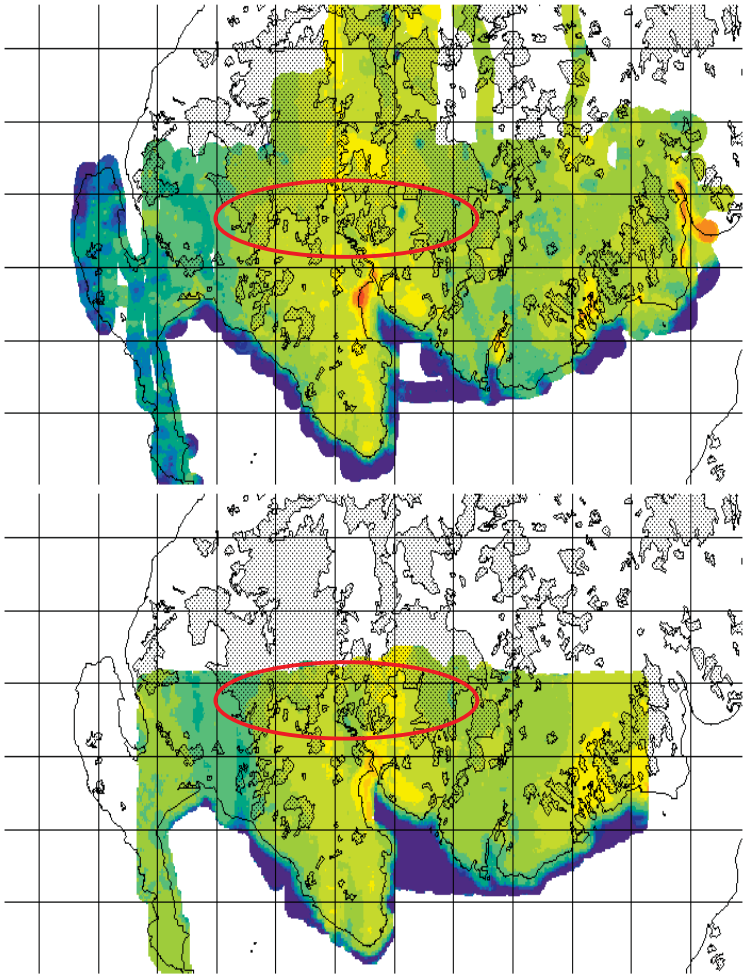
Assessing longer term forest evolution in UK environments – opportunities for analogue studies

ECCOMAGS exercise composite mapping task 2002 in SW Scotland, showing 137Cs distribution across a 90x40 km area
(69000 spectra; data acquired in 3 days, published on-line within a week)





^{137}Cs in SW Scotland in 1993 (above)

and 2002 (ECCOMAGS composite left)

Forested areas shaded outlines

Existing AGS data sets cover Chernobyl deposition on forest areas in SW Scotland recorded 6 years and 16 years after deposition

Carborne tests (2014), samples, and short flight trials have verified that ^{137}Cs remains still present

Some areas are being harvested but opportunities remain to examine the distribution of activity and inventory changes on 30 years timescales

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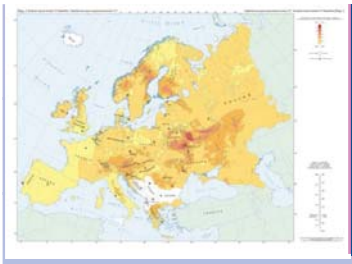
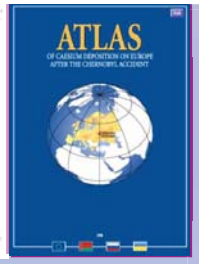




Needs for integration & intercalibration

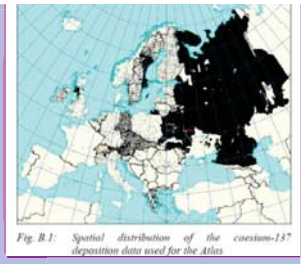
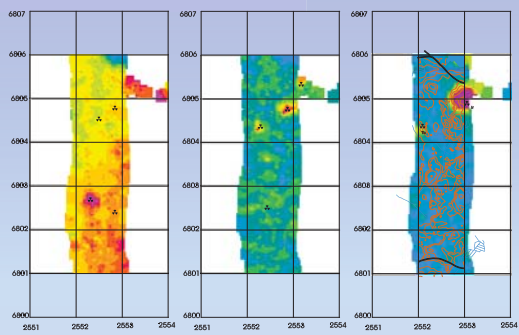


Fig. B.1: Spatial distribution of the caesium-137 deposition data used for the Atlas

- RESUME 95 – Central Finland 1995 (ISBN 87-7893-014-6)
  - 10 hidden sources in 5x1 km area (^{137}Cs,^{60}Co,^{192}Ir, ^{99m}Tc)
  - 1 hour task for 10 AGS teams, prompt reports
- RESUME 99 – Gävle, Sweden, 1999 (ISBN 87-7893-065-0)
  - CGS deposition mapping (compared with earlier AGS)
  - 2 hidden sources (^{137}Cs, ^{99m}Tc) on car-route
- BARENTS RESCUE (LIVEX 2001) N. Sweden (ISBN 87-7893-108-8)
  - Civil/Military & Cross-border rescue cooperation
  - Gamma search exercise with 10 AGS teams and 15 CGS teams
  - 44 hidden sources (^{60}Co, ^{137}Cs, ^{99}Mo/^{99m}Tc,^{192}Ir,^{131}I,^{226}Ra,^{241}Am)
- ECCOMAGS 2002 , SW Scotland 2002 (ISBN 0-85261-783-6)
  - Quantitative AGS, CGS and in-situ comparisons



Some of the EU exercises post-Chernobyl

Needs and opportunities for Japan

- Testing data exchange formats
- Establishing traceability to reference sites
- Extending calibration models from open field to complex topographies and source distributions.
- Potential network in Asia?

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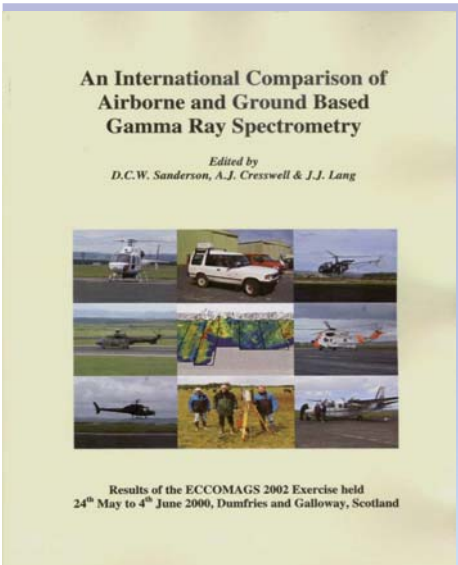


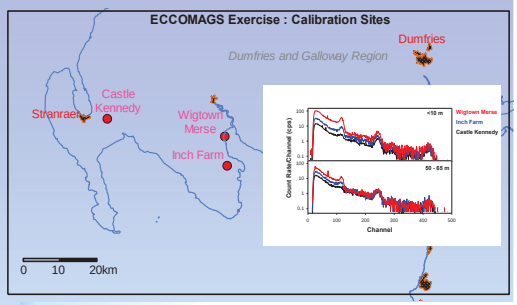
Venue
- SW Scotland May 24th-June 3rd 2002

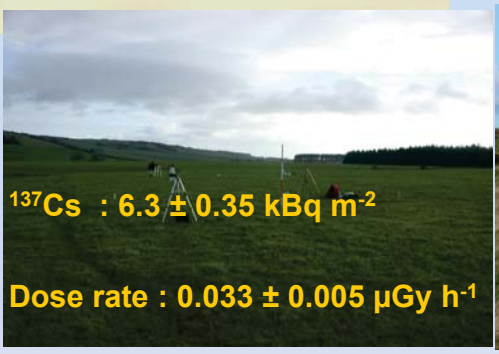
Organisation
- International Steering Committee (ISC)
- National Organising Committee, (NOC)
- Design and Evaluation Group (DEG)

Participants
- 150 participants
- from 18 institutions in 10 countries

Achievements
- >120,000 AGS measurements
- ~150 In-situ and field dose rate measurements
- >750 laboratory gamma spectrometry results
- CGS data from 3 teams

Reference sites created for international AGS comparison - resampled 2012,2013





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Exercise report – 387p book published – includes protocols, team reports and results
Radiation Protection Dosimetry,Vol. 73, Nos 1–4, pp. 213–218 (1997);Journal of Environmental Radioactivity, 53 (2001) 411-422; Radiation Protection Dosimetry (2004), Vol. 109, Nos 1-2, pp. 119-125

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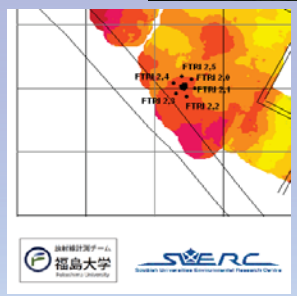
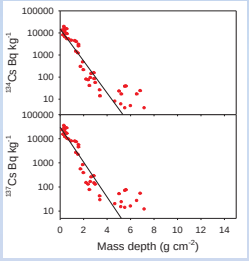
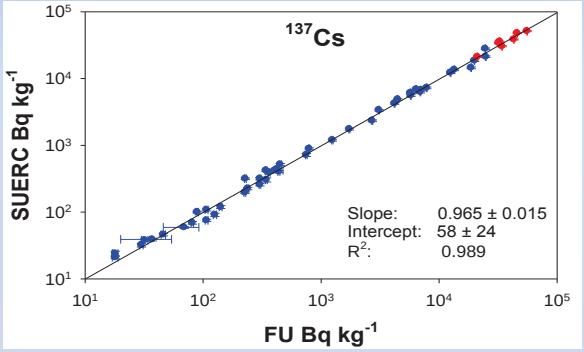
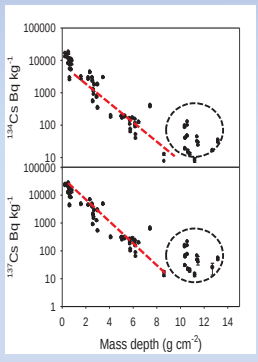


Reference sites sampled at Fukushima University and FTRI

- Size and use
- Sampled in 2012 using the spatial patterns of Tyler et al 1996,*J. Environ. Radioactivity, 33(3), 213-235.*
- Soil cores in good agreement between FU and SUERC
- Changes since 2012
- Can be used by research or commmunity groups
- Need for larger sites – vehicle and AGS







Year	137Cs /kBq m2	134 Cs kBq m-2	Mass depth /g cm-2	Dose Rate µGy hr-1
2012	245 ± 30	135 ± 20	0.7 ± 0.2	1.06 ± 0.11
2014	225 ± 15	84 ± 10	(0.8± 0.2)	0.76 ±0.05

Year	137Cs /kBq m2	134 Cs kBq m-2	Mass depth /g cm-2	Dose Rate µGy hr-1
2012	265 ± 20	165 ± 20	0.9 ± 0.1	1.24 ± 0.13
2014	192 ± 10	74 ± 5	(1.2± 0.2)	0.64 ±0.06

Plans for future actions

- Preparations for joint airborne operations with JAEA
  - Systems prepared and tested in UK
  - Carborne and Airborne tests including measurements on EU calibration sites
  - Shipping to Japan
  - Flight plans
- Investigation of next generation Ge technology for carborne and airborne used
  - Application to high precision isotope ratio measurements
- Access to remote sensing output
  - SUERC has an extensive set of digitally available reports and outputs
  - EU exchange formats for data exchange
  - Opportunity to test data exchange with JAEA

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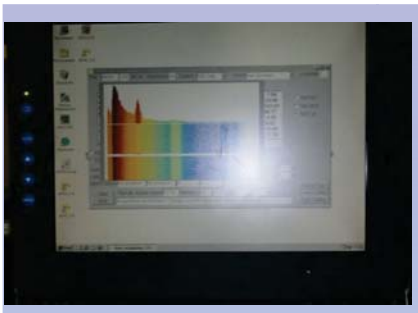

Preparing for joint flights with JAEA
Systems prepared and initial inspection in Scotland

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Discussion and conclusions

Ideas for future development to meet Fukushima challenges

- as recovery moves from reactive to pro-active stages it is important that data validation, standardisation and integration are progressed
- that models be tested and improved to understand radionuclide behaviour and provide a framework for predictive management
- that work to understand the behavioural characteristics of radionuclides is progressed with a view to enhancing remediation
- that activities are undertaken to help to restore confidence amongst affected communities through enhanced knowledge and understanding

- All of which need to be underpinned by abundant and accessible radiometric measurements

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