Radiological Characterisation
Experience with Magnox Reactors
Introduction

There is a great variety of radiological characterisation for decommissioning, but the examples here will be restricted to:

- measurements to verify the inventory neutron activation calculations within the bioshields
- contaminated plant such as the gas circuits and fuel route, which cannot be predicted and must be found from measurement
- vaults and tanks containing activated and contaminated solid waste and contaminated resins and sludges
- clearance monitoring of land and buildings for site delicensing
Magnox Sites

- 10 sites operated by Magnox
- Calder Hall operated by Sellafield sites
- Only Wylfa still operating
Magnox Reactor

• Graphite Core
• CO2 Primary Coolant
• Water Secondary Coolant
• Spent Fuel Cooling Ponds
Radioactive Inventory Within the Bioshield

- Fuel >99.9% of activity
- 85% of remaining activity from neutron activation
- Factors affecting calculations
  - Irradiation history
  - Materials inventory
  - Elemental composition
  - Nuclear data
Validation of Calculated Inventory

- Trace elemental compositions
- Gamma spectrometry of in-core items
- Bioshield cores
- Dose rate measurements
Validation of Calculated Inventory

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Wigner Probes

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Fe-59 Activity (Bq cm$^{-3}$) vs. Distance from Reflector (m)

- **Calculated**
- **Measured**

Legend:
- **RPV**
- **Thermal shield**
- **Bioshield**

Distance from Reflector (m):
- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3

Activity (Bq cm$^{-3}$):
- $1 \times 10^2$
- $1 \times 10^3$
- $1 \times 10^4$
- $1 \times 10^5$
- $1 \times 10^6$
- $1 \times 10^7$
- $1 \times 10^8$
Validation of Calculated Inventory

• Trace elemental compositions

• Gamma spectrometry of in-core items

• Bioshield cores

• Dose rate measurements
Bioshield Cores

The graph shows the decay rates of different isotopes as a function of distance. The isotopes include H-3, Co-60, Ba-133, and Eu-152. The decay rates are plotted on a logarithmic scale for the activity per gram (Bq g⁻¹) against distance (mm). The graph includes calculated (calc) and measured data points for each isotope.
Validation of Calculated Inventory

- Trace elemental compositions
- Gamma spectrometry of in-core items
- Bioshield cores
- Dose rate measurements
In-Core Dose Measurements
Contaminated Plant - Boilers

INVENTORY (Bq) vs. TIME (Y)

- Fe-55
- Co-60
- H-3
- Ni-63
- C-14
- Cl-36
- TOTAL

INVENTORY (Bq) vs. TIME (Y)

0 50 100 150

TIME (Y)
Contaminated Plant - Boilers
Contaminated Plant – Ponds
Contaminated Plant - Ponds

Graph showing inventory (Bq) over time (years) for different isotopes and total. The isotopes include:
- H-3
- C-14
- CL-36
- Fe-55
- Sr-90
- Cs-134
- Cs-137
- Eu-154
- Pu-241
- TOTAL ALPHA
- TOTAL

The graph plots inventory against time, with different lines representing each isotope and the total. The y-axis represents inventory in Bq, and the x-axis represents time in years, ranging from 0 to 150 years.
Waste Vaults and Tanks

- wastes accumulated in vaults and tanks on site
- retrieve and package
- radionuclide inventory - each package - regulatory requirement

Fuel Element Debris (FED) Vault

- Magnox metal
- nimonic springs
  - Ni/Co alloy
  - activated
- some fuel fragments

fuel ➔ reprocessing

splitter/spider ➔ vault
Trawsfynydd FED Assay System

- waste retrieved → tray
- high-resolution gamma detector
- large detector crystal = good signal to noise ratio (peak to Compton)
- narrow V-shape collimator reduces counts to detector
- improved $^{137}$Cs detection against high $^{60}$Co spectral background = faster assay
- waste grouted in 3m$^3$ box
Radiological Characterisation of FED at Trawsfynydd

Correcting for Fuel Fragment Self-Attenuation

- important because uranium so dense
- high attenuation of gamma rays from within fuel fragment
- can grossly underestimate $^{137}\text{Cs}$ activity if not corrected

- fuel activity > general contamination
- above threshold $^{137}\text{Cs}$ signal, assume fuel piece present
  - equates to a few grams of fuel ($^{137}\text{Cs}$ activity $\sim 3\times 10^8$ Bq)

- best estimate correction made for self-shielding according to $^{137}\text{Cs}$ signal detected
Radionuclide Fingerprints for FED at Trawsfynydd

Assay system measures $^{137}\text{Cs}$ and $^{60}\text{Co}$
Other radionuclides accounted for using fingerprints

Fuel fragments
- FISPIN, cooling ponds $^{137}\text{Cs}$ leaching factor of 0.5
fission products : $^{137}\text{Cs}$

Nimonic springs
- activation calculations
$^{63}\text{Ni} : ^{60}\text{Co}$

Magnox metal
- representative sampling
fission products : $^{137}\text{Cs}$
activation products : waste mass
Radiological Characterisation of FED at Trawsfynydd

- 13 waste packages produced to date (approx. 12 tonnes)
- ~1 kg spent fuel fragments
- $^{137}\text{Cs}$ package activities ranged from $4 \times 10^8$ Bq to $2 \times 10^{11}$ Bq
- $^{60}\text{Co}$ package activities ranged from $1 \times 10^{10}$ Bq to $5 \times 10^{11}$ Bq

(at reference date 01/04/2011)
Radiological Characterisation of FED

104 drums of FED assayed on turn-table stand-alone gamma spec

Calculations using MicroShield / spreadsheet rather than automatically in assay system software

Bespoke method suitable for smaller quantities of waste
Lower cost than developing/purchasing an assay system
Ion Exchange Resin

- removes radioactivity from pond water and active effluent
- currently stored in large tanks on site
- dose rate from resin dominated by $^{137}$Cs
- dose rates on outside of tanks only ‘see’ ~20 cm into resin so not useful for assessment of bulk activity
- characterised by sampling from different depths
Ion Exchange Resin

- retrieved and grouted in shielded drums

- sample data used to:
  - predict drum shielding thickness required to keep operator doses to acceptable levels
  - produce radionuclide fingerprint

- max. contact dose rate on each drum converted to $^{137}\text{Cs}$ activity using simple model

- radionuclide inventory calculated for each drum
**Delicensing**

Two Magnox sites partially delicensed: Berkeley (2005/06) and Oldbury (2010/11)

**Berkeley**

- power station (operated 1962 to 1989)
- research labs, shielded test cells, offices

Approach agreed with regulator up-front
- regulatory expectations for delicensing
- site history
- zoning - depending on likelihood of contamination
- in-situ measurement, sampling and analysis plan
Delicensing criteria based on regulations and guidance in 2005

- Substances of Low Activity (SoLA) Exemption Order
  - 0.4 Bq/g total activity

- Annex 1 of Basic Safety Standards Directive (Euratom 96/29)
  - doses to members of the public <10 μSv / year
Characterisation for Delicensing - Berkeley

- 600+ gamma spectra in-situ in buildings
- 300 particulate samples
- 600 swab samples
- Health Physics Surveys
- Land survey HRGS measurements
- In-drain LRGS measurements
- Samples for radiochemical analysis
Delicensing - Berkeley

Delicensing Safety Case accepted by regulator in 2006
Power station and shielded facility remain within licenced site boundary
Delicensing - Oldbury

Oldbury
- power station (operated 1967 to 2012)
- adjacent land and buildings (~32 hectares)

Similar approach to Berkeley Delicensing, except that:

- Regulators now favoured radionuclide specific exemption values, based on IAEA guidance
- Data Quality Objectives (DQO) used
  - step by step process for characterisation
  - balances uncertainty and resource
Delicensing - Oldbury

Site study:

- no history of radioactive works - area outside security fence
- authorised aerial and liquid discharges
- buildings used for training, visitors and security
  - previously contained small sealed sources for demonstrations
  - all sources had been removed
Delicensing - Oldbury

Preliminary data

Small number of samples for radiochemical analysis

In-situ land surveys

- 329,000+ LRGS gross counting = more rapid survey
- 1564 HRGS spectra

High gross count rate alarms investigated using HRGS results

- $^{137}\text{Cs}$ - mostly on silt lagoon
- $^{41}\text{Ar}$ - routine release from reactor
- $^{214}\text{Bi}$ - naturally occurring
Delicensing - Oldbury

Area zoned:
- terrain type
- site study

1, 2 silt lagoon
3, 5 grassland - disturbed
4 grassland
6 roads, car parks, drains
7 buildings
8 construction waste
Delicensing - Oldbury

Max $^{137}\text{Cs}$ result = 0.065 Bq/g
(95% upper confidence level)

Other radionuclides insignificant

Borehole results confirmed no elevated activity at depth

Below Exemption Order value of 0.4 Bq/g total
and IAEA Guidance value of 0.1 Bq/g $^{137}\text{Cs}$

Delicensing granted in 2011
~80 acres = largest plot delicensed in UK at one time
Conclusions

Radiological characterisation in decommissioning Magnox reactors has allowed assessment of:

- How much radioactivity remains after defueling
- How the radionuclide inventory varies with time

Good quality data reduces uncertainties and conservatism in assumptions. This provides the following environmental, safety and cost benefits:

- More accurate prediction of waste arisings
- More effective segregation of waste for re-use, recycling, exemption
- Better informed strategy and prediction of dose to workers
- Reduced overall project risk