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

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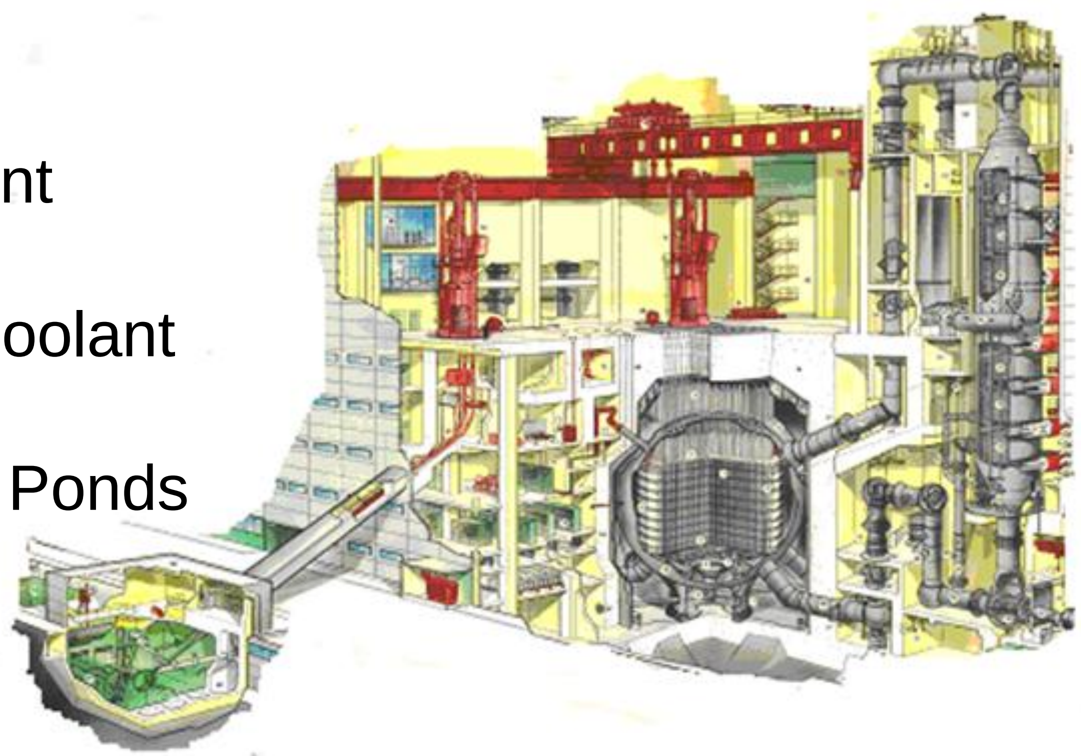
Magnox Reactor

- Graphite Core
- CO_2 Primary Coolant
- Water Secondary Coolant
- Spent Fuel Cooling Ponds



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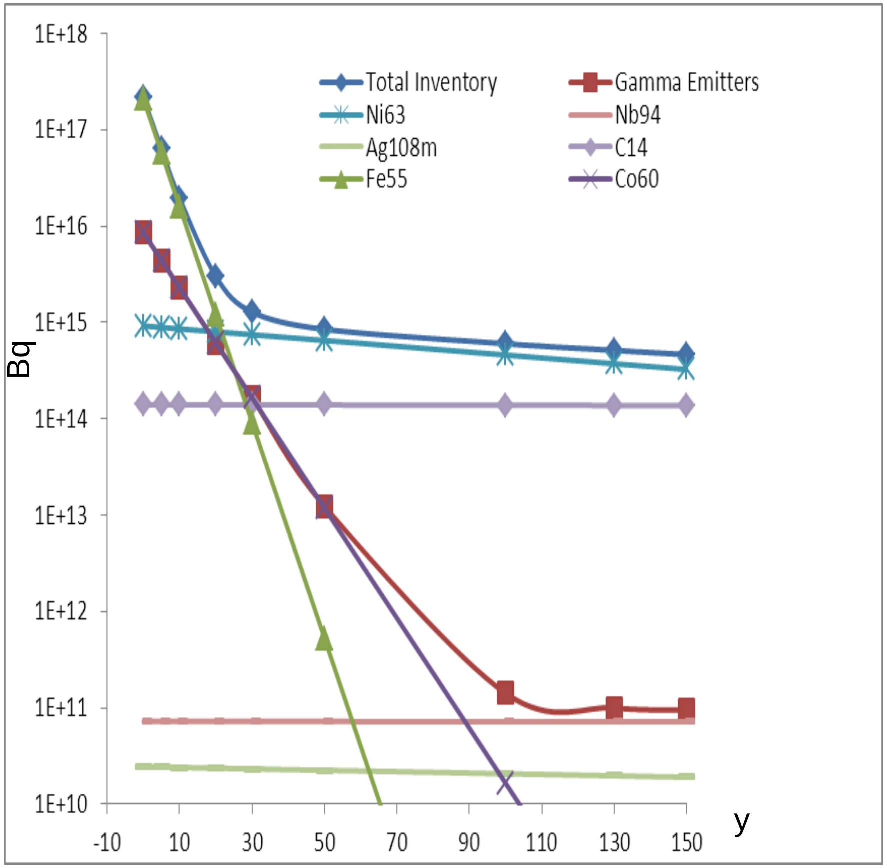
Radioactive Inventory Within the Bioshield

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



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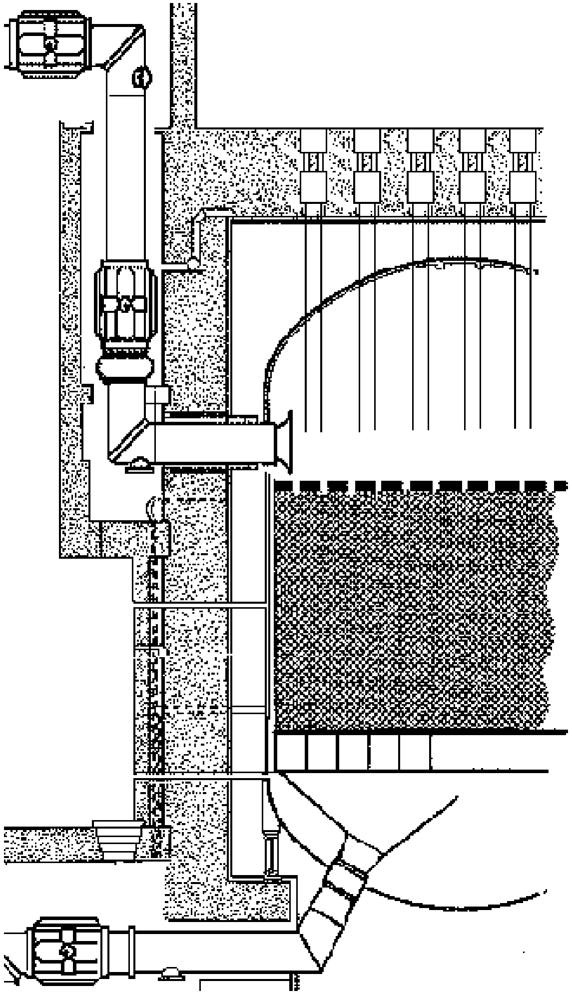
Validation of Calculated Inventory

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



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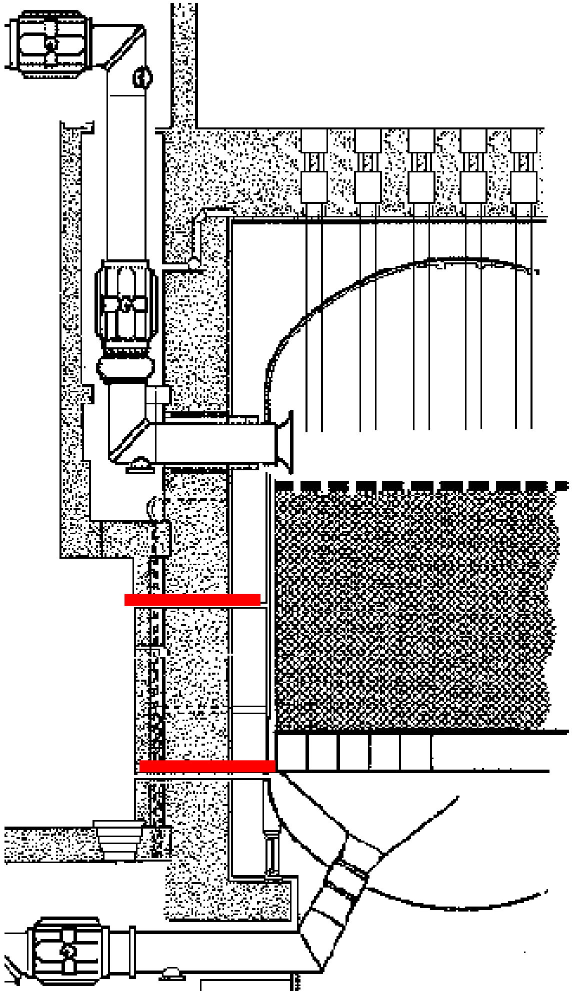
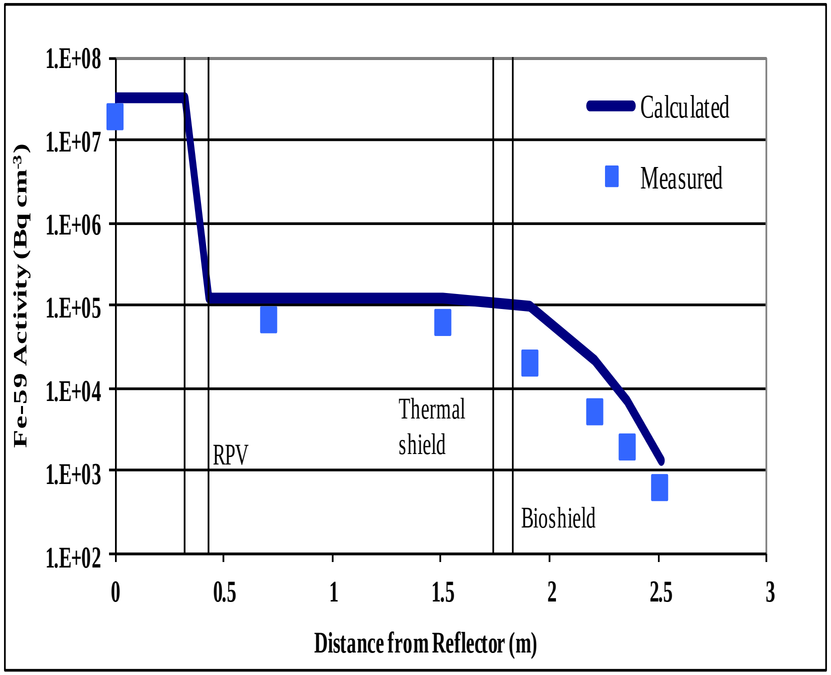


Wigner Probes



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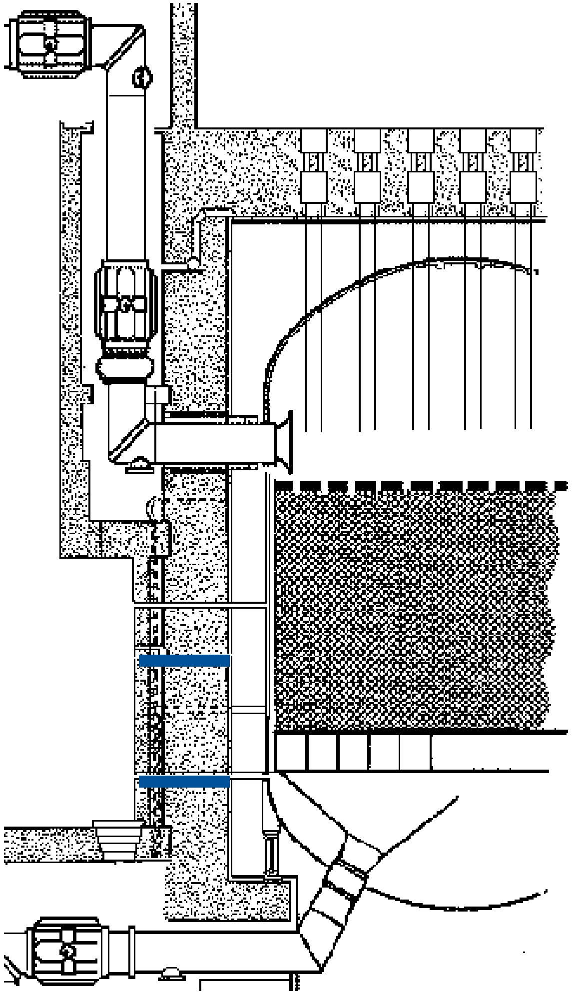

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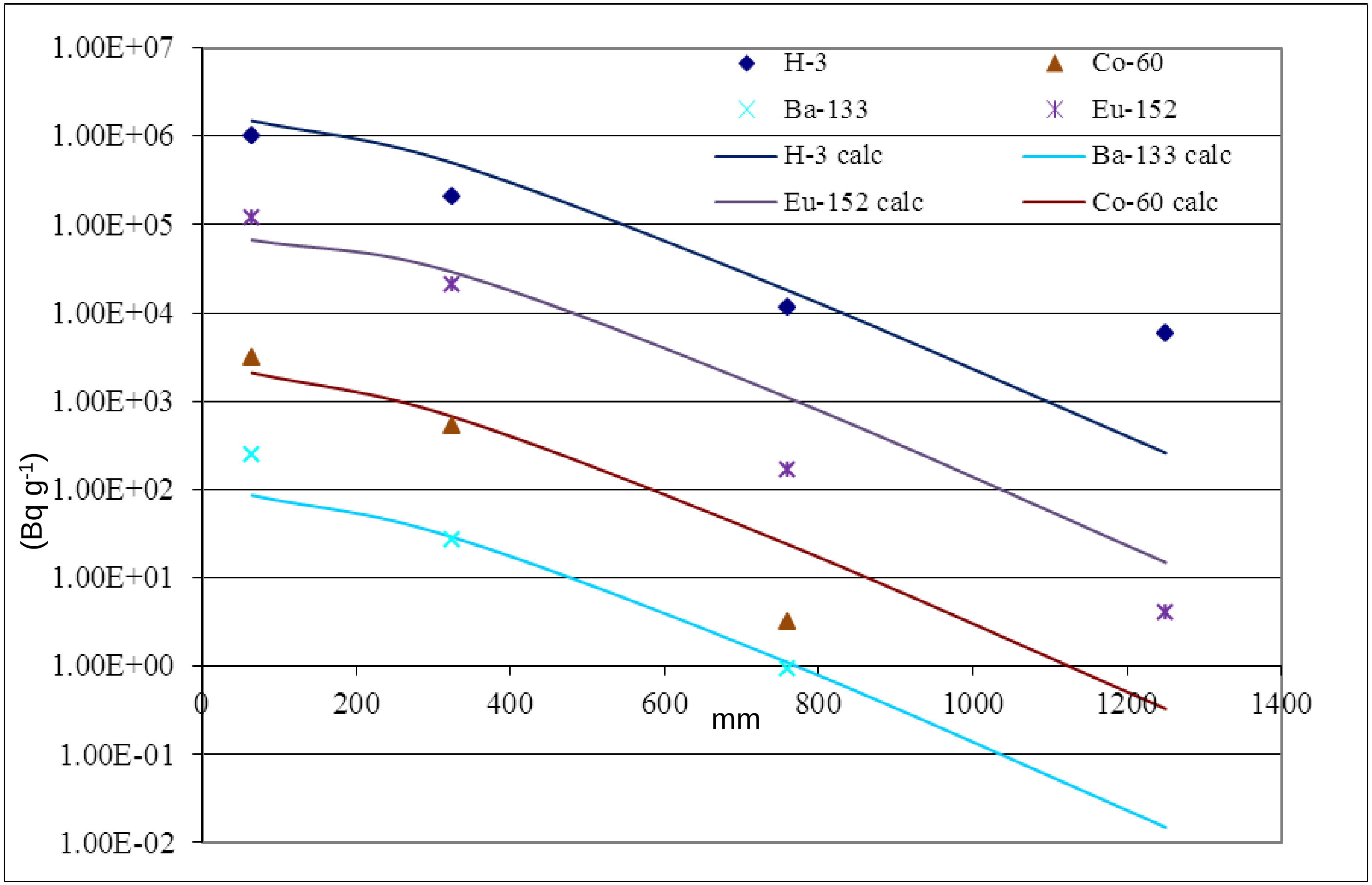
Bioshield Cores



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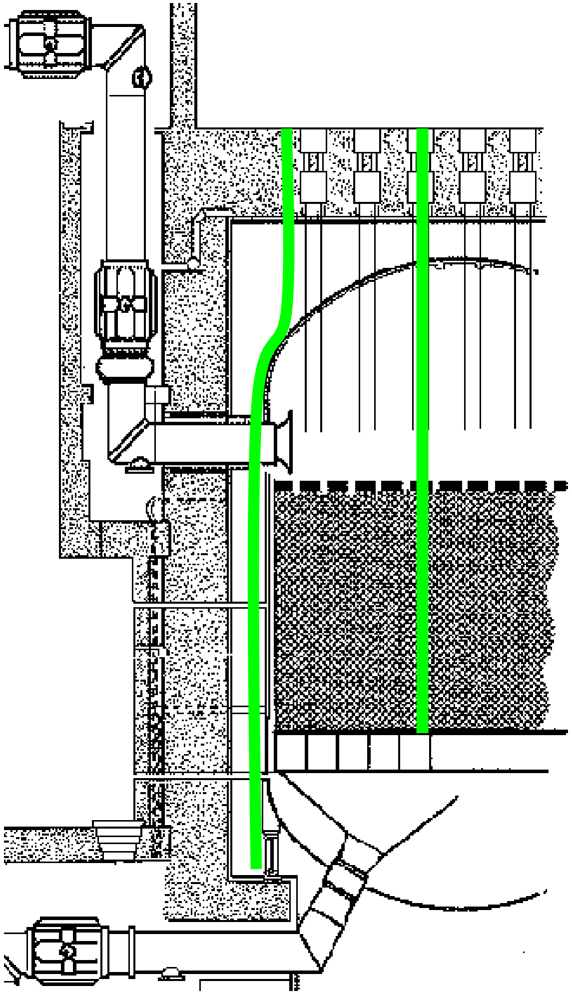

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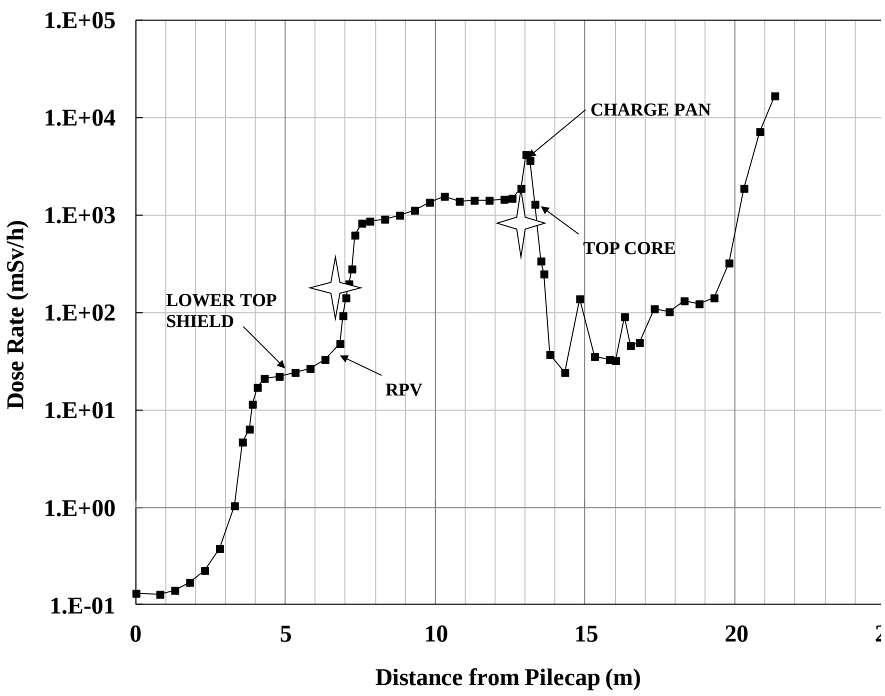
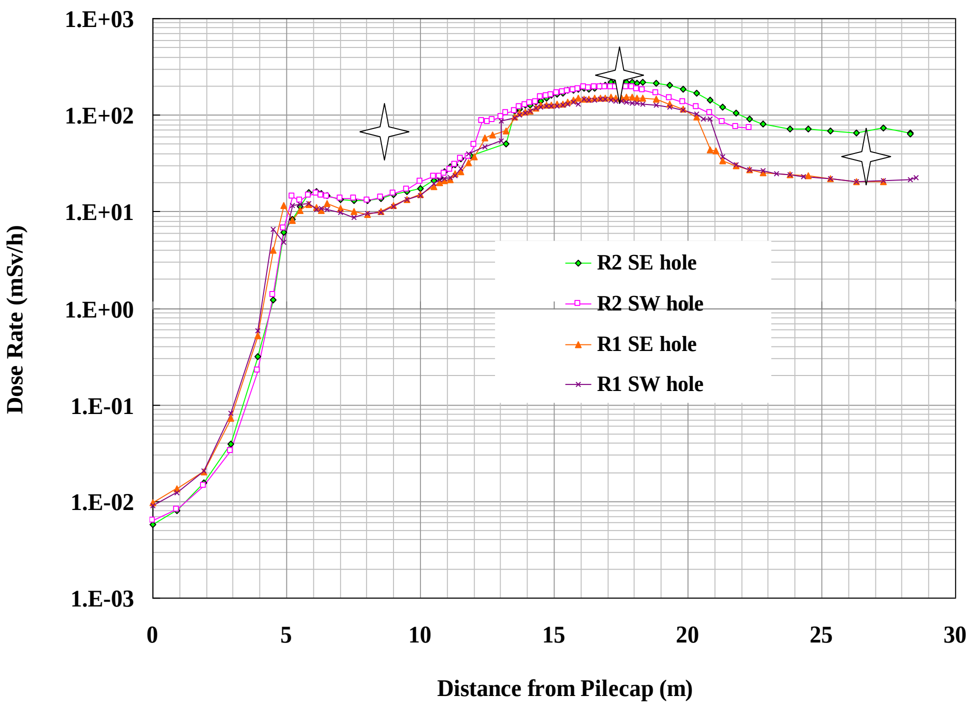
In-Core Dose Measurements





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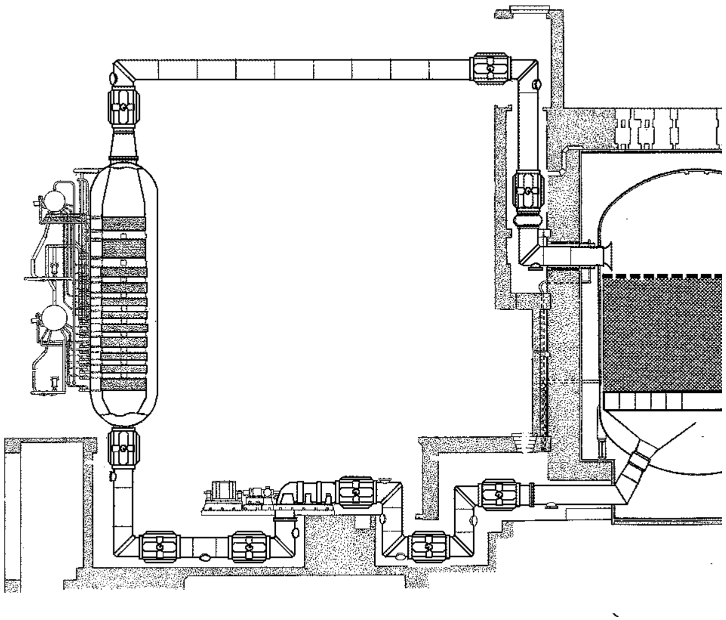
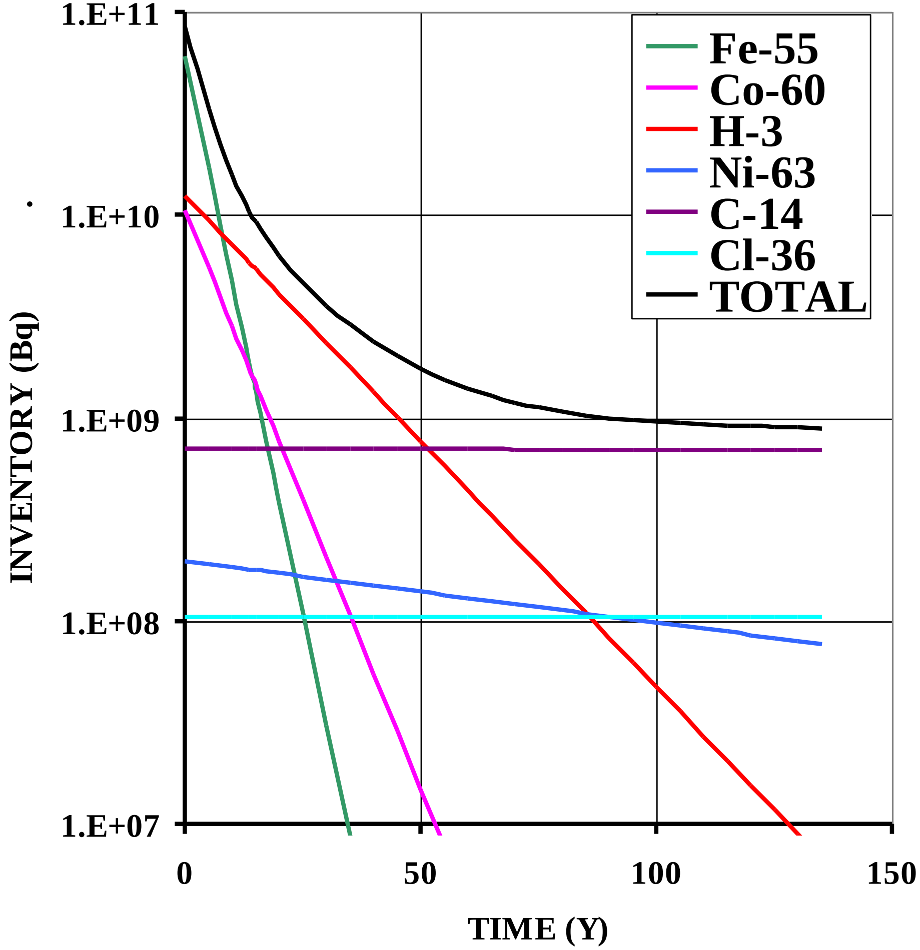
Contaminated Plant - Boilers





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Contaminated Plant - Boilers

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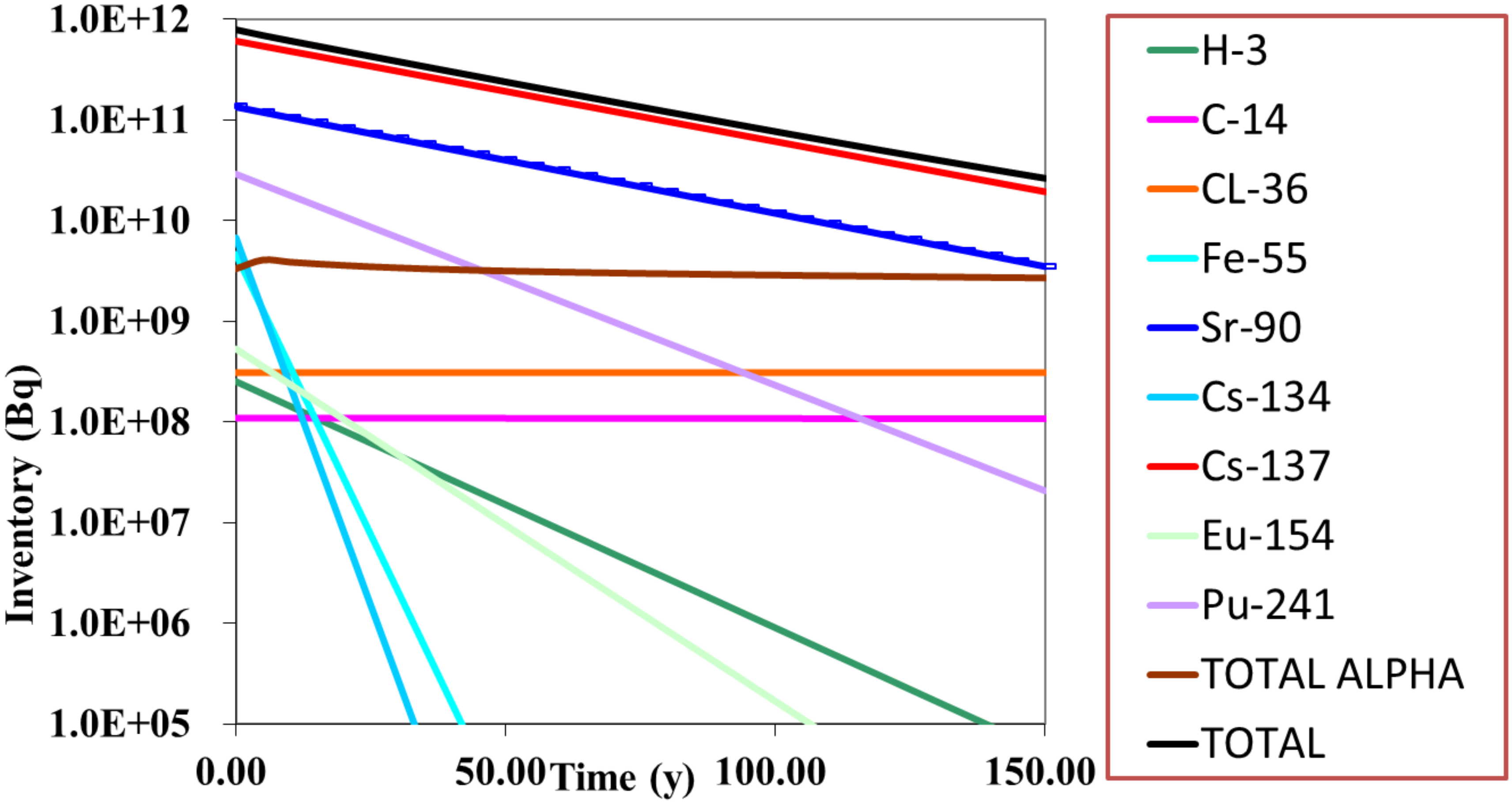
Contaminated Plant – Ponds

Contaminated Plant - Ponds



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Waste Vaults and Tanks

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

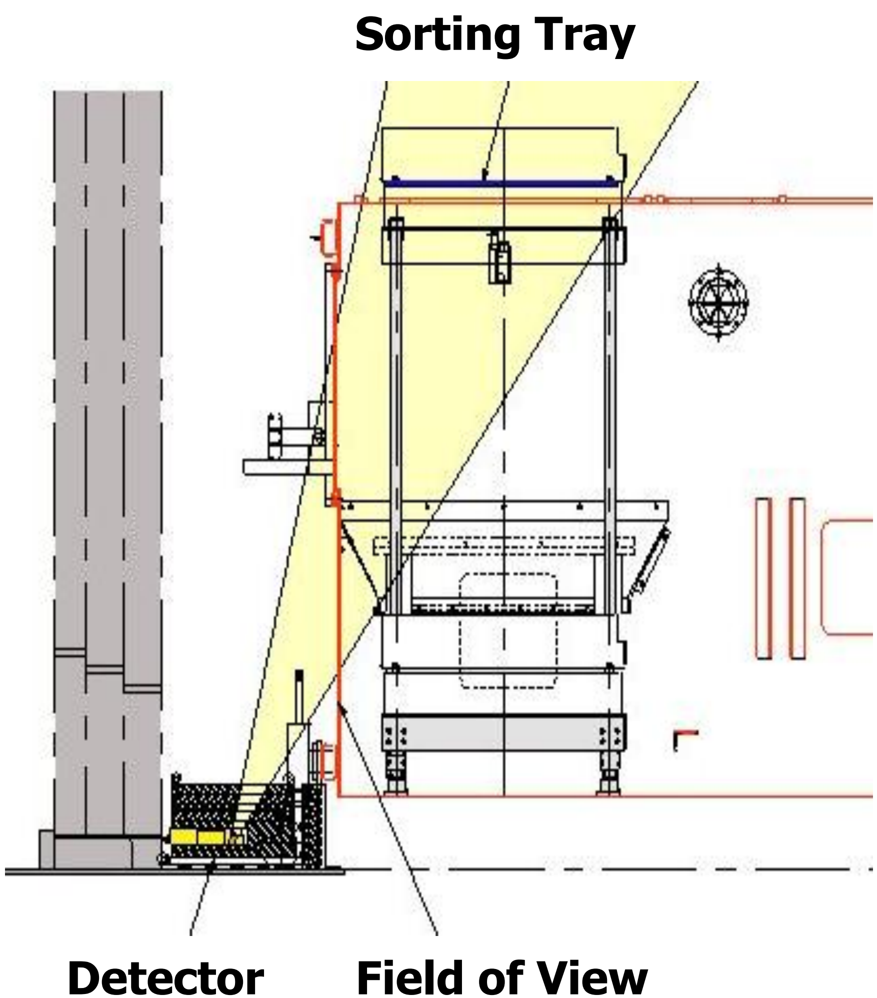
Fuel Element Debris (FED) Vault

fuel ⇨ reprocessing

splitter/spider ⇨ vault

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

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}Cs activity if not corrected

- fuel activity > general contamination
- above threshold ^{137}Cs signal, assume fuel piece present
  - equates to a few grams of fuel (^{137}Cs activity ~3E8 Bq)

- best estimate correction made for self-shielding according to ^{137}Cs signal detected

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Radionuclide Fingerprints for FED at Trawsfynydd

Assay system measures ^{137}Cs and ^{60}Co

Other radionuclides accounted for using fingerprints

<u>Fuel fragments</u>

- FISPIN, cooling ponds ^{137}Cs leaching factor of 0.5

fission products : ^{137}Cs

<u>Nimonic springs</u>

- activation calculations

^{63}Ni : ^{60}Co

<u>Magnox metal</u>

- representative sampling

fission products : ^{137}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}Cs package activities ranged from 4E8 Bq to 2E11 Bq
- ^{60}Co package activities ranged from 1E10 Bq to 5E11 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

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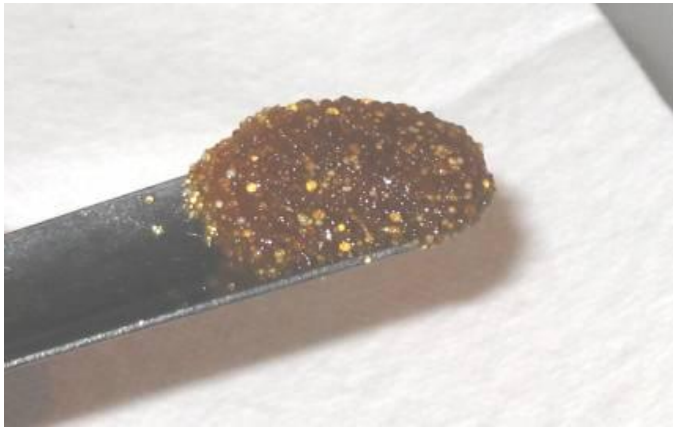
Ion Exchange Resin

- 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}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 - Berkeley

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

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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}Cs - mostly on silt lagoon
- ^{41}Ar - routine release from reactor
- ^{214}Bi - naturally occurring

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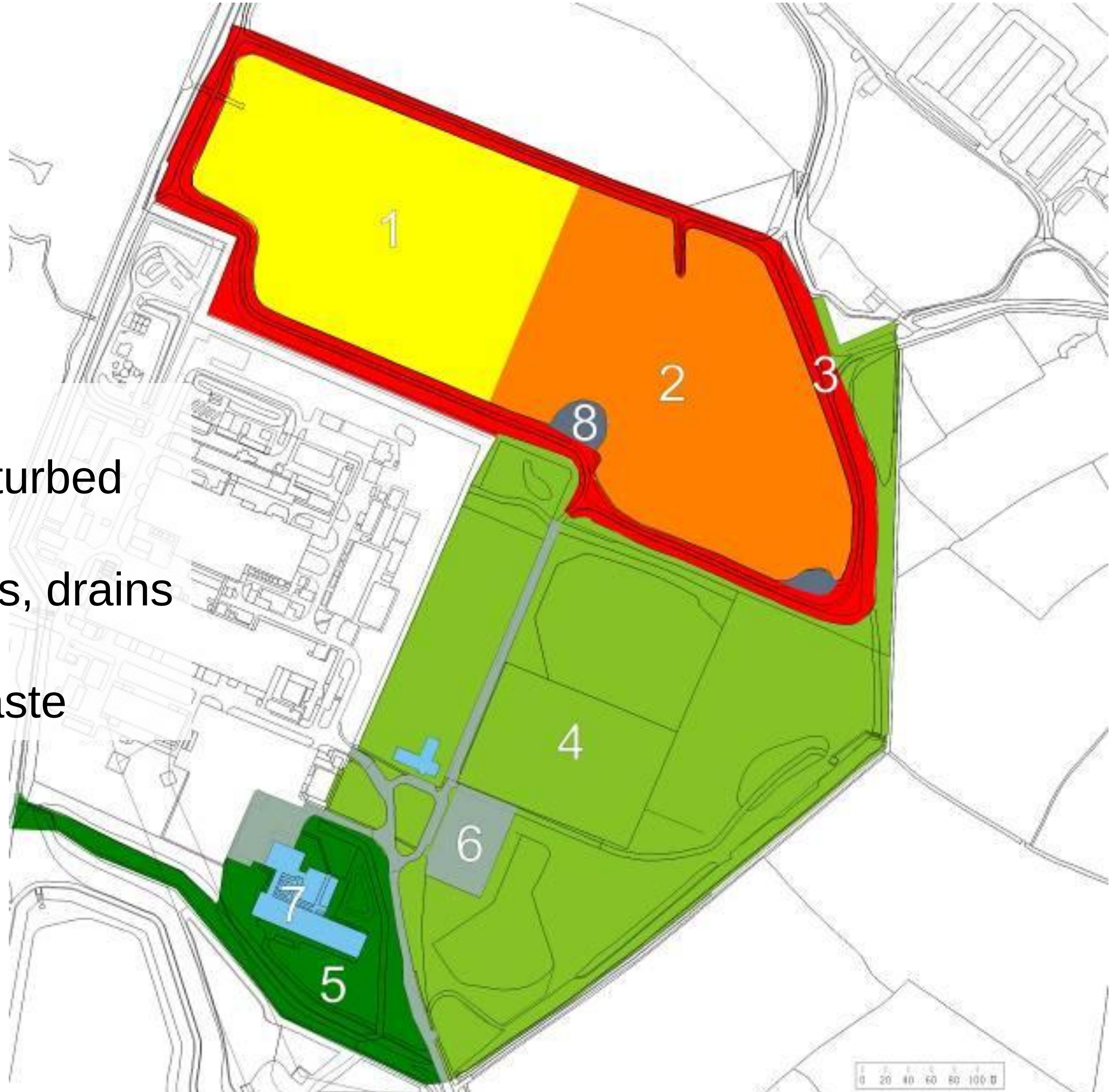
Delicensing - Oldbury

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}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}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