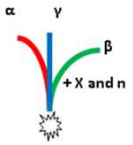

WASTE AND MATERIALS CHARACTERISATION

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Remember – good monitoring saves money over poor monitoring!

Concentrating on surface contamination

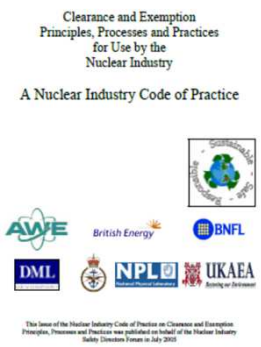
- Clearance measurement is a large subject!
- From the measurement point of view, I'm going to focus on surface contamination.
- I'm saying little on the measurement of bulk contamination and activation this time

Clean can only be by history!

- Clean CANNOT be by measurement
- There's always a Limit of Detection (looking downwards from a higher level)
- Or Maximum Missable Activity (MMA), looking up
- ALWAYS ask the question: can this process reliably demonstrate that materials are below whatever limiting activity is acceptable?
- If it can, it's good.
- If it can't, it's useless

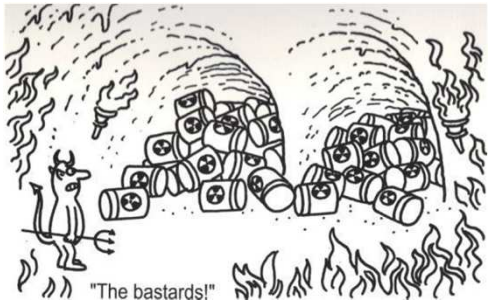
The clearance, exclusion and exemption process

- Most of the UK nuclear industry (and many other organisations) refer to the Clearance and Exemption Working Group Code of Practice when managing potentially exempt waste
- A set of flow charts and management principles that helps determine whether waste is exempt or not
- Backed up by technical guidance
- See http://www.nuclearinst.com/write/MediaUploads/SDF%20documents/clearance_and_exemption_code_of_practice_final_issue_2_min_size.pdfe



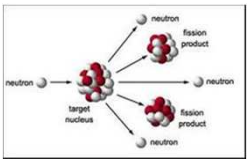
Benefits of Exclusion

- Waste not subject to regulation as radioactive waste
- Able to avoid costly radioactive waste sentencing practices
- Avoids sending waste to low level waste facility
- Potential to re-use or re-cycle waste elsewhere



Essentials to think about - fingerprint

- Waste characterisation often refers to a fingerprint (nuclide vector), rather than quantifying individual nuclides
- **There is not, and there never will be, a Bq meter**
- Any detection mechanism is radiation type and energy dependent
- Many waste assessments rely on one or two easily detectable nuclides
- For bulk measurement, gammas from Cs-137 for fission, Co-60 for activation, Bi-214 for radium
- So getting the fingerprint right is vital



Fingerprints

- History
  - What was the process?
  - Which nuclides were produced by chemical separation, activation or fission?
  - What will be left after allowance for decay?
- Sampling
  - take samples of activated material or contamination
- Analysis
  - Gamma spectrometry and radiochemistry

If history and measurement agree, you have a fingerprint or fingerprints

- These should be kept under review
- They will change
- You will find something unexpected
- Remember to try to stay well ahead of the demolition or clearance process
- Radiochemistry takes time - days, weeks, months
- If history and measurement don't agree, revise the history
- Don't just add the extra nuclide

Averaging areas and masses

- Always go for the largest area or mass that is justifiable
- Makes monitoring and handling cheaper.
- Worry about the potential for hot spots
- Make sure that the area or volume is basically the same material with the same radionuclides in a not too wide range of activities

Nuclide classification

- **Low toxicity nuclides generally emit beta or X rays, have relatively low decay energies, short half lives and low biological incorporation**
- **High toxicity ones include alpha emitters and very energetic gamma emitters**
- **European Commission RP122 and IAEA RS-G-1.7 give values of suggested clearance levels based on dose modelling**

Levels

- UK values are currently based on RP122 Part 1 values
- The reference value is 10 µSv per annum to the most exposed people
- Additional recommendations for liquids and gases by HPA
- 0.01 Bq g^{-1} to 10 kBq g^{-1}
  - **A range of 1 million!**
- In the future, UK will follow the revised BSS and move to RS-G-1.7 values, leading to a further change in UK exclusion levels.
- Many changes, many up, some down
- Main change, Cs-137, from 1 Bq g^{-1} to 0.1 Bq g^{-1}

Some examples of low toxicity nuclides

Nuclide	Decay energy, type, probability and half life	RP122 value (Bq g^{-1})	Production
Fe-55	5.9 keV X-rays, 36 %, 2.73 y	100	Activated steel
Ni-63	67 keV beta, 100 %, 100 y	100	Activated steel
H-3	18.6 keV beta, 100 %, 12.3 y	100	Activation and ternary fission
Ca-45	257 keV beta, 100 %, 163 days	100	Activated concrete
C-14	156 keV beta, 100 %, 5730 y	10	Activated nitrogen
Tl-204	764 keV beta, 97 %, 3.78 y	10	Activated Tl-203

Some examples of higher toxicity nuclides

Nuclide	Decay energy, type, probability and half life	RP122 value (Bq g^{-1})	Production
Co-60	1.17 and 1.33 MeV gamma, 200 %, 5.27 y	0.1	Activated steel
Cs-137	0.662 keV gamma, 85 %, 30 y	1	Uranium fission
Pu-239	5.1 MeV alpha, 100 %, 24110 y	0.1	Uranium activation
U-238+ including Th-234, Pa-234m and Pa-234	4.2 MeV alpha, 2.27 MeV beta, 100 % + 100 %, 4.47 x 10^9 y	1	Separated uranium
Ra-226+ including Rn-222, Po-218, Pb-214, Bi-214 and Po-214	Four alphas, plus beta and gamma , 1600 y	0.01	Natural

The limiting activity – nuclide specific

- Express each nuclide as a fraction of the total activity (e.g. 15% Co-60)
- Divide each fraction by the limiting activity (e.g. 15% Co-60/0.1 + 85% others/100)
- Sum the results (in the example above this will be 1.509)
- Divide the fraction of the nuclide to be measured by this sum to get a limiting Bq g^{-1} value
- Taking Co-60 as the most likely nuclide to be measured this is 15%/1.509 = 0.099 Bq g^{-1}
- Sounds complicated but isn't

How to express a measurement?

- Clearly the total activity limit is fingerprint specific
- **Bq are misleading as for one fingerprint the limit could be 0.15 Bq/g and for another might be 35 Bq/g**
- In the UK, the term Out of Scope Limit is popular
- Otherwise, OoSL
- Something that's at 0.5 OoSLs complies
- Something at 1.8 OoSLs fails

Tritium

- Tritium is extremely mobile
- Diffuses significantly into concrete to 20+ cm depths
- Much further than any other nuclide
- Hence large volumes of concrete can end up being contaminated by tritium alone
- Heavy water moderated reactors such as SGHWR at Winfrith

Post Irradiation examination building

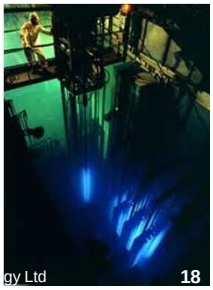
- Total activity limit (OoSL) for the fingerprint shown is 0.88 Bq g^{-1}
- When we move to RS-G-1.7 values, Cs-137 goes to 0.1Bq g^{-1}
- Resulting OoSL value then equals 0.12 Bq g^{-1}
- Cs-137 is the important gamma emitter at a limit of 0.72 Bq/g or 0.098 Bq/g
- Easy to monitor in bulk

Nuclide	Major emission	Fraction (%)	RP122 limit (Bq/g)
Pu-238	Alpha	0.1	0.1
Pu-239	Alpha	0.2	0.1
Pu-240	Alpha	0.3	0.1
Cm-244	Alpha	0.3	0.1
Am-241	Alpha + low E gamma	0.5	0.1
Pu-241	Very low E beta	1.8	1
Sr-90 (+Y-90)	High E beta	13.3	1
Ni-63	Low E beta	1.6	100
Cs-137	Gamma + medium E Beta	81.6	1
Co-60	Gamma + low E Beta	0.4	0.1

Fuel cooling pond

- OoSL = 0.46 Bq g^{-1}
- Two useful gamma emitters
- Again susceptible to changes for Cs-137
- Moves to 0.16 Bq g^{-1}
- Easy gamma monitoring target

Nuclide	Major emission	Fraction (%)	RP122 limit (Bq/g)
Cs-137	Gamma + medium E Beta	46	1
Co-60	Gamma + low E Beta	17	0.1
H-3	Very low E beta	23	100
Fe-55	Very low E X-ray	4	100
Ni-63	Low E beta	7	100
C-14	Low E beta	2	10
Sr-90 (+Y-90)	High E beta	1	1



Activation and fission product contamination

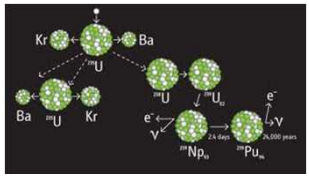
- OoSL is 0.112 Bq g^{-1}
- Three useful gamma emitters
- Will change quite quickly with time – mainly the influence of Co-60 decay

Nuclide	Major emission	Fraction (%)	RP122 limit (Bq/g)
Co-60	Gamma + low E Beta	44.8	0.1
Eu-154		15.9	0.1
Cs-137	Gamma + medium E Beta	13.9	1
Sr90 (+Y-90)	High E beta	7.0	1
Eu-152	High energy gamma + beta	6.0	0.1
Ni-63	Low E beta	5.0	100
Cd-113m	Medium energy beta	2.0	0.01
Fe-55	Very low E X-ray	2.0	100
Eu-155		2.0	10
Pu-241	Very low E beta	1.0	1
Am-241	Alpha + low E gamma	0.2	0.1
Pu-238	Alpha	0.1	0.1

*Likely limit will be 1 Bq g^{-1}

Plutonium from high burn-up fuel

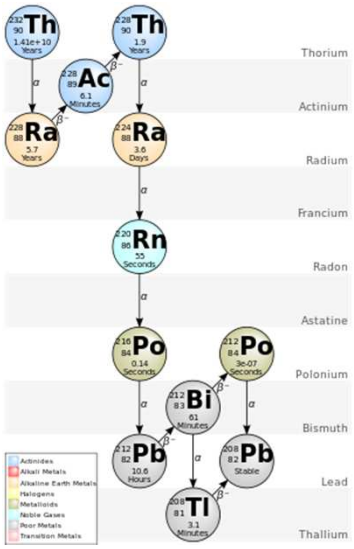
- OoSL is 0.73 Bq g^{-1}
- Dominated by the very high fraction of Pu-241
- Very low energy beta emitter
- Decay product is Am-241
- Concentration will peak at about 3.3 % of original Pu-241 activity
- No useful gamma



Nuclide	Major emission	Fraction (%)	RP122 limit (Bq/g)
Pu-238	Alpha	0.25	0.1
Pu-239	Alpha	1.1	0.1
Pu-240	Alpha	1.1	0.1
Pu-241	Beta	95.9	1
Am-241	Alpha + low E gamma	1.6	0.1

Real difficulties

- Fingerprints containing very high toxicity radionuclides - nuclides at 0.01 Bq g-1
- Generally naturals – long decay chains, many alpha stages, plus energetic gammas and betas
- High external gamma dose rates from bulk waste
- High dose per unit intake



Measurement difficulties

- U-238, U-235 and Th-232 complete chains and the Ra-226 chain are at 0.01 Bq g^{-1}
- Generally below the limit of *in situ* detection
- Present in building materials, soil etc naturally
- How can we see an enhancement of Ra-226 activity of 0.01 Bq g^{-1} over natural levels in excess of 0.1 Bq g^{-1} U-238?

Surface contamination

- Two measures – surface activity and a corresponding bulk activity = total (both sides) surface activity/material thickness in g/cm^2
- No significant loose activity
- Bulk activity for materials being reprocessed, e.g. melted to a limit to the corresponding RP122 value.
- For materials to be re-used, surface activity to give 10 µSv/a to a future user.
- RP89 values used
- Often approximately 0.4 Bq/cm^2 beta and to not detectable above background (about 0.1 Bq/cm$^{2)}$ for alpha.

Equipment for clearance monitoring

- This demands more care and, generally, bigger detectors than routine monitoring.
- It is possible using ratemeters but there is an argument for using scaler timers
- Use object specific backgrounds – steel plate will have a lower background than brick, for example
- In situ or move all the material to a relatively low background area?

Beta monitoring

- A 100 cm^2 thin windowed scintillation detector with a good low energy performance.
- Alternatively a proportional counter can be used.
- Calibration is by determining the response to the range of standard anodised aluminium calibration sources
- Then the responses to other nuclides are determined by interpolation.

Beta monitoring

- These numbers are then combined with the fingerprint to give a response for the overall mix.
- This is used to set an action or alarm level
- Monitoring can be performed in contact using spacers as only areas with low fixed activity are generally monitored
- Typical responses for a 100 cm^2 beta detector are 8 to 30 cps/Bq/ cm^2 over the energy range from C-14 (159 keV) to Y-90 (2.2 MeV)
- Typical fingerprint responses are usually dominated by Cs-137 and Sr-90 + Y-90

Beta monitoring

- This gives a fingerprint 0.4 Bq/cm^2 response of about 8 cps above background
- Typical backgrounds are 5 to 10 cps
- Therefore easily detectable on a ratemeter with care over a few seconds

- Why, then, use a scaler timer
- (1) Not subjective
- (2) Better identification of trends
- (3) More precise to record “85 counts” than write down “BG”
- (4) Easier to check for falsification of data

Beta monitoring

- Problems for betas
  - **limited low energy performance, doesn’t see tritium and Ni-63, both common nuclides**
  - **low energy fingerprints give low responses and are susceptible to self absorption in dirt layers on the surface**
  - **magnetic fields reduce probe performance**
  - **easily damaged probe**

Beta monitoring

- More problems
  - **awkward objects like cable and pipe are difficult to monitor directly**
  - **activity under paint is difficult to detect**
  - **some materials have high surface beta levels, such as tiles**
  - **dual phosphor probes often have a poor low energy beta response**

Alpha monitoring

- Alphas are easily stopped by dust, grease, few cm of air, paint, etc
  - So the surface to be monitored must be clean, flat, dry, etc
  - The probe must have a very thin and therefore delicate window
  - Probe must be held within 10mm of the surface without touching and risking contamination.
  - Slow painstaking work, but under good conditions 0.1Bqcm^2 is possible
- So fairly often alpha monitoring is impossible

3
0

Alpha monitoring

- Any beep should be treated as significant
- For a clean surface a typical 100 cm^2 probe response is 20 cps for Pu-238
- 0.1 Bq/cm^2 gives about 2 cps. Even 0.4 Bq/cm^2 only gives 8 cps
- The response for uranium is much lower

Alpha monitoring

- Probe damage is very likely
- Do NOT use probes that fail to danger if the window is punctured
- How about using the X-rays?
- See next lecture!

Summary

- Every situation is different
- Understand the fingerprint
- Look at what is going to happen to the material
- Determine the OoSL
- Establish the averaging area or mass
- Look at potential monitoring methods – be imaginative
- Trial them
- Pick the one that gives the lowest overall project cost
- Remember – good monitoring saves money over poor monitoring!