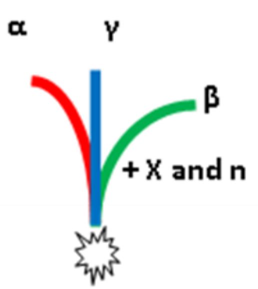

WASTE AND MATERIALS CHARACTERISATION

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Remember – good monitoring saves money over poor monitoring!

Concentrating on surface contamination

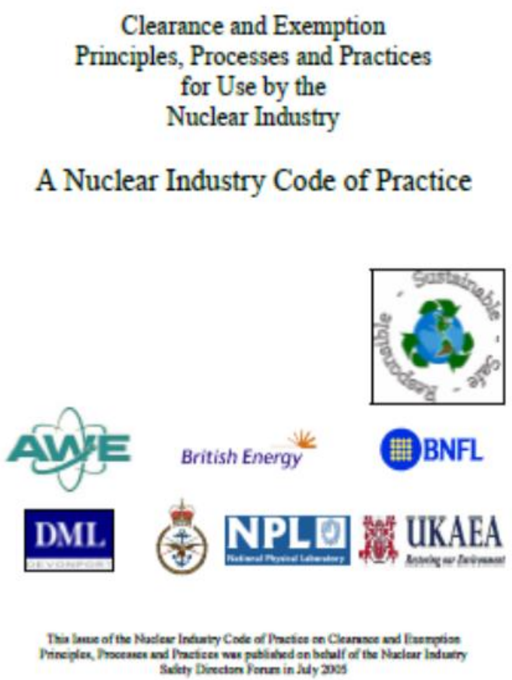
- Clearance measurement is a large subject!
- From the measurement point of view, I'm going to focus on surface contamination.
- I'm saying little on the measurement of bulk contamination and activation this time

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

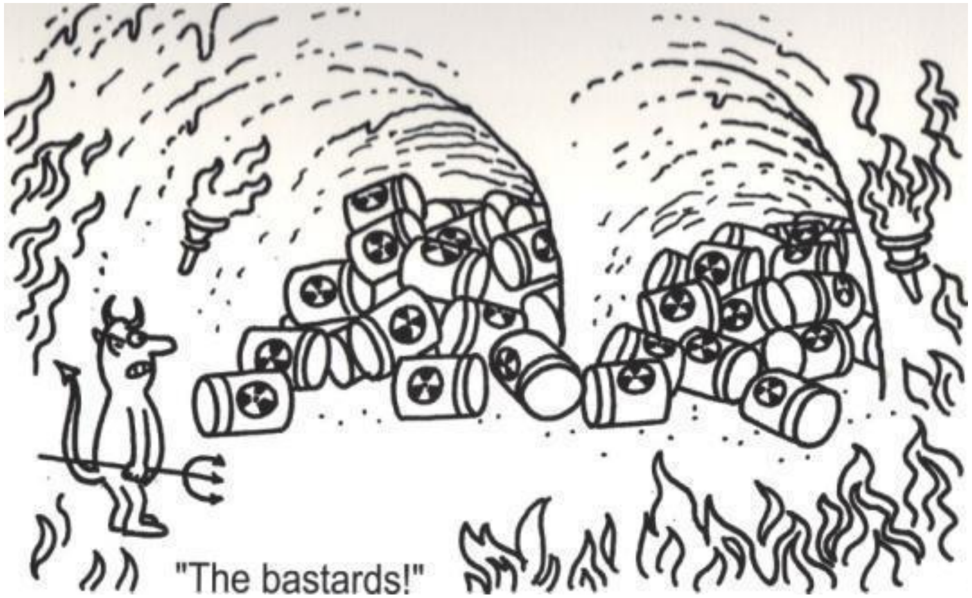

Clearance and Exemption
Principles, Processes and Practices
for Use by the
Nuclear Industry

A Nuclear Industry Code of Practice

This issue of the Nuclear Industry Code of Practice on Clearance and Exemption Principles, Processes and Practices was published on behalf of the Nuclear Industry Safety Directors Forum in July 2005

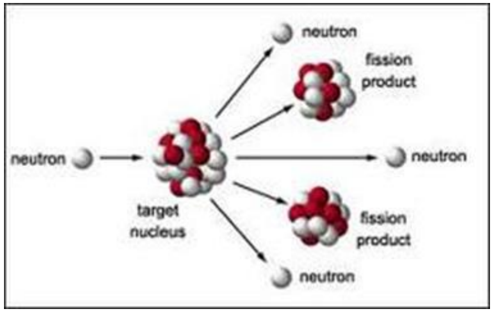
Benefits of Exclusion

- 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 RP89, RP122 and IAEA RS-G-1.7 give values of suggested clearance levels based on dose modelling**

Levels

- UK bulk 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 may 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

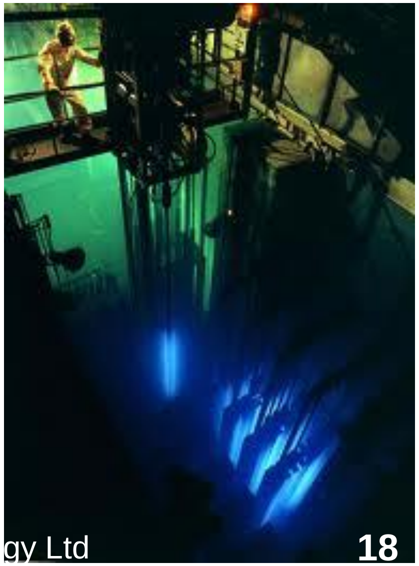
- Total activity limit (OoSL) for the fingerprint shown is 0.88 Bq g^{-1}
- When we move to RS-G-1.7 values, Cs-137 goes to 0.1Bq g^{-1}
- Resulting OoSL value then equals 0.12 Bq g^{-1}
- Cs-137 is the important gamma emitter at a limit of 0.72 Bq/g or 0.098 Bq/g
- Easy to monitor in bulk

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

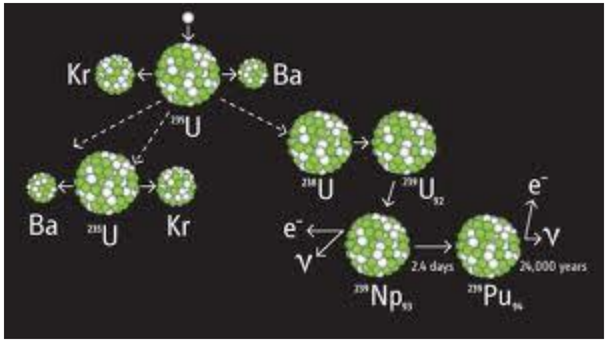
- OoSL is 0.112 Bq g^{-1}
- Three useful gamma emitters
- Will change quite quickly with time – mainly the influence of Co-60 decay

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

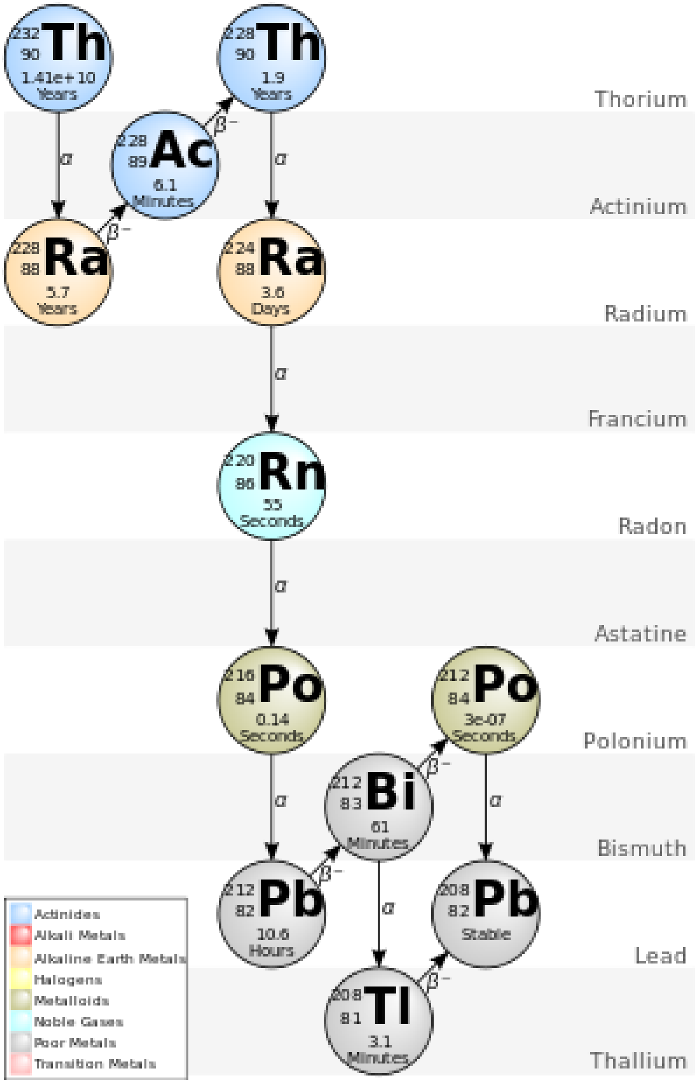
- OoSL is 0.73 Bq g^{-1}
- Dominated by the very high fraction of Pu-241
- Very low energy beta emitter
- Decay product is Am-241
- Concentration will peak at about 3.3 % of original Pu-241 activity
- Only a 36 % 60 keV gamma
- Hence no useful gamma overall



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 $0.1 Bqcm^2$ is possible
- So fairly often alpha monitoring is impossible

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!**