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# Hydrogeological aspects of Risk Assessment in relation to Decommissioning Nuclear Sites

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# What is different on nuclear sites to conventional contaminated land sites?

- Not Much!
- You will find metal contamination (mercury, beryllium, cadmium, etc).
- You will find organics - diesel, mineral oils, solvents, etc.
- On some you will find conventional explosives contaminants:
  - Sellafield was a RO Factory as was Drigg
  - Harwell Research Establishment was a WWII Airfield as was AWE Aldermaston and the Bradwell Magnox Station.
- You still have to assess the source, pathway & receptor relationship (although the land use will probably not include housing with gardens).
- H&S is taken very seriously – but probably no more so than in the Oil and Gas industry.

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# The differences

- You might find radioactive material
- Your H&S plan (and your people on the ground) must deal with this eventuality (and without protracted delay)
- BUT
  - Unlike an agrichemical plant making “ethyl methyl death” – on a nuclear site with the right monitoring equipment you will know (instantly) if there is an issue – rather than “when the blood test results come back”.
  - Levels of detection for the majority of the contaminants are incredibly low and overall radiation levels and actual dose can be measured in the field.
  - You will rarely need to deal with organic chemistry (which to me is good) BUT you might need to learn a new sub-set of the English language in order to communicate with the operators (e.g. a pond is not an area where you feed the ducks, rather, it is a chamber used to store used fuel rods – under water).

# The Challenges (Management)

- Getting data in some of the most challenging locations within a nuclear site (either a power station, a reprocessing plant, or weapons plant) is never easy.
  - Most investigations will require drilling to obtain samples and installation of monitoring wells.
  - On many sites this will require an application to the Plant Safety Committee.
    - They will be worried about buried services, possible changes to the routine operation of their bit of the plant, and whether you can undertake your work without injuring yourselves or other workers.
  - The H&S plan will need to be updated almost daily

# Challenges - Physical

- Most of this site is already built over, and the areas that are not are riddled with buried services – expect 50% of locations to be rejected.
- Even where physical assess is possible – other restrictions may well get in the way – high dose rates, need to maintain open roadways for emergencies, etc

# Developing the conceptual model

- Drill or desk study?

- What are you looking for when you drill an investigatory well?
  - To gain an insight into the geology?
  - To obtain samples of the vadose zone?
  - To monitor water levels?
  - To monitor water quality?
  - To undertake an aquifer hydraulic test?
- You would not/should not drill into an area without first undertaking some form of desk study, or monitoring down gradient of the facility to see if a leakage source is probable or not.
- Drilling into an unknown leak site might expose your drill crew to high levels of radiation and contamination and should be avoided wherever possible!



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# History is important

- Understanding the nature of historical leaks, and general activities is “critical” to being able to understand whether sources are likely, and what they are likely to contain.
- Here the usual rules of contaminated land apply:
  - Speak to people who remember what went on;
  - Look for old photos (not common in the nuclear industry);
  - Gain an understanding of the processes that the site has operated, where and when – i.e. did the site have an in-house disposal area.

# Precautions

- Expect to take significant precautions to avoid spreading contamination or contaminating your contractors.
- Work rates will be perhaps 1/3rd of normal drilling rates.
- Shifts will be shorter – no one would want to work for 10 hours in a PVC suit while wearing a respirator!
- Minimise waste generation when drilling as disposing of contaminated soil and water can cost a small fortune (certainly in high %ages of the entire investigation – LLW to Drigg – circa £3000/t and ILW £££???).
- Expect to have every aspect of rig safety scrutinised to the highest degree possible.
- We have used a variety of methods but on the most critical projects we would use rotary sonic coring as preferred method.

# Types of Radionuclides on Reactor and Reprocessing sites

- Where **nuclear fuel** is involved the main components within the context of contaminated land will be Uranium (U-234, U-235 and U-238). These isotopes are all alpha emitters. Ultimately, if these materials are left long enough, there will be in-growth of Th-230 and Ra-226 but for most contaminated land investigation the timescales involved for in-growth would not be long enough.
- The medium half-life **fission products** that are commonly seen include Sr-90, Tc-99, Cs -137 and I-129. They are all beta emitters and Cs and Tc are also gamma emitters.
- The principal **activation products** will be H-3, C-14, Cl-36, Fe-55, Co-60, Ni-63, Cs-134, and Pu – 238, 239, 240, 242 – with the Pu all being alpha emitters and the remainder beta or beta-gamma emitters.

# What might you find during the investigation

- If there have been leaks from buildings containing used fuel elements you might find actinides and fission products (and commonly Tritium).
- If there has been leakage or decommissioning of a reactor vessel then a variety of activation products might also be found – many of which might originate as contaminants within the graphite core.
- Understanding the finger print of what you find might help to guide you to the origins of its source.

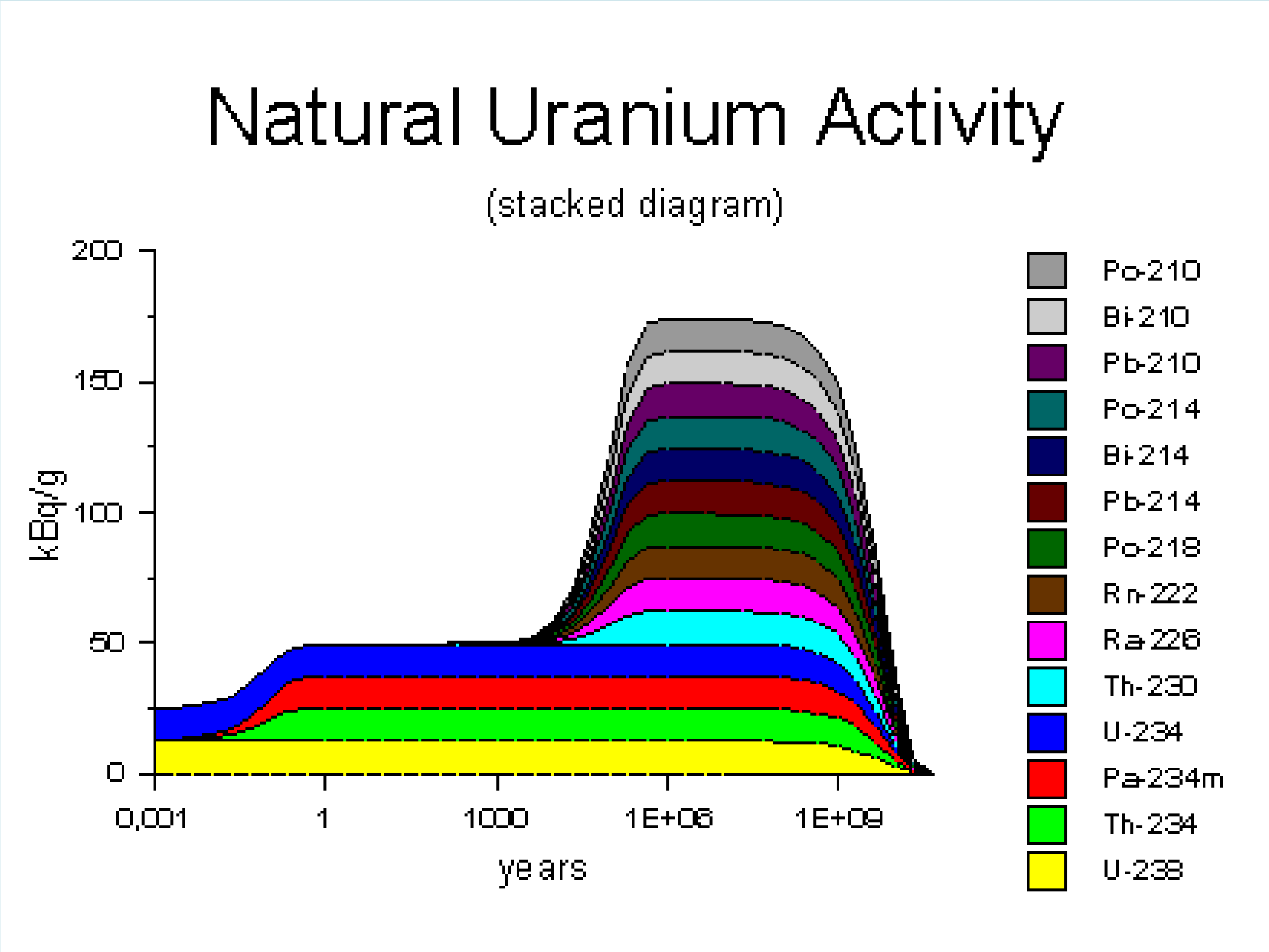
# Contaminant mobility

- There has been a huge amount of academic effort expended in examining the fate and transport properties of radionuclides – driven by research into high level nuclear waste disposal and the environmental performance assessment that goes hand in hand with the overall safety case development for these types of facility.
- Some of this information can be used (with care) when undertaking fate and transport modelling of common radionuclides.
- The most common contaminants that I see are:
  - Tritium (H-3) Half-life 12.3 yrs, weak beta emitter, nearly zero Kd
  - Strontium (Sr-90) Half-life 28.6 yrs, beta emitter, high Kd controlled by CEC
  - Caesium (Cs-137) Half-life 30.2 yrs, beta and gamma emitter, very high Kd
  - Technetium (Tc-99) Half-life 21,000 yrs, beta and weak gamma emitter with highly variable Kd – it can be extremely mobile.

# Type of radionuclide will point to source

- The key activation products (with the exception of tritium) (Fe55, Co-60, Cl-36, C-14) are rarely seen in any quantity until the actual contents of the reactor pressure vessel undergo decommissioning, although small amounts may well be present in the various cooling circuits associated with the reactor and within the fuel rod Ponds.
- Cooling ponds will contain fission products, but the activation products tend to stay in the reactor core, and in the case of Magnox reactors, often bound into the graphite core.
- Some specific radionuclides can be both fission products and activation products (e.g Technetium-99).
- C-14 and Cl-36 both have relatively long half-lives (5,700 and 301,000 y respectively) and both will be readily mobile with low Kds.

# Activity will vary with time




U238 “decay” does not mean that the activity necessarily decreases, as there is in-growth of daughters which can have higher activities.



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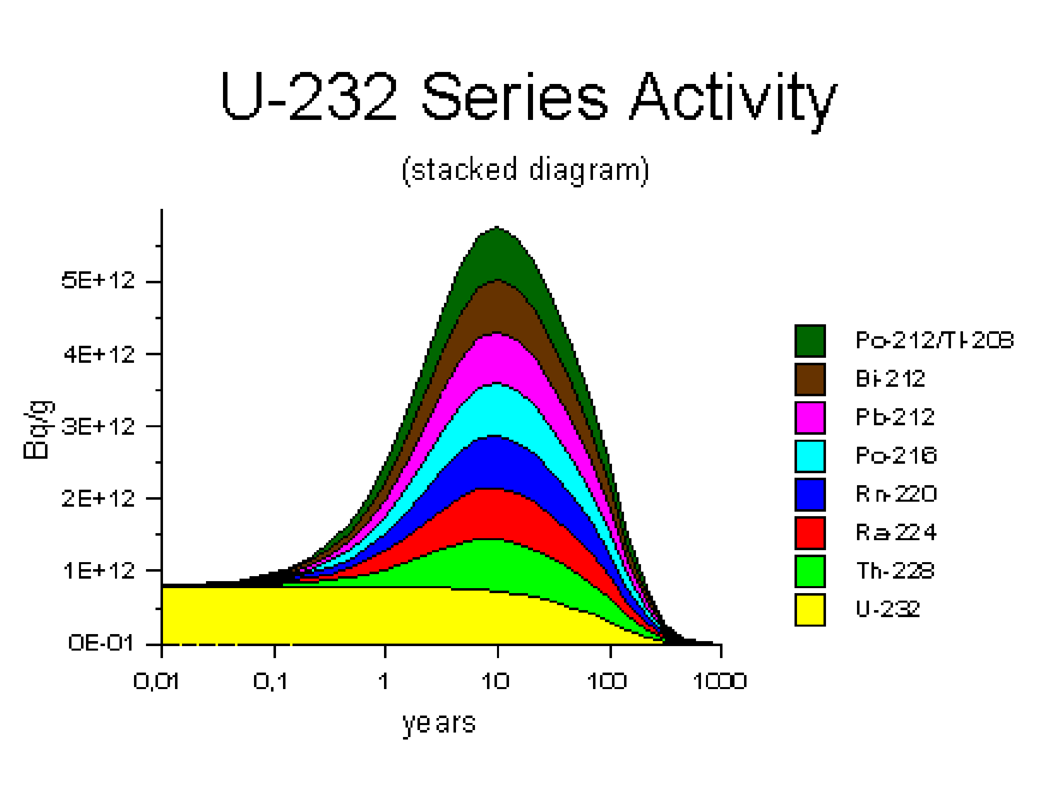
# And depending upon the starting isotope, the decay series can be very different!




Note that this is a "contaminant" within Reprocessed fuel and peaks at over $5e^{+9}$ KBq/g within 10 years & that Th-228 is a very strong gamma emitter. However, the entire chain will decay within a 1000 year period.



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# Half-lives

- Unlike organic contaminants which often need exactly the right redox conditions to degrade, radionuclides half-lives are dependable and the degradation will occur whether the atom is in solution (as an ion), sorbed to clay mineral or imbedded in the molecular structure of a complex compound.
- Because decay reduces the mass of a specific contaminant any modelling to predict the fate and transport often has to start with a prediction of the actual entrained activity within a specific spillage or leak. It therefore becomes necessary to back calculate the actual activity and make-up present at the time of the leak in order to complete the process of modelling the migration of the leaked material.

# Other methods of investigation

- Clearly, in the centre of a major leak you might not want to use conventional drilling techniques for fear of contaminating and exposing the drilling crew unnecessarily.
- The use of other techniques will depend to an extent on the inventory of what has leaked.
  - In high dose environment, surface monitoring/mapping techniques using gamma spec could prove invaluable.
  - Driven blind tubes can allow downhole gamma spec to identify the nature and concentration of some of the contaminants (provided they are gamma emitters – alpha and beta particles will not penetrate steel tubes).
  - Using groundwater sampling as an integrator of all upstream contamination might also avoid drilling into source areas.
  - Cone penetration has also proved invaluable on some sites, especially where it is a genuine “journey into the unknown”.


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# Cone penetration rig

- It can help to characterise soil type
- Produces minimal waste material
- Rods can be withdrawn by a separate jacking system to avoid contamination of the truck and to permit more speedy work.
- Specially adapted cones can be used to obtain liquid samples, or provide information on gamma radiation, or volatile solvent concentrations and a host of other useful things.
- Minimal dose to operatives
- Very quick to survey an area once clearance to operate has been issued.

# Aquifer Tests

- Pumping tests can be a specific challenge but will yield invaluable information.
- Commonly, the levels of contamination (if present) will increase shortly after pumping starts unless your well is already in the centre of a plume or in a completely clean area.
- Common problems derive from **where to pump the water to**, how much can you pump in total, and will the drawdown cause **“unacceptable” building settlement** (noting that in some cases, the contents of some building might mean that any settlement is unacceptable).

# Dipping during a pumping test

# Common areas where contamination is often found

- Turbine halls invariable contain lubricating oils (and solvents from the attendant workshops).
- “Solvent abuse” seems rife on many nuclear sites and I recall one wonderful quote from one of our nuclear weapons sites – “dispose of solvents by evaporation – heck it’s not rocket science!” – so far we have recovered a few tonnes of TCE from the ground and still counting!
- Nuclear civil engineers have utter faith in the “total impermeability” of structural concrete (probably a very similar faith that landfill operators have in their liners). Concrete can crack, especially when it gets hot.
- Ponds (concrete structures full of water) are always a likely source of contamination. Effluent treatment plants and active drains are another likely source, closely followed by known spills and leaks (often “pipeline or valve related).
- Transformer stations (at the older stations) may have PCB contamination associated with oil spills from oil cooling circuits.

# Risk Assessment

- The Risk Assessment method will used will depend upon the nature of the risks being evaluated.
- We have used ConSim for numerous groundwater risk assessments on Nuclear Licensed Sites.
- We have also used complex 3-D numerical groundwater models to develop groundwater vectors to then use in performance assessment models such as RIP or GoldSim to calculate dose to the most exposed receptor group.
- If you are building a new plant then the safety case requirements will be very high.  If you are confirming that the status quo is safe, or simply scoping whether there is a problem or not, then more generic tools are quite appropriate.
- At the end of the day it comes down to producing a robust, defensible conceptual model – because if you get that bit wrong, the best computer code in the world will not rescue the situation.

# Finding the source of the problem is often the hardest part

# Thank you – Questions?

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