Problems Experienced when dealing with the Decommissioning of NORM Contaminated Oil Production Installations and Floating Production Operations

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Oil production facilities can become significantly contaminated by NORM materials which also contain hydrocarbon and other hazardous materials. The decommissioning of these facilities can have to take place in countries which do not have a developed infrastructure for dealing with radioactive materials. The problems are outlined, particularly those of dealing with radioactive wastes and an inexperienced work force. Some suggested solutions are presented from experience of this work.

NORM, Oil Production Facilities, Decommissioning

1. Introduction

The rock strata containing oil and gas also contains uranium 238 and thorium 232 in varying amounts and in varying ratios depending on the geology of the area of production. The average concentrations of the radio-elements found in common sedimentary rocks varies. The highest values of uranium and thorium are found in shales. Whilst common shales have uranium and thorium values very close to the average for the continental crust, the very high uranium concentrations in black shales are probably due to their augmented organic content. The greater part of the uranium in sandstones, orthoquartzites and arkoses, is disseminated through the quartz grains themselves, whilst thorium tends to be associated mainly with resistate grains. The uranium content of limestones is held largely within the crystal lattice of calcium carbonate where the uranium ions substitute for the calcium. A similar substitution of phosphate ion occurs in phosphatic limestones, which frequently contain several hundred parts per million of uranium. Thorium, however, does not enter the carbonate lattice easily and, in consequence, thorium values tend to be low and held mainly in the clay and heavy mineral fractions.

As well as oil and gas the rock formation also contains formation water which is essentially brine, sodium chloride, but which also has dissolved in it the cations barium, strontium and calcium at levels which again depend on the geology of the rock formation. The anions present in addition to the chloride are bicarbonate and a trace of sulphate. Both uranium and thorium decay through a series of radioactive progeny (fig 1 and fig 2) before they become a stable element, lead 206 in the case of uranium 238 and lead 208 in the case of thorium 232. In both decay series two changes take place which are important for the oil and gas industry. The first is at radium. The elements above radium are essentially insoluble in formation water. However radium dissolves in formation water as the salt radium chloride. This results in all formation water being radioactive, sometimes to such an extent that the by-product produced water discharged from an oil producing installation can often be classed as radioactive under the country of production national legislation. The second change is at radon. Since the half-life of radium-226 is 1620 years, its concentration within these brines will be sufficient to generate a steady stream of radon-222. This will be carried into the gas reservoir above by the much greater flow of methane from the seams producing the natural gas. Under favourable circumstances can also escape from the parent mineral grain and migrate through the surrounding pore spaces and fissures. This separates the radon and its daughters from the parent uranium-radium. A radon isotope is also present in the thorium decay series, but its range of migration is limited by its very short half-life.

The radon-222 decays to polonium-218 which exists initially as a positively charged ion but can oxidize and form a nucleus to which a cluster of water molecules becomes bound. The radon decay products can therefore become either partially or totally attached to aerosol particles within the natural gas.

All natural gas is, to a greater or lesser extent, radioactive.

Fig 1   Uranium 238 Decay Series

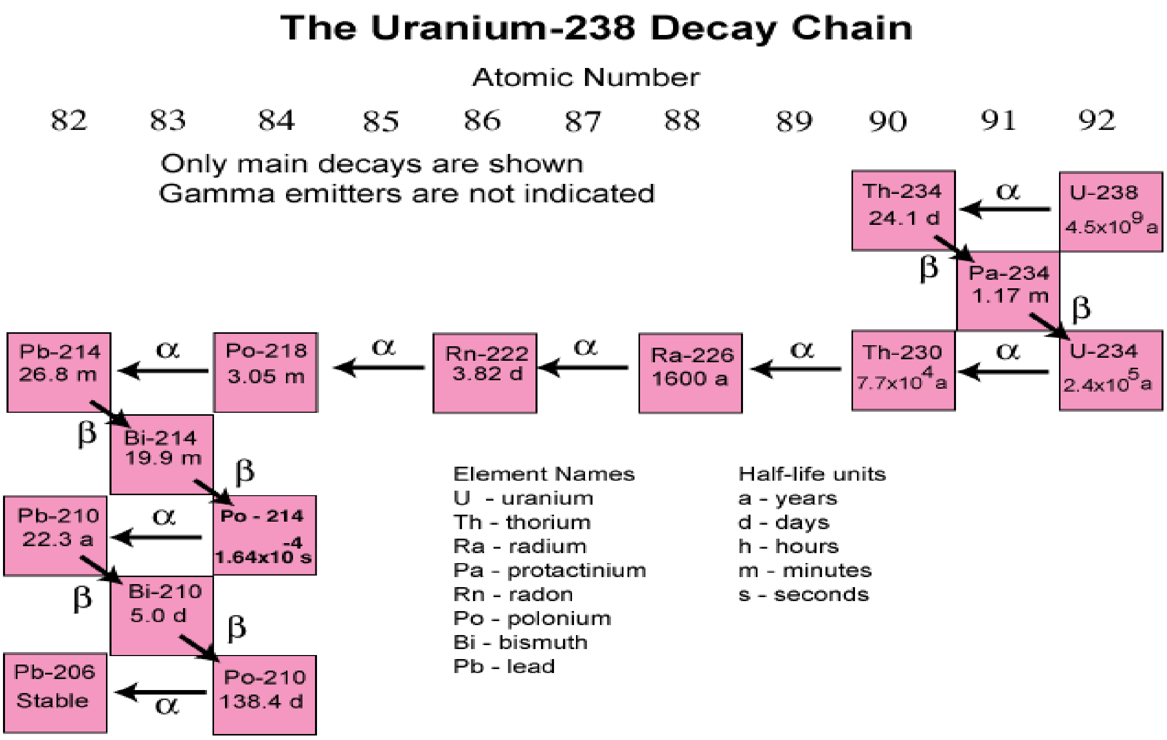
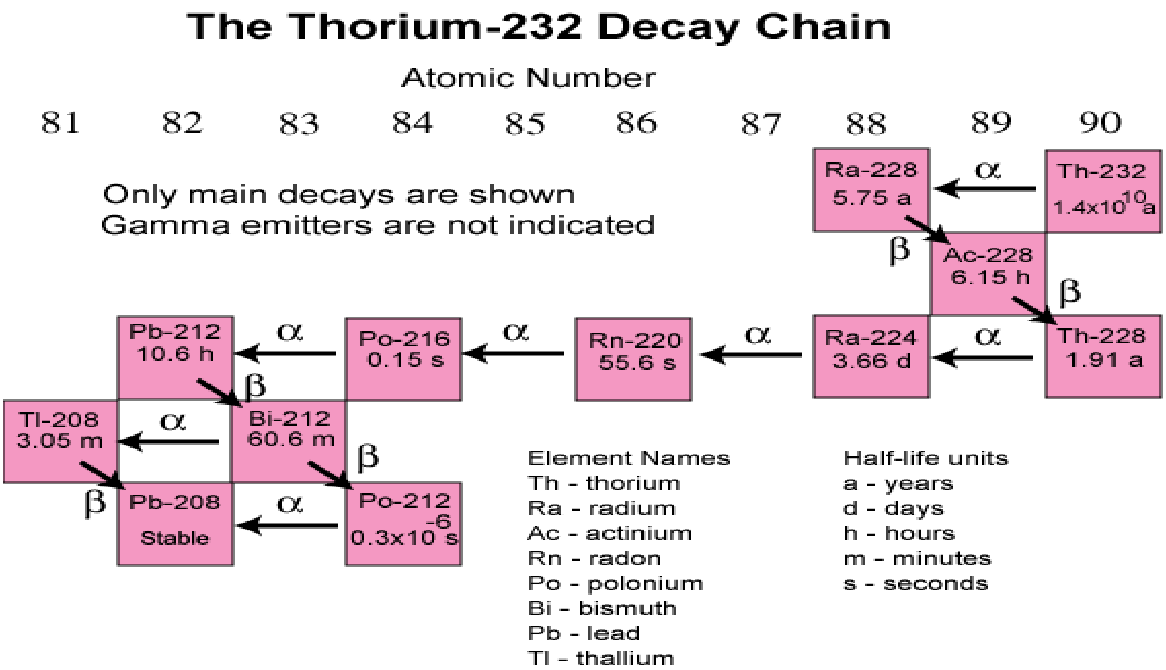


Fig 2 Thorium 232 Decay Series



NORM deposits in oil and gas production facilities had been known about since the early 20th century but because they were naturally radioactive no-one assumed that there would be any radiological consequences if worked with. It was not until they occurred in the UK sector of the North Sea oil production area that the realisation that they may be a radiological problem was identified. At the time the UK was one of a very few countries that had legislation which applied to NORM material. This legislation was not only in place but also had very low levels at which NORM material came within the scope of the legislation.

For several years the problem of NORM was considered to be a UK North Sea problem which was particularly acute because of the very aggressive policy which was being carried out of injecting sea water to enhance production. It is now realised that it can be found to a greater or lesser extent in oil fields throughout the world.

2. Radioactive Scale Formation

The initial production of oil and gas from a reservoir is usually dry. However, as the natural pressure within the formation falls, the water present in the reservoir will also be produced with the oil and gas. As previously described, this formation water contains dissolved mineral salts, a very small proportion of which are naturally radioactive.

The injected seawater may be more saline than the formation water and consequently may dissolve additional radioactive salts from the mineral present in the various geological strata. In some areas produced water is injected either to maintain pressure or as a means of disposal. Seawater, although sodium chloride like the formation water, carries with it sulphate ions which are almost totally absent from formation water.

The produced water, comprising formation water and injection seawater, contain various ionic species in solution as described above. The cations are all from Group II A of the periodic table. These particular cations and anions comprise the soluble components of some very sparingly soluble inorganic salts. Once the solubility product for a particular pair of ions e.g. Barium and Sulphate, is exceeded, precipitation or deposition occurs. Various thermodynamic factors influence the solubility of any particular pair of ionic species, for example, temperature, pressure, pH and ionic strength.

The scales that form may be either simple salts, for example, Barium Sulphate or complex salts, for example, Barium Strontium Sulphate, since the final composition depends upon the relative abundance of the ionic species present in the produced water. Since Radium is also a Group II A element, the chemistry of its inorganic salts is similar to that of the other Group II A elements. Calcium, Strontium and Barium consequently will co-precipitate the Radium to form complex inorganic sulphates. The process not only traps the radium in the scale matrix but under some circumstances concentrates it. The radium is very tightly bound into the scale matrix and is very difficult to extract. Although deposited as pure radium it will then reach equilibrium with its progeny. Measurements of progeny show that the gaseous radon isotopes do not escape to any extent and the progeny are in equilibrium.

The physical form of the deposit varies according to location, but is typically a white/brownish brittle solid which adheres tenaciously to the substrate on which it has formed. The deposits are exceedingly difficult to remove by chemical means although in recent years some cocktails have been produced which if heated and flowed across a scale surface for several hours will work. Generally the cleaning of surfaces has to be undertaken using high or ultra high pressure water jetting.

3. Vessel Deposits

As well as barium sulphate scales being radioactive it is also possible for silt, sludges and other materials such as anthracenes and napthanates, which can be deposited in vessels, to be radioactive. The latter materials can be extremely difficult to clean out of the vessel. The activity in sludges and silts is probably present for two reasons. The clays present are particularly effective at absorbing ions from the produced water and tend to concentrate the radionuclide present in the clay structure. The second reason is a consequence of the use of the scale inhibitors which are put into the down hole production system to stop scale formation. These works in several different ways depending on the chemical used but the most common used works by stopping the scale formed adhering to the surface of metals. Some of this sulphate scale, with radium trapped in it, falls out and mixes with the sludge in the vessels.

4. Oil Production Facilities

In the off shore environment these essentially fall into two groups. The first are platforms which sit on the sea bed. Most of the wells on such an installation will be drilled from the platform and the production pipe work will come directly from the sea bed onto the platform. Some installation will also be fed by remote sub-sea wells that are tied back to the platform by an umbilical. The alternative to an installation is a floating production and storage facility (FPSO) sometimes purpose built, but often a converted tanker, which carries out the same operations as a platform but which is always supplied by subsea wells fastened back to it by umbilicals. Production platforms have a production lifetime which is often longer than predicted as new drill techniques (and the value of the oil) enable smaller parts of the field to be exploited. It is generally of the order of 20-30 years after which it must be decommissioned and removed. FPSOs are a little different. When the field they are serving comes to the end of its lifetime (or the contract with the field operator comes to an end) they can simply be moved to another field to continue production there. However before going back on station they are always "rebuilt" to ensure they are fit to operate for another period of time. Rebuilding and decommissioning involves completely emptying all the radioactive sludges/silts etc from vessels, removing scale on the sides of vessels and removing and disposing of scaled pipe work.

5. Activity levels

The activity levels found in scale can be as high as several 100 Bq/g of radium 226 and radium 228 in partial if not complete equilibrium with their progeny. In the series following radium 226 the half life of lead 210 (22.3 years) limits in growth during even the full production lifetime of a platform, but some in growth does occur.

The dose rates on the outside of vessels and tubulars are rarely of great significance and are generally less than 7.5 µSv/h. However, occasionally when pulling well production tubulars or inside a separator, waste or storage vessel dose rates can rise well above 7.5 µSv/h.

The primary hazard from scale and silts follows from ingesting or inhaling it, particularly during any cleaning operations. Scale which is ingested through the mouth will probably pass straight through the digestive system and be excreted. Scale that is inhaled through the nose stands, depending on the particle size, a chance of becoming trapped in the lungs. Once trapped it cannot be removed. As many of the radionuclides in the decay series decay with alpha particle emission and the scale particle is in contact with the bronchial mucosa surface cells, this is potentially dangerous. Any cleaning operations involving the removal of radioactive scale must therefore ensure that the chance of ingesting or inhalation is reduced to an absolute minimum.

6. Procedures

Procedures fall into two relatively separate groups. Those involved with topside production systems and those involved with downhole equipment and material. A systematic monitoring program of all the topside areas where scale or contaminated silt is likely to accumulate should be undertaken. If found it must be brought to the attention of anyone involved in cleaning operations. This will avoid delays due to extra working facilities having to be set up if it is found retrospectively.

Monitoring may not always detect the presence of low levels of radioactive scale inside thick vessels. It is essential therefore that even if nothing has been detected on the outside of the vessel a check is made inside the vessel when it is opened.

All work over operations involving the removal of downhole tubulars or valves must assume that radioactive scale may be present. It is sometimes possible to take a log of the well prior to the workover to actually measure the increase in activity. Both oil production wells and water injection wells have been found to contain radioactive scale. Basically all tubulars and valves removed during a workover must be monitored when they are removed.

In production equipment all pipework, vessels, drains and flowlines which have been in contact with produced water either before or after separation may be contaminated and have to be monitored.

7. Other associated hazardous materials

The disposal of scales and sludges is further complicated by the presence of other hazardous elements, particularly mercury, and hydrocarbons in the waste. Waste facilities which are capable of accepting

NORM, hazardous material and hydrocarbon wastes are very few in virtually all countries and non-existent in many.

8. Decommissioning Planning.

The counties where oil is produced have a very wide range of regulations and infra structure for dealing with ionising radiations and radioactive waste. Some, such as those in Europe have a very clear set of operational regulations but even in some of these countries e.g. the UK the facilities for dealing with the resulting wastes are not easily identified or available. In other countries virtually no regulations exist for controlling either work with ionising radiations or dealing with radioactive wastes. A direct consequence of this is that there is not an indigenous work force that is familiar with the practices that have to be adopted. Also in many of these countries the standards of general safety and safety culture are not yet well developed.

When decommissioning a FPSO a further complication can arise in that this work could well be carried out in another country which may have stricter regulations regarding what constitutes a radioactive material in place than the country of origin. If material is considered radioactive under their regulations there is likely to be a total prohibition of leaving any behind as radioactive waste after refurbishment work has been completed .

It is essential that the levels of activity at which material must be removed to be left in the country of origin must be identified early in the planning exercise as this can significantly affect the time that must be allowed for it to be removed. Suitable on shore repositories for the waste must be identified in advance of the demolition operations starting.

Similarly when decommissioning installations a similar consideration has to be given when identifying a country to which the big modules which are removed from the main installation structure are going to be sent to be finally broken down. A major problem with most major installations is that the operators have insufficient data to accurately predict what material is likely to be found in vessels and pipework etc until they are actually opened for cleaning. Carrying this out is therefore not easy.

9. Work procedures.

In countries with well developed procedures in place where people are experienced in working with these oil field NORM materials an experienced work force can be available. Working practices are therefore well controlled and existing procedures rarely need altering very much. In other counties the availability of a work force with the requisite working skills and personnel who are able to carry out proper monitoring for NORM contaminated materials is very low or even non-existent causing severe problems.

The environment in which this demolition/decommissioning work is carried out is harsh and difficult in cold climates. In hot climates the addition heat extremes make many of the recommendations for working such as face masks or not drinking or eating in a work area very unattractive and very difficult to enforce. The immediate hazards are the ones of most concern and the wearing of additional PPE to protect against a hazard which may manifest itself sometime in the future is not an easy concept to understand for some workforces. Additionally, in many of these operations, time is a major constraint and the nature of the work contracts is such that any over runs from the agreed schedule result in stringent financial penalties being incurred. The slowing down of an operation because of the unexpected restrictions of procedures to deal with radioactive materials is not welcome by many project managers.

10. Suggested Strategy for answering some of the problems

- Start planning to deal with any NORM as soon as the project is first conceived. It must not be left until other plans are in place which are difficult to change.
- Communicate with the local regulators to ensure that all actions are understood by them and they, as a consequence, will support.
- Try to identify magnitude of problem by looking at past disposal records and external monitoring. This is can give a good "feel" for the magnitude of the problem but should not be allowed to drive it as external monitoring cannot be used to indicate the specific activity of deposits inside a pipe, vessel etc. Internal monitoring and sampling can only do this.
- Identify routes of disposal for any NORM contaminated materials.
- Establish what working regulations are going to be used. Clearly the national ones if proper ones are present but this may not be the case and "best practice" must be adopted.
- Establish what defining criteria must be adopted for identifying radioactive NORM material, paying particular attention to where final refurbishment or demolition will take place. It may well be that additional costs dealing with problems that arise because of this could out way other commercial considerations.
- Ensure that properly trained local supervisors are available. This can be difficult because experience in other radiation work areas does not always translate easily to working in the oilfield environment or controlling oilfield/demolition workers. It is essential that these supervisors are capable of giving tool box talks in a manner that can be understood and accepted by the work force. Training of the supervisors in working with NORM in a demolition environment is essential prior to them starting work.
- Establish clear working procedures which the supervisors can and must enforce.
- Ensure all managers understand that completion times cannot be used to try to reduce standards.