AN INTRODUCTION TO THE SCIENCE & TECHNICAL APPLICATION OF RADIOISOTOPES FOR SAFE, ACCURATE & RELIABLE PIG TRACKING

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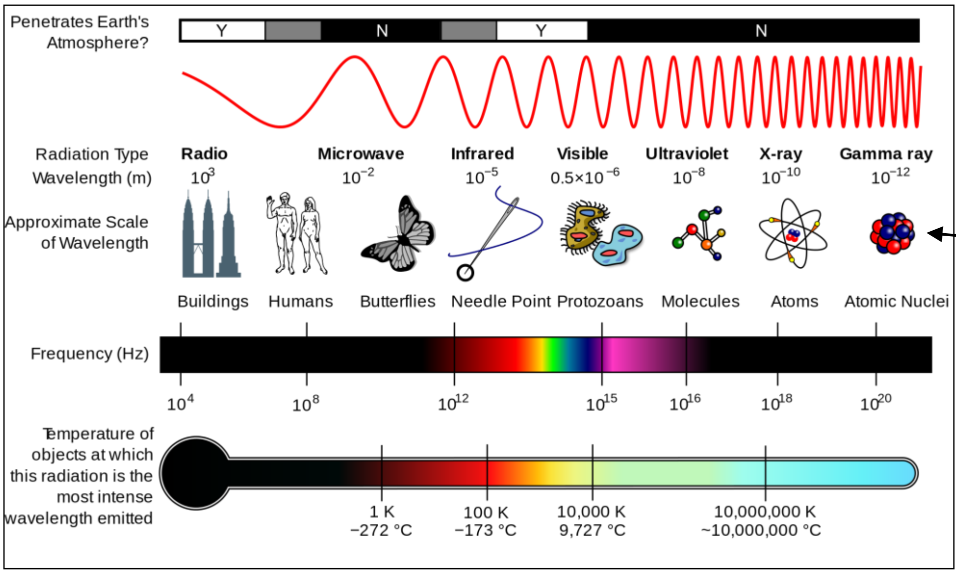
1. Radioactivity

Weapon testing, power station accidents, assassin's tools, even Marvel comic characters. When the terms radioactivity, nuclear, isotopes, gamma radiation etc are used to describe the properties of atomic elements, it tends be associated with a negative reaction and heightened sense of caution or danger. This is understandable as with most forms of radioactivity the effect cannot always be detected or quantified without the use of special monitoring instruments. The loss of an industrial radioactive source from a mining measuring instrument no larger than small coin in the Australian outback made international headlines requiring a high-profile search and recovery mission. The perception versus the reality of the potential danger to people or the environment are in most circumstances quite different. This paper will explore the foundations of using radioactive sources in the pipeline pigging industry. When used by competent persons in a controlled manner it provides a highly effective and reliable method to track and position pigs without harm to people or the environment.

2. Electromagnetic Waves

Electromagnetic (EM) radiation can be described in terms of a stream of mass-less particles, called photons, each travelling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy. The different types of radiation are defined by the amount of energy found in the photons. Radio waves have photons with low energies, microwave photons have a little more energy than radio waves, infrared photons have still more, then visible, ultraviolet, X-rays, and the most energetic of all are gamma-rays. We are mostly likely at some point to have encountered gamma and X-rays via medical instruments. The ability of these high frequency EM waves to pass through objects of varying density (including several inches of steel) with the received photons detected and quantified provides many industrial applications including that of distinct 'markers' to track pipeline pigs.



We are surrounded by naturally occurring EM radiation every day. Most is in low enough doses to be harmless or if protected by a good covering of sunscreen. Most mined elements that are used for industrial radioactive sources are benign and require intervention in a reactor to create an isotope that will provide the radiated gamma energy.

Fig1

3. Gamma Radiation

Gamma rays (photons) are emitted from the nucleus of an unstable atomic particle during its decay. Excited energy bands in the nucleus reverting to zero or “ground state” give rise to discrete energies of gamma radiation. The gamma-ray energies and relative intensities are characteristic for a particular isotope and if measured using energy selective equipment can be used to confirm identity (i.e. provides a gamma-ray fingerprint for an isotope which can be matched against known data). In addition to gamma rays, certain isotopes will also emit Alpha & Beta particles. These types of emission have charge and mass that interacting strongly with any matter. They consequently have short path lengths in most materials (e.g., a thin piece of paper or film of water is usually sufficient to absorb these emissions).

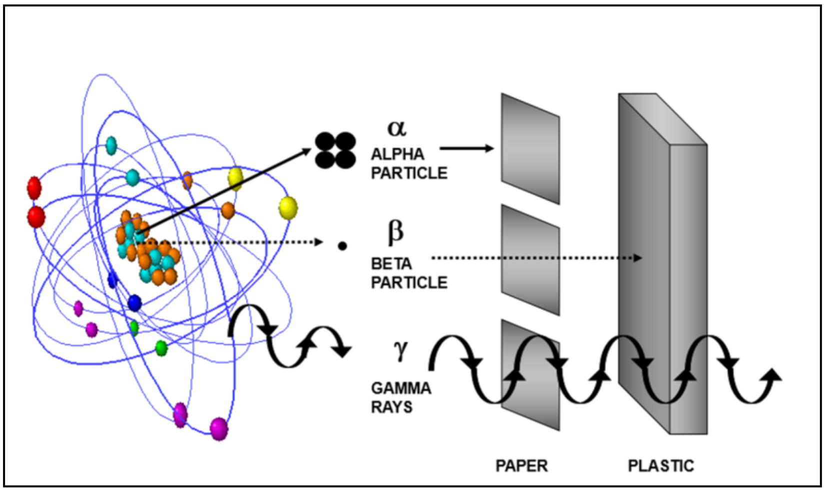


Fig 2

In order to create a radioisotope, it is usually necessary to convert a normally stable atom of an element into an unstable form. This can be achieved in a number of ways and usually requires a charged particle or neutron to be introduced into the nucleus of the normally stable atom. This process requires the incident radiation to have sufficient energy to overcome nuclear forces and penetrate the nucleus giving rise to the required instability. One way of creating isotopes is to introduce target elements into a nuclear reactor. This typically how the sources are manufactured for pig tracking.

Typical industrial Radio isotopes that are manufactured from a base element or by product of nuclear reaction. i.e. Cs is element Caesium, 137 is the atomic mass number. Tantalum (Ta-182) and Cobalt (Co-60) are common isotopes used for pig tracking.

ISOTOPE	RADIATION	HALF LIFE
Cs-137	β, γ	30 Years
Co-60	β, γ	5 Years
Ir-192	β, γ	80 Days
Ta-182	β, γ	115 Days
H-3	β	12 Years
Ra-226	α, β, γ	1600 Years

Fig 3

4. Radioactive Decay – Half Life

The activity of any given radioactive isotope decreases with time as the number of unstable nuclei are reduced by decay. The rate at which this occurs varies from radionuclide to radionuclide and reflects the degree of instability. For each radionuclide, there is a decay constant which describes the rate at which the atoms proceed to achieving eventual stability and the rate at which they emit their radiations. Radioactive decay is an exponential process and the term "half-life" defines the time it takes for a given number of radioactive atoms to be reduced by half. Over two half-lives the original activity would reduce by a factor of 4, over three half-lives by a factor of 8, over four half-lives by a factor of 16 and so on. The range of half-lives is vast covering fractions of a second to thousands of years.

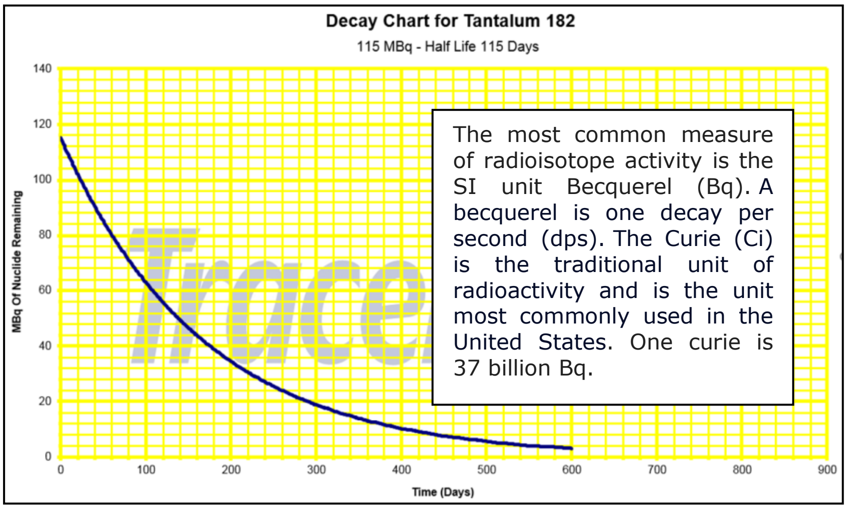


Fig 4

5. Half Value Thickness

The term "half thickness" or Half Value Thickness (HVT) is used to describe the ability of materials to attenuate (shield) gamma radiation. This is effectively the thickness of material required to reduce the initial gamma radiation intensity by a factor of 2. Materials with a high atomic number (heavy elements) tend to be better at absorbing gamma radiation than low atomic number (lighter elements) and hence steel and lead would be preferable as gamma radiation shields than Aluminum.

Shielding and distance are two important parameters used to ensure radiological safety and minimise unnecessary exposure. The strength of the gamma source drops significantly with distance. Double the distance reduces the energy intensity to a quarter. By careful design and material selection, shielding will cut off emissions completely.

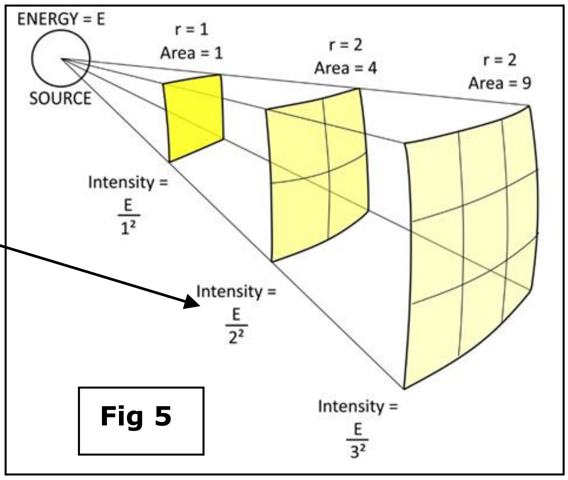


Fig 5

6. Absorbed Dose and Dose Rate

It is generally known that EM radiation can interact with biological matter. The impact is directly correlated to the strength and proximity to the source. Not all sources have a detrimental effect, but as the source type moves toward the higher frequency, high energy part of the spectrum the effect is more pronounced. **Absorbed dose** is the quantity of energy imparted by Ionising Radiation to unit mass of an absorbing medium. **Dose rate** is a measure of the presence of ionising radiation and indicating the rate at which energy is being deposited in an absorbing medium over a time period. Radiation exposure is categorised in two types Deterministic for immediate, short-term effects (i.e. burns, sickness) and Stochastic for chronic, long-term effects (i.e. cancer). As doses are additive, a high emphasis is placed on keeping the total exposure as low as reasonably practical. The UK Government Ionising Radiations Regulations 2017 (IRR17) apply to a wide range of work practices and requires employers to comply and minimise exposure. There are specific stated doses which must not be exceeded. Risk assessments are mandatory for all activities including project specific requirements. Employees that work with sources are monitored for daily allowable limits and lifetime dose. A common standard used is to ensure a dose rate less than or equal to 7.5µS (Sievert) per hour. This will assist determining a safe exclusion distance for non-involved worker.

7. Source Hardware & Physical Dimensions

Gamma sources used for pig tracking are very small and compact. The isotope material from the reactor comes in the form or a wire or powder. This is sealed inside a special capsule shown in the figure. This is then housed within a sprung loaded 'pencil' holder at the opposite end of the threaded section. The length of the pencil is variable to suit the application and is designed so to put distance between the person handling the source and assist reduction of the accumulated dose.

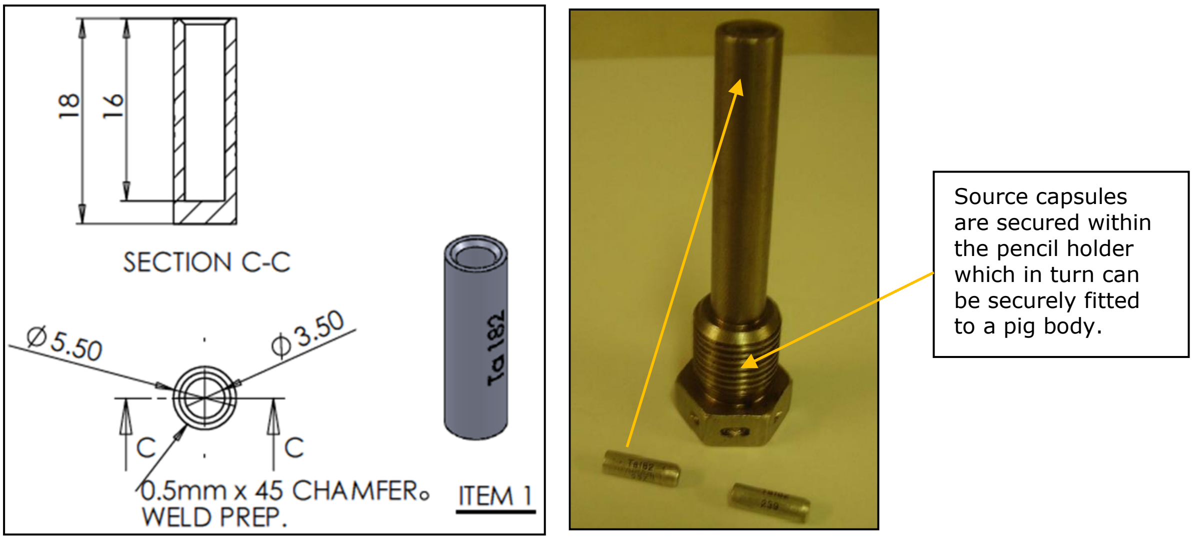


Fig 6

8. Fitting to Pigs

Fitting the source pencil holder to the pig body requires a standard ½" BSPP thread. On standard steel mandrel bodies for BIDI pigs this can be on the main body or via a bolted bracket which can readily be retro fitted. Once torque set in place, a secondary security wire is attached on the head of the holder in the unlikely event the pencil manged to back out.

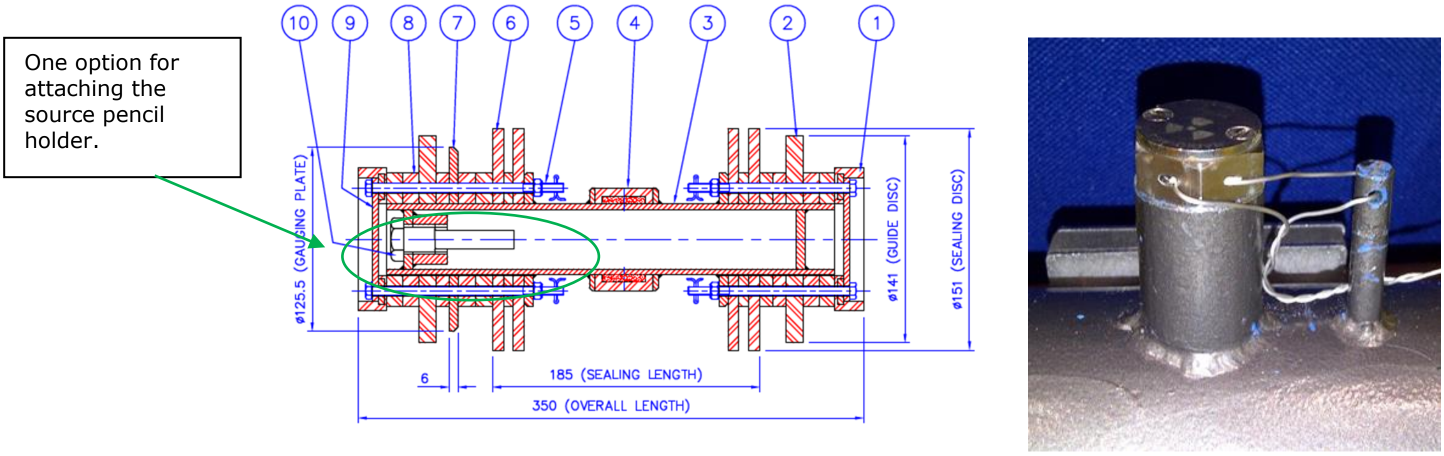


Fig 7

9. Source Optimisation

The two main methods to reduce the amount of exposure is to introduce shielding and distance from the source. For every pig tracking requirement using a radioisotope, optimisation of the source strength and characteristics is key aspect. The source strength needs to be sufficient to penetrate the surrounding path of steel, liquid, coating etc and reach the position of the detector unit (Tracerco own Gamma Trac™). This is also to ensure that just the required amount of energy is used in order to minimise the safe working area and dose rate for involved persons to as low as reasonably practical (ALARP principle). Orientation of the pig is also taken into account for the longest possible path length of material densities. The source decay is also calculated to determine the residual strength on recovery, again to minimise the exposure when recovering.

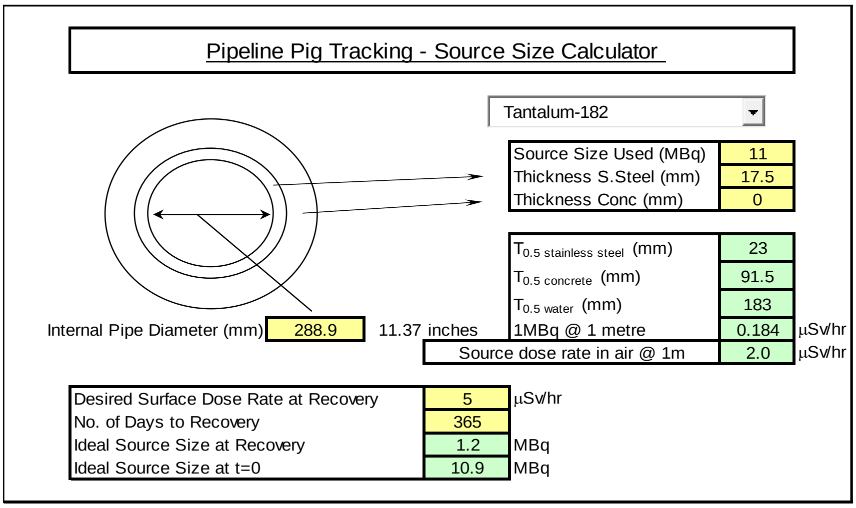


Fig 8

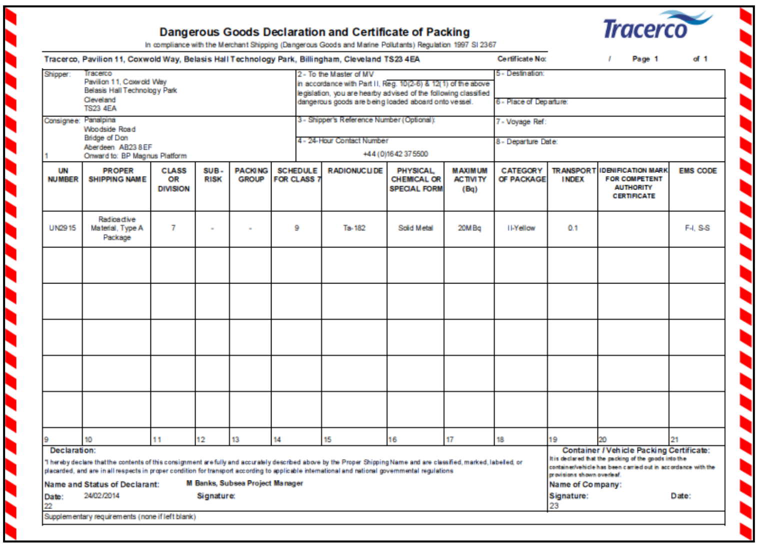
For the sources with an activity of 65MBq the controlled area barrier distance around the pig locations will be at 1.13m. At this time a person would need to spend 15 hours sitting on the spool/PLR in order to exceed the 1mSv dose limit for a non-classified worker. Everybody living in the UK receives 2.2 millisieverts every year from natural radiation sources. The Sun, food and the environment. It is twice this amount if you live in Aberdeen because of the granite. If a worker is outside the 1.13m boundary there will be no harmful effects arising from the radiation present.

10. Transportation, Security & Licencing

The use of radioisotopes for industrial applications is highly regulated. Almost all countries will operate a licencing system with very prescription rules that govern the storage, movement and safe use. Transport of sources requires pre-planning as when moving between different regulatory jurisdictions it requires transfer from one licence to another e.g., when moving from UK to Angola it requires a licence to temporarily import the sources in country. The licence is held by a local entity or 3rd party. There may also be a requirement to apply for a specific area licence when working offshore depending on location.

A ‘Type A’ container is a special shielded container that the sources/pencil pots can be shipping (air/sea/road) in a safe and secure manner. The Type A containers are categorised under normal shipping regulations for goods type and are transported globally on a regular basis. Due to the shielding on the Type A containers, Tracerco have ‘known consignor’ status to address the screening/X-ray part of the out or inbound goods process.

Particularly for pre-commissioning works pig with sources fitted may be pre-loaded in a PLR, prior to shipping offshore and being hooked up as part of the construction works. To comply with the global standards for shipping of radio isotopes the PLR needs to have a temporary certification as a Type A container.


Dangerous Goods Declaration and Certificate of Packing
In compliance with the Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulation 1997 SI 2367

Tracerco

Tracerco, Pavilion 11, Coxwold Way, Belasis Hall Technology Park, Billingham, Cleveland TS23 4EA — Certificate No: / Page 1 of 1

Shipper: Tracerco, Pavilion 11, Coxwold Way, Belasis Hall Technology Park, Cleveland, TS23 4EA	2 - To the Master of MV in accordance with Part II, Reg. 10(2-6) & 12(1) of the above legislation, you are hearby advised of the following classified dangerous goods are being loaded aboard onto vessel.	5 - Destination: / 6 - Place of Departure:
Consignee: Panalpina, Woodside Road, Bridge of Don, Aberdeen AB23 8EF, Onward to: BP Magnus Platform (1)	3 - Shipper's Reference Number (Optional): / 4 - 24-Hour Contact Number +44 (0)1642 375500	7 - Voyage Ref: / 8 - Departure Date:

UN NUMBER	PROPER SHIPPING NAME	CLASS OR DIVISION	SUB-RISK	PACKING GROUP	SCHEDULE FOR CLASS 7	RADIONUCLIDE	PHYSICAL, CHEMICAL OR SPECIAL FORM	MAXIMUM ACTIVITY (Bq)	CATEGORY OF PACKAGE	TRANSPORT INDEX	IDENIFICATION MARK FOR COMPETENT AUTHORITY CERTIFICATE	EMS CODE
UN2915	Radioactive Material, Type A Package	7	-	-	9	Ta-182	Solid Metal	20MBq	II-Yellow	0.1		F-I, S-S
9	10	11	12	13	14	15	16	17	18	19	20	21

Declaration:
"I hereby declare that the contents of this consignment are fully and accurately described above by the Proper Shipping Name and are classified, marked, labelled, or placarded, and are in all respects in proper condition for transport according to applicable international and national governmental regulations
Name and Status of Declarant: M Banks, Subsea Project Manager
Date: 24/02/2014 **Signature:**
22

Container / Vehicle Packing Certificate:
It is declared that the packing of the goods into the container/vehicle has been carried out in accordance with the provisions shown overleaf.
Name of Company:
Signature: **Date:**
23

Supplementary requirements (none if left blank)

Fig 9

11. Advantages of using Radioisotopes for Pig-Tracking

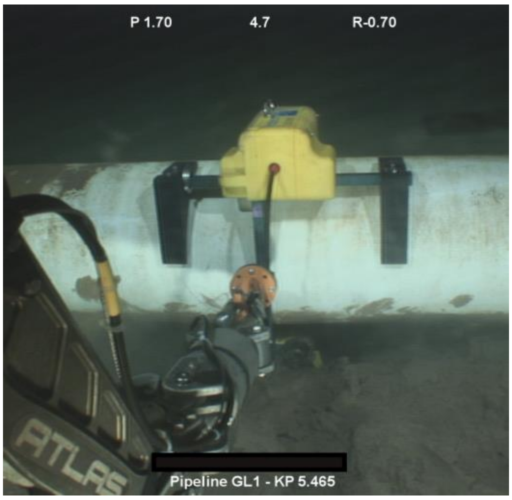
Radioisotopes are an established methodology of tracking position of pigs. There is a particular advantage in the pre-commissioning market where extended periods of pre-loaded pigs in subsea PLR's may need to wait weeks or months before being run. The science is well understood and this means any elevated risk using radioisotopes can be carefully controlled when using a competent and reputable company.

- Provides an accurate, highly reliable method to tag and track pigs.
- Radioisotopes outlasts equivalent battery systems by a significant margin – effectively doesn't turn off.
- Effect in pipeline systems that cause interference to other electro/magnetic systems i.e. PiP, Electrical Heat tracing etc
- Accurate positioning +/- 5cm.
- Very small footprint, minimal additional payload.
- Retrofit to wide range of pigs.
- Trackers rated to 3000msw - long battery life up to 3000hrs.
- Excellent safety & environmental record.

12. Case Study – Location of lost/stuck pigs that have no tracking device fitted.

Even with careful planning and robust procedures, stuck pigs or isolation plugs are a reality of pipeline operations. Not all pigs are fitted with tracking devices particularly for routine operational pigging runs. If a situation occurs where they become lost or stuck, location can be challenging. An alternative method of locating a stalled or stuck pig that has no positional technology attached is to use an adaptation of a gamma ray technique. Adapted from subsea inspection technology (FMI), a collimated source with a detection unit is used to measure mean changes in density across subsea structures and indicate whether dry, partially or fully flooded.

An offshore production platform exported oil through a 16" subsea pipeline to another platform some 70Km distance. A boost in production and flow rate provided a window to run a standard bi-di pig, although the pipeline had a history of paraffin wax deposit. After a relatively short time the pipeline pressure increased and no net flow was practical. A best estimate by pumped volume put pig location at 4-7Km <10% of total distance. A transient pressure pulse method provided pig distance at 15.2Km, nearly double the estimated distance. This method although providing a better estimate, still had a sizeable error banding due to certain uncertainties in the measurement process. A gamma source and detector arrangement deployed by ROV was used to pinpoint the pig body centre within a few cm. The source/detector was situated on the exposed sections of pipe at the 3-9 o'clock position. The detector measured mean density across the pipe diameter by strength of the received emission from the gamma source. The pig body provided a significant change in density which gave a step change reduction in gamma counts. The measurement location was repeated with the same accuracy and response for the same distance. This provided a very strong indication of the exact location of the pig assembly some 100m from the estimated location of the pressure wave method. The bigger challenge was the 800-900m wax candle the pig had pushed in front of it.



The gamma source provides through transmission across the pipeline. Assumed fixed densities of water path, pipeline steel and internal product are calculated and expected counts received at the detector. Any reduction in counts is correlated to an increase in density of what most likely would be the body of the pig or plug.

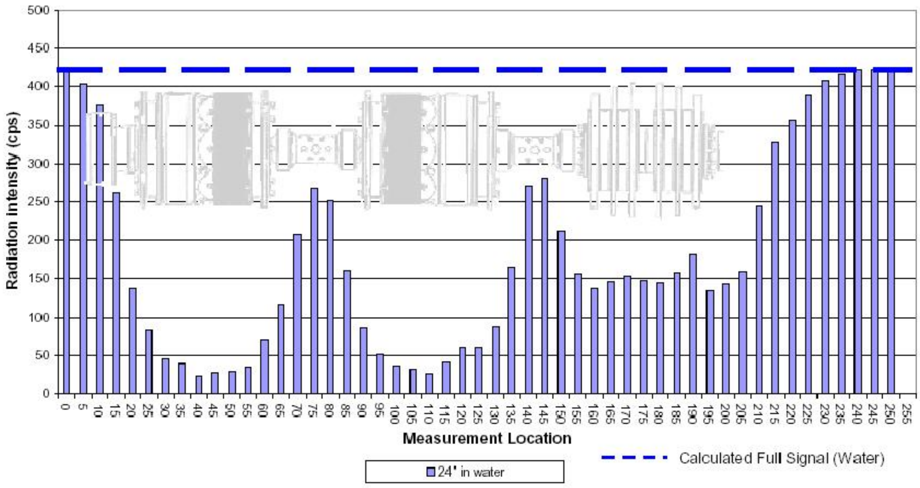


Fig 10