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RADIOISOTOPE APPLICATIONS: CASE STUDIES IN THE OIL AND GAS INDUSTRY, REFINERIES AND CHEMICAL PROCESS PLANTS.

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RADIOISOTOPE TECHNIQUES FOR PROBLEM SOLVING IN THE OFFSHORE OIL AND GAS INDUSTRY

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SUMMARY **The current usage of radioisotopes in problem solving, process optimization and control in the offshore oil and gas industry is reviewed. Recent developments are described with applications ranging from subsea, through measurements on the production platform, to studies at onshore terminals.**

I. INTRODUCTION

Radioisotope technology has been used for almost half a century by the oil and gas industry to solve problems and to help optimize process operations[1]. The use of radioactive isotopes to investigate the effectiveness of well stimulation procedures and to measure the sweep-out patterns of oil and gas in secondary recovery processess is well known[2,3]. The applications of radioisotopes to study features of plant and process operation has been less widely reported though the economic benefits deriving from such applications are very great.

Nevertheless, there has been continuous development in the range of application and in the design of equipment to facilitate the use of the technology at remote environments - such as an oil or gas platform. Some indication of the current usage of radioisotope techniques may be obtained from examination of Table I, which lists projects carried out in the UK's North Sea fields by ICI Tracerco, which is the world's largest radioisotope applications service group.

Typical Annual Work Spectrum of ICI Tracerco on North Sea Oil and Gas Installations

APPLICATION	NUMBERS
Density profiles in separators	15
Levels and interfaces in process vessels	22
Pipeline scans for deposition measurements	6
Subsea flooded member detection	14
Pipeline pig tracking	2
Flowrate measurements	6
Residence time studies	4
Leak detection on sub-sea umbilicals	1
Sand fracture tracing	15
Well perforation/marking	10
Gas/Waterflood tracing	10

This does not include studies on downstream units such as refineries and petrochemical plant where many hundreds of applications are carried out each year.

Table I

Applications range from down-hole studies on the well and reservoir, through subsea examination of production platforms and peripherals, to topside studies on the platform and on onshore terminals. Although there are many different kinds of application, for purposes of description they can be divided into two broad categories: techniques which utilize sealed sources of radiation and radioactive tracer techniques. Down-hole applications, as has been noted, are amply described in the literature and for this reason they will not be considered further in this paper.

2. SEALED SOURCE TECHNIQUES

The essential feature of all sealed source techniques is that the radioactive isotope remains permanently sealed within a capsule and makes no contact with the plant or process material. Radiations from the source are directed at the plant vessel of interest and by observing changes in the transmitted or the scattered radiation we can draw conclusions about the contents of the vessel. Because oil platforms and associated plant are of substantial construction, only highly penetrating radiations may be used and for this reason the sealed source techniques described are based upon the use either of gamma-ray or of neutron sources.

2.1 Gamma-Ray Absorption Techniques

A large number of useful applications is based upon the phenomenon of gamma-ray absorption. The basic principles are as follows:

A source of gamma-radiation is positioned on one side of the vessel of interest and a radiation detector is positioned on the opposite side. They are then moved together up or down and the intensity of the radiation transmitted through the vessel is recorded as a function of position. For a narrow beam of radiation, the intensity, I, transmitted through a medium of thickness x and density d is described by the equation:

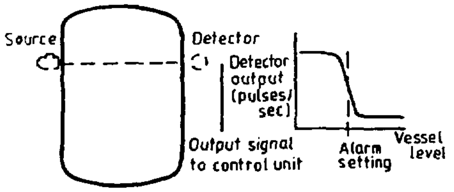
$$I = Io \exp(-mdx) \quad (1)$$

where Io is the intensity of the incident radiation and *m* is a constant called the *mass absorption coefficient*. If the separation of the source and detector is kept constant, the intensity of transmitted radiation is a function of the density of the medium. Thus, as the source and detector scan through vapour a high radiation countrate is obtained whereas, when the 'scan line' intersects a liquid or solid phase a lower radiation countrate is observed. Changes in the intensity of the transmitted radiation therefore reveal levels and interfaces in vessels as well as internal mechanical structure.

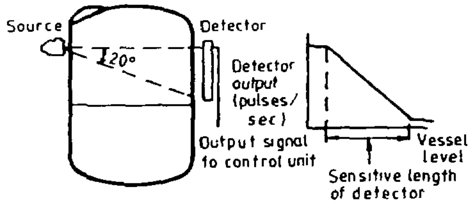
The changes experienced in moving from regions of low intensity to high intensity are not perfectly sharp. Sometimes, the reason is simply that the levels or interfaces are diffuse, but there is also an effect from radiation scattering because wide-beam, instead of narrow beam source-detector geometry is usually used. This is necessary because the shielding required to produce narrow beam radiation would make the source container too heavy and unwieldy to use.

In its simplest form, this technique can be used to identify and measure liquid level in a tank. Alternatively, if the source and detector are fixed in one position (Figure 1) then the level in the tank will be recorded as it passes this point. This is the principle of the high or low level alarm ("level switch"). By using an extended detector and by angling the source beam to span the detector length, the system can be converted into a level gauge.

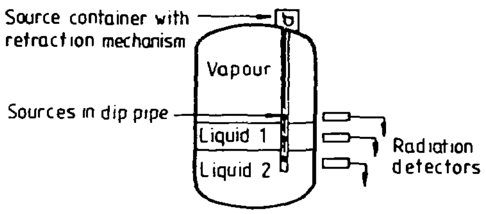
Level gauges generally work on the principle of complete obscuration of the gamma-ray beam by the fluid in the vessel. However, if the path length through the liquid is kept short, the gamma-ray transmission is a function of the liquid density (Equation 1). This is the principle of gamma-ray density gauges (Figure 1). The same concept has been applied in installed gamma-ray gauges designed to detect and monitor the interface between materials of different density (Figure 1).



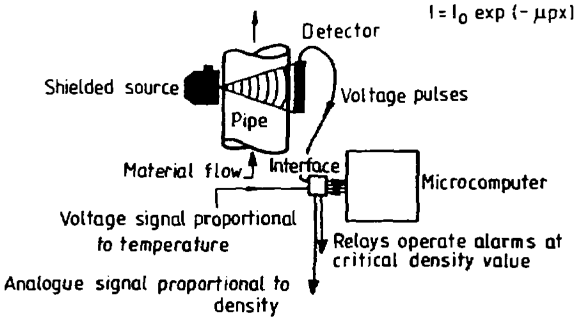
(a) Level Alarm



(b) Proportional Level Indicator



(c) Liquid Interface Position Indicator



(d) Density Gauge

Figure 1 Principles of Installed Nucleonic Gauges for Level and Density Measurement

Instruments based on the gamma-ray absorption phenomenon are commonly used in offshore locations. Table II, which is a listing of gauges supplied to North Sea oil and gas installation by ICI Tracerco provides some indication of usage.

DUTY	NUMBER		
	On Shore	Topsides	Sub-Sea
Level Alarm	13	9	
Level Gauge	12	15	25
Interface Detector/Monitor		30	1
Density Gauge (Process Fluids)	2	5	1
Density Gauge (Cement Grout)			600

Table II

These so-called "nucleonic" gauges possess a number of advantages over more conventional instrumentaions:

(a) The instruments have no contact with the process material and operate either outside of the vessel or in sealed dip tubes. Thus, there are no problems in operating with corrosive, viscous or toxic liquids or with materials at high temperature and pressure.

(b) There are no moving parts and the instruments are of rugged construction. Little or no maintenance is required and the reliability of the systems is high. These are important considerations, especially so for instruments installed sub-sea where access is difficult.

(c) The systems are intrinsically safe from an electrical point of view.

(d) Instruments can often be installed on a vessel while the vessel is on line thus averting the need for a costly shut-down.

For these reasons, nucleonic gauges are now standard for some of the more difficult control applications. Examples are given later in the paper.

2.2 Neutron Backscatter Technique

Techniques based on the phenomenon of neutron backscatter may complement, or be used as alternatives to gamma-ray absorption methods. The principle underlying these techniques is described with reference to Figure 2.

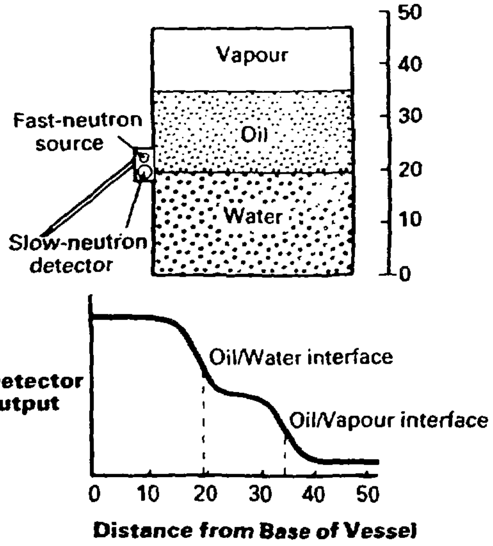


Figure 2 Measurement of Levels and Interfaces using a Neutron Moderation Technique

Radioisotope neutron sources emit energetic or "fast" neutrons. Of all chemical elements, hydrogen is outstanding in its ability to slow down or moderate neutrons to lower energies. Thus, when fast neutrons from an isotope source are directed into a hydrogenous material, the number of slow neutrons produced is, to a good approximation, proportional to the hydrogen concentration.

Thus, if a probe comprising a slow neutron detector and a fast neutron source is moved up and down over the surface of a vessel containing hydrogenous material the detector response provides an indication of the position of the level of the material. Interfaces between materials having different hydrogen contents may similarly be detected.

3. APPLICATIONS OF SEALED SOURCE TECHNIQUES

3.1 Onshore and Topsides Applications

The gamma-ray absorption technique has been used widely to determine the extent and magnitude of scale build up in oil pipelines. A portable system (Figure 3) is used to survey sections of the line to determine the overall density of the material inside it. Provided that the line is running full (or completely empty) and the oil density is known, the additional attenuation of the transmitted signal due to scale thickness may be estimated. Scale thicknesses can generally be measured to within a few millimetres.

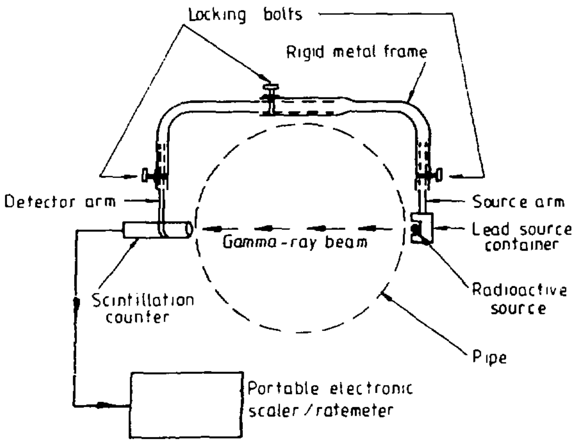


Figure 3 A Portable Gamma-Ray Absorption Pipe Scanner

Lines which contain deposits and which are partially full of oil or water can sometimes be studied using the gamma ray absorption technique and neutron backscatter technique in combination. Figure 4 shows a typical result obtained from scans carried out on a partially full slug-catcher. The neutron backscatter technique was used to determine the level of the hydrogenous liquid - in this case, condensate - and from this information, together with the results of a number of diametric gamma-ray transmission scans made around the pipe the radial distribution of the deposit was inferred.

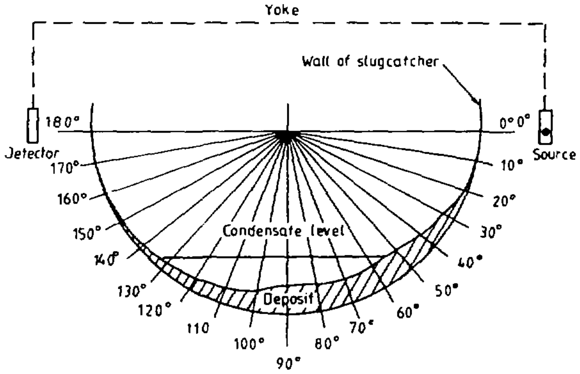


Figure 4 Measurement of Deposit Distribution in Slugcatcher

The gamma-ray absorption technique is also used to study foaming in separators. Foaming is generally combatted by the addition of an anti-foaming agent. However, anti-foams are expensive: the correct anti-foam must be selected and it must be used at the correct concentration. The gamma-ray absorption technique provides a means of directly studying the effect of anti-foam addition. The principle of the measurement is illustrated in Figure 5 which shows typical results obtained from scans on horizontal vessels. The presence of foam above the liquid level modifies the transmission profile. Figure 6 shows the results obtained from a separator with different dosages of a particular anti-foam. With the higher dosage, the interface is much sharper and the vapour region less dense, indicating that the foam is effectively suppressed. The ability to study the effects of the anti-foam directly and without any disruption to the process is clearly advantageous and can result in significant economic benefits by reducing anti-foam usage and optimizing the operation of the separator.

Figure 5a Gamma-Ray Transmission Scan Through an empty Horizontal Vessel

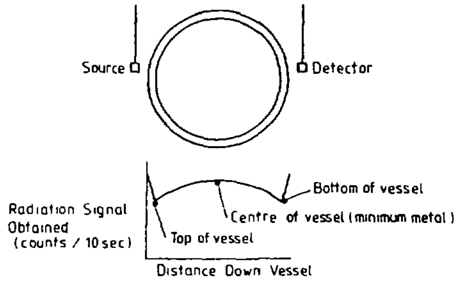


Figure 5b Gamma-Ray Transmission Scan Through Partially Full Horizontal Vessels

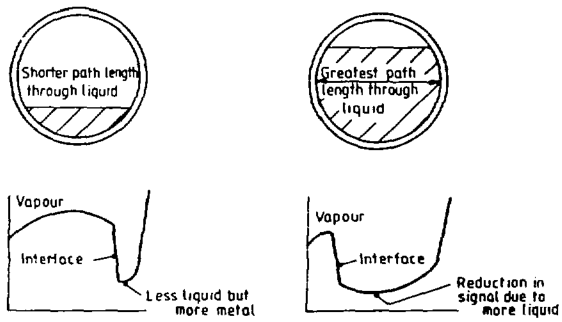


Figure 5 Gamma-Ray Scans of Separators: Principles

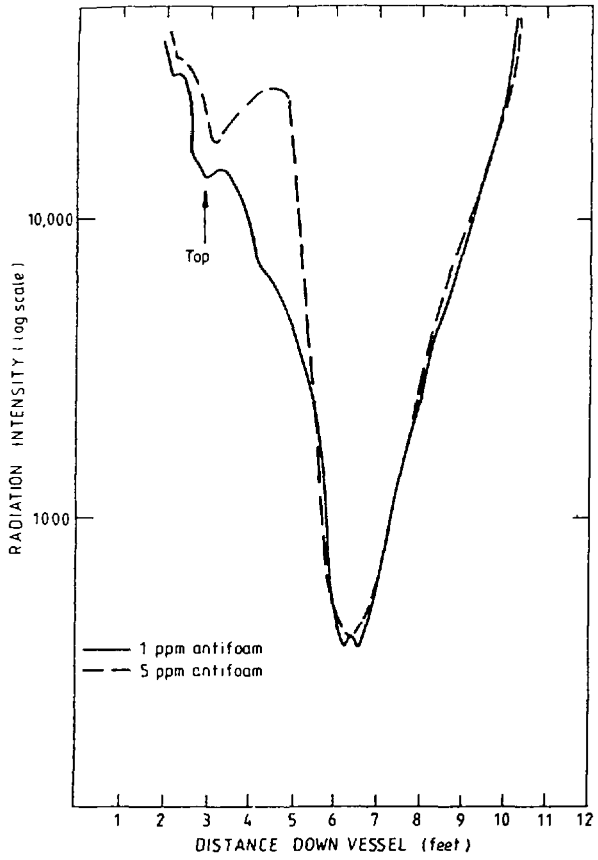


Figure 6 Gamma-Ray Transmission Scans of a Separator to Investigate the Efficiency of Antifoam Dosage

A common use of nucleonic gauges on topsides and onshore installations is the measurement and control of interfaces in separators and other vessels (Table 2). These applications merit further description since the control of interfaces can be difficult and radioisotope gauges often present the only viable solution.

Figure 7 shows an instrument arrangement which has been used very successfully on oil/water separators.

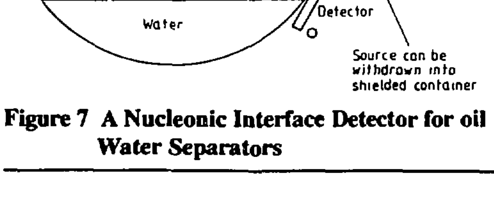


Figure 7 A Nucleonic Interface Detector for oil Water Separators

A radioactive source is inserted into the vessel in a sealed dip tube. Usually the tube is inserted horizontally through an available nozzle, though other configurations have also been used. The system incorporates a shielded container into which the radioactive source can be withdrawn at such times that vessel entry is required. An elongated radiation detector is positioned on the outside of the vessel to receive the radiation from the source. Radiation from the source is attenuated more by the (denser) water than by the oil (Equation 1) so that the detector output signal is a function of the oil/water interface position.

A portable neutron-backscatter instrument is often used to calibrate the system by providing independent measurements of the interface position.

Installed gamma-ray gauges also find extensive use in the control of foaming levels. An example is illustrated in Figure 8.

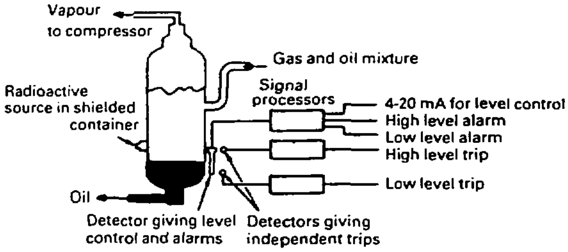


Figure 8 Gas Compressor Protection using a Nucleonic Level Control and Alarm System

In the North Sea, oil and gas are transported together by pipeline to onshore terminals. There, the gas is separated from the oil fractions and is recompressed for onward distribution. This is a very foamy process and fluctuations in the foam level occur unpredictably. These fluctuations were causing carryover of oil droplets in the gas stream with serious consequences for the downstream compressor. Density profile measurements were carried out using portable gamma-ray scanning equipment and these showed that the interface between the oil and the foam fluctuated and that there were variations in the density of the foam layer.

The variability in the foam height, foam density and position of the oil/foam interface rendered conventional methods of control impossible. However, using a nucleonic proportional level gauge to measure the oil/foam interface and a high level nucleonic alarm to give warning of excessive upward excursions of the foam we were able to provide a system which effectively eliminated the carryover problem and protected the gas compressor.

Neutron sources are also used topsides, though usually in portable gauges rather than in installed instruments. Apart from its use in detecting the position of oil water interfaces, the neutron backscatter technique has been applied to:

a) Locate a pig and packer in pipelines prior to cutting the line to install emergency shut-down valves.

b) To check for the presence of brine in oil pipelines.

c) To identify water ingress into platform tubular members above the waterline.

The latter application was, for a time, used to detect flooded members below the sea[4]. However for this application the neutron technique has been entirely supplanted by a gamma-ray absorption method, which is described in Section 3.2.

3.2 Sub-sea Applications

The technology used topside is also used below the sea, though of course the design of the equipment is modified in a manner appropriate to the marine environment. A portable gamma-ray absorption gauge, mounted on an ROV is used routinely to examine sub-sea structures to detect flooded members. The source and detector, mounted on a yoke, are positioned on either side of the tubular using the ROV. The signal from the detector is fed to the surface to an electronic system which records the level of transmitted radiation. Water inside the subsea section will result in a decrease in the transmitted signal which is easily identifiable.

The measurement is rapid (less than two minutes) and requires no prior cleaning of the tubular. It is unambiguous and fail-safe: any failure of the equipment will indicate that the member is flooded. Also, of course, the ROV is controlled from topsides: no divers are required and measurements can be carried out for extended periods. For these reasons, this is rapidly becoming the standard method of inspecting the platform tubulars in the North Sea.

The gamma-ray absorption principle is also applied sub-sea in installed level switches. These are being used to control the level of oil in Texaco's slug-catcher which is installed on the sea bed next to Texaco's Tartan A platform in the North Sea. The slug-catcher is designed to contain large high-speed slugs of liquid as they arrive at the platform after being transported eight miles through an under sea pipeline from a remote multi-well template.

Twelve nucleonic switches are installed, fitted to bridles which are attached to the slug-catcher and the output from each is wired to a topside control unit on Tartan A. The system features fail-safe operation, automatic fault recognition and automatic transfer of control to back-up detectors in the event of primary detector failure. The instruments were designed for a 20 year life span at a depth of 150 metres. Since their installation in 1985 they have proved to be extremely reliable and facilitate control of the rate at which oil is forwarded from the slug-catcher to the platform.

The economic exploitation of marginal fields will undoubtedly require more sub-sea operations and measurement and nucleonic gauges clearly have a part to play. For example, we have recently fitted sub-sea level gauges to a sub-sea separation unit. Radioactive sources are suspended in sealed dip pipes projecting into the interior of the various vessels and diver-accessible detectors are mounted externally. The detectors are able to measure liquid level in first stage gas separator, interface position between oil and water in the second-stage separator and oil and water levels in a compartmentalized storage vessel. Data from the detector is fed to a central sub-sea computer and used to control all the levels in the process.

One further application of sealed source technology is the recently developed "Gammatrac" system for monitoring the progress of pigs through sub-sea pipelines. The approach here is to deploy at suitable intervals along the pipeline gamma-ray detection systems which are equipped with radiation - activated LED displays. A gamma-emitting radioisotope is fitted into a pocket in the pig on the launch platform and the pig is launched. As the pig passes each detector station the LED display turns from white to red. Visual inspection of the detectors by a diver can then confirm that the pig has passed down the line. Should the pig become stuck the section of line in which this has occurred can be identified. Thus, by strategically deploying the detectors the free movement of the pig through critical sections of line - such as through newly installed valves can be checked.

Further development of this system which will enable even more accurate tracking of the pig is in hand.

4 UNSEALED SOURCE TECHNIQUES

Unsealed source, or "radiotracer" techniques differ fundamentally from those involving the use of sealed sources of radiation. In this instance, radioactive material in a form compatible with the process fluid is injected into the process stream. The subsequent movement of the radiolabelled process material through pipes and process vessels can be monitored using strategically positioned radiation detectors. This forms the basis of a number of methods for studying mass transport and fluid dynamics of process systems.

4.1 Flowrate Measurement

Flowrate measurement is one of the most useful categories of application. There are several ways in which radiotracers can be used to measure flow[5]: arguably the most useful is that known as the pulse velocity technique.

The basic arrangement for pulse velocity measurements is illustrated in Figure 9. A sharp pulse of radiotracer is injected into the line and mixes with the process stream. A pair of radiation detectors is positioned downstream from the injection point at measured separation. The distance downstream of the first detector from the injection point is such as to allow complete lateral mixing of the tracer in the stream. As the tracer pulse passes down the pipe the detectors respond in turn and their output signals are fed to a chart recorder or computer. The time interval between the centroids of the two response curves, which corresponds to the mean transit time between the detectors is measured.

From this and the measured separation of the detectors the mean linear velocity of the tracer, and hence of the flowing medium, can be readily computed. The volume flowrate can then be calculated if the mean cross-sectional area of the pipeline is known.

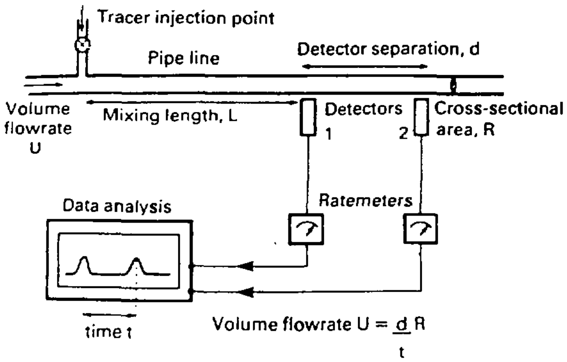


Figure 9 The Radiotracer Pulse-Velocity Technique

This technique has been used in the offshore oil and gas industry to measure oil, water and gas flowrates. For example because of statutory limits on the amount of gas which can be flared it is important to measure these flowrates. Accordingly, we have measured the flare gas flowrates on many platforms for calibration of installed meters and to provide confirmation of the accuracy of calculation of the tonnages flared. We have also used the pulse velocity method to monitor the injection-water flowrate in waterfloods. The technique can also be used to detect bypass-flows and offer a rapid method of identifying passing valves.

4.2 Residence Time Studies

The pulse injection of radiotracer also facilitates the measurements of residence times and residence time distribution[6]. If a pulse of tracer is injected at the inlet to a vessel, a detector mounted on the outlet will produce a response curve which is representative of the residence time distribution of elements of fluid in the vessel. Analysis of this curve yields important information both about the mean residence time (MRT) and the mixing characteristics of the vessel.

The method has been used to study the performance of oil/water separators. Residence times of oil and water phases are measured separately. To perform the measurements, radiation detectors are placed on the inlet pipe and on the oil and water exit pipes. A pulse of organic radiotracer is then injected upstream of the inlet detector and the time of its entry into the vessel with the organic phase and the detector on the oil exit records the residence time distribution (RTD) curve. Since separation is not perfect, some of the tracer also appears at the water exit causing the detector located there to respond. This procedure is then repeated using a water-soluble radiotracer.

Analysis of the residence time distribution curves permits calculation of the degree of plug flow of the two components and also provides measurement of the separation occurring in the vessel.

4.3 Sub-sea Leak Location

A further application of the use of radiotracers is the location of leaks in sub-sea umbilical cables. Umbilical cables between offshore platforms and other installations are essential links covering distances up to 50 kilometers. The cables are generally run in bundles contained in an outer sheath. Each cable in the bundle may be as small as 5mm but a leak on such a cable can be a safety hazard to personnel or the environment and can cause loss of production due to downtime. A quick and accurate method of pinpointing the location of the leak can save considerable time and money. ICI Tracerco has developed such a technique. A piece of radioactive gold wire is secured inside a plastic "pig". The pig is inserted into one end of the leaking umbilical cable. The other end of the cable is sealed and pressure is applied to the insertion end. The only fluid movement in the umbilical will be towards the leak.

The pig is carried along the cable by the flowing fluid and when it reaches the leak it stops. From outside the umbilical bundle a radiation detector mounted on an ROV monitors the progress of the pig and accurately locates the position at which it stops. This portion of the umbilical can be brought on board the supply boat and repaired saving the replacement of a costly umbilical bundle.

5. CONCLUSION

Though the specific examples discussed in the paper were drawn from experience in the North Sea, radioisotope techniques have a generality which makes them of great value throughout the offshore oil and gas industry world-wide. The techniques offer on the one hand a unique window through which the inner workings of production plant can be observed and on the other a method of studying the distribution and flow patterns of the process material. These insights into the operating plant, which cannot be obtained in any other way, can realize large savings on continuous production plant by diagnosing faults on line and by providing input data for process optimization.

It is these considerations which have been responsible for the expansion in the usage of radioisotopes within the oil and gas industry and which will ensure that growth continues in the future.

6. REFERENCES

1. Howell, L.G. and Frosch, A., "Detection of radioactive cement in cased wells", Trans. AIME 136 (1940) p 71.

2. Mott, W.W. And Dempsey J.C., "Review of radiotracer applications in geophysics in the United States of America", Radioisotopes Tracers in Industry and Geophysics, IAEA, Vienna 1967 pp 111-131.

3. Priest, M.A. "Improved Procedures for Injecting Radioisotopes During Fracturing Operations", Journal of Petroleum Technology, January 1989 pp 46-54.

4. Charlton, J.S., "Radioisotope Techniques for Problem Solving in Industrial Process Plants", Leonard Hill, Glasgow and London (1986) pp 302-303.

5. Edmonds, E.A. and Charlton, J.S. "Experience in the Use of Radioisotopes, Offshore Installations and Pipelines", Oil loss Control in the Petroleum Industry, John Wiley and Sons (1985) pp 199-217.

6. Guidebook on Radioisotope Tracers in Industry, IAEA, Vienna, (1990) pp 39-101.