1. Introduction

Radioactive isotopes were first applied to investigate industrial problems some sixty years ago and since then, there has been a continuous expansion in their usage. The oil industry, in particular, was quick to recognise the potential usefulness of this technology and one of the earliest industrial studies in the literature is concerned with the use of radioactive material to tag the cement of oil-well casings [1].

Today, radioisotope technology is in routine use throughout the international oil/gas industry for trouble-shooting and process optimisation on large-scale industrial process plants. By analogy with the use of radioisotopes in medical diagnosis, these applications have come to be known as “process diagnostics.”

The success of process diagnostics is due primarily to the ability conferred by the unique properties of radioactive materials to collect, on-line, valuable information, which cannot be obtained by other investigative techniques [2]. This can result in very large economic benefits, which are derived either from the inputs made to process optimisation exercises or from the minimisation, or elimination of plant shutdown time. Case studies have shown that a benefit to cost ratio from a typical study is approximately 20:1[3], though in certain circumstances, as we shall see, it may be vastly greater than this.

The development and exploitation of offshore oil and gas reserves has presented new challenges to radioisotope technology, operating at remote locations and in the marine environment, to name just two. However, the methodology of radioisotope applications has kept pace with industrial developments so that all of the onshore diagnostic applications can be successfully carried out offshore.

Radioactive tracers have been used extensively for the optimisation of oil-well operations, as described in an extensive literature [4,5]. The diagnostic applications of radioisotopes are less well known, but no less valuable. To exemplify this type of application, this paper presents a number of case studies and provides an indication of the economic benefits that may be derived.

Though radioisotope technology, applied to trouble shooting and process optimisation is extremely useful and valuable, by virtue of the unique insights it gives into the operating process, it is, arguably, of even greater value when it is applied to actually solving the problem: that is, when it provides the cure, as well as the diagnosis. This may be achieved by the use of installed nucleonic gauges, sometimes known as Nucleonic Control systems (NCS). These gauges incorporate a sealed radioisotopic source and measure or control industrial processes by making use of the interaction of the emitted radiation with the process material [6]. Nucleonic gauges are widely used throughout the offshore oil/gas industry for the measurement and control of levels in process vessels and for monitoring the density of flowing process fluids [7]. The gauges are usually installed on the oil platform, but may also be installed on sub-sea storage vessels and liquid slug-catchers. The designs of the gauges are becoming increasingly sophisticated, in line with the continuous quest for process improvement.

A recently developed gauge, used to facilitate the control of three-phase separators, is described together with an illustrative case study.
2. Radioisotopes in process diagnosis

The applications of radioisotopes, though numerous, can be divided into two broad categories: techniques that utilise sealed sources of radiation and those that utilise radioactive tracers.

The essential feature of all sealed source techniques is that the radioactive material remains permanently sealed within a small source-capsule and makes no contact either with the plant or with the process material. Radiation from the source is directed at the item of interest (perhaps a process vessel), and by analysing changes either in the transmitted or scattered radiation beams, it is possible to draw conclusions about the vessel and its contents.

In contrast to the sealed source technique, the essential feature of a radiotracer application is that radioactive material in appropriate physical or chemical form is injected into the flowing process material. A portion of the material thus becomes ‘labelled’ with radioactivity and, provided that the radiotracer faithfully follows the behaviour of the process material, its subsequent movement through the plant can be monitored using external radiation detectors. This gives rise to a range of methods for studying the fluid dynamics, distribution and mass-transfer properties of process streams.

2.1 Applications on the production platform (“Topside”)

The primary purpose of the topside facilities is to separate the well fluid into its components (oil, gas, gas condensate and water) such that they are in a form suitable for storage on the offshore facility, for disposal, or for export to an onshore processing plant via a sub-sea pipeline. It is vitally important that the separators should perform efficiently. They are at the upstream end of the processing train and problems here can impact seriously on the downstream process, leading to operational difficulties and loss of efficiency.

2.1.1 The Diagnosis of problems in Production Separators

In oil production, the crude oil coming from the wellhead is mixed with water, gas and sand and must be separated from these components before further processing can take place. This function is performed by production separators, which are generally horizontal vessels typically three metres in diameter and up to twenty-five metres long. The mixed fluids from the well enter the vessel and, as the mixture flows along it, the constituent parts separate, progressively, under gravity, allowing the oil, water and gas to exit from their appropriate outlets (Figure 1). Under ideal conditions, by the time that the process fluids have reached the weir, separation is complete, so that the oil, water and gas are present as distinct stratified phases. Unfortunately, the situation is often much more complicated. Excessive sand deposition, foaming and the formation of emulsions are among the more commonly encountered problems. Radioisotope techniques are able to investigate and, as we shall see in Section 3, control the performance of these vessels.

![Figure 1. A typical three-phase separator](image)

Use of radioactive tracers in optimizing separator performance

In order to optimise the performance of a separator it is usually necessary to obtain information about its
flow characteristics. Generally, it is the residence time distributions of the several phases flowing through the vessel that are of most interest. These can be measured using a radiotracer technique. Radiation detectors (NaI scintillation counters) are deployed on the inlet line, the oil and water outlets and at strategic locations around the surface of the vessel. The radioactive tracer is injected as a sharp pulse into the incoming well fluid. The water may be traced using K\(^{82}\)Br in aqueous solution while, for the oil, bromododecane, tagged with \(^{82}\)Br, has been found to be appropriate. The aqueous tracer has negligible solubility in the organic phase and vice versa. Thus, by making separate injections of the aqueous and organic tracer the movement of the oil and the water through the separator can be individually traced by examining the responses of the radiation detectors. Tracing the gas flow is a less-common requirement, but if necessary this can be carried out using either \(^{79}\)Kr or \(^{85}\)Kr as the tracer.

**Case study: North Sea oil production platform**

Residence time distribution measurements were carried out on a production separator on a North Sea oil platform that was experiencing operational difficulties. If the process was operated at its design rate the production separator was unable to dehydrate the oil sufficiently for it to be transferred on shore by pipeline. This had the effect of limiting process throughput and the platform was producing 10,000 barrels per day below expectations. The measurements showed that the residence times both of the oil and the water phases were approximately 50% of their design values: essentially, fluid was short-circuiting through the vessel, so that there was not sufficient time for effective separation. The source of the problem was traced back to an earlier decision to remove internal baffles from the vessel in order to cope better with dense hydrocarbons in the well fluid. Based on the results of the residence time measurements, a decision was made to install new baffles in the vessel. This brought about an immediate throughput improvement of 20,000 barrels per day and then, with further modifications, a further 20,000 barrels per day. At today’s oil price, the overall increase in production is worth approximately $3 million per day.

2.2. **Subsea Applications**

To perform measurements below the sea, three requirements must be met. Firstly, the equipment must be waterproof and be of a sufficiently robust construction to withstand any impacts that it might sustain as a result of wave action. Secondly, there must be a means of transporting the equipment below the sea and of locating it precisely on the object of interest. Thirdly, there must be a means either of transmitting data back to the surface or of interrogating the sub-sea data acquisition device *in-situ*. The first requirement is met simply by good electrical and mechanical design. To meet the second and third requirement it is common to utilize Remote Operated Vehicles (ROVs), specially designed for work subsea. In this way, practically all of the sealed source techniques carried out on land can also be performed below the sea. (Figure 2)

![Image of ROV deployed subsea](image)

**Figure 2. Gamma ray transmission density gauge deployed on an ROV**

3. **The cure: radioisotopes in process measurement and control**
In the offshore oil and gas industries, as in most other process industries, nucleonic instruments are used extensively
to control process operations. Their operating principles and usage have been described in an extensive literature.
(See, for example, References 8 and 9). Nucleonic gauges possess a number of advantages over more conventional
instrumentation:

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.

(a) There are no moving parts and the instruments are of rugged construction.

(b) Little or no maintenance is required and the reliability of the systems is high.

(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 avoiding the need for a costly
shutdown.

For the reasons listed above, nucleonic gauges are particularly suitable for subsea applications, as they require
essentially no maintenance and are extremely reliable. The economic exploitation of marginal fields, requiring the
location of control systems on the seabed, rather than on a platform, is expected to stimulate significant growth in the
subsea application of nucleonic instruments.

3.1 The Tracerco Profiler™

To illustrate how a nucleonic gauge can “cure”, or at least ameliorate, an operational problem, a novel type of
nucleonic instrument will be described. This has been developed as a result of a perceived need on the part of the oil
industry to optimise the performance of production separators

In many cases the nature of the wellhead fluids complicates the separation process to the point where
efficient phase separation is very difficult to achieve. Excessive sand deposition, foaming and oil/water
emulsification are three major problems. Sand accumulation reduces the working volume of the vessel,
thereby shortening the residence time of the fluids and reducing separation efficiency.

Foam results in liquid hydrocarbon in natural gas, which can damage downstream compressors. Emulsification
can cause oil to be discharged with the water, producing slicks. Additionally, emulsion
carried over the weir can leave water in the exported oil, which is unacceptable.

The "standard" method of measuring and controlling the level and interface inside the separator has
been a float chamber connected to the separator by bridle pipe work, but even under good conditions
such measurements are often unreliable as there is a time lag between real events, happening inside
the separator, and what occurs in the float chamber. In addition, relatively small deposits of sand around
the tapping points can cause the float to give incorrect readings.

Equally problematic, these instruments are, of course, unable to measure adequately or take account of
foam and emulsion layers or sand deposition.

The TRACERCO Profiler™ is a new type of nucleonic instrument that has been specially developed for
separator control.

It measures simultaneously, and provides a visualization of, the several different phases within the
separator. The instrument is shown schematically in Figure 3.
Figure 3. The TRACERCO Profiler™: schematic representation

It comprises a vertical array of small, gamma ray emitting radioactive sources the radiation from which is monitored by a vertical array of radiation detectors. The source and detector assemblies are secured in dip-pipes, projecting into the separator. The radiation beam from each source is collimated so that only the radiation detector at the corresponding elevation detects it. The attenuation of the beam in the process material between the source and detector is precisely related to the density of the material in the beam. Thus, each source/detector pair is effectively a nucleonic density gauge. When, after mathematical processing, the outputs from the detectors are displayed as a function of their elevation, the resulting distribution is the vertical density profile of the fluids inside the separator. Figure 4 is a screen shot of the visual display unit of a Profiler installed in a separator offshore Angola. This shows the information provided to the operator in real time.

Figure 4. Screen shots of the Profiler’s visual display unit

Case Study
The economic benefits derived from the Tracerco Profiler are best illustrated with reference to a case study. The separation process on one of the oil platforms in the UK sector of the North Sea was particularly difficult. The oil was of high viscosity and possessed a density close to that of the produced water. Consequently, emulsion bands formed frequently and unpredictably, resulting in severe reductions in separation efficiency. A profiler was installed in this separator five years ago and has resulted in substantial operational improvements. The main benefits are:
Unscheduled shutdowns have been eliminated with resulting production savings.

Elimination of oil spills—an obvious environmental benefit.

Reduction of usage of antifoaming agents and de-emulsifiers: the operators receive immediate feedback on the results of adding these expensive chemicals and are thus able to realize significant savings by optimizing the dosages.

Elimination of damage to expensive downstream equipment.

Optimization of the separation process resulting in increased production and improved oil quality.

The overall financial benefit is estimated to be several millions of pounds sterling per annum.

4. Conclusions

Radioisotope technology is playing an important part in solving problems and optimizing production in the offshore oil and gas sector and in industry generally. There is little doubt that the growth in offshore applications will continue, in line with the global expansion of the industry.

5. References