

**Training Course Series**

# ***Leak Detection using Radiotracers***

***Material for on-job training for radiotracer practitioners***

***October 2007***

IAEA/RCA

October 2007

## FOREWORD

The International Atomic Energy Agency (IAEA) has been playing a major role in facilitating the transfer of the radiotracer technology to developing Member States. The major radiotracer techniques have been implemented through IAEA Technical Co-operation projects and adopted by many MS; some hundred radiotracer and end users' specialists have been trained in radiotracer techniques and their applications; nearly 50 radiotracer laboratories equipped with basic facilities have been working in this field. The training of radioisotope practitioners was recognized as being vital to the provision of quality services to industry. To facilitate training and to ensure harmonization of training standards the IAEA has been preparing comprehensive training packages in various aspects of radiation and radioisotope technologies.

The preparation of new specialists in radiotracer technology and the continuous training of radiotracer practitioners are important for the sustainable development and dissemination of the technologies. The use of radiotracer technology relies heavily on the accumulation of different kinds of knowledge's. This training course series on leak detection using radiotracers addresses the needs of the radiotracer groups and their end users. It is intended for continuous technical education and on-job training of radiotracer practitioners worldwide. Besides training purposes, this material will assist developing Member States in establishing their quality control and accreditation systems.

The training course series is prepared in a didactic and comprehensive manner based on many technical reports, papers and experiences worldwide. Many outstanding specialists all over the world have contributed directly or indirectly in drafting of this material. Mr. J. Thereska, consultant, has compiled it. The IAEA wishes to thank all the specialists for their valuable contributions.

The IAEA officers responsible for this publication are Mr. Dias P.M., RCA Focal Person from the Department of Technical Cooperation, and Mr. Jin, Joon-Ha, technical officer of the Division of Physical and Chemical Sciences.

### *EDITORIAL NOTE*

*This publication has been prepared from the original material as submitted by the authors. The views expressed do not necessarily reflect those of the IAEA, the governments of the nominating Member States or the nominating organizations.*

*The use of particular designations of countries or territories does not imply any judgments by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.*

*The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.*

*The authors are responsible for having obtained the necessary permission for the IAEA to reproduce, translate or use material from sources already protected by copyrights.*

## CONTENTS

INTRODUCTION .....	1
1. LEAK DETECTION METHODS.....	2
1.1. Leak inspection .....	2
1.2. Heat exchangers .....	3
1.3. Leak detection methodes in processing vessels .....	6
2. LEAK DETECTION IN PROCESSING VESSELS USING RADIOTRACERS.....	10
2.1. On-line and off-line detection techniques .....	10
2.2. Radiotracer techniques for on-line leak detection in processing vessels .....	12
2.3. Radiotracer techniques for leak detection in processing vessels.....	26
2.4. Examples of radiotracer techniques for leak detection in processing vessels.....	29
2.5. Heat exchanger leak testing without tracers.....	32
2.6. Case studies: Radiotracer techniques for leak detections in processing vessels .....	34
3. LEAK DETECTION IN UNDERGROUND PIPELINES USING RADIOTRACERS.....	58
3.1. Background .....	58
3.2. Radiotracer techniques for leak inspection from the surface .....	58
3.3. Case studies using radiotracer surface inspection .....	60
3.4. Radiotracer technique using “pig” for leak detection in underground pipelines .....	70
3.5. Location of leakage in underground pipelines with cleaning chambers using pig technique. ....	71
3.6. A sensitive pig method for online leak inspection in underground oil pipeline.....	78
3.7. Simple low cost detection pig .....	82
GUIDELINES FOR TESTING FEED / EFFLUENT HEAT EXCHANGER SYSTEMS USING RADIOACTIVE TRACERS.....	85
BIBLOGRAPHY RELATED WITH RADIOTRACER APPLICATIONS FOR LEAK DETECTIONS ..	92
CONTRIBUTORS TO DRAFTING AND REVIEW .....	93

## INTRODUCTION

Leak detection and leak location using radiotracer techniques are probably the most widespread applications of radiotracers in industrial troubleshooting. The economic benefit is considerably high and recognized by the end users. Arguably, this is best done by presenting case studies, which exemplify the benefits that can be realized. These show that benefit to cost ratios of between 10:1 and 4000:1 may be achieved. In absolute term savings of up to million \$US can be obtained, in particular in petrochemical plants and oil & gas transporting pipelines.

Leaks create serious problems in process plants or in pipelines, spoiling the quality of the final product or reducing the capacity of the water, oil and gas pipelines. The contamination of surface and ground water, and soil could happen as well in the case of oil or toxic fluids. The safety problems are also related with leaks. There is an increasing demand for sensitive inspection methods to avoid pollution incidents caused by subsurface leakage from oil transmission pipelines. As of March 2005, almost 450000 underground storage tanks and pipelines leaks had been confirmed worldwide. A pipeline section leaking 10 liters of oil per hour to the environment has a potential of contaminating 240000 m<sup>3</sup> of groundwater per day. Radiotracer techniques are very sensitive, effective and competitive for leak detection in underground storage tanks and buried pipelines. Radiotracers allow an early detection of leakages before small leakages develop into major pollution incidents.

In modern, highly complex, large-capacity chemical plants, the necessity to minimize expensive down time has led to increased use of radiotracer techniques. Leaks in processing vessels and heat exchangers are more frequent problem in many processing plants of petrochemical industry. Leak inspection is possible with various conventional techniques, in particular with search gas methods, but radiotracers still remain the most competitive techniques for on line leak detection and localization. Detection limits of 0.5% of stream flow can be achieved.

There is little experience in teaching radiotracer techniques for leak detection. This text is the result of our belief that there is a need to explicit and preserves the tacit knowledge in this field. The book consists of three main parts. The first part gives general consideration about the leak inspection methods. The second part deals with radiotracer techniques for leak detection in processing plants, in particular in heat exchangers. Leaks in heat exchangers are more frequent and difficult problems in many processing plants of petrochemical and chemical industries. Tracer concept and requirement, special characteristics of radiotracers, their advantages, the selection and preparation of radiotracers, radiotracer detection systems, on-line and off-line detection modes are developed in the second part. The third part presents the radiotracer techniques for leak detection in underground storage tanks and buried pipelines. Inspection of leaks in heat exchangers and underground pipelines calls for two different methodologies. Detection of leaks into underground pipes is a more complicated problem, in particular when the pipe is buried more than 1 m under the soil surface. In this case the gamma radiation emitted by radiotracers does not penetrate through thick soil to be detected from the surface. The gamma detector and recorder should be applied inside the pipe. So called "intelligent pig" technique (pig = pipeline inspection gauge is just a detector with a data logger) is used for leak detection in oil and gas transporting pipes. At the end the guidelines for testing heat exchangers using radiotracers are provided. Guidelines can be considered as standard for accreditation to end users.

Although many applications are included as illustrations, this is not intended as a bibliography of applications. The application illustrations chosen represent the major problems of industry where the radiotracer techniques are very competitive and sometimes unique to search for leak and solve the problem.

The training course series is prepared in a didactic and comprehensive manner reflecting the long experience achieved in this field. It is intended for on-job training of radiotracer practitioners' worldwide.

## **1. LEAK DETECTION METHODS**

### **1.1. LEAK INSPECTION**

Any undesirable interconnection between isolated parts of a system or between two systems is a leak. A leak is suspected if there is any abnormal behavior of a system, such as loss of pressure, contamination of product or loss of process efficiency.

A leak means an unintended crack, hole or porosity in an enveloping wall or joint which must contain or exclude different fluids and gases allowing the escape of closed medium. The basic functions of leak detection are the localization and size measurement of leaks in sealed products and systems. For majority of examples, a leak test procedure is a quality control step to assure device integrity, and is one-time nondestructive test. Typical products in which the leak detection has to be used are: vacuum chambers, hermetically sealed electronic components, pressure vessels, heat exchangers, aerosol containers, pumps, chemical and nuclear plants, beverage cans, products containing metal bellows, electron microscopes, peace makers, etc.

There is a constantly growing need for products and technologies that for their realization require hermetically closed elements, vessels and tubes. Envelopes with greater or smaller vacuum tightness had to assure a satisfactory isolation between external atmosphere and inside over- or under pressure. For leak inspection different techniques are known but among them there is no a universal method. Each leak testing is suitable only for a selected leak rate or for fixed forms and technologies.

The shapes of leaks (cracks, fissures, porosity, damages, etc ... ) are very different, unknown and non-uniform. Therefore it is impossible to measure their sizes with any geometrical dimension. How then to define the leak size? A generally accepted method became the observation of gas or fluid flow through it in certain conditions of temperature and pressure difference. The maximum acceptable leak rate for a given product depends on the nature of product. Since the cost of leak detection (and manufacturing too hermetic envelopes) increases in inverse proportion to a leak rate, it follows that testing for unnecessary small leaks causes unnecessary rise of production costs. It is possible to state there are no ideal products without leakage.

According to the techniques and targets, leak detection methods are grouped in two categories:

- leaks in plant processing units, vessels and lines (heat exchanges, valves, flares, boilers, heating water distribution network),
- leaks in underground pipe lines (oil and gas transporting pipes, urban water distribution network, cables).

A leak can be detected by several methods with or without radiotracer, some can be used on-line and others can be applied off-line; sometimes the same method can be used in both situation (off-line or on-line) but with different sensitivities. Radiotracer methods are mostly used for on-line leak detection in plant processing units and underground pipelines. This is the main subject of this book.

Heat exchangers are the most important hermetically closed vessels in petrochemical and chemical plants. Leak inspection in heat exchangers is crucial for the performance of processing lines and the quality of final products. Detection of leaks in heat exchangers is very difficult task due to their complexity and harsh operational conditions. Radiotracers for on-line leak detection in heat exchangers are the most competitive and sometimes unique techniques. This is the reason that radiotracer techniques for leak inspection in heat exchangers are largely covered in this book.

## 1.2. HEAT EXCHANGERS

A heat exchanger is a device built for efficient heat transfer from one fluid or gas to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted. They are widely used in petroleum refineries, chemical plants, petrochemical plants, natural gas processing, refrigeration, power plants, air conditioning and space heating. One common example of a heat exchanger is the radiator in a car, in which a hot engine-cooling fluid, like antifreeze, transfers heat to air flowing through the radiator

Heat exchangers may be classified according to their flow arrangement. In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is most efficient, in that it can transfer the most heat (Fig.1).

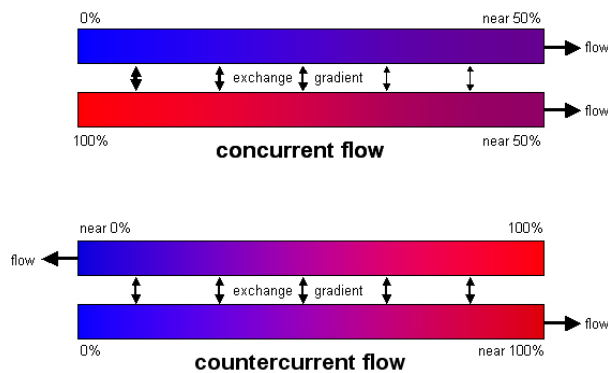


FIG. 1. Counter current design is most efficient, in that it can transfer the most heat.

A typical heat exchanger, usually for higher-pressure applications, is the shell and tube heat exchanger which consists of a series of tubes, through which one of the fluids runs (Fig. 2). The second fluid runs over the tubes to be heated or cooled. The set of tubes is called tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

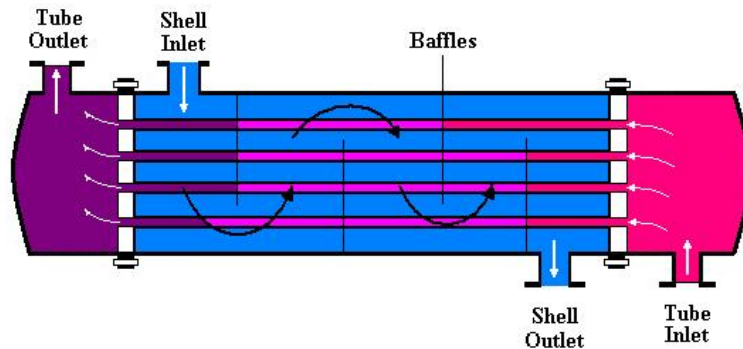


FIG. 2. Typical shell and tube heat exchanger design



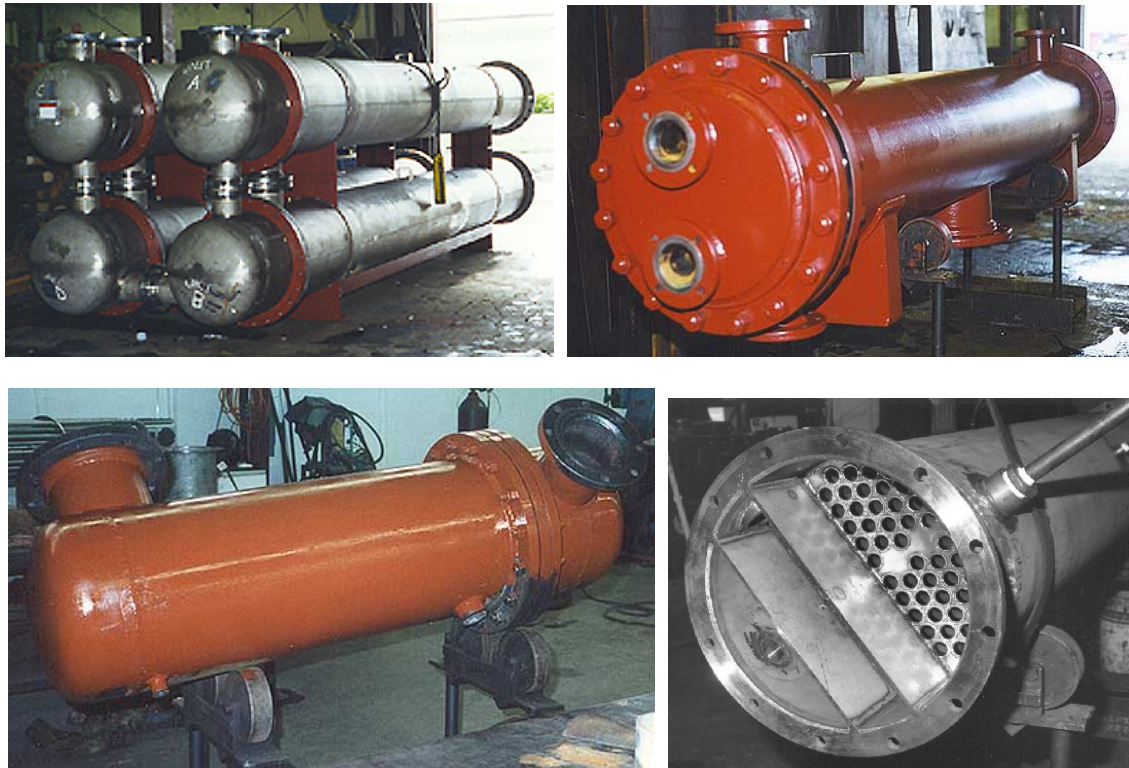
*FIG. 3. Bundle of tubes inside the shell*

A shell and tube heat exchanger is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it (Fig. 3). One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, so there are many tubes. In this way, waste heat can be put to use. This is a great way to conserve energy.

To be able to transfer heat well, the tube material should have good thermal conductivity. Because heat is transferred from a hot to a cold side through the tubes, there is a temperature difference through the width of the tubes. Because of the tendency of the tube material to thermally expand differently at various temperatures, thermal stresses occur during operation. This is in addition to any stress from high pressures from the fluids themselves. The tube material also should be compatible with both the shell and tube side fluids for long periods under the operating conditions (temperatures, pressures, pH, etc.) to minimize deterioration such as corrosion. All of these requirements call for careful selection of strong, thermally-conductive, corrosion-resistant, high quality tube materials, typically metals. Poor choice of tube material could result in a leak through a tube between the shell and tube sides causing fluid cross-contamination and possibly loss of pressure.

Figure 4 shows some types of heat exchangers, while figure 5 shows typical faults experienced in heat exchangers.





*FIG. 4. Some heat exchangers used in various industries*



*FIG. 5. Typical tube deterioration and faults in heat exchangers*

### 1.3. LEAK DETECTION METHODES IN PROCESSING VESSELS

#### 1.3.1. Leak detection using conventional methods

There are various non-destructive techniques (NDT) for detection of leakages. A short description of main conventional leak detection techniques are given below.

*Visual inspection:* this is a technique carried out by NDT inspectors in almost all industrial plants (process, safety, maintenance and management), either looking for or accidentally discovering leaks of process fluids.

*Chemical reagent tests:* some process gases give chemical reactions with simple reagent, e.g. leaking ammonia gas may be detected by its reaction with hydrogen chloride producing dense white fumes of ammonium chloride.

*Pressure change method* uses pressure gauges which are ordinary used to monitor the system performance. Suspected leak sites can be squirted with a solvent (i.e. acetone or similar) while watching the gauge for a pressure rise that occurs when the solvent enters the leak. This method has limited sensitivity (depending also on the type of pressure measurement cell) and some shortcomings (possibility of solvent freezing causes temporary stuffing of leak, solvents may attack vacuum grease and elastomer gaskets).

*Overpressure methods (bubble test)* can be performed by fluid or gas with which the tested element must be filled. As a fluid usually the water from house installation is used. Observing the outside surface the wetted areas show us great leaks and smaller ones up to approx. 1 mbarL/s. Testing with gas, the vessel is subjected to overpressure of some bars (depending on material and wall thickness) and immersed into the water. At leaks the gas bubbles begin to escape. In this manner, leaks up to  $1 \cdot 10^{-3}$  mbarL/s can be detected. If the vessel is too great for immersion, the suspected points should be painted by soap solution and again we can see the bubbles escaping if there is a leak. This method enables detecting the leakage up to  $10^{-5}$  mbarL/s and is usable also for very large systems.

*Dye penetrant method* is an adaptation of a technique used to find cracks in metals and defects in welds. It uses a low viscosity fluid that exhibits a high rate of surface migration. This fluid is painted on one side of a suspected leak site, and after a time, it is detected on the other side of the wall. The test is simple, low cost, it leaves records, and the sensitivity can be as high as  $10^{-6}$  mbarL/s

*Acoustical leak detection* uses the sonic or ultrasonic energy generated by gas as it expands through an orifice. All leaks of liquid or gas generate noise in either the sonic or ultrasonic region; the strength and frequency of the signal being a function of the differential pressure and the size and geometry of the hole. Pressurized gas proceeds from tested system through leaks which are detected outside by sensible microphone (typically about 40 000 Hz). Acoustical leak detection is widely used in testing high pressure lines, ductworks etc. It requires modest instrumentation; it is simple and fast but is limited to about  $10^{-3}$  mbarL/s.

*Thermographic tests:* either simple temperature measurements or sophisticated thermal imaging equipment may be used to detect leaks in lagged sections of plant, if the escaping fluid increases or decreases the temperature of the lagging appreciably from the ambient level.

*Search gas methods:* a search gas, such as sulphur hexafluoride gas ( $\text{SF}_6$ ), helium or a chlorinated hydrocarbon, is injected into the system under test and any leakage from flanged joints or welds can be detected by external monitoring. The detection equipment depends upon the choice of tracer (helium mass spectrometer or electron capture gauge, as appropriate).

*Halogen gas leak detectors* are used in the detector-probe mode (to  $10^{-3}$  mbarL/s), requiring that the system be pressurized with a gas containing an organic halide, such as one of the Freon's. The exterior of the system is then scanned with a sniffer probe sensitive to traces of the halogen -bearing gas. The principle is based on the increased positive ions (K or Na) emission because of sudden halide composition presence. The ion current is the measure for a leak size. Halogen detectors can be used also in turned mode: evacuated vessel is connected to detecting instrument and is sprayed by Freon. In this manner its performance is up to  $5 \cdot 10^{-7}$  mbarL/s and is used in rough, medium and high vacuum.

*Mass spectrometers as leak detectors* are used as most sensitive instruments for stating leak existence and pin-point the exact location of the leak. Helium leak detection technique (or helium mass spectrometer technique) is largely used in off-line inspection for leaks in heat exchangers and other vessels (Fig. 6). For units under pressure the helium is added to the vessel under investigation at a suitable test pressure. Sampling and measurement at locations within the system into which the helium may leak is then carried out using a helium portable mass spectrometer. This method sensitivity is up to  $1 \cdot 10^{-9}$  mbarL/s.

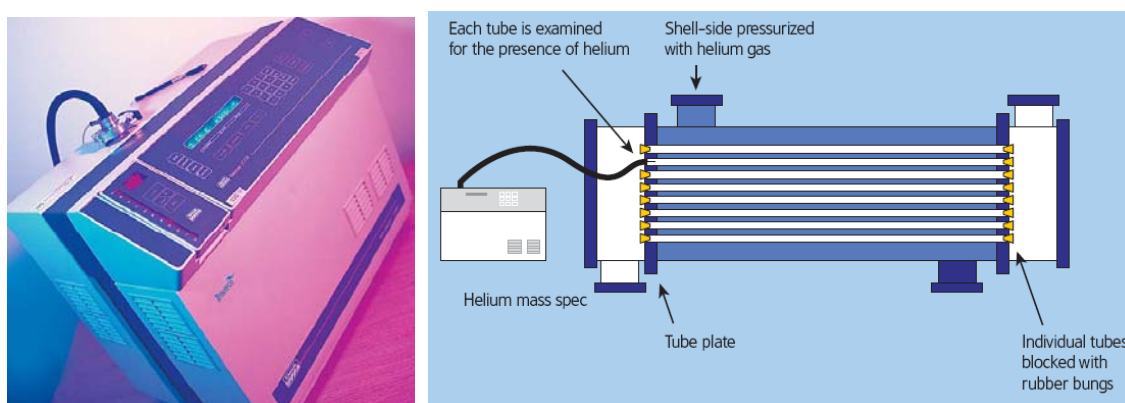


FIG. 6. Off-line mode for leak detection in heat exchanger using helium mass spectrometer technique

The first next suitable gas for leak detection purposes would be  $H_2$  but it is dangerous and residual atmosphere in vacuum systems always contains this gas. There are also spectrometers adjustable to other gases e.g. argon.

The leak rate  $Q$  does not only depend on the geometric dimensions (diameter, length) of the leak but also on the physical properties of the gas (or the liquid), such as viscosity, relative molecular mass and on the pressure difference. For example, in the same environment conditions helium flows through orifices 2.7 times faster than air. Because of different results if the same leak is measured by various mediums it must be always noted with which gas a testing was performed.

### 1.3.2. Leak detection using radiotracers

Radiotracers are used in routine for detection of leaks in processing plants (Fig.7). One of the most difficult leaks to detect is internal leakage as from the tube-side to the shell-side of a heat exchanger. Highly sensitive and versatile radiotracer methods are developed for locating such leaks.



## Leak detection

Difficult to locate, internal process leaks often cause serious problems... Tracer techniques offer an effective response to this problem. Typical detection threshold is between 1% and 0.1%, but lower levels are obtainable in some cases.

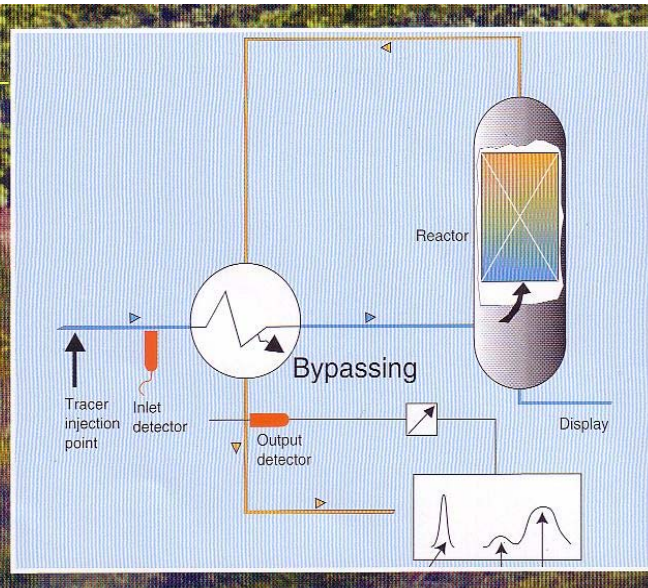


FIG. 7. Radiotracer techniques for leak detection in processing vessels

A very small amount of a compatible radioisotope is injected as a sharp pulse into the higher pressure process stream. The radiotracer mixes with the flowing process fluid, providing a label that permits monitoring of the position and the rate of progress of the stream through the exchangers. If the leak exists, some of the tracer will pass into the lower pressure stream. There will be detected either by sampling the process fluid downstream of the exchanger or by monitoring the movement of the radiotracer using detectors mounted externally. Detection limits of 0.1 % of one stream leaking to other stream can be achieved with online external detection, while sampling can identify leaks as small as 0.01% of the main fluid flow rate.

The way radiotracers are employed for the detection of leaks in different situation of processing plants is classified in slightly different three techniques, as follows:

- The flow rate measurement. A gamma radiotracer is injected instantaneous into a pipe or vessel. The leak flow rate (if there is a leak) is measured using two radiation detectors displaced few meter from the injection point and from each other. The volume flow rate of the leak is calculated knowing the physical volume of pipe section between two detectors. This is the typical case of leakage through a bypass line.

- The residence time distribution (RTD) measurement. Leaks can be found from the length of time taken by radiotracer to appear at a detector. A sharp pulse of appropriate radiotracer is injected into the feed inlet. An externally mounted detector records the instantaneous concentration of the tracer (proportional to detector count rate) leaving the vessel. The RTD curve provides the leak indication (if there is a leak). The leakage is detected by a subsidiary peak preceding the main peak and the leakage rate is calculated as ratio of these two picks areas.

- The "direct" tracer technique. Two processing streams in different pipes are moving in close contact. A radiotracer is injected in one of these streams and then search is performed to detect the presence of radiotracer into the second stream (if there is a leak) by sample analysis or external measurement.

Radiotracer technique is very sensitive; it enables the measurement of leak flows up to  $10^{-10}$  mbarL/s. The table I gives a comparison of the sensitivity of various techniques.

TABLE I. COMPARATIVE SENSITIVITIES OF LEAK DETECTION TECHNIQUES

Technique	Leakage rate (mbar. L.s <sup>-1</sup> )	
	On-line	Off-line
Visual inspection	$10^{-1}$ to $10^{-2}$	
Bubble test		$10^{-3}$
Ultrasonic inspection	$10^{-2}$	$10^{-3}$
Reactive gas	$10^{-2} - 10^{-3}$	
Hot wire thermal conductivity	$10^{-4}$	$10^{-4}$
Positive emission	$10^{-5}$	$10^{-5}$
Electron capture gauge	$10^{-10}$	$10^{-10}$
Helium mass spectrometer (over pressure mode)	$10^{-8}$	$10^{-8}$
Helium mass spectrometer (vacuum mode)	$10^{-10}$	$10^{-10}$
Radiotracer	$10^{-10}$	$10^{-10}$

Note: The leak rate unit mbar L/s is a technical unit largely used in vacuum technology. This unit is equivalent with  $\text{at. m}^3 \cdot \text{s}^{-1}$ . From vacuum theory, leak flow rate is related with pressure  $p$  and volume  $V$  of a vessel with formula:  $Q = p V/t$  (mbarL/s)

## 2. LEAK DETECTION IN PROCESSING VESSELS USING RADIOTRACERS

Radiotracer techniques for leak detection are complementary to other conventional tests (in particular to pressure test), and plant engineers call for radiotracer test when they fill and suspect that something wrong is happening in the process (contamination or spoil of final product, drop of pressure, etc.). The radiotracer test is very competitive and in many cases the most sensitive and accurate technique available. To find out leaks (or to state that no leaks) radiotracer tests should be prepared, executed and interpreted very carefully; and sometimes to be repeated at least twice.

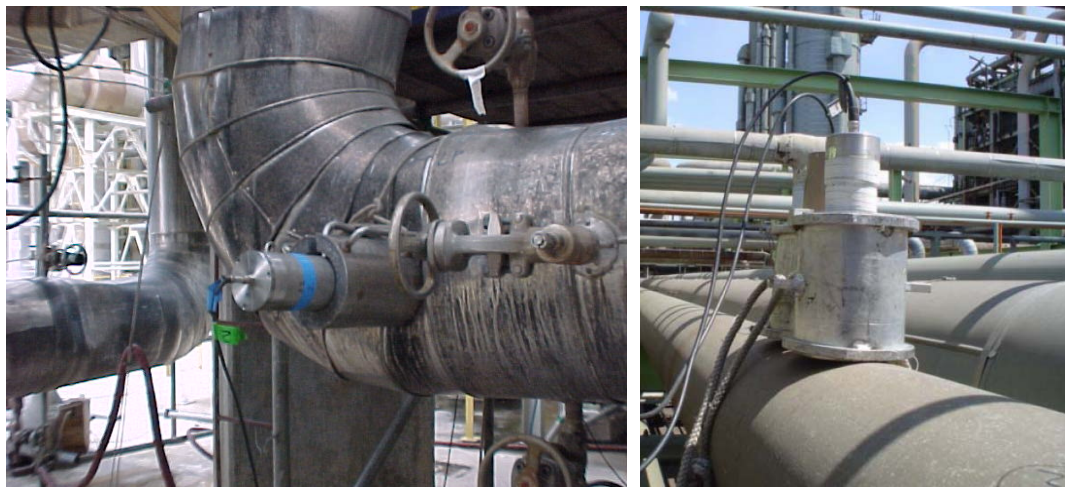
Radiotracer technique for leak detection in heat exchanger is applied in commercial routine service to petrochemical and chemical industries in many developed and developing countries. A radiotracer test in heat exchanger costs several thousand US\$ (cost of the radiotracer, labor cost and materials) but the benefit for end users is huge, hundred times more (saving in shutdown maintenance, in material and labor cost). There are few short-term investments, which will give a return of this magnitude. The cost effectiveness of radiotracer applications for leak detection should be widely promulgated to encourage industrialists to take full advantage of the technology.

### 2.1. ON-LINE AND OFF-LINE DETECTION TECHNIQUES

There are on-line leak detection techniques carried out during production, and off-line performed during a maintenance shutdown. In fact some of the techniques are applied in the same way to both situations, although the performance and the sensitivity achieved are not necessarily the same in both circumstances. Conventional NDT techniques for off-line leak detection are competitive and largely used, while for on-line leak detection the radiotracers are the most competitive and method of choice.

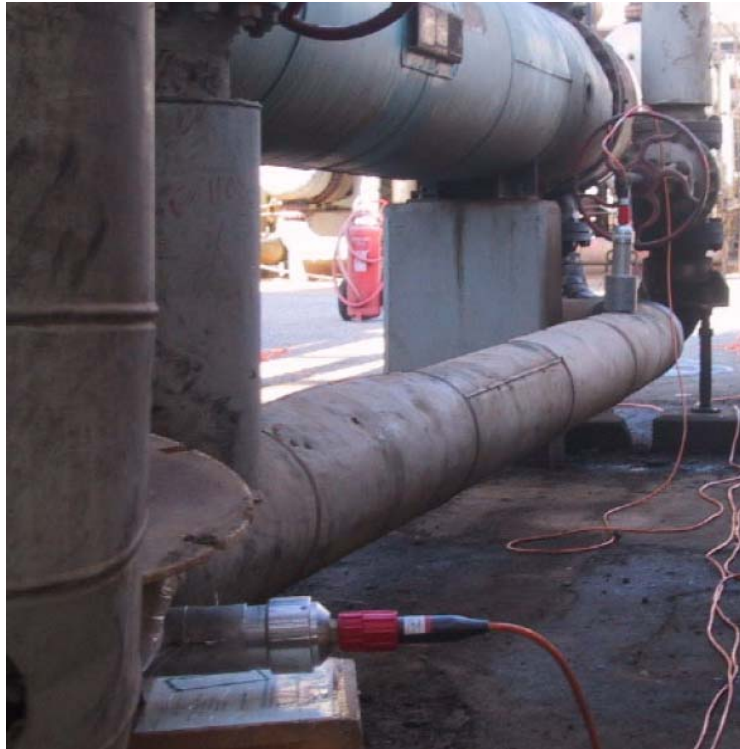
#### 2.1.1. On-line leak detection using radiation detectors

Generally on-line leakage testing is carried out by injecting a radioactive tracer into the process stream from which the leakage originates, and seeking the presence of that tracer in adjacent streams or in the environment. Radiation detectors used for leak detection are generally two inches sodium iodide NaI (TI) scintillation detectors coupled to a data acquisition system (Fig. 8).



*FIG. 8. NaI probes mounted to the exist of a heat exchanger*

Figure 9 shows the placement of radiation detectors during a radiotracer test in a heat exchanger.



*FIG. 9. Placement of radiation detectors in a heat exchanger*

Several factors can affect the calculation of the leak size and corrections should be made for the following, if necessary:

- *Different detector efficiencies*: it is not always possible to have all the detectors with the same efficiency and each detector must be calibrated prior to the experiment so that the areas under the peak can be corrected appropriately.

- *Detector geometry*: if the lines carrying the fluid under investigation are of different size and wall thickness, then the volume of material producing the response at the detector may be different or reduced by the extra metal of the wall. An appropriate correction must be made.

- *Difference in fluid flow rate*: the detector response is dependent on the time the radioactive tracer is passing in front of it and is consequently dependent on the flow velocity. Detector response is measured in counts per second, or, if the detector efficiency is 100%, it is measured in disintegrations per second (Bq). If in this latter case, for example A Becquerel's of activity moving in front of the detector in one second, A disintegrations in that second have to be recorded. However, if the radioactive cloud crosses the detector view in two seconds 2A disintegrations is counted, i.e. the count rate is inversely proportional to the velocity of the fluid passing in front of the detector.

Leakages of approximately 0, 1 % of the total flow rate can be measured using external detection technique. However, care must be exercised when using this technique, as confusion can be caused by erroneous responses of the leak detector from adjacent pips or vessels carrying the injected radiotracer.



In closely-confined congested areas on modern plants, it is generally necessary to shield and collimate the detector (to surround the highly sensitive leak detector with lead or tungsten shielding) in order to make it unresponsive to possible extraneous influences.

On line leak detection tests can be also divided into:

- external leakage to atmosphere from a pressurized system or pipe,
- internal leakage (bypassing) in closed systems, e.g. leakage from the inner tube side to shell side of a heat exchanger.

There is also a variant of the on-line leak detection technique by sample analysis; that means after radiotracer injection samples are taken and their radiation is measured by a well shielded detection system. But this technique is very seldom used in practice because of no evident advantage to other conventional techniques.

### **2.1.2. Off-line leak detection**

Off-line leak detection techniques are performed during a maintenance shutdown. A known quantity of radioactive tracer (A, MBq) is injected into the inlet fluid feed of a heat exchanger (or any other vessel), and the radiation is recorded either by detection probes installed around the vessel, or by sample analysis taken at the product outlet over a period of time. Ideally the length of the sampling time should be such as to span the entire "leak peak". These samples are then measured for radiotracer content using a highly efficient, large-volume, sodium iodide detector. This method gives much greater sensitivity with practical leak detection limit of approximately 0,01% of the total flow rate. But again radiotracer techniques are not often used in routine for off-line leak detection of processing vessels because there are other conventional techniques that compete during a maintenance shutdown.

## **2.2. RADIOTRACER TECHNIQUES FOR ON-LINE LEAK DETECTION IN PROCESSING VESSELS**

The heat exchangers are the typical complex operation units where the leakage process happens frequently. Shell-and-tube heat exchangers are the most common type of heat-transfer equipment in chemical and petrochemical plants. The experimental set up and typical radiotracer leak detection record is more or less the same for all internal leakages in closed processing vessels. Fig. 10 shows typical heat exchangers in petrochemical plants.



*FIG. 10. Typical heat exchangers in petrochemical plants*



### 2.2.1. Principle of radiotracer method

With both single and multiple exchangers, the radiotracer is injected into the higher pressure side with detectors placed on the lower pressure side piping leaving the exchanger (Fig. 11).

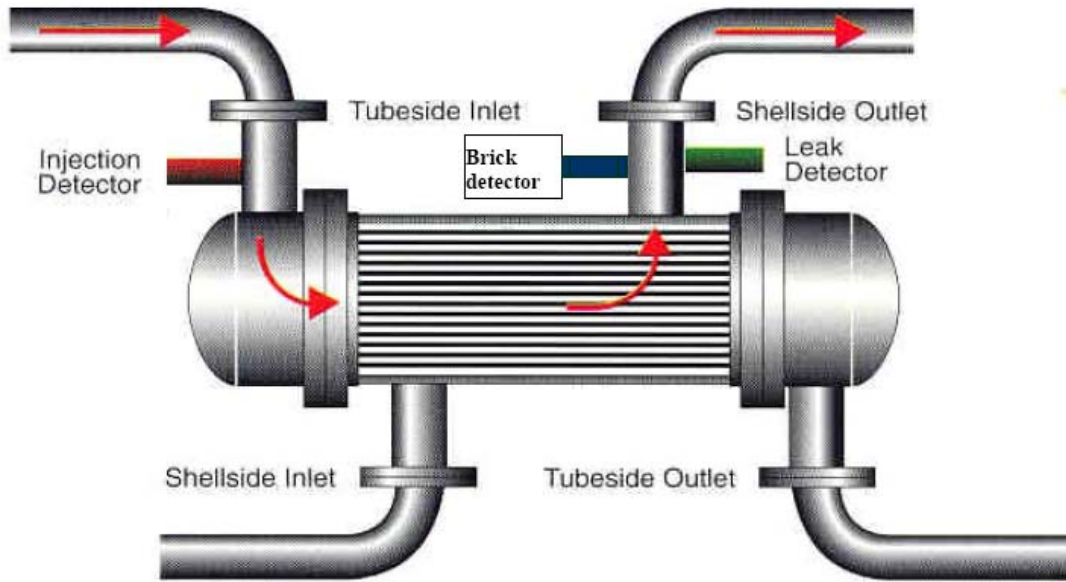


FIG. 11. Radiotracer leak testing a single pass co-current flow heat exchanger

The detector mounted at the tube side inlet (high pressure) monitors the injection peak and time; and the leak detector mounted at the shell side outlet (low pressure) indicates the presence of a leak (hypothetical leak flow is shown by red arrays).

Other detectors can be mounted around the exchanger to monitor the radiotracer movement into the whole processing line and help to identify better the presence of the leak peak.

Normally, there are two identical detectors mounted at the suspected leak side near each other, one is leak detector (shielded and open-collimated from leak side) and the other is “brick detector” (shielded from all sides, black color in Fig. 11). Mounting another completely shielded detector (brick detector) in the same place with the leak detector and comparing their records facilitates the interpretation of radiotracer test and ensures very reliable identification of the real leak peak (Fig. 12).

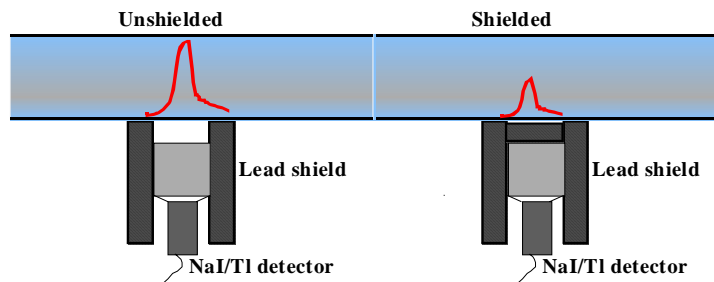


FIG. 12. Typical arrangements of detectors showing shielded and unshielded effects

Leak detector (collimated but not shielded from upper side) and brick detector (shielded from all sides) are mounted near each other (Fig. 13). If the brick detector records a smaller peak (in comparison of leak detector) it confirms the radiotracer is passing in front of both detectors and the peak is originated from a leak. If peaks recorded by both detectors are nearly the same, this confirms that they are originated from unwanted influences outside the measuring point. This false leak peak proves that there is no leak in this line.

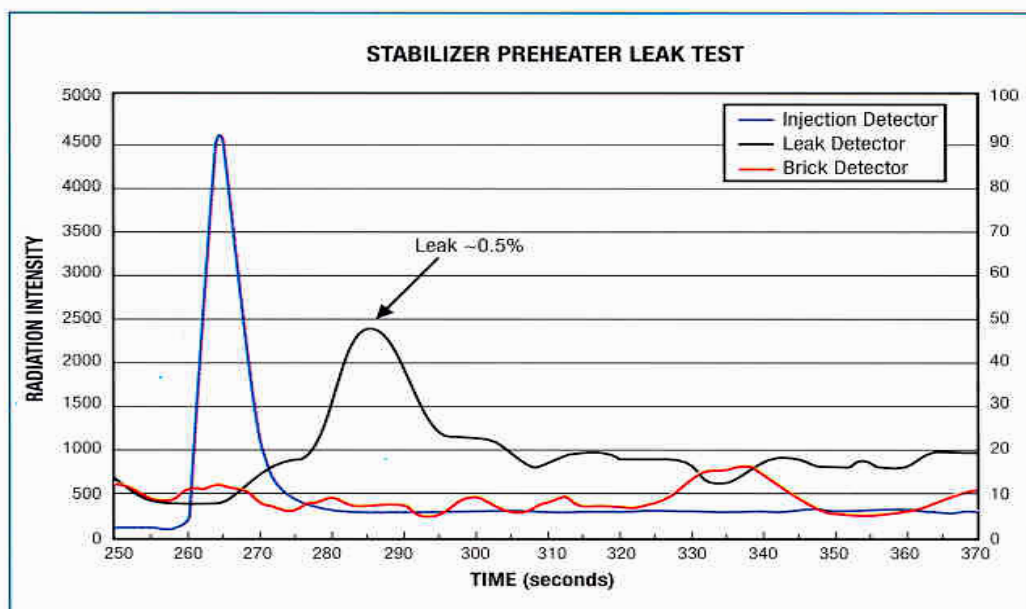


FIG. 13. Radiotracer test results: injection(blue trace) peak; black and red traces recorded by leak and brick detectors indicate presence of the leak peak in lower pressure tube

Figure 13 shows radiotracer experimental responses obtained in a test conducted in the preheater of figure 12. The “brick detector” (red trace) monitors background radiation and detect radiation influences from surroundings that are not leak related. Leak detector records (black trace) a clear peak, which is thought to indicate a real peak.

Comparing records of “leak and brick” detectors it facilitates the interpretation of radiotracer test and ensures very reliable identification of the real leak peak. Leak flow rate was estimated nearly 0.5% of injection flow, as ratio of the peak areas of leak (black) curve, which has the right side scale, to injection (blue) curve, which scale is left of graphic.

Typical radiotracer experimental set-up in any kind of shell-tube heat exchanger (single pass or multiple) is shown in Fig. 14. The sharp pulse of radiotracer is injected into the tube inlet and detectors 1, 2, 3 and 4 are positioned to monitor its passage through the exchanger. Detector 1 shows the tube inlet injection pulse, while detectors 4 and 2 show the outlet responses from the tube and converter. Detector 3 (so called “leak detector”) will only respond if there is any leakage from the tube to the shell (low pressure) side of the exchanger. Typical detector responses are shown in fig 15.

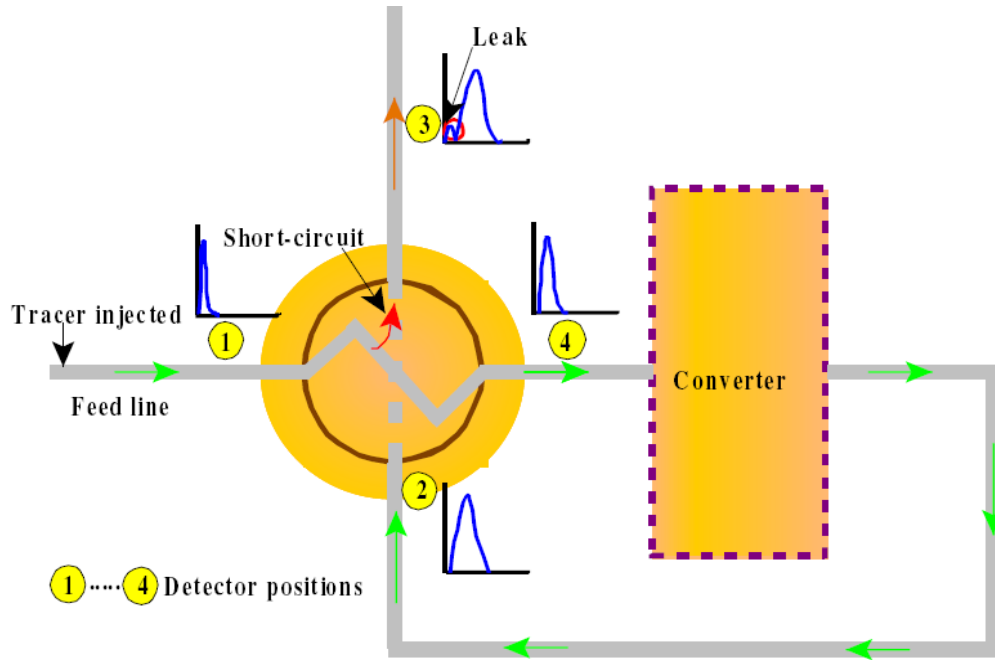


FIG. 14. Typical radiotracer experimental set-up in heat exchanger

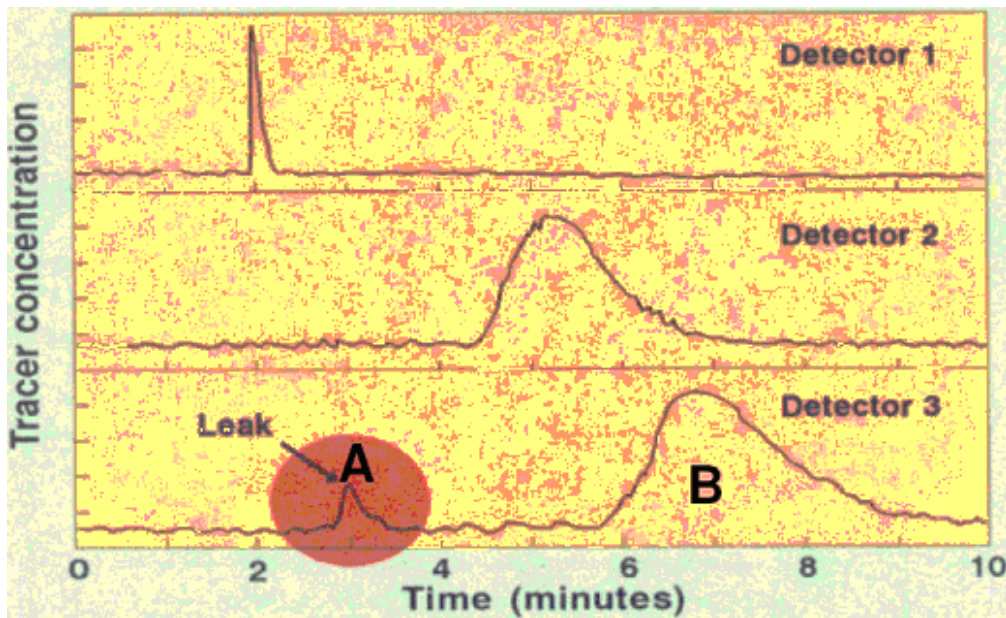


FIG. 15. Detection records of gamma probes

Detector 1 shows a typical instantaneous injection of radiotracer (few seconds duration), detector 2 presents the residence time distribution (RTD) of the tracer into the system (it reflects the axial dispersion flow of the fluid) and the detector 3 (leak detector) indicates a suspect for leak peak just before the mainstream dispersed peak. In this case only leak detector collimated was placed at the outlet (no brick detector was used in this case).

The interpretation of the small “leak” peak coming before the mainstream peak needs a careful analysis. It could be a “false signal”. The “false leak peak” could come also from radiotracer at the injection moment or during the circulation inside the processing line, if the leak detector is not well collimated (shielded around) and it is mounted near the injection point or other pipes. Good shielding of the detector with lead collimator is important to ensure the peak is coming only from the real leak passing in front of detector and not from influences from surroundings. Peaks time analysis helps in correct interpretation of this effect. Peaks time analysis in the figure 15 indicates the existence of the “real leak”. Calculation of the amount of leakage is made by comparison of the respective areas under the main peak and the leak peak (assuming the same detection geometry) such as:

$$L\% = S_A / (S_A + S_B)$$

### 2.2.2. Selection of radiotracers

Selection of a suitable radiotracer is very important for the success of the leak detection test. Most of the radiotracers commonly used in industrial tracer experiments are gamma emitting tracers. The energy of the gamma radiation should be sufficiently high to penetrate through the wall of the pipes or vessels. The parameters considered for the selection of a radiotracer are the physico-chemical behavior, the half life, the specific activity, the type and energy of radiation:

- physico-chemical behavior: it should be the same as the fluid being traced
- half life of the radiotracer: should be comparable to the duration of the experiment
- type and energy of radiation: gamma radiation can be detected outside walls; its energy should be sufficiently high to penetrate through the material(s) between the process stream and the detector
- activity: it should be enough to be detected with a good accuracy.

The physico-chemical behavior of the tracer should be same as the fluid being traced. For example  $^{24}\text{NaCl}$  is an ideal tracer for tracing water fluids. Para-dibromobenzene labeled with Br-82 is used to investigate the hydrodynamic behavior of organic fluids. The radiotracer compounds depending on the chemical and physical characteristics of fluids flowing inside the processing line under investigation. The most used radiotracer compounds are:

- Gas tracer: Ar-41, Kr-79 and  $\text{CH}_3^{82}\text{Br}$
- Liquid organic tracer: Dibromobenzene
- Liquid water phase:  $\text{Na}^{131}\text{I}$ ,  $\text{NH}_4^{82}\text{Br}$ ,  $\text{K}^{82}\text{Br}$ ,  $^{99\text{m}}\text{TcO}_4^-$

Gas methylbromide labeled with Br-82 ( $\text{CH}_3^{82}\text{Br}$ ) has low boiling point ( $4.6^\circ\text{C}$ ) that makes it difficult to apply at lower external temperatures. Kr-85 and Xe-133 are weak gamma emitters, while Ar-41 has rather short life.

Dibromobenzene labeled with Br-82 ( $\text{C}_6\text{H}_4^{82}\text{Br}$ ) is a liquid in normal conditions. It is a good tracer of organic fluids. There are two kinds of dibromobenzene molecules, para and ortho dibromobenzene (p-  $\text{C}_6\text{H}_4^{82}\text{Br}$  and o-  $\text{C}_6\text{H}_4^{82}\text{Br}$ ). Di-bromo parabensene (p- $\text{C}_6\text{H}_4^{82}\text{Br}$ ) is more often used for leak detection in organic phase.

The half life of the radiotracer should be comparable to the duration of the study. It should be long enough for detection till the end of the experiment and at the same time short enough not to interfere with further test (if repeated).

Tracer tests for leak detection run from few minutes (heat exchangers) to several hours (underground pipelines), thus best radiotracers for leak detections are those that have half lives compatible with this interval, that means from several hours to few days (taking account the transport time and preparatory work).

Table II presents most commonly used radiotracers for leak detection.

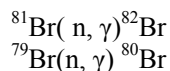
TABLE II. MOST COMMONLY USED RADIOTRACERS FOR LEAK DETECTION

Radioisotope	Half-life	Radiation and Energy (MeV)	Chemical Form	Tracing of Phase
Sodium-24	15 h	$\gamma$ : 1.37(100%) 2.75(100%)	Sodium carbonate	Aqueous
Bromine-82	36 h	$\gamma$ : 0.55 (70%) 1.32 (27%)	Ammonium bromide, Methylbromide	Aqueous Gases
Iodine-131	8.04 d	$\gamma$ : 0.36 (80%) 0.64 (9%)	Dibromobenzene Potassium or sodium iodide,	Organic Aqueous
Technetium-99m	6 h	$\gamma$ : 0.14 (90%)	Iodobenzene, Hippuran Sodium technetate	Organic Aqueous
Krypton-85	10.6 y	$\gamma$ :0.51(0.7% )	Krypton	Gases
Krypton-79	35 h	$\gamma$ : 0.51 (15%)	Krypton	Gases
Xenon -133	5.27 d	$\gamma$ :: 0.081 (37%)	Xenon	Gases
Argon-41	110 min	$\gamma$ : 1.29(99% )	Argon	Gases

$^{82}\text{Br}$  is the most frequently used gamma emitter in industrial tracing applications, in particular in countries that have nuclear reactor. Br-82 has a very convenient half-live,  $t_{1/2} = 36$  h, that is long enough to use it for as long as one week after irradiation (or even more depending on the sensitivity of the detector and the conditions at the measurement site), but not so long as to cause radiation protection problems. The advantages of Br-82 are:

- It is relatively to be produced in nuclear reactor through (n,  $\gamma$ ) reaction in high specific activities because of high cross section,
- It is a radioisotope within short and medium half lives available in organic, water and gas compounds with a large spectrum of applications.

Bromine has two non radioactive isotopes, ( $^{79}\text{Br}$ ,  $^{81}\text{Br}$ ) with natural abundance 50.6% , 49.4 respectively. Nuclear reactions formed are:



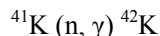
The parent  $^{81}\text{Br}$  has isotopic abundance of 49.3 % and thermal neutron cross-section  $\sigma = 2.43$  b. Bromine irradiation has one peculiarity: since the other stable bromine isotope,  $^{79}\text{Br}$ , occurs in nature with a slightly higher abundance (50.7 %) and has an also slightly higher neutron cross-section  $\sigma = 2.6$  b, metastable  $^{80\text{m}}\text{Br}$  (decays by isomeric transition) and  $^{80}\text{Br}$  (decays by both beta and positron emission) and will also be produced in nearly the same proportion. Fortunately these by-products have much shorter half-lives:  $t_{1/2} = 4.4$  h for  $^{80\text{m}}\text{Br}$  and  $t_{1/2} = 18$  min. for  $^{80}\text{Br}$ ; if the user is only patient enough and uses the irradiated bromine the day after the irradiation,  $^{80\text{m}}\text{Br}$  will be practically vanished.

The following target materials can be used for the production of the  $^{82}\text{Br}$  radioisotope:

- Inorganic bromides:  $\text{NH}_4\text{Br}$ ,  $\text{KBr}$
- Inorganic bromates:  $\text{NaBrO}_3$ ,  $\text{KBrO}_3$ , Organic bromine compounds:  $\text{C}_6\text{H}_4\text{Br}_2$

The most convenient target in terms of radioactive purity is ammonium bromide,  $\text{NH}_4\text{Br}$ . Potassium bromide,  $\text{KBr}$ , which is less chemically active and more resilient to radiolysis, is quite satisfactory as well.

The target KBr can be irradiated to significantly higher specific activities, even if  $^{42}\text{K}$  ( $t_{1/2} = 12.4$  h,  $\sigma(^{41}\text{K}) = 1.5$  b, isotopic abundance ( $^{41}\text{K}$ ) = 6.7 %) is formed:



Potassium bromide gives unwanted radioactivity (Kr-42) due to this competing reaction, but the period of K-42 is much smaller than of Br-82, so after a reasonable cooling time of nearly one day, it almost disappears and does not disturb Br-82 tracer measurements and results.

Ammonium bromide compound is preferred, however, its irradiation at high neutron fluxes cause evolution of gas due to the decomposition of bromide. It is obvious that low flux reactors with associated low temperatures at irradiated sites may be used to avoid this problem.

To avoid working with irradiated material, organic phase soluble  $^{82}\text{Br}$  tracer compounds have been produced with some difficulty by direct irradiation organic bromine compounds. Dibromobenzene has been chosen as target, as it is comparatively resistant to radiolysis, and gives high specific activity. Although the overall  $^{82}\text{Br}$  yield is only a few percent, specific activities of the order of  $3 \times 10^5$  mCi/mg can be attained.

The performance of a leak test using brominated hydrocarbons does not damage the catalyst or affect production. First, only about 5 grams of the brominated hydrocarbon is used. Second, the absorption of the bromine onto the catalyst is temporary. In 36 to 72 hours, depending on the height of the bed and the liquid flow, the tracer will migrate through the bed and exit the reactor diluted in the product diesel.

Radioisotope generators are very important in tracer work in developing countries without nuclear reactors. There are three useful radioisotope generators for remote tracer experiments mostly in liquid phase: Mo-Tc-99m, Sn-In-113m, Cs-Ba-137. Only Mo-Tc-99m, which is largely used in nuclear medicine, is available in the market. It has rather limited applications in industry due to short live and low gamma energy. It counts for nearly 20% of total tracer applications in industry.

$^{99\text{m}}\text{Tc}$  in sodium pertechnetate form was reported as radiotracer for organic phase in leak detection in a high voltage cable with oil insulation. This is certainly not to suggest that aqueous and organic tracers are universally interchangeable. Clearly, there are many systems, such as multiphase flows, where the use of this approach would produce erroneous results. However, it is useful to recognize that under normal temperature and pressure conditions, for simple and single-phase flow the leak detection it is often possible to use an aqueous tracer to trace an organic flow.

Sn-In-113m generator can be found from few suppliers. It has longer live and larger gamma energy in comparison with Tc-99m, but is two-three times more expensive. It can be used as complementary to Tc-99m for covering other tracer applications in industry.

Using the  $^{113}\text{Sn}/^{113\text{m}}\text{In}$  generator to produce tracers that are compatible with organic flows is generally more difficult. A common approach to producing an organic-compatible tracer has been to chemically treat the eluate from the generator so that the radioactive species is incorporated into an organic complex. However, in some circumstances, it has been found possible to directly trace an organic flow using the aqueous eluate from the generator. To demonstrate the validity of this type of approach, the pulse velocity technique was used to measure the flow rate along a gasoline pipeline on a refinery using the eluate from a commercially sourced  $^{113}\text{Sn}/^{113\text{m}}\text{In}$  generator as the tracer. The flow rate was then measured using paradibromobenzene, labelled with  $^{82}\text{Br}$  as the tracer. The results were identical within the limits of accuracy of the measurements ( $\pm 2\%$ ).

Cs-Ba-137 generator produces very short live radiotracer but has practically very long live (several years at least). This is a very useful radiotracer generator for routine service to end users, in particular for liquid flow rate measurement and leak detection in processing plants, because of its high gamma energy which can be easily detected from outside pipes, and of its safety. The Cs-Ba-137 generator is not available in the market. There are some tracer companies that produce home-made Cs-Ba-137 generator for their own use.

Commercially available generators are generally eluted using aqueous liquids, so that the eluates are compatible with the flows to be measured. This is certainly true of the eluate from the commercially available  $^{113}\text{Sn}/^{113\text{m}}\text{In}$  generator, which is eluted with dilute solution of HCl.

These three generators make tracer groups of developing countries independent on radiotracers supply from abroad and can be used for leak detection in some processing lines.

In fact, another potential radioisotope generator with perspective for many radiotracer investigations is Ge-68/Ga. The half life of the parent, Ge-68, is 258 days, so that the generator may be used for several years. The half-life of the Ga-68 daughter is only 68 minutes, but this is adequate for many studies, particularly if the data collection system has a decay-correction facility. The Ga-68 also has a high-energy gamma-ray at 1.08 MeV so that the tracer can be used in plants of substantial construction. Ga-68 is a positron emitter. There is currently no commercial supplier of this potentially valuable radioisotope generator. In the near future it is possible to produce this radioisotope generator through the network of international cooperation among nuclear establishments. It will enlarge the routine applications of radiotracer techniques for leak detection as well.

The behavior of tracer under conditions of the processing vessels (physical & chemical conditions) is very important. One must know, before injecting a tracer, how it will behave in the process. In certain circumstances, the tracer injected into a system may undergo decomposition, phase changes, undesirable absorption & adsorption, chemical interaction with system constituents, etc., leading to incorrect results. For example para-dibromobenzene when used at high temperature in some heat exchangers and fluid catalytic cracking units in oil refineries, is adsorbed on the surfaces of plant vessels and does not follow, faithfully, the liquid phase.

Or, another example: Br-82 as dibromobiphenyl was tested in a trickle bed reactor operating at high temperature and pressure. The boiling temperature of dibromobiphenyl at atmospheric pressure is  $370^{\circ}\text{C}$ . Since the pressure in the reactor was about  $170\text{ kg/cm}^2$ , the tracer will not vaporize and will remain in liquid phase at  $400^{\circ}\text{C}$ . The results of the tracer tests carried out at temperature of  $250^{\circ}\text{C}$  show that the tracer did not appear at the outlet of the reactor indicating the adsorption of the tracer on the catalyst particles. Another test carried out at lower temperature ( $\sim 150^{\circ}\text{C}$ ), showed the tracer did appear at the outlet but the intensity was much less than in the inlet. This indicates partial adsorption of the tracer on catalyst particles.

### **2.2.3. Estimation of amount of radiotracer**

After selecting a suitable radiotracer for a particular application, the amount of tracer required to be used is the second important step in designing a radiotracer experiment. The lower limit of the amount of tracer is estimated according to measurement sensitivity, accuracy desired, dilution between injection and detection points, background radiation level *etc.*. However, the upper limit is set by radiological safety considerations.

The amount of radiotracer required for a leak detection test depends on the following factors:

- Accuracy
- Efficiency of measurement or calibration factor of detection system
- Expected level of dilution/dispersion
- Half life of radiotracer used

- Background radiation level
- Mode of injection and detection
- Expected losses of tracer.

Accuracy is given by the standard deviation of the intensity of radiation. In field work an accuracy of 5-10 % is acceptable. Efficiency of radiation detection is expressed in counts per second per specific activity unit cps/ $\mu\text{Ci}/\text{m}^3$  (or:  $\text{counts}^{-1} \text{Bq}^{-1} \text{m}^3$ ). The efficiency of detection depends upon the following factors:

- Geometrical factor
- Intrinsic efficiency of the detector
- Absorption coefficient of material between the source and detector
- Radiation field *i.e.*, volume ( $v$ ) seen by the detector.

Scintillation detectors NaI(Tl) are commonly used for industrial tracer applications because of their high efficiency for gamma ray detection. The intrinsic efficiency a 1" thick NaI(Tl) crystal size detector for 100 keV, 500 keV and 1 MeV energy photon is about 39%, 26%, 10% respectively. For NaI(Tl) 2"x2", which are commonly used in field tests, the intrinsic efficiency is almost four times higher than for 1".

The background radiation (cosmic radiation and natural radioisotopes) level is required to be known prior to the tracer test for the estimation of the amount of activity required. In general the radiotracer concentration (maximum count rate coming from the radiotracer only) should be at least 5-10 times the background radiation level at the measuring points. However, high accuracy demands that maximum count rate could be about 100 times that of the background radiation level. The losses due to splitting of tracer stream, adsorption, evaporation *etc.*, should be taken into consideration while estimating the amount of activity for a particular radiotracer experiment (these effects are known from the plant engineers).

An empirical simple way to calculate radiotracer activity for a leak test is to consider radiotracer completely homogenized in total volume of the pipe or vessel. In this case, A activity distributed uniformly in V volume of the pipe provides a specific activity of  $A/V$  ( $\text{Bq}/\text{m}^3$ ). The sensitivity  $k$  of the detection system is normally known from the laboratory (laboratory calibration imitating process conditions in bench model gives the correspondence between count rate  $I$ , cps and activity  $A$ ,  $\text{Bq}/\text{m}^3$ ). Radiation intensity  $I$ , cps that gives an acceptable accuracy is also known (5-10 times more than the radiation background intensity  $I_b$ ). In this case the activity is calculated simply by relation:

$$A (\text{Bq}) = V (\text{m}^3) \cdot I (\text{cps}) \cdot k ((\text{Bq}/\text{m}^3)/\text{cps})$$

This simple approach gives much higher estimation of radiotracer needed for a test because it considers the tracer uniformly distributed in the whole volume of pipe or vessel, that is not the case, tracer is moving as a dispersed cloud occupying only a limited volume of the vessel. Normally the half of this calculated activity is taken in practice because tracer is moving in peak form cloud where the concentration in the peak wave is several times more that calculated.

#### 2.2.4. Injection of radiotracer

The injection equipment depends on the physical nature of the stream to be injected, the pressure, the temperature and the toxicity of the stream.

In general, for the liquid injection into liquid stream, we use a hand-operated hydraulic pump for stream pressures limit up of approximately  $5 \cdot 10^6 \text{ Pa}$  (50 bar); for the gas stream the radioactive gas is injected with an inert backing gas, such as nitrogen, from a cylinder of pressure exceeding that in the line. For high-pressure liquid and gas systems, special injection systems are needed.



Figure 16 shows the principle of radioactive gas injection system, while the figures 17 and 18 show typical injectors for gas and liquid radiotracer injection into pipe and vessels under low and medium pressure (up to around 50 bar).

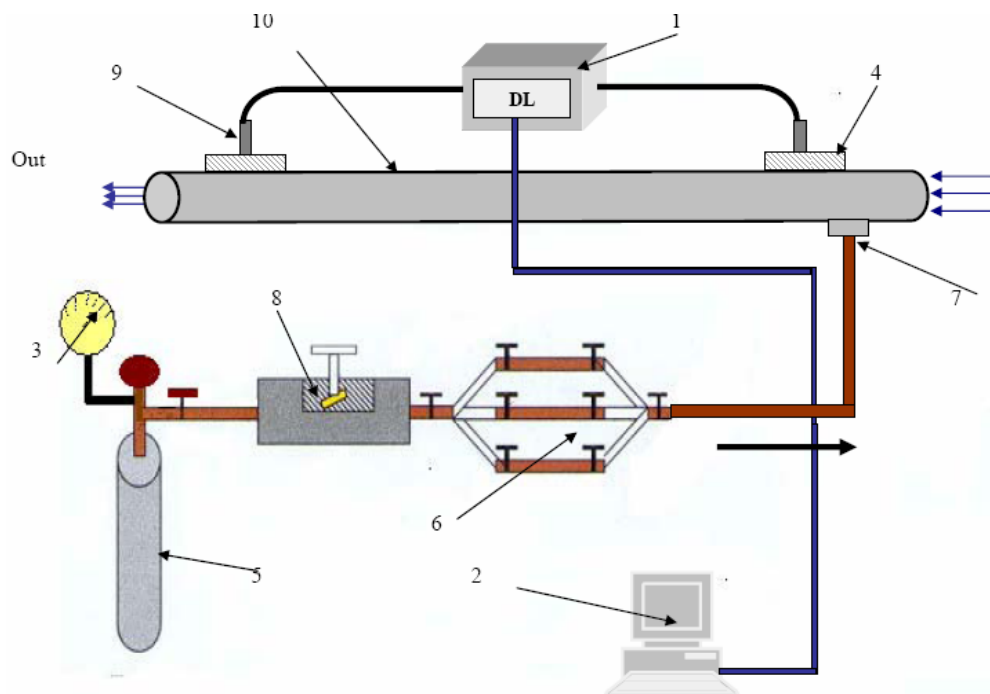


FIG. 16. Principle of gas injection system for  $^{41}\text{Ar}$

The injection system consists of the following items:

1. Data logger (DL); 2. Computer; 3. Monometer; 4. Collimator for radiation detectors; 5. Bottle of dry  $\text{N}_2$  for gas injection up to 20-30 bars; 6. Manifold; 7. Injection of  $^{41}\text{Ar}$  into the pipe (or vessel); 8. Breaker of the  $^{41}\text{Ar}$  capsule; 9. Two NaI(Tl) detectors installed outside the pipe; 10. Pipe or vessel under investigation.

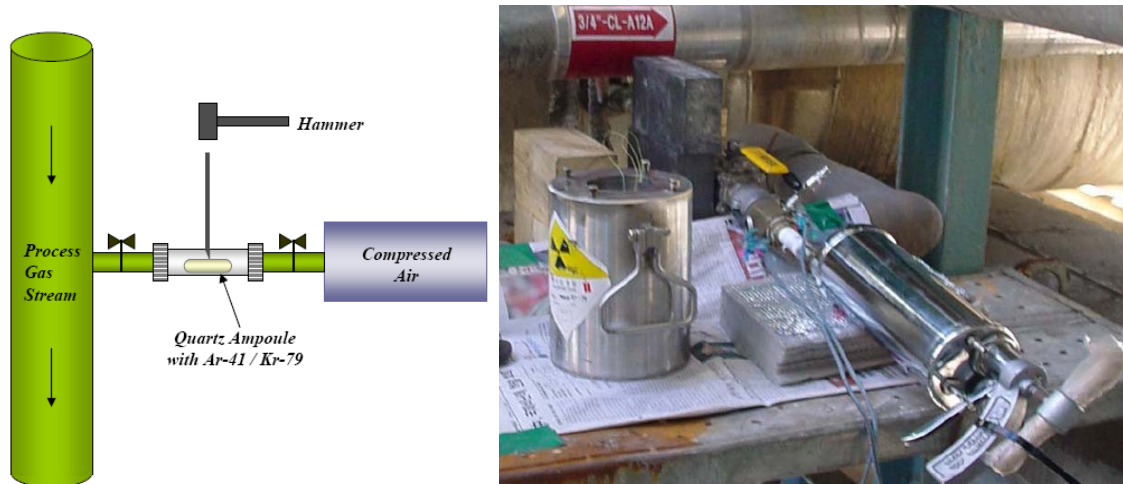


FIG. 17. Radioactive gas injector.



*FIG. 18. Radioactive liquid injector*

### **2.2.5. Radiation detection**

Radiotracer once injected in the system can be monitored continuously (on-line) or by sampling (off-line). One of the advantages of the radiotracer for investigating opaque processes compared to other tracers is the possibility for on-line measurement, thus the online method has preference to sampling. Since on-line radiotracer techniques involve most commonly only gamma-ray, the most common gamma-ray scintillator in use is the thallium- activated sodium iodide NaI(Tl) single crystal.

Three radiation detectors are needed for simple radiotracer leak inspection, such as measurement of the leak detection in a simple heat exchanger. More detectors (4-6) are needed for collecting additional comparative information in particular sites of the processing vessels, and as many as possible ( $> 10-20$ ) are needed for complex engineering reactors like fluid catalytic cracking units (FCCU) or bank of heat exchangers. The most commonly used in field condition is NaI(Tl) detector in waterproof casting. It is very sensitive sensor for gamma radiation, for example a 1''x 1'' NaI (Tl) scintillation detector for detection of  $^{82}\text{Br}$  in water, in an infinite detection geometry condition, gives 65 cpm/kBq/m<sup>3</sup>.

Detection probes are mounted at selected locations at the inlet and outlet of the processing vessel and are shielded by lead collimators to protect them from the natural background and other parasite radiation may come from around. If needed, detectors are protected from heat (for temperature higher than 60-70°C) by placing aluminum plate between the detector and reactor walls.

The data acquisition system, which collects signals from the radiation detectors, is the basic equipment for online radiotracer leak inspection (Fig. 19). The data acquisition system ensures collection, treatment and visualization of the data. Dead time between two measurements is normally less than 1  $\mu\text{s}$ . The visualization of data is as close as possible to "real time" experiment. The measurements are simultaneous and the minimal dwelling time is 1-2 ms. Standard portable data acquisition systems for industrial radiotracer work are PC based data logger with unlimited possibility in the number of connected probes. There are several prototypes of data acquisition system (commercial or homemade). Fig. 19 shows some of them:



FIG. 19. Data acquisition systems for online radiotracer tests

### 2.2.6. Units of radiation activity and dose

Curie (Ci) is old long-used unit of radioactivity. It has been replaced with the SI unit, the Becquerel (1 Bq = 1 disintegration per second):

$$1 \text{ Ci} = 3,7 \cdot 10^{10} \text{ Bq}$$

The Curie is a large amount of radioactivity while the Becquerel is a very small amount. For convenience, milli- (1 thousandth) and micro- (1 millionth) Curies or Mega- (million) and Giga (billion) Becquerel's are used in everyday practice.

Dose is a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent or total effective dose equivalent. Each of these is defined below:

*Absorbed dose:* It is the energy imparted by ionizing radiation per unit mass of irradiated material, and its measurement unit is the Gray (Gy). Gray is defined as a unit of energy absorbed from ionizing radiation, equal to 10 000 ergs per gram or 1 joule per kilogram of irradiated material. The unit Gray can be used for any type of radiation; it does not describe the biological effects of the different radiations. The old unit of absorbed dose is "rad". New and old units are relation is: 1 Gray (Gy) = 100 rads.

*Equivalent dose:* This relates the absorbed dose in human tissue to the effective biological damage of the radiation. It is a multiplication of (absorbed dose) x (quality factor) x (other necessary modifying factors of interest). The Sievert (Sv) is a unit used to derive the "equivalent dose". Normally, the equivalent dose is expressed in milliSieverts (mSv).

Not all radiations have the same biological effect, even for the same amount of absorbed dose. Equivalent dose is calculated by multiplying absorbed dose (Gy) by a quality factor (QF) that is unique to the type of incident radiation. Quality factors (QF) for some radiations are:

- Gamma and X rays: 1
- Beta particles: 1
- Alpha particles: 20
- Thermal neutrons (lower energy): 2
- Fast neutrons (higher energy): 10
- Protons: 10
- Heavy ions: 20

*Roentgen (R)*: The roentgen is an old unit used to measure a quantity called "exposure." This unit is used only for gamma and X rays < of energy less than 3.5 MeV and only applies in air. One roentgen is equivalent to depositing  $2.58 \times 10^{-4}$  coulombs per kg of dry air. It is a measure of the ionizations of the molecules in a mass of air. The main advantage of the Roentgen is that it is easily measured directly.

There is an empirical relation between the radiation dose rate in air (exposure in R/h) and the activity A (Ci) of a point source of gamma rays in a distance R (m):

$$P = \Gamma \cdot A/R^2$$

where: dose rate factor  $\Gamma$  is an empirical factor for the specific radioisotope that includes absorption, geometry, photon per disintegration, energy, and all other factors that affect the dose rate from the radioisotope at unit distance. The inverse-square law of gamma absorption in air is assumed as long as the source can be considered a point source. The absorption of gamma rays in air is also assumed to be negligible. This empirical relation is used in field radiotracer work as a simple approach for rough calibration of radiation detectors.

Dose rate factors are given in R/h for 1 Ci at 1 m.  $\Gamma$  factors are usually tabulated for activity of 1 Ci and distance of 1 m. For example,  $^{60}\text{Co}$  has the dose rate factor of 1.35,  $^{137}\text{Cs}$  of 0.30, and  $^{198}\text{Au}$  of 0.23.

### 2.2.7. Radiation safety considerations

Radiotracers emit ionizing radiations, which are potentially hazardous to health and therefore radiation protection measures are necessary throughout all stages of operations. Prescribed safety and legal regulations have to be followed during a radiotracer experiment. After estimating the amount of activity for a particular radiotracer investigation, it is required to take clearance from competent authorities. The legal procedure and maximum amount of radioactivity to be allowed for a tracer experiment depends upon country to country.

Basically the safety regulations include justification of the use of radiotracer, optimisation of radiation exposures and annual dose limits in order to prevent unnecessary exposures. By justification means that the competent authority should not allow the use of radiation unless there arises a net positive benefit from its use.

For exposures from any source, except for therapeutic medical exposure, the doses, the number of people exposed and the likelihood of incurring exposures shall all be kept As Low As Reasonably Achievable (ALARA principle). The design of a radiotracer experiment has to ensure optimization of radiation exposures. It should be emphasized that the most important aspect of dose limitation, assuming that the practice is justified, is to keep radiation doses As Low As Reasonably Achievable.

The principles of dose limitation are briefly summarized below:

- no application of radiation should be undertaken unless justified,
- all doses should be kept “as low as reasonably achievable (ALARA principle)”, economic and social factors being taken into account,
- in any case, all individual doses must be kept below dose limits.

The optimization of radiation exposures primarily depends upon distance, time and shielding. The dose rate at a point is inversely proportional to the square of the distance between the source and the point. Therefore a radiation worker has to maintain maximum possible distance from a radiation source. The dose received is directly proportional to the time spent in handling the source. Thus the time of handling should be as short as possible. The radiation intensity at a point varies exponentially with the thickness of shielding material. Thus a radiation worker has to use an optimum thickness of shielding material against the radiating source.

The most elementary means of protection is known as "TDS" or "Time, Distance and Shielding."

- Decreasing the time spent around a radiation source decreases the exposure
- Increasing the distance from a source decreases the exposure
- Increasing the thickness of shielding to absorb or reflect the radiation decreases the exposure

Figure 20 shows different types of radiation and their penetration in the matter. For gamma rays mostly employed in on-line radiotracer tests the most commonly used material for shielding is lead.

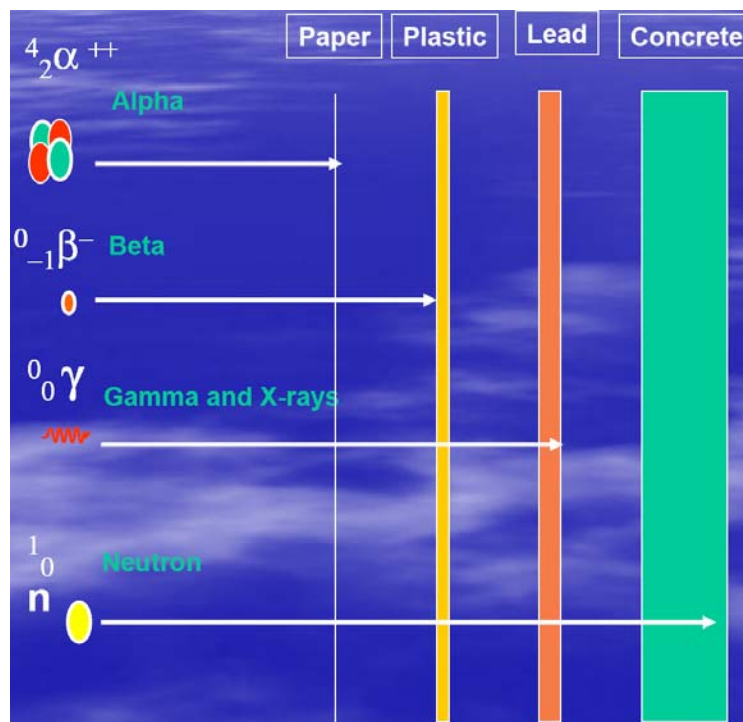


FIG. 20. Shielding for various type of radiation



### 2.3. RADIOTRACER TECHNIQUES FOR LEAK DETECTION IN PROCESSING VESSELS

Radiotracer techniques for leak detection in processing vessels could be on-line (during vessel operation) and off-line (during shutdown maintenance); principles of the techniques are the same (detection mode is different) and the sensibility almost the same. We have already highlighted that the main advantage of radiotracer techniques is their utilization on-line; this aspect makes the radiotracers very competitive and method of choice for leak detection in processing vessels; otherwise for off-line leak detection the competitiveness of all conventional or radiotracer techniques is open and should be decided case by case.

There are three basic techniques for on-line leak detection using radioisotope tracers:

- by measurement of flow rate
- by residence time distribution (RTD) measurement
- by 'direct' tracer technique.

#### 2.3.1. Radiotracer leak detection by flow rate measurement

The simplest and most straightforward technique for leak detection uses the pulse velocity technique to measure the leakage flow rate directly. The experimental set up is shown in fig 21. The leakage itself can be detected using only first detector. The second detector is added to measure the flow rate of the leak. The most common applications of this method are:

- measurement of leakage through relief valves to flare systems
- measurement of leakage penetrating isolation valves.

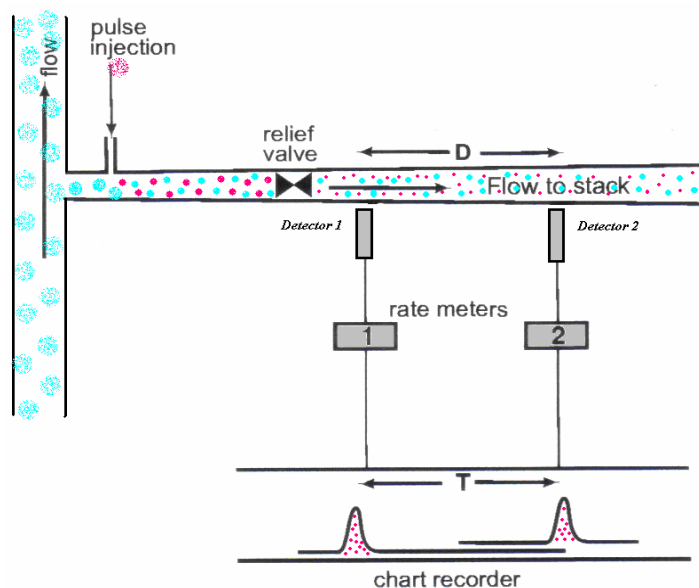


FIG. 21. Leak detection using the pulse-velocity technique

A sharp pulse of radioactive fluid is injected into the process stream, upstream of the relief valve, and two detectors, appropriately placed on the line to the flare stack, downstream of the valve, measure the velocity of the leakage flow. This linear velocity can be converted to volume flow rate knowing the mean diameter of the section of pipe between the two detectors. The volume flow rate of the leakage,  $Q$  [ $\text{m}^3\text{h}^{-1}$ ], is given by:

$$Q = \pi \cdot d^2 / 4 \times D / t$$

where:

- d is the diameter of the pipe in m,
- D is the length between two detectors in m,
- t is the time interval between two detection peaks in seconds.

In fact, detector 1 detects the leak through the valve, and in combination with detector 2 (placed few meters away) provides the leak flow rate as well.

### 2.3.2. Radiotracer leak detection by residence time distribution (RTD) measurement

Another radiotracer technique for leak detection is the residence time distribution (RTD). When the tracer pulse entering the vessel is of very short duration (few seconds) the response curve from the exit detector is known as the residence time distribution (RTD) curve. Such curve can be analyzed in detail because contains rich information about potential leaks as well. This technique involves the examination of the experimental RTD curve for a subsidiary early peak. The experimental set up is shown in figure 22.

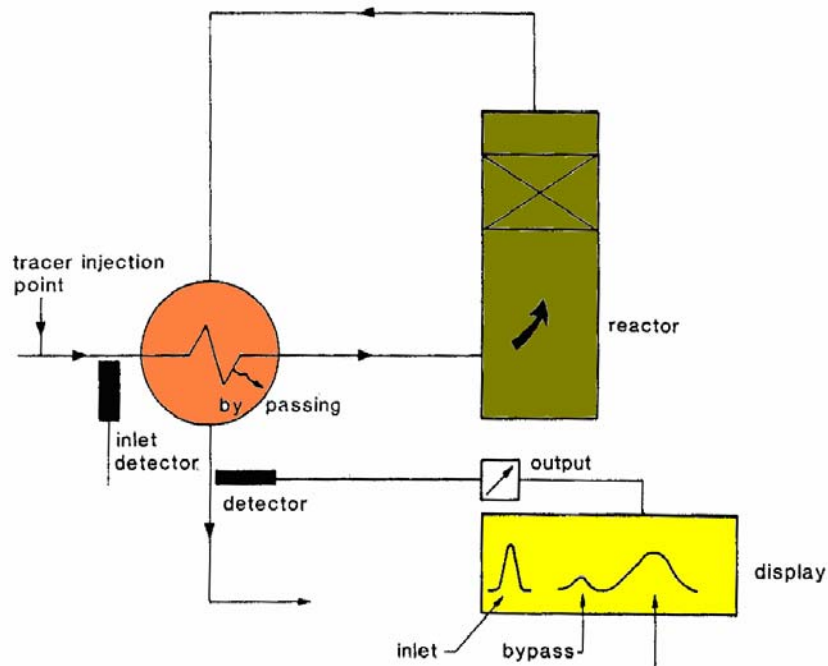


FIG. 22. Experimental method for leakage detection using RTD technique.

A sharp pulse of a suitable radioactive tracer is injected into the process stream and its movement is monitored through the vessel by externally-mounted radiation detectors. The first probe shows the activity of the radiotracer entering the vessel and the second detector records the activity leaving the vessel. The response from the second detector is the residence time distribution (RTD) curve from which the mean residence time would be calculated.

Any leakage throughout the central baffle could be indicated by a subsidiary peak (so called bypass peak) preceding the main peak. The main peak represents the flow pattern of the fluid flowing from inlet to outlet in normal way (going through all the system), while the subsidiary peak represents the leak because it goes in abnormal way bypassing the normal flow and consequently making short way appearing in front of detector before the main peak.

The outlet detector monitors the total activity injected, and then the leakage rate, expressed as a percentage of the total flow rate, is the area of the leakage peak expressed as a percentage of the sum of the areas of the subsidiary and main peaks.

### 2.3.3. Leak detection by "direct" tracer technique

This technique is probably the most common and involves the injection of a suitable radiotracer into the process stream, which is suspected of leaking, and seeking the presence of that tracer in the outlet. This can be done either by sampling the product outlet line and assaying for radiotracer content, or by using sensitive radiation detector ("leak detector") mounted externally on the outlet pipe. The system shown in figure 23 is used in this case.

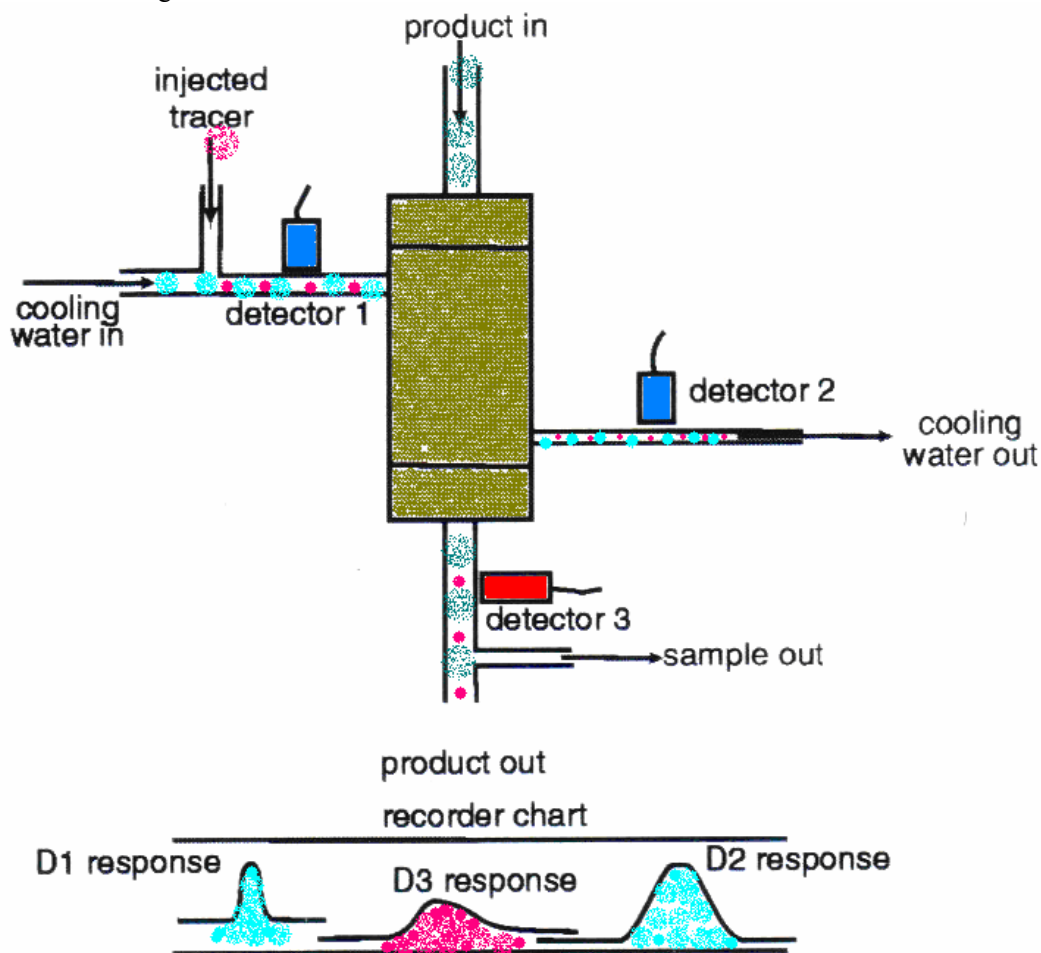


FIG. 23. Leakage detection using "direct" tracer techniques

The direct tracer technique is largely used in leak detection in heat exchangers. Minimum of three detection probes is necessary to apply this technique. Normally, next to "leak detector"  $D_3$  another total shielded detector ("brick detector") is installed to differentiate between false and true leaks. Lack of using brick detector and proper collimation of leak detector, a careful time and amplitude analysis of all tracer experimental response curves is necessary to identify the real peak coming from the real leak from other false peaks coming from surrenders (radiotracer moving inside apparatus around).



## 2.4. EXAMPLES OF RADIOTRACER TECHNIQUES FOR LEAK DETECTION IN PROCESSING VESSELS

### 2.4.1. Leak detection in bank of heat exchangers

This is an example of the direct tracer technique. A suitable radioisotope tracer is injected into the high-pressure inlet line to a bank of heat exchangers (Fig. 24). Radiation detectors installed on the low-pressure exit lines of each exchanger in the bank can identify the individual exchanger that is leaking.

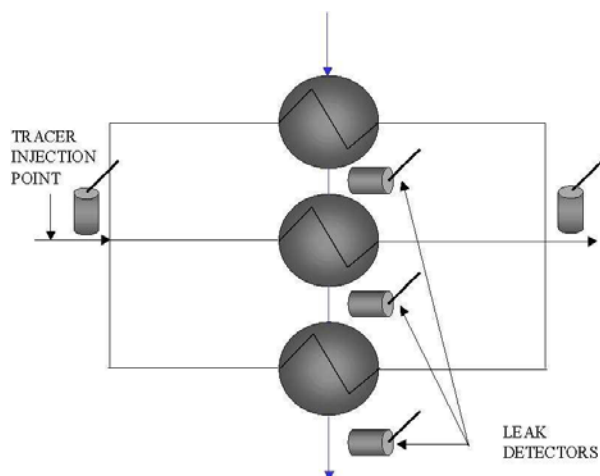


FIG. 24. Radiotracer technique for leak detection in a line of bank heat exchangers

This is a very useful tool for shutdown planning purposes, so that the repairs can immediately be focused on the exchanger that is leaking, rather than wasting valuable time and money testing each exchanger in turn during the shutdown.

### 2.4.2. Leak detection in a feed-effluent exchanger/reactor system

This is an example of the radiotracer technique for leak detection by residence time distribution (RTD) measurement (Fig. 25).

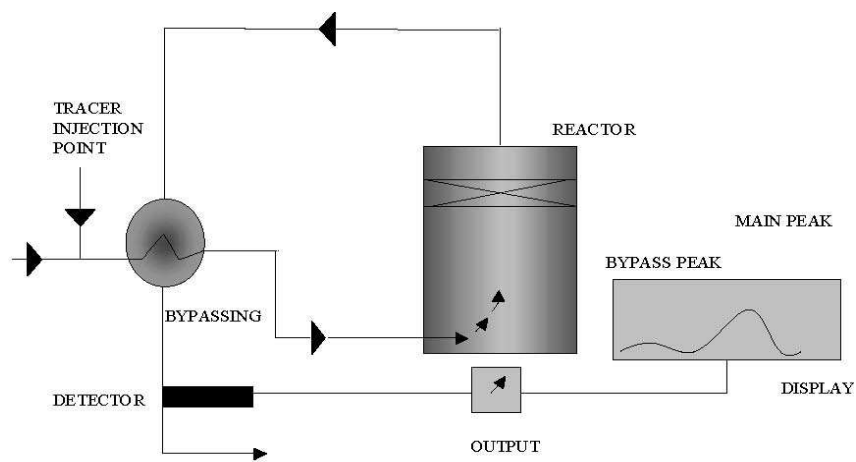


FIG. 25. Leak detection in a feed-effluent exchanger/reactor system

The radiotracer injection is performed to confirm the presence of a leak in a feed-effluent exchanger/reactor system when it is unclear if observed inefficiency is due to poor catalyst performance, or the fact that an exchanger is leaking, causing a proportion of the process to bypass the reactor. Detector installed at the output of the reactor and any initial leak through the exchanger will be observed as a small bypass peak before the main peak exit the reactor is observed.

#### 2.4.4. Leak inspection in passing valves

If it is suspected that valves are passing on a relief valve system, a suitable radiotracer can be injected upstream of the valves, and radiation detectors placed downstream of each valve under investigation will check for leaks (Fig. 26). If any of the valves are leaking, the radiotracer will follow the leak and be detected by the relevant detector. This is a combination of direct radiotracer and flow rate measurement techniques.

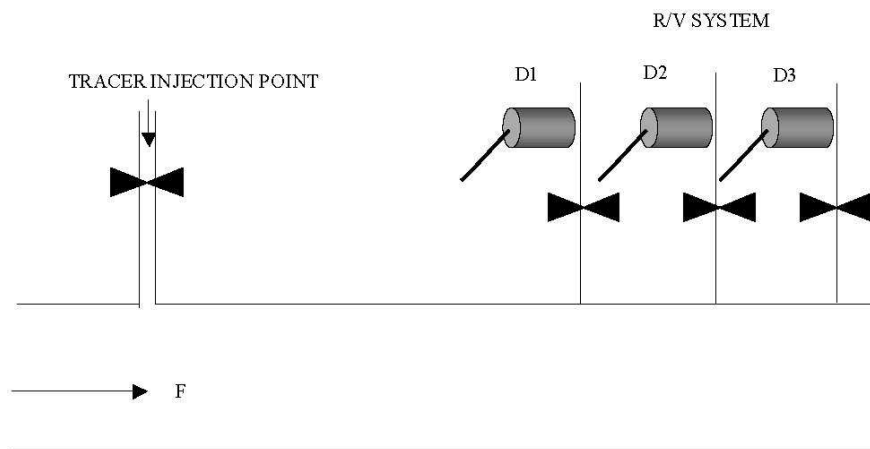


FIG. 26. Leak detection in passing valves

#### 2.4.5. Leak detection in a heat exchanger in a refinery

Direct radiotracer technique is probably the most common technique for online leak inspection in processing vessels and heat exchangers in petrochemical and chemical industries. Fig. 27 shows the experimental setup of a radiotracer test for leak inspection of a heat exchanger in a refinery.

Three characteristic detectors employed in the direct tracer technique were:

- D1 (injection detector) at the inlet of the tube feed,
- D2 at the outlet of the tube side,
- D3 (leak detector) at the outlet of the shell side.

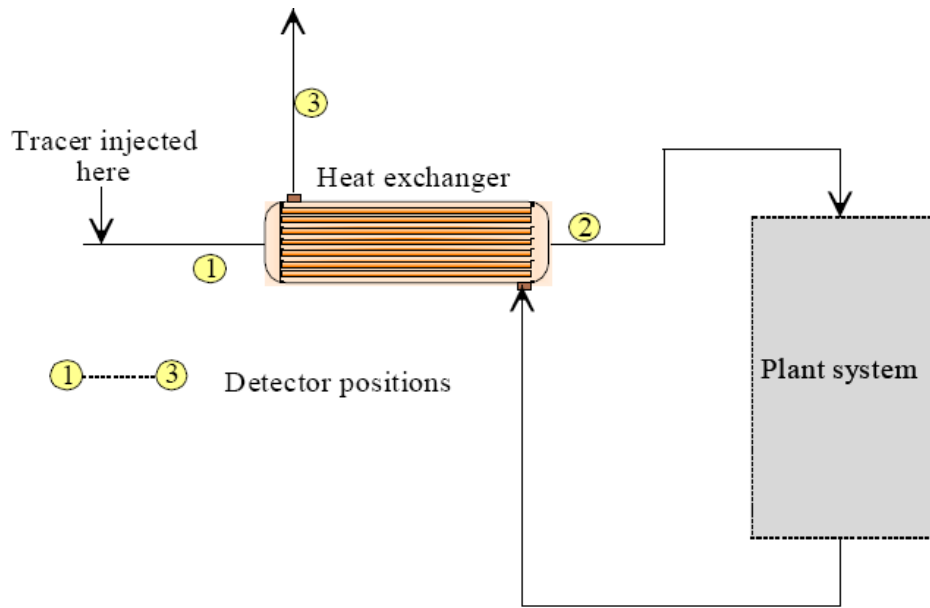


FIG. 27. Experimental setup for radiotracer leak inspection in a heat exchanger in a refinery

The experimental response curves recorded by three radiation detectors are presented in the fig. 28 (D1-brown, D2- blue and D3-red).

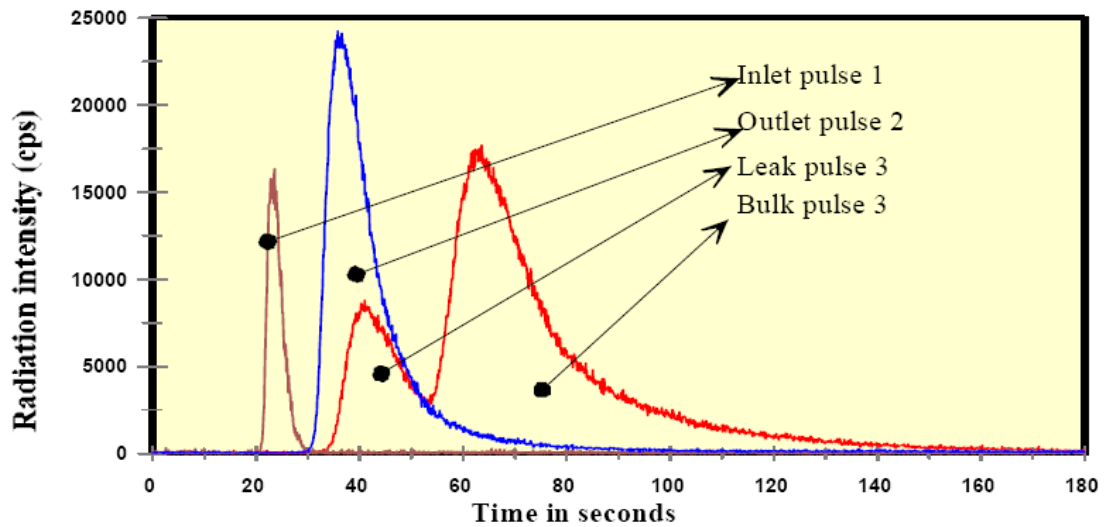


FIG. 28. Experimental response curves recorded by three radiation detectors

The experimental response curve of D3 clearly indicates the existence of an important leak peak from the tube to shell side. The first peak of red curve attributed to the leak has a relative area of nearly 25% that means that the estimation of the leak rate is nearly 25% of the inlet flow, quite a big leak.

The radiotracer test was repeated three times for reliability of results. Fig. 29 shows the results of the three runs. As can be seen the repeatability is excellent.

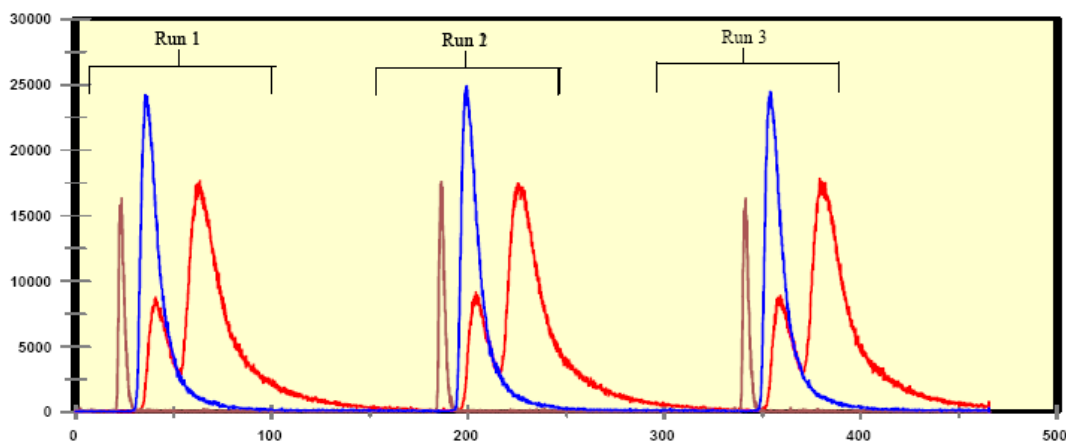


FIG. 29. Three runs of radiotracer test for leak inspection

*Note: The experimental response curves are measured with three different radiation detection probes (NaI), this is the reason of apparent confusion in their amplitudes. Normally, the injection detectors gives the highest peak as tracer is more concentrate in short interval injection. But, as the figure 29 shows, this is not granted, and the case above confirmed that the peak amplitudes can be without any logic order; they follow experimental orders, that means the geometrical efficiency of injection detector (and its size) was apparently smaller than those of detectors 2 and 3.*

## 2.5. HEAT EXCHANGER LEAK TESTING WITHOUT TRACERS

A customer has requested to perform a leak test on six intercooler exchangers because one or more of them were suspected of leaking cracked process gas into the cooling water. When asked to perform a leak test of exchangers, the common sense almost invariably is to use a radiotracer technique. In planning the use of a radiotracer, consideration must be given to its acquisition and transportation, and obtaining permission from regulatory authorities. This can lead to significant delays, resulting in operational and financial burdens on the customer, particularly if the facility is located in a remote area. Although the use of radioactive tracers for carrying out leak tests on heat exchangers is a valuable, well used and successful technique there are times when equally valuable results can be obtained using a sealed source technique. A situation where this applies is when a significant density change occurs because of the leak.

The system shown schematically in figure 30 was one of six intercoolers in a cracked process gas compressor train. The process gas pressure was higher than the closed circuit cooling water. In the cooling water circuit there was a buffer drum at the suction of the recirculation pumps. The drum had a nitrogen blanket and was fitted with a relief valve. The relief valve was found to be opening to atmosphere. Analysis of this vented gas showed it to contain cracked gas. To minimize maintenance effort and shutdown time, the customer needed to know which of the six intercoolers was leaking.

The traditional way to carry out a leakage test on this type of system would be to inject gaseous radiotracer into the high pressure process gas side and to deploy sensitive radiation detectors at strategic positions on the low pressure cooling water side. Since this plant was in a remote area this would have involved the importation of the radiotracer into the country following the slow process of obtaining the necessary legislative approval to carry out an unsealed radioactive tracer study. The customer needed to know quickly which of their exchangers was leaking.

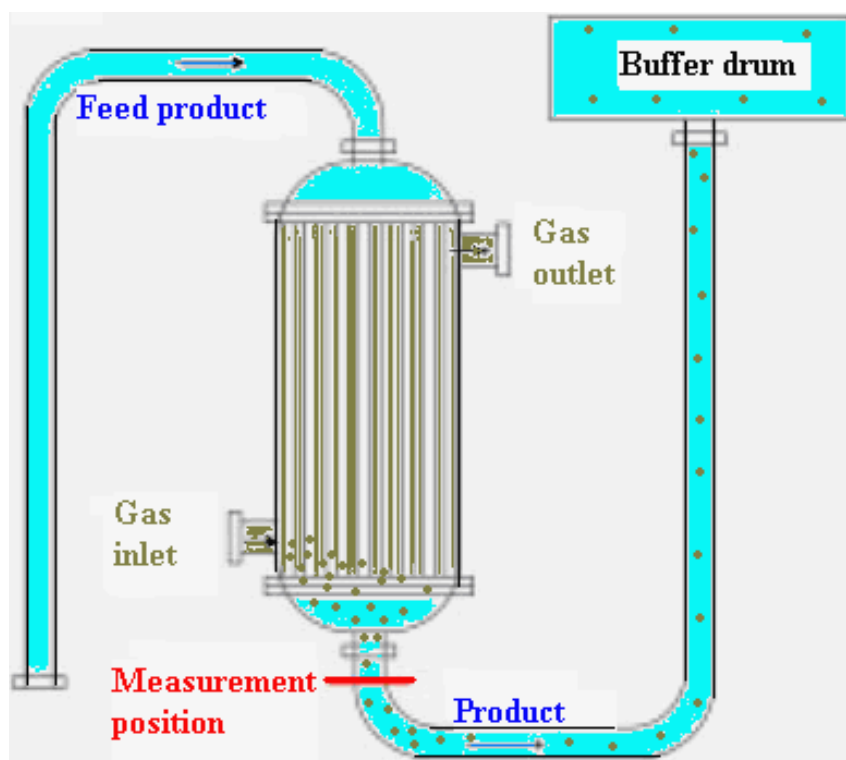


FIG. 30. A schematic illustrating one of six intercoolers in a cracked process gas compressor train

The innovative solution was to use the hypothesis that if cracked process gas was leaking into cooling water, then it would have the effect of reducing the density of the water immediately downstream of the leaking intercooler. If the density in the cooling water line from each exchanger could be measured non-intrusively then the leaking exchanger could be identified. Gamma transmission technique was used to measure the density of the material in the cooling water exit line of each intercooler and determine which one was leaking. Measurement of radiation intensity passing through the cooling water inlet and exit pipes was measured at the indicated location for each exchanger (red line in Fig. 30). After careful calibration in laboratory with the same pipe and detector for various gas cooling in water, the registration of detectors were converted to the amount of aeration in the cooling water exit lines. The percentage of gas for the six exchangers is shown below:

Exchanger	% Gas in cooling water exit line	Conclusion
A	0	Not Leaking
B	9.6	Leaking
C	0	Not Leaking
D	0	Not Leaking
E	0	Not Leaking
F	4.6	Leaking

The sensitivity of this type of test depends upon a number of factors such as the total amount of transmitted radiation and the path length through which the radiation beam passes. It was calculated that in ideal situations this technique was capable of detecting changes in the density of the water caused by a leak as low as 0.5% of the gas in liquid. In this case, the variations within the pipes, such as welds, etc., reduced the sensitivity to a leak rate limit of detection of 2.8% of the gas in liquid.

### *Conclusion*

The test showed that exchangers B and F were leaking. This work was carried out in a matter of a few days, instead of the weeks of planning and preparation that would have been required for a traditional radiotracer leak test in this particular country, significantly reducing the customer's operational and financial burden.

## **2.6. CASE STUDIES: RADIOTRACER TECHNIQUES FOR LEAK DETECTIONS IN PROCESSING VESSELS**

As mentioned above the heat exchangers are the most important hermetically closed processing vessels in petrochemical and chemical plants. Leak inspection in heat exchangers is crucial for the performance of processing lines and the quality of final products. Thus most of case studies described in this chapter are dealing with applications of radiotracers for leak inspection in heat exchangers.

### **2.6.1. Leak detection in heat exchanger at an oil refinery**

#### ***1. Problem description***

The unit under investigation is shell and tube type heat exchanger. It is a vertical heat exchanger with 25 m height, 1.194 m internal diameter and 48 mm wall thickness. It is a single pass heat exchanger with a fluid capacity of 25.5 m<sup>3</sup> (shell = 19.5 m<sup>3</sup>, tube = 6 m<sup>3</sup>). The crude oil is pre-heated using the high temperature refined product. The refined product, at a temperature of 470°C, enters the top of heat exchanger, flows through shell-side and leaves the heat exchanger bottom at a temperature of 115°C. The crude oil, at a temperature of 68 °C, enters the bottom of heat exchanger, flows through tube side and leaves the heat exchanger top at a temperature of 420 °C. The quality control department found contamination in refined product, which led to suspicion of leakage in heat exchanger. As there was a difference of opinion between plant engineers and quality control department, the plant engineers decided to get "Radiotracer leak test" done before taking any further action.

#### ***2. Radiotracer test***

The tracer group conducted radiotracer test using <sup>82</sup>Br in the form of di-bromo-benzene. Although, di-bromo-benzene is not an ideal tracer in given temperature conditions, it had to be used because there was no other most suitable tracer available.

A brief feasibility of experimental set up was carried out and necessary arrangements were made in cooperation with plant engineers before test conduction. Radiotracer injection was made through a by-pass arrangement. Radiotracer Br-82 in the form of di-bromo-benzene with an activity of 130 mCi was injected at 14: 32 hours. Following monitoring stations were set up to record the passage of radiotracer in the exchanger loop.

The relative positions of various detectors are shown in figure 31.

- Detector-1: At the tube inlet, just before the tube inlet pipe enters the exchanger
- Detector-2: At the tube outlet, away from the exchanger
- Detector-3: At the shell inlet, away from the exchanger
- Detector-4 (leak detector): At the shell outlet, just after the shell outlet pipe goes away from the exchanger
- Detector-5: At the shell top, against the shell wall at the level of tube bundle (for leak double check and comparison with D4).

All the ratemeters and computer were time synchronized. Data recording was started at 14:23 hours (just few minutes before the injection of the radiotracer in order to register the background and monitor the injection procedure). The detector 4 mounted at shell outlet to monitor leakage (if any) was connected to computer for data acquisition. The data from other detectors was recorded manually.

The data of detector 4 was also recorded manually to avoid data loss in case of any problem with the computer. Data of detector 4 was recorded every 5 seconds while for other detectors; data was recorded for every 10 seconds.

### *Tracer injection*

Valves V-1 and V-3 of the injection port (see figure 30) were closed. The flange at the top of valve V-2 was removed and the valve V-2 was opened. The oil level in the horizontal pipe between valve V-1 and V-3 was maintained such that  $\frac{3}{4}$  of pipe diameter was filled with oil. Specially designed device to crush the silica glass ampoule was inserted vertically in the pipe through valve V-2.

Two glass ampoules containing radiotracer Br-82 (in the form of di-bromo-benzene powder) were inserted in the crushing device. Ampoules were crushed and tracer was mixed in oil in the pipe. The ampoule-crushing device was rinsed (inside the pipe) with inactive oil before it was taken out and stored safely. The valve V-2 was closed and valves V-3 and V-1 were opened. The radiotracer was injected into the system by starting the pump.

The injection was made at 14:32 hours in the tube inlet pipe through injection port as described above. The data was recorded from 14:23 to 16:00 hours (i.e. for 1 hour & 37 minutes). Data was analyzed and plotted as shown in figures 32 and 33.

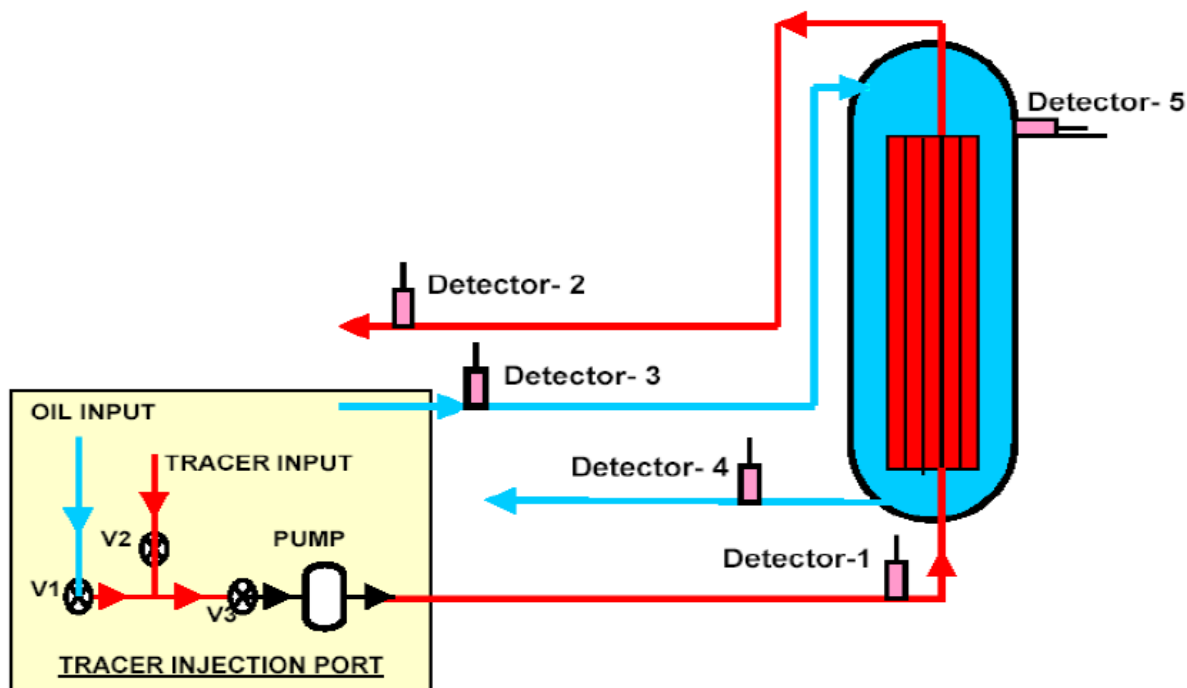


FIG. 31. Schematics of experimental set-up showing tracer injection port and position of various detectors

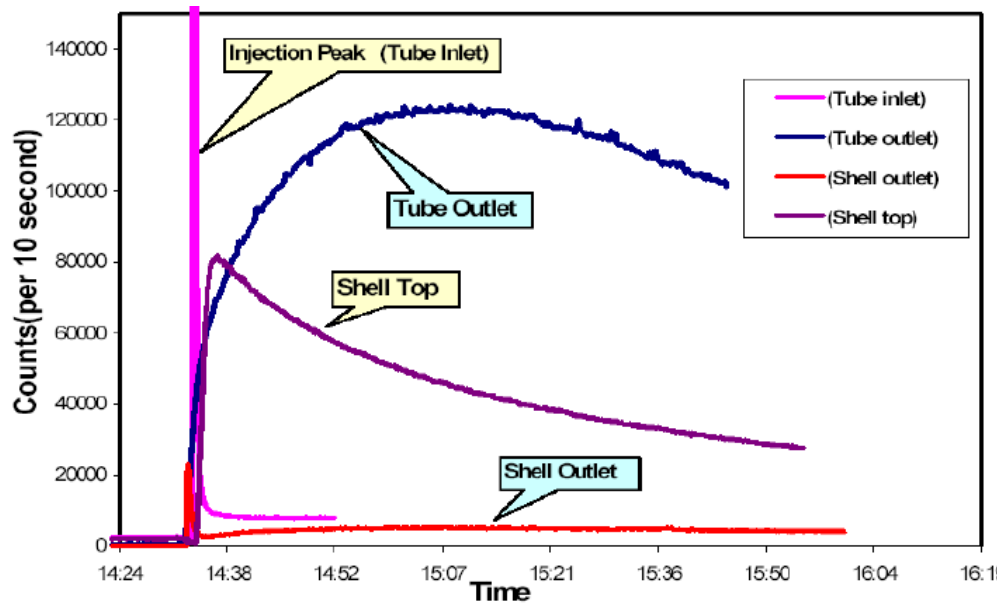


FIG. 32. Response of detectors 1, 2, 4 and 5 with 10 second counting time

### 3. Discussion of results

The data obtained from detector 1,2,4 & 5 is plotted in figure 32. The experimental curve obtained by detectors 2 (at the tube outlet) represents the residence time distribution (RTD) of the fluid in the tube system inside the shell; more or less the same shows the detector D5 at the shell top side that means the radiotracer leaving the tub in normal way. Both curves registered by D2 and D5 detectors do not indicate any thing about the existence or not of leaks. The records of detector 1, monitoring the injection of tracer into the tub inlet, and detector 4 (monitoring leakage, if any, in shell outlet) have to be analyzed carefully (Fig. 33).

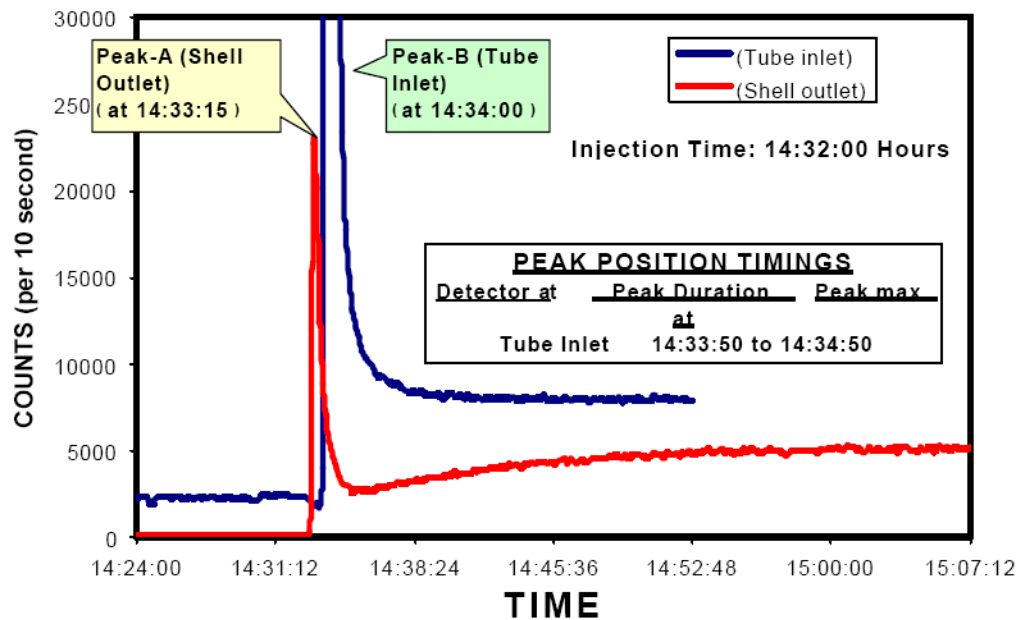


FIG. 33. Responses of detector-1 (Injection) and detector-4 (Leak detector)



Tracer injection was made away from detector 1 at 14:32 hours (almost as very sharp Dirac pulse). The tracer plume of injection reached detector 1 at 14:33:50 hours and the tracer plume passed detector 1 at 14:34:50 with duration of 60 seconds. The maximum of injection peak was recorded at 14:34:00 hours (see peak-B, figure 33). A peak was also recorded by detector 4 placed at shell outlet. The tracer peak arrived at detector 4 at 14:33:05 hours and passed away at 14:34:05 hours with 60-second duration. The maxima of the peak was recorded at 14:33:15 hours (see peak-A, figure 33).

The detector 1 and detector 4 recorded the peak for the same duration i.e., for 60 seconds and the peak maxima reached within 10 seconds of the arrival of tracer peaks on both detectors. However, detector 4 recorded the tracer peak 45 seconds earlier than detector 1. That means detector 4 recorded tracer peak before the tracer entered the exchanger. This indicates that the peak recorded by detector 4 at 14:33:05 hours was not related to any leakage in the exchanger but this peak is due the fact that detector 4 has seen activity of injection plume while tracer passed through the tube inlet pipe in the near vicinity. This is a typical false peak that could have been avoided with a heavier shielding of the detection probe D4. Using high gamma energy Br-82 as radiotracer the lead collimator should have a thickness of more than 5 cm around the detector, while using low gamma energy I-131 collimator walls around the detector have to be around 2-3 cm thick.

### *Result*

The radiotracer test reveals that there is no leakage in the exchanger.

## **2.6.2. Radiotracer leak test of a heat exchanger tower**

### **1. Problem**

The heat exchanger of Texas tower (Fig. 34), a tube and shell heat exchanger, was suspected for leaks from tube side into shell side as indicated by contaminants found from laboratory analysis. To identify the problem, radiotracer technique has been applied by injecting a gamma radiotracer into the tube side inlet and monitoring gamma radiation at the tube and shell outlets.

### **2. Radiotracer test**

The experimental setup is shown in figure 37; four collimated detectors were installed at inlets and outlets of tube and shell sides. Radiotracer dibromobenzene labeled with Br-82 (half-life 36 hours) in liquid form was injected into the process line through tube inlet. Detectors were located as follows:

- Detector 1 about 5 meter before the injection point (before entry of naphtha feed line)
- Detector 2 at tube inlet (naphtha inlet line, tube side)
- Detector 3 at tube outlet (naphtha outlet line, tube side)
- Detector 4 (leak detector) at shell outlet (reformate outlet line, shell side).

Detectors were connected to data acquisition system at 0.05 s measuring interval. The activity of injected radiotracer was approximately 15 mCi Br-82 at 15 bars into the process stream of 8 bars. Transmitted gamma ray intensities at each position was recorded and processed by Excel as gamma intensity vs. time graph for evaluation/interpretation.

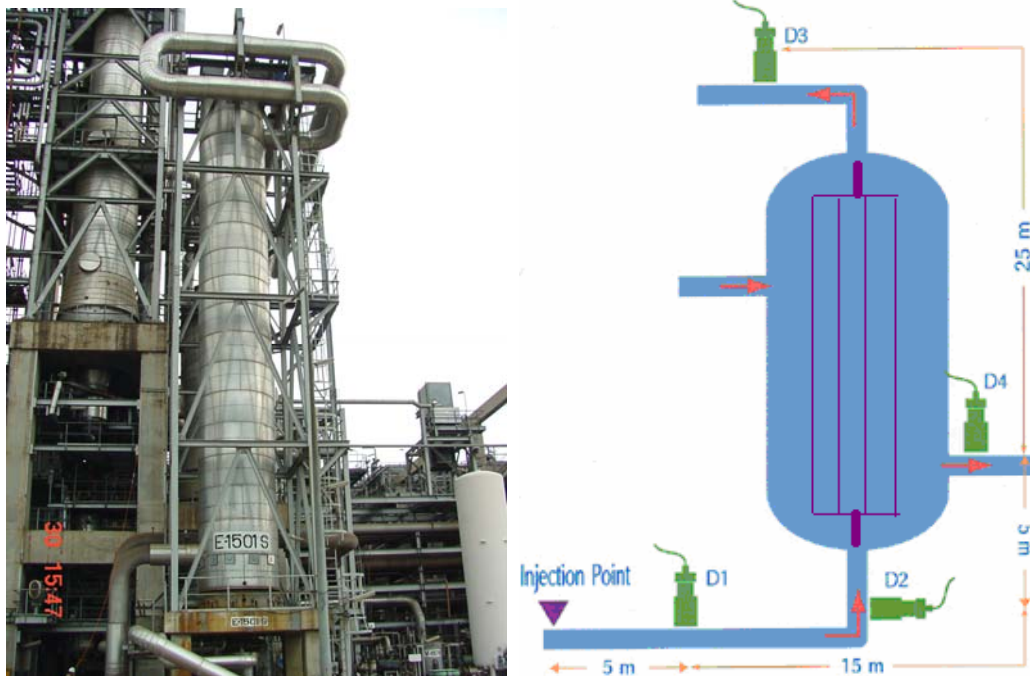


FIG. 34. Texas Tower tested for leaks and experimental setup

Figures 35-37 show the different aspects of the experimental work.



FIG. 35. D1 (left) at injection point and D2 (right) at naphtha inlet of tube side



*FIG. 36. D3(left) at tube outlet and D4 (right) at shell outlet*



*FIG. 37. Injection facility(left) and data acquisition system (right)*

### **3. Results**

Figures 38 and 39 shows the experimental curves obtained for four detectors during the radiotracer test. The records obtained from “leak detector” D4 are zoomed for better interpretation of the data.

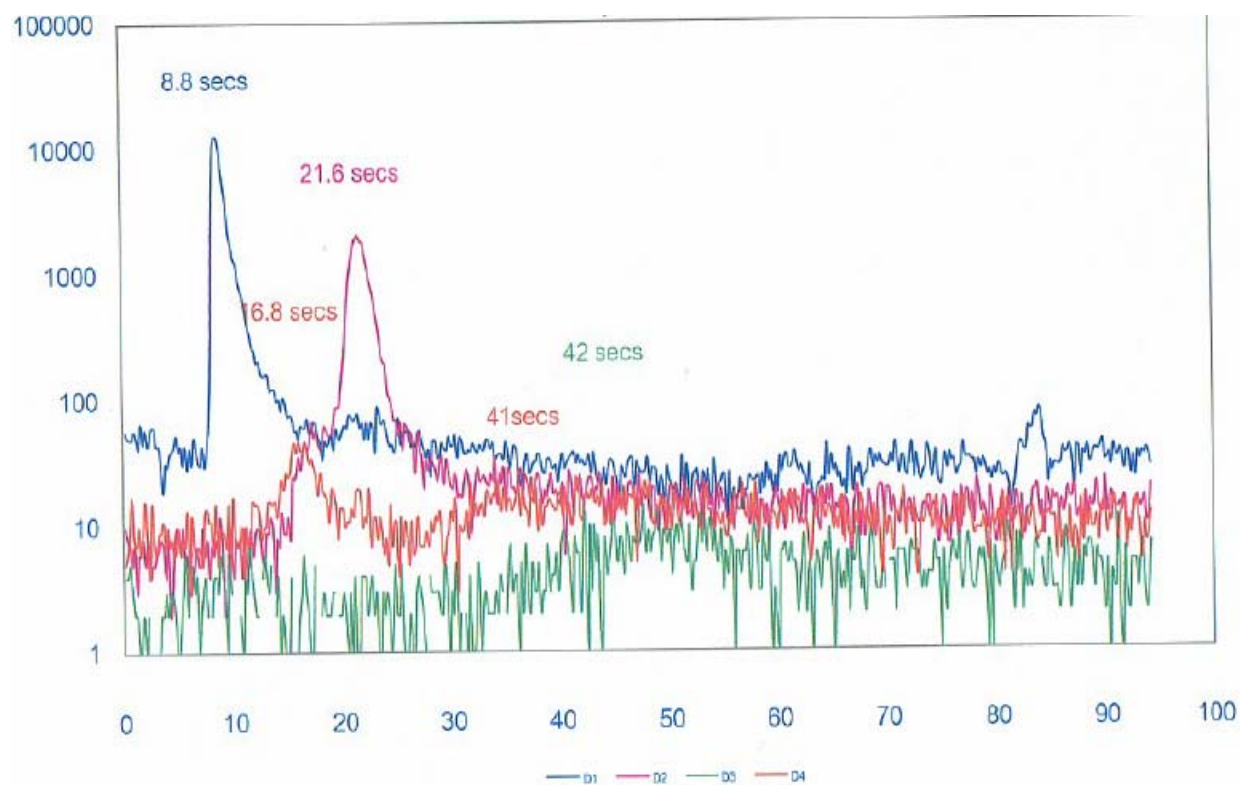


FIG. 38. Radioactive detection curves

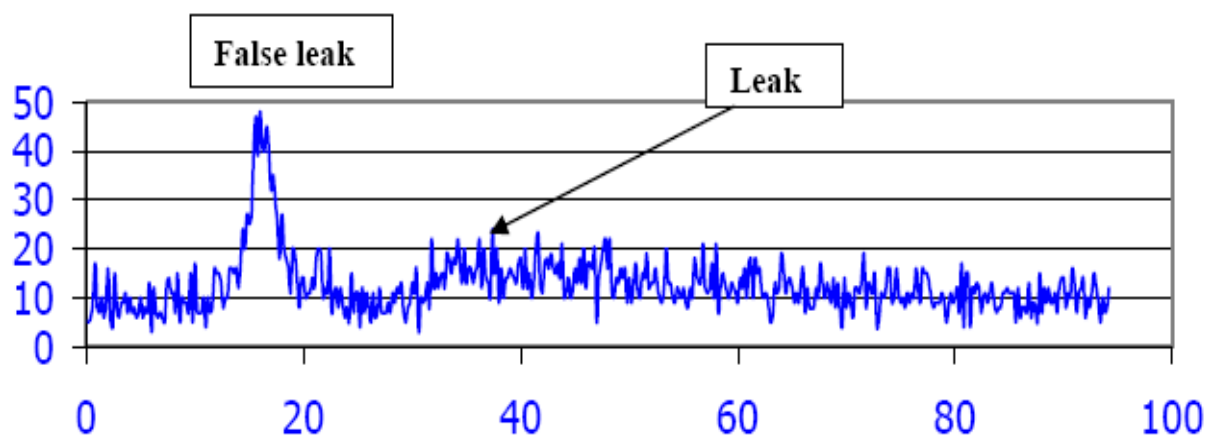


FIG. 39. Experimental curve of "leak detector" D4 zoomed; the first peak indicates false leak, while the second small peak indicates the leak.

Table III presents the results of the radiotracer test.

TABLE III. ARRIVAL TIMES AFTER INJECTION (SECONDS):

Detector	Peak interval (s)	Peak center (s)	Peak area (counts)
D1	7- 17	8.8	
D2	17-27	21.6	26000
D3	40-60	47	
D4 (leak detector): two peaks	11- 25 & 30-50	16.8 & 41	1300 (for second peak)

#### 4. Comment

Experimental curve obtained by D4 (leak detector) shows two peaks (Fig. 39); the first (higher) peak at 16.8 s and the second (smaller) peak at 41 s after injection, respectively. The first peak at 16.8 s after injection at the shell outlet is from pickup of the injection of radiotracer in the tube side, because it arrives before the radiotracer enters the tube side (D2 peak at tube inlet is recorded at 21.6 s). Thus, the first peak is interference from radiotracer injection because apparently the detector was not well and enough shielded. The second peak represents the leak.

The ratio of peak areas D4/D2, after correction for the background) gives the approximate size of the leak e.g. 5% of the inlet fluid is leaking:

$$\text{Ratio of sum peaks D4/D2} = 1300/26000 = 5 \%$$

To confirm the result of online radiotracer test, reformate samples (Fig. 40) were taken from the line to analyze their radioactivity in the laboratory. Trace of Br-82 was detected that confirmed the online radiotracer test conclusion.



FIG. 40. Reformate samples for Lab test found contamination



The radiotracer test finding was confirmed later also by visual inspection after heat exchanger shut down, where the leak point was small but quite visible (Fig. 41).



*FIG. 41. Visual inspection after shut-down shows leak point*

### **2.6.3. Radiotracer leak test on a heat exchanger at an ammonia plant**

#### ***1. Problem***

Plant engineers suspected a leak on a heat exchanger serving a converter at an ammonia plant (Fig. 42) because the pressure drop across the line was decreased significantly since start-up after a maintenance shutdown. Radiotracer leak test was carried out in the heat exchanger to identify the leak problem.



*FIG. 42. Ammonia plant where radiotracer leak test was conducted and the radiotracer gas Ar-41 injection.*

#### ***2. Radiotracer test***

100 mCi  $^{41}\text{Ar}$  radiotracer gas was injected as a pulse into the feed line to the heat exchanger. Progress of the radiotracer was followed by means of NaI (Tl) scintillation detectors placed at appropriate positions. Figure 43 shows radiotracer injection and detection positions. Four radiation detectors were placed as follows:

- Detector-1: At the tube inlet, just before the tube inlet pipe enters the exchanger
- Detector-2: At the shell inlet from converter
- Detector-3 (leak detector): At the shell outlet, just after the shell outlet pipe goes away from the exchanger
- Detector-4: At the tube outlet, away from the exchanger (indication of this detector is not significant for leak detection, so the corresponding experimental curve is not presented in fig.44).

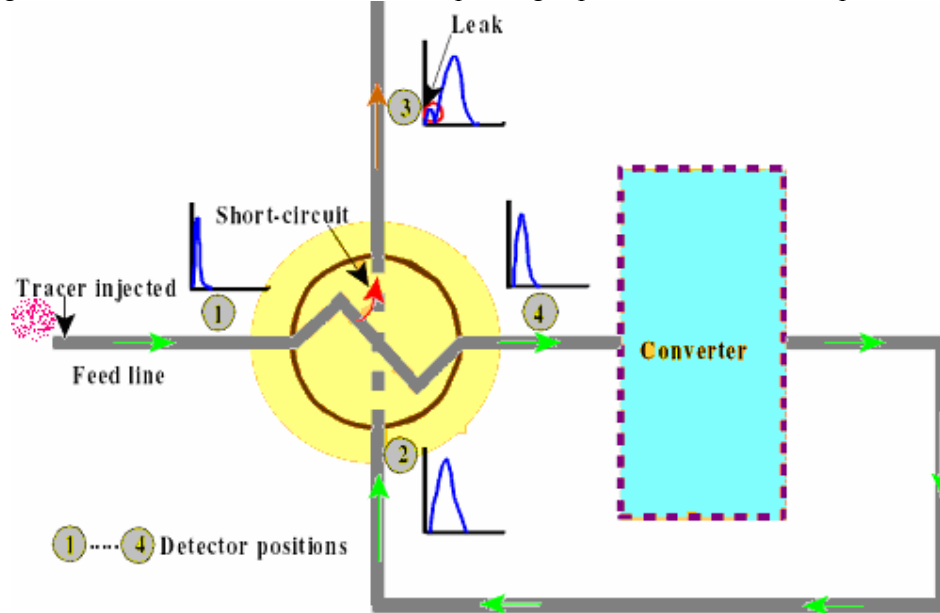


FIG. 43. Experimental setup: Injection and detection positions

The responses of the detectors are shown graphically in Figure 44.

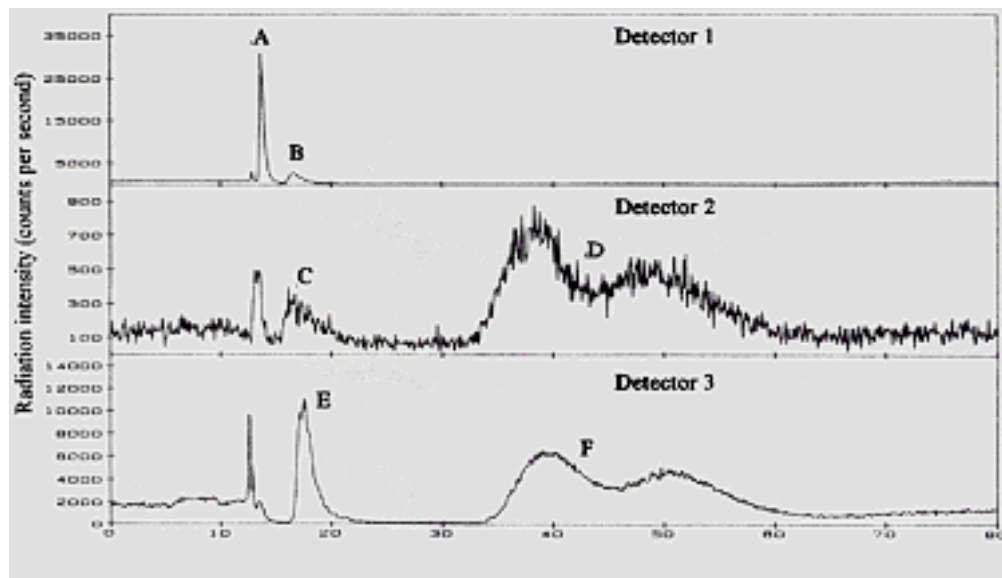


FIG. 44. Experimental response curves of radiation detectors



### 3. Interpretation of results

The recorded pulse A in Figure 44 indicates the injection moment ( $t = 0$ ). Radiation peaks recorded by other two detectors at that moment ( $t=0$ ) were due to external exposure to radiotracer when Ar-41 moved from the well-shielded injection equipment to the line inlet, thus these are “false” peaks and should be ignored.

The outlet pipe of the heat exchanger feeding the converter was fairly close to the injection point where detector 1 was placed, so radiotracer moving along this line on its way to the converter was “seen” for a while by detector 1 providing the false peak B, which should be ignored as well.

Detector 2 was placed at the tube outlet, which by construction was very near to the feeding pipe to the converter where the radiotracer enters. The recorded peak C is considered as false similar to the peak B. Signal D recorded by detector 2 after the converter provides the residence time distribution (RTD) of the radiotracer inside the converter. The RTD form provides information about the process development inside the converter. It could be interpreted as two parallel flow model or axial dispersion model with back mixing, but is not related with leak detection test.

Detector 3 placed at the outlet of heat exchanger records leaks if any, so this curve should be analyzed very carefully comparing with detectors 1 and 2. Signal F is similar to the signal D of detector 2, which is normal because in this part of the line tracer is moving according to the model of the converter. Detector 3 recorded peak E much before bulk of the tracer (pulse F) passed in front of it. This peak E indicates a potential leak in the exchanger (i.e. feed short-circuiting to outlet).

Let us analyze the reasons for this quite important peak (much higher than peaks B and C occurred at nearly the same moment). One possibility for this peak is being caused by the exposure to radiotracer moving from heat exchanger to the converter (like other two detectors 1&2 that have indicated false peaks B and C). Detector 3 was approximately at the same distance from feeding pipe as other detectors 1 and 2, so the peak E should have been much smaller if was a false peak. Peak E is obviously much higher than false peaks B and C, thus it indicates the presence of the leak as well. In fact the peak E overlaps the leak peak and false peak together.

Since the possibility that radiotracer radiation from the converter feed line affected the response of detector 3 could not be ruled out, the accurate leak size was difficult to be determinate in this test. Moreover a brick detector (that could have estimated the false peak) was not used in this case. The simple approach used to solve this problem was to consider the false peak (part of peak E) similar with false peak B recorded by detector 1 (according to the experimental set up the detector 1 and 3 had the same distance from the feeding line). The area under pulse E was corrected for false peak B and the size of the leak was estimated from the ratio of the corrected area under pulse E to the total area under E and F. The leak size of 14 % was obtained (17 % is the estimation without correction of the false peak).

The table below summarizes the mean residence times of radiotracer recorded from all detectors.

Pulse	Mean residence time (s)
A	0
B	3.1
C	3.9
D	30.4
E	4.1
F	31.8

#### 4. Conclusions

The results of radiotracer test on heat exchanger showed conclusively that nearly 14% of the feed gas entering exchanger short-circuited directly via a leak to its outlet. This is a relatively big leak. The identification of the leak by radiotracer test was confirmed by visual inspection of the heat exchanger performed after the shutdown.

The identification of the leak was very difficult due to the overlap of false peak interfering from external sources (radiotracer moving in pipes very near to the detector positions). The comparative interpretation of all detector records provided the weight of each factor and allowed quantification of the leak size as well.

It was chance that the leak was quite big (near 14%) that it was discovered; otherwise if the leak was less than 5% (normal leaks in general) no possibility to identify it from noises (false peaks). Heavier collimation of detectors (5 cm lead shield around the detector is needed for high energy Ar-41 and Br-82, when for medium energy radiotracers like I-131, 3 cm lead are enough), better positioning of detectors (as far as possible from other processing lines) and repetition of the radiotracer test placing another brick detector near the leak detector is suggested in similar leak test situations to obtain more accurate and reliable results as well as to identify relatively small leaks.

##### 2.6.4. Radiotracer Leak detection in heat exchanger of an Alkylation's production unit

The objective of the radiotracer test was to inspect the heat exchanger E 18008 of the Alkylation's production unit for possible leaks (Fig. 45). A potential leak in the heat exchanger E18008 will result in a portion of the feed gas short-circuiting directly to the effluent line, and thus adversely affecting the performance of the process.



FIG. 45. Shell and tube heat exchanger and shielded detector

The schematic layout of the Alkylation's process is presented in Fig.46 with the position of radiation detectors and the injection point. Ar-41 gas radiotracer was used with activity of 100 mCi.

Six detectors were installed in all the alkylation's production line, including heat exchanger and treaters A and B. Detectors D1, D2 and D5 (D6) are significant for leak detection in heat exchanger, the others are for investigating any potential leak in the block valve.

Detector D1 was installed at the tube inlet so it indicates the injection time, which is reference for other records and helps in interpretation of results.

Detector D2 measures radiotracer going through tube outlet. Detectors D5 and D6 located at the shell outlet are significant for leak detection (“leak detectors”). There were installed two detectors in the same position for double check.

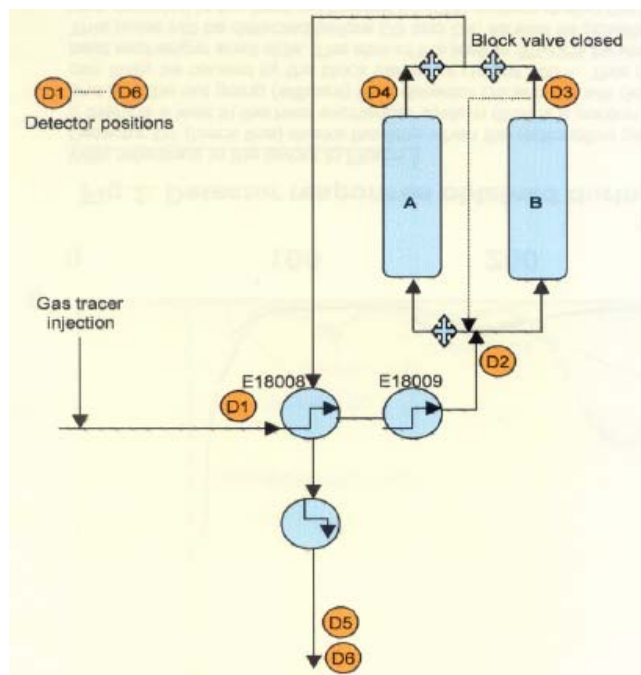


FIG. 46. Schematic layout of Alkylation's process

Detector responses are shown in figure 47.

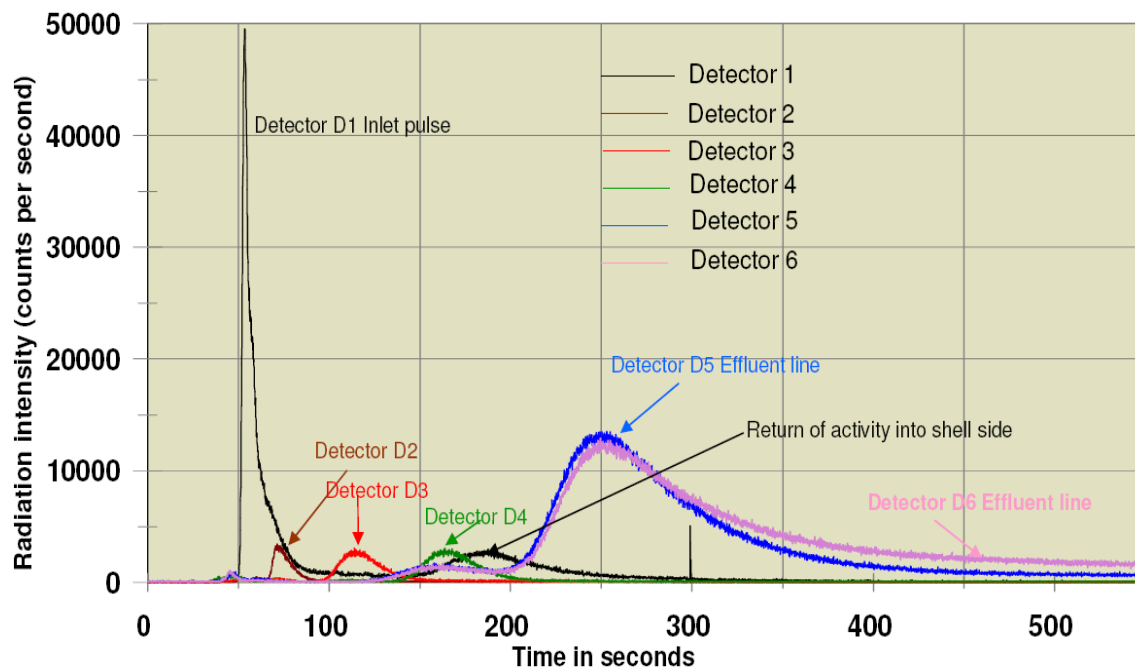


FIG. 47. Detector responses.

Detector D1 (black line) marks the time when the radioactive gas tracer enters the tube side of the heat exchanger system. Other experimental curves are regularly shifted without showing any sign of any “leak peak”. If there is a leak in the heat exchanger a portion of the injected activity should have short-circuited directly into the shell side and with effluent flow out of exchanger from shell output where detectors D5 and D6 were installed. Thus, if leak was present the detectors D5 and D6 should have indicated a signal before tracer signal comes to detector D2. Apparently, this was not the case.

In order to compare better the experimental curves provided by detector, the detector responses were zoomed (fig. 48). It appears that detectors D5 and D6 have recorded a small signal in nearly the same time the tracer was passing in front of detector D4 (or better moving from detector D3 to D4). This small peak apparently was caused by radiotracer leaking through the block valve situated at the position of detector D3.

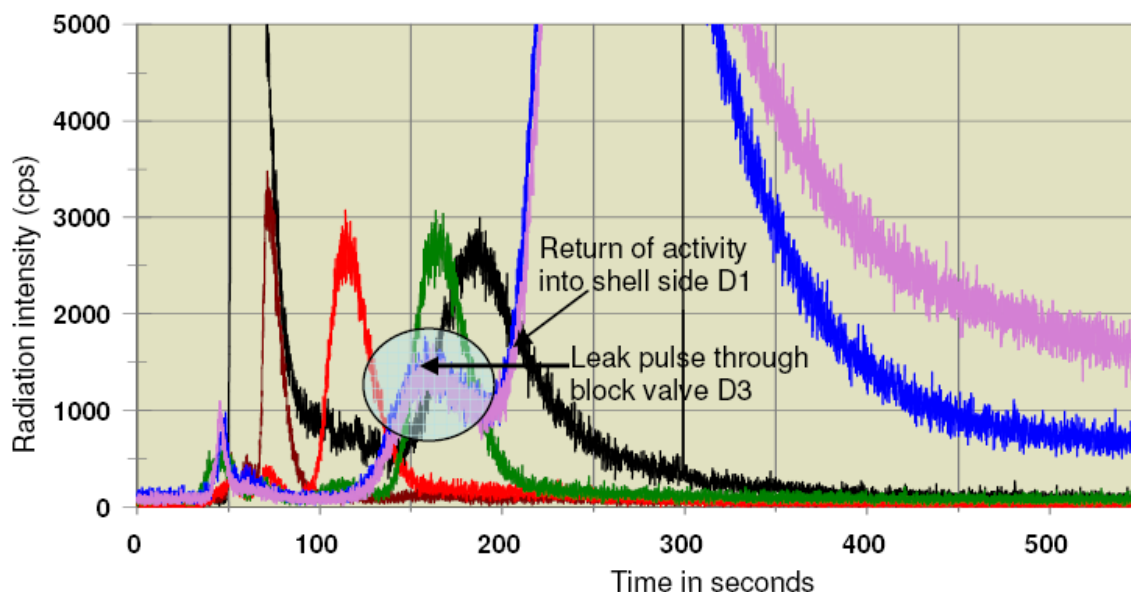


FIG. 48. Detector responses zoomed

As conclusion, because detectors D5 and D6 did not measured any tracer signal before detector D2, it was concluded that there was no leak in the heat exchanger E18000 during the time of investigation.

The pulses recorded by D5 and D6, at time app. 160 s, are caused by activity leaking through the block valve situated at position D3. Possibly, the block valve was not 100% blocked and the radiotracer leaking through it enters the heat exchanger shell side.

#### 2.6.5. A pre-shutdown diagnostic assessment of ammonia synthesis line

As part of investigation to assist in pre-shutdown planning, a customer wanted to establish why the ammonia synthesis line was not performing as efficiently as expected. The reasons could either be poor catalyst performance, internal bypassing (leakage) of the catalyst bed, or leakage through a faulty bypass valve that should have been closed. A series of radiotracer tests were carried out for troubleshooting of different processing loops of ammonia synthesis and converter line. A pre-shutdown diagnostic assessment of main reactors of ammonia production plant was performed, mostly related with detection of suspected leaks in different processing loops. The objective of the diagnostic work was:

- To determine and identify potential areas or locations of leakage within the loop, where the process gas is bypassing the equipment, either internally or externally,
- To finalize inspection work requirements on high pressure equipment,
- To assess the need to open high pressure equipment and catalyst vessels

Figure 49 shows the diagramme of the ammonia synthesis loop. Four tests were performed, the first test in the gas-gas heat exchanger, the second in the ammonia converter, the third in the booster reactor and the fourth in the waste heat boiler.

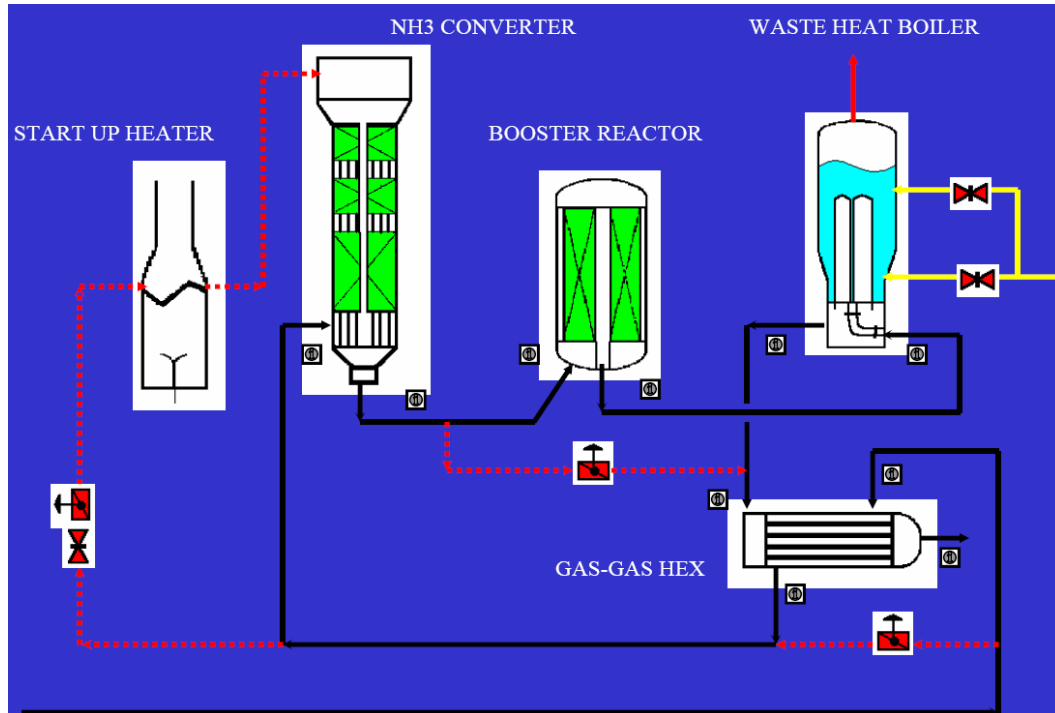
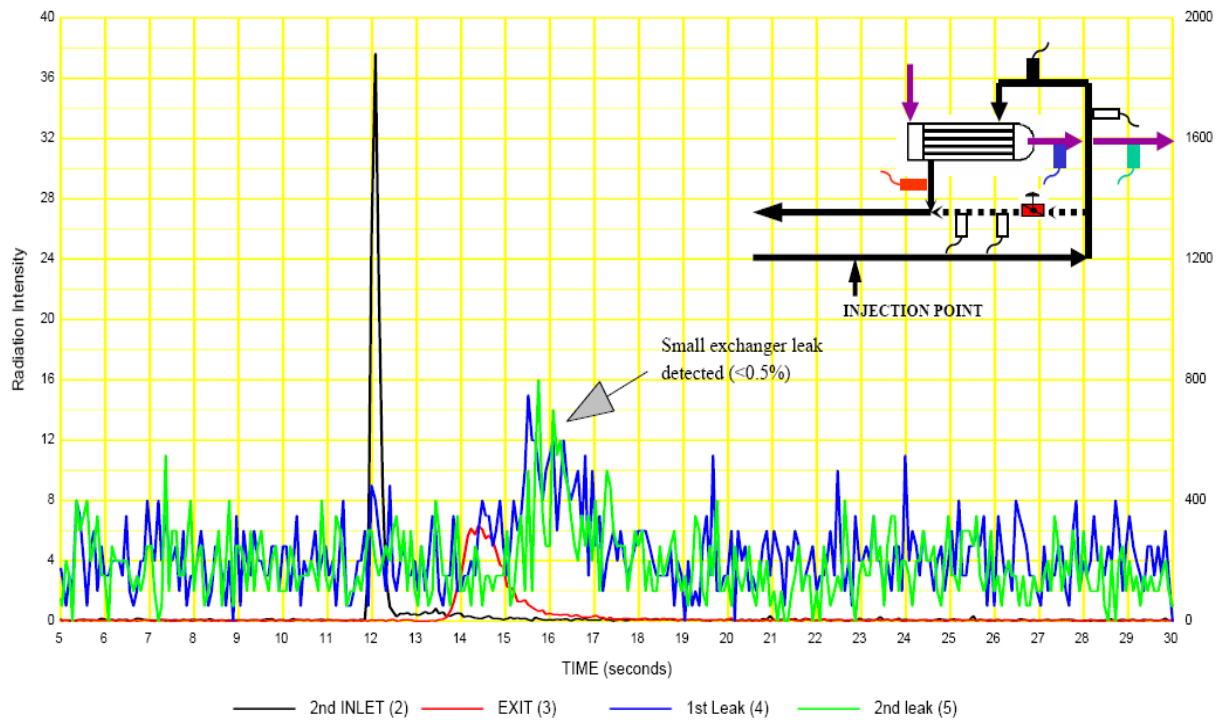


FIG. 49. Synthesis loop diagram

### 1. Test 1 - Internal leakage through gas-gas heat exchanger and leak in bypass valve

Four radiation detectors were active in this test: injection detector (black) at shell inlet; red at shell outlet; leak detectors (blue and green) with a valve bypass between them (Fig. 50). The experimental response curves of four radiation detectors employed in this test are given in fig. 50.

The black curve indicates the injection peak (time = 0); the red curve represents the tracer RTD in the shell (characteristic for an axial dispersion model); the radiation intensity scale for these two detectors is on the right side of the graph. The blue and green curves represent the leak peak because if no leak both curves would remain in the background level. This is not false peak because both peaks were recorded ~4 s after injection and have more or less the same amplitude (left scale in the graph ~ 15 cps) despite the fact they were several meters from each other and quite far from injection point and shell outlet. In fact, between blue and green detectors was a bypass valve, which connects the outlet with inlet pipes (see fig. 50); in normal condition this valve is closed not to allow the outlet gas to entry to the inlet. Comparison of experimental response curves of both blue and green detectors shows that there was not any leak through the valve. If valve leak was present another peak would have been shown in the curve.



Conclusions of test 1 were:

- Small shell to tube leak in the heat exchanger detected ( $<0.5\%$ ) - not a major effect on loop performance.
- No bypass valve leak.

## 2. Test 2 - Internal leakage through ammonia converter

The experimental setup shown in figure 51 was very simple in this case. There were two detection detectors only, the injection detector (at the converter inlet) and leak detector (at converter outlet).

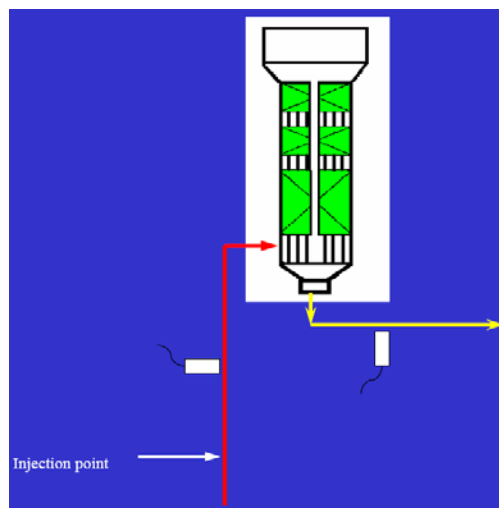


FIG. 51. Experimental setup for radiotracer inspection of internal leak through ammonia converter

The leak detector installed at the converter outlet did not record any radiotracer signal but remained in the background level, this simply means that no leak in the ammonia converter.

Conclusions of test 2 were:

- No leakage in the ammonia converter
- All internal interchangers in good condition
- No significant bypassing of the catalyst
- No requirement for vessel inspection

### 3. Test 3.- Internal leakage through ammonia booster converter and leak in bypass valve

The leak inspection of booster converter bypass was performed as the third test. A radioisotope tracer was injected before the bypass valve, and four detectors were placed as shown in figure 52.

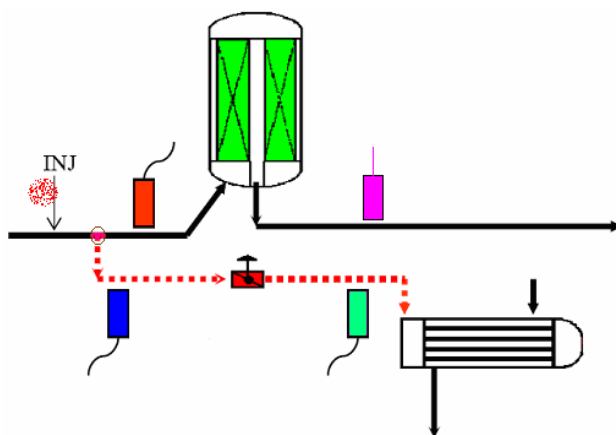


FIG. 52. Leak inspection through the booster converter bypass

The experimental response curves of the radiation detectors are shown in figure 53.

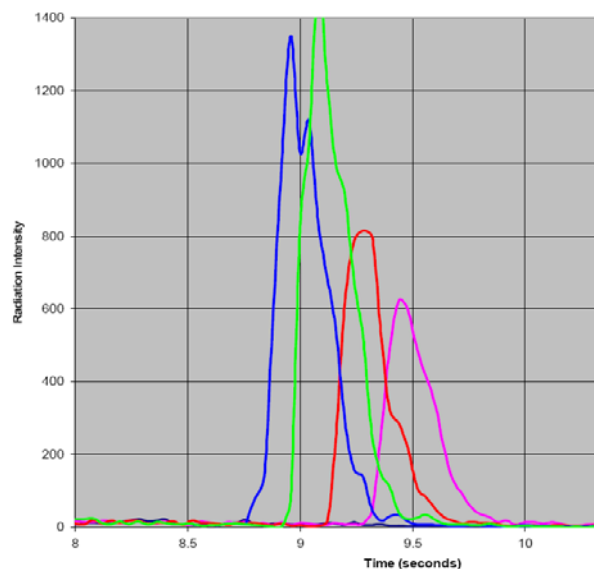


FIG. 53. Experimental response curves in booster converter bypass test



Both detectors (blue and green) installed at the bypass valves recorded significant peaks that indicate the presence of the leaks through the bypass valves that means these valves were not completely closed.

The radiotracer test for leak inspection of valves in bypass lines around converter, which are expected to be closed, arrived in the following conclusions:

- Major bypassing of the ammonia booster-converter loop
- Significant failure of the bypass valve
- Significant contributor to poor overall loop efficiency.

No internal bypassing was observed on the reactor exit line, but leakage through the bypass valve was identified, which was the main cause of rather low efficiency of ammonia converter loop.

#### 4. Test 4: Internal leakage through the waste heat boiler.

The waste heat boiler (WHB) is independent part of the ammonia production line that means its operation is not strictly related with the performance of the ammonia synthesis loop. Nevertheless, a radiotracer test was carried out in the waste heat boiler as well because it was not operating efficiently, with the exit temperature of the process gas much higher than expected. There was a suspicion that this may be due to internal bypassing of some of the gas at an inlet flanged bellows arrangement, and as a planned plant shut down was imminent, a radiotracer test was requested to confirm this theory.

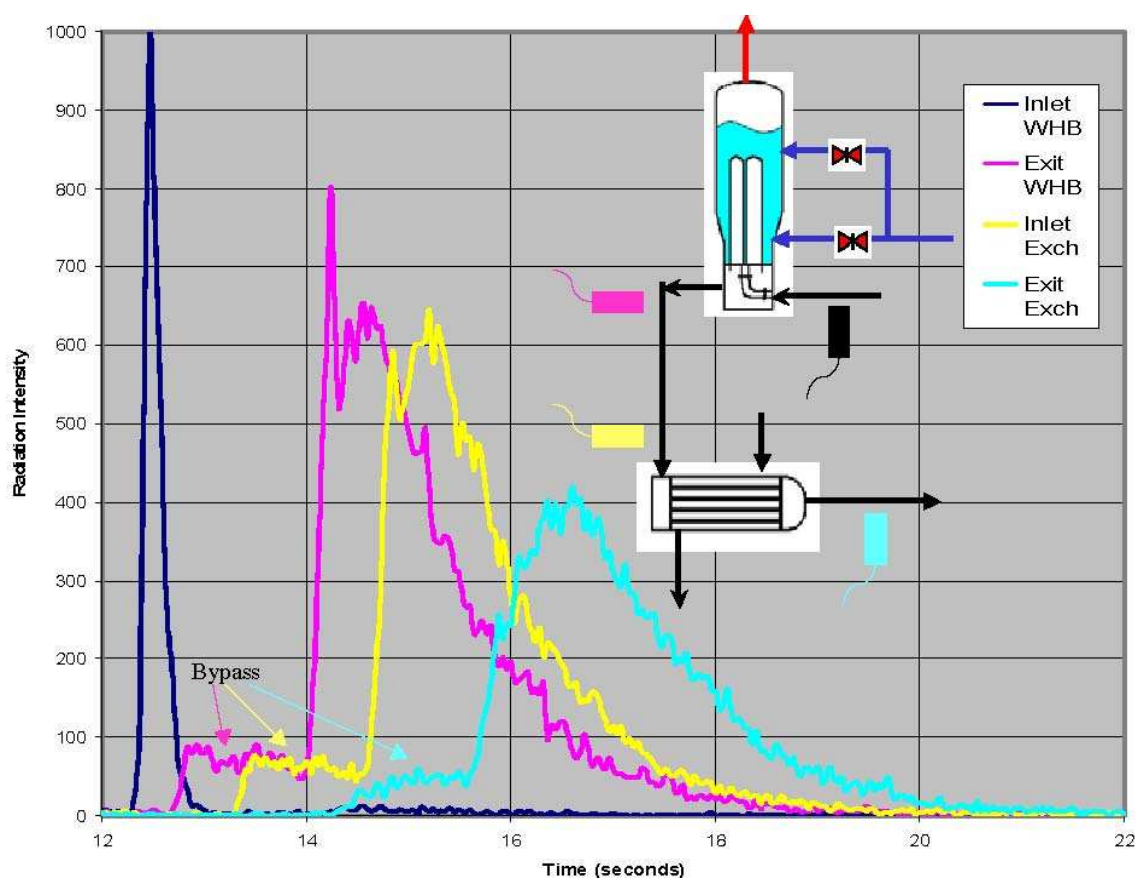


FIG. 54. Detection of vessel internal bypassing

A suitable radiotracer was injected and detectors were installed on the gas exit line to analyze the exit pulse. Two leak detectors (red and yellow) were installed at the gas exit line to confirm the existence of the leak (if any) and to measure the leak flow rate (second detector –yellow is needed for flow rate measurement). The arrangement and subsequent detector responses are shown in figure 54.

The black curve indicates the injection peak (time = 0). The experimental RTD curve obtained at the exit of the WHB (red line) shows the initial bypass peak, which is characteristic of leakage (internal bypassing). As can be seen from the graph, next detector (yellow) has shown the same initial bypass peaks, which confirms the existence of the leak. The same characteristic of the experimental RTD curve was provided by the additional detector (green), which was installed at the exit of heat exchanger for obtaining additional information about the heat exchanger performance (in fact the utilization of this detector has no significance for the detection of the peak and is not justified).

In short, initial bypass peaks were recorded by every detector, prior to the main pulse of tracer being observed (in regular sequences). This conclusively proved that internal bypassing was occurring, and a replacement bellows inlet device was ordered to be installed in the forthcoming shutdown.

### **5. Conclusion of the pre-shutdown diagnostic assessment of ammonia synthesis line.**

The pre-shutdown diagnostic assessment of the ammonia production line was completed successfully. All logistic issues have been addressed and overcome.

Radiotracer tests concluded that:

- Small shell to tube leak in the heat exchanger detected (<0.5%) was detected, but this very small leak does not have a major effect on loop performance.
- No bypass valve leak was found in the gas-gas heat exchanger.
- No leakage in the ammonia converter was observed; all internal interchangers were found in good condition
- Major bypassing of the ammonia booster-converter loop, caused by a significant failure of the bypass valve, was found to be the significant contributor to poor ammonia synthesis loop efficiency.
- The internal bypassing observed in waste heat boiler might have a minor negative role in the overall performance of the ammonia production line.

The leak inspection using radiotracers has allowed a better understanding of the performance of critical equipment. Maintenance work has been re-scheduled to focus on issues and avoid unnecessary inspection.

### 2.6.6. Leak detection in bank of heat exchangers in a refinery

Refinery engineers suspected a leak in a heat exchanger (Fig. 55). Radiotracer test was carried out for leak detection. Bromine-82 as dibromo-biphenyl was used as a radiotracer. 50 mCi was injected in the feed inlet to the exchanger. Three tests were conducted to receive reliable data and results.



*FIG. 55. Bank of heat exchangers in refinery where radiotracer test was carried out to search for leaks*

The schematic diagram of heat exchanger system and radiation detector location is shown in figure 56. Seven radiation detectors were installed in different position of the system. Detector 1 is so called “injection detector” that means records the injection fast and high peak at time zero. Detector D7 is in the feed outlet; its experimental response curve is not related with the existence of peaks only shows the residence time distribution (RTD) of radiotracer inside the system of five heat exchangers.

Detectors D2 –D6 are so called “ leak detectors”; if no leak they should measure only the background. The peak areas indicated by detectors D2-D6 are proportional with the leak rate. The value of leak rate is calculated from equation:

$$\text{Leak rate (\%)} = \frac{\text{Area of leak peak}}{\text{Area of input peak}} \times 100$$

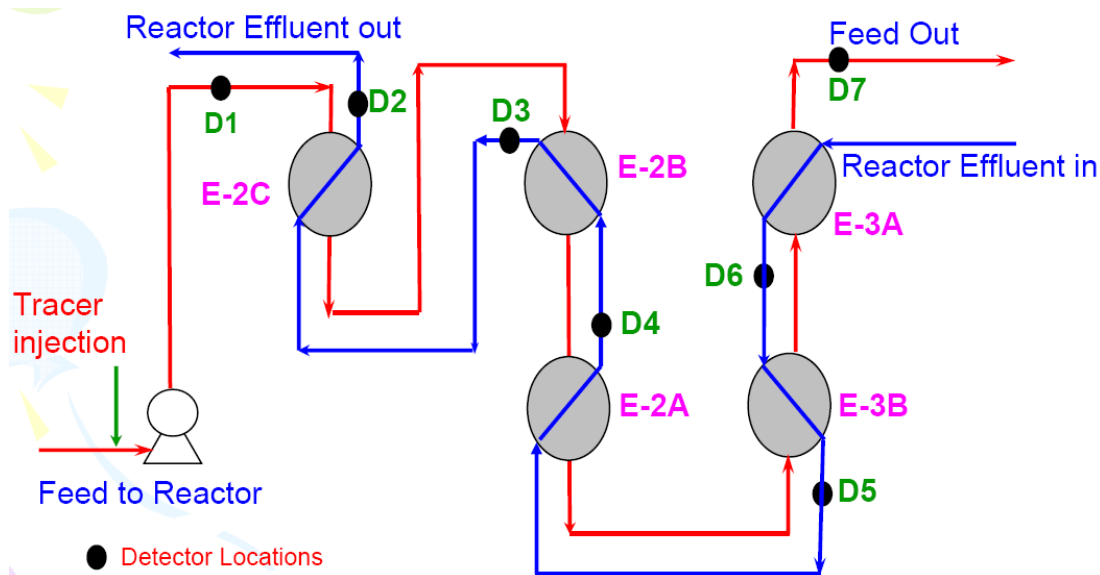


FIG. 56. Schematic diagram of heat exchanger system and tracer monitoring locations (D1-D7: Radiation detectors)

Figure 57 shows the experimental response curves obtained during the first test. Peaks recorded by detectors D2-D5 indicate the presence of important leaks. In fact, peaks recorded from detector D2 are coming relatively late from injection moment; this fact indicated that the heat exchanger E-2C is not leaking because if there was leak in this exchanger the peak response would have been appeared much faster.

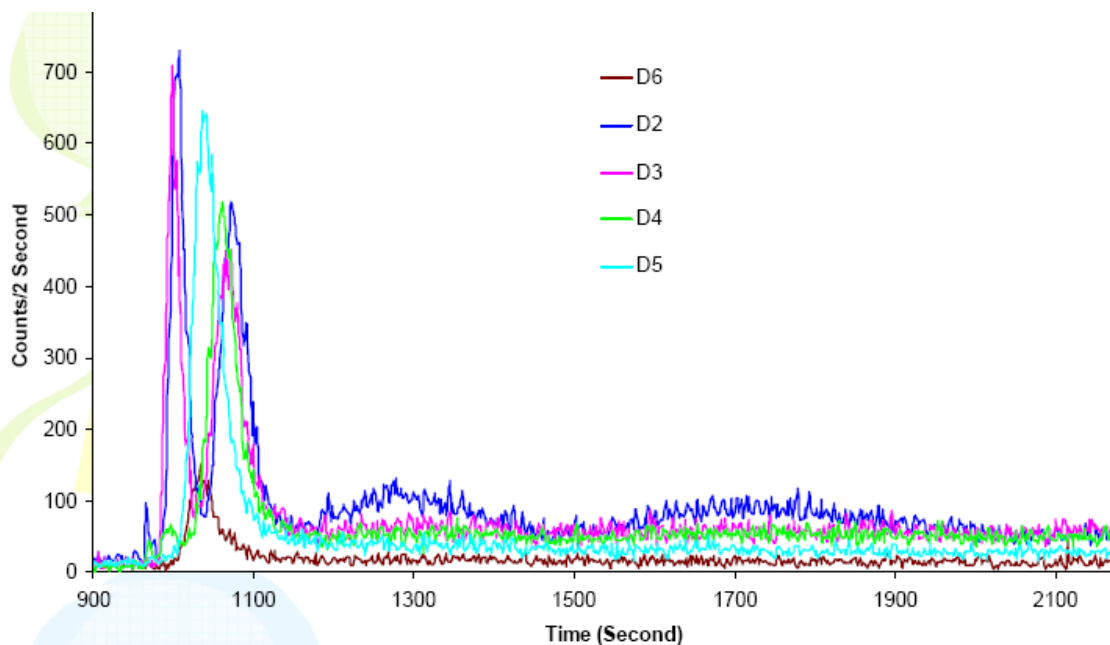


FIG. 57. Radiotracer response curves recorded by different detectors (Test 1)

Figure 58 shows the experimental response curves of seven detectors, including very high peaks of feed injection and exit that are not related with the existence of the leak in the bank of heat exchangers. Leak detectors D2-D6 showed more or less the same results of the test 1.

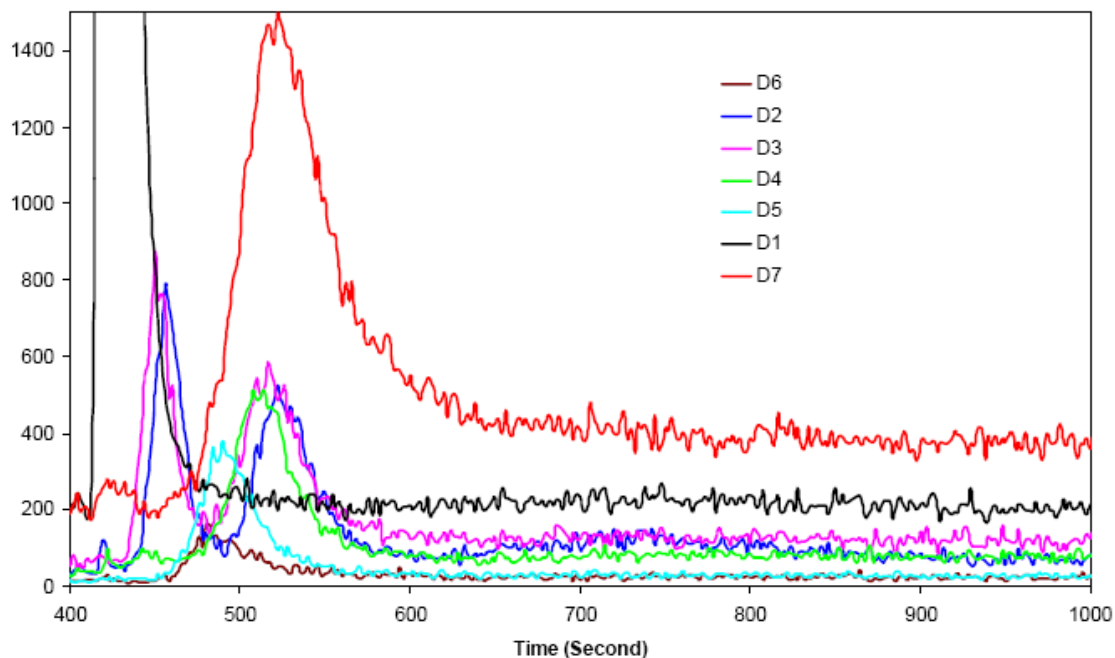


FIG. 58. Radiotracer response curves recorded by all seven detectors (Test 2)

Figure 59 shows the experimental response curves of detectors D2-D3-D4 for comparing their data in order to quantify leak origins and rates.

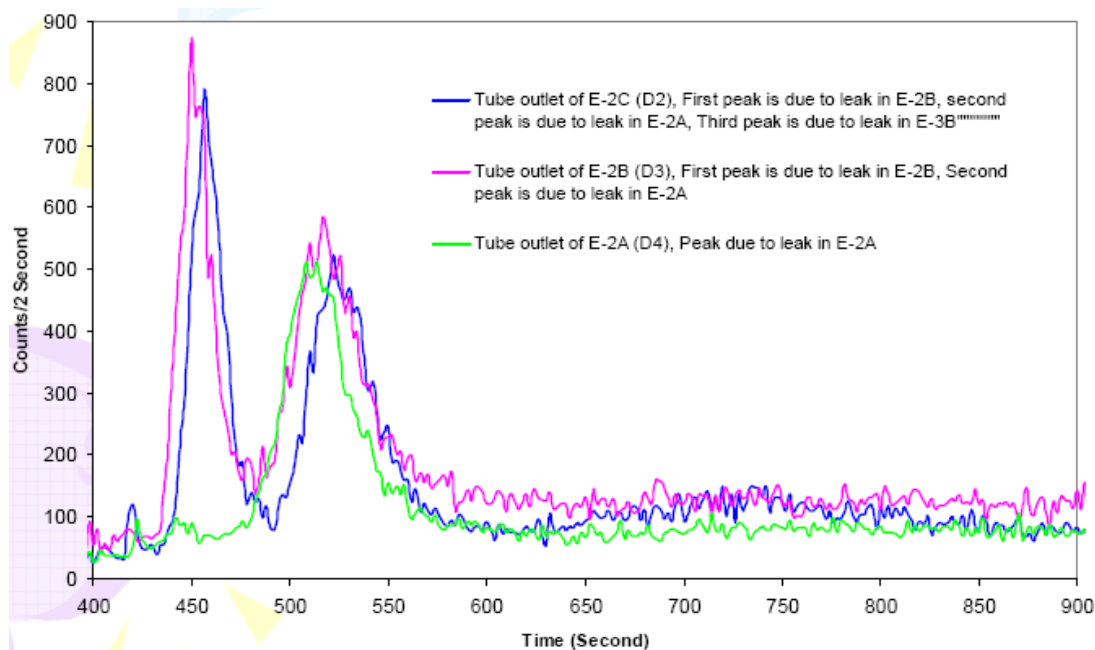


FIG. 59. Radiotracer response curves recorded at the tube outlets of heat exchangers E-2A, E-2B and E-2C (Test 2)

Figure 60 gives the experimental response curves of detector D5 and D6. Both peaks are coming from leaks in exchangers E-3A and E-3B.

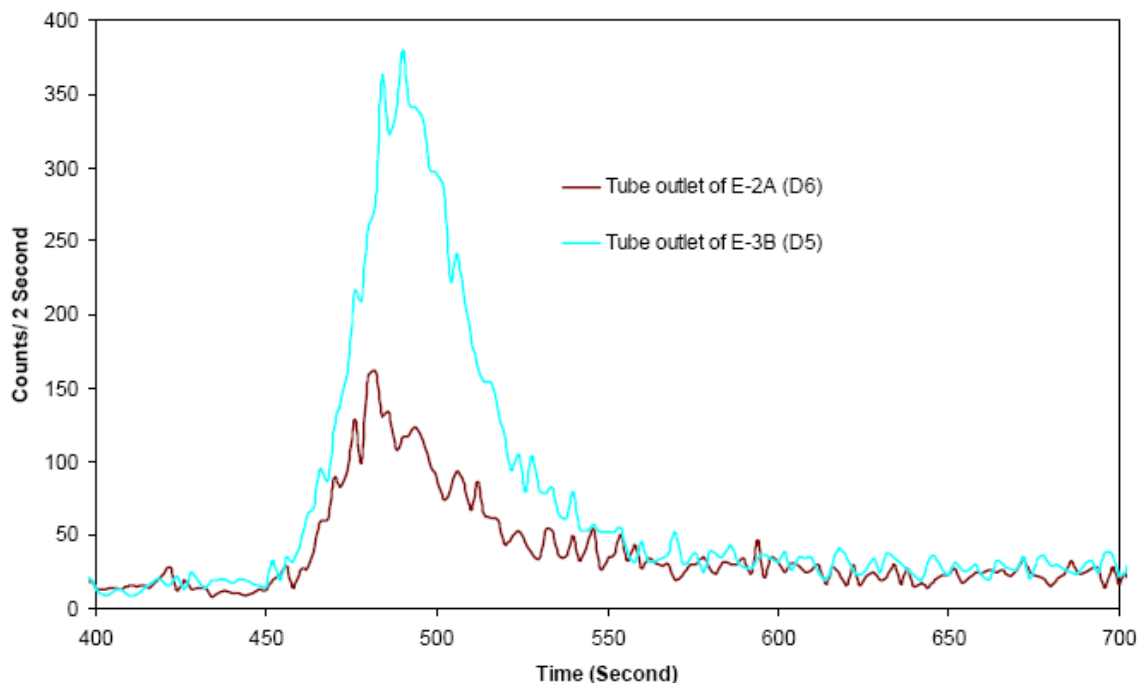


FIG. 60. Radiotracer response curves recorded at the tube outlets of heat exchangers E-2A, E-3B and E-2C (Test 2)

The third test provided more or less similar results. The careful time and peak analysis of experimental response curves concluded that out of five heat exchangers, four were leaking. Results of three tests are presented in the table IV.

TABLE IV. RESULTS OF THREE TESTS

Run No	Leak rates in individual heat exchangers (%)				Total leak rate (%)
	E-2B	E-2A	E-3B	E-3A	
1.	3.7	4.7	7.7	9.4	25.5
2.	7.2	8.6	6.6	9.0	31.4
3.	5.0	6.7	7.7	10.4	29.8
Mean	5.3	6.7	7.3	9.6	28.9

#### Conclusion

Four heat exchanger units of the bank of five were found leaking. Remedial measures planned. Leaks visually confirmed during shutdown. Benefit in terms of downtime which was reduced by 12 days.

### 2.6.7. Radiotracer leak test in a bank of heat exchangers

Leaks on a heat exchanger usually result in off-spec material being produced. If the system has a “bank” of exchangers then it is very difficult to identify which one (or pair) is leaking using laboratory sampling alone. A client had a problem with a feed-effluent exchanger system consisting of five exchangers in series (Fig. 61).



FIG. 61. Bank of heat exchangers

A diagram showing detector positions is presented in figure 62. Br-82 in the form of the ammonium bromide ( $\text{NH}_4^{82}\text{Br}$ ) was used as radiotracer for liquid organic phase. A sharp pulse of liquid tracer (50 mCi of Br-82) was injected into the feed. The passage through the system was monitored by four detectors, with (D4) on the final product line being the “leak detector”. This indicated that a leak of feed to product of approximately 2.5% was present in the system. By using the other detectors and residence time calculations it was possible to determine that exchanger “A” was leaking.

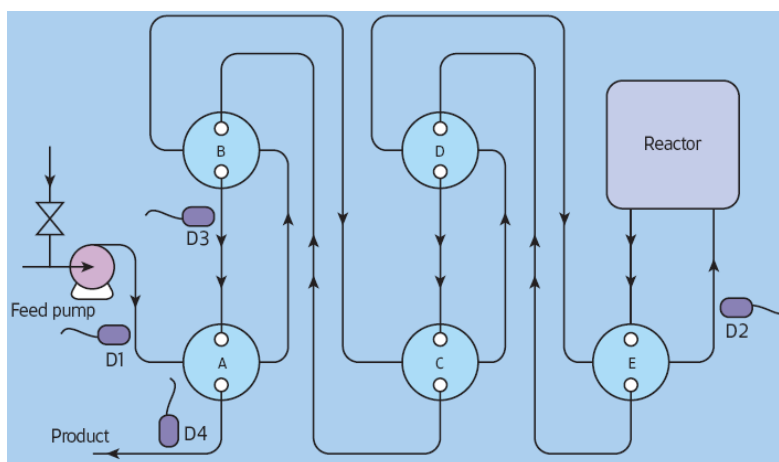


FIG. 62. Radiotracer test for leak detection in a bank of heat exchangers

Therefore only one exchanger needed to be removed from duty and repaired. This minimized loss of production and eliminated unnecessary down time for inspections.



### **3. LEAK DETECTION IN UNDERGROUND PIPELINES USING RADIOTRACERS**

#### **3.1. BACKGROUND**

Radiotracer techniques are extremely useful in the detection of leaks in underground pipes because of their very competitive sensitivity in comparison with other conventional NDT techniques

The general principle of the radiotracer technique for leak detection in underground pipelines is again a radiotracer injection method similar to the method used in processing vessels. But the detection procedure is quite different. Thus, an appropriate radiotracer is injected into the pipeline inlet. The radiotracer mixes with the fluid of the pipe and moves towards the expected leak (if any). Arriving at the leak the transported fluid (mixed with radiotracer) is flowing out the pipe and it migrated towards the ground surface (if it is a gas radiotracer) or is adsorbed on the soil or thermal insulation around the pipe (mostly liquid radiotracers). The measurement of radioactivity discovers the leak location.

In fact, the measurement of the radioactivity is different for shallow pipelines (less than 1 m depth), where the detection of the radiotracer is performed from the ground surface above the pipeline trace, and deeply buried pipelines (more than 1 m depth) where the detection of radiotracer is performed by a pig (pipeline inspection gauge) moving inside the pipeline.

Br-82 is very energetic gamma radio emitter. Its gamma rays can penetrate more than 1 m soil material. Br-82 is used in three chemical forms: water like ammonium bromide, hydrocarbon like bromobenzene, and gaseous like methyl bromide. The main disadvantage of Br-82 is its short life ( $T_{1/2} = 36$  hours). Only radiotracer groups that have nuclear reactor support in their countries can use it.

Gaseous methyl bromide labeled with Br-82 exhibits the best properties as radioactive tracer for the leak proof control for both liquid and gas phases. This radiotracer is prepared from potassium bromide irradiated with thermal neutrons in a nuclear reactor. The transformation of the solid potassium bromide to gaseous methyl bromide is carried out in a mobile chemical reactor, called methyl bromide generator, specially constructed for this purpose. Depending on the type of the generator amounts up to 10 Ci (370 GBq) can be handled and transported.

Radiotracer activity injected is calculated based on fluid flow rate, detection sensitivity and suspected leak size estimation. Experience shows that radiotracer activities of the order of 1 mCi (37 MBq) per fluid flow rate of 1 cubic meter are normal for underground leak detection with good accuracy. This permits to attain a sensitivity of leak detection of about 0.001 L/min. when using internal pig detection. Surface detection of migrated radiotracer is less sensitive, detection limit is lower one order of magnitude as least.

There are two measuring techniques for searching leaks in underground pipelines: detection from the surface above the pipeline (when the pipeline is buried less than 1 m from ground surface), and detection from inside the pipe with a detection pig moving inside the pipe (when the pipeline is buried more than 1 m).

#### **3.2. RADIOTRACER TECHNIQUES FOR LEAK INSPECTION FROM THE SURFACE**

Precondition is that the pipeline must be buried less than 1m from ground surface. Inspection for leaks is based on the detection of gamma radiation emitted by the radiotracer that penetrates through the leak out of the pipeline and migrates towards the surface of the ground.

The pipeline section suspected for leaks (the pipeline does not keep the designed pressure, the flow rate has changed, some local indications) shutdowns. The radiotracer is injected from one side together with the liquid (water or oil) and left filled out for few hours in order to activate the leaks and establish a leak flow regime. The detector is moved then just above the ground surface along the whole length of the pipeline (Fig.63). Pipeline trace has to be well known beforehand.



*FIG. 63. Searching for the leaks in shallow underground pipelines*

The sensitivity of leak detection in this case does not exceed 1 L/h. The leak detection depends on the size of the expected leak as well as on the length and the diameter of the pipeline. These factors affect the dynamics of the radiotracer along its way from the injection site to the leak.

Individual variants of this detection from the surface method differ in respect to the way of tracer injection, pumping liquid (or gas) and detection technique.

### **3.2.1. Technique of labeling the whole volume of the pipeline**

This technique is used for examination of short pipelines with expected small leaks. The fluid and the tracer are pumped into the pipeline at several points in order to accelerate the homogenization of the tracer in the whole volume of the pipe. To better activate leaks and radiotracer flows through them it is recommended to apply high pressure. After reaching a preset pressure the pumping is interrupted. The detection from the surface is carried out only after several hours in order to allow the radiotracer to penetrate through leaks out of the pipe and migrate as much as possible into the soil.

Moving the detector along the pipeline projection on soil leaks can be found as peaks above the background radiation in the data logger. This technique has the advantage of finding all leaks in one detection profile, but it has relatively low sensibility due to high radiotracer dilution and poor detection geometry. Gas radiotracer can migrate easier through the soil and the chances for finding leaks are higher when gas radiotracer is used instead of liquid radiotracer in this technique.

### **3.2.2. Technique of single pulse injection of the radiotracer**

This technique is used for control of relatively short pipelines with expected large leaks. The examined pipeline is filled with fluid up to a preset pressure and closed down. Then the radioactive tracer is introduced as single pulse at a point located in the middle section of the pipeline. The radiotracer moves together with the fluid to the leak where it penetrates to the ground and migrates towards its surface. By injecting the radiotracer into the middle of the pipeline and measuring the radioactivity from the surface with two detection systems placed few meters from injection point both sides, the rough estimation of leak presence from left or right of injection point is quickly obtained. Then the search for localization of the leak can continue only at that side where the radiotracer is moving. Radiometers placed on both sides of the labeling site permit to define the direction of the radiotracer movement, which eliminates the necessity of control of the other part of the pipeline.

A further modification of this technique is to inject the tracer from one end and monitor continuously its migration inside the pipe towards the leak.

Another variant of this technique is to perform a continuous radiotracer injection instead of pulse injection. Taking account that pulse injection of radiotracer might be insufficient for the tracer to reach the leaks the pumping of the radiotracer is carried out continuously under constant pressure. In order to have a longer detection time and possibility for finding a leak, sometimes it is necessary to maintain a constant inflow of the radiotracer to create a longer flow process through the leak.

### **3.2.3. Velocity drop technique**

In radiotracer pulse migration technique, a pulse of radiotracer is injected into an isolated section of the pipeline through one end by closing the other end. Radiotracer pulse migrates towards the leak under the disturbed flow regime caused by the leak flow. Passage of the radiotracer pulse inside the pipeline is monitored using radiation detectors logged into pits dug at regular intervals along the ground projection of the pipeline. Dug pits are few tens centimeter depth to shelter the detection probe as much as possible near the pipeline but also to be easy for drilling. Because of the constant leak rate at the operating pressure the tracer pulse attains constant velocity. Radiation detector records show tracer cloud passing in front of each detector. Non-arrival of the tracer pulse in a dug pit (within the stipulated time calculated by tracer travel velocity) indicates the leakage zone between this dug pit and previous one. Further investigation is needed in smaller scale to localize the leak place with proper accuracy.

The dug pit interval depends on the pipeline section length to be investigated. For several kilometers pipeline the dug pits could be drilled every several hundred meters. This technique normally is not used for leak detection in long pipelines (more than 20-30 kilometers) because is very laborious and not enough accurate. Long pipelines should be searched for leak section by section, but not always is possible to isolate a section and to keep it under the pressure.

## **3.3. CASE STUDIES USING RADIOTRACER SURFACE INSPECTION**

Above mentioned techniques of surface detection are called radiotracer surface migration techniques. Using tracer pulse migration method leaks of the order of 1 liter per minute (relatively large leak size) can be detected. The chance to find small leaks in large diameter pipelines using the tracer pulse technique is rather scarce because the tracer concentration decreasing under the influence of pulse broadening and diluting with respect to time. However, for larger leaks this method works quite well.

### 3.3.1. Case study: Radiotracer leak inspection in an underground ethylene gas pipeline

A 10.4 km section of 76 km long underground 10" diameter pipeline carrying ethylene gas was suspected leaking since it was not holding the pressure. Conventional techniques failed to detect the leak. Radiotracer pulse migration method was used to locate the leak. About 10 mCi of  $^{82}\text{Br}$  in the form of methyl bromide gas trapped in a stainless steel container was used as radiotracer.

A sharp pulse of radiotracer was injected through one end (SV6 end) of the pipeline after closing the other end (PIL factory end). Pressure in the pipeline was maintained to about 3 kg/cm<sup>2</sup> with the help of compressed air. Passage of the tracer pulse was monitored with the help of scintillation detector connected to a ratemeter. Pits were dug at approximately every one kilometer distance. Figure 64 shows the experimental design and position of detectors.

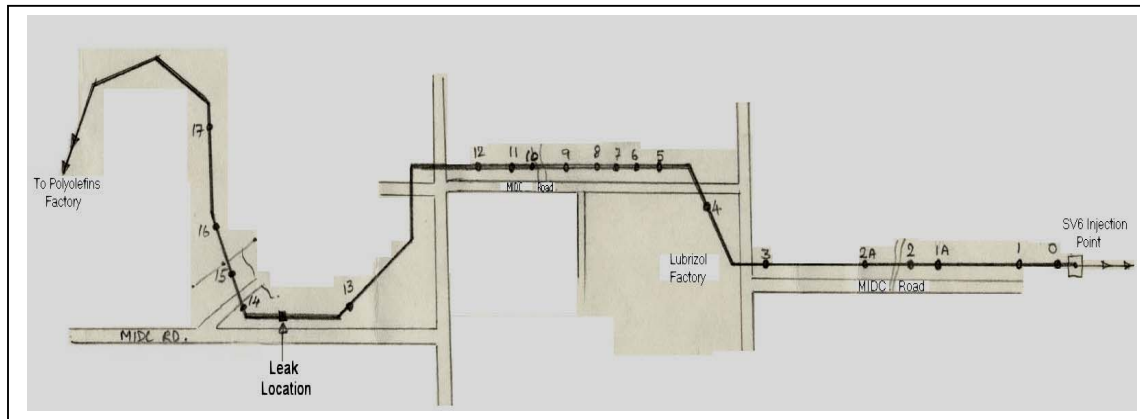


FIG. 64. Experimental design using of tracer pulse migration technique.

Tracer pulse moved consistently at a constant speed of about 2 km/hour and was monitored up to the pit number 13 within predetermined time but a detector placed in pit no. 14 did not show any rise in count rate for double the expected duration. This indicated that the gas must have leaked out between the pits 13 and 14. Pressurization from the SV6 end was discontinued. Area between pit no. 13 and 14 was assayed with the help of hand held scintillation detector. Background count rate started increasing after about 200 meters from pit no. 13. Maximum count rate of the order of 55000 counts per minute was observed at 244 meters from pit no. 13. The area was excavated and a hole to the pipeline was visually observed.

This tracer pulse migration technique is considered as off line (or static) technique because the pipeline section under investigation is isolated and shutdown from oil line service.

### 3.3.2. Case study: Radiotracer leak inspection in an underground naphtha pipeline

Primarily this is an on line application, that means that the pipeline remains in service (it not possible to shut it down) and the tracer injected from the inlet side. It is called the pulse-velocity technique because monitors the tracer pulse intensity decrease with the time and distance from injection. However, this is less sensitive than the tracer pulse migration method. Hence this method is used for larger leaks mostly of the order of few hundred liters per hour. A pulse of activity is injected into the line and the velocity along the underground pipe is measured, either with radiation detectors at the ground surface (if the pipe is less than 1 m below the surface) or with detectors in discretely placed bore holes for greater depths. The velocity of the liquid drops sharply as it passes the leak (when the leak flow is relatively comparable with main fluid flow inside the pipe).

8" diameter 5 km long underground pipeline carrying naphtha from a petroleum refinery to a processing factory was suspected leaking as 20% of the naphtha delivered from the refinery was not received at the other end. Because of the several reasons flow of naphtha could not be discontinued. Hence application of other methods like tracer patch migration and detector pig method were not feasible. Therefore for online usage, velocity drop method was used. Pits were dug after every 500 meters to reach up to the pipe surface. Scintillation detectors coupled to count rate meters were placed in the dug pits. 10 mCi of  $^{82}\text{Br}$  in the form of paradibromobenzene dissolved in kerosene was used as a radiotracer.

A sharp pulse of radiotracer was injected from the refinery end. The passage of radiotracer pulse was monitored by successive ratemeters. Detectors have nearly the same efficiency and geometry for comparison of results (peak records). The velocity of about 2 km/hour was found till the seventh pit. However, it took about double the time for the diminished peak to arrive at the eighth pit. This sharp drop in velocity prompted for existence of leak between seventh and eighth pit.

There was a railway track between seventh and eighth pit. A large water pond was also seen near the track. The area between seventh and eighth pit was surveyed with the help of handheld scintillation detector. The pond water started showing higher background. The soil near the railway track was excavated where naphtha was seen coming out from the vicinity of pipe which indicated that the pipe was leaking below the track.

### 3.3.3. Radiotracer leak detection in an underground cooling water pipeline at a thermal power station

#### 1. Description of the problem

Cooling water is being pumped from the water pump to the condensers of a thermal power plant by a 400 meter long buried pipeline (figure 65). Two pumps are feeding water to pipeline, which is made of mild steel having internal diameter of 2240 mm with 12 mm wall thickness. The total volumetric flow rate in the pipeline was 29043 m<sup>3</sup>/hour. This pipeline was buried ~ 2 meters deep under the soil until it enters the plant building. Inside the plant building, the pipe was buried under one meter thick reinforced concrete floor. Under the concrete floor, there is further 0.5 to 1.0 meter soil cover over the pipeline.

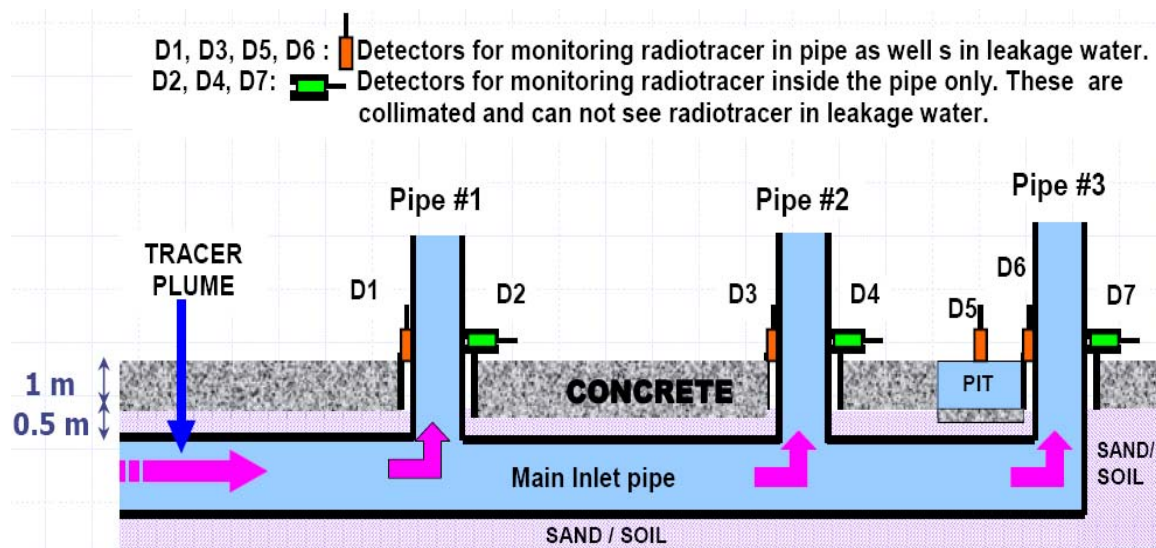


FIG. 65. Layout of "teeing-off" pipes and leakage monitoring plan



At the distribution point, inside the building, three pipes (labeled as Pipe #1, Pipe #2 and Pipe #3 as shown in figure 67) are teeing-off vertically upwards from the main pipeline. Each teeing-off pipe has a metal sleeve around it separating the pipe from the concrete floor. There is a gap (1" to 2" wide) between teeing-off pipe and metal sleeve.

Leakage water was flowing out from the gap between pipe and sleeve around all three teeing-off pipes. The first teeing-off pipe is supplying water to various services and has volume flow rate of 1543 m<sup>3</sup>/hour. The second and third pipes are supplying water to condensers with a volume flow rate of 13750 m<sup>3</sup>/hour each. Apparently, much more water is leaking from Pipe # 1 as compared to Pipe # 2 & 3. Further more, there is a pit (~ 2' x 2' x 2') between Pipe # 2 & 3 (just adjacent to Pipe #3 as shown in figure 67). A small amount of water was also leaking from the pit.

Plant engineers informed that this pit was dug in a bid to find the leakage point and was filled with concrete again. The plant engineers abandoned this plan, as it was not considered a safe way of leakage location. It may be mentioned that a number of plant installations are present in the near vicinity of leakage point and it is not easy/advisable to dig out the floor without knowing exact position of leakage. Apparently, leakage water is coming out around all three teeing-off pipes and in first instance it looks that the leakage is at teeing-off joints. But as mentioned earlier, there is one-meter thick reinforced concrete floor overlying the pipeline and all around inside the building area.

Therefore, any leakage in portion of the pipeline, which is inside the building, can only come out on the floor from these three metal sleeves around pipe # 1, 2, 3 and the pit dug in floor near pipe #3 (see figure 65). Any leakage in the area outside the plant building has a little chance to appear inside the building because of soil nature and natural drainage conditions. Therefore, leakage may be anywhere in the pipeline after it enters the building. The objective of the radiotracer study is to identify the leakage point(s) so that the repair plan may be prepared accordingly.

## 2. Experimental procedure

Direct radiotracer technique was used to investigate this problem. An activity of ~50 mCi of <sup>131</sup>I in the form of NaI solution was injected at the pump inlet in the sump pit close to the suction point. A glass vial containing liquid radiotracer was crushed inside water using a specially designed vial crushing mechanism. Radiotracer injection was monitored at pump outlet using a collimated sodium iodide (NaI) detector of 2"x 2" crystal. Figure 66 shows the experimental response curve registered by injection detector.

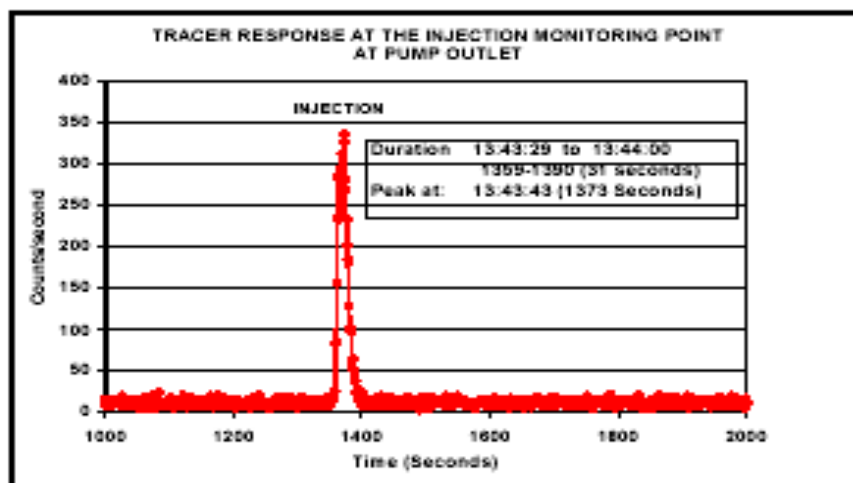


FIG. 66. Radiotracer response at injection monitoring point

The volume flow rate of cooling water inside the pipeline is 29043 m<sup>3</sup>/hour at a pressure of 2 kg/cm<sup>2</sup> and linear speed of around 2 m/s. Therefore, radiotracer flowing inside the pipeline will be traveling fast along with the cooling water. However, when water leaks out, its speed and pressure become lower. Further, it may experience retardation to its flow when it travels through the soil around the leakage point until it comes out from the gap between pipes and metal sleeves and reaches the detectors.

Two radiation detectors were installed side by side at the exit point of leakage water at each teeing-off pipe to detect radiotracer flowing inside the pipeline and radiotracer present in leakage water. So there must be an appreciable time-lag between the arrival, at detectors, of radiotracer flowing inside the pipe and radiotracer present in leakage water. Logically, radiotracer flowing inside the pipeline should arrive the detection point earlier than the radiotracer present in leakage water. Similarly, radiotracer present in leakage water should appear earlier at those radiation detectors that are relatively closer to the leakage point.

Seven radiation detectors (NaI, 2" x 2" crystal size) were installed around the suspected leakage points for monitoring of radiotracer present in water flowing inside the pipelines as well as in potential leakage water. Detectors D1, D3 and D6 were installed adjacent to pipe #1, pipe #2 and pipe #3 respectively. These detectors were not collimated and were dipping inside the leakage water coming out from the sleeves of the respective pipes. The purpose of these detectors was to monitor radiotracer present in the leakage water outside the pipes but these could also see the radiotracer passing inside the pipes because these are installed just near the pipes.

Figure 67 shows the experimental response curves recorded by 7 detectors.

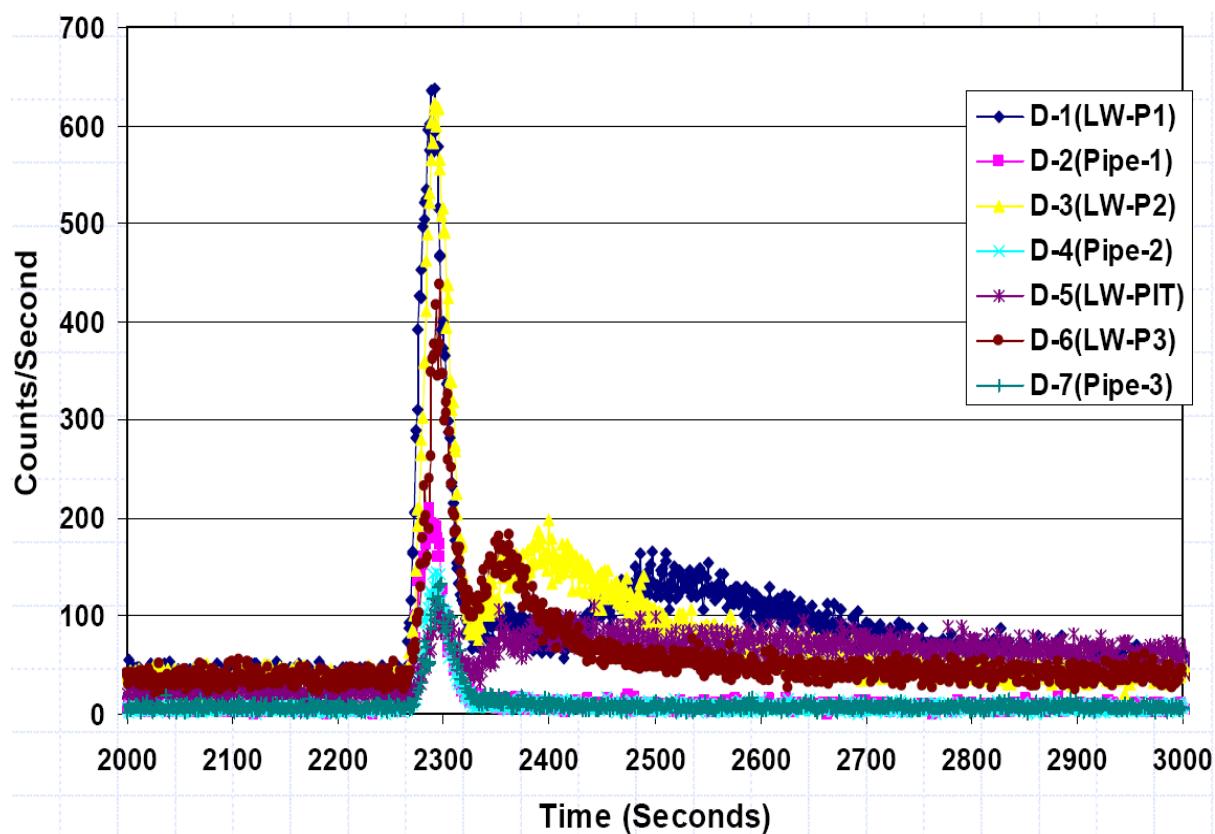


FIG. 67. Radiotracer experimental response curved registered by detectors



Detectors D2, D4 and D7 were collimated with lead shielding and were installed horizontally against pipe #1, #2 and #3 respectively. The purpose of these detectors was to monitor radiotracer passing inside the pipes only, i.e., they were made blind to the tracer in leakage water. Detector D5 was uncollimated and installed in the pit water. It could see radiotracer inside adjacent pipe #3 as well as radiotracer present in leakage water. The leakage water from pipe #1, #2, #3 and pit was isolated, on the floor, from each other so that the leakage from one point must not mix with leakage from any other point until it goes away from radiation detectors and is discharged into the drain. On-line data acquisition was carried out using a data acquisition system coupled with a computer.

### 3. Results and discussion

The tracer responses of all seven detectors installed around the leakage point are plotted in Fig. 67. The summary of radiotracer arrival and peak timings at various detectors is given in table V. The comparison between the relative timings of leakage peaks helps determine the leakage points.

TABLE V. RADIOTRACER ARRIVAL AND PEAK TIMINGS AT DIFFERENT DETECTORS

Detector	D-1 (LW-P1)	D-2 (P1)	D-3 (LW-P2)	D-4 (P2)	D-5 (PIT)	D-6 (LW-P3)	D-7 (P3)
Tracer Arrival Time (sec)	2266	2266	2269	2269	2272	2272	2272
Peak-1 (signal from pipe)	2291	2287	2292	2293	2292	2296	2298
Peak-2 (Leakage)	2349	-	2399	-	2389	2362	-
Peak-3 (Leakage)	2497	-	-	-	-	-	-

\* Detectors installed at pipe #1, pipe # 2, water pit and pipe # 3 to detect leakage water (LW)

\*\* Detectors installed at pipe #1, pipe #2 and pipe # 3 to detect radiotracer inside pipe only

#### *Tracer response of detectors D1 & D2 installed at pipe #1:*

Radiotracer response of detectors D1 and D2 installed at pipe #1 is shown in figure 68. The arrival of radiotracer at detectors D1& D2 is recorded at the same time i.e., at 2266 seconds. Detector D1 has recorded three peaks. Peak-1 is due to tracer flowing inside the pipe #1 while peak-2 and peak-3 are due to leakage. However, detector D2 has recorded only one peak because it is seeing radiotracer flowing inside pipe #1 only and is blind to radiotracer present in leakage water.

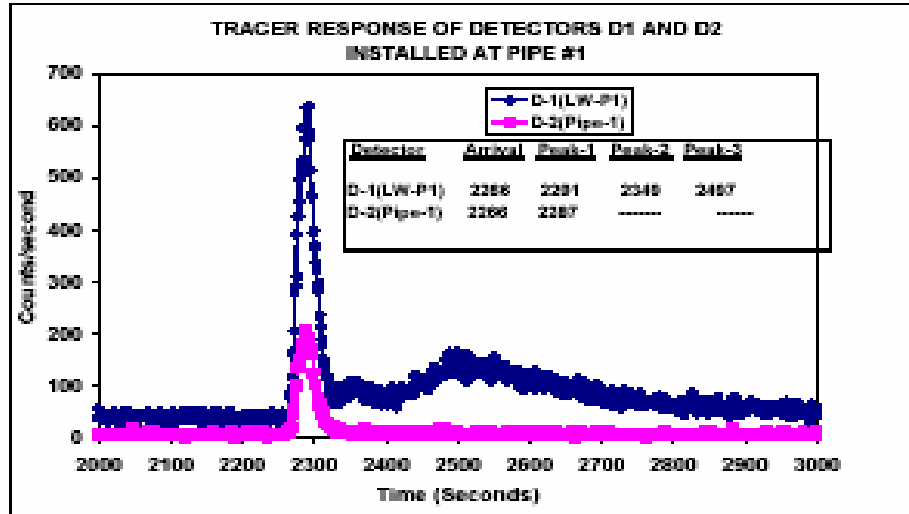


FIG. 68. Radiotracer response of detectors D1&D2 at pipe #1

**Tracer response of detectors D3 & D4 installed at pipe #2:**

Radiotracer response of detectors D3 and D4 installed at pipe #2 is shown in figure 69. The arrival of radiotracer at detectors D3 & D4 is recorded at the same time i.e., at 2269 seconds (3 seconds after radiotracer arrival inside pipe #1). Detector D3 has recorded two peaks, peak-1 is due to tracer flowing inside pipe #2 and peak-2 is due to leakage. However, detector D4 has recorded only one peak because it is seeing radiotracer flowing inside pipe #2 only and is blind to radiotracer present in leakage water.

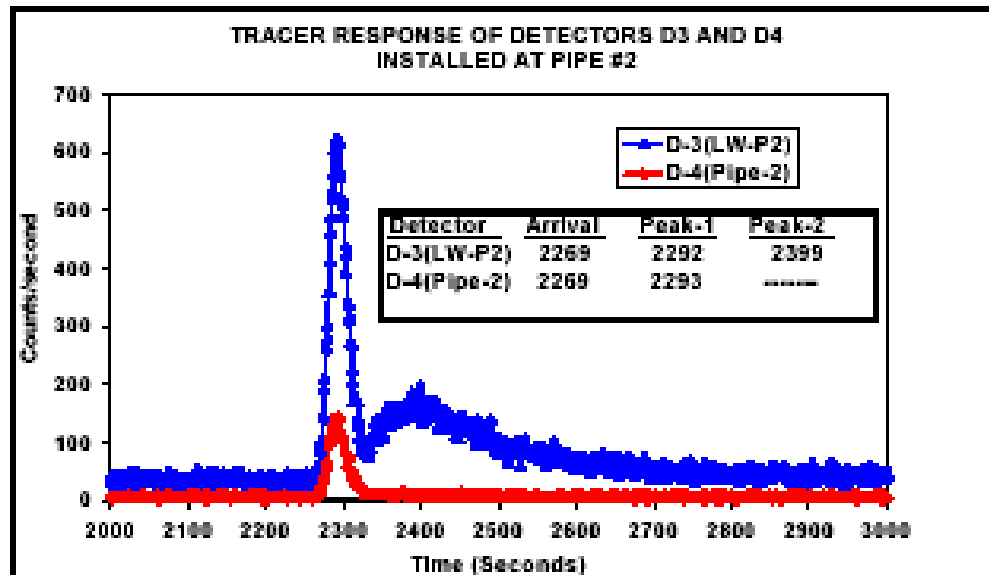


FIG. 69. Radiotracer responses of detectors D3&D4 at pipe # 2

**Tracer response of detector D5 installed at water pit near pipe #3:**

Radiotracer response of Detector D5 installed at water pit adjacent to pipe #3 is shown in figure 70. Arrival of radiotracer at detector D5 is recorded at 2272 seconds. This detector has recorded two peaks. Peak-1 is recorded at 2292 seconds and it is due to radiotracer inside pipe #3 while peak-2 recorded at 2389 seconds is due to leakage.

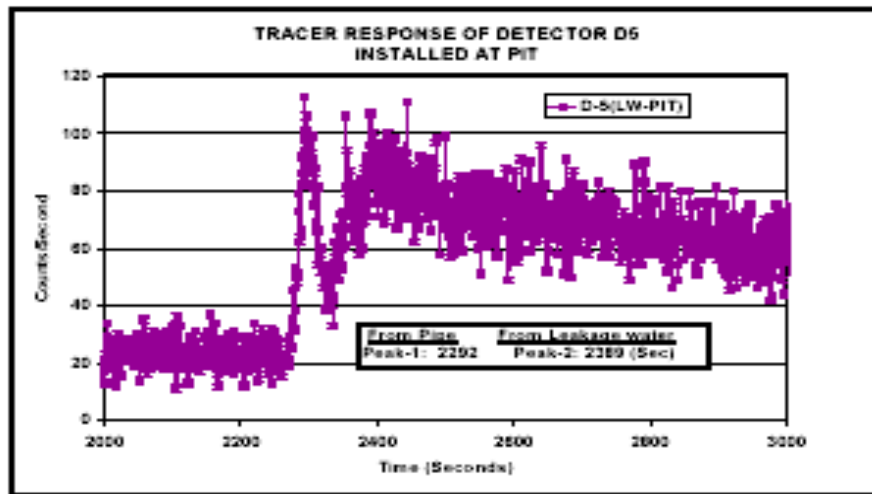


FIG. 70. Radiotracer response of detector D5 at water pit

**Tracer response of detectors D6 & D7 installed at pipe #3:**

Radiotracer response of detectors D6 and D7 installed at pipe #3 is shown in figure 71. The arrival of radiotracer at detectors D6 & D7 is recorded at the same time i.e., at 2272 seconds (3 seconds after radiotracer arrival at pipe #2). Detector D6 has recorded two peaks. Peak-1 is due to tracer flowing inside pipe #3 and peak-2 is due to leakage water. However, detector D7 has recorded only one peak because it is seeing radiotracer flowing inside pipe #3 only and is blind to radiotracer present in leakage water.

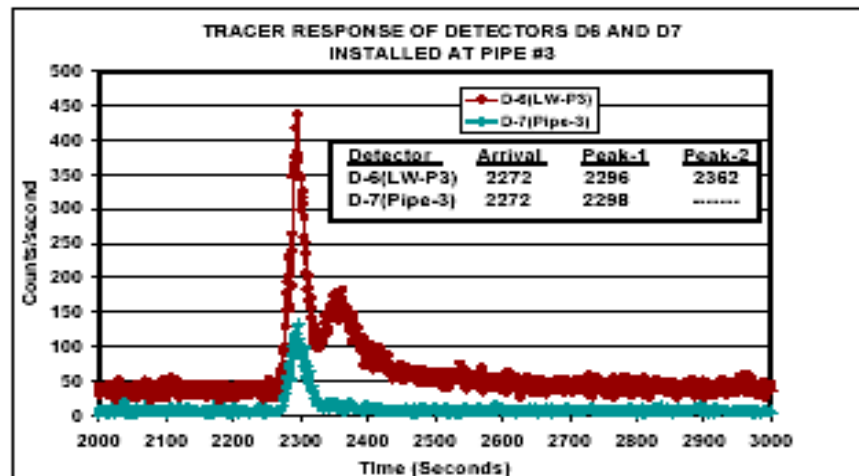


FIG. 71. Radiotracer responses of detectors D6&D7 at pipe #3

#### ***Tracer response of detectors D2, D4 and D7:***

Tracer response of collimated detectors D2, D4 and D7, which are monitoring radiotracer flowing inside the pipes only, is combined in figure 72. The response of these detectors shows only one peak that is from the radiotracer passing inside the pipe. The arrival of radiotracer at detector D2 is recorded at 2266 seconds with peak maximum at 2287 seconds. The arrival of radiotracer at detector D4 is recorded at 2269 seconds with peak maximum at 2293 seconds. The arrival of radiotracer at detector D7 is recorded at 2272 seconds with peak maximum at 2298 seconds. This shows that radiotracer, flowing inside the pipeline, arrives from pipe #1 to pipe #2 in 3 seconds and again from pipe #2 to pipe #3 in 3 seconds.

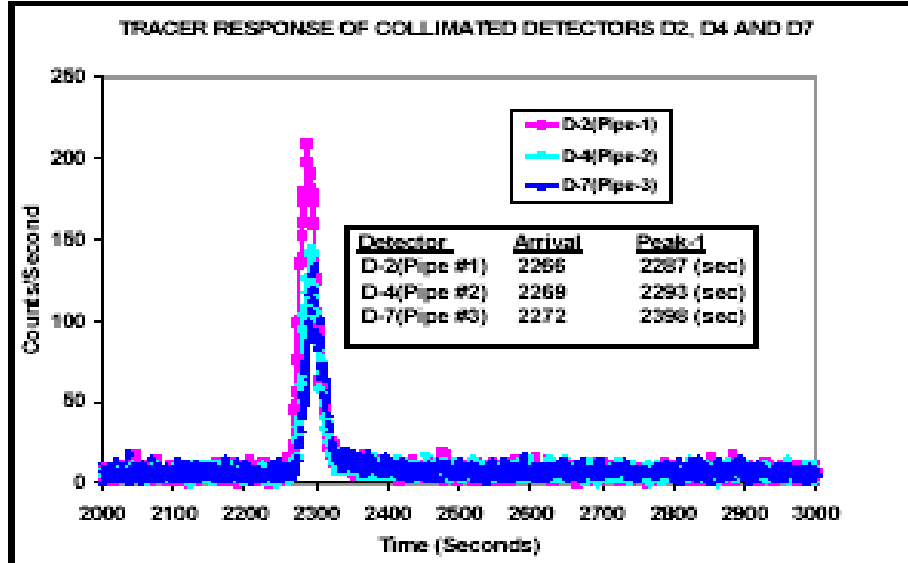


FIG. 72. Radiotracer responses of collimated detectors D2, D4 and D7

#### ***Tracer response of detectors D1, D3, D5 and D6:***

Tracer response of un-collimated detectors D1, D3, D5 and D6, which are monitoring radiotracer flowing inside the pipes as well as from leakage water, is combined in figure 73. Radiotracer arrival at detectors D1, D3 & D6 is recorded exactly at the same time as it is recorded at collimated detectors D2, D4 & D7 respectively. Detector D5 also recorded the same arrival time as that of Detector D6 & D7. Peak-1 of all the four detectors represents the radiotracer passing through the pipes while peak-2 of all detectors and peak-3 of detector D1 represent the leakage water.

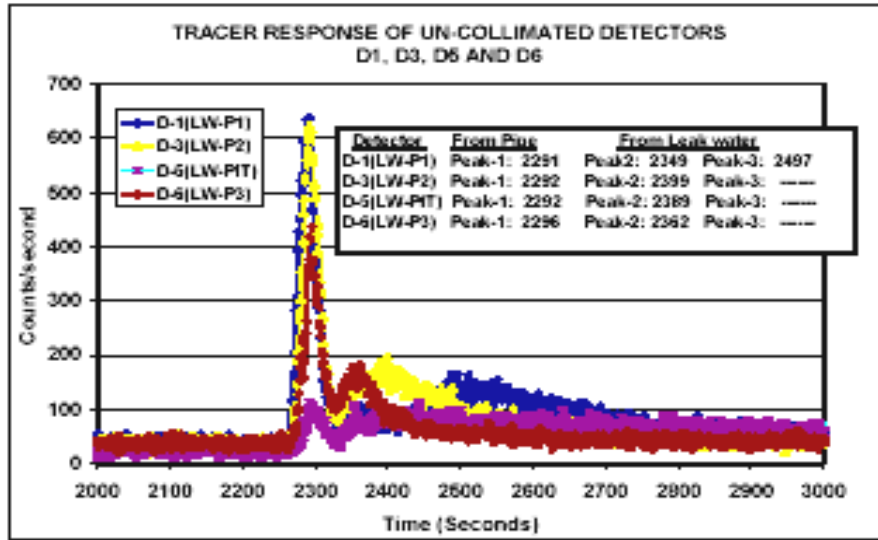


FIG. 73. Radiotracer responses of un-collimated detectors D1, D3, D5 and D6

#### 4. Conclusions

- Leakage peak first appears at detector D1 (installed at pipe #1) at 2349 seconds which indicates leakage near pipe #1 and then it appears at detector D6 (installed at pipe #3) at 2362 seconds indicating leakage near pipe #3.
- The leakage water near pipe #3 travels backwards in the soil along the outer surface of the pipeline and reaches the detector D5 (installed in pit water) at 2389 second. The same leakage water travels further backwards and reaches detector D3 (installed at pipe #2) at 2399 seconds. This leakage water travels further more towards pipe #1 and reaches detector D1 (installed at pipe #1) at 2497 seconds.
- The leakage near pipe #1 is not recorded at any other detector except detector D1 installed at pipe #1. However, the leakage near pipe #3 is first recorded at pipe #3 (2362 sec.) then at water pit (2389 sec.), then at pipe #2 (2399 sec.) and later on at pipe #1 (2497 sec.).
- Leakage peak corresponding to pipe #1 contains maximum of 109 counts/second while the peak, corresponding to leakage water from pipe #3, arriving at pipe #1 (peak-3 of detector D1 installed at pipe #1) contains 165 counts/second at the same position. This higher count rate of 165 counts/second shows a higher leakage rate near pipe #3. This higher count rate is despite the fact that this leakage water is further diluted while traveling from pipe #3 to pipe #1 before reaching detector D1.
- This situation shows that the leakage near pipe #1 is small as compared to leakage near pipe #3. The higher rate of leakage near pipe #3 is maintaining hydrostatic pressure around leakage point and nearby surroundings and is not allowing the leakage water near pipe #1 (which is smaller in quantity hence at lower pressure) to flow towards pipe #2, water pit and pipe #3.

*Result:* Leakages were found near Pipe #1 and Pipe #3. Leakage near pipe #1 is small as compared to pipe #3. There is no leakage near pipe #2.

### 3.4. RADIOTRACER TECHNIQUE USING “PIG” FOR LEAK DETECTION IN UNDERGROUND PIPELINES

#### 3.4.1. Principle of the method

The general principle of the method consists in introducing to the underground pipe a radiotracer, which after having mixed with the working medium travels towards the leak, where it is adsorbed on natural (soil, thermal insulation) sorbents. The detection of the radioactivity is performed by a pig (pipeline inspection gauge) sensor for recording signals inside the pipeline. Radiation detection pig consists of the gamma radiation detector and data logger assembled together inside a compact watertight tool (cylinder). Pig moves inside the pipelines. It has higher efficiency in leak detection due to close contact with the leak surrounds. Radiometric measurement carried out by pig permits to precisely locate the leak or to exclude its presence. Figure 74 gives the principle of radiotracer leak detection in buried pipelines using pig technique.

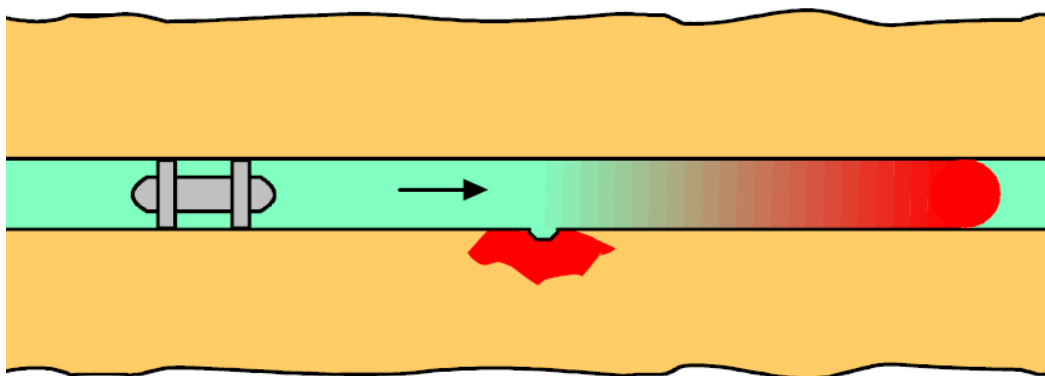


FIG. 74. Principle of radiotracer leak detection in underground pipelines

Basic advantages of the radiotracer pig detection technique for searching and locating leakage in pipelines are: ease of using, short time of experiment, relatively low cost (around 1000 \$US/km), short preparatory time to make an object ready for inspection, and very high sensitivity.

#### 5.4.2. Control of pipelines with cleaning chambers (pig launcher or injector)

The importance of cleaning chamber is to introduce the pig detection system into the pipe. Both gas and liquid radiotracers are used depending on the flow phase flowing inside the pipeline. In the case of gas transporting pipelines the gaseous methyl bromide labeled with bromine-82 is mostly employed; Ar-41 can be used as well. In the case of liquid flow pipelines, the  $\text{NH}_4^{82}\text{Br}$ ,  $\text{K}^{82}\text{Br}$ , and  $\text{Na}^{131}\text{I}$  are used in case of water, and dibromobenzene labeled with Br-82 ( $\text{C}_6\text{H}_4^{82}\text{Br}$ ) is a good tracer of organic fluids. There are two kinds of dibromobenzene molecules, para and ortho dibromobenzene ( $p\text{-C}_6\text{H}_4^{82}\text{Br}$  and  $o\text{-C}_6\text{H}_4^{82}\text{Br}$ ). Di-bromo parabensene ( $p\text{-C}_6\text{H}_4^{82}\text{Br}$ ) is more often used for leak detection in organic phase.

The radiotracer is introduced to the medium flowing in the pipeline directly from special containers with the aid of compressed air or nitrogen. The leak (if present) is detected by means of a special gamma-ray detector-pig (placed in a pressure casing) moving together with the medium. The radiation detection pig is introduced to the pipeline at a preset time after the radioactive tracer has passed. It continuously records the natural background in the pipeline as well as peaks of Br-82 in the leak (if present). The activity of Br-82 in the leak necessary for distinct registration amounts to 1-10  $\mu\text{Ci}$  (37-370 kBq).

The obtained record called “general localization of the leak” provides information as to the location of the leak with an accuracy of several to several tens meters depending on the distribution frequency of distance markers (Co-60 sources) placed on the outer walls of the pipeline.

Accurate location of the leak is obtained by carrying out radiometric measurements of the ground below or the space above the pipeline in the zone selected on the basis of the “general localization”. The minimum detectable leak is  $500 \text{ cm}^3/\text{h}$ . It is possible to control pipelines with diameters of 200 to 600 mm. The control of pipelines with cleaning chambers is carried out during their normal exploitation.

### **3.4.2. Control of pipelines without cleaning chambers**

The control of pipelines to which a follow-up detector (pig) cannot be introduced is based on the detection of gamma radiation emitted by the tracer that penetrates through the leak in the pipeline and migrates towards the surface of the ground. That means if there is no possibility to introduce the pig inside the pipeline, the only known technique if the detection from the surface above the pipeline described above; but this surface detection technique has little chance to detect leaks when the pipeline is buried more than 1 m from ground surface). Nevertheless, you can try it.

The detector is moved just above the ground surface along the whole length of the pipeline. For this purpose the examined section of the pipeline must be shut down in order to make it possible to follow and control the movement of the tracer. The sensitivity of leak detection does not exceed 1 L/h. As explained above, the way of examination depends on the expected size of the expected leak as well as the length and the diameter of the pipeline. These factors affect the rate of movement of the tracer along its way from the site of labeling to the leak. The surface detection techniques that are still valid for this case are:

- Method of labeling the whole volume of the pipeline
- Method of single pulse dispensing of the tracer
- Method of pulsed dispensing of the tracer at several points of the pipeline.
- Method of pulse injection of the tracer with simultaneous pumping in the gas.

These methods are used for control of pipelines of limited length with expected large leaks. Taking into account that single pumping of the gas may be insufficient for the radiotracer to reach the leaks, the compressing of the gas is carried out continuously under constant pressure. Continuous pumping is advantageous for location of leaks because it accelerates the detection process. In order to quickly locate the leak it is necessary to maintain a constant inflow of the gas to compensate its out flow through the leaks.

### **3.5. LOCATION OF LEAKAGE IN UNDERGROUND PIPELINES WITH CLEANING CHAMBERS USING PIG TECHNIQUE.**

Pig technique is used only in those pipelines where the introduction/recover of the pig into/from the pipe is possible. There might be different ways to introduce/recover the pig into/from the pipe, but the most common mode of pig introduction into a pipeline is through a cleaning chamber (pig launcher or injector). Generally, almost all long and important oil and gas pipelines have cleaning chambers (or launcher/recover), which are used for different purposes (cleaning pipe inside walls from the wax and other impurities or using other NDT inspection tools). The following text will deal with pipelines that have (or can easy install) a pig launcher/recover possibility.



### 3.5.1. Method and tracer

In general, the method of radioisotope leak control is based on recording the intensity of radiation coming from the tracer in the leakage. The tracer is introduced into the pipeline. Under the effect of pressure or working medium movement it is passing in the direction of the leakage, then acts outside and is absorbed in the soil around the leakage for some time. Radiometric measurement allows precise location or excluding of leakage.

The most commonly used radiotracer for both gas and oil transporting pipelines is gaseous methyl bromide labeled with bromine Br-82. Methyl bromide  $\text{CH}_3\text{Br}$  is an organic halogen compound. It is a colorless gas at room temperature and a liquid below  $4.6^\circ\text{C}$  or when compressed. It is usually shipped as a liquefied, compressed gas. Specific gravity as a gas 3.27 (air = 1).

The gaseous methyl bromide labeled with Br-82 has been proved to be the best tracer for detecting leaks in underground pipelines. This compound is synthesized from potassium bromide irradiated in reactor in the thermal neutron flux. Conversion of solid potassium bromide to gaseous methyl bromide proceeds in especially constructed mobile chemical reactor called methyl bromide generator according to the following reaction:

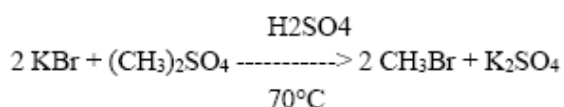


Figure 75 shows the methyl bromide generator system constructed in Poland.



FIG. 75. Methyl bromide gas generator: converting  $\text{K}^{82}\text{Br}$  to gaseous  $\text{CH}_3^{82}\text{Br}$

Figure 76 shows the construction of the Polish methyl bromide generator. The generator can be used for a radioactive tracer of maximum activity of 10 Ci (370 GBq). It consists of two lead containers (15 cm Pb) mounted on a steel plate, a reaction vessel, a dispenser, fittings and a thermostat. The overall weight of the generator is 900 kg. Labeling of the examined object (pipeline), i.e. filling the pipeline with gaseous tracer from the generator is carried out with the aid of compressed nitrogen from a small gas cylinder ( $2000 \text{ cm}^3$ ).

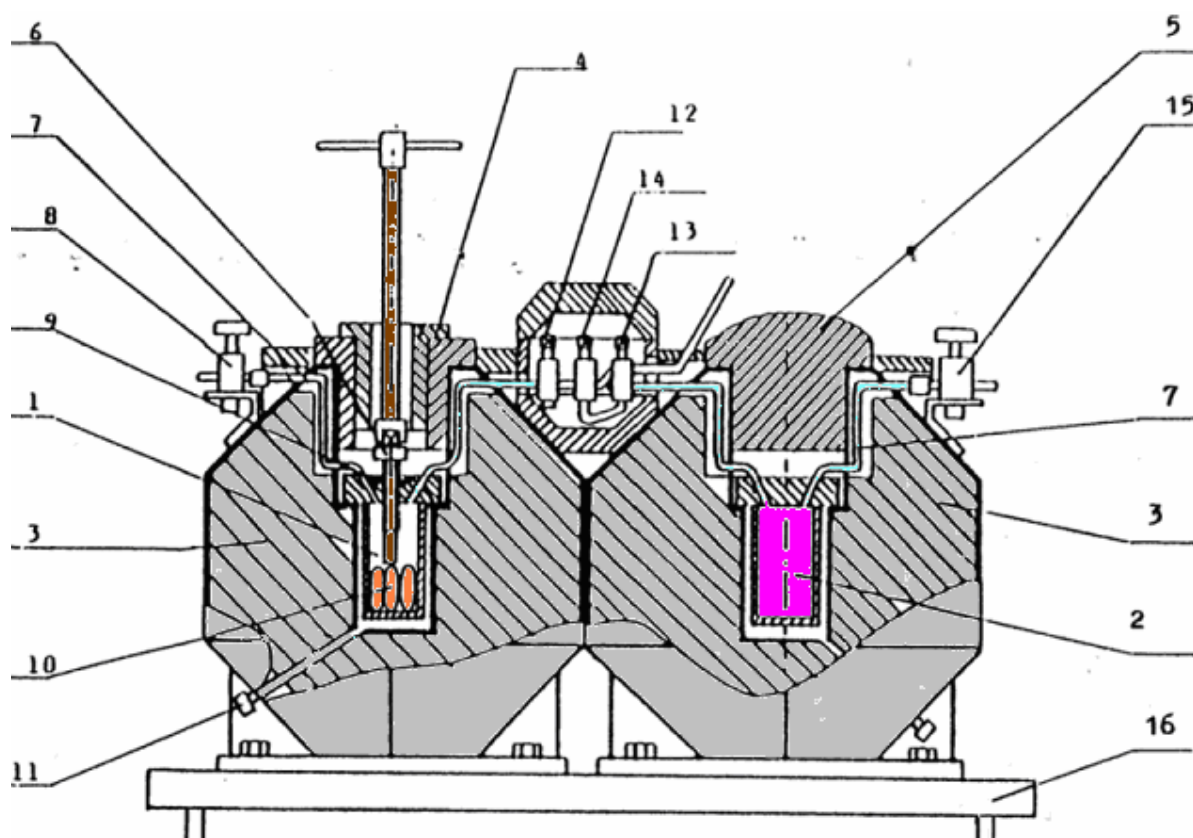


FIG. 76. Construction of the Polish methyl bromide generator

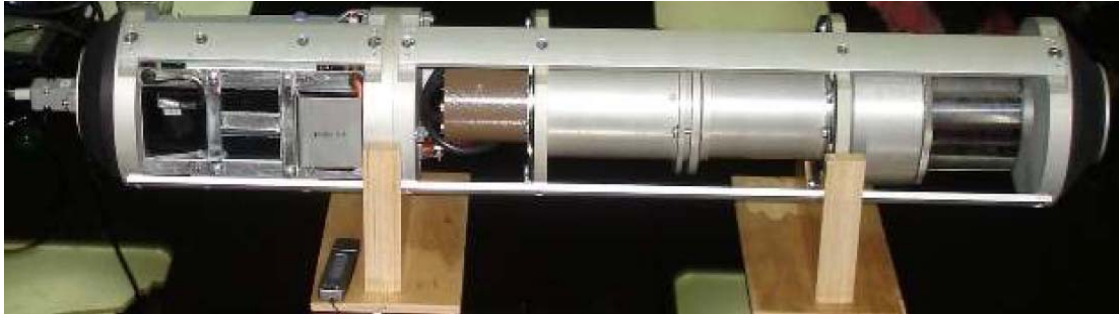
The Polish methyl bromide generator consists of these parts:

1. Methylene bromide generating system (reaction vessel),
2. Methylene bromide generating system (feeder)
3. Lead container
4. Protective plug
5. Protective plug
6. Breakdown mill
7. Steel pipe
8. V1 valve
9. Teflonseal
10. Quartz ampoules with potassium bromide
11. Pipe for carrying away water supplied by the thermostat
12. V2 valve
13. V3 valve
14. V4 valve
15. V5 valve
16. Steel plate

### 3.5.2. Polish pig for leak inspection in underground piping

The radiation detection pig (or mobile radiation detector) is designed for measuring and recording radiation intensity of a radioactive tracer absorbed at the leak inside a pipeline. The measurement is carried out inside the piping. The detector is adapted to operation inside the piping. It is shockproof and resistant to mechanical damage. The detector operates in gas-tight housing. The measuring and recording units are supplied from batteries, which can be used continuously for 100 hours. The detection sensitivity is 37 kBq/1  $\mu$ Ci of Br-82. It can be used for leak inspection of pipes with diameter 200 – 600 mm.

Figure 77 shows the Polish pig (mobile radiation detector), model DN -1. A NaI scintillation detector is installed inside the pig.



*FIG. 77. Polish pig design*

Hermetic case of the DN -1 (so called “pig”) has the following parameters:

- total length including guides 970 mm
- maximum diameter of metal part 167 mm
- total mass with guides 35 kg.

Figure 78 shows the Polish pig ready for leak testing using radiotracer.



*FIG. 78. Hermetic case of the DN-1 mobile detector (so called “pig”)*

The DN-1 model has the following dimension characteristics:

- diameter 100 mm
- length 660 mm
- mass 8 kg.

DN -1 model has the NaI(Tl) scintillator of 3"x3". The signal coming from the scintillation detector is supplied to the input of the amplifier, which gain can be varied in that way that amplitude of the output signal should not exceed 5V. The counter's content is read each 1 ms. Sum of counts in the programmed time (time per channel) is stored in subsequent 16 bits words in data memory of microprocessor.

Polish detector –data logger system has the following performance characteristics:

- Measuring time can be set in range from 0.1 to 3276 s
- Maximum number of samples (channels) possible to record is 262144.
- Memory records are transferred to the IBM computer with serial transmission interface RS-232 allowing data transmission with speed 19200 bits/s
- Maximum recording time 100 h.

### 3.5.3. Pig detection technique

A watertight tool containing radiation detector coupled to ratemeter and recorder placed in a cylindrical pig (known as radiation detection pig) is sent through the pipeline at a constant speed by hydraulic or pneumatic push. After retrieving the pig at the other end, the recorder is played to see the location of leak with respect to the marker source locations. The precision of leak localization in this case is several meters. Modern pigs have positioning instrument (GPS system) included inside, in addition to detector and data logger. Their precision of leak localization is less than 1 m.

Radiotracer inspection of the pipeline is being made in two pig runs. In the first run the natural background inside the pipeline as well as counting level of Co-60 markers are recorded. They are needed for calculating total activity of tracer, necessary for realization of assumed sensitivity control. In the second run (after radiotracer injected and pipeline washed up) the detection of leaks is being searched. Radiotracer inspection of pipelines is carried out during their routine operation, that means this is an on line and non intrusive test.

Preparation of the pipeline for leak inspection is connected also with installation of distance markers placed in the pits dug at regular intervals on ground level. Co-60 sealed sources of 1-4 MBq (50-100  $\mu$ Ci) are installed in pits above the pipeline to mark the pig records. Calibration markers (three sources Co-60, activities: 0.1, 0.2 and 0.4 MBq) are installed as well at know distances along the pipeline to calibrate the mobile detector and correspond the response with the specific activity. Figure 79 gives the principle of pig detection technique.

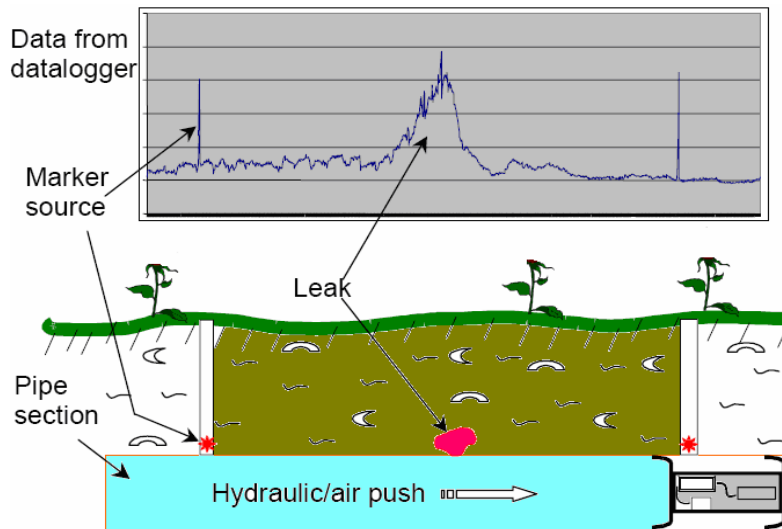


FIG. 79. Principle of detection of an underground leak using "pig"



Figure 80 shows a Co-60 marker installed in a control well above the pipeline.



*FIG. 80. Co-60 marker installed in a control well*

Firstly, radiotracer is pumped into the pipeline as a tracer plug without interrupting process operation. Figure 81 shows injection of methyl bromide (Br-82 10 Ci) from generator to the pipeline.

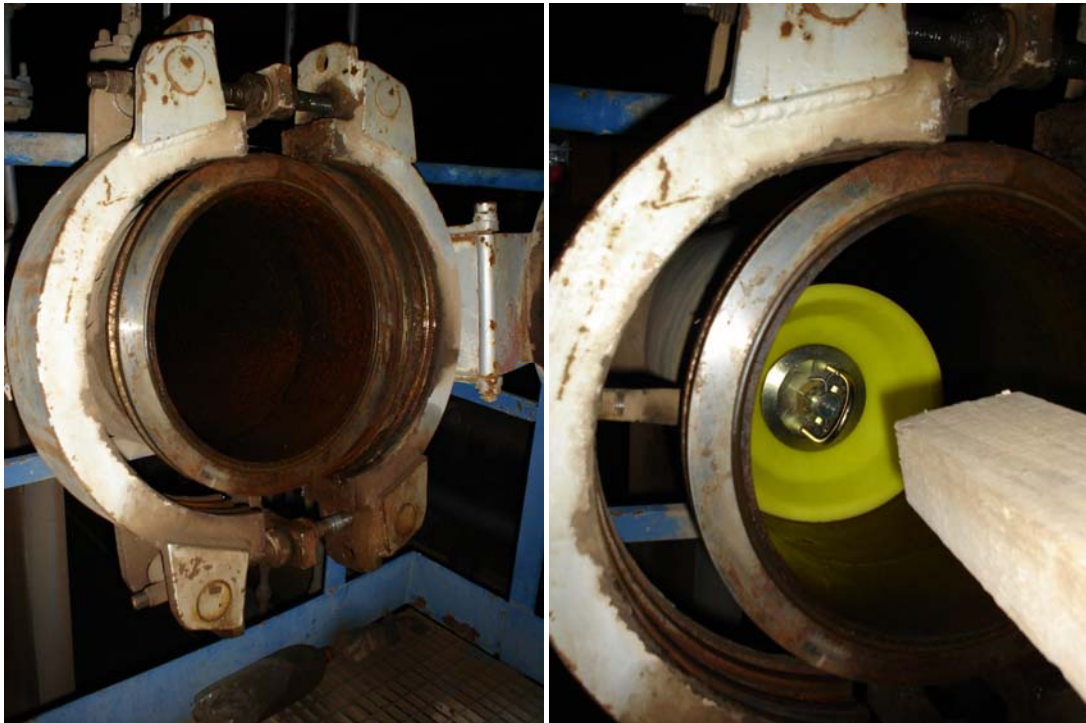


*FIG. 81. Radiotracer gas- methyl bromide ready for injection by manometer gauge*

Where the “tracer plug” meets holes or fractures a small amount of the tracer will penetrate and be trapped outside the pipe wall. The fluid (oil or other liquid) following the “tracer plug” will clean the pipe’s internal walls for residues of the radiotracer. In the second step, the radiation detection pig is launched into the pipeline for leak detection run. The pig has to be launched a certain time interval or cleaning distance after the radiotracer plug, long enough to secure the pipe’s interior is free of the “tracer plug”. Figure 82 shows the pig before entering the cleaning chamber of the pipeline, while figure 83 shows the pig already introduced in the cleaning chamber.



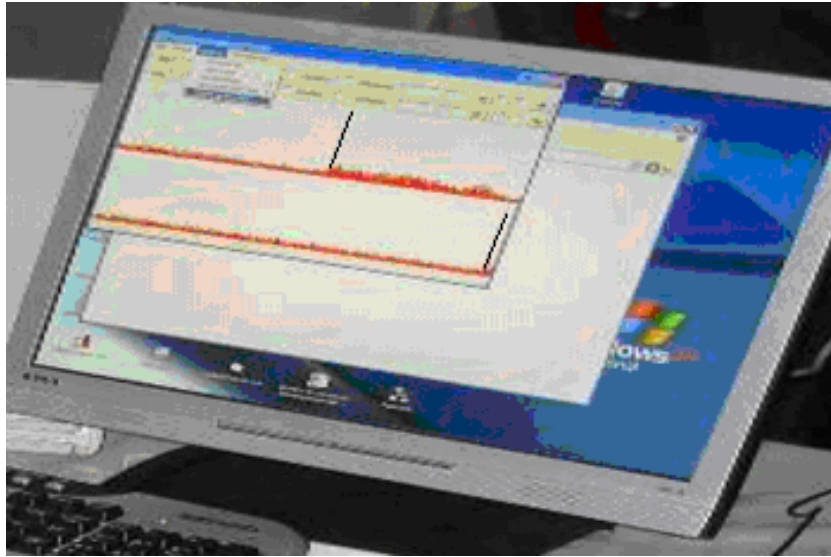
*FIG. 82. Pig ready for entering the cleaning chamber of the pipeline*



*FIG. 83. Introducing the pig into the cleaning chamber of the pipeline*

The pig will record during its run the background radiation and additional radiation from tracer leaked to the external side of the pipe. The pig is retrieved at the end of the inspected pipeline.

Analysis of results obtained from the passage of the pig inside the whole pipeline is done just after the test finishes. The data acquisition software allows the automatic search of markers and leaks providing the real distance from the starting point.



*FIG. 84. PC screen showing the pig records; background (red line), markers and no leak.*

The following types of radiation are recorded by the pig:

- distribution of natural radiation in the area surrounding the pipeline
- radiation intensity coming from the radioisotope distance markers
- radiation intensity coming from radioisotope calibration markers
- leak peaks if any.

The test performed in a 40 km gas pipeline concluded that no leak is present in this line (Figure 84).

### **3.6. A SENSITIVE PIG METHOD FOR ONLINE LEAK INSPECTION IN UNDERGROUND OIL PIPELINE.**

#### **3.6.1. Danish pig method**

FORCE Technology, Denmark has developed a very sensitive pig method for online leak detection in underground pipelines. The trials of the pig method were performed in the 16" and 20" test loops in underground oil pipeline. Pig has two sections composed of a "Driving module" and a "Detector module". The Driving module houses power supply and odometer instrument for determination of travel distance. The Detector module houses two highly sensitive radiation detectors and their data logger. The leakage inspection with this pig has proven to be capable of identifying very small leaks – less than 1/10 of the capability of e.g. acoustic leakage pigs. In oil pipelines like the Danish carrying 1500 m<sup>3</sup>/h leakages down to 1 liter per hour can be detected. Leakages can be positioned with a precision of less than 1 meter.

Figure 85 shows the Danish test pig for 16" pipelines: there are two flexible parts: driving and detection parts.



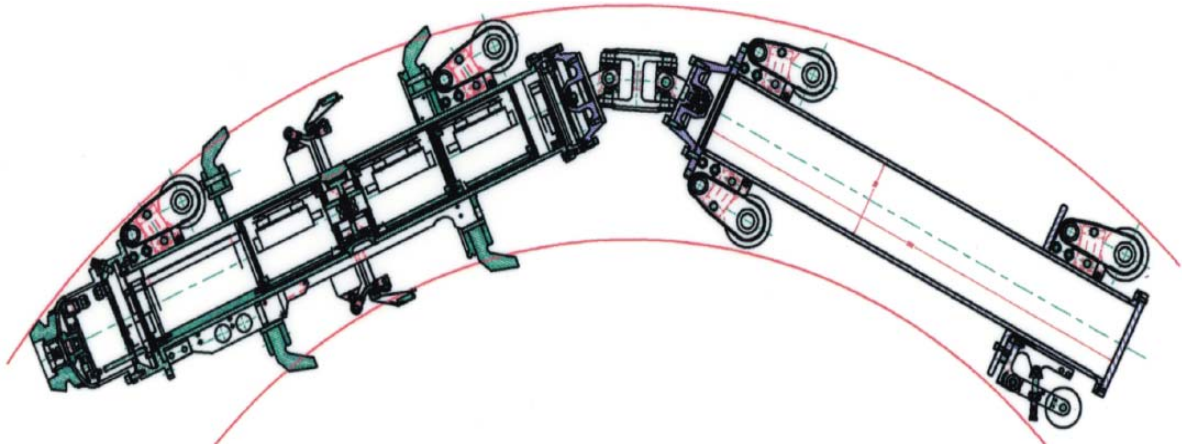


FIG. 85. Danish pig for leak detection in underground oil pipelines using radiotracer: driving pig and detection pig

Figure 86 shows the 16" launcher during a test loop trial.



FIG. 86. Test loop trial

Figure 87 shows the result of calibration of the pig during test loop trial in the 16" pipeline.

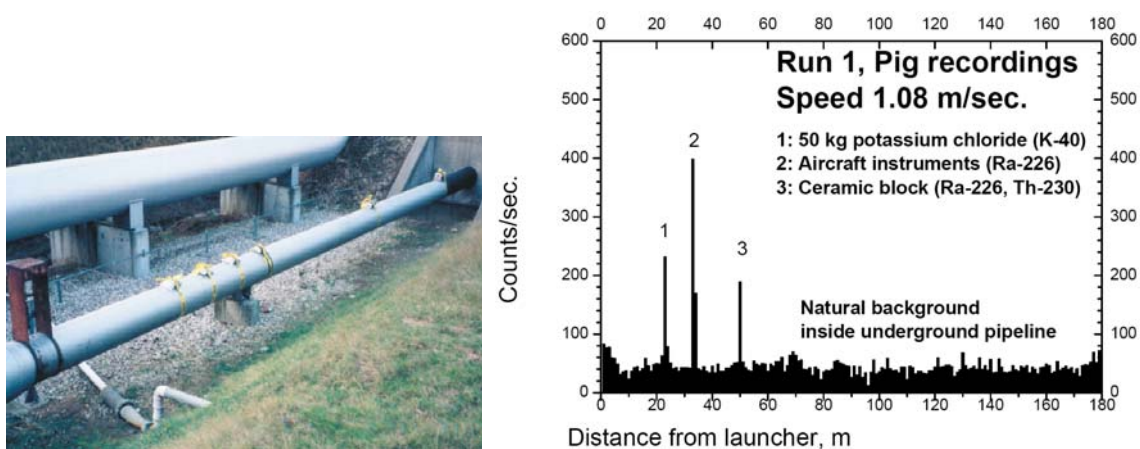


FIG. 87. Pig detection sensitivity calibration in test loop trial

The second test of the online pig method was conducted in a 20" oil pipeline under the normal operation of the line. The underground pipeline was 106 km long and had 13 valve stations. The oil flow rate was 1500 m<sup>3</sup>/hour. Figure 88 shows the pig launcher part of the pipeline (left), and the pig injector inside the launcher (right).



FIG. 88. Launcher(left) and pig injector (right)

Figure 89 shows the pipeline terminal where the pig was recovered after the test.



FIG. 89. Pipeline terminal where the pig was recovered at the end of test





FIG. 90. The driving pig carrying wax from the pipeline

After recovering and opening the pig, the signal recorded during the test was developed in the PC. Figure 91 shows a typical record.

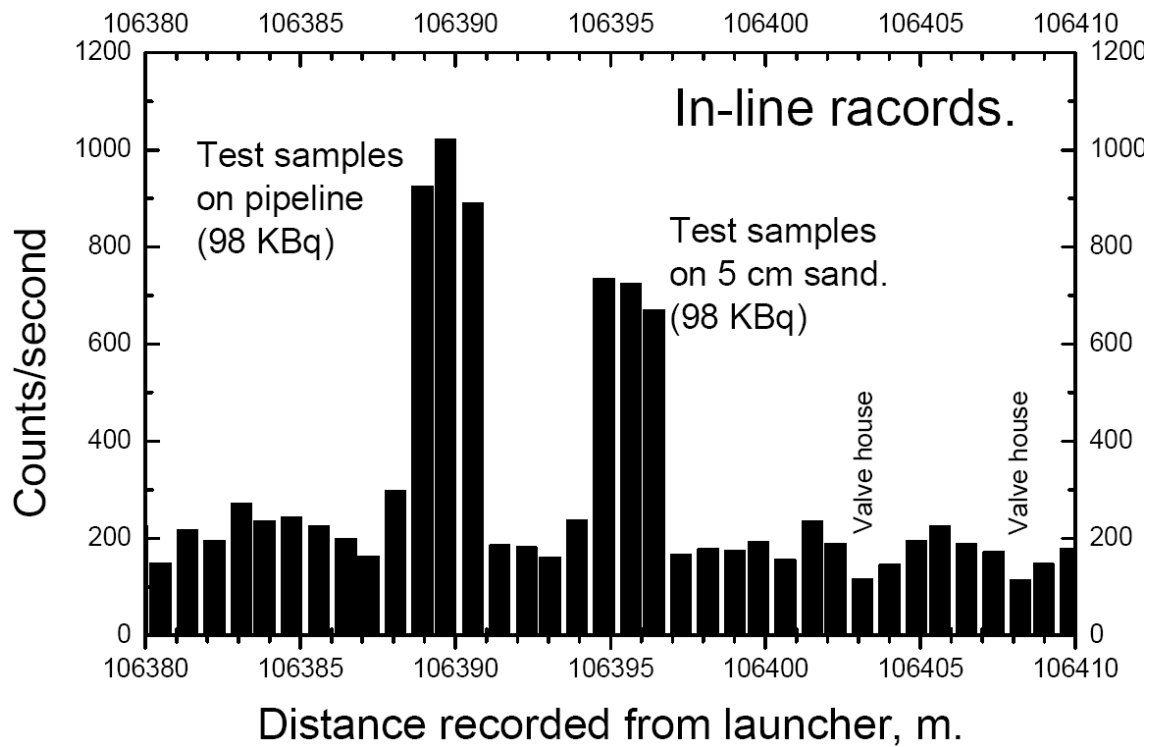


FIG. 91. Pig record

**Conclusion:** It has been assessed that leak rates down to 1 L/h may be detectable on the 20" oil pipeline. Leaks can be positioned with accuracy less than 1 m.

*Note: The pig method for leak detection in underground pipelines is mostly employed for oil and gas pipelines where the cost benefit ratio is huge. But it can be used for leak inspection in any kind of liquid or gas transporting pipelines where other conventional methods are unsuccessful; it could be for example a water transporting pipeline with particular importance and site conditions.*

*At FORCE Technology, Denmark a tracer assisted on-site leak testing of three central heating transmission pipelines under installation in a 4.2 m diameter tunnel system constructed 40 m below central Copenhagen is planned to be carried out soon. It is 500 mm diameter stainless steel pipelines with external insulation and a covering steel mantel. Two of the pipelines are 2.5 km long and one is 1.5 km long and all assembled by welding together 12 meter long sections. These pipelines shall be pressure tested and if the pressure test indicate leaks these must be located. A tracer assisted leak detection method is recommended. KBr-82 as radiotracer will be employed and that will be injected into the water used during the pressure testing of the pipeline. The Pipeline Leak Detection Pig incorporating a 3"x6" NaI scintillation detector will be introduced inside the pipeline through the cleaned media chamber. A background detection test will be performed prior to the leak test in order to calculate the sensitivity of the leak test. It is calculated that 400 m<sup>3</sup> water will be labeled with radiotracer; a safe removal of the 400 m<sup>3</sup> tracer labeled water from the pipe is foreseen as well from radiation protection point of view.*

### **3.7. SIMPLE LOW COST DETECTION PIG**

Commercial radiation detection pigs are relatively expensive in the market. They cost around \$US 50000. Of course, they pay off the initial price very fast and even generate a huge income when dealing with oil pipelines. But for small tracer groups and seldom use of the pig, simple and low cost radiation detection pigs are preferred.

Figure 92 shows a simple home made radiation detection pig, where a Minekin data logger and a NaI 2x2" probe were tighten together and introduced into the pipeline.



*FIG. 92. Simple home made detection pig*

In fact, this very simple pig might not be reliable and operational in harsh condition of real oil and gas pipelines. The tracer group of the Bhabha Atomic Research Center (BARC) in India is designing and developing simple low cost radiation detection pigs. Figure 93 shows a pig constructed at the BARC, India.



*FIG. 93. Simple low cost pig designed and constructed in India*

After laboratory trials and partial real industrial tests, the Indian tracer group at the BARC is developing further this simple and low cost pig to make it operational in harsh field conditions. The radiotracer pig they are developing have the following features:

- Battery operated unit (Dry cell or Duracell's for 8 Hrs.)
- Integral with 2"x 2" NaI(Tl) detector, HV supply, pulse processing electronics, data acquisition and storage
- Flash card memory for data storage and retrieval
- Water tight stainless steel enclosure
- Counting time : Settable between 1 to 999 seconds
- No of Events: Up to 100000
- HV Supply: Settable up to 1000V @ 100 $\mu$  Amps

***Case study: Leak detection in an underground pipeline using Indian radiation detection pig***

A 12" diameter 62 km length pipeline wrapped with 5 mm polyethylene buried 1-1.5 m below the soil surface was found leaking. The pipeline was cut into different sections and each section was individually hydro tested.

Out of 62 km length of the pipeline, 59 km was successfully hydro tested and could hold the pressure of 108 kg/cm<sup>2</sup>. A section of length 3 km was finally spared for locating the leak using radiotracer pig method. About 1 Ci of <sup>82</sup>Br in the form of aqueous solution of ammonium bromide was used as radiotracer. Diluted radiotracer was filled in the pipe section and was pressurized to 108 kg/cm<sup>2</sup>. Since the leak rate suspected was about 40 liters per minute, the pipeline was kept under pressure for about four hours. The pipe section was then thoroughly washed with water. The marker sources (50 µCi <sup>60</sup>Co sealed source) were placed in dug pits at an interval of 350 m.

The detection pig was made to move inside the pipeline with uniform velocity using water pressure. After about 4 hours inspection the pig was received at the other end. Data from the datalogger was downloaded in a PC and analyzed (Fig. 94).



FIG. 94. Radiotracer pig records

The obtained experimental results are presented in the figure 95. One peak was observed between starting point and first marker source. Another one was observed between second and third marker Co-60 sources. These two peaks other than marker sources correspond to two leaks.

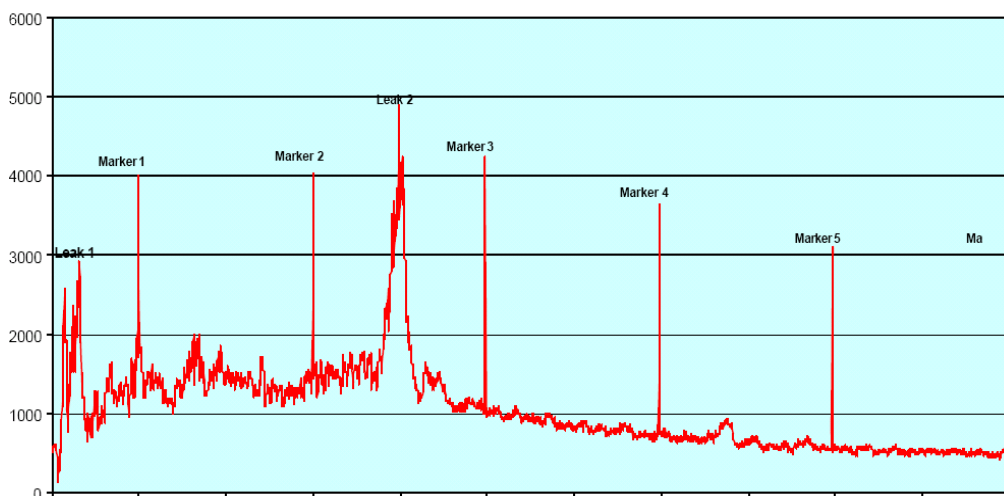



FIG. 95. Two leak peaks and marker signals recorded by the pig

**GUIDELINES FOR TESTING FEED / EFFLUENT HEAT EXCHANGER SYSTEMS  
USING RADIOACTIVE TRACERS**

		
<b>International Atomic Energy Agency (IAEA)</b>		
<b>GUIDELINES FOR TESTING FEED / EFFLUENT HEAT EXCHANGER SYSTEMS USING RADIOACTIVE TRACERS</b>	C. No.	
	Rev. No.	0
	Date	
	Page	1 of 7
<b>CONTENTS –</b>  1 OBJECTIVES 2 SCOPE 3 METHOD STATEMENT 4 RESPONSIBILITIES 5 WORKSCOPE PLANNING 6 EQUIPMENT REQUIREMENTS 7 EXECUTION OF WORK AT WORK SITE 8 DATA PROCESSING AND REPORTING  APPENDIX 1 – SELECTION OF RADIOTRACER APPENDIX 2 – CALCULATION OF QUANTITY APPENDIX 3 – INJECTION EQUIPMENT APPENDIX 4 - CALCULATION OF LEAK SIZE APPENDIX 5 – EXAMPLE OF TECHNIQUE  REFERENCES		
<b>1. OBJECTIVE</b>  Radioactive tracer techniques are widely used in the oil, gas and chemical industry for detecting leakage in banks of feed /effluent heat exchangers. These guidelines are written to show the steps that should be taken to enable the leakage tests to be carried out in a systematic manner. It is also intended that the guidelines can be incorporated into the service providers own quality system, whilst at the same time giving sufficient latitude to enable the supplier to vary the procedure to meet specific test requirements.		
<b>2. SCOPE</b>  The guidelines shall be applicable to leakage testing in banks of feed / effluent type's heat exchangers. using radioactive tracer techniques.		
<b>3. METHOD STATEMENT</b>  A sharp pulse of suitable radioactive material is injected into the process material, upstream of the exchanger bank on the high pressure side. Any leakage within the system will be from the high pressure side to the low pressure side. Because the radioactive tracer mixes thoroughly with the inlet fluid, if there is a leakage within the system some of the radioactive tracer will enter the low pressure side. Suitable deployment of sensitive radiation detectors will confirm the presence of a leak and indicate which one of the exchangers is leaking. Detailed analysis of the data will enable the size of the leak to be quantified.		



#### 4. RESPONSIBILITIES

To enable leakage tests to be carried out efficiently, responsibilities should be clearly defined prior to any work taking place.

They usually take the following format:-

**Client** – Responsible for supplying the service provider with sufficient information to enable the work to be carried out, safely, and efficiently in an agreed manner. It is expected that he will provide such help and assistance as could reasonably be expected between contractor and client, be responsible for providing safe access and issuing an appropriate work permit.

**Projects Manager** - Person ultimately responsible for the planning and execution of entire job. This includes defining the work scope, allocation of sufficient trained and competent manpower and resources to conduct the work. He is responsible for ensuring compliance with any statutory legislation to ensure protection of the workforce, members of the public and the environment. He is ultimately responsible for interpretation of the obtained data and supplying a suitable report to the customer within an agreed time period.

**Senior Field Technician** – The person on-site responsible for carrying out the instructions of the Projects Manager. He shall be responsible for ensuring that the site work is carried out safely and in accordance with the agreed workscope. He will ensure that suitable barriers and warning signs are deployed so as not to compromise the safety of the site workforce and members of the public.

**Junior Field Technician** – Depending upon the complexity of the proposed work there will be one or more junior field technicians. They will be responsible for safely and efficiently carrying out the instructions of the Senior Field Technician.

#### 5. WORKSCOPE PLANNING

Prior to carrying out any work the Projects Manager should agree with the client the objectives of the work. He will need to ascertain the composition of fluids within the system, the temperature and pressure inlet and exit each exchanger and also the phase composition. He must ascertain the flowrate through the system and agree the sensitivity of the test.

#### 6. EQUIPMENT REQUIREMENTS

Equipment required for on-line feed effluent heat exchanger leakage testing will depend upon the precise nature of the agreed work. It will comprise the following:

- Suitable radioactive tracer
- Suitable injection equipment
- Suitable detecting system
- Suitable data acquisition system
- Appropriate “tools of trade” such as radiation and contamination monitors, barriers, warning notices, activity handling tools, protective equipment

It is recommended that a check list is prepared and items checked off before shipment

## **7. EXECUTION OF WORK AT WORK SITE**

Upon arrival at the work site the Senior Field Technician will ensure that a suitable permit to work is obtained.

- He will inspect the work site and ensure that there is safe access.
- He will visually inspect the type A container to ensure that it is not damaged and confirm by monitoring that the radioactive material is still present.
- He will immediately report any abnormalities and after consultations with the Project Manager take such remedial action as is required.
- He will carry out the leakage tests in the agreed manner.

Any deviation to the agreed leakage test procedure must be approved by the Project Manager after due consultation with the client.

## **8. DATA PROCESSING AND REPORTING**

After carrying out the tests the data will be processed, and the findings relayed to the client. These will be confirmed in a written report to the customer within 14 days or in such time as agreed between the two parties. If no leakage is detected the report must show the minimum detectable limit for the tests.

## **APPENDIX 1- SELECTION OF RADIOTRACER**

When carrying out leakage tests it is essential that the radioactive tracer that is used can physically get to the leakage location on the high pressure stream in order to pass from the high pressure stream to the low pressure stream. Liquid organic, liquid aqueous, gaseous or a mixture of these phases can be encountered. It may be necessary to inject more than one type of radiotracer in order to be certain that the radiotracer will reach the leakage location. This is particularly so when phase changes occurring within the system. It may for example to inject a liquid radiotracer and a gaseous radiotracer.

Among the parameters that should be considered for the selection of a radiotracer are:

- the physico-chemical behaviour, the half life, the specific activity, the type and energy of radiation.
- the physico-chemical behaviour should usually be the same as the material being traced.
- the half life of the radiotracer should be comparable to the duration of the experiment; if the half life is short we can inject a high specific activity.
- the type and energy of radiation should be sufficiently high to penetrate through the material(s) between the process stream and the detectors. The wall thickness will have a significant effect upon the amount of radiotracer that is required.
- The availability of the radioactive tracer

The specific activity is an important factor to be considered from the safety point of view.

Before finally selecting a particular radiotracer a safety assessment should be carried out.

## APPENDIX 2- CALCULATION OF QUANTITY OF RADIOTRACER REQUIRED.

Several factors can affect the calculation of the amount of radiotracer that is required.

These include the following:-

**Sensitivity of the test** – As a general rule the more radioactivity that is injected, then the more sensitive the test becomes and the minimum detectable leakage rate becomes smaller. There are however limits on the amount of radioactivity that it is acceptable to use on a particular test. The use of radioactive material must be justified so that the advantages outweigh the disadvantages. Beyond a certain amount the test can no longer be justified. This quantity must be calculated on each occasion using data supplied by the ICRP.

**Detector efficiency** - Usually we use sodium iodide crystal detectors. The efficiency of detection will vary depending upon the physical dimensions of the crystal and its physical condition. The most efficient detectors should be used to maximise the sensitivity of the test. It is not always possible to have all the detectors with the same efficiency and each detector must be calibrated prior to the experiment so that the areas under the peak can be corrected appropriately.

**Flow rate within the system** - the detector response is dependent on the time that the radioactive tracer is passing in front of it, consequently for higher flows we need more radiotracer.

**Wall thickness** – The detector response will get smaller as the wall thickness is increased.

## APPENDIX 3 – INJECTION EQUIPMENT

The injection equipment depends on the physical nature, the pressure, the temperature and the toxicity of the stream into which the radiotracer is to be injected.

A variety of pumps can be used, but each must be appropriate for the duty that it has to perform. Such pumps may include hand-operated hydraulic pumps, or air operated pumps for stream pressures of up to about 35 bars, for liquid injection into liquid streams. For injection of radioactive gases a system using inert backing gas, such as nitrogen, from a cylinder having a higher pressure than the line pressure may be used.

For high-pressure liquid and gas systems, special injection systems are needed.

It is important to ensure that the injection rig has a higher rating than the duty that it is required to perform.

#### APPENDIX 4 – CALCULATION OF LEAK SIZE

When calculating the leakage size consideration should be given to the following:-

**Detector geometry:** if the lines carrying the medium under investigation are of different size and wall thickness, then the volume of material producing the response at the detector may be different or reduced by the extra metal of the wall. An appropriate correction must be made.

**Difference in pipe diameters:** the detector response is dependent on the time the radioactive tracer is passing in front of it and it is inversely proportional to the velocity.

After all of the relevant factors have been taken into consideration the leakage size can be calculated by comparing the size of the leakage peak with the size of the inlet peak.

It is normal to consider that leakages of approximately 0,1% of the total flow rate can be measured using this technique. However, each case must be calculated individually taking into account the physical features of the equipment under test. Great care must be exercised when using this method, as confusion can be caused by erroneous responses of the leak detector from adjacent pips or vessels carrying the injected radiotracer. In closely-confined congested areas on modern plants, it is generally desirable to surround the highly sensitive leak detector with lead shielding so that it is unresponsive to possible extraneous influences.

## APPENDIX 5 – EXAMPLE OF TECHNIQUE

The following figure gives an indication. This technique is probably the most common and involves the injection of a suitable radiotracer into the process stream, which is suspected of leaking, and seeking the presence of that tracer in the outlet. This can be done by using sensitive radiation detectors mounted externally on the outlet pipes. The system shows one exchanger only. The principle is the same for multiple exchangers.

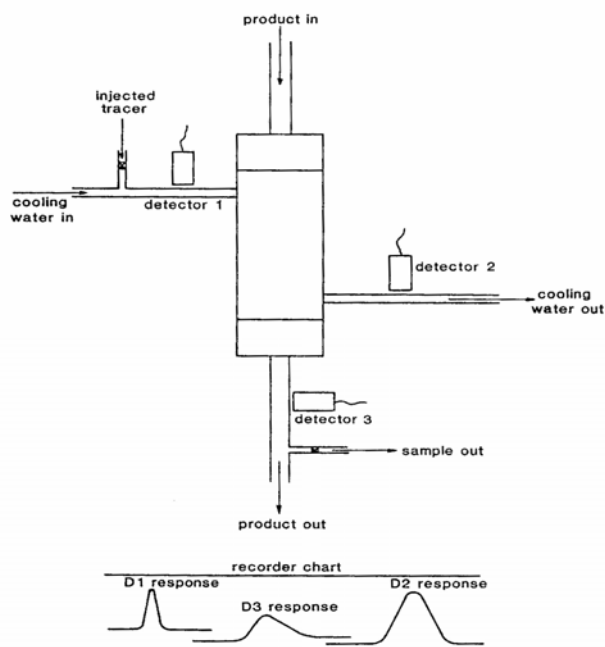


Fig. 1: Leakage detection using external detectors.

The sharp pulse of activity is injected into the inlet on the high pressure side and detectors 1, 2 and 3 are positioned as shown to monitor its passage through the exchanger. Typical detector responses are shown in the figure. Detectors 1 and 2 show the inlet and outlet responses, whilst detector 3 will only respond if there is any leakage from the shell side to the tube side of the exchanger. Calculation of the amount of leakage is made by comparison of the respective areas under the main inlet peak and the leak peak.

Several factors can affect the calculation of the leak size and corrections should be made for the following, if necessary:

- **Different detector efficiencies:** it is not always possible to have all the detectors with the same efficiency and each detector must be calibrated prior to the experiment so that the areas under the peak can be corrected appropriately.
- **Detector geometry:** if the lines carrying the medium under investigation are of different size and wall thickness

## REFERENCES

- [1] Charlton, J.S; (Ed), 1986, "Radioisotope Techniques for Problem-Solving in Industrial Process Plants".
- [2] IAEA, 1990, "Guidebook on Radioisotope Tracers in Industry", Tech. Report Series No 316, Vienna..
- [3] IAEA 2004, "Radiotracer applications in industry – Guidebook", Technical Report Series No. 423, Vienna, June2004.
- [4] IAEA, 2004, "Radiotracer techniques for leak detection:", Brochure, Vienna, March 2004
- [5] TRACERCO, "Leak detection techniques", July 1999, pp. 62-69.
- [6] BROCHURE, Process Vision Services, "Fluid tracing technology", Tracer technology company, Brussels, Belgium, 1997.
- [7] BROCHURE. Process diagnostic services Tru-Tec Services, Process Diagnostic Division, Texas, USA, 2000.

## **BIBLIOGRAPHY RELATED WITH RADIOTRACER APPLICATIONS FOR LEAK DETECTIONS**

- [1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidebook on radiotracer in Industry, Vienna (1990). Technical Report Series n° 316
- [2] CHARLTON J.S. Radioisotope techniques for problem-solving in industrial process plants. Leonard Hill, Glasgow and London, 1986
- [3] FRIES B.A. Method of detecting aircraft fuel line leaks with radioactive gas tracers. US patent document 3,809,898, 7 May 1974
- [4] FRIES.B.A. Krypton-85. A versatile tracer for industrial process applications. Int. J. Appl. Radiat. Isot. (Oct-Nov 1977). V. 28 (10-11), p. 829-832.
- [5] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiotracer technology as applied to industry. TECDOC-1262, Vienna, December 2001
- [6] GARDNER R.P., ELY R.L. Radioisotope measurement applications in engineering, North Carolina, USA, 1967
- [7] KRAS J. ET AL. New tracer and adsorbents for checking the tightness of technological units in petroleum industry. 4<sup>th</sup> Conference on Radioisotope application and radiation processing in industry, Leipzig, 19-23 September 1988. Proceedings, Vol. I, p. 451, Leipzig, 1999
- [8] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiotracer applications in industry A Guidebook. Technical Report Series 423, Vienna, 2004.
- [9] JIN, J-H. ET AL. Radiotracers and labelling compounds for applications in industry and environment. Report of the CM, Warsaw, Poland, 16-19 June 2004
- [10] CHMIELEWSKI A.G., ET AL. Application of radioisotope techniques, 4<sup>th</sup> Conference, Leipzig, 19-23 September 1988, Proceedings, Vol. I, p. 143, Leipzig, 1989.
- [11] BROCHURE, "TRACERCO Diagnostics<sup>TM</sup> Leak Study", published by Tracerco, Billingham UK, 1998.
- [12] TRACERCO NEWS, Vol. 1 Edition 3, 2006.
- [13] CHARLTON J.S., HURST, J.A. Radioisotope techniques for problem solving in the offshore oil and gas. Petroleum technology, 1992.
- [14] GENDERS, S. Brochure on FORCE Institute activities, Denmark, 1997.
- [15] BROCHURE, Process Vision Services, "Fluid tracing technology", Tracer technology company, Brussels, Belgium, 1997.
- [16] HILLS A. Radioisotope applications for troubleshooting and optimizing industrial processes. Brochure, South Africa, 1999.
- [17] PANT H.J. Current status of industrial applications of radioisotopes in India. Technical meeting, RSA/8/107, August 2007, Sri Lanka.
- [18] CHUEINTA S. Radioisotope applications in industry. Thailand country report. AGM, IAEA/RCA Bangkok, October 2003.
- [19] IQBAL HUSSAIN KHAN. Radioisotope applications in industry. Pakistan country report. AGM, IAEA/RCA Bangkok, October 2003.
- [20] ZHANG PEIXIN. Radioisotope applications in industry. China country report. AGM, IAEA/RCA Bangkok, October 2003.
- [21] MAGGIO.G. Guidebook on radiotracer applications in industry. ARCAL/IAEA, Argentina, 1999.
- [22] SANTOSO, S. Radioisotope applications in industry. Indonesian country report. AGM, IAEA/RCA Bangkok, October 2003



## CONTRIBUTORS TO DRAFTING AND REVIEW

Brisset, P.	DIMRI, CEA, Saclay France
Charlton, S.	Johnson Matthey PLC Oatley, Australia
Chmielewski, A.	Department of Nuclear Methods of Process Engineering, Institute of Nuclear Chemistry and Technology Warszawa, Poland
Chueinta, S	OAEP, Bangkok, Thailand
Genders, S.	FORCE Technology, Denmark
Griffith, J.M.	Instituto Cubano de Investigaciones Azucareras (ICINAZ) Departamento de Tecnicas Nucleares Quivican La Habana, Cuba
Hills, A.	Isotope Production Centre, NECSA Pretoria, South Africa
Jin, J.H.	International Atomic Energy Agency, NAPC, Industrial Applications and Chemistry Section Vienna, Austria
Khan, I. H.	Pakistan Institute of Nuclear Science and Technology (PINSTECH); Radiation and Isotope Applications Division (RIAD) Islamabad, Pakistan
Martins Moreira, R.	Centro de Desenvolvimento da Tecnologia Nuclear (CDTN), Belo Horizonte, Minas Gerais, Brazil.
Pant, H. J.	Bhabha Atomic Research Centre (BARC), Mumbai , India
Thereska, J.	Consultant and expert, Tirana, Albania