Report of the Consultants’ Meetings on the “Establishment of a training and certification system for radiotracers and NCS applications”

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FOREWORD

The International Atomic Energy Agency (IAEA) has been playing a major role in facilitating the transfer of the radiotracer and sealed sources technologies to developing Member States. The major techniques have been implemented through IAEA Technical Co-operation projects and adopted by many Member States. The expertise and knowledge gained should be preserved. The sustainability of technology and knowledge preservation calls for creation of young specialists and for continuing good practices.

As a part of its involvement in human resource development, the IAEA is aware of the important need to prepare standard syllabi and training course materials for education of specialists in different fields of nuclear technologies. Training course materials on the radiotracer and sealed sources methods for industrial and environmental applications have been developed for the cultivation of radiation technologies specialists and for continuing technical education of practitioners worldwide. The wide interest in radiotracer technology has created the need for high-level professional education and training in this field, which are not necessarily covered by traditional University courses.

Radiotracers are playing more and more important roles in industry. These roles will continue to expand, especially if students and engineers are exposed in their academic training to the many possibilities for using this tool in research, development and applications.

Beside this academic teaching aspect, it appears the need to create a structured training system, mainly for practitioners to ensure sustainability of the activity and to improve the recognition of the technologies and personal by the industries.
1. INTRODUCTION

The Consultant’s meetings on “the Establishment of a training and certification system for radiotracers and NCS applications” convened in Vienna, VIC, Austria from 2 to 6 December 2013 and from 17 to 21 March 2014 brought together 5 experts from Morocco, Tunisia, Croatia, Indonesia and Albania to discuss and evaluate issues related to the development of a training system associated with a certification system for radiotracer and sealed sources applications.

Nuclear techniques, as tracers and sealed sources applications, have been widely used in various industries to optimize and monitor processes, improve product quality, save energy and materials and reduce environmental impact. Their technical, economic and environmental benefits have been well demonstrated and recognized in many industrial sectors. The major radiotracer and sealed source techniques have been transferred to many developing MS through IAEA TC projects.

The usefulness of nuclear techniques in evaluation or trouble shooting industrial processes has been proved beyond doubt. There are many instances, where nuclear techniques based on either open or sealed sources have been used on laboratory and industrial scales to provide solutions to problems which otherwise would have been insoluble.

The radiotracer technology developed at earlier stages is now being applied by developed countries as routine procedures and their results are not often reported in literature. Many developing countries have also gathered a considerable technical knowledge and experience to apply this useful technology to the benefit of local industry. International Atomic Energy Agency has played an important and leading role in transfer of technical knowledge and the technology itself from developed to developing member states through its Technical Cooperation Programme.

There are lack of technical knowledge, experience and qualified manpower in general, limitations due to lack of equipment, non-availability of radioisotopes, strict regulations not technically related with real radiological safety impact, etc. The society for radiotracer and sealed source is requested to solve the problems through various cooperative activities.

Training is provided by IAEA through fellowships, expert missions for group training and regional training courses. But it appears clearly that a complementary training system is necessary to develop the activities and to ensure its sustainability among Member States. This system would be based on the example of the system used in NDT. This requires the development of a training system under a Quality Management System (QMS). Obviously such QMS in general would be developed in each MS institute for management, laboratory practices, etc... but this general organization is out the scope of the meeting.
2. QUALITY MANAGEMENT SYSTEMS (QMS)

As general information we are presenting here some considerations about QMS, mainly as it is used in NDT.

A QMS process is an element of an organizational QMS. The ISO9001:2008 standard requires organizations seeking compliance or certification to define the processes which form the QMS and the sequence and interaction of these processes.

In the case of NDT, the need for effective qualification and certification personnel certification schemes for NDT personnel has been recognized as a significant part of the technology since the early 1960’s. Over last few decades, international organizations including IAEA, ISO and ICNDT have dedicated considerable effort to designing systems for credible and harmonized systems of qualifying individuals who carry out non-destructive testing. QMS is focused on sustainability issues and assume that other quality problems will be reduced as result of the systematic thinking, transparency, documentation and diagnostic discipline that sustainability focus implies.

NDT personnel often make critical decisions that can have significant health and safety, environmental, financial or even political consequences; there is a great need to demonstrate confidence in their knowledge and skills. Many NDT methods employ equipment that does not produce a permanent record; the report of the operator is the only permanent evidence of the test results.

The competence of the operator has significant influence on the accuracy and contents of the test results. Many product standards, codes of construction and contract documents recognize that the human element is critical to the reliability of the test and mandate formal certification of the NDT personnel performing the test.

Sustainability is the capacity to endure. Sustainability is the potential for long-term maintenance of well-being, which has ecological, economic, political and cultural dimensions. Sustainability requires the reconciliation of environmental, social equity and economic demands - also referred to as the "three pillars" of sustainability.
The scheme below gives general structure of QMS which is used for NDT training and qualification of personnel and would be used for radiotracers and sealed sources applications.
The standards named in the scheme above are:

**ISO/IEC 17025:**

This standard is for general requirements for the competence of testing and calibration laboratories and is the main ISO/CASCO standard used by testing and calibration laboratories. Originally known as ISO/IEC Guide 25, ISO/IEC 17025 was initially issued by the International Organization for Standardization in 1999. There are many commonalities with the ISO 9000 standard, but ISO/IEC 17025 is more specific in requirements for competence. And it applies directly to those organizations that produce testing and calibration results. Since its initial release, a second release was made in 2005 after it was agreed that it needed to have its quality system words more closely aligned with the 2000 version of ISO 9001.

The standard was first published in 1999 and on 12 May 2005 the alignment work of the ISO/CASCO committee responsible for it was completed with the issuance of the reviewed standard. The most significant changes introduced greater emphasis on the responsibilities of senior management, and explicit requirements for continual improvement of the management system itself, and particularly, communication with the customer.

The contents of ISO/IEC 17025 - The ISO/IEC 17025 standard itself comprises five elements that are Scope, Normative References, Terms and Definitions, Management Requirements and Technical Requirements. The two main sections in ISO/IEC 17025 are Management Requirements and Technical Requirements. Management requirements are primarily related to the operation and effectiveness of the quality management system within the laboratory. Technical requirements include factors which determine the correctness and reliability of the tests and calibrations performed in laboratory.

Laboratories use ISO/IEC 17025 to implement a quality system aimed at improving their ability to consistently produce valid results. It is also the basis for accreditation from an accreditation body. Since the standard is about competence, accreditation is simply formal recognition of a demonstration of that competence. A prerequisite for a laboratory to become accredited is to have a documented quality management system. The usual contents of the quality manual follow the outline of the ISO/IEC 17025 standard.

**ISO 9001:2008:**

The **ISO 9000** family of standards is related to quality management systems and designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to the product. The standards are published by ISO, the International Organization for Standardization, and available through National standards bodies. ISO 9000 deals with the fundamentals of quality management systems, including the eight management principles on which the family of standards is based. ISO 9001 deals with the requirements that organizations wishing to meet the standard have to fulfill.

Third party certification bodies provide independent confirmation that organizations meet the requirements of ISO 9001. Over a million organizations worldwide are independently certified, making ISO 9001 one of the most widely used management tools in the world today. Despite widespread use, however, the ISO certification process has been criticized as being wasteful and not being useful for all organizations.

The global adoption of ISO 9001 may be attributable to a number of factors. A number of major purchasers require their suppliers to hold ISO 9001 certification. In addition to several stakeholders' benefits, a number of studies have identified significant financial benefits for organizations certified.
to ISO 9001, with a 2011 survey from the British Assessment Bureau showing 44% of their certified clients had won new business. Corbett et al. showed that certified organizations achieved superior return on assets compared to otherwise similar organizations without certification. Heras et al. found similarly superior performance and demonstrated that this was statistically significant and not a function of organization size.

While the connection between superior financial performance and ISO 9001 may be seen from the examples cited, there remains no proof of direct causation, though longitudinal studies, such as those of Corbett et al. (2005) may suggest it. Other writers, such as Heras et al. (2002), have suggested that while there is some evidence of this, the improvement is partly driven by the fact that there is a tendency for better performing companies to seek ISO 9001 certification.

The mechanism for improving results has also been the subject of much research. Lo et al. (2007) identified operational improvements (cycle time reduction, inventory reductions, etc.) as following from certification. Internal process improvements in organizations lead to externally observable improvements. The benefit of increased international trade and domestic market share, in addition to the internal benefits such as customer satisfaction, interdepartmental communications, work processes, and customer/supplier partnerships derived, far exceeds any and all initial investment.

ISO9712-2012:
Nondestructive testing or Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The terms Nondestructive examination (NDE), Nondestructive inspection (NDI), and Nondestructive evaluation (NDE) are also commonly used to describe this technology. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods include ultrasonic, magnetic-particle, liquid penetrant, radiographic, remote visual inspection (RVI), eddy-current testing, and low coherence interferometry. NDT is commonly used in forensic engineering, mechanical engineering, electrical engineering, civil engineering, systems engineering, aeronautical engineering, medicine, and art.

Successful and consistent application of nondestructive testing techniques depends heavily on personnel training, experience and integrity. Personnel involved in application of industrial NDT methods and interpretation of results should be certified, and in some industrial sectors certification is enforced by law or by the applied codes and standards.

The following definitions for qualification and certification are given in ISO 9712:

- **Certification**: "Procedure, used by the certification body to confirm that the qualification requirements for a method, level and sector have been fulfilled, leading to the issuing of a certificate".

- **Qualification**: "Demonstration of physical attributes, knowledge, skill, training and experience required to properly perform NDT tasks".

Non-Destructive Testing (NDT) training is provided for people working in many industries. It is generally necessary that the candidate successfully completes a theoretical and practical training program, as well as have performed several hundred hours of practical application of the particular method they wish to be trained in. At this point, they may pass a certification examination. While online training has become more popular, many certifying bodys will require additional practical training.
There are two approaches in personnel certification:

1. **Employer Based Certification:** Under this concept the employer compiles their own *Written Practice*. The written practice defines the responsibilities of each level of certification, as implemented by the company, and describes the training, experience and examination requirements for each level of certification. In industrial sectors the written practices are usually based on recommended practice SNT-TC-1A of the American Society for Nondestructive Testing. ANSI standard CP-189 outlines requirements for any written practice that conforms to the standard.

2. **Personal Central Certification:** The concept of central certification is that an NDT operator can obtain certification from a central certification authority that is recognized by most employers, third parties and/or government authorities. Industrial standards for central certification schemes include ISO 9712 and ANSI/ASNT CP-106 (used for the ASNT ACCP scheme). Certification under these standards involves training, work experience under supervision and passing a written and practical examination set up by the independent certification authority. EN 473 was another central certification scheme, very similar to ISO 9712, which was withdrawn when CEN replaced it with *EN ISO 9712* in 2012.

In the United States employer based schemes are the norm, however central certification schemes exist as well. The most notable is *ASNT Level III* (established in 1976-1977), which is organized by the American Society for Nondestructive Testing for Level 3 NDT personnel. *NAVSEA 250-1500* is another US central certification scheme, specifically developed for use in the naval nuclear program.

Central certification is more widely used in the European Union, where certifications are issued by accredited bodies (independent organizations conforming to ISO 17024 and accredited by a national accreditation authority). Certifications issued by a national NDT society which is a member of the European Federation of NDT (EFNDT) are mutually acceptable by the other member societies under a multilateral recognition agreement.

Most NDT personnel certification schemes listed above specify three "levels" of qualification and/or certification, usually designated as *Level 1*, *Level 2* and *Level 3* (although some codes specify roman numerals, like *Level II*). The roles and responsibilities of personnel in each level are generally as follows (there are slight differences or variations between different codes and standards):

- **Level 1** are technicians qualified to perform only specific calibrations and tests under close supervision and direction by higher level personnel. They can only report test results. Normally they work following specific work instructions for testing procedures and rejection criteria.

- **Level 2** are engineers or experienced technicians who are able to set up and calibrate testing equipment, conduct the inspection according to codes and standards (instead of following work instructions) and compile work instructions for Level 1 technicians. They are also authorized to report, interpret, evaluate and document testing results. They can also supervise and train Level 1 technicians. In addition to testing methods, they must be familiar with applicable codes and standards and have some knowledge of the manufacture and service of tested products.

- **Level 3** are usually specialized engineers or very experienced technicians. They can establish NDT techniques and procedures and interpret codes and standards. They also direct NDT laboratories and have central role in personnel certification. They are expected to have wider knowledge covering materials, fabrication and product technology.
3. PROCESS INVESTIGATION AND RADIATION EXPLORATION TECHNOLOGIES: METHODS AND TECHNIQUES

Example for NDT: NDT is divided into various methods of nondestructive testing, each based on a particular scientific principle. These methods may be further subdivided into various techniques. The various methods and techniques, due to their particular natures, may lend themselves especially well to certain applications and be of little or no value at all in other applications. Therefore choosing the right method and technique to be used by competent personnel is an important part of the performance of NDT.

The same process will also be applied for diagnostics methods. In the following we will describe briefly the different methods and related techniques.

3.1. MAJOR RADIOISOTOPE METHODS AND APPLICATIONS

Major mature radioisotope techniques applied in routine services to industry are:

- Radiotracers Applications
  - Radiotracer RTD for troubleshooting, diagnosis and modelling
  - Radiotracers for leak detection in heat exchangers and underground pipelines
  - Radiotracers for flow rate calibration of liquid and gas fluids in pipes
  - Radiotracers for enhancing oil recovery
  - TLA technique for wear and corrosion monitoring

- Sealed sources applications
  - Radioisotope Gamma Scanning for columns and pipes troubleshooting inspection
  - Neutron backscattering for level and interface detection

Other techniques are still under development at different levels:
- computed tomography (CT),
- single photon emission computed tomography (SPECT),
- Computed Assisted Radioactive Particle Tracking (CARPT),
- nanotracers, etc…

![FIG.1. Radiation and Radioisotopes Applications in Industry.](image-url)
3.2. RADIOTRACERS APPLICATIONS

A tracer is any substance whose atomic or nuclear, physical, chemical, or biological properties provide for the identification, observation and following of the behaviour of various physical, chemical or biological processes (dispersion, mixing, kinetics and dynamics), which occur either instantaneously or in a given lapse of time (Fig. 10). There are many kinds of tracers. The radioactive tracers are mostly used for online diagnosis of industrial reactors.

For conducting a radiotracer investigation, various requirements need to be met before starting the actual test. The most important of all the requirements is the “Radiotracer” itself. It is of fundamental importance that the radiotracer compound should behave in the same way as the material to be traced. Therefore, the selection of an appropriate tracer is crucial to success of a tracer study. For reliable and meaningful results, an industrial radiotracer must meet the basic requirements such as suitable half-life and energy of radiation, physical and chemical stability, easy and unambiguous detection. It is often difficult to meet all the requirements of an ideal tracer and certain compromises have to be made. Even if a radiotracer meets the required criteria, it may not be available to tracer groups in developing countries.

Table I lists some of the commonly used radiotracers in industry.
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Radiation and Energy (MeV)</th>
<th>Chemical Form</th>
<th>Tracing of phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tritium (3H)</td>
<td>12.6 y</td>
<td>Beta, 0.018(100%)</td>
<td>Tritiated water</td>
<td>Aqueous</td>
</tr>
<tr>
<td>Sodium-24</td>
<td>15 h</td>
<td>Gamma: 1.37(100%) 2.75(100%)</td>
<td>Sodium carbonate</td>
<td>Aqueous</td>
</tr>
<tr>
<td>Bromine-82</td>
<td>36 h</td>
<td>Gamma: 0.55 (70%) 1.32 (27%)</td>
<td>Ammonium bromide, p-dibrom-benzene, Dibrobiphenyl CH₃ Br, C₂H₂Br</td>
<td>Aqueous Organic Organic Gases</td>
</tr>
<tr>
<td>Lanthanum-140</td>
<td>40 h</td>
<td>Gamma: 1.16 (95%) 0.92 (10%) 0.82(27%) 2.54 (4%)</td>
<td>Lanthanum chloride, Lanthanum oxide</td>
<td>Aqueous/Solids Solids</td>
</tr>
<tr>
<td>Gold-198</td>
<td>2.7 d</td>
<td>Gamma: 0.41 (99%)</td>
<td>Chloroauric acid Gold glass</td>
<td>Aqueous/Solids Sand</td>
</tr>
<tr>
<td>Mercury-197</td>
<td>2.7 d</td>
<td>Gamma: 0.077(19%)</td>
<td>Mercury metal</td>
<td>Mercury</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>8.04 d</td>
<td>Gamma: 0.36 (80%) 0.64 (9%)</td>
<td>Potassium or Sodium iodide, Iodobenzene</td>
<td>Aqueous Organic</td>
</tr>
<tr>
<td>Chromium-51</td>
<td>28 d</td>
<td>Gamma: 0.320 (9.8%)</td>
<td>Cr-EDTA, CrCl₃</td>
<td>Aqueous</td>
</tr>
<tr>
<td>Technetium-99m</td>
<td>6 h</td>
<td>Gamma: 0.14 (90%)</td>
<td>Sodium pertechnetate (TcO₄⁻) Reduced SnCl2</td>
<td>Aqueous Mud, sludge</td>
</tr>
<tr>
<td>Indium-113m</td>
<td>1.7 h</td>
<td>Gamma: 0.39 (65%) 0.24 (20%)</td>
<td>Indium chloride</td>
<td>Solids</td>
</tr>
<tr>
<td>Scandium-46</td>
<td>84 d</td>
<td>Gamma: 0.89(100%) 1.84(100%)</td>
<td>Scandium oxide Scandium glass Scandium chloride ScCl₃ (Sc³⁺)</td>
<td>Solids Sand Aqueous/Solids</td>
</tr>
<tr>
<td>Iridium-192</td>
<td>74 d</td>
<td>Gamma: 0.30 (100%) 0.32 (80%) 0.57 (48%) 0.60 (9.3%) 0.61 (6.3%)</td>
<td>Iridium Glass</td>
<td>Sand</td>
</tr>
<tr>
<td>Hafnium-181+175</td>
<td>45 d</td>
<td>Complex spectrum</td>
<td>Hafnium chloride</td>
<td>Mud, sludge</td>
</tr>
<tr>
<td>Silver-110</td>
<td>253 d</td>
<td>0.66 (94%) 0.88 (72.5%) 0.94 (34%) 1.40 (24%)</td>
<td>Wire</td>
<td>pebbles</td>
</tr>
<tr>
<td>Xenon-133</td>
<td>5.27 d</td>
<td>Gamma: 0.08 (100%)</td>
<td>Xenon</td>
<td>Gases</td>
</tr>
<tr>
<td>Krypton-85</td>
<td>10.6 y</td>
<td>Gamma: 0.51(0.7%)</td>
<td>Krypton</td>
<td>Gases</td>
</tr>
<tr>
<td>Krypton-79</td>
<td>35 h</td>
<td>Gamma: 0.51 (15%)</td>
<td>Krypton</td>
<td>Gases</td>
</tr>
<tr>
<td>Argon-41</td>
<td>110 min</td>
<td>Gamma: 1.29(99%)</td>
<td>Argon</td>
<td>Gases</td>
</tr>
</tbody>
</table>
3.2.1. Flowrate Measurement

There are a number of ways in which radiotracers can be used to measure flow rates:

**Pulse velocity method**

By injecting a pulse of tracer into a process stream and measuring its transit time between two or more externally positioned detectors the flow velocity and, by inference, the volume flowrate can be measured. This method is commonly used to:

- Calibrate installed flow meters on line
- Provide flow data for mass-balance calculations
- Measure the efficiency of pumps and turbines
- Determine flow distributions in manifolds and branch lines
- Measure leakage flows in flare-header systems

An international standard, ISO 2975/VII, covering water flow in closed conduits is current; another, ISO 4053/IV, covering gas flows in closed conduits has lapsed. The pulse velocity method is both useful and widely used, so the reasons why the gas flow standard has lapsed should be explored.

3.2.2. Dilution flow method

The measurement of liquid flow in open channels by tracer dilution methods is the subject of an international standard, ISO 9555-2. This method is well suited to the measurement of environmental flows. No standards relate to gas dilution flow measurements: various methods were developed and used successfully in the past, but are not in current use.

*FIG. 4. Flow measurement.*
3.2.3. Leakage testing in heat exchangers

This is an important application since, in the absence of sampling, radiotracer techniques are uniquely capable of performing the measurement.

Internal leakage in heat exchangers and similar vessels can be detected and quantified by injecting a radioactive material into the high pressure side of the system (say, the tube side in a shell-tube heat exchanger) and positioning radiation detectors on the low-pressure side (the shell-side outlet) to identify whether any of the radio-labelled material exits by that route. Frequent applications are:

- Identifying which of a number of exchangers in a system is leaking
- Measuring bypassing in feed-effluent exchangers

The common requirement for leakage testing, together with the benefits realised by the measurements, suggest that the drafting and promulgation of an appropriate work procedure should be given high priority.

Radiotracers Technique is also applied for leak detection in underground pipelines.
3.2.4. Residence time distribution (RTD) studies

The Mean Residence Time (MRT) and Residence Time Distribution (RTD) are parameters that are extremely pertinent to the operation of chemical reactors, influencing, as they do, both the throughput and the quality of the product. Both can be investigated using radiotracer technology. A sharp pulse of radioactive tracer is injected upstream of the vessel or system of interest and a detector located at the inlet marks time-zero. A second detector, located at the outlet, records the passage of the tracer from the system. The response of this detector is the residence time distribution, from which the mean residence time can be calculated. The results can be compared with theoretical calculations to determine whether the system is meeting its design specifications. Such studies are of great value to process and plant designers.

FIG.6. Residence Time Distribution and Troubleshooting Analysis.
3.2.5. **Interwell tracing**

Monitoring the flow of the injected material through the reservoir in a waterflood or a gas injection operation can provide valuable information the operating company, leading to significant production improvements and cost reduction. Using radioactive (and other) tracers to tag the injected material, we can determine, (inter alia):

- The percentage of injection water, or gas, flowing from an injector to a specific producer.
- The volumetric sweep efficiency of the flood.
- Reservoir preferential flow trends
- Fault block or channel communication
- Whether high-permeability channels are present.

Of the above applications, distillation column scanning and heat exchanger leakage testing have been selected as appropriate subjects to exemplify the type of guideline that will be needed for inclusion in Quality Management Systems. Standard Operating Procedures (SOP) need to be formulated to demonstrate the competence of a laboratory to produce technically valid data and results.

![FIG. 7. Principle of tracer injection method for interwell communications.](image)
3.2.6. Wear, Erosion, corrosion measurement – Thin Layer Activation Technique (TLA)

**FIG. 8. Thin Layer Activation Technique – Principle.**

3.2.7. Sediment transport Studies

The investigation of sediment transport in sea and rivers is crucial for civil engineering and littoral protection and management. Coastlines and sea beds are dynamic regions with sediments undergoing periods of erosion, transport, sedimentation and consolidation. Main causes for erosion in beaches include storms and human actions like the construction of seawalls, jetties, and the dredging of stream mouths. Each of these human actions disrupts the natural flow of sand. This crisis is mostly manmade. Current policies and practices are accelerating beach erosion process. There are viable options available to mitigate this damage and provide for sustainable coastlines. Time is short; sand is short ... and the water rises.

Radioactive methods can help in investigating sediment dynamics providing important parameters for better designing, maintaining and optimizing civil engineering structures. Radioisotopes as tracers and sealed sources have been useful and often irreplaceable tools for sediment transport studies.

Radioactive tracers are the only unequivocal method of direct real time assessment of sediment transport pathways. Radiotracer are more sensitive and provide more accurate parameters than
conventional tracers. During the last few decades, many radiotracer studies for the investigation of sediment transport in natural systems have been conducted worldwide, and various techniques for tracing and monitoring sediment have been developed by individual tracer groups.

The sediment transport techniques cover applications for bed-load transport measurement, dispersion of pollutants from outfalls studies, dispersion of fine particles from dumping operation of dredging-products, etc… All these applications are mainly based on a Lagrangian approach, meaning the mapping of concentration as a function of position at one time.

In addition to radiotracers, sealed source techniques can provide density of the sediments deposited in a channel of navigation, as well as the concentration of sediments circulating in suspension. This technique will be described further, in the section dedicated on NCS.

3.3. SEALED SOURCES APPLICATIONS

3.3.1. Gamma ray transmission scans

Gamma ray transmission scanning is used in a wide number of applications. A source of gamma radiation is placed on one side of the vessel of interest and a radiation detector is positioned on the other. The amount of radiation that is transmitted is a function both of the density and the thickness of the material through which the beam passes. Thus, if the source-detector separation is kept constant, variations in the intensity of the transmitted beam can be related to variations in the density of the material.

To perform the scan a source of gamma-radiation is positioned on one side of the column and a radiation detector is positioned horizontally opposite, on the other side. These are then moved synchronously down the tower and the intensity of the transmitted radiation. The resulting curve or “transmission characteristic” can be related to the density profile of the column.

All types of distillation column may be scanned, including those with trays and those with packed beds. The scans are capable of identifying process problems such as flooding, foaming, entrainment and excessive liquid loading and can also identify displaced/damaged trays or other column internals.

Often, a study, known as a “baseline scan” will be carried out when the column is performing well. This not only provides information about the column hydraulics that is immediately useful to the process engineer but also acts as a useful benchmark against which to compare future scans carried out to investigate malfunctions.
Column scans are frequently part of “pre-shutdown surveys”, carried out on line to give maintenance personnel advance warning of equipment problems which may be facing them at the turnaround.

The versatility of column scanning, together with the large economic benefits that may accrue as a result of its application, has ensured its acceptance, worldwide. It is the most commonly used of all the process diagnostic techniques.

3.3.2. Pipe scanning

The gamma ray scanning technique provides a quick and convenient on-line method of inspecting pipe work. This is used for a wide variety of applications including:

- Measurement of deposit thickness (e.g. coke in furnace overhead lines)
- Location of blockages, or partial blockages
- Measurement of the depth of liquid condensates in gas pipelines
- Checking flare headers and other systems for polymer build-up
- Determining gas void fractions in liquid pipelines
- Detection and quantification of liquid entrainment in gas lines

**FIG. 10. Two examples of column scanning systems.**
3.3.3. Neutron backscatter technique

By using a probe consisting of a fast neutron source and a slow neutron detector a number of useful measurements are performed on process vessels. Unlike the gamma ray scanning technique, this method, being based on scattering of radiation, rather than on transmission, requires access to one side of the vessel only. The probe is held against the wall of the vessel. Fast neutrons from the source penetrate the vessel wall and become slowed down by collision with the vessel’s contents. Hydrogen is much more effective than any other material in slowing down fast neutrons so that, to a good approximation, the number of slow neutrons that scatter back out of the vessel is proportional to the hydrogen concentration of the contents. Thus, the response of the slow-neutron detector is proportional to the hydrogen concentration of the material in the vessel adjacent to the probe. Practically all of the neutron slowing-down takes place within about 150 mm of the vessel wall. Thus the technique is useful for investigating the distribution of material around the periphery of the vessel.

FIG. 11. Scheme of a pipe scanning system.

FIG. 12. Scheme of Neutron Backscattering System.
Applications include:

Measurement of liquid/liquid interfaces
In process vessels such as oil/water separators, decanters and slop tanks in which two immiscible liquids are present, determining the position of the interface between them is often a problem as installed instrumentation is notoriously unreliable. Provided that the two liquids differ in hydrogen concentration, which is almost always the case, the neutron backscatter technique can provide a rapid on-line measurement of the liquid position. The position and extent of mixed phases, such as emulsions, can also be quantified. The technique is also useful for determining liquid/vapour interfaces, for measuring sludge levels and for investigating the presence of foaming.

Investigation of downcomer levels in distillation columns
Because the technique effectively interrogates only the 150mm of material adjacent to the wall, neutron backscatter is ideally suited to distinguish between the level of liquid on the tray and that in the downcomer. This is useful for investigating downcomer-flooding situations.

Because of its wide application, together with its ability to provide information complementary to that obtained by gamma ray scanning, the neutron backscatter technique must be regarded as an important industrial application of sealed source technology.

3.4. NUCLEONIC CONTROL AND MEASUREMENT SYSTEMS (NCS)

Nucleonic Control and Measurement Systems can be defined as being used for the ‘’control by instrumental measurement and analysis as based on the interaction between ionizing radiation and matter’’.
Several hundred thousand NCS (or nucleonic gauges) are installed and operating in industry worldwide. They are used by various industries to improve the quality of products by optimizing and controlling processes saving energy and materials.

FIG. 13. Statistics about NCS.
Most of NCS are based on a few most common nuclear techniques:
- Natural gamma-ray
- Single energy gamma ray transmission
- Dual energy gamma ray transmission
- Gamma ray backscattering
- Beta ray transmission
- Neutrons transmission
- Neutrons backscattering
- Prompt gamma neutron activation analysis (PGNAA)

FIG. 14. Examples of NCS in industry.
3.5. VISUALIZATION TECHNIQUES

Computed Tomography (CT)

**First generation**

**Second generation**

(a) Translation-rotation of a beam in parallel

(b) Translation-rotation of multiple sources in parallel

(c) Rotation of a fan-beam

(d) Detector fixed-rotation source

D: NaI(Tl) multidetector array
F: radioactive source
C: lead collimator
O: object of study.

**Third generation**

**Fourth generation**

FIG. 16. The different types of Industrial Process Gamma CT.
FIG. 17. Example of a CT system associated with column-scanning.

Single Photon Computed Tomography (SPECT): visualization of the tracer concentration in a cross-section of a pipe

FIG. 18. Left: device with 36 detectors. Right: the result.
**Computed Assisted Radioactive Particle Tracking (CARPT)**

Principle: a single radioactive particle is tracked by some detectors. From the trajectories of many single particles, it is possible to obtain the flow patterns and turbulence of the flow.

![Image of CARPT system](Image)

**FIG. 19. Example of a laboratory model of a CARPT system.**

3.6. CONCLUSION OF THIS SECTION

As a conclusion of this section, we propose to split the technologies in Methods and Techniques as following:

- **Artificial Radiotracer Method**
  - RTD and mixing
  - Flow Rate and Leak Detection
  - Wear and corrosion testing
  - Sediment transport, dilution
  - Interwell studies
  - SPECT, CARPT (only research techniques)

- **Artificial Non-radioactive Tracer Method**
  - Chemical tracers
  - Fluorescent / colored tracers,
  - Others...

- **Sealed Sources Method**
  - Column scanning
  - Nucleonic gauges
  - Computed tomography

- **Mixed methods/specialization**
  - XPTV, Contrast agent tracer

*Etc...*
**TABLE 2. METHODS, TECHNIQUES AND ABBREVIATED TERMS (SEE APPENDIX 1)**

<table>
<thead>
<tr>
<th>NDE method</th>
<th>Abbreviated terms</th>
<th>NDE Technique</th>
<th>Abbreviated terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial Radioactive Tracer</td>
<td>RTM</td>
<td>RTD, mixing, flow-rate and leak detection</td>
<td>RTD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wear and corrosion testing</td>
<td>TLA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sediment transport, dilution</td>
<td>STE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interwell studies</td>
<td>IWS</td>
</tr>
<tr>
<td>Artificial Non-radioactive Tracer</td>
<td>NTM</td>
<td>Chemical Tracers</td>
<td>CTT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluorescent / colored Tracers</td>
<td>FTT</td>
</tr>
<tr>
<td>Sealed Sources</td>
<td>SSM</td>
<td>Scan Techniques</td>
<td>SCT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nucleonic control system</td>
<td>NCS</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **CONCLUSION - PROPOSAL FOR A PERSONNEL QUALIFICATION AND CERTIFICATION SCHEME FOR PROCESS INVESTIGATION AND RADIATION EXPLORATION TECHNOLOGIES**

The objective is to create a training and certification system on the model of the NDT. The scheme to be established would be simpler than in NDT, more flexible, adapted to the needs of the technologies, unified and recognized at the international level.

Globally the scheme would be:

- The International Society being recognized as the unique international certification body. It would be created during the International conference on tracers and tracing methods to be held in Marrakech, Morocco, 13-15 October 2014. This means it would act as a third party certification body but not under ISO 17024. It would manage a certification between peers system. A draft of its statutes is in Annex 4. It would be also a scientific society.
- The International Society would prepare its Quality Management System and Internal procedures.
- The International Society would prepare with the help of IAEA and based on its documents:
  - a syllabus for the methods recognized of practical interest (see Annex 1)
  - recommended practices, protocols covering the main techniques (see Annex 2)
  - a question bank for examination (see Annex 3)
- Training and examination center(s) would be established through a call for application according to specific procedures to be established.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Month</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>01</td>
<td>02</td>
</tr>
<tr>
<td>Formulate Statutes of the society</td>
<td>D</td>
<td>V</td>
</tr>
<tr>
<td>Preparation of QMS of the society (LDA, procedures,…</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Call for Application for Training and Certification centers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Call for recognition Level 3 Generation 1</td>
<td>Inf</td>
<td></td>
</tr>
<tr>
<td>Formulate Syllabus on methods and techniques (RTD, FLD, CST, NCS, etc…)</td>
<td>D1</td>
<td>D2</td>
</tr>
<tr>
<td>Formulate Training Guidelines on methods and techniques (RTD, FLD, SCT, NCS, etc…)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Formulate selected Recommended practices (RTD, FLD, CST, NCS, etc…)</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Formulate Strategic Planning</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Question Bank (RTD, FLD, SCT, NCS, etc…) through voluntary participation</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Official creation of the Society, Executive Committee, regional Sections, Working Groups</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Establish website</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect existing standards (flow-rate, etc..)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training center in Seibersdorf (for the 1st RTC)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX I. DRAFT PROPOSAL FOR A TECDOC (ANALOG TO TECDOC 628 IN NDT)

1. Scope
This document specifies requirements for principles for the qualification and certification of personnel who perform Industrial Process Investigation and Radiation Exploration.
Note: the term industrial implies the exclusion of applications in the field of medicine.
The system specified in this document can also apply to other process investigation methods or to new techniques within an established method.
The international society certification covers proficiency in one or more of the following methods:
- Artificial Radiotracer Method
- Artificial Non-radioactive tracer method
- Sealed sources Method
  - Radiopharmaceuticals
  - Infrared
  - XRF (normes > A.Karydas)
- Etc…

2. Normative references
In the field only a few technical standards are, or have been, available (and no standards related to training and certification):
- ISO 16000-8-2007 : Indoor air – Part 8: Determination of local ages of air in buildings for characterizing ventilation conditions

The lack of official standards would be filled by preparation and recognition of Recommended Practices by the society, to be transformed into ISO standards later on.

3. Terms and definitions

For the purpose of this document, the following terms and definition apply.

3.1. Authorized qualification body
Body, independent from the employer, authorized by the certification body to prepare and administer qualification examination.

3.2. Basic examination
Written examination at Level 3, which demonstrated the candidate’s knowledge on the science and technology related to the technique, the specific qualification and certification system and the basic principles of methods as required for Level 2.

3.3. Candidate
Individual seeking qualification and certification who gains experience under the supervision of personnel having a qualification acceptable by the certification body.

3.4. Certificate
Document issued by the certification body under specified provisions, indicating that the named person has demonstrated the competences defined in the certificate.

3.5. Certification
Procedure used by the certification body to confirm that the qualification requirements for a method and level have been fulfilled, leading to the issue of a certificate.

3.6. Certification body
Body that administers procedures for certification according to specified requirements

3.7. Examination center
Centre approved by the certification body where qualification examinations are carried out.

3.8. Examiner
Person certified to Level 3 in the method for which he is authorized by the certification body to conduct, supervise and grade the qualification examination.

3.9. Industrial experience
Experience, acceptable to the certification body, gained under qualified supervision, in the application of the method, needed to acquire the skill and knowledge to fulfill the provision of qualification.

3.10. Main-method examination
Written examination, at level 3, which demonstrates the candidate’s general and specific knowledge and the ability to write procedures for the method as applied in the industrial sector for which the certification is sought.

3.11. Multiple choice examination question.
Wording of a question giving rise up to four potential replies.

3.12. Method
Discipline applying a physical principle.

3.13. Procedure
Written description of all essential parameters and precautions to be applied to perform investigation.

3.14. Practical examination
Assessment of practical skills, in which the candidate demonstrates familiarity with, and the ability to perform investigation tasks.

3.15. Qualification
Demonstration of physical attributes, knowledge, skills, training and experience required to properly perform investigation tasks.

3.16. Qualification examination
Examination, administered by the certification body or the authorized qualification body, which assesses the general, specific and practical knowledge and the skill of the candidate.

3.17. Qualified supervision
Supervision of candidates gaining experience by personnel certified in the same method under supervision or by non-certified personnel who, in the opinion of the certification body, possess the knowledge, skill, training, and experience required to properly perform such supervision.

3.18. Specification
Document stating requirements

3.19. Practical test bench
Sample or system, producing a known result, used in practical examinations, which is representative of products or systems typically existing.

3.20. Specimen master report
Model answer, indicating the optimum result for a practical examination given a defined set of conditions (equipment type, settings, technique, specimen, etc..) against which the candidate’s test is graded.
3.21. Supervision
Act of directing the application performed by other personnel, which includes the control of actions involved in the preparation of the test, performance of the test and reporting of results.

3.22. Validation
Act of demonstrating that a verified procedure works in practice and fulfills its intended function, normally achieved by actual witnessing, demonstration, field or laboratory tests or selected trials.

3.23. Renewal
Procedure for revalidation of a certificate without examination at any time up to five years after success in an initial, supplementary or recertification examination.

3.24. Recertification
Procedure for revalidation of a certificate by examination or by otherwise satisfying the certification body that the published criteria for recertification are satisfied.

4. Methods, techniques and abbreviated terms

<table>
<thead>
<tr>
<th>TABLE 4. METHODS AND ABBREVIATED TERMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDE method</td>
</tr>
<tr>
<td>Artificial Radioactive Tracer</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Artificial Non-radioactive Tracer</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Radioactive Sealed Sources</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Radiation generators</td>
</tr>
<tr>
<td>Others…</td>
</tr>
</tbody>
</table>
5. Responsibilities
5.1. General

The certification system, which shall be controlled and administered by a certification body, includes all procedures necessary to demonstrate the qualification of an individual to carry out tasks in specific method and product or industrial sector leading to certification of competence.

5.2. Certification body

The certification body:

a. shall initiate, promote, maintain and administer the certification scheme
b. shall publish specifications for training courses that include the syllabi which embody the content of recognized documents
c. shall approve properly staffed and equipped examination centers which it shall monitor on a periodic basis
d. shall establish an appropriate system for the maintenance of records, which shall be retained for at least one certification cycle
e. shall be responsible for the issue of all certificates
f. shall be responsible for the definition of sectors
g. shall be responsible for ensuring the security of all examination materials (specimen, master reports, question bank, etc.)
h. shall require all candidates and certificate holders to give a signed or stamped undertaking to abide by a code of ethics which it shall develop for the purpose and publish.

5.3. Examination center

The examination center shall:

a. Work under the control of the certification body
b. Apply a documented quality procedure approved by the certification body
c. Have the resources needed to administer examinations, including the calibration and control of equipment
d. Prepare and conduct examinations under the responsibility of an examiner authorized by the certification body, using only those examination questionnaires and specimens established or approved by the certification body for that purpose.
e. Maintain appropriate qualification and examination records according to the requirements of the certification body.

5.4. Candidate

Candidates, whether employed, self-employed or unemployed shall:

a. Provide documentary evidence of satisfactory completion of a course of training
b. Provide verifiable documentary evidence that the required experience has been gained under qualified supervision
c. Abide by a code of ethics published by the certification body

5.5. Certificate holders

Certificate holders shall:

a. Undergo a periodic medical test in accordance with national regulation and submit the test to the employer
b. Notify the certification body and the employer in the event that the conditions for validity of certification are not fulfilled

c. Abide by a code of ethics published by the certification body

6. Levels of qualification

6.1. Level 1

6.1.1. An individual certified to Level 1 has demonstrated competence to carry out investigation according to written instructions and under the supervision of Level 2 or Level 3 personnel. Within the scope of the competence defined in the certificate, Level 1 personnel may be authorized by the employer to perform the following in accordance with instructions:

a. Set up equipment
b. Perform the tests
c. Record and classify the results of the tests according to written criteria
d. Report the results

6.1.2. Level 1 certified personnel shall neither be responsible for the choice of test method or technique to be used, nor for the interpretation of test results.

He is responsible for safety and efficiently carrying out the instructions of Level 2.

6.2. Level 2

An individual certified to Level 2 has demonstrated competence to perform investigation according to procedures. Within the scope of the competence defined in the certificate, Level 2 personnel may be authorized by the employer to:

a. Select the technique for the method to be used
b. Define the limitations of application of the method
c. Translate codes, standards, recommended practices and procedures into working instructions adapted to the actual working conditions
d. Set up and verify equipment settings
e. Perform and supervise tests
f. Interpret and evaluate results according to applicable standards, codes, specifications or procedures
g. Carry out and supervise all tasks at or below Level 2
h. Provide guidance for personnel at or below Level 2
i. Report the results of investigation

Level 2 is the person on site responsible for carrying out the instructions of the Level 3. He shall be responsible for ensuring that the site work is carried out safely and in accordance with the agreed work scope. He will ensure that suitable barriers and warning signs are deployed so as not to compromise the safety of the site work force and members of the public.

6.3. Level 3

6.3.1. An individual certified Level 3 has demonstrated competence to perform and direct operations for which he is certified. Level 3 personnel have demonstrated:

a. The competence to evaluate and interpret results
b. Sufficient practical knowledge of applicable, materials, process, and product technology to select methods and establish techniques
c. A general familiarity with other methods

The Level 3 is the person ultimately responsible for the planning and execution of the entire job. This includes defining the work scope and allocating sufficient trained and competent personnel and the resources to conduct the work.

6.3.2. Within the scope of the competence defined in the certificate, Level 3 personnel may be authorized to:

a. Assume full responsibility for a test facility or examination centre and staff
b. Establish, review for editorial and technical correctness, and validate instructions and procedures
c. Designate the particular test methods, procedures and instructions to be used
d. Carry out and supervise all tasks at all levels
e. Provide guidance for personnel at all levels

He is responsible for insuring compliance with any statutory legislation to ensure protection of the work force, members of the public and the environment. He is ultimately responsible for interpretation of the data obtained and for supplying the suitable report to the customer within an agreed time period.

4.1. ELIGIBILITY

7.1. General

The candidate shall fulfil the minimum requirements for training and industrial experience prior to the qualification examination.

7.2. Training

7.2.1. The candidate shall provide documentary evidence acceptable to the certification body, that he has satisfactory completed training in the method and level for which the certification is sought.

7.2.2. For all levels, the candidate shall satisfactorily complete a course of theoretical and practical training recognized by the certification body.

For Level 3 in addition to the recommended training given in table 5, the preparation for qualification can be completed in different ways dependent on the scientific and technical background of the candidate, including attendance at other training courses, conferences or seminars, publishing articles, books, etc…

7.2.3. The recommended duration of training undertaken by the candidate for certification shall be as defined in table 5 for the applicable method and technique.

The training is based upon candidates possessing adequate mathematical skills and prior knowledge of materials, processes and physics. If it is not the case, additional training may be required by the certification body.

Training hours include both theoretical and practical courses.

Direct access to Level 2 requires the total recommended hours shown in table 5 for Levels 1 and 2.

Direct access to Level 3 requires the total hours recommended in table 5 for levels 1, 2 and 3.
### TABLE 5A. RECOMMENDED TRAINING REQUIREMENTS (TO BE PRECISED AND OPTIMIZED)

<table>
<thead>
<tr>
<th>NDE Method</th>
<th>NDE Technique</th>
<th>Level 1 hours</th>
<th>Level 2 hours</th>
<th>Level 3 hours</th>
<th>Syllabus modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation protection</td>
<td>For all methods</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>A3</td>
</tr>
<tr>
<td>General knowledge</td>
<td>For all methods</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>A1 + A2</td>
</tr>
<tr>
<td>RTM General knowledge</td>
<td>RTM</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>A4+B1+B2+B3+B4</td>
</tr>
<tr>
<td></td>
<td>RTD</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>B5+B6+B8+B12</td>
</tr>
<tr>
<td></td>
<td>TLA</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>B7</td>
</tr>
<tr>
<td></td>
<td>STE</td>
<td>24</td>
<td>32</td>
<td>24</td>
<td>B13</td>
</tr>
<tr>
<td></td>
<td>IWS</td>
<td>24</td>
<td>16</td>
<td>24</td>
<td>B14</td>
</tr>
<tr>
<td>NTM CTT</td>
<td></td>
<td>16</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>FTT</td>
<td></td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>SSM CST</td>
<td></td>
<td>24</td>
<td>24</td>
<td>16</td>
<td>C1+C2</td>
</tr>
<tr>
<td>NCS</td>
<td></td>
<td>24</td>
<td>24</td>
<td>40</td>
<td>C4</td>
</tr>
<tr>
<td>others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.3. Industrial experience

7.3.1. General

The recommended duration of experience to be gained in the method where the candidate is seeking certification shall be as given in Table 3.

### TABLE 6. MINIMUM INDUSTRIAL EXPERIENCE

<table>
<thead>
<tr>
<th>NDE method</th>
<th>Experience (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.3.2. Level 3

Level 3 responsibilities require knowledge beyond the technical scope of any method. This broad knowledge may be acquired through a variety of combinations of education, training and experience. Table 3 details minimum experience for candidates who have successfully completed a technical school, or at least two years of engineering or science study at an accredited college or university. If it is not the case, the duration has to be multiplied by a factor of 2.

7.3.3. Credit for work experience may be gained simultaneously from publications in conferences or journals, industrial experience, academic degrees in a relevant field.

The credit system will be developed in the next step.
APPENDIX II. THE INTERNATIONAL SOCIETY

1. Preamble

The first conference on "Tracers and tracing methods" was arranged in Nancy, France, in November 1998 as a national French event. The main organizer was the former Laboratoire des Sciences du Genie Chimique, (LSGC, UPR CNRS 6811) that became in 2010 Laboratoire Réaction et Génie des Procédés (LRGP, UPR 3349).

The second conference on the same subject was organized as an international event, also in Nancy and by the same main organizer as the first conference. It took place in May 2001.

The third conference briefly called "Tracer 3", moved outside France to the small holyday resort city of Ciechocinek in Poland and was arranged in June 2004. The main organizer was Warsaw University of Technology.

The fourth conference, "Tracer 4" moved back to France to the small village of Autrans and was arranged in October 2006. The main organizer was Commissariat à l'Energie Atomique, CEA, Grenoble.

The fifth conference, "Tracer 5" moved outside Europe to the cultural heritage village of Tiradentes in the state of Minas Gerais in Brazil, and was arranged in October 2008. The main organizer was Centro de Desenvolvimento da Tecnologia Nuclear, CDTN, in Belo Horizonte, Brazil.

The sixth conference, "Tracer 6" moved back in the north of the all continent to Oslo, the beautiful capital of Norway, and was organized in June 2011 by the Institut For Energy technology (IFE).

The society was set up during the "Tracer 7" conference held in Marrakech, Morocco and organized in October 2014 by the Centre National d'Études, des Sciences et Techniques Nucléaires (CNESTEN). ISNDE was set up as a non-profit organisation with the aim of promoting international cooperation.

2. Name, Seat and Activities (proposal)

The association is named the INTERNATIONAL SOCIETY OF PROCESS INVESTIGATION AND RADIATION BASED EXPLORATION. Its abbreviation is INSPIRE. The graphic symbol is the name of the society printed on a world map. The association has is seat in Vienna, Austria and operates worldwide.

3. Purpose

3.1. The society is a non-profit organization devoted to the international development of the science and practice of artificial radioactive and non-radioactive tracers, sealed sources, nucleonic control systems, XXXX and related technologies, later on named "the technologies". The Society's activities are dependent on the voluntary actions of its members.

The purposes are in particular:
3.2. to promote and support the technologies for the benefit of the involved public in general.
3.3. to promote international collaboration in all matters relating to the technologies, including collaboration with international organisations with an interest in the technologies, e.g. International Organisation for Standardisation (ISO), International Atomic Energy Agency (IAEA), UNIDO, other national and international associations, etc.
3.4. to encourage the foundation, development, strengthening and cooperation of existing and new national and regional Societies or institutions.
3.5 to disseminate results of research and experience and assign the place and organisation of the World “Tracer” Conference to an appropriate institution or society, or group of societies, at intervals of three years.
3.6 to establish and implement membership policies of the society in collaboration with Regional Groups.
3.7 to support research activities and award distinctions honouring outstanding services in the area of the technologies.
3.8 to encourage the formulation of international standards on the technologies in collaboration with the International Organisation for Standardisation, and other standards bodies.
3.9 to promote best practices in the technologies and to encourage international harmonisation in this area.
3.10. to improve and promote standards of education

4. Means of achieving the purpose of the association

4.1 The non-profit objectives of the Association are achieved specifically by the assignation of the place and organisation of the World “Tracer” Conference held every three years, the maintenance of worldwide contacts and the exchange of experience in the area with societies, institutions and other organizations, national or international, with interests in the technologies, holding scientific lectures and issuing publications in this area.

4.2 The necessary funds shall be raised through membership fees, subsidies, other donations (including from the “Tracer” Conference organizers) and income generated by the Association’s assets.

5. Types of Membership

The membership of the Society shall be of two types without any restriction on number.

5.1. Individual members,
5.2. Institutional members which may be educational and scientific institutions, government and non-profit organizations, business enterprises, etc. An institutional member shall be entitled to designate a representative whom attend meetings of the Society and participate in the scientific programme of the meetings with the same privileges as the individual members. Institutional members shall be entitled to receive one set of the publications of the society on the same conditions as individual members.
5.3. Honorary (or Liaison) Members: other societies, IAEA, etc…

6. Acquiring and terminating Membership
6.1 Candidates that wish to join the society as Members shall submit a written application in accordance with the application procedure defined by the Executive Committee.

6.3 Membership shall be terminated through the loss of legal status, loss of contact, failure to pay membership fees or (in the case of individuals) death, or voluntary termination or expulsion.

6.4 Voluntary termination shall be implemented on 31 December of any given year by submitting a written resignation, at least 3 months prior to the date of withdrawal.

6.5 Expulsion may be ruled at the decision of the Executive Committee on the grounds of a violation of membership duties or of dishonourable behaviour or on other serious grounds. A Member so expelled will have a right of appeal to the next full General meeting of the society.

6.6 The termination of membership for whatever reason shall not affect the duty of paying the membership fee for the full year.

7. Rights and Duties of the Members

7.1. Every Full Member shall appoint two delegates (one voting), who shall have the right to participate in the Executive Committee. Each Full Member shall have one vote in all matters brought to a vote. This vote shall be cast by the respective delegate of the two who has been appointed voting delegate.

7.2. All members are obliged to heed the Constitution of the Association and to promote its objectives.

7.4 The members of the Association shall not receive any payments from the funds of the Association except for reimbursement of any necessary expenses approved in advance by the Executive Committee.

8. Bodies of the society

The bodies of the society are:

(i) The General Assembly
(ii) The Executive Committee
(iii) The Certification and Qualification Council (CQC)
(iv) The World Conference President and conference working group
(v) The regional sections, composed of members of each region

All officers are appointed for three years. Re-election is possible without limitation.
8.1. The General Assembly

The General Assembly is composed by all full members of the society, forms the General Meeting pursuant to the Austrian law on Associations of 2002. It is the decision-making body and has the following tasks:
• to take decisions on the acceptance and exclusion of members
• to elect the Chairman, the General Secretary, the Treasurer for a duration of three years from a world conference to the next one
• to agree the amount of membership fees (Individual Member fee and Institution Member fee)
• to accept the report by the Chairman
• to approve of financial reports, accounts and budgets
• to possibly dissolve the Association

The General Assembly shall be convened by the Chairman. It shall meet at least during each World Conference held every three years and if possible once a year between World Conferences, in conjunction with an appropriate event. Furthermore, it shall convene if at least one tenth of the members file a respective demand with the Executive Committee.

At General Assembly meetings, every full member shall have one vote. Members who are unable to attend may nominate in writing another member representative to vote on their behalf. No member may exercise more than one proxy vote.

The quorum of the General Assembly shall be at least one third of the voting membership.

Decisions shall be taken by a simple majority of the voting delegates present. Decisions may also be taken, as the need arises, by means of circulation to be organised by the Executive Committee by fax, e-mail or letter, whereby a period of at least 8 weeks is to be granted for voting.

8.2. The Executive Committee

The Executive Committee shall manage the business of the Association as a cooperative leadership body under the leadership of the Chairman. The Executive Committee's task is to advise and support the Chairman and Secretariat in the operations of the society, to supervise the execution of policy approved by the General Assembly, in accordance with these Statutes.

The Executive Committee shall consist of the following persons:

• Chairman
• Vice-Chairman
• World Conference President
• General Secretary
• Treasurer
• Immediate Past Chairman
• Chairman of each Regional section

The Executive Committee may nominate Working Groups and Committees (e.g. the World Conference Working Group) to execute particular tasks. The Working Groups shall report on their work to the Executive Committee and the General Assembly.

Every member of the Executive Committee present shall have one vote. Decisions shall be taken on a simple majority of the votes cast, whereby at least three members need to be present for a quorum. The Chairman has the decisive vote in case of an equal number of votes cast.
Working Groups (proposal):

- Qualification and Certification
- Information and Communication Technology (ICT)
- Research and University Education
- E-Learning
- Strategic plan
- Standardization

Other working groups can be created if necessary to meet specific needs.

8.2.1. **The Chairman** shall administer all actions of the society in accordance with the objectives, strategies and Operating Procedures of the Association and act as Chairman for all meetings of the society and the Executive Committee. He shall represent the Association solely vis-à-vis third parties, except for matters relating to the current treasurership.

In the absence of the Chairman, the vice-chairman shall act as chairman with the responsibilities of the chairman. In the absence of both chairman and vice-chairman, one of the following shall act with the responsibilities of the Chairman (in order of precedence):

- Immediate past chairman
- General Secretary
- Treasurer

8.2.2. **The General Secretary** shall serve as an assistant to the Chairman and shall be responsible through the Secretariat for recording all matters associated with the society between meetings as well as for recording and distributing minutes of General Assembly and Executive Committee meetings held during his term of office. Furthermore, the General Secretary shall also arrange for the Secretariat to maintain a Register of Members and of the names and addresses of appointed representatives accessible to all members and the public via the society Website.

8.2.3. **The Treasurer** shall be responsible for keeping the current records of income and expenditure as well as the preparation of an annual financial report, in the form of income and expenditure accounts, including an overview of the assets as well as the budget to be submitted to the Executive Committee for approval. He shall arrange for eventual audit of the annual accounts. He shall prepare a financial report for each General Assembly of the society.

8.2.3. **The World Conference President** shall organise and conduct the forthcoming World Conference as directed by the Member Institution responsible for the Conference, during his term of office and with the aid of a World Conference Organising Committee, and shall liaise with the society via the Committees in which he is an ex-officio member.

The World Conference President and the Conference Secretary shall be appointed by the society Member Institution chosen by the society membership to host the next World Conference.
8.2.4. The immediate Past-Chairman

The duties of the Immediate Past Chairman shall be to advise the Chairman and perform other such duties as delegated by the Chairman.

8.3. Secretariat of the society

A Member shall be elected by the society to provide a Secretariat service under the direction of the General secretary to the society Chairman, World Conference President, the Executive Committee, the Regional sections and all working groups.

Duties of the Secretariat shall include (but not be limited to):

- the society website and the society Newsletter
- maintaining a register of member’s, Working Groups and officers and publishing it on the website.
- issuing agendas and minutes of meetings and publishing them on the website
- arranging elections
- supporting the Treasurer
- collection of fees

8.4. Regional Sections

Four regional sections are established:

- Africa
- Americas
- Asia-Pacific
- Europe

Each section is managed by a regional Committee of at least 3 persons elected by the members of the region:

- Chairman
- Vice-chairman
- Secretary

8.5. Certification and Qualification Council (CQC)

The CQC shall manage the certification process inside the society.

The certification process includes the recognition of examination centres, the examination of application files from candidates, the delivery of certificates.

The members of CQC are nominated by the executive committee.
## APPENDIX III. LIST OF APPLICABLE DOCUMENTS WITHIN THE SOCIETY – QMS

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APPENDIX IV.

DRAFT SYLLABI FOR RADIOTRACER AND SEALED SOURCE TECHNOLOGY AND METHODOLOGY AS APPLIED TO INDUSTRY AND ENVIRONMENT

IV.1. PART A. BASIC KNOWLEDGE FOR RADIOTRACER AND SEALED SOURCE TECHNOLOGIES

MODULE A-1. RADIATION PHYSICS

1. Radiation and radioisotopes
   1.1. Radiation and radioisotopes
   1.2. Structure of the atom
   1.3. Alpha, Beta, and Gamma
   1.4. Penetration of matter
   1.5. Neutrons
   1.6. Radioactive decay (half-life)
   1.7. Activity calculation for radioactive decay
   1.8. X ray production
   1.9. Radiation units
   1.10. Natural radioactivity

MODULE A-2: RADIATION DETECTION

1. Interaction of gamma radiation with matter
   1.1. Photoelectric effect
   1.2. Compton scattering
   1.3. Pair production
   1.4. Energy spectrum and resolution
   1.5. X-ray fluorescence

2. Interaction of neutrons with matter
   2.1. Neutron induced reactions
   2.2. Radiative capture
   2.3. Inelastic scattering
   2.4. Electron capture
   2.5. Slowing down of neutrons
   2.6. Cross sections
   2.7. Neutron activation
   2.8. Delayed gamma neutron activation analysis - DGNAA
   2.9. Prompt gamma neutron activation analysis - PGNAA

3. Radiation detectors for gamma and X-rays
   3.1. Principles of radiation detection
   3.2. Gamma and X-ray detectors
   3.3. Gas filled radiation detectors
   3.4. Geiger Muller detectors
   3.5. Scintillation radiation detectors
3.6. Inorganic Scintillators
- Sodium Iodide NaI(Tl) Detector
- Bismuth Germanate (BGO) detector
- Caesium Iodide (CsI) detector
3.7. Organic Plastic Scintillator
3.8. Semiconductor (Solid state) detectors
- Germanium detector
- HPGE-detectors for gamma radioisotope measurement and identification
- Lithium-drifted silicon detectors
- Cadmium zinc telluride detectors (CdZnTe or CZT)
- CMOS (complementary metal oxide semiconductors) detectors for digital radioscopy
3.9 Detector efficiency

4. Neutron detectors
4.1. $^3$He proportional detector
4.2. BF$_3$ Neutron proportional counters
4.3. Neutron Sensitive Scintillating Glass Fibre (PUMA) detectors

5. Statistics of radiation counting
5.1. Accuracy in radiation detection – statistics of radiation counting
5.2. Uncertainty of a measurement
5.3. Various error types
5.4. Random and systematic errors
5.5. Accuracy and precision
5.6. Statistical evaluation based on repeated observations.
5.7. Arithmetic mean and the experimental standard deviation of the mean.
5.8. Level of confidence
5.9. Estimation of counting uncertainty using the square root of the observed counts
5.10. Detection and quantification
5.11. Minimum detectable concentration (MDC)

MODULE A-3. RADIATION PROTECTION AND SAFETY

1. Components of radiation protection
1.1. Natural radiation sources
1.2. Artificial radiation sources

2. Dose and dose rate
2.1. Radiation dose units
2.2. Relation dose rate versus activity for a punctual sealed source.
2.3. Gamma constants

3. Principle of radiation protection
3.1. Internal and external exposure
3.2. Radiation protection by distance
3.3. Radiation protection by shielding
3.4. Radiation protection by time
3.5. How can exposure to radiation be minimized?
3.6. ALARA principle
4. **Radiation protection of staff and public**
   4.1. Occupational dose for professional workers
   4.2. Public dose

5. **Personnel monitoring equipment**
   5.1. Policy for assigning dosimetry to individual workers
   5.2. Workers provided with personal dosimeter
   5.3. Type of dosimeters
   5.4. Dosimeter service
   5.5. Control of internal contamination

6. **Surveillance program**
   6.1. Classification of areas
   6.2. Supervised area
   6.3. Warning signs
   6.4. Storage area survey

7. **Rules for handling of radioactive substances**
   7.1. National regulations and authorisation of practices
   7.2. Occupational and public exposure
   7.3. Transport and control of radioactive packages
   7.4. Regulations governing waste disposal

8. **Radiation safety considerations in radiotracer applications**
   8.1. Safety planning form (SPF):
       - Plant visit and feasibility assessment
       - Selection of radiotracer and amount of radiotracer required
       - Approval from Regulatory Authority
       - Preparation of work area and execution of tracer test
       - Analysis of radiation hazards
   8.2. Safety rules and risk assessment
   8.3. Dose assessment in radiotracer work
   8.4. Role of the Radiation Safety Officer (RSO).

9. **Radiation safety considerations in sealed source and nucleonic gauge applications**
   9.1. Guidelines for users of nucleonic gauges for compliance with radiation safety regulations in force
   9.2. Application for approval of nomination of radiological safety officer for nucleonic gauge installations
   9.3. Standard authorization procedure for use of nucleonic gauging devices
   9.4. Application for authorisation / no objection certificate to procure & use nucleonic gauges or radioactive sources
   9.5. Application for registration of nucleonic gauges containing radioisotope and x-ray gauges
   9.6. Application for permission to move nucleonic gauges units
   9.7. Logbook format for use and maintenance of nucleonic gauges
IV.2. PART B: RADIOTRACER TECHNOLOGY AND METHODOLOGY AS APPLIED TO INDUSTRY AND ENVIRONMENT

MODULE B-1: RADIOTRACER METHODOLOGY

1. Radiotracer principle
   1.1. Concept of tracer
   1.2. Type of tracers; ideal and non-ideal tracers
   1.3. Radioactive and activable tracers
   1.4. Radiotracers and other tracers; advantages of radiotracers
   1.5. Selection of a radiotracer
   1.6. Commonly used radiotracers
   1.7. Methods and techniques for labelling
   1.8. Sample irradiation
   1.9. Mass and surface labelling
   1.10. Good mixing length estimation
   1.11. Various injection techniques for reducing mixing length

2. Radiotracer injection
   2.1. Radiotracer injection techniques
   2.2. Gas radiotracer injection
   2.3. Liquid radiotracer injection
   2.4. Solid radiotracer injection

3. Radiotracer detection
   3.1. On-line and off-line measurements
   3.2. On-line measurements using gamma radiotracers
   3.3. Factors influencing the radiotracer activity
   3.4. Influence of the gamma energy
   3.5. Influence of scintillator crystal nature and dimensions
   3.6. Influence of shielding and collimation
   3.7. Data acquisition systems
   3.8. Off-line measurements
   3.9. Sampling measurements
   3.10. Beta measurements
   3.11. Gamma measurements

4. Radiotracer activity calculation
   3.1. Activity calculation for radiotracer test design
   3.2. Error and uncertainty in radioactivity measurement
   3.3. Efficiency of detection system
   3.4. Radiotracer activity calculation
   3.5. Estimation of radiotracer activity for RTD test
MODULE B-2. PREPARATION OF RADIOTRACERS

1. Important considerations in the selection of a radiotracer
   1.1. Radiotracer as a representative of the traced material
   1.2. Behaviour of radiotracers in the traced material

2. Radionuclide production techniques
   2.1. Neutron activation
   2.2. Charged particle activation
   2.3. Fission products
   2.4. Radionuclide generators
   2.5. Activable tracers

3. Preparation of irradiation targets
   3.1. Targets for nuclear reactor irradiation
   3.2. Targets for charged particle irradiation
   3.3. Estimation of activity developed in target material

4. Methods and techniques for labeling
   4.1. Solid materials
   4.2. Aqueous systems
   4.3. Organic materials
   4.4. Gaseous materials
   4.5. Production of a labelled compound
   4.6. Specification of a labelled compound

5. Procedures for preparing most commonly used radiotracers
   5.1. $^3$H as Tritiated Water
   5.2. $^{24}$Na as Sodium Carbonate, Sodium Nitrate, Sodium Acetate, and Sodium Naphtenate
   5.3. $^{46}$Sc as Scandium Chloride
   5.4. $^{51}$Cr as Chromium-EDTA, Chromium Chloride and Sodium Chromate
   5.5. $^{56}$Mn as Manganese Chloride and Manganese Naphtenate
   5.6. $^{82}$Br as Ammonium Bromide, Para-dibromobenzene, Bromo-naphtol, Bromododecane
   5.7. $^{99}$Mo as Sodium Molybdate
   5.8. $^{131}$I as Sodium Iodide, Potassium Iodide, and Iodo-benzene
   5.9. $^{140}$La as Lanthanum Oxide and Lanthanum Salts
   5.10. $^{198}$Au as Chlorauric Acid, Colloidal Gold

6. Validation of radiotracers
   6.1. The reason and importance of validation
   6.2. Pitfalls in use of tracer compounds
   6.3. Validation regarding radioactivity issues
   6.4. Validation of tracer performance

7. Radiotracer field work
   7.1. Shielding, container and transportation
   7.2. Radiotracer injection
   7.3. Safety considerations

MODULE B-3. RADIOTRACER GENERATORS FOR INDUSTRIAL APPLICATIONS

1. Radionuclide generators
   1.1. Mother/daughter nuclear relationships and the Bateman equation
   1.2. Radioactive equilibrium
   1.2.1. Secular equilibrium
1.2.2. Transient equilibrium
1.3. Radionuclide generator principle
1.3.1. Properties of an ideal industrial radionuclide generator (IRNG)
1.3.2. Additional specific criteria for an industrial radionuclide generator
1.4. Radionuclide generator types
1.4.1. Generators based on mother fixed on to solid support in columns
1.4.2. Column-based generator with heating cap
1.4.4. Generators based on separation by distillation or sublimation
1.4.5. Generators based on cryogenic distillation
1.4.6. Generators based on chemical precipitation
1.4.7. Generators based on electrochemical separation
1.4.8. Generators based on supported liquid membrane (SLM) separation
1.4.9. Special case: Generator based on electrostatic radionuclide separation
1.5. Testing the generators

2. Potentially useful radionuclide generators
2.1. Requirement for industrial radionuclide generators
2.2. Potentially useful radionuclide generators for industrial and environmental tracer applications
2.3. The $^{44}$Ti/$^{44}$Sc radionuclide generator
2.4. The $^{68}$Ge/$^{68}$Ga radionuclide generator
2.5. The $^{85}$Sr/$^{85}$Rb radionuclide generator
2.6. The $^{99m}$Mo/$^{99m}$Tc radionuclide generator
2.7. The $^{113}$Sn/$^{113m}$In radionuclide generator
2.8. The $^{137}$Cs/$^{137m}$Ba radionuclide generator
2.9. The $^{144}$Ce/$^{144}$Pr radionuclide generator
2.10. The $^{172}$Hf/$^{172}$Lu radionuclide generator

3. Radiotracer preparation from generators
3.1. Radiotracer generators based on radionuclide generators
3.2. Design of an industrial radionuclide generator for radiotracer production
3.3. Radionuclide generators from on-site activation with isotropic neutron sources
3.4. Radionuclide (radiotracer) generator based on on-line use of neutron generators
3.5. Radiotracers from $^{68}$Ge/$^{68}$Ga generator
3.5.1. Preparation of $^{68}$Ga-DOTA
3.5.2. Practical preparation methods for $^{68}$Ga compounds
3.5.3. Validation of the stability of the radiotracer
3.5.4. Quality control
3.6. Radiotracers from $^{99m}$Mo/$^{99m}$Tc generator
3.6.1. Possible areas of application of eluted compound
3.6.2. The probable need for chemical treatment/complexation
3.6.3. QC test procedures for Mo/Tc generator
3.7. Radiotracers from $^{113}$Sn/$^{113m}$In generator
3.7.1. Possible areas of direct application of eluted compound
3.7.2. The probable need for chemical treatment/complexation
3.7.3. Practical preparation methods
3.7.4. Quality control
3.8. Radiotracers from $^{137}$Cs/$^{137m}$Ba generator
3.8.1. Possible areas of application of eluted compound
3.8.2. Practical preparation methods
3.9. Radiotracers from $^{44}$Ti/$^{44}$Sc generator
3.9.1. Possible areas of direct application of eluted compound
3.9.2. The probable need for chemical treatment/complexation
3.9.3. Practical preparation methods
3.9.4. Quality control
3.10. Experiences with operation of available generators
3.10.1. Elution efficiency and breakthrough of $^{68}$Ge/$^{68}$Ga and $^{137}$Cs/$^{137m}$Ba
3.10.2. Possible methods for reduction of breakthrough and increase of the practical shelf-life of the generator
3.11. Examples of radiotracer generators not based on a mother/daughter nuclear relationship
3.11.1. The methyl bromide generator

4. Guidelines for chemical preparation of radiotracers from generators
4.1. Water tracers
4.1.1. Sodium pertechnetate, Na\(^{99m}\)TcO\(_4\)
4.1.2. Aquocomplex-ion \([^{99m}\text{Tc(CO)}_3(H_2O)_3]^+\)
4.1.3. Gallium chloride, \(^{68}\text{GaCl}_3\)
4.1.4. Macrocyclic chelates \([^{68}\text{Ga}]-\text{DOTA}, [^{68}\text{Ga}]-\text{NOTA}\) and the complex \([^{68}\text{Ga}]-\text{EDTA}\)
4.1.5. Barium chloride, \(^{137m}\text{BaCl}_2\)
4.1.6. \(^{113m}\text{In}\) in EDTA complex
4.2. Tracers for organic phases
4.2.1. Technetium organic tracers
4.2.2. Gallium organic tracers
4.3. Particle tracers
4.3.1. Indium-113m
4.3.2. Technetium-99m
4.5. Operation with radiotracer based radionuclide generators
4.5.1. Control of radionuclide generators before use

MODULE B-4. PLANNING AND EXECUTION OF A RADIOTRACER EXPERIMENT

1. Procedures for conducting field radiotracer applications in industry
1.1. Plant visit and feasibility assessment
1.2. Selection of radiotracer and amount of radiotracer required
1.3. Approval from Regulatory Authority
1.4. Analysis of radiation hazards
1.5. Prepare equipment and radiotracer
1.6. Transport of radiotracer to the site
   - Type of packages
   - Radiation level permitted on the surface of the packages
   - Information/labelling on the package
1.7. Co-ordination with radiation safety officer of the plant

2. Preparation of work area and execution of tracer test
2.1. Elution of tracer
2.2. Injection of radiotracer
2.3. Detection of radiotracers

3. Monitoring of occupational radiation exposures
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3.2. External Radiation Monitors
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3.4. Area Monitoring
3.5. Environmental Monitoring
3.6. Radioactive waste management
3.7. Waste minimization strategies
3.8. Post-injection surveillance and assessment of radiation hazards

4. Regulatory and licensing aspects of radiotracer applications in laboratory
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4.3. Personnel Monitoring Services
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4.5. Procurement of radioisotopes

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   1.2. Tracer balance or total-count method
   1.3. Tracer rate balance or dilution method
   1.4. Calibration for the total-count and dilution methods
   1.5. Radiotracers for flow meter calibration
   1.6. Flare gas flow measurement
   1.7. ISO standard for flow rate measurement by radiotracer
   1.8. Radiotracers applied for flow measurement of water, oil and gas flows
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2. Radiotracer methodology for leak detection
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       • Leak detection by residence time distribution (RTD) measurement
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       3.4.2. Estimation of the activity of radiotracer
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   1.3. Dilution principle for the estimation of the material fraction which recirculates also in a continuous system.
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2. Radiotracer techniques for batch mixing measurement
   2.1. Required mixing time - external detector method
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   2.3. Experimental determination of the time required for mixing in batch mixing process
       - Determination of required mixing time and homogeneity in the batch mixers for refractory bricks.
       - Radiotracers for optimization of batch mixing of sand

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   1.2. Labelling techniques
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   1.4. Accelerators irradiation
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   1.6. Ultra thin layer activation technique
   1.7. Practical irradiation set-up
   1.8.Possibilities and limitations

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   2.4. TLA with isotope diffusion
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1. RTD formulation
   1.1. Dirac injection
   1.2. Data correction
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       - Decay correction
       - Dead time correction
       - Sampling time correction
       - Counting time correction
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   - time-domain curve fitting,
   - frequency-domain curve fitting,
   - method of moments.

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       - Calculation of mean residence time (MRT) and variation
   1.2. Dead/stagnant volume
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       - Estimation of short circuiting

2. RTD system analysis
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       - Elementary models
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3. RTD software for modeling simple flows
   3.1. RTD software
   3.2. Description of models available in the RTD software

4. Integration of RTD tracing with CFD simulation
   4.1. Background of computational fluid dynamics (CFD) simulation.
   4.2. CFD simulation using software packages
   4.3. Comparing CFD simulation and RTD systemic approaches
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5. Single particle tracking (SPT)
   5.1. Computer Aided Radioactive Particle Tracking (CARPT) method
   5.2. Positron Emission Particle Tracking (PEPT) radiotracer method
   5.3. Experimental design of SPT techniques:
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       - Particle labelling
       - Calculation of activity
       - Selection of detectors
       - Collimation of detectors
       - Positioning of detectors
       - Data acquisition systems
       - Gamma cameras
       - Data processing and image construction
       - Measuring time and statistics of measuring
       - Algorithms for position construction
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1. Important characteristics and response parameters of NaI (Tl) gamma-ray scintillation detectors and liquid scintillation detectors.
   1.1. Scintillation detector NaI (Tl)
   - counting rate versus the voltage characteristics of a scintillation detector;
   - features of a gamma-ray pulse-height spectrum;
   - calibration of a NaI(Tl) scintillation spectrometer;
   - counting efficiency and energy resolution as a function of gamma-ray energy for a NaI(T l) scintillation detector.
   1.2. Liquid scintillation counting
   - liquid scintillation counter set-up for counting tritium;
   - effect of quenching by aqueous samples;
   - counting efficiency for an aqueous sample using an internal standard.

2. Determination of the time required for mixing in batch mixing process and a test for homogeneity of the final product.
   2.1. Batch mixing process
   - Required mixing time - external detector method
   - Required mixing time - sampling method
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3. Detection of dead space and channelling
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   3.2. Determination of the channelling in a stirred tank system

4. Determination and analysis of residence time distribution in process vessels
   4.1. Experimental procedure for obtaining residence time distribution (RTD) curves from impulse injections of radiotracer,
   4.2. Analysis of experimental RTD curves for the selection of process models and the estimation of model parameters.

5. RTD curves and parameter estimation in combined model systems
   5.1. RTD response curves obtained from a stirred tank followed by a plug flow region
   5.2. RTD response curves obtained from a series of stirred tanks in parallel

6. Flow rate measurement in pipes
   6.1. Transit time or peak-to-peak method
   6.2. Tracer balance or total-count method
   6.3. Tracer rate balance or dilution method
   6.4. Calibration for the total-count and dilution methods
   6.5. Water flow rig for laboratory RTD tests

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   1.1. Basic chemistry; chemical reactors/ equilibrium
   1.2. Reactor kinetics, rate constants, order of the reactions
   1.3. General concepts of chemical engineering
   - Concept of material balance, mass, moles and molecular mass
   - Concept of energy balance, types of energy
   - Concept of tracer/ role and properties of a suitable tracer; measurements
2. **Types of chemical engineering operations**
   2.1. Separation techniques and use of tracers in equipment’s and operations:
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   2.1.2. Absorption
   2.1.3. Adsorption
   2.1.4. Extraction
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   3.1.2. Stirred reactors, single and multiphase
   3.1.3. Column reactors, packed beds and fluidized bed
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4. **Hydrodynamics of reactors**
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   4.3. Phase-phase interaction
   4.4. Energy dissipation and continuous phase circulation
   4.5. Transport process and transfer coefficient

5. **Data analysis and interpretation**
   5.1. Mathematical models
   5.2. Estimation of parameters
   5.3. Trouble shooting, control and optimization.

6. **Major targets of radiotracer applications**
   - Petrochemical, chemicals and refineries
   - Mineral ore processing/ Gold, Copper, Cobalt, Phosphate
   - Metallurgy
   - Cement
   - Fertilizer
   - Waste water treatment plants (WWTP)
   - Sugar
   - Paper

7. **Petrochemical industry**
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   7.2. Aniline production reactor
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   8.1. Diagnosis of leaching and flotation processes
   8.2. Diagnosis of flotation machines for copper ore enrichment
   8.3. Investigation of cobalt recovery and mass flow dynamics in a copper melting process
   8.4. Estimation of laterite grain erosion in a fluidised bed calciner
   8.5. Estimation of coal-ash dust cyclone efficiency
   8.6. Improvement of a grinding process
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8.8. Investigation of the superphosphate production chamber
8.9. Investigation of a superphosphate granulation operation
8.10. Performance diagnosing of a concrete mixing machine
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MODULE B-12: RADIOTRACER APPLICATIONS IN WASTEWATER TREATMENT PLANTS

1. Wastewater treatment technologies
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   1.2. Application of wastewater treatment processes
   1.3. Process units of Wastewater Treatment Plants and possible radiotracer applications

2. Tracer techniques and their utilization in wastewater treatment plants
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   2.3. Limitations of conventional tracers in Wastewater Treatment Plants investigations

3. Radiotracer techniques
   3.1. Selection of radiotracers for investigation of Wastewater Treatment Plants
   3.2. Radiotracer measurement
   3.3. Radiation protection and safety considerations in radiotracer investigations in Wastewater Treatment Plants
   3.4. Typical radiotracer applications in a Wastewater Treatment Plant

4. Case studies
   4.1. Radiotracer investigation of wastewater chlorinate process
   4.2. Radiotracer investigation of equalizer – clarifier tank
   4.3. Radiotracer investigation of mixer- distributor unit
   4.4. Radiotracer investigation on the sand filter of a Wastewater Treatment Plant
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   4.6. Radiotracer investigations of primary clarifier, aeration tank and secondary clarifier
   4.7. Radiotracers for diagnosing the performance of a secondary clarifier
   4.8. Diagnosis of a cylindrical two-stage anaerobic sludge digester
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   4.10. Radiotracer investigation of an anaerobic digester
   4.11. Radiotracer investigation of a municipal biological aeration tank
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   4.14. Tracer hydrodynamics study in an aeration unit of a Wastewater Treatment Plant
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   1.2. Some sediment characteristics
   1.3. Modes of sediment transport
   1.4. Sedimentary processes and measurement of sediment transport
   1.5. The mechanics of fluids applied to sediment transport
   1.5.1. Interaction of sediments with water
   1.5.2. Acting forces
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1.7. Dynamics of littoral and problem
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3.1.2. Scattering gauges
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2.2.1. Preparation of a technical safety report
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2.2.4. Actions for radiation safety at injection site
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2.3.3. Laboratory tracer analysis
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   1.2. Advantages of gamma scanning
   1.3. Gamma scanning profile
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       • Gamma profile of column part with collapsed tray
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   2.1. Experimental design of gamma scanning
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   3.2. Flooding in a pre-fractionation column
   3.3. Feints distillation column: Flooding as a result of deposit (debris) in the downcomer
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   3.6. Wash vacuum column.Collapsed bed with anomalies
   3.7. Coke formation
   3.8. Grid scan on a Ketone structured packed bed column
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   4.2. Pipe scan applications
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   4.5. Pipe inspection for defects: blockages, intrusion and corrosion.
   4.6. Deposit build up in Furnace header

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   1.1. Major neutron sealed sources applied for level and interface measurement
   1.2. Typical portable neutron backscatter gauge

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- Gamma sealed source profiler for monitoring oil/water separation process in oil separator
- Neutron backscatter technique in investigating oil separator

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1. **Gamma transmission tomography**
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2. **Gamma emission tomography**
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   6.1. Mathematics of the gamma transmission CT
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   6.5. Software

7. **Some applications of gamma transmission CT**
   7.1. Design of a single source-detector gamma CT for multipurpose investigation
   7.2. Gamma CT to investigate soil compaction in core samples
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   7.4. Draft tube bubble column in lab scale
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   • On-line (process),
   • Off-line (process),
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   • Used in laboratory (on samples), and
   • Portable, for site measurements

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5. Typical models of nucleonic gauges
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   5.2. Density, concentration and thickness measurement gauges
   5.3. Gamma nucleonic gauges for on-line coal ash analysis
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   5.5. XRF for elemental analyses
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6. Nuclear techniques for mining and logging
   6.1. Nuclear borehole logging
      • Natural gamma logging (n-g)
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6.4. On-Line Ash in Coal: Applications
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• Monitoring at shipping ports
• Power Station: feed monitoring

7. Emerging new application techniques and trends,
7.1. Computer simulation (Monte Carlo) for optimising gauge design,
7.2. Multi-gauge systems and Hybrid systems,
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V.1. EXAMPLE OF DRAFT RECOMMENDED PRACTICE FOR GAMMA SCANNING OF INDUSTRIAL PROCESS COLUMNS

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2. SCOPE
3. METHOD STATEMENT
4. RESPONSIBILITIES
5. WORKSCOPE PLANNING
6. EQUIPMENT REQUIREMENTS
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APPENDIX 5: PRE JOB CHECK LISTS

1. OBJECTIVE
The gamma-ray column scanning technique is widely used in the oil, gas and chemical industries. It is used to a lesser extent in many other industries. These guidelines are written to show the steps that should be taken to enable scans to be carried out in a systematic manner. It is also envisaged that the guidelines could be incorporated into the supplier’s quality system, whilst at the same time giving sufficient latitude to enable the supplier to vary the procedure to meet particular local requirements.

2. SCOPE
The procedure shall be applicable to the inspection of all columns. These shall include columns with different diameters, wall thicknesses and tray configurations and shall also include columns with packed beds.

3. METHOD STATEMENT
Gamma-ray scanning is based upon the principle that when a gamma-ray passes through a column the intensity of the emerging beam is related to the path length and density of material through which the beam passes.

An appropriate source and detector are aligned at the same elevation opposite each other on the column. This may be on a diameter or on a chord depending upon the requirements of the scan.

Measurements of radiation intensity are taken at appropriate elevations as the source and detector system is either raised or lowered on the column.

The data obtained is then represented in some appropriate format to show radiation intensity as a function of elevation.

Detailed analysis of these data enables the service provider to make assessments about the
material within the column.

4. RESPONSIBILITIES

To enable column scans 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. He will be responsible for providing safe access and for issuing an appropriate work permit.

**Level 3 - Projects Manager:** Person ultimately responsible for the planning and execution of the entire job. This includes defining the work scope and allocating sufficient trained and competent personnel 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 data obtained and for supplying a suitable report to the customer within an agreed time period.

**Level 2 - Senior Field Technician:** The person on site responsible for carrying out the instructions of the Level 3. He shall be responsible for ensuring that the site work is carried out safely and in accordance with the agreed work scope. 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.

**Level 1 - Junior Field Technician:** Depending upon the particular column and work scope there will be one or more Level 1. He is responsible for safely and efficiently carrying out the instructions of the Level 2.

5. WORK SCOPE PLANNING

Prior to carrying out any work the Projects Manager should agree with the client the objectives of the work. He will require details of the column diameter and wall thickness and details of the trays or packed beds. He will require a suitable general arrangement drawing showing the location of features within the column. He will need to ensure that there is suitable safe access to the parts of the column where the scanning team needs to position themselves.

He will ensure that there are sufficient resources to carry out the work and that a suitable radioactive source is available.

6. EQUIPMENT REQUIREMENTS

Equipment required for a column scan includes the following:

- A suitable radioactive source or sources
- A suitable source container in which the source can be raised or lowered on the column
- A suitable detection system by which the radiation intensity can be measured and
recorded at different elevations on the column. This usually involves using a nominal 0.5 inch, 1 inch, 2 inch or 3 inch sodium iodide crystal

- A suitable means of displaying the data in an agreed manner
- A suitable calibrated radiation monitor so that a “controlled area” can be defined. The dose rate at the boundary of a controlled area is usually defined by national legislation.
- Sufficient barriers and warning notices to cordon off the “controlled area”.
- Appropriate handling tools for the safe transfer of the radioactive source into the column scanning source container

The equipment should be in good working order, tested in the laboratory before deployment to the site and securely packaged for transportation to the work site.

The radioactive source should be transported to the worksite in an approved Type A container, labelled and documented in accordance with international legislation.

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

7. EXECUTION OF WORK AT WORK SITE

Upon arrival at the work site the Level 2 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 will confirm by monitoring that the source is still present. He will immediately report any abnormalities and, after consultation with the Projects Manager, take such remedial action as is required.

He will carry out the scan in the agreed manner. Any deviation to the agreed scanning procedure must be approved by the projects manager after due consultation with the client.

After carrying out the scan 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.

8. DATA PROCESSING AND REPORTING

The measurement of radiation intensity obtained by the radiation detector is recorded in some convenient format. This is most commonly expressed as counts per given time interval. A graphical representation is usually produced. This is then studied and conclusions are then drawn about the behavior within the column. A suitable computer program is usually used to produce the graphical representation.

The result will be confirmed in a written report to the customer in such time as agreed between the two parties.

APPENDIX 1: CALCULATION OF RADIOACTIVE SOURCE STRENGTH

In determining the strength of the radioactive source that is required, consideration should be given to the column diameter and wall thickness and the nature of the problem.
Usually Cobalt-60 or Caesium-137 sources are used.

The activity required for the gamma scanning can be estimated using the following the formula:-

$$\text{Activity (mCi)} = \frac{D d^2 \times 2^{e/X_{1/2}}}{T}$$

where:

D = Dose rate required at the detector (microSieverts per hour),

d = internal diameter of the column (m),

e = double wall thickness of the column (mm),

$X_{1/2}$ = half-value thickness (mm) for steel and the source (e.g. 22 mm for the steel if 60Co) is used

T = gamma constant for the gamma source (e.g. 13.3 microSieverts per hour from 1 millicurie (37 MBq) at a distance of 1 meter from the source if using Cobalt-60

Note: Approximately 200 mm needs to be added to the column diameter to take into account the distance of source and detector positions from the column.

In deciding the dose rate that is required at the detector consideration needs to be given into the sensitivity of the detection system and the number of counts per second required from the detector to give sufficient statistical accuracy.

The sensitivity can be determined by comparing the dose rate and counts per second given by the detector at a particular position.

Typically it has been found that if a 2 inch sodium iodide crystal is used then a dose rate of 10 microSieverts per hour at the detector is suitable.

**APPENDIX 2: EXAMPLE OF SOURCE ACTIVITY CALCULATION**

A gamma source is needed to scan a distillation column, which has the following parameters:

- Internal diameter = 2.9 m
- Wall thickness = 15 mm

The activity is calculated using the following equation

$$\text{Activity (mCi)} = \frac{D d^2 \times 2^{e/X_{1/2}}}{\Gamma}$$

Let us assume we require a dose rate of 10 microSieverts per hour (D)
d = 2,900 mm (ID) + 2 x15 mm (wall thickness) + 200 mm (for source detector column position)

e/ x0.5  = 1.364

Γ = 13.32

Substituting we obtain: Activity = 18.9 mCi (or 699.3 MBq)

APPENDIX 3: COLUMN SCANNING SOURCE CONTAINER

There are a number of different column scanning source containers depending upon personal preference and on likely dose rates. The source container should be capable of giving a collimated, or partially collimated, beam and the position at which the beam emerges from the container should be clearly indicated. A suitable means of moving the source container up and down the column is required and some method is needed to reduce lateral movement.

When large diameter or thick walled vessels are to be scanned, consideration should be given to reducing the doses received by workers by making the column scanning source container an integral part of the Type A container.

APPENDIX 4: SELECTION OF SOURCE AND DETECTOR ORIENTATIONS

Scanning of trayed columns:

The selection of the scan lines depends on the orientation of the downcomers and the availability of suitable access platforms on the column.

Ideally the scan - lines should avoid the tray downcomers as shown below,
However, it is acceptable to scan through the down comer region when information is required about the down comers or when access problems exist.

**Scanning of packed-bed columns:**

To inspect packed beds, a system of multi-chord scans, or grid scans is required. In addition one scan line should pass through a diameter. This technique can also be used to examine distributors and to investigate the uniformity of the distribution of incoming liquid feed. The schematics of grid scanning are shown below:

In general, four grids are recommended for the inspection of packed columns. However, the number can be increased depending upon the information required. One scan should also be carried out through the diameter.
The Procedure of grid scanning

The following steps need to be taken:
- Obtain drawings showing the mechanical design of the column.
- Select the scan line directions to avoid external structures.
- Select the reference point (zero point) just above the packed bed in order to perform 4 comparable profiles.
- Mark the positions of the scan lines on the column
- Carry out all the scans under identical conditions

APPENDIX 5: PRE-JOB CHECK LISTS

Preparation of the check-list:

The service provider should make his own check list. Items may include

<table>
<thead>
<tr>
<th>Electronic equipment and accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
</tr>
<tr>
<td>Computer (laptop or palmtop)</td>
</tr>
<tr>
<td>Measuring tapes (2)</td>
</tr>
<tr>
<td>Detector cable(s)</td>
</tr>
<tr>
<td>Computer cables</td>
</tr>
<tr>
<td>Guide steel wires or cables (2)</td>
</tr>
<tr>
<td>Portable scaler-ratemeter or data-logger or…</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gamma source:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60 or Cs-137 or Ir-192</td>
</tr>
<tr>
<td>Source holder/source container – with collimator</td>
</tr>
<tr>
<td>Handling tools and accessories: tongs, gloves, plastic sheet, etc..</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiological safety equipment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey meters</td>
</tr>
<tr>
<td>Personnel monitors</td>
</tr>
</tbody>
</table>

| Others: Detail as required                                                |

Pre-checking the operation of the acquisition system, detector and radiological safety equipment

The service provider should carry out all necessary pre-job checks prior to mobilization. These should include checks to confirm compliance with statutory legislation.
1. OBJECTIVE

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.

2. SCOPE

The guidelines shall be applicable to leakage testing in banks of feed/effluent types heat exchangers using radioactive tracer techniques.

3. METHOD STATEMENT

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. He will be responsible for providing safe access and for issuing an appropriate work permit.

**Level 3 - Projects Manager:** Person ultimately responsible for the planning and execution of the entire job. This includes defining the work scope and allocating sufficient trained and competent personnel 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 data obtained and for supplying a suitable report to the customer within an agreed time period.

**Level 2 - Senior Field Technician:** The person on site responsible for carrying out the instructions of the Level 3. He shall be responsible for ensuring that the site work is carried out safely and in accordance with the agreed work scope. 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.

**Level 1 - Junior Field Technician:** Depending upon the particular column and work scope there will be one or more Level 1. He is responsible for safely and efficiently carrying out the instructions of the Level 2.

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 flow rate 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 Level 2 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 Level 3 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 occur 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 systems can be used, but each must be appropriate for the duty that it has to perform.

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.](image)

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
APPENDIX VI. PRELIMINARY DRAFT QUESTION BANK

1. QUESTIONS ON RADIOTRACER METHODOLOGY AND TECHNOLOGY

I. Radioactivity
1. What does "A" refer in discussing the nucleus?
- Total number of protons
- atomic number
- atomic mass number

1. Which of the following isotopes are artificially made:
   a. Ra-226 and Ir-192
   b. U-238 and Co-60
   c. Ir-192 and I-131
   d. Cs-137 and Am-241

2. What is the difference between X-ray and gamma ray:
   a. both have short wavelength
   b. both are produced during the disintegration of nucleus of radioisotopes

3. Co-60 radioisotope is produced by:
   a. irradiating Co-59 in a nuclear reactor
   b. irradiating Co-59 in an accelerator
   c. processing spent fuel from a nuclear reactor,
   d. none of the above.

4. Interaction of gamma radiation with matter involves:
   a. Compton scattering
   b. Photoelectric effect
   c. Pair production
   d. All of above.

5. One gram of pure cobalt is placed in a thermal-neutron flux of \(10^{13}\) neutrons.cm\(^{-2}\)/sec for 24 hr. If the cross section for the Co-59/(n, gamma)/ Co-60 reaction is 22.5 barns and the half-life of Co-60 is 5.30 years, how many Co-60 atoms are present after the 24-hr irradiation, how much is the activity in Ci and in Bq (Answer: 1.98 \times 10^{17} \text{ atoms})

5. Calculate the percentage of beta particles that will pass through an absorber of density thickness 80 mg/cm\(^2\) if the maximum energy of the source of beta particles is 1.00 Mev. (Answer: 17.2%)

6. Calculate the total attenuation cross section, \(\mu\), for an alloy that contains 20.0 wt.% lead and 80.0 wt.% iron for a 10.0 MeV photon (Answer: 0.0340 cm\(^2\)/g)
7. Calculate the percentage of energy that would penetrate the density thickness of the lead-iron alloy (20.0 wt.% lead and 80.0 wt.% iron) from a source of 10-Mev photons if the build-up factor is 2.50 (Answer: 8.32%).

8. What is the error introduced in counting a sample of P-32 if the source-backing material is changed from aluminium to steel? (Answer: 13.3%)

8. Calculate the average number of collisions necessary to moderate a neutron with an energy of 10.0 MeV down to thermal energy of 0.025 eV in pure carbon. (Answer: 125 collisions)

II. Statistics in radiation detection and measurement

1. The number of counts recorded during a test was N = 10 000 counts. What is the relative standard deviation in percentage?
   a. 1%
   b. 10%
   c. 0.1%

2. What is the standard deviation in counts per second (cps) for the count rate: I = 10000 counts / 10 s.
   a. 100 cps
   b. 1 cps
   c. 10 cps

3. What is the true average number of disintegrations in a 10-min interval from a radioisotope source that originally contains $10^6$ radioactive atoms if the radioisotope has a decay constant of $\lambda = 2 \times 10^{-3}$ min$^{-1}$? (Answer: 20 000)

4. What is the counting time necessary to produce a standard deviation of 0.1% if the true average counting rate is 1000 counts/min? (Answer: 1000 min).

5. The number of gross (sample plus background) counts obtained in 10 min was 12000. The number of background counts obtained in 5 min was 160. What is the net counting rate, and what is the standard deviation of the net counting rate? (Answer: 88 counts/min and 4.3 counts/min).

6. If the resolving time of a given detection system is 300 sec, what is the true counting rate for an observed counting rate of 20 000 counts/min? (Answer: 22 000 counts/min).

III: Radiotracers

1. What is the difference between passive (ideal) tracer and active (non-ideal) tracer? What is $^3$H (HTO) and $^{131}$I (NaI) for water?

2. Which of the following characteristics of a radioisotope are used to select it as a tracer:
   a. half-life
   b. physico-chemical behaviour
   c. type of energy emitted
3. For tracing organic liquid in a processing vessel, which of the following tracer is most suitable:
- Br-82 as ammonium bromide
- Br-82 as methyl bromide gas
- Br-82 as paradibromo benzene

4. For in situ detection which one of the radiotracers is preferred:
- beta- emitter
- neutron emitter
- gamma emitter
- alpha- emitter

5. For field work with gamma emitters radiotracers can be used: Geiger Muller or Scintillation detectors? What is more efficient?

6. There are several scintillation detectors for gamma rays: NaI (Tl), CsI (Tl), BGO. What is more efficient detector, and what is more common used detector in field tracer work, why?

7. For which radiotracers is used liquid scintillation detector?

8. Which kind of neutron sources are used in industry, and what is the best?

9. What are commonly used neutron detectors and what is the best?

10. What are the radioisotope generators used in industrial applications?

11. What are the radiotracers for gaseous tracing?

12. How it can be prepared a radiotracer for solid phase?

13. What are the best radiotracers for water tracing?

14. What are the best radiotracer for interwell communications in oil fields?

**IV. Applications of radiotracers**

1. The common methods of flow measurement with radiotracers are:
- the dilution method
- the venturi meters
- the transit time method

2. A continuous injection of tracer is made into a stream flow. The injection is 23.5 litres per minutes of 1003 Bq/ml of tracer. Downstream after complete mixing the concentration is measured as 5.02 Bq/l. The flow is:
- 4.70 x 106 l/min
- 4.70x 108 l/min
- 7.83x105 l/s
3. Flow rate measurement using radiotracer is required for:
   - calibration of flow meters
   - blockage detection
   - mixing studies
   - none of the above

4. For flow rate measurement in closed conduits, which method is used:
   - constant rate ejection method
   - transit time method
   - continuous dilution method

5. Where should the first detector be installed for flow rate measurement using transit time method:
   - just near the injection point
   - 100 diameter away above the injection point
   - 50 diameters away above the injection point

6. Residence time distribution is defined as:
   - response of the system to an impulse input
   - response of the system to a steep input
   - response of the system to a wide tracer pulse

7. Area under a normalized RTD curve should be:
   - infinity
   - unity
   - ten
   - hundred

8. Mean residence time is:
   - second moment of RTD curve
   - first moment of RTD curve
   - tenth moment of RTD curve

9. A long tail in the measured RTD curve indicates:
   - dead volume with exchange
   - plug flow
   - well mixed flow
   - none of the above

10. An ideal mixer can be represented by number of tanks in series:
    - $N=1$
    - $N=10$
    - $N=100$
    - $N=1000$

11. A perfect plug flow can be represented by Pecklet number:
    - $P=1$
    - $P=10$
    - $P=100$
12. The axial dispersion model is usually applicable to:
- Well mixed systems
- Plug flow system
- Plug flow with axial dispersion
- Well mixed flow with dead volume

13. RTD can be used for:
- troubleshooting
- validation of mathematical models
- to investigate the hydrodynamic behaviour of a system
- to all of the above

14. Use of stir in a tank:
- enhance the mixing
- reduce the mixing
- both of the above

15. In the reactors or process vessels having no mixing in the direction of flow takes place, then the flow can be characterized as:
  a. back mixed flow
  b. channeling or bypassing
  c. plug or piston flow
  d. stagnant zone

16. A radiotracer study was carried out in the White Portland Cement Factory to investigate the RTD of raw feed materials in a rotary kiln. The raw material (80% of limestone, 15% of white clay and 5% of silica sand) mean residence time within the kiln, calculated by process engineer dividing the filled physical volum V (m³) by the feed flow rate Q (m³/s) is 40 minutes. This time is needed to ensure good quality of the end product. In order to verify this data, the radiotracer test was conducted using La-140 as tracer. The experimental date are:

<table>
<thead>
<tr>
<th>Time, t (min)</th>
<th>C(t), Count/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>18000</td>
</tr>
<tr>
<td>10</td>
<td>33926</td>
</tr>
<tr>
<td>15</td>
<td>71721</td>
</tr>
<tr>
<td>20</td>
<td>75456</td>
</tr>
<tr>
<td>25</td>
<td>99120</td>
</tr>
<tr>
<td>30</td>
<td>139390</td>
</tr>
<tr>
<td>35</td>
<td>157020</td>
</tr>
<tr>
<td>40</td>
<td>98550</td>
</tr>
<tr>
<td>45</td>
<td>89140</td>
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<tr>
<td>50</td>
<td>59240</td>
</tr>
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<td>55</td>
<td>54355</td>
</tr>
<tr>
<td>60</td>
<td>35050</td>
</tr>
<tr>
<td>65</td>
<td>35777</td>
</tr>
</tbody>
</table>

Using the above radiotracer experimental data calculate the actual mean residence time of the clinker inside the kiln.
V. Radiation protection and safety

1. Radiation dose received by the individual from radiotracers during preparation, transportation, injection and measurement depend upon:
   a. time he spent with and near the radiotracer,
   b. activity of the radiotracer,
   c. distance from the radiotracer container and injection point
   d. all above

2. Calculate the dose rate in air from a 1 Curie source of Cs-137 at a distance of 30 cm (assume $B=1$). (Answer: near 3.6 R/hr).

3. What is the best shield material for radiotracer transportation:
   a. lead
   b. steel
   c. deplated uranium
   d. tungsten (wolfram)

4. How is the Category of a package determined in the IAEA transport regulations?
   a. by measuring the radiation level on the surface of the package
   b. by measuring the radiation level at one meter from the package
   c. by measuring the radiation level on the surface and at one meter from the package (*)
   d. by measuring the content of the package

5. What is the meaning of Transport Index (TI) introduced in the IAEA transport regulations?
   a. it is the maximum radiation dose in mSv/hr measured on the surface of the package
   b. it is the maximum radiation dose in mrem/hr measured at 1 m from the surface of the package (*)
   c. it is the maximum heat level in J/hr measured on the surface of the package
   d. it is the maximum activity of the material that can be put into a package

6. Which of the following types of radiation has the highest quality factor?
   - X rays
   - beta particles
   - neutrons
   - gamma rays

7. What sign would you expect to see around a 5600 Ci Cobalt-60 teletherapy unit?
   - Caution - Radiation Hazard
   - Grave Danger - Very High Radiation Area (*)
   - Danger - Radioactive Hazard
   - Caution - Radiation Hazard Area

8. The risk of cancer death is approximately _____ % per 10 mSv for acute doses.
9. The effects of radiation exposure as seen in an individual are referred to as:

- Teratogenic effects
- Somatic Effects (*)
- Genetic effects
- Electromagnetic effects

10. The TI (Transport Index) is a measure of:

- Radiation levels inside the passenger compartment of the transport vehicle
- Amount of maximum radioactivity allowed per package
- Exposure rate as measured at 1 meter from package surface
- Package integrity for withstanding accidents

11. The Sievert is a unit used to measure:

- Radiation dose in terms of the amount of energy absorbed
- Radioactivity
- Radiation dose in terms of the amount of the biological effect caused by the amount of energy absorbed
- Radiation exposure

12. Radiation received by the body over a short period of time is:

- Acute exposure
- Sublethal exposure
- Supralethal exposure
- Chronic exposure

13. The occupational dose limit to the foetus during gestation is:

- 0.50 mSv
- 5 mSv
- 10 mSv
- 0 mSv

14. The occupational dose limit for a minor is:

- 0.50 mSv
- minors may not receive any dose
- 50 mSv
- 5 mSv

15. The average US citizen receives approximately _______ mSv of radiation each year.
16. Acute radiation sickness occurs beginning at doses greater than:
   - 1 Sv
   - 1 mSv
   - 70 mSv
   - 3 mSv

17. The body's immune system become compromised at doses greater than:
   - 10 Sv
   - 1 mSv
   - 3 Sv
   - 3 mSv

18. Scientists' knowledge of the effects of ionizing radiation come from all but:
   - atomic bomb survivors
   - accident victims
   - hospital workers
   - radium watch dial painters

19. Radiation dose from radioactive materials is affected by all BUT:
   - age of recipient
   - type of radiation
   - amount of radiation
   - proximity to radiation source

20. Contamination levels are typically reported in:
   - mGy
   - mSv
   - dpm/cm²
   - mR

21. Most scientists subscribe to the ________ model of risk.
   - threshold
   - quadratic
   - exponential
   - linear

22. Medical sources of radiation account for approximately _______ of radiation per year to the average citizen.
   - 70 mSv
23. The unit of absorbed dose is the:
- R
- Sv
- Gy
- Bq

24. Exposure in air is quantified by the:
- rem
- R
- rad
- Curie

2. QUESTIONS FOR RADIOTRACERS, SEALED SOURCES AND NUCLERONIC GAUGES TECHNIQUES AND APPLICATIONS IN INDUSTRY

1. Which of the following isotopes are artificially made:
   - Ra-226 and Ir-192
   - U-238 and Co-60
   - Ir-192 and I-131
   - Cs-137 and Am-241

2. What is the difference between X-ray and gamma ray:
   - both have short wavelength
   - both are produced during the disintegration of nucleus of radioisotopes

3. One gram of pure cobalt is placed in a thermal-neutron flux of $10^{13}$ neutrons.cm$^{-2}$/sec for 24 hr. If the cross section for the Co-59 /$(n, \gamma)$/ Co-60 reaction is 22.5 barns and the half-life of Co-60 is 5.30 years, how many Co-60 atoms are present after the 24-hr irradiation, how much is the activity in Ci and in Bq (Answer: $1.98 \times 10^{17}$ atoms)

4. Calculate the percentage of beta particles that will pass through an absorber of density thickness 80 mg/cm$^2$ if the maximum energy of the source of beta particles is 1.00 Mev. (Answer: 17.2%)

5. Calculate the total attenuation cross section, $\mu$, for an alloy that contains 20.0 wt.% lead and 80.0 wt.% iron for a 10.0 MeV photon (Answer: 0.0340 cm$^2$/g)
6. Calculate the percentage of energy that would penetrate the density thickness of the lead-iron alloy (20.0 wt.% lead and 80.0 wt.% iron) from a source of 10-Mev photons if the buildup factor is 2.50 (Answer: 8.32%).

7. Calculate the average number of collisions necessary to moderate a neutron with an energy of 10.0 Mev down to thermal energy of 0.025 ev in pure carbon. (Answer: 125 collisions)

8. What is the true average number of disintegrations in a 10-min interval from a radioisotope source that originally contains $10^6$ radioactive atoms if the radioisotope has a decay constant of $\lambda = 2 \times 10^{-3} \text{ min}^{-1}$? (Answer: 20 000)

9. What is the counting time necessary to produce a standard deviation of 0.1% if the true average counting rate is 1000 counts/min? (Answer: 1000 min).

10. The number of gross (sample plus background) counts obtained in 10 min was 12000. The number of background counts obtained in 5 min was 160. What is the net counting rate, and what is the standard deviation of the net counting rate? (Answer: 88 counts/min and 4.3 counts/min).

11. What is the error introduced in counting a sample of P-32 if the source-backing material is changed from aluminium to steel? (Answer: 13.3%)

12. If the resolving time of a given detection system is 300 sec, what is the true counting rate for an observed counting rate of 20 000 counts/min? (Answer: 22 000 counts/min).

13. Calculate the dose rate in air from a 1-Curie source of Cs-137 at a distance of 30 cm (assume B=1). (Answer: near 3.6 R/hr).

**Applications of radiotracers**

14. The common methods of flow measurement with radiotracers are:
- the dilution method
- the venturi meters
- the transit time method

15. A continuous injection of tracer is made into a stream flow. The injection is 23.5 litres per minutes of 1003 Bq/ml of tracer. Downstream after complete mixing the concentration is measured as 5.02 Bq/l. the flow is:

- $4.70 \times 10^6 \text{ l/min}$
- $4.70 \times 10^8 \text{ l/min}$
- $7.83 \times 10^5 \text{ l/s}$
- $7.83 \times 10^3 \text{ l/s}$

16. Which source and detector combination is used for column scanning:

- Co-60 with scintillation detector
- Co-60 with GM detector
- Tc-99m with GM detector
- Br-82 with scintillation detector
- Cs-137 with scintillation detector

17. In column scanning source and detector are generally mounted:

- diametrically opposite
- same side of the column
- one above the other

18. The radiation intensity in a column scan at tray location will be:

- lower than the intensity at vapour space
- same as the intensity at vapour space
- higher than the intensity at vapour space

19. In column scanning:

- source and detector are both collimated
- source alone is collimated
- detector alone is collimated

20. Flow rate measurement using radiotracer is required for:

- calibration of flow meters
- blockage detection
- mixing studies
- none of the above

21. For flow rate measurement in closed conduits, which method is used:

- constant rate ejection method
- transit time method
- continuous dilution method

22. Where should the first detector be installed for flow rate measurement using transit time method:

- just near the injection point
- 100 diameter away above the injection point
- 50 diameters away above the injection point.

23. Residence time distribution is defined as:

- response of the system to an impulse input
- response of the system to a steep input
- response of the system to a wide tracer pulse

24. Area under a normalized RTD curve should be:

- infinity
- unity
- ten
25. Mean residence time is:
- second moment of RTD curve
- first moment of RTD curve
- tenth moment of RTD curve

26. A long tail in the measured RTD curve indicates:
- dead volume with exchange
- plug flow
- well mixed flow
- none of the above

27. An ideal mixer can be represented by number of tanks in series:
- N=1
- N=10
- N=100
- N=1000

28. A perfect plug flow can be represented by Pecklet number:
- P=1
- P=10
- P=100

29. The axial dispersion model is usually applicable to:
- Well mixed systems
- Plug flow system
- Plug flow with axial dispersion
- Well mixed flow with dead volume

30. RTD can be used for :
- troubleshooting
- validation of mathematical models
- to investigate the hydrodynamic behaviour of a system
- to all of the above

31. Use of stir in a tank:
- enhance the mixing
- reduce the mixing
- both of the above

32. For tracing organic liquid in a vessel, which of the following tracer is most suitable:
- Br-82 as ammonium bromide
- Br-82 as methyl bromide gas
- Br-82 as paradibromo benzene

33. Which of the following characteristics of a radioisotope are used to select it as a tracer:
- half-life
- physico-chemical behaviour
- type of energy emitted
34. For in situ detection which one of the radiotracers is preferred:
- beta- emitter
- neutron emitter
- gamma emitter
- alpha- emitter

35. For field work with gamma emitters (radiotracers or sealed sources) can be used: Geiger Muller or Scintillation detectors? What is more efficient?

36. There are several scintillation detectors for gamma rays: NaI (Tl), CsI (Tl), BGO. What is more efficient detector, and what is more common used detector, why?

37. For which radiotracers is used liquid scintillation detector?

38. Which kind of neutron sources are used in industry, and what is the best?

39. What are commonly used neutron detectors and what is the best?

40. What are the radioisotope generators used in industrial applications?

41. What are the radiotracers for gaseous tracing?

42. How it can be prepared a radiotracer for solid phase?

43. What are the best radiotracers for water tracing?

44. A radiotracer study was carried out in the White Portland Cement Factory to investigate the RTD of raw feed materials in a rotary kiln. The raw material (80% of limestone, 15% of white clay and 5% of silica sand) mean residence time within the kiln, calculated by process engineer dividing the filled physical volume V (m³) by the feed flow rate Q (m³/s) is 40 minutes. This time is needed to ensure good quality of the end product. In order to verify this data, the radiotracer test was conducted using La-140 as tracer. The experimental data are:

<table>
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<th>Time, t (min)</th>
<th>C(t), Count/min</th>
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<tr>
<td>5</td>
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</tr>
<tr>
<td>65</td>
<td>35777</td>
</tr>
</tbody>
</table>
Using the above radiotracer experimental data calculate the actual mean residence time of the clinker inside the kiln.

3. QUESTIONS FOR NUCLEONIC GAUGES TECHNIQUES AND APPLICATIONS IN INDUSTRY

1. Which of the following isotopes are most applied in nucleonic gauges:
   Ir-192
   Co-60
   I-131
   Cs-137
   Tc-99
   Am-241

2. What is the similarity between X-ray and gamma ray?
   - both have short wavelength
   - both are produced during the disintegration of nucleus of radioisotopes

3. What are advantages of replacing radioisotope sealed sources with X ray machines?
   - easy to transport
   - easy to get licence
   - no risk of activity when it works
   - high flux of radiation

4. Which source and detector combination is used for the sugar density gauge:
   - Co-60 with scintillation detector
   - Co-60 with GM detector
   - Tc-99m with GM detector
   - Br-82 with scintillation detector
   - Cs-137 with scintillation detector

5. Radioisotope sealed sources in nucleonic gauges have to be replaced:
   - every 2 years
   - every 10 years
   - no replaced for ever.

6. The intensity of backscatter thermal neutrons is:
   - lower from water than from oil
   - higher from water than from oil
   - higher from sediments than from oil

7. In a thickness gamma scattering gauge:
   - source and detector are both collimated
   - source alone is collimated
   - detector alone is collimated

8. For online detection of paper sheet thickness which kind of radioisotope is preferred?
   - beta- emitter
   - neutron emitter
- gamma emitter
- Alpha- emitter

9. For gamma level gauge can be used:
- G-M
- Scintillation detector

10. There are several scintillation detectors for gamma rays: NaI (Tl), CsI (Tl), BGO. What is more efficient detector, and what is more common used detector, why?
- NaI (Tl) because is cheaper than others
- BGO because is performing better in high temperature
- CsI (Tl) is less hygroscopic than BGO
- CsI (Tl) because consumes less energy.

11. Which kind of neutron sources are used in industry, and what is the best?
- Cf-252 is the best because lives longer
- $^{241}$Am-Be is better because is cheaper
- Cf-252 is better because is cheaper

12. What are commonly used gas neutron detectors and what is the best?
- G-M
- He-3
- BF3

He-3 gas proportional detector is worse than BF3 neutron proportional counters because:
- Boron10 has a higher efficiency for thermal neutrons compared with He-3.
- BF3 counter functions at much higher voltages (3-4kV), than 3He counters (1-2 kV).

13. Radioisotope sources used for gamma scanning compared with gamma sources for radiography NDT:
- have the same activity
- have 10 times higher activity
- have 100 times lower activity

14. Comparing HPGe, NaI, and CZT detectors:
- HPGe has the higher resolution
- HPGe has the lower resolution
- HPGe is the best for field work
- CZT is a scintillation detector
- CZT has a high efficiency
- CZT has a resolution between NaI and BGO
- NaI is the best for field work

15. He-3 neutron detector is used for measurement of:
- fast neutrons
- thermal neutrons
- gamma radiation

16. Neutron gauges are used for:
- Density measurement
- moisture measurement

17. GM tubes:
- have an infinite operating life
- five year life

18. What rays emit Am-241?
- X-ray only
- Gamma rays only
- Both X and γ rays.
APPENDIX VII. BIBLIOGRAPHY

IAEA Publications on Radiotracers, Sealed Sources and NCS

- IAEA, Technical Report Series No. 316
  Guidebook on applications of radiotracers in industry, IAEA, 1990
- IAEA-TECDOC-845
  Nuclear techniques in the coal industry, IAEA, November 1995
- IAEA, Computer Manual Series No.11
  Residence Time Distribution (RTD) Software Analysis, IAEA, 1996
- IAEA, TECDOC-924
  The thin layer activation method and its applications in industry, IAEA, January 1997
- IAEA, Technical Report Series No. 393
  Nuclear Geophysics and its applications, IAEA, 1999
- IAEA-TECDOC-1142
  Emerging new applications of nucleonic control systems in industry, IAEA, March 2000
- IAEA, TECDOC-1262
  Radiotracer technology as applied to industry, IAEA, December 2001
- IAEA, Technical Report Series TRS, 423,
  Radiotracer Applications in Industry - A Guidebook, IAEA, September 2004
- IAEA, TECDOC-1412
  Integration of tracing with CFD for industrial process investigations, Vienna, February 2005
- IAEA, TECDOC-1459.
  Technical Data on Nuclear Gauges, IAEA Vienna, July 2005
- IAEA, TECDOC-1589
  Industrial Process Gamma Tomography, IAEA, Vienna, May 2008
- IAEA TCS 31
  Radiotracer RTD method for industrial and environmental applications, IAEA, June 2008
- IAEA TCS 38
  Leak detection in Heat Exchangers and Underground Pipelines using Radiotracers, IAEA, Vienna, 2009
- IAEA TCS 49
  Radiotracer applications in Wastewater Treatment Plants, IAEA, Vienna 2011
- IAEA Radiation Technology Series No. 3
  Applications of Radiotracer Techniques for Interwell Studies, IAEA, Vienna 2012
- IAEA Radiation Technology Series No. 5
  Radiotracer generators for industrial applications, IAEA, Vienna, 2013
- IAEA TCS (in process)
  Radiotracer and sealed source applications in sediment transport study, IAEA, Vienna 2014
Publications

- FRIES B.A. Training the engineer for radiotracer applications in industry. In “Radiation engineering in the academic curriculum”, Proceedings of a study group meeting organized by the IAEA and held in Haifa, Israel, 26 August to 4 September 1973, Panel Proceedings Series, IAEA, 1975.
• CHUEINTA S. Radioisotope applications in industry. Thailand country report. AGM, IAEA/RCA Bangkok, October 2003.
• IQBAL HUSSAIN KHAN. Radioisotope applications in industry. Pakistan country report. AGM, IAEA/RCA Bangkok, October 2003.
• MAGGIO.G. Guidebook on radiotracer applications in industry. ARCAL/IAEA, Argentina, 1999.
• BERNE, PH., BLET, V., Correcting the results of radioactive tracer experiments for the effects of the detection chain (International Congress on Tracers& Tracing Methods, Nancy) (2001).
• SEVEL T., PEDERSEN N.H., GENDERS S. Tracing of Oil, Gas, and Water in the Oil and Gas Industry, 7th ECNDT Conference, 26-29 May (1998)
• PANT H.J., THYN J., WALINJKAR O., NAVADA S.V., BHATT B.C., ZITNY C.; Radioisotope tracer study in sludge hygienisation research irradiators, IJARI, Nov. 2000.
• AIREY, P. et al.. Practical Applications of Radioactivity and Nuclear Radiations, Cambridge University Press, Sep 15, 2005
• BRISSET, P. et al. Use of the Indium-113m in the laboratory to improve the knowledge on the behaviour of the discharges of muddy dredged material. International Conference on Tracing and Tracing Methods, Tracer 2, Nancy, France, 2001.
• BRISSET, P. Les apports des techniques nucleaires a la sedimentologie dynamique, 8eme Rencontres Instrumentation Oceanographique, Brest, November 1997.
APPENDIX VIII. LIST OF PARTICIPANTS

Consultant meetings on

Establishment of a training and certification system for radiotracers and NCS applications

2 to 6 December 2013
17 to 21 March 2014

International Atomic Energy Agency, Vienna, Austria

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