Chemists' Role in Using Radioisotopes in Industries

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The role of chemists in utilizing radioisotopes in industries is significant. Radioisotopes, characterized by their emission of various types of radiation like alpha and beta particles, gamma rays, or x-rays, include both naturally occurring elements such as ^{238}U, ^{232}Th, ^{14}C, and ^{40}K, as well as synthetic radioisotopes tailored for specific applications. While natural radioisotopes, except for ^{235}U in nuclear power, are often underutilized due to long half-lives or compatibility issues, synthetic radioisotopes are custom-made to meet specific industry needs. This article is intended to give an overview of radioisotopes, both natural and artificial, applicable in various industries in which chemists can significantly be involved.

Radiopharmaceuticals

In the competitive global pharmaceutical industry, radiopharmaceuticals, which integrate radioactive materials into pharmaceuticals, play a crucial role. They enable diagnostic imaging and targeted therapy for conditions like cancer. Radiopharmaceutical formulation consists of radioactive isotopes that can emit radiation often with gamma rays or positron. When radioisotopes are exposed to a target or to a patient's body, an image can be obtained for diagnosis using techniques such as single photon emission computed tomography (SPECT) and positron emission tomography (PET). Technetium-99m (^{99m}Tc) is a common nuclear medicine in diagnosis purposes. Fluorine-18 (^{18}F) is another popular radiopharmaceutical utilized in formulations of fluorodeoxyglucose (FDG) in PET scanning.

Some radiopharmaceuticals are employed in therapeutic applications including Iodine-133 (^{133}I) for thyroid disorders and Lutetium-177 (^{177}Lu) in neuroendocrine tumors. Radioactivity in certain radiopharmaceutical can also be incorporated for very specific therapy upto molecular level.

Radioisotope Production and Radiolabeling in Radiopharmaceutical Process

Radioisotopes are often produced by nuclear reactors or cyclotrons. Under a magnetic field, charged particles are accelerated to achieve high energy before bombardment of isotope reaction. Most of these charged particles are protons. F-18, C-11 and N-13 are some examples of isotopes produced from such accelerators. Cyclotrons can produce very short-lived isotopes while nuclear reactors are used to produce short- and long-lived isotopes. Molebdinium-99 (^{99}Mo) is an radioisotope produced in nuclear reactors. ^{99}Mo subsequently decays to metastable state of Technetium (^{99m}Tc). In diagnostic imaging 99mTc is often used via Mo-99/Tc-99m generator system.

Synthesized radioisotopes are then incorporated to certain biologically active drug molecule that would lead to create the desired radiopharmaceutical for nuclear imaging or therapy. This is known as radiolabeling. Radiolabeling involves attaching a radionuclide to a biomolecule, often a protein. Common radiolabeling methods include direct labeling, with chelation or via prosthetic groups.,F-18 can radiolabel glucose analogs such as fluorodeoxyglucose (FDG) in PET scanning. FDG is used in metabolomic imaging and cancer diagnosis.

Radiolabeled molecule is designed to specifically bind a particular biological target enhancing the diagnostic accuracy and therapeutic efficacy. Radiopharmaceutical processes have been advanced to produce personalized medicine while minimizing healthy cell damages.

Today on-site radiopharmaceutical production is available when cyclotron accelerators are integrated with radiolabeling facilities allowing on-site radiopharmaceutical production. Radio pharmaceutics are getting cost effective because of those advanced facilities. Furthermore, radiopharmaceutical diversification is getting wider for various imaging and therapeutic applications with different combinations of radioisotopes and radiolabeling techniques.

Nuclear Power Production and Uranium Chemistry

As countries worldwide focus on sustainable energy, nuclear power is getting attention as a highly efficient, green energy source. Understanding uranium chemistry is crucial not only for optimizing nuclear energy production but also for ensuring reactor safety, addressing environmental concerns associated with nuclear fuel cycle, uranium reprocessing and waste management.

Uranium is the key element in the nuclear fuel cycle, naturally existing primarily as uranium-235 (~ 0.4 %) (^{235}U) and uranium-238 (^{238}U) (~99.9%). The nuclear fuel cycle encompasses mining, milling, conversion, enrichment, fuel fabrication, reactor operation, spent fuel management and waste disposal. Uranium coordination chemistry is involved in almost all those fuel cycle steps.

Uranium is mined from underground uranium ores found certain locations of the world. Uranium ore consists of a low concentration of uraninite mineral. There are different mining methods such as open-pit mining, underground mining, and in-situ mining. Followed by mining, milling steps are undertaken to extract the uranium concentrate from the rest of the components in the ore. The product obtained at the end of the milling process is known as "yellow cake". The yellow cake is then converted to uranium hexafluoride (UF6) gas in the conversion step. UF6 is then sent to enrich ^{235}U from ^{238}U because enriched ^{235}U is needed to achieve sustainable fission reaction in the nuclear power production. The most common enrichment methods are diffusion method, gas centrifugation and laser isotope separation method. Enriched uranium is then sent to process the uranium pellets in the form of uranium dioxide (UO2). Those pellets are then assembled to make fuel rods and fuel assemblies to be sent to nuclear reactors for power generation.

In nuclear reactors, uranium undergoes fission reactions, releasing energy as shown in Figure 1.

Fission reactions produce many radioactive daughter products in addition to the energy generation, and they accumulate in the spent fuel rods. Spent fuel can be reprocessed to extract the ^{235}U to be sent back to nuclear power generation. Reprocessing of uranium also lead to reduce the volume of radioactive waste. After reprocessing, the remaining waste after uranium extraction consists of fission products and transuranic elements that are highly radioactive and need to undertake special handling, separation methods as well as storage and disposal methods. Waste disposal of high level and low-level nuclear waste may need chemical separation followed by disposal strategies. For high level nuclear waste geological repositories are required. This may also include some chemical barriers. Furthermore, nuclear waste disposal should be coupled with radioactivity monitoring to make sure the nuclear waste is not leaching out. This may include continuous water, soil, and plant radioactivity monitoring and radiological studies. Innovative approaches including advanced separation technologies and novel reactor designs aim to minimize nuclear waste generation and improve overall sustainability.

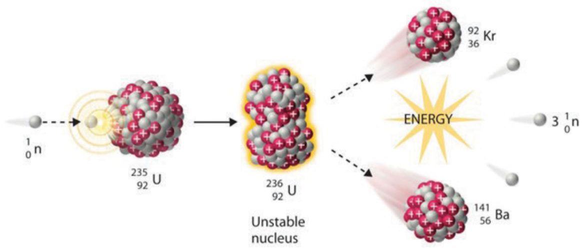

Figure 1 : An example of an induced fission reaction that can typically under during nuclear reactor operation

Source : https://trzylykienergetyki.blogspot.com/2016/05/reakcja-rozszczepienia.html

Radioisotopes as Industrial Tracer

Tracers aid in understanding fundamental processes and development of new technologies across diverse industrial sectors. Radioisotopes provide a way to monitor and trace the movement of materials, fluids and processes, offering insight into efficiency, quality control and safety. Following are few of the industrial applications of radiotracers.

Oil and Gas Industry

Radioisotopes can be used as tracers to study fluid flow and migration in oil reservoirs. This helps in optimizing well placement and enhancing oil recovery. Radioactive tracers can be injected into pipeline infrastructure.

Mineral Processing

Radioisotopes are employed to monitor the movement of ores and minerals during extraction and processing. Tracers can assist in optimizing the separation process and identify the areas that needed improvement.

In Chemical Processing Plants

In Chemical plants radiotracers can assist in tracking the progress of the chemical reaction, identifying reaction pathways and optimizing reaction conditions. In addition, tracers are used in processing plants to optimize the fluid dynamics, mixing and dispersion facilitating the quality control.

Food and Beverage Industry

Radioisotopes can be applied to trace the flow of liquids in food and beverage industries to ensure the proper functioning of pipelines and equipment in the processing plants. Radiotracers enable to monitor the effectiveness of cleaning processes as well as to monitor the removal of contaminants from processing equipment.

Environmental Monitoring

Radiotracers can be used to study the dispersion of pollutants in air water and soil. These studies will assess the effectiveness of waste management in various industrial activities and effective pollution control measures. This phenomenon also can be incorporated to nuclear waste management in the nuclear fuel cycle.

Quality Control in Manufacturing Processes

Radioisotopes as tracers can be helpful in the quality control process in assessing uniformity, irregularity consistency and manufacturing defects of material in various industries such as polymers, textile, paper, oil etc.

Food Irradiation and Medical Device Sterilization

Gamma radiation emitting from radioisotopes such as Cobolt -60 (^{60}Co) and Cesium-137 (^{137}Cs) are used to be exposed to food products for preservation purposes while medical devices such as gloves and syringes are exposed to sterilization. Alternative to gamma radiation electron beams and proton beams are also can be utilized. Emission of high energy rays such as gamma or electron beams effectively kills microorganisms leading to food preservation and sterilization of medical equipment.

Research and Development

Radioisotopes are valuable tools in various research and development on material studies, biological processing and chemical reactions and synthesis research.

Conclusion

Chemists play a crucial role in leveraging radioisotopes for various industrial applications including radio pharmaceutics, radiotracers and nuclear power production. The potential to improve efficiency, effectiveness, and quality control in various industries using radiotracers is substantial. There are more paths yet to be explored and more research and developments should be undertaken, that would pave the way for further industrial developments.

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Versatility of Raman Spectroscopy as an Analytical Tool for Chemists

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Often used as a tool in analytical chemistry, Raman spectroscopy is a highly utilized non-destructive vibrational spectroscopic technique. Incident light interacts with the molecules, and the inelastically scattered light is analyzed in Raman spectroscopy. The energy of the scattered photons is shifted due to the vibrational transitions in the molecule. Vibrational modes involve the periodic motion of atoms within a molecule, such as the stretching and bending of chemical bonds. In Raman spectroscopy, a vibrational mode is Raman-active if it induces a change in polarizability. Various scientific disciplines benefit from the rich information provided by Raman spectroscopy about the molecular composition and structure of compounds. Raman spectroscopy is extensively used by analytical chemists for molecular identification, structural analysis, and reaction monitoring. In particular, Raman spectroscopy offers high sensitivity and specificity in the analysis of pharmaceutical compounds, including drug formulations, polymorphs, and the study of drug interactions with biomolecules. Raman offers many advantages in the characterization of materials, including polymers, ceramics, semiconductors, and nanomaterials. Raman spectroscopy is applicable to solids, liquids and gasses and is applicable for pollutant analysis, air quality monitoring and water quality testing. Raman is a versatile tool for studying vibrational and electronic transitions in materials and it provides insights into lattice dynamics, phonons, and other physical properties. Biologists use Raman spectroscopy for cellular and tissue analysis, drug detection, and studying biomolecular structures. Due to off-the-shelf electronics and the high computational capability of embedded systems, the technique can be now packaged into a compact portable spectrometer. Applications requiring high throughput, rapid, and in-situ testing benefit from portable Raman techniques. Food quality testing and authentication, forensic analysis (for the identification and characterization of substances, including drugs and forensic evidence) and archaeometry (identification of pigments, dyes, and materials in artworks and cultural artifacts) are some fields that benefit from portable Raman spectrometry. With the onset of embedded AI technologies, machine learning is expected to transform Raman Chemometrics (chemometrics involves the use of mathematical and statistical methods to extract meaningful information from complex chemical data). We are about to enter into a new regime of Analytical Chemistry related to spectroscopy, where machine learning algorithms provide insights on the underlying chemistry and structure of compounds via multidimensional data provided by Raman spectra.

Recently, a new optical research facility equipped with a research-grade Raman spectrophotometer was established at the Faculty of Science, University of Colombo. Funding for the facility was provided under the grant scheme, Accelerating Higher Education Expansion and Development (AHEAD)-Development of Research (DOR) which is a World Bank funded Sri Lankan government operation to support higher education. As a result of the initiative, a multidisciplinary