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An Overview of Nuclear-chemistry

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Abstract
The study of atomic nuclei and how they work is known as nuclear chemistry and is important in many different fields. The impact of nuclear chemistry on health, energy, environmental science, materials science, agriculture, and archaeology is detailed in this review. It delves into basic ideas. Looking at the composition of nuclear nuclei, the way that radioactivity appears in beta, gamma, and alpha decays. Nuclear chemistry has many important applications. Radioactive isotopes are used in chemistry for targeted radiation therapy and diagnostic imaging, which is changing health care. The world energy landscape is shaped by nuclear power plants that produce large quantities of clean energy through regular fission. Radioisotope tracing is useful in environmental science because it helps to understand contamination processes and enables the safe handling of nuclear waste. Radiation techniques improve agricultural production by reducing the impact of pests and providing a longer shelf life for food. Radioisotope analysis is a tool used by materials scientists to better understand the properties and behaviour of materials and to improve analytical methods. Radiocarbon dating is transforming archaeology and providing invaluable insights into past civilizations round the world. This summary highlights the multiple applications and central role of nuclear chemistry in the development of science, technology, and society. The importance of nuclear chemistry in various fields stimulates innovation and shapes our understanding of the natural world, which becomes even stronger as it continues to develop.

Keywords: *Nuclear chemistry, health, energy, environment, materials, agriculture, archaeology*

Introduction
Most advances in chemistry, such as nuclear chemistry, have a long historical past. In 1895, nuclear activity was first introduced discovered by Wilhelm Röntgen, a German scientist. Supporting that is the fact that electrons interact with surfaces. He discovered that the surface of a glass object or material responds to electrons by emitting visible light. The term "X-ray" refers to this radiation. The mechanism of radiation was demonstrated by X-ray detection. On the other hand, X-ray findings did not show the presence of radioactivity. The French scientist Henri Bequerel was looking at the idea that certain substances can emit X-rays when exposed to sunlight (Gregory R. Choppin, 2002). Bequerel used the element uranium for his experiment. He discovered that some radioactive elements, such as uranium, release particles of special energy when exposed to the sun. We refer to this process as spontaneous radioactivity. When Becquerel discovered that spontaneous radioactivity led to evidence of radioactivity, he introduced the becquerel (Bq) as the corresponding SI unit. Since radioactivity is the foundation of nuclear chemistry, Becquerel's observations and conclusions are significant.

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Definition and Application of Nuclear Chemistry

The study of the structure, properties, and modifications of atomic nuclei is known as nuclear chemistry. It examines nuclear processes, radioactivity, and elemental synthesis. Our knowledge of the universe has greatly benefited from nuclear chemistry, which in turn has led to ground-breaking experiments in many disciplines, including materials science, energy, environmental science, and chemistry. With its relevance in a wide range of industries, nuclear chemistry has had a profound impact on society. Radioactive isotopes are used in nuclear chemistry for therapeutic and diagnostic imaging purposes. In addition to targeted radiation therapy to kill malignant cells, radioisotopes can be used to monitor physiological processes and diagnose disorders.

Power: Nuclear power plants use the energy produced during nuclear fission to generate electricity. Fission reactions are a clean and efficient source of energy that contribute significantly to the world's electricity generation.

Environmental Science: The study of nuclear chemistry is important for environmental monitoring and sanitation. Nuclear waste management policies seek to minimise the environmental impact of nuclear activities while using radioisotope analysis to monitor environmental contamination.

Materials science: Atomic chemistry can be used to investigate the properties of materials and create new materials with improved properties. Radioisotope techniques are used to produce improved materials for many applications to investigate corrosion mechanisms, propagation mechanisms, and material defects.

Culture: Nuclear chemistry techniques such as radiocarbon dating are used to trace artefacts and determine the age of artifacts. These methods provide important insights into the cultural practices and historical periods of past civilizations.

Key Considerations in Nuclear Chemistry

The following are some basic concepts in atomic chemistry.

Structure of the atomic nucleus: The atomic nucleus is made up of protons and neutrons and is held together by a strong nuclear force. The mass number (A) is determined by the total number of protons and neutrons, while the atomic number (Z) is determined by the number of protons.

Radioactivity: The spontaneous fission of unstable atomic nuclei, giving off excess energy and particles, is known as radioactivity. Alpha, beta, and gamma decay are the three main forms of radioactive decay.

Reactions Nuclei: Atomic nuclei can undergo transformations known as nuclear reactions, which involve the release or absorption of energy. There are two main types of nuclear reactions: fission and fusion. A heavy nucleus can be split into two lighter nuclei by fission, and the two lighter nuclei can combine to form a heavier nucleus.

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To show that radioactivity is the basis of nuclear chemistry, nuclear chemistry can be derived in this way: Nuclear chemistry involves the activity of atoms, which in turn deal with radioactive elements, and radioactive elements derive radioactivity. The process of producing radioactive elements is called radioactivity. These elements are radioactive because their atoms contain unstable nuclei. Because of their large nuclei, the nuclei of radioactive elements are unstable. The shape of the nucleus of a particular radioactive element can vary. We call this unique process an isotope. Elements with specific atomic numbers but the same mass number are called isotopes. Every radioactive element has a large nucleus with many isotopes. The larger nuclei of these electrolytes undergo a decay process that reduces their nuclear mass, making them very stable. This destructive process requires the release of a large amount of energy. Corrosive electrolytes can degrade in three ways. These three decays are gamma, beta, and alpha. The half-life is the time it takes for a conductive material to decay to half its mass.

Radioactive elements have different half-lives depending on the stability of the isotope. Technetium, 4.21 x 106; Promethium, 17.4 years; Polonium, 102; Astatin, 8.1 hours; Radon, 3.82 days; Franciam, 22 minutes; Radium, 1600; Actinium, 77; Thorium, 7.54 x 104 years; Protactinium, 3.28 x 104; and Uranium, 2.34 x 107 years are a few examples of radioactive elements and their associated half-lives (Helmenstine, 2017). Every element on the list is radioactive and can decompose. Consequently, radioactivity can be defined simply as the energy released during the decay of radioactive materials (L'Annunziata, 2007).

There is more to nuclear chemistry than radioactivity. Radiation, nuclear power generation, and the absorption of radiation at surfaces are some other important areas of nuclear chemistry. The branch of nuclear chemistry called radiation chemistry studies the effects of radiation from radioactive materials on the environment, etc. The branch of nuclear chemistry that uses radioactive materials is called "nuclear chemistry." This branch of nuclear chemistry deals with everything from the disposal of radioactive waste after power generation to the removal of radioactive elemental ores. The radiation component is called the effect of radiation on various surfaces. The construction of nuclear power plants and radioactive waste disposal sites requires an understanding of this area of nuclear chemistry.

Objectives of the study

1. Explore the many applications of nuclear chemicals in chemistry, energy production, environmental science, materials science, agriculture, and archaeology.

2. Explore basic nuclear chemistry concepts such as radioactivity, nuclear mechanisms, and the structure of the atomic nucleus.

3. Examine how radioactive isotopes have changed health care practice through their use in targeted radiation therapy and diagnostic imaging.

4. Assess how nuclear power plants, which produce cleaner and more efficient energy through standardised fission processes, have shaped the world energy landscape.

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Need of the study

1. Understanding cross-industry effects: Examine how the widespread use of nuclear chemistry in energy, materials, chemistry, agriculture, and archaeology advances cross-sectoral understanding of these and other industries in another instance.

2. Innovation and Technological Advances: Examine how nuclear chemistry is a key driver of technological advances that support advances in the physical sciences, energy production, environmental management, and research used for diagnosis.

3. Social Scope and Development: Examine the effects and benefits of nuclear chemistry on society, focusing on its contributions to historical understanding, health care quality, non-emission sources of energy, the environment, agricultural innovation, and environmental protection.

4. Continued Development and Future Prospects: Examine how nuclear chemistry affects scientific knowledge, technological advances, and the ability to solve new problems in a rapidly changing world.

Applications in Power Generation:

Nuclear chemicals can be used to generate electricity. In a power plant, the steam powers a turbine to produce energy. However, in order for water to freeze, the temperature must be raised by an external source of energy. The energy from the coal was heated in a coal-fired power plant. Similarly, nuclear power plants use the energy in reactors to produce electricity utilizing radioactive materials in nuclear power plants. Nuclear fission is the process by which radioactive materials in a nuclear power plant raise the temperature of the water. The atomic nucleus can be broken into smaller pieces by a decay process called nuclear fission. The process takes place in a nuclear reactor. Uranium is a common element used in nuclear reactors. The uranium shells are usually packed in various containers, and these container bags are then placed in a reactor filled with water. Heat is released, while energy is released during nuclear fission. This heat energy increases the temperature of the water in the reactor. Water begins to evaporate at 1000 °C. This steam powers the turbines in nuclear reactors. The rotation of the turbine generates electricity (Atomic Energy Institute).

Applications in Biological Research:

For the most part, biological research is about observing events that occur in living organisms. Often, in order to see the system individually and identify these trends, researchers would need to dissect a story. Because of the complexity or decentralisation of organs, many biological systems cannot be observed with this dissection technique. Scientists must use an understanding of nuclear chemistry to identify such structures in living organisms. Most biological processes can be seen on computed tomographic scans. Nuclear chemistry concepts provide the basis for computed tomographic scans. It uses particles of X-rays to create complex images of organs that are necessary for viewing. This is useful to present the findings of your research. Researchers

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can use computed tomographic scans to obtain images to validate their theories (Chemistry Libretexts, 2017).

Biological Effects of Radiation:

When it comes to the effects of radiation, cancer is usually the next disease to arise. Radiation has both beneficial and harmful ecological effects, even if it causes cancer. Every organism has a nucleus in every cell. Embedded in this nucleus are important genes. Genes are the basic building blocks of genes, and genes include deoxyribonucleic acid (DNA). Many of the proteins used in living organisms are encoded by their DNA. It contains signals or instructions for the synthesis of certain proteins. Exposure to radiation alters the DNA of organisms. Mutations are sudden changes in a DNA sequence. The instructions or rules in the DNA sequence change as these changes occur, and consequently, the protein synthesised also changes. These changes in protein synthesis lead to the expansion of the body's organs in the wrong way. The harmful effects of radiation are responsible for this abnormal growth called cancer. Radiation therapy is a common method of getting rid of malignant cells from the bodies of cancer patients. Radiation has a positive effect on such creatures. Radiation therapy involves the targeted application of radiation to a cell. The goal of radiation is either to kill the malignant cells or to significantly reduce their spread. Gamma and X-rays are used in radiation therapy. According to the National Cancer Institute, these particles target malignant cells and damage the DNA that codes for the killed cell.

Marie and Pierre Curie extracted the first radioactive elements, radium and polonium, from a few tonnes of uranium ore in 1898. The advances in our knowledge of the atom brought about by scientists like Rutherford and Bohr showed the phenomenon of radioactive nuclear material in the early 20th century. In the early 20th century, the subject became a very diverse discipline. In addition to frontier research, nuclear chemistry has found important applications in a variety of applied industries, including radiopharmaceutical manufacturing, nuclear repository maintenance and safety, nuclear energy, nuclear chemistry and isotope production, the science of separation, the production and reduction of nuclear waste, and the separation of waste to do the work. Although by no means exhaustive, this chemical review covers the basic topics of nuclear analysis and some selected applications. Cutler et al. discuss the use of radioactive isotopes in radiation, imaging, and diagnostics in chemistry. More than 10,000 hospitals use medical isotopes worldwide, and technetium-99 is used in 80% of all nuclear chemistry applications, totaling approximately 30 million units per year. The authors now explore the processes, materials, preclinical research, and nuclear characterization of radionuclides used in nuclear imaging and therapy.

A description of nuclear forensic science is provided by Meyer et al. Relatively simple nuclear forensics combine radiochemistry, nuclear physics, and materials science to obtain hidden nuclear materials. This review focuses on the nuclear forensic analysis of uranium and plutonium because these materials contain fissile isotopes, and their origin, intended use, and history can raise national security issues.

The study examines several areas in basic nuclear chemistry research that provide critical information for a better understanding of radionuclide transport in surface and subsurface

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contaminated sites. This information is essential to conducting operational assessments in geographically high nuclear waste potential areas. Groundwater or groundwater access to a nuclear waste site is the worst possible environment for risk assessment. This can lead to waste decomposition, which can release radionuclides into the environment. Waste decomposition, radionuclide solubility, redox-complexity interactions, precipitation with inorganic, natural, and anthropogenic water sources, and finally various geochemical and physical processes, both the host rock and its components, play a role in controlling the amount of actinides released. Nuclear storage is the primary source of gas, as explosive materials with short half-lives decay over hundreds of years. The redox chemistry of the primary actinides—U, Np, Pu, Am, and Cm—is very rich. They appear in different oxidation states: +3 and +4 for curium, +3 to +6 for American, and +3 to +7 for neptunium and plutonium. It is interesting that Pu (IV), Pu (V), and Pu (VI) can coexist in oxic water because of their comparable redox potentials.

Table 1: Applications of Nuclear Chemistry in Various Fields

Field	Application
Chemistry	Nuclear imaging, radiation therapy
Energy	Nuclear power generation
Environmental Science	Radioisotope tracing, nuclear waste management
Agriculture	Crop irradiation, pest control
Materials Science	Radioisotope tracing, material modification
Archaeology	Radiocarbon dating, artifact analysis

Energy: Nuclear power plants use the energy generated during nuclear fission to produce electricity. Carefully controlled nuclear fission processes in reactors generate huge amounts of heat. This heat is converted into clean and efficient energy sources by generators and steam turbines. Nuclear power contributes significantly to the world's electricity production.

Environmental Science: The migration and fate of a contaminant in the environment are monitored by radioisotope analysis. Tracking radioactive isotopes entering the atmosphere and diffusing into the atmosphere to better understand contamination kinetics and properties treatment, storage, and safe disposal of radioactive waste produced by nuclear power plants and other nuclear activities is the primary objective of the nuclear waste management system.

Agriculture: By killing pests, wind farms help reduce the demand for pesticides. Fruits and vegetables, for example, have a longer shelf life and avoid decay caused by strong winds. Radiation-based pest control methods are also used to manage pest populations and reduce their impact on agriculture.

Materials Science : By analysing the displacement and distribution of atoms in materials, radioisotope analysis reveals the properties and behaviour of materials. Radiation-based modification methods can change the energy, density, or energy of a substance, among other properties.

Archaeology: Radiocarbon dating measures the rate at which radiocarbon (carbon-14) in a material decays to determine the age of living organisms. Since this method can reconstruct the

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history of historical civilizations and provide accurate dates for old objects, it has revolutionised archaeology by using radioisotope methods of analysis, providing historical data valuable insights into technical and cultural trends.

Radionuclide species in solid water, which may result from chemical interactions with groundwater components and surrounding geological processes, are important to support geochemical transport models. Advances in thermodynamics and aqueous chemistry have been made in actinide chemistry by Altmaier et al. The findings of these studies enhance thermodynamic databases that analyse the risk of radioactive migration to potentially corrosive waste and contaminated sites. Furthermore, because the heat of decaying nuclear waste in underground storage can cause temperature increases of several hundred degrees, high temperature data should be obtained immediately. Knopp and Soderholm have described experimental experiments with actinide hydrates and their solubility and hydration properties. These studies provide direct structural information about bond lengths in terms of solution-metal ligand coordination numbers. Significant improvements in the field can be achieved by recent improvements in existing techniques, such as X-ray scattering techniques applied to different solutions, especially X-ray scattering with high energy (HEXS), and synchrotron-based X-ray enhanced and improved spatial resolution rays. used for absorption microstructure (EXAFS) studies. Such studies are important for calibrating and improving theoretical molecular modelling calculations, as they provide a solid gauge for better interpretation of thermodynamic resolution measurements. Walther and Denek offer the origin, distribution, and analysis of naturally occurring and synthetic actinide colloids and particles from thorium and uranium minerals tools, as well as spent uranium munitions and weapons to continue the theme with actinides in particular in the environment.

These colloids are considered to be important support species for the leaching of certain radionuclides. Colloidal-sized particles can form or associate with tetravalent plutonium ions, representing another pathway for actinides to disperse globally. Unlike dissolved plutonium, these colloids exhibit significantly different mobility, impacting their behavior in combination with surrounding materials. Depending on their size and energy relative to the surrounding porous medium, colloids can move faster or slower than the velocity of groundwater Pu(IV) colloids, also known as Pu(IV) polymers, have been studied as real or eigen colloids for the last 50 years. They are closely related to the tetravalent Pu(IV) amorphous hydroxide, or PuO2(am, hyd). According to recent studies, Pu(IV) colloids exist in solution as nanocrystalline PuO2, which has a broad ability due to cluster formation because the contact medium between nanocrystals may not be sensitive to X-ray diffraction, therefore aqueous plutonium dioxide, or PuO2 (am, hyd) can be subjected to X-ray diffraction. According to beam-diffraction, it may be an amorphous material PuO2 (am, hyd) may actually be a nanocrystal line material. Studies by Walther, Denek, Knopp, and Soderholm also confirm this discrepancy. It is hoped that further research on this subject will also lead to a greater understanding of the synthesis, composition, and stability of Pu(IV) colloids.

"Our knowledge of actinides in the environment is summarized by Geckes and his co-authors. They explore circulation mechanisms with actinides " of the outer and inner sphere surfaces as to the present state of actinide reactions" and test mineral aqueous solutions. The actinide theory, geochemical modelling of sorption, and the reaction mechanism of actinide addition are

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discussed. In 'A Study of the Density Functional Theory of the Electronic Structure of Cubic State Actinide Oxide', theoretical predictions of band gaps, optical and magnetic properties, lattice constants, and electronic density states are examined.

Qiu and Burns examine clusters of actinides containing oxides, focusing on systems formed by hydrogen or peroxide. Differences are found in analyses between plutonium and neptunium and thorium and uranium clusters, possibly due to difficulties in conducting α-radiation experiments. Separation of spent nuclear fuel and associated materials can be greatly affected by understanding the basic nanoscale of actinide clusters. Andrews and Cahill focus their work on "uranyl" compound materials that also include hexavalent uranyl and address the effects of pH change, water content, and choice on coordination groups. Gaunt-Jones is addressed in "Recent Advances in Structural Chemistry and Synthesis of Nonaqueous Actinide Complexes", discuss the evolving topic of aqueous actinide coordination chemistry. The aim is to provide an understanding of the electronic structure and bonding theories of a variety of ligands associated with industrial nuclear activity, and environmental control has been improved.

New techniques are needed to regenerate highly spent nuclear fuel in the fourth generation of fast neutron reactors (GEN IV). Continuous radionuclide separation from transient radionuclides for high actinide turnover to minimise interference from complex lanthanide neutron absorbers and preparation methods for removal or diversion with a short half-life are important. Removal of some radionuclides from nuclear waste is necessary. These include fission products and trivalent actinides such as americium and curium.

Recent progress in the extraction and extraction of trivalent lanthanides from americium-curium seeds is described in Panak and Guest's book, "Trivalent Actinide Complexation Extraction and Triazinylpyridine N-Donor Ligand-Mediated Lanthanides."

In conclusion, Türler and Pershina's study on 'Advances in Supersolid Materials Production and Chemistry' shows that over the past three decades, the Joint Nuclear Research Institute (JINR), Lawrence Livermore National Laboratory (LLNL), and... Russia have jointly synthesised and confirmed the existence of eight new compounds. The six new compounds (113–118) and 50 equivalents (113–118) have been synthesised by irradiation and apply to neutral objectives derived from the battle code and to the wind of the battle ray. and Flarovium improved our knowledge of compounds such as (Fl).

Future Recommendations

1. Technological Advances: More research should be focused on more accurate and tailored treatments, improved imaging techniques, and new diagnostic methods.

2. Sustainable energy initiatives: More needs to be done to increase the safety, efficiency, and waste management of nuclear reactor construction. Advanced reactor technology and fusion energy research could open the door to reliable and sustainable energy sources.

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3. Safety in the environment: Future research should explore more efficient ways to control and dispose of nuclear waste, minimise environmental impact, and develop alternatives to monitor and manage nuclear contamination.

4. Materials Science and Archaeology: These fields benefit greatly from new experimental applications of radioisotope analysis in materials science, especially in the understanding of material properties and the development of new products in the 19th century, and from extending radiocarbon dating methods for more accurate historical time series.

5. Interdisciplinary collaboration: Encouraging collaboration between nuclear chemistry and other sectors generates new ideas and solutions. Interdisciplinary research programs can provide comprehensive solutions to complex problems.

6. Public Awareness and Education: Efforts should be made to educate the general public on the benefits, safety, and success of the field to eliminate misunderstandings and encourage thoughtful discussion regarding the use of nuclear chemistry and its consequences.

Conclusion

The wide range of applications in nuclear chemistry highlights its role in a wide range of industries, including health, energy, environment, materials, agriculture, and archaeology. This comprehensive review reveals fundamental concepts of nuclear chemistry—such as radioactivity, nuclear mechanisms, and the formation of nuclear nuclei—that turned out to be many academic objects. Nuclear chemistry has had a profound impact on society, with applications ranging from targeted radiation therapy to clean-energy nuclear reactors. Radioactive isotopes used in research and the power of nuclear power devices are highly flexible, and the knowledge gained from radioisotope analysis has spurred developments in a variety of industries. The work also illustrates how nuclear chemistry is constantly evolving and driving advances in technology and society. Nuclear chemistry offers new breakthroughs as it advances in health care, renewable energy, environmental stewardship, agricultural development, and historical understanding. The conclusions of the study highlight the importance of nuclear chemistry for society, research, and technological development. Applied to a variety of industries, it allows us to be creative and changes the way we think about the natural environment. Nuclear chemistry remains very important in all disciplines and has grown tremendously as humanity has progressed.

References:

1. Choppin, G. R., Lilley, J. S., & Rydberg, J. (2006). Radiochemistry and nuclear chemistry. Elsevier.
2. Greenwood, N. N., & Earnshaw, A. (1997). Chemistry of the elements (2nd ed.). Elsevier.
3. Helmenstine, T. (2017, July 05). List of Radioactive Elements. Retrieved November 19, 2017, from ThoughtCo.: https://www.thoughtco.com/list-of-radioactive-elements-608644
4. Chemistry Libretexts. (2017, October 2). Application: Radiation in Biology and Medicine. Retrieved November 19, 2017, from Chemistry Libretexts: https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Nuclear_Chemistry

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/Applications_of_Nuclear_Chemistry/Application%3A_Radiation_in_Biology_and_Medicine
5. Lilley, J. S. (2001). Nuclear reactions and nuclear spectroscopy. Oxford University Press.
6. Martin, B. R., & Livshits, G. (2008). Nuclear and particle physics: An introduction. Academic Press.
7. Mazzilli, F. (2018). Nuclear chemistry: Basic concepts and applications. CRC Press.
8. National Research Council. (1966). Nuclear chemistry: A current review. National Academies Press.
9. Seaborg, G. T., & Katz, J. J. (1949). The chemistry of the actinide elements. Methuen.
10. Siegel, S. (2004). Nuclear chemistry and radiochemistry: A concise introduction. CRC Press.
11. Thomas, J. J. (1963). Nuclear chemistry. J. Wiley.
12. Wapstra, A. H., Audi, G., Thibault, C., Blachot, J., & Holden, N. E. (2015). Nuclear and atomic data tables. International Atomic Energy Agency.
13. Whitten, G. L., Davis, R. E., Peck, M. L., & Stanley, L. A. (2013). Chemistry (10th ed.). Cengage Learning.
14. Zumdahl, S. S., & Zumdahl, S. A. (2014). Chemistry, Brooks/Cole.
15. U.S. Department of Energy. (2009). Fundamentals of nuclear chemistry. U.S. Department of Energy.
16. The Open Chemistry Initiative. (2011). Nuclear chemistry. The Open Chemistry Initiative.
17. Khan Academy. (n.d.). Nuclear chemistry. Khan Academy.