WORLD NUCLEAR UNIVERSITY

WNU Nuclear Olympiad 2015 Report

Nuclear Techniques for Global Development

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Nuclear Techniques for Global Development
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Contents

1 Introduction

The Nuclear Olympiad is a World Nuclear University programme launched to raise awareness about the applications of nuclear science and technology for global development. This objective was met as the World Nuclear University Olympiad reached thousands of students and their supporters worldwide, connecting with students who are excited about nuclear science and technology, and giving them a voice in an international setting. From quite a modest starting point in March, over the year the World Nuclear University Olympiad drew an increasingly large audience as it progressed, especially on social media. The final presentations and award ceremony of the Nuclear Olympiad were hosted by the IAEA as a General Conference side event. The World Nuclear Association sponsored five finalists to fly to Vienna, where a panel of international judges would evaluate their presentations. The World Nuclear University Olympiad and Developing a Youth Pipeline was a unique event in those scheduled during the General Conference 2015.

The World Nuclear University Olympiad had several phases starting in March 2015. The first stage was a call to students from any discipline to research and submit a short video on the topic of *nuclear applications for global development*. To involve students from around the globe, the World Nuclear University reached out through the academic institutions who participated in its founding in 2003, as well as participants and collaborating institutions of WNU courses, such as the Radiation Technologies School and the WNU Short Courses. Additionally over 200 universities and ninety research centres were contacted. Videos were submitted from each continent looking at many different types of nuclear applications and approaching the topic in very different styles.

Of these, ten were selected by a panel of judges, and were submitted to public vote on YouTube. The videos reached 50,000 views and in the region of 30,000 'likes', with the five entries with the highest number of 'likes' going through to the final round. All videos could be easily identified on YouTube as they included the tag WNU Nuclear Olympiad 2015 and Nuclear Sciences and Applications.

The winner of this challenge not only promoted her video through her university and nuclear engineering networks, but also on the radio and in national newspapers. Alice Cunha da Silva from Brazil, Vivek Maradia from India, Zulhelmi Zulkifly from Malaysia, Dhruv Dharmashi from India, and Anton Tanquintic from the Philippines were the five students to make it through to the final round.

The five finalists submitted essays on *radioisotopes: how are they produced* which were then presented to a panel of judges in Vienna. The World Nuclear University selected the Olympiad judges with a view to creating a diverse panel from different professional and academic backgrounds. This was important, as the challenge invited students from all disciplines; therefore they were evaluated on the overall value of their work and not purely the technical aspects. The judges included Jeremy Gordon, chief editor of World Nuclear News; Nate McDonald, Judge for Matagorda County in Texas, USA; Luca Capriotti, International Youth Nuclear Congress 2016 Technical Programme Chair; Joao Alberto Osso Jr, Section Head of the Radioisotope Products and Radiation Technology Section.

Despite having one common topic, each six minute presentation had an individual approach. Vivek Maradia, who came third in the competition, promoted the idea of a World Radiation Day, using the slogan "A day without radiation is a day without sunshine". Dhruv Dharamshi on the other hand took a technical outlook, showing diagrams and chemical equations related to the production of radioisotopes. Alice Cunha da Silva, the winner of the Olympiad, recounted a personal story on radiation used during cancer treatment in her family. Alice Cunha da Silva ended her presentation by calling attention to the work still to be done, in spite of the many current advances. All of the presentations were noteworthy and the finalists were exceptionally good presenters. In particular one excellent speaker, Anton Tanquintic, had a talent for drawing in the audience, provoking a few laughs and slipping in his candidacy for an internship, whilst also delivering an impactful presentation. Each finalist showed their enthusiasm during the competition for pursuing internships and professional opportunities in the nuclear field.

Nuclear Olympiad judges

Nuclear Olympiad finalists

Aldo Malavasi IAEA Deputy Director General of the Department of Nuclear Science and Applications, and Janice Dunn Lee, IAEA Deputy Director General of the Department of Management, observed and spoke at these presentations. They praised the quality of the content, and the delivery of the Olympiad presentations. Both IAEA Deputy Directors reinforced the important message behind this WNU challenge, which is to encourage students to pursue studies and careers in nuclear sciences. Accompanying the Olympiad in this event, the secondary students of the Vienna International School presented on nuclear projects. This combination of secondary and then university level showed how students can be encouraged to explore nuclear sciences.

After the evaluation of the presentations by each judge, the overall score was calculated, taking into consideration the marks achieved in the earlier videos and essays. The IAEA Director General Yukiya Amano announced the winner of the World Nuclear University Olympiad as Alice Cunha da Silva and presented the awards to the finalists.

Yukiya Amano, IAEA Director General and Patricia Wieland, Head of WNU

Lylah Davies, Project Officer, Alice de Cunha da Silva, winner of the Olympiad and Patricia Wieland, Head of WNU

"All Nuclear Olympiad Finalists are excellent ambassadors and well-spoken advocates for nuclear"

Nate McDonald, WNU Nuclear Olympiad Judge

2 Remarks by the Head of WNU

2.1 Welcome

Welcome to the final stage of the World Nuclear University Olympiad. This year in collaboration with the IAEA, Department of Nuclear Sciences and Applications and with the support of the Department of Management.

We are absolutely delighted to be part of a General Conference side-event and together with the Vienna International School competition, being part of the Talent Pipeline Project.

2.2 Objective

The 2015 WNU Olympiad is an international challenge for undergraduate and graduate students on the topic of Nuclear Techniques for Global Development. This is a unique opportunity for students to showcase originality, creativity, knowledge and communication skills.

2.3 The Olympiad

Over the last 12 years, WNU programmes have reached students, young professionals and future nuclear leaders with a number of programmes on both nuclear energy and on the radiation technologies. The Olympiad is the specific programme targeted to university students, to reach out to students, raise awareness of the nuclear area and to open future career opportunities.

The first international WNU Olympiad was held in 2011 in South Korea. It was a contest to develop a national plan for effective communication about nuclear energy.

This year the candidates for the Olympiad 2015 carried out research into Nuclear Sciences and Applications and the positive impact it has on human lives. In the first stage of the competition, participants created a video of up to 60 seconds and posted on YouTube open to the public view (can be easily found under WNU olympiad).

The videos were evaluated by the jury regarding the relevance to the current global context, creativity and impact on the viewer. Eleven short-listed videos were put to public vote. The authors worked very well on marketing their videos and they got altogether more than 53,000 views and more than 24,000 'likes'! They can be watched from the World Nuclear University website. We appreciate very much the young fresh and new perspectives presented in the videos.

The authors of the 5 most liked videos entered the final stage when a five-page essay on Radioisotopes production had to be produced. The top finalists are here today and they will present their work orally now for you and for the distinctive judges.

Before I introduce the top finalists, I will introduce Lylah Davies, WNU project officer, who worked intensively for the success of the nuclear Olympiad and the judges:

1. Joao Alberto Osso Jr, IAEA Section Head of the Radioisotope Production and Radiation Technology Section, Division of Physical and Chemical Sciences. He has a PhD in Nuclear Chemistry with experience as a lead R&D researcher in different fields of Nuclear and Radiation Applications.
2. Nate McDonald, Judge for Matagorda County, Texas, USA. A County Judge who communicates effectively with both constituents and all federal and state officials. He works directly with health care providers, chemical producers, as well as, oil and gas producers involving the radioisotopes being used in their many processes.
3. Jeremy Gordon, Head of Information Management of World Nuclear Association and founding editor of the World Nuclear News. He is a WNU Summer Institute fellow 2006.
4. Luca Capriotti, Nuclear engineer, International Youth Nuclear Congress 2016 Technical Programme Chair. He is knowledgeable and qualified in nuclear technology and representative of the young generation.

3 WNU Olympiad finalists

Alice de Cunha da Silva
Nuclear saves lives
14,869 likes

Alice is from Brazil, she is 25 years old and is in her final year of the Nuclear Engineering Undergraduate program at Federal University of Rio de Janeiro (UFRJ).

After graduation, Alice intends to work in the nuclear industry and pursue a master's degree. She is interested in creating and developing educational projects and co-founded the UFRJ's Nuclear Student Section, the first one in Latin America.

Zulhelmi Zulkifly
Nuclear for Brighter Future
736 likes

Team with Jeremiah Mbazor (Nigeria)

Zulhelmi is from Malaysia, he is 25 years old and has a BSc in Electronic Engineering from Inha University, South Korea. He will be graduating with an MSc in Nuclear Power Plant Engineering from KEPCO International Nuclear Graduate School in February 2016. He is a sports enthusiast who enjoys playing football and recently completed his first duathlon in Seoul.

After graduation, Zulhelmi plans to gain work experience by getting a job in a nuclear related company where he can share his expertise while acquiring more knowledge from people inside the industry.

Joining this competition was seen as a golden opportunity to visit Vienna where he can not only meet nuclear experts from all over the world, but enjoy the beautiful culture that Austria has to offer.

Anton Tanquintic

Nuclear Solutions

1655 likes

Team with Antoinette Patrice T. Tanquintic

Anton is from the Philippines, he is 22-year-old and has a BSc Applied Physics and BSc Materials Science & Engineering with honours.

He found out about the WNU Olympiad from a friend in the Philippine Nuclear Research Institute and saw it as a great way to effectively communicate science to the public.

Outside science and engineering, Anton likes learning new things and trying out different and exciting activities – be it reading books, learning a new language, or meeting new & interesting people.

Dhruv Dharamshi

Fascinating applications of Nuclear Science

1149 likes

Dhruv is from India, he is 22 years old and a graduate student at Amity University studying Nuclear Science and Technology in India. He would like to further his education after graduating.

Dhruv feels that competing in this Olympiad is a great opportunity to rub shoulders with some of the brightest minds in the community while gaining crucial knowledge of the subject.

Vivek Maradia

World Nuclear Radiation Day

4,165 likes

Vivek is from India, he is 24 year old and has a BSc in Engineering in Electronics & Communication from Gujarat Technological University, and a Master's of Technology in Nuclear Engineering from Pandit Deendayal Petroleum University and Graduate Certificate course in Nuclear Security from Texas A&M University. He continues his studies in Nuclear Engineering by enrolling in a PhD course.

The theme of the Nuclear Olympiad, "Nuclear Techniques for Global Development" touched his heart as his family has benefited from nuclear technology.

The Nuclear Olympiad is a once-in-a-lifetime opportunity for students to build an international peer network with nuclear professionals from all over the world. In future he wants to be a part of IAEA.

4 Finalists' essays and presentations on Radioisotopes: How are they produced

Alice Cunha da Silva essay

1. Introduction

A radioisotope is an isotope of a chemical element that has an unstable atomic nucleus which emits energy when it transforms into a more stable isotope. The process of shedding this excess of energy is known as radioactive decay (Farracho, 2011). Radioisotopes can be natural or artificially produced. The ones found in the nature can be from the Uranium and Thorium series. There are a few other sources of naturally occurring radioisotopes such as the cosmic radiation originated from the sun and the earth's atmosphere. The rest of the radioisotopes encountered in the world are manmade (Positron, 2013). Both types are used in a variety of applications in medical, industrial and scientific fields.

Radioisotopes are an essential part of radiopharmaceuticals. In fact, they have been used routinely in medicine for decades. Some used in nuclear medicine have very short half-lives, which means they decay quickly; others with longer half-lives take more time to decay, which makes them suitable for therapeutic purposes. Industry uses radioisotopes in a variety of ways to improve productivity and gain information that cannot be obtained in any other way. They are commonly used in industrial radiography, which uses a gamma source to conduct stress testing or check the integrity of welds. A common example is to test airplane jet engine turbines for structural integrity. They are also used by industry for gauging (to measure levels of liquid inside containers, for example) or to measure the thickness of materials.

Radioisotopes are also widely used in scientific research, and are employed in a range of applications, from tracing the flow of contaminants in biological systems, to determining metabolic processes in small animals. They are also used on behalf of international nuclear safeguards agencies to detect clandestine nuclear activities from distinctive radioisotopes produced in weapons programs. (ANSTO, n.d.).

Overall there are some 1800 radioisotopes. At present, there are up to 200 radioisotopes used on a regular basis, and most must be produced artificially. Example of natural ones are: Chlorine-36 used to measure sources of chloride and the age of water (up to 2 million years); Lead-210 used to date layers of sand and soil up to 80 years; Tritium (H-3) used to measure 'young' groundwater (up to 30 years); and Carbon-14 used for carbon dating (WNA, December 2014).

There are three radioisotopes production methods addressed in this work: Nuclear Reactors, Accelerators and Separation. These are the principal methods used in the world. Although not mentioned in this work, there are other methods for dealing with radioisotopes like enrichment and purification, but in the literature they comply more with the category of beneficiation than production.

2. Production methods

Radioisotopes can be manufactured in several ways, where the most common methods are production with nuclear reactors or via accelerators (linear or cyclotron). Other method is production through separation. Most of the elements produced through these methods require further processing to obtain them in a form suitable for use. Although that is not the objective of this work, specifications for final products and testing procedures for ensuring quality are an essential part of a radioisotope production. (IAEA, 2003)

2.1. Reactor

Radioisotopes are produced by exposing suitable target materials to the neutron flux in a nuclear reactor for an appropriate time, which involves the capture of a neutron by the nucleus of an atom resulting in an excess of neutrons (neutron rich). There are two types of reactor that can be used for this purpose: Swimming pool type and cooled tank type.

In the swimming pool type reactors, the core is compact and visible, and is accessible from the top of the pool. Target materials to be irradiated are sealed in primary capsules, loaded in specially designed irradiation jigs and then lowered in predetermined locations in the core for irradiation. In swimming pool reactors, the core is very accessible, so loading and unloading of targets is easy, and can be carried out from top of the pool using simple devices. The irradiated targets are then loaded in appropriate shielding containers and transported to the radioisotope processing laboratories (IAEA, 2003).

In the tank type reactors, the irradiation assemblies contain a large number of target capsules and are lowered using specially designed jigs. The irradiation assembly is lowered into a hot cell fitted with master slave manipulators for carrying out loading and unloading of target capsules subsequent to irradiation.

Production of radioisotopes with high specific activity will depend on the target as well as irradiation conditions. There are several types of reactions that result in the production of radioisotopes: $(n, \gamma) \rightarrow \beta^-$ *reaction*, (n, γ) *reaction*, (n, p) *reaction*, (n, α) *reaction and Fission*. The factors that determine the type of nuclear reaction taking place and the rate of production of the product are: energy of the neutrons and the neutron flux; characteristics of the target material and activation cross-section for the desired reaction. (IAEA, 2003)

Brazil has only one reactor for radioisotope production, the IEA R1 (1958), an open pool reactor localized at the Institute of Energetic and Nuclear Research

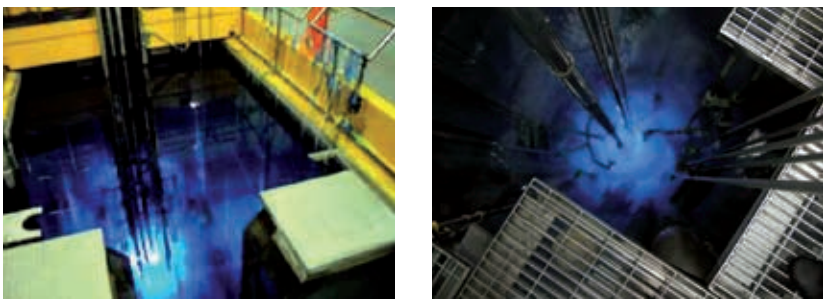

Figure 1: IEA R1 – Brazilian open pool reactor and SAFARI-1 (South Africa) tank type reactor of Oak Ridge design (AIPES, 2007)

(IPEN- Sao Paulo) (Prinzio, 2014). While a planned multipurpose reactor is not under construction, the country imports most of the required radioisotopes from Canada, especially Mo-99 (parent of Technetium-99), the most common radioisotope used in diagnosis.

2.2. Accelerators

Accelerators are used to bombard production targets with beams of charged nuclei which impinge on targets to produce a wide range of isotopes, including many proton-rich nuclei (F-18, C-11) that are not available from reactors. Beams of protons and deuterons are primarily used, but alpha particles and heavier ion beams can also in principle be used. Possible alternatives involve bombarding a primary target to produce neutrons or photons, which then impact the production target to form the isotopes of interest. (NIDC, n.d.) There are two types of accelerators that can be used for this purpose: Linear and Cyclotrons.

2.2.1. Linear Accelerators

In the case of LINACs, electrons do not knock out nucleons directly. Instead, being incident on a converter they break and produce bremsstrahlung photons, which cause photo-nuclear processes. Typically, a high energy electron beam (20-40 MeV) is used to produce a cone of bremsstrahlung photons. (Starovoitova, et al., 2013)

This type of accelerator can generate higher energies than the cyclotron. For example, Brookhaven Linac Isotope Producer (BLIP) on Long Island, NY is operated at 200 MeV and the main isotopes produced are: Ge-68/Ga-68, and Sr-82/Rb-82, also Zn-65, Mg-28, Fe-52, Rb-83.

2.2.2. Cyclotron

The first cyclotron was developed in 1932 by Lawrence and Livingston. The range of particle energies and intensities vary between facilities: 10 - 100 MeV for commercial cyclotrons dedicated for isotope production, with higher energies available at some research accelerators. (NIDC, n.d.). Although there are several linear accelerators, the cyclotrons are the most common type of accelerator for this purpose. The radioisotopes produced by this mean are generally used in nuclear medicine for diagnoses (PET and SPECT). The procedure's equipment determines the range of energy need to produce the radioisotope. For example: It can be in a range of 9 to19 MeV for PET radionuclides or about 30 MeV for SPECT radionuclides. The radioisotopes that are manufactured in a cyclotron in which protons are

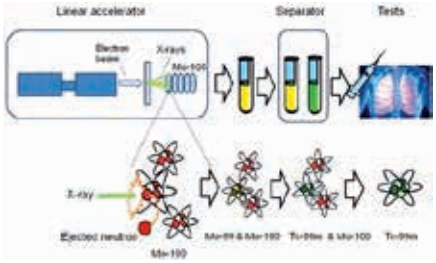

Figure 2- Linear Accelerator process of Mo-99/Tc-99 production (Canadian Light Source, n.d.)

introduced to the nucleus resulting in a deficiency of neutrons are proton rich. Examples of proton-rich isotopes are: F-18, Sr-82, Cu-64, O-15, C-11, Br-77, I-124, Y-86, Ga-66, Cu-60, Cu-61, Zr-89.

Currently there are 14 cyclotrons in operation in Brazil producing radioisotopes, especially F-18 for the composition of the radiopharmaceutical FDG, and 2 others are currently under the licensing process. (Facure, et al., 2015)

2.3. Separation

This method is widely used to produce certain short-lived radioisotopes. It involves obtaining a relatively long-lived radioisotope which decays into the short-lived isotope of interest. A good example is Tc-99m which is the most widely used radioisotope in nuclear medicine today. This isotope has a half-life of six hours which is rather short if we wish to have it delivered directly from a nuclear facility. Instead the nuclear facility supplies the isotope Mo-99 which decays into Tc-99m with a half-life of about 2.75 days. (wikibooks.org, 2013)

So the nuclear facility produces the parent isotope which decays relatively slowly into the daughter isotope and the daughter is separated chemically from the parent at the hospital/clinic. The chemical separation device is called, in this example, a Tc-99m Generator.

The Mo-99 sodium molybdate is immobilized on a column of alumina (Al2O3; aluminum oxide) due to its very high affinity for alumina prior to putting in the generator. Then a 0.9% saline solution (the eluant) is passed through the column and sodium pertechnetate, the daughter of Mo-99 decay, is eluted from the column due to its almost total lack of affinity for alumina. The pertechnetate is collected in a shielded, evacuated sterile vial and calibrated prior to use. It is referred to as the eluate. The solution of sodium pertechnetate may then be added in an appropriate concentration to the organ-specific pharmaceutical to be used, or sodium pertechnetate can be used directly without pharmaceutical tagging for specific procedures requiring only the 99mTcO4− as the primary radiopharmaceutical (Nucmedtutorials, 2015).

3. Conclusions

The radioisotopes are produced directly by nuclear reactions or indirectly by decay of a parent radionuclide. These reactions occur between particle beams and nuclei (targets), producing new nuclei and new particles. These processes are done in nuclear reactors and particle accelerators. Also, there is the separation process to produce short-lived radioisotopes from the decay of relatively long-lived radioisotope.

The importance of radioisotopes is constantly increasing in several fields. Technologies has been developed such that radioisotopes are at the disposal of Man to improve life quality and to contribute to the development of even better diagnoses, therapy, and industry/science techniques for the most varied needs. Using nuclear medicine as an example of the importance of radioisotopes: over 10,000 hospitals worldwide use radioisotopes in medicine and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99, with some 40-45 million procedures per year (16.7 million in USA in 2012, 550,000 in Australia), accounting for 80% of all nuclear medicine procedures worldwide. (WNA, April 2015).

Although the development and importance of these elements is clear, some countries in development, like Brazil, still have trouble producing and distributing the radioisotopes. Brazil has planned to construct a multipurpose reactor in order to become independent in the production of Mo-99, but for lack of investments and political reasons this project has been delayed for several years. Also, the production is usually concentrated in metropolitan centers and the transportation to smaller cities is impaired by various laws (like the transportation of short life, low activity radioisotopes are forbidden on some important bridges) and sometimes even by lack of knowledge (like an airplane pilot refusing to transport radiopharmaceuticals due to the fear of getting cancer), forcing people to come to the metropolitan centers for treatment and sometimes leaving the poor population untreated.

Ultimately, radioisotopes are used for applications that touch the lives of almost everyone including detecting smoke from a house fire, diagnosing and irradiating cancerous tumors, and imaging the heart in stress tests. But, in spite of this great importance and the advance of technology to produce them, there is still a lot of work to be done to allow everyone to be touched by the benefits of this great technology.

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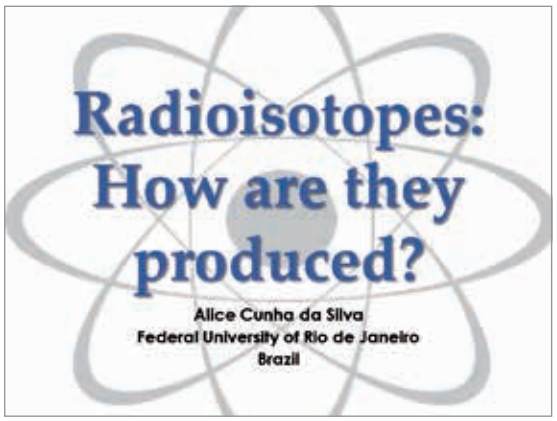
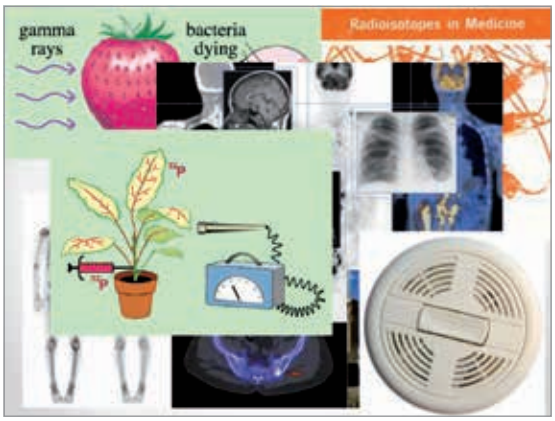
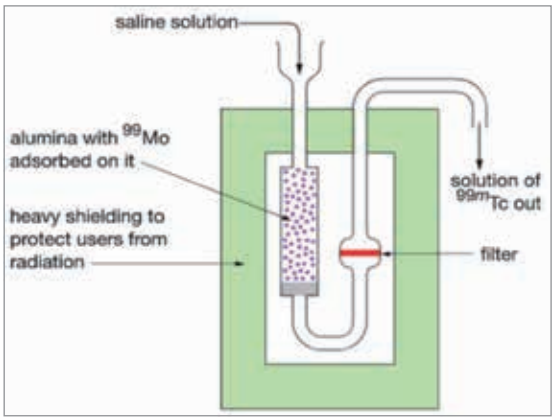
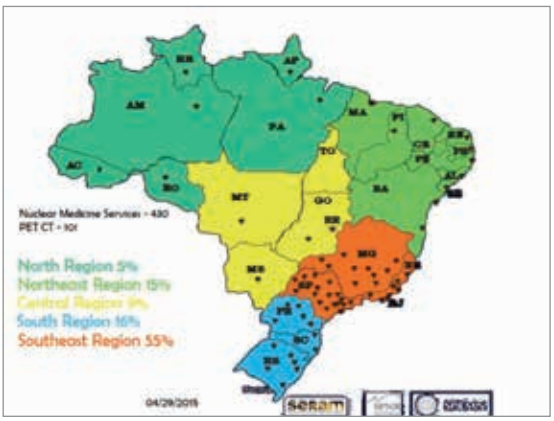
Alice Cunha da Silva presentation








Cyclotron at the Brazilian Nuclear and Energy Research Institute

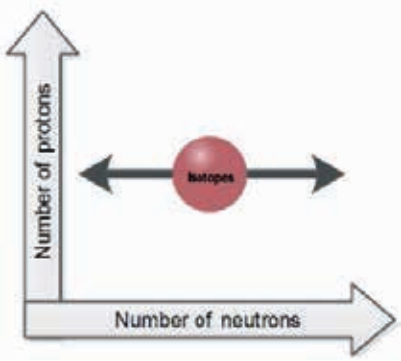


Zulhelmi Zulkifly essay

Zulhelmi Zulkifly & Jeremiah Mbazor
KINGS A+ Team

Introduction

The first practical application of radioisotopes dated back to 1911 when G. de Hevesy tried to prove the accusation he made to his landlady. Hevesy accused her of having a bad habit serving recycled food. To prove this, he used radiation detection instrument to check if the food was radioactive and he succeeded! Since then, the application of radioisotopes spans through all facet of human endeavour. It is applied in agriculture, disease control, measurement, medicine, hydrology, oil exploration and so on. Yes! It is indeed, we human have been using radioactive material since ages without many of us realising it. Now it is time to take few minutes reading this essay as we are going to explain what radioisotopes are and how they can be produced. Of course, better understanding of radioisotope's application will help us see clearly the positive impact of nuclear application to mankind.



What is radioisotope?

Isotopes are atoms of an element with different mass number (neutrons) but same atomic number (protons). Isotopes of an element have the same chemical properties because they have the same atomic number. Different isotopes of the same element have the same number of protons in their atomic nuclei but differing numbers of neutrons. Examples of isotopes are shown in the table below (red in colour are unstable, black are stable radioisotope):

Isotopes	Elements
Carbon	${}^{12}_{6}C$, ${}^{13}_{6}C$, ${}^{14}_{6}C$
Hydrogen	${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{3}_{1}H$
Uranium	${}^{234}_{92}U$, ${}^{235}_{92}U$, ${}^{238}_{92}U$

Radioisotopes are radioactive isotopes of an element. Radioisotopes can be derived from stable isotopes or radioactive ones (ANSTO, 2015). They can also be defined as atoms that contain an unstable combination of neutrons and protons. The combination of neutrons and protons makes the atoms of the radioisotope unstable, hence to attain stability, they release energy in form of radiation through the process called radioactive decay.

$${}^{A}_{z}X \rightarrow {}^{A\pm1}_{z}B + \gamma$$

Where: X is the parent nuclide; B is the daughter nuclide, and; γ is the energy release in form of radiation or particle.

Radioactive decay is the spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter from the nucleus. The illustration above is the typical way radioactive decay occurs. Series of parent and daughter nuclide may occur in a decay chain. It could be natural or artificial; direct or indirect accompanied with the release of energy in form of radiation. This radiation is what is used primarily in many industrial applications. This is the fundamental principle of radioisotope production.

Radioisotope production

As have been explained earlier, the radioactive decay process could be natural or radioactive. In most cases, radioisotopes are bombarded with neutron or proton as a process of creating artificial decay. Generally, there are three main processes of producing radioisotopes; (1) By reactor; (2) By accelerators, and; (3) Isotope separation.

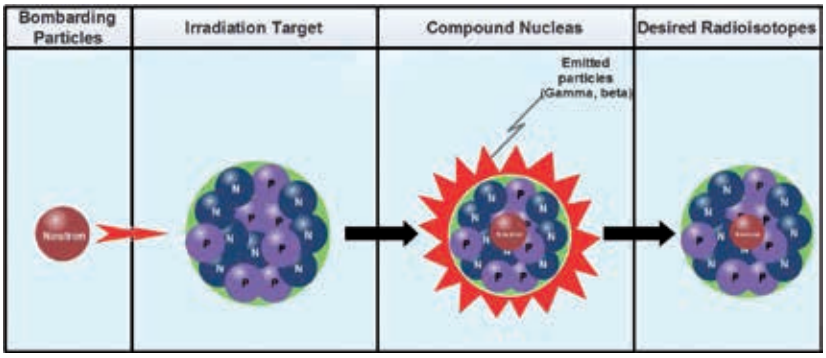


Figure 2: Radiative capture (McMaster University, 2015)

Radioisotope production by nuclear reactors

The main kind of reaction (as illustrated in figure 2) that governs production of radioisotopes from reactors is the (n, γ) reaction (also known as radiative capture).

During the process, the target is exposed to high neutron flux for an appreciable amount of time. Afterwards, the irradiated targets are loaded in appropriate shielding containers and transported to hot chemistry labs for processing. The process may be indirect such that the irradiated target emits β particles before producing the desired radioisotope with the associated γ $or X$-ray.

An example of a radioisotope produced in reactors and even nuclear power plants is the famous Technetium-99m, ${}^{99m}_{43}\mathrm{Tc}$. It is the desired radioisotope used in medicine and popularly produced in reactors around the world. The process equation is:

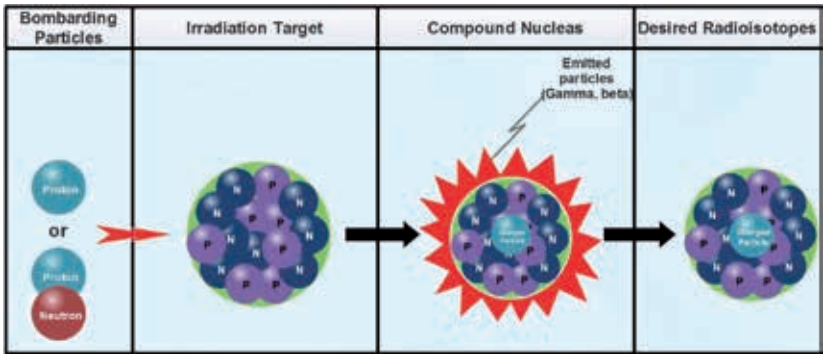
First: $${}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \xrightarrow{\text{fission}} {}^{99}_{42}\mathrm{Mo} + {}^{134}_{50}\mathrm{Sn} + {}^{1}_{0}3\mathrm{n} + \gamma + \mathrm{heat}$$

Second: $${}^{99}_{42}\mathrm{Mo} \xrightarrow{\beta}_{\gamma} {}^{99m}_{43}\mathrm{Tc} \rightarrow {}^{99}_{43}\mathrm{Tc} + \gamma$$

It has the half-life of 6 hours while the parent radioisotope, Molybdenum-99, $^{99}_{42}\mathrm{Mo}$ has a half-life of 66 hours. Due to the short half-life of $^{99m}_{43}\mathrm{Tc}$, the production facility is usually located close to the end-usage facility. These days it is practically more suitable to use generators using $^{99}_{42}\mathrm{Mo}$ to extract $^{99m}_{43}\mathrm{Tc}$ through a process known as elution (ANSTO, 2015).

Other radioisotopes produced from reactor are but not limited to $^{125}_{53}\mathrm{I}$, $^{186}_{75}\mathrm{Re}$, $^{89}_{38}\mathrm{Sr}$, $^{59}_{26}\mathrm{Fe}$ and so on. Generally, these radioisotopes are known as neutron-rich.

Radioisotope production by accelerators



Accelerators are used to bombard irradiation targets with beams of charged nuclei impinge on targets to produce a wide range of isotopes, including many proton-rich nuclei (F-18, C-11) that are not available at reactors. Beams of protons and deuterons are primarily used, but alpha particles and heavier ion beams can also, in principle, be used.

Possible alternatives involve bombarding a target to produce neutrons or photons, which then impact the production target to form the isotopes of interest. The range of particle energies and intensities vary between facilities.

Some cyclotrons are dedicated to medical isotope production for either the Single Photon Emission Computed Tomography (SPECT) or Positron Emission Tomography (PET) applications and some other machines are non-dedicated. Often, cyclotrons producing isotopes for positron emission tomography are built and operated close to PET centers. The cyclotrons have to be close to PET facilities owing to the short half-lives of the isotopes used by PET cameras. The main radioisotopes produced by those cyclotrons are those needed to operate PET cameras, e.g. C-11, N-13, O-15 and F-18 while those for SPECT include Ga-67, In-111, I-123 and Tl-201.

Generally, the radioisotopes produced from accelerators are known as proton–rich or neutron deficient.

Radioisotope production by isotope separation

Approximately more than 300 different stable radioisotopes of some 60 heavy and light elements have been produced by separation technologies. The most important radioisotope produced by separation from fission products is Molybdenum-99 ($^{99}_{42}\mathrm{Mo}$), a parent isotope for Technetium-99m ($^{99m}_{43}\mathrm{Tc}$) generators which are used widely in nuclear medicine procedures.

Other heavy isotopes and alpha emitters like Ac/Bi 213 225 and Bi 212 are also produced using this process. Even though isotopes have nearly identical chemical behavior, chemical methods have been used for over 60 years to provide significant quantities of separated stable isotopes. Some of the earliest examples include the separation of Uranium isotopes by electromagnetic separation, gaseous diffusion, chemical exchange processes to produce C-13 and N-15, and thermal diffusion and distillation to produce O-18, S-34, S-36, and some isotopes of the rare gases.

Major separation techniques include: (1) those that directly exploit the atomic mass of the isotopes; (2) those that exploit slight differences in chemical reaction rates due to different atomic masses, and; (3) those based on the (often significantly different) atomic properties of different isotopes (US National Isotope Development Center, 2015). This process is used for isotope enrichment which uses lasers and centrifuge technology.

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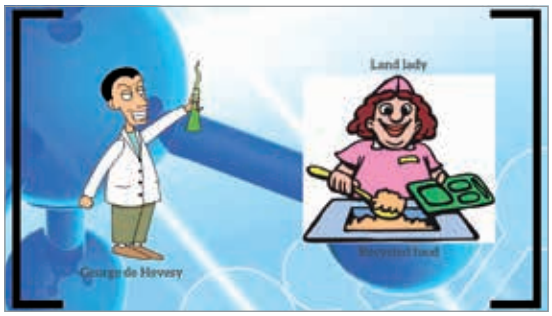
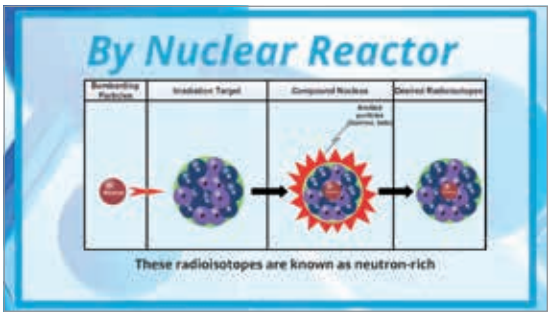
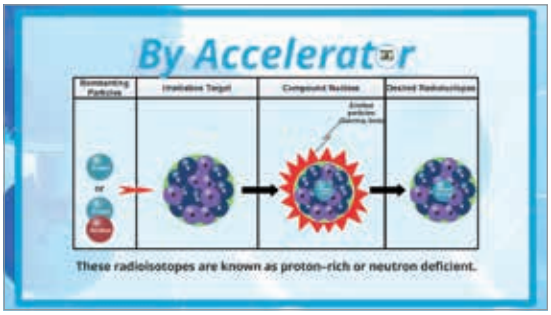
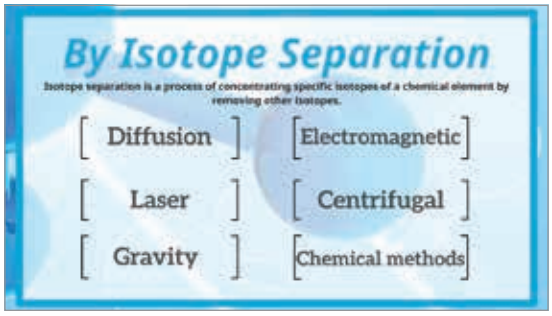
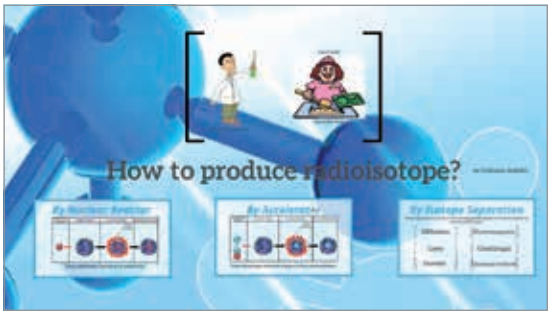
Zulhelmi Zulkifly presentation











Anton Philippe T. Tanquintic essay

One looks back upon history and marvels at how far we've gone since Democritus and the concept of the indivisible "atomos". Fast forward more than a thousand years later and we find John Dalton and his Atomic Theory, where he adds that all atoms of an element are alike in every way. The century that followed not long after then saw the series of research by Roentgen, Becquerel, and the Curies which culminated in the discovery of radioactivity [1]. Finally, with Rutherford's "splitting of the atom", a clearer picture of the dynamics of the atom was born; one thing became certain – Dalton's ideas were incomplete. Not all atoms are alike, and not all atoms of an element are made equal. While the proton number of a nucleus determines the element of an atom, the neutron number can differ to produce variants of an element called isotopes. Isotopes can be stable, or at the least, considerably metastable, wherein decay is observed along with the emission of radiation to seek a more stable configuration over time [2]. Today, we know these are called radioisotopes – isotopes that are also radiation sources; today, we know more thanks to men like Dalton.

In fact, we already know enough about them to harness the different types of radiation they emit for numerous beneficial uses in various fields. Radioisotopes have been found to be invaluable to nuclear medicine, where they meet a wide range of applications – from treating diseased organs or tumours to mapping the human body via nuclear imaging [3]. Thallium-201 is used to detect damages in heart muscle, Carbon-11 to study brain physiology, and Cobalt-60 in the sterilization of hospital medical equipment [4]. Outside medicine, we find gamma sources at work in numerous ways. Manufacturing plants use them to assess the structural integrity of products like jet engines, while the food industry uses them to sterilize food in packaging and canning. Truly, the presence of radioisotope applications in our lives is ubiquitous. So, where do they come from and how are they made?

Some radioisotopes exist in nature, like Uranium-238 due to its half-life of 4.5 billion years. Others, on the other hand, are continuously made by natural processes – such as Carbon-14 via bombardment of Nitrogen by cosmic rays in the atmosphere [2]. While sources like these can be mined or extracted, most other radioisotopes of elements do not typically exist in nature and are thus synthesized. The first artificial radioisotope was made by the Joliot-Curies, forming Phosphorus-30 after bombardment of an aluminum sheet by particles emitted from Polonium [4]. Today, most of the radioisotopes used commercially are man-made, manufactured from an artificial combination of neutrons and protons to form an unstable atom. Typical production procedures make use of a prepared target material of stable matter, which is then bombarded for activation and then chemically processed for extraction of the radioisotope content. Conventionally, the most common ways for manufacturing radioisotopes are via nuclear reactors or particle accelerators [5].

The use of nuclear reactors requires nuclear fuel, typically in the form of Uranium-235, and neutrons moderated by water to induce further nuclear fission. Pool-type reactors use enriched Uranium in light water, where the core is visible and accessible from an open top. Target materials are merely loaded in designed jigs and submerged to predetermined locations, whereby they are

easily unloaded afterwards with simple devices. On the other hand, cooled tank type reactors use natural uranium in heavy water, and possess irradiation assemblies for larger numbers of target capsules lowered into a hot cell for automated loading and unloading [6].

Figure 1: Visible Interior of Pool-type Reactor (Left); Closed Tank-type Reactor (Right) [6]

Through fission of the Uranium, a large neutron flux is generated and encourages further splitting of more Uranium atoms, causing a chain fission reaction. This intense neutron flux can then be directed onto a target capsule containing the stable material, typically in the form of encapsulated granules or powder. Via neutron capture by the target material's atomic nuclei, significant amounts of radioisotope are generated over time, with irradiations lasting from minutes to weeks [7]. Afterwards, irradiated samples are then loaded in shielding containers and sent to labs for processing. While desired radioisotopes can already be obtained this way, other systems called radioisotope generators exist where irradiation produces a relatively long-lived parent radionuclide. This parent can then be isolated and transported in hot cells, where its slow decay into the desired radioisotope is convenient for longer storage and use, such as in the production of the artificial element Technetium-99 from parent Molybdenum-99 [8]. While these have been longstanding and proven techniques, recent times have seen development of alternative technologies aside from reactor use due to competitive advantages posed by other methods.

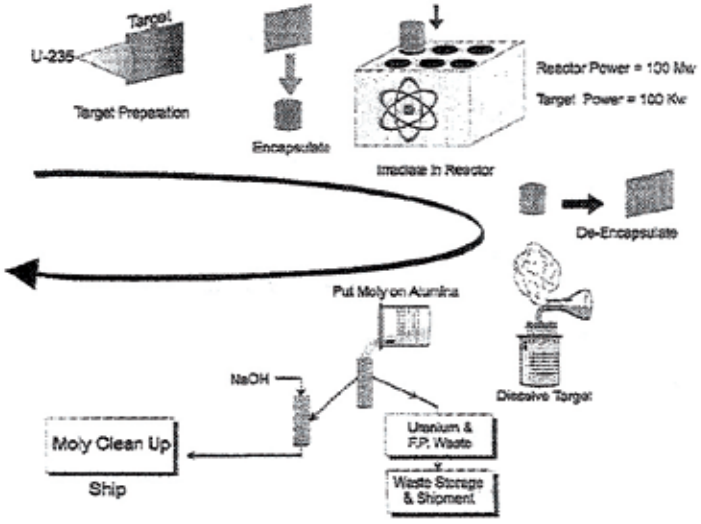


Figure 2: Radioisotope Production Process in Reactors (Moly is Mo-99) [18]

The other common method for radioisotope production utilizes particle accelerators to collide charged particles, typically in the form of protons or deuterons, with stable target atoms [5]. Here, positively charged Hydrogen atoms or deuterons are accelerated by magnets and alternating electrical fields, allowing velocities as high as 75% the speed of light. In their collision, the target nucleus absorbs the projectile in fusion to become a more massive nucleus in its excited state. The atom then de-excites by emitting particles and radiation to form a metastable radioisotope, which then emits radiation until it converts into its more stable configuration.

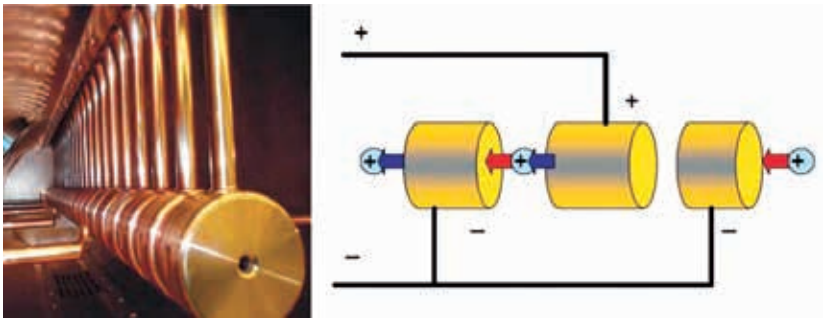


Figure 3: Typical Drift Tube LINAC (Left), Acceleration of Positive Charge by Alternating Fields (Right) [10]

Typically, there are two categories of particle accelerators for radioisotope production: LINACS, or linear accelerators, and cyclotrons. LINACS are accelerators that follow straight configurations, and thus require operation of a device built over large amounts of land to accelerate a charged particle up to energies over hundreds of MeV. On the other hand, cyclotrons are more compact due to the nature of their operation, where they accelerate charged particles in a ring continuously until velocities are high enough for collision. While this allows cyclotrons more moderate sizes, this also limits the range of energies they provide to less than 100 MeV [2]. However, proton energies for radioisotope production are most effective under 150 MeV due to maximization of radioisotope generation while minimizing coproduction of radioactive waste material, which allows suitable use of a cyclotron.

Compared to reactor use, operation of either particle accelerator offers a safer and less tedious process for radioisotope production, especially since accelerators require only electricity and not nuclear fuel [9]. This eliminates both maintenance costs as well as potential risks for catastrophes, especially with lower output of hazardous byproducts. On the other hand, reactors are still able to produce a wider variety of radioisotopes in larger batches at a time, as compared to lower yields from accelerators [10]. Moreover, reactor radioisotopes are typically neutron-rich atoms, while accelerator radioisotopes are usually proton-rich [5]. Thus said, the selection of either method is thus heavily dependent on the type and amount of radioisotope desired, as well as considerations regarding available resources. In meeting the world's growing demand for radioisotope supplies, both methods can be maximized and used jointly.

Irradiated target materials then require further processing before being useful commercially, especially if unwanted byproducts or traces of the original

Table 1: Summary of Key Differences between Reactor and Accelerator Use

	Production via Reactor	Production via Accelerator
Production Rate	Higher production rate via simultaneous irradiations	Lower production rate; fewer collided materials at a time
Product Range	Larger variety of isotopes; neutron-rich	Moderate variety of isotopes; proton-rich
Fuel/Requirements	Nuclear fuel (e.g. Uranium-235)	Electricity, expensive enriched target material
Byproducts of Process	Large amounts of radioactive waste	Smaller amounts of radioactive waste
Logistics	Large facilities requiring high maintenance	Varied; LINACS require large spaces; Cyclotrons minimal space requirements

material are present. To do so, chemical techniques are applied to separate and isolate radioisotope material from the rest. Separation techniques exploit differences in the properties or behaviours displayed by isotopes compared to the other sample contents [5]. Differences in isotope mass and chemical reaction rates when tested are commonly used bases. Distillation is a technique based on mass difference effective for light elements such as Helium, Lithium, and Carbon; those that are too heavy undergo gaseous diffusion using a centrifuge [11]. Such heavier radioisotopes include Iron, Nickel, Zinc, and even Uranium. Other methods even employ lasers to raise desired radioisotopes to an excited state while not affecting other isobars; non-excited contents are then separated by other mechanisms. By applying multiple stages of separation techniques, one achieves an isolated radioisotope product fit for commercial application.

Where highly pure radioisotope samples are desired, electromagnetic separation can be applied. This technique exploits mass differences of isotopes to change their deflection in a magnetic field. While being very costly and slow, this produces the highest purity radioisotopes and can be used for almost all elements [11]. Typically, isotopes for Thallium, Palladium, Strontium, and many of

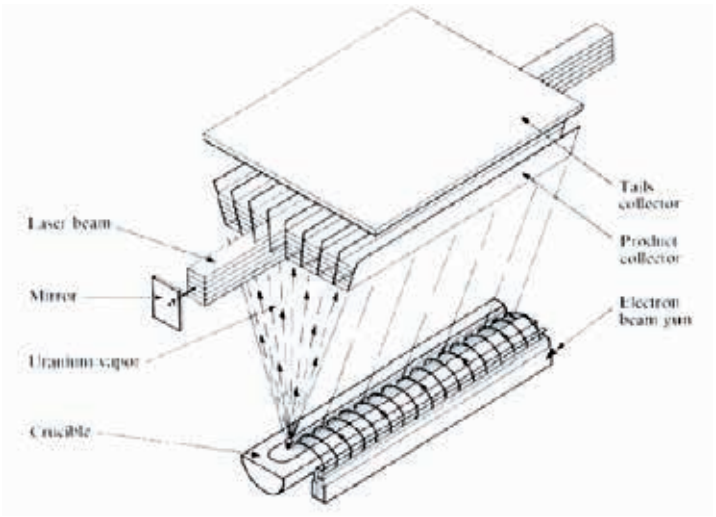


Figure 4: Separation of Isotopes by Use of Laser [11]

the Lanthanide group are isolated this way. However, alternative techniques exist for cost-effective separation of a highly pure substance, as exemplified in the Tungsten-188 generator from which Rhenium-188 is obtained [12].

Figure 5: Technetium-99 Hot Cell Facility at Philippine Nuclear Research Institute [14]

Moving forward, the future of radioisotope production looks bright! While challenges still remain with meeting the projected demand for radioisotope supplies over the next few years, newer technologies and the establishment of more production facilities raise hopes of overcoming such difficulties [13]. In the Philippines, the development of nuclear technologies is still mired by negative stigma associated with fear for their destructive uses. But change is happening – increased support from the government in recent times has allowed the Philippine Nuclear Research Institute to establish its own sustainable radioisotope facility for the local production of Technetium-99 [14]. Moreover, many studies elsewhere have explored safe and more efficient means to produce various radioisotopes as well. In Russia, efforts are underway to incorporate the use of low-enriched uranium for production in facilities [15]. Low power reactors that make use of homogeneous aqueous solutions of uranyl sulfate or nitrate as fuel are also being developed for production of Molybdenum-99 [16,17].

For post-irradiation processes, efforts have been made as well to further develop cost-efficient and effective alternatives in radioisotope separation and enrichment. Column chromatography is a solid-liquid separation technique which isolates radioisotopes by means of affinity toward an adsorbent. In the production of Rhenium-188, research as early as 1975 reported purities of 99.99% with 50% yield from chromatography based on zirconium oxide and distilled water [12]. Knowledge in this field has greatly improved since the 70s, with current advancements made in developing high capacity and nanomaterial adsorbents, or even innovated chromatography designs. Beyond this, other methods have also been explored, such as solvent extraction between immiscible liquids or the separation of volatilized species via thermochromatography, to name a few. Personally, as a fresh graduate of Applied Physics and someone entirely new to the nuclear science scene, I must say that all these developments are amazing! Truly, the discoveries and innovations in producing radioisotopes have passed hundreds of milestones, all done with the combined efforts of generations of men and women in science, with utmost focus on the pursuit of knowledge and the benefit of mankind – and here I am, ready to be one of them. This is how the nuclear dream for a better tomorrow will be realized, and this is how atoms for peace are created: by standing on the shoulders of giants.

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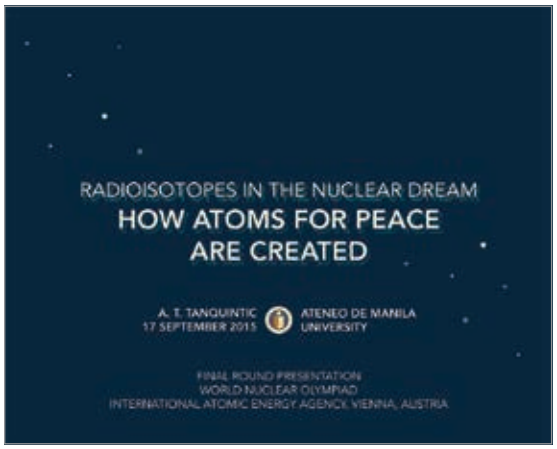
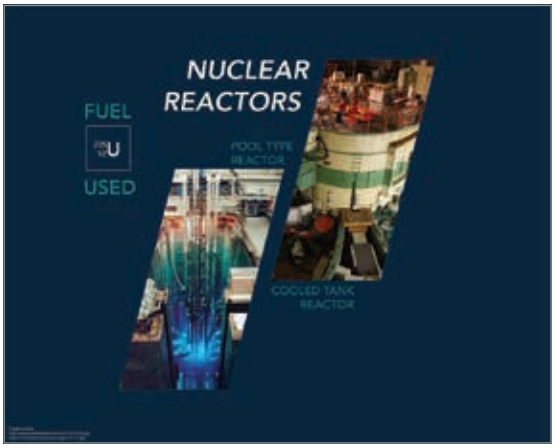
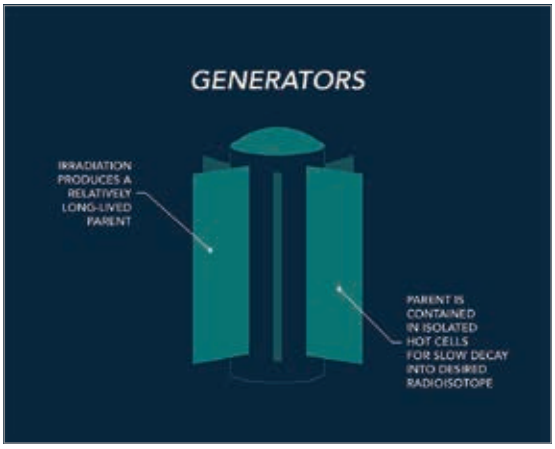
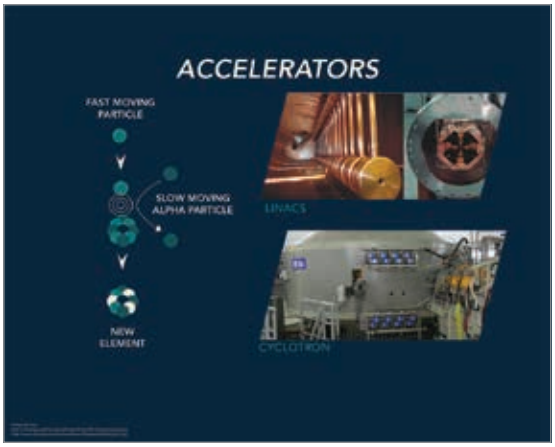
Anton Philippe T. Tanquintic presentation





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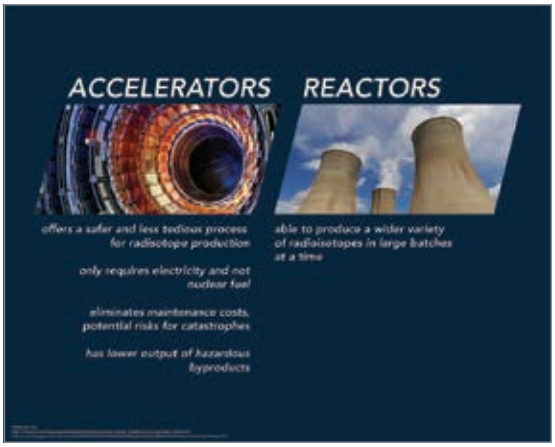
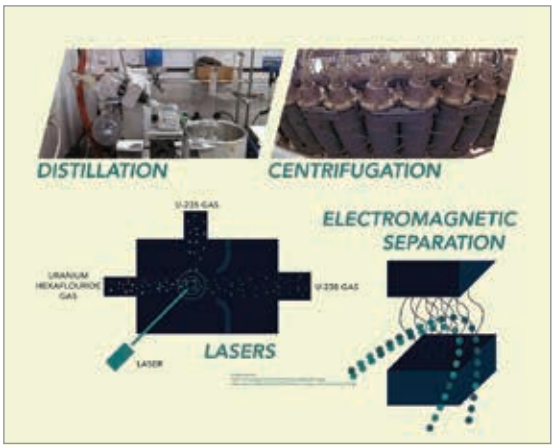
NEW ELEMENT
LINACS
CYCLOTRON


ACCELERATORS
REACTORS
offers a safer and less tedious process for radioisotope production
only requires electricity and not nuclear fuel
eliminates maintenance costs, potential risks for catastrophes
has lower output of hazardous byproducts
able to produce a wider variety of radioisotopes in large batches at a time


DISTILLATION
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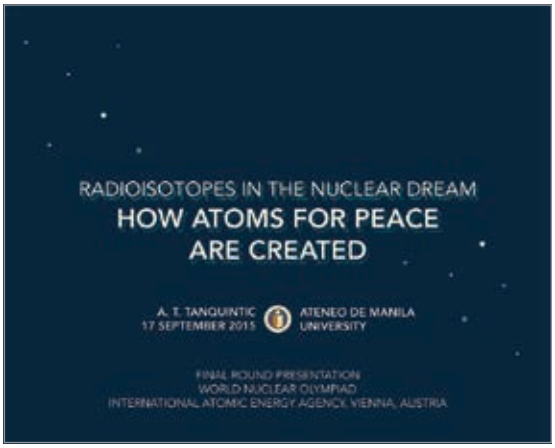
ELECTROMAGNETIC SEPARATION
LASERS
LASER


PHILIPPINES
RUSSIA


STANDING ON THE SHOULDERS OF GIANTS


RADIOISOTOPES IN THE NUCLEAR DREAM
HOW ATOMS FOR PEACE ARE CREATED
A. T. TANQUINTIC
17 SEPTEMBER 2015
ATENEO DE MANILA UNIVERSITY
FINAL ROUND PRESENTATION
WORLD NUCLEAR OLYMPIAD
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, AUSTRIA

Dhruv Dharamshi essay

Introduction

Every element in the periodic table has at least one isotope which is radioactive, while some have as many as 30 radioisotopes. Out of about 200 isotopes of known elements, 275 are stable, the rest being radioactive with half-lives ranging from microseconds to trillion years. The long lived radioisotopes ^{40}K, ^{87}Rb, ^{235}U, ^{238}U and ^{232}Th survived from the time of creation of the terrestrial elements about 4.5 x 10^9 years ago. Radioisotopes like ^{14}C which are relatively short-lived are continuously formed by the cosmic ray interaction in the upper atmosphere. All elements heavier than Uranium are called transuranium elements and are both man-made and radioactive.

Given the large amount of radioisotopes and their wide range of applications in science, medicine and technology; it is crucial that we understand how they can be produced. Cyclotrons and reactors of at least moderate flux may be employed for this purpose and they generally do not produce the same isotope of an element.

Charged particles such as protons, deuterons and α-particles are bombarded on a target to give the product radioisotope after the emission of one or more particles to remove the excess excitation energy. The products obtained are usually neutron deficient in comparison to their stable counterparts. The advantage of using cyclotrons is that the product is not isotopic with the target and hence the ease in separation leads to higher specific activities of the desired radioisotope. For instance, the production of $^{22}_{11}Na$ ($t_{1/2}$ 2.6 y):

$$^{24}_{12}Mg\,(d,\propto)\,^{22}_{11}Na$$

Reactors on the other hand produce neutron rich isotopes by neutron capture reactions. As the products are isotopic with the target element, separation is not as easy as in the case of cyclotrons. However, as a large number of targets can be irradiated in the reactor at a time, this method is more economical in case of production on a routine basis. If the same isotope can be produced by either of the methods, cyclotrons are preferred in case high specific activity is desirable. A heavier isotope of $^{23}_{11}Na$, namely $^{24}_{11}Na$ ($t_{1/2}$ 15.0 h) can be produced as follows:

$$^{23}_{11}Na\,(n,\gamma)^{24}_{11}Na$$

The production of fission fragments resulting from the fission process can also be considered as they cover a wide range of atomic numbers of varying abundances. They have a higher specific activity than the neutron capture products but their separation procedure from other radioactive elements can be lengthy.

In case of certain short lived radioisotopes, it is more convenient to produce them on-site using their longer lived parent isotopes, also known as radioisotope generators.

The mode of production depends on various factors. The length of time it takes for the production to start to the delivery of the product to the application

site, taking into consideration the duration of the experiment/process together determines the half-life with which it is practical to work. The type of experiment and equipment available for handling and measurement determines the preferable decay type and intensity. For example, if an experiment requiring sodium tracer is to last several weeks, the use of reactor produced ^{24}Na is excluded and cyclotron-produced ^{22}Na is employed.

Although these considerations are important, the possibilities of production may be limited either by the availability of facilities or simply by the reaction cross-sections.

A (n, γ) reaction and a (d, p) reaction yields the same product. The choice of reaction depends on the particular nuclides available, projectile energy, and the cross-sections.

Neutron bombardment

The nuclear reactor serves as the source of neutrons. At present there are three research reactors in India at BARC, Mumbai, namely, Apsara, CIRUS and Dhruva to cater to the needs of isotope production. The maximum flux obtainable in Apsara, CIRUS and Dhruva are $5x10^{12}$, $6x10^{13}$ and $1.8x10^{14}$ n/cm^2/s respectively. Even neutrons of low energy are capable of causing nuclear reactions like (n, γ), (n, p) and (n, α) as they are electrically neutral. These are briefly discussed below.

The most common form of interaction of thermal neutron is called radiative capture denoted as (n,γ) and gives a product which has mass number increased by one unit relative to the target nucleus. Generally the radionuclide formed decays by β- emission. The specific activity is limited by the available neutron flux and cross section. A few typical reactions are given in the table below.

Table 1: Production of radioisotopes by (n, γ) reactions

Target	Radioisotope	$\sigma_{n\,(b)}$	$t_{1/2}$	Decay mode
^{59}Co (n, γ)	^{60}Co	36	5.274 y	β-
^{98}Mo (n, γ)	^{99}Mo	0.14	65.94 h	β-
^{23}Na (n, γ)	^{24}Na	0.53	14.9512 h	β-

Some (n, γ) reactions produce a short lived radioisotope which decays to another radioisotope having a longer half-life. For example, (n, γ) reaction with Tellurium yields a product 131I. The product is easily separable from the target and leads to high specific activity.

$$^{130}_{52}Te\ (n,\gamma)\ ^{131}_{52}Te \xrightarrow{\beta^-}\ ^{131}_{53}I \xrightarrow{\beta^-}\ ^{131}_{54}Xe$$

If enough excitation energy is available to the compound nucleus, emission of charged particle such as proton or α particle is possible. As the product is non-isotopic with the target, it can be separated from the target and very high specific activity is attainable by this route.

Table 2: Production of radioisotopes by (n,p) reaction

Target	Radioisotope	$\sigma_{n\,(b)}$	$t_{1/2}$	Decay mode
^{32}S (n,p)	^{32}P	65 mb	14.262 d	β-
^{58}Ni (n,p)	^{58}Co	90 mb	70.86 d	β-, EC
^{14}N (n,p)	^{14}C	1.82 b	5730 y	β-
^{35}Cl (n,p)	^{35}S	0.35 b	87.38 d	β-

Table 3: Production of radioisotopes by (n,α) reactions

	Target	Radioisotope	$\sigma_{n\,(b)}$	$t_{1/2}$	Decay mode
Fast (n)	^{27}Al (n,_)	^{24}Na	0.56 mb	14.9512 h	β-
Thermal (n)	^{6}Li (n,_)	^{3}H	950 b	12.33 y	β-

The neutron induced fission of ^{235}U or ^{239}Pu during normal reactor operation provides a wide variety of radioisotopes as by-products. Long lived fission products of industrial importance are ^{137}Cs, ^{90}Sr, ^{85}Kr, ^{147}Pm etc. These isotopes can be separated from fission products waste solution during nuclear fuel reprocessing. Short lived fission products ^{99}Mo, ^{140}Ba, ^{89}Sr, ^{131}I, ^{133}Xe etc. are produced by irradiating natural or enriched uranium targets in nuclear reactors for a short duration followed by conventional radiochemical separation. Fission products ^{90}Sr, ^{106}Ru, ^{132}I, ^{137}Cs and ^{140}Ba cannot be obtained by the (n,γ) route.

The (n,γ) reaction sometimes causes chemical effects, owing to the recoil energy of the nucleus when γ -ray is emitted. The recoil energy is sufficient to rupture chemical bonds. If after the rupture, the product atom exists in a different chemical state and separable from that of the target, then the product can be isolated from the large mass of inactive target. This process is known as Szilard-Chalmers process. This provides a means of obtaining high specific activity product even though the target and the product are isotopic.

Szilard and Chalmers discovered that when ethyl iodide was irradiated with neutrons, ^{128}I atoms formed from ^{127}I (n, γ) ^{128}I recoil out of the compound and end up as free iodine which could be extracted with water.

$$C_2H_5{}^{127}_{53}I \xrightarrow{n} [C_2H_5{}^{128}_{53}I]^* \xrightarrow{\gamma} C_2H_5 + {}^{128}_{53}I^*$$

The liberated ^{128}I loses its kinetic energy and stabilises as iodine atom or iodide ion. A significant fraction of radionuclide appears in a chemical form different from that of the target (C_2H_5I).

Charged particle bombardment

High energy charged particles like p, d, α and He^{3+}, obtained from accelerators, are used for the production of neutron deficient radionuclides. As the charged particles have small penetrating power (range), the targets in accelerator are in most cases very thin metal foils. Targets are also prepared by depositing oxide layer on a suitable substrate. In accelerator bombardment the product is normally an element different from the target and chemical separation yields a high specific activity product. In the low to medium energy charged particle induced reactions, depending on the energy of the projectile, the following reaction channels are probable.

i. (p,α), (p, d), (p, xn) (p, xn, yp)
ii. (d,α),(d, p),(d, xn),(d, xn, yp)
iii. (α, xn),(α, xn, yp)

where x, y = 1, 2, 3...

In the proton induced reaction on ^{127}I, ^{123}Xe, ^{125}Xe and ^{121}Xe are formed by (p,5n), (p,3n) and (p,7n) exit channels respectively. From the knowledge of excitation functions, the energy of the proton beam is so chosen to primarily yield ^{123}Xe by (p, 5n) reaction.

Cyclotron produced isotopes such as ^{67}Ga, ^{111}In, ^{123}I and ^{201}Tl decay by EC and are extensively used in nuclear medicine. Positron emitting isotopes such as ^{11}C, ^{13}N, ^{15}O and ^{18}F are short lived ($t_{1/2}$ in the range of minutes). Their production in cyclotron is followed by rapid radiochemical processing to yield labelled molecules.

Radioisotope generators

In a generator, a longer lived parent is chemically fixed, which decays to shorter lived daughter and comes into radioactive equilibrium. The daughter nuclide is selectively milked out from the generator making use of the difference in the chemical properties of the two elements. Some examples of generator systems are ^{137}Cs - ^{137m}Ba, ^{140}Ba - ^{140}La, ^{99}Mo - ^{99m}Tc, ^{90}Sr - ^{90}Y and ^{113}Sn - ^{113m}In.

The parent radioisotope is either produced in a reactor or in a cyclotron and is normally adsorbed on a material support, for example - an ion exchange resin in a small packed column. The short lived daughter is eluted from the system by using selective solvents. Daughter nuclide continues to grow and reaches a maximum activity after a period of 3 to 4 times its half-life. Therefore, repetitive milking is possible.

Irradiation yields

It is important to know how much of a radionuclide is formed when the target of an element is subjected to neutron or charged particle bombardment. Number of particles incident/cm^2/s on a target is the flux (φ) .A beam of charged particles in a cyclotron is usually referred to as beam current rather than flux. Beam current is expressed in amperes (A). Beam current of one ampere corresponds to 6.24 x 10^{18} protons/s or 3.12 x 10^{18} α particles/s.

Production rate of nuclide in cyclotron irradiation is given by

$$\frac{dN}{dt} = 6.24 * 10^{28} i z^{-1} \sigma N_a$$

where i = beam current in amperes, z = charge on the projectile, σ = reaction cross section (cm^2) and N_a = Number of target atoms per cm^2 in the beam path

Production rate of nuclide by neutron irradiation is given by

$$\frac{dN_1}{dt} = \varphi \sigma N_t$$

where N_1 = Number of product atoms at any time t, N_t = Number of target atoms, φ = neutron flux (n/cm^2/s) and σ = reaction cross section (cm^2)

Conclusion

As previously mentioned, it needs to be stressed upon that apart from the production of nuclides by the modes of nuclear reactors, cyclotrons, fission reactions or radioisotope generators; separation of those produced radioisotopes (a topic beyond the scope of this essay) from the target material to give a desirable amount of specific activity is a factor that needs to be weighed into equally when determining whether a particular mode of production is feasible.

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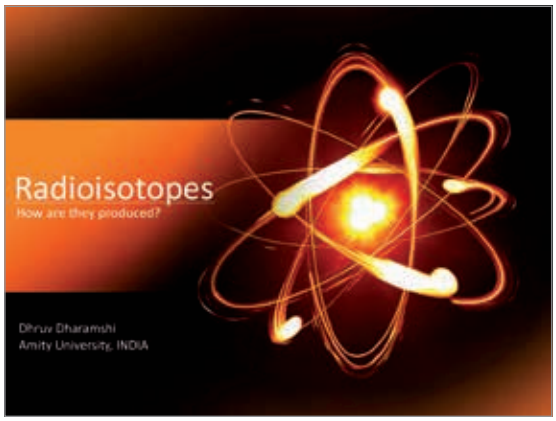
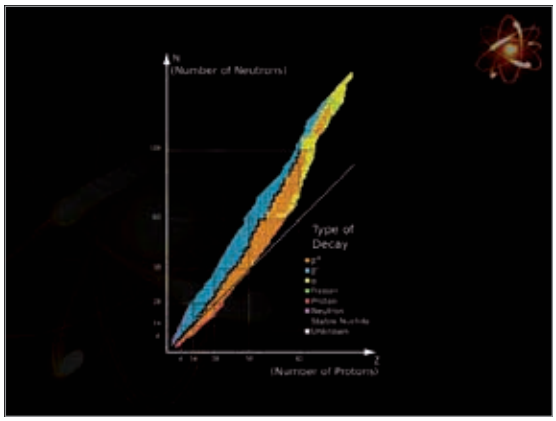
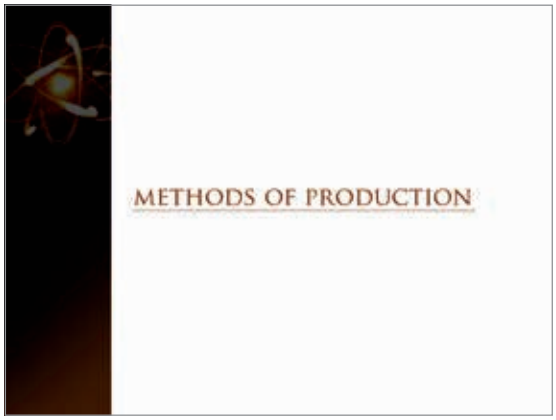
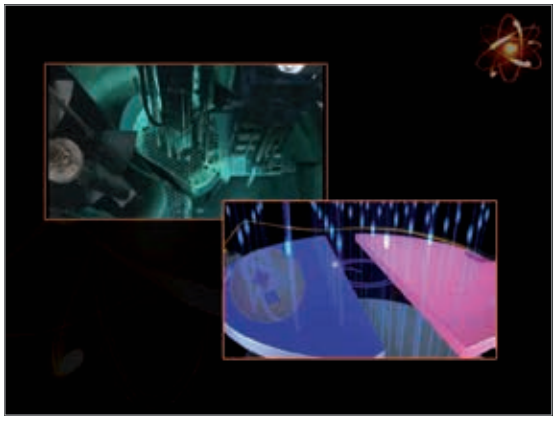
Sood, D. D., Reddy, A. & Ramamoorthy, N., 2010. *Fundamentals of Radiochemistry*. 4 ed. s.l.:Indian Association of Nuclear Chemists and Allied Scientists.

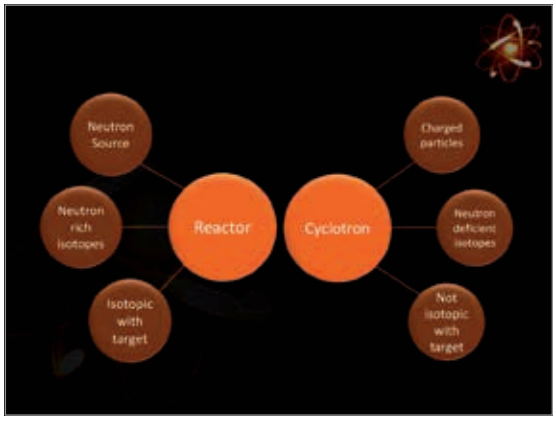
Dhruv Dharamshi presentation

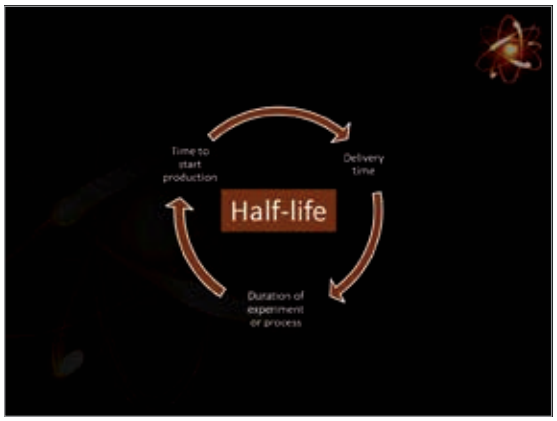


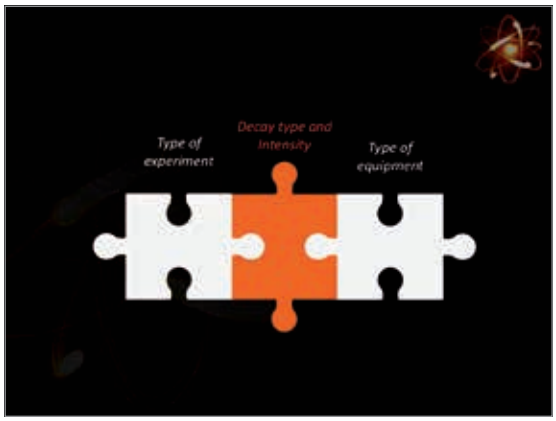


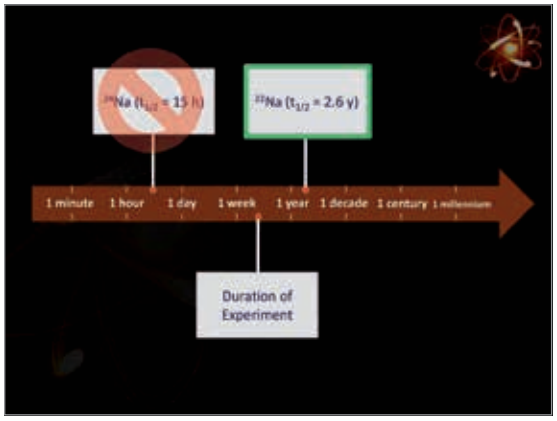


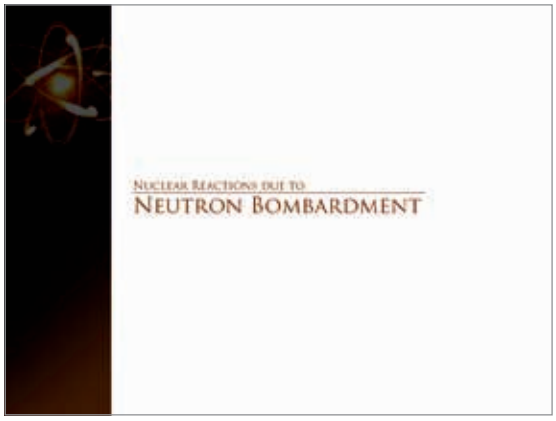


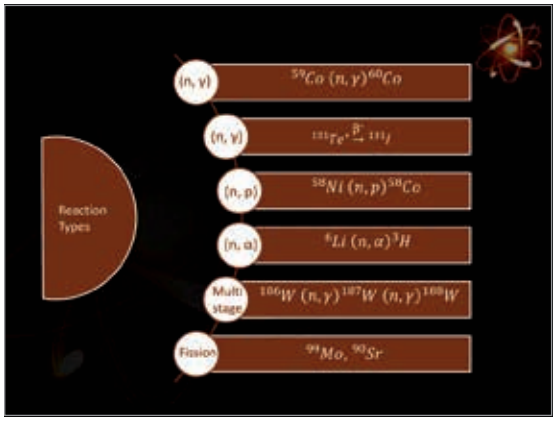


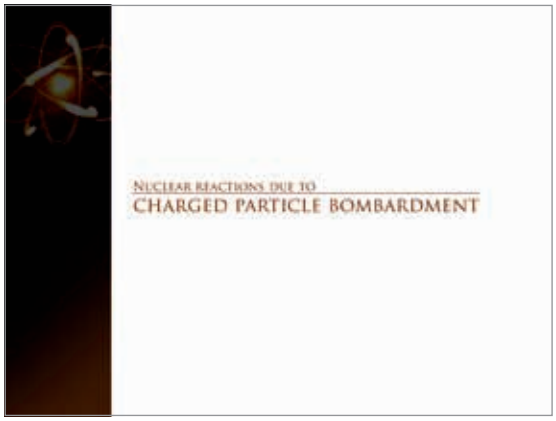

Time to start production
Delivery time
Half-life
Duration of experiment or process


Type of experiment
Decay type and intensity
Type of equipment


^{24}Na ($t_{1/2}$ = 15 h)
^{22}Na ($t_{1/2}$ = 2.6 y)
1 minute
1 hour
1 day
1 week
1 year
1 decade
1 century
1 millennium
Duration of Experiment

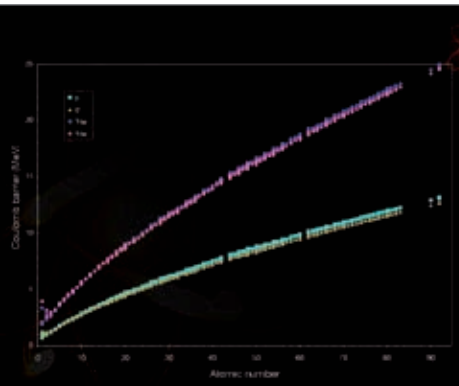

Nuclear Reactions due to
Neutron Bombardment

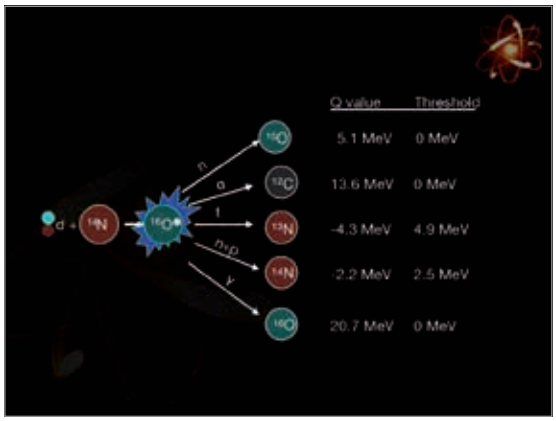

Reaction Types
(n, γ)
$^{59}Co\ (n,\gamma)^{60}Co$
(n, γ)
$^{131}Te \xrightarrow{\beta^-} {}^{131}I$
(n, p)
$^{58}Ni\ (n,p)^{58}Co$
(n, α)
$^{6}Li\ (n,\alpha)^{3}H$
Multi stage
$^{186}W\ (n,\gamma)^{187}W\ (n,\gamma)^{188}W$
Fission
$^{99}Mo,\ ^{90}Sr$

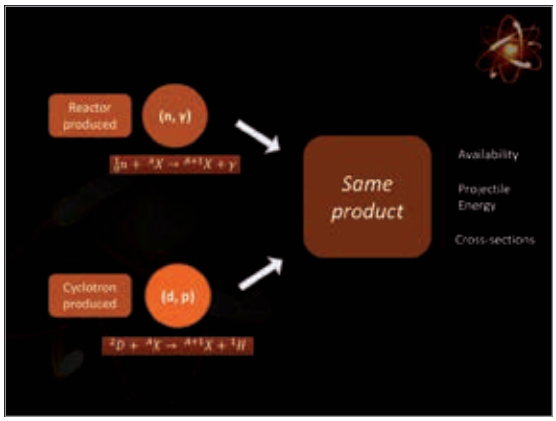

Nuclear Reactions due to
Charged Particle Bombardment

Potential Barriers

Coulomb barrier	Q value
• Electrostatic repulsion • $B = Ze^2/R$	• Exothermic reaction or endothermic reaction • Q (MeV) = 931.4 ΔM • $\Delta M = (m_y + M_f) - (m_x + M_i)$







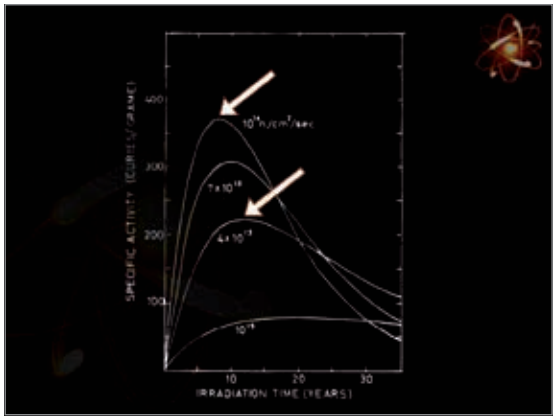
Yield and Reaction Cross-Sections
Part 1: Reactors

Production yield in reactor

$\frac{dN'}{dt} = \phi\sigma_{act}N_T$	Activation per second when target us under irradiation
$\frac{dN'}{dt} = \phi\sigma_{act}N_T - \lambda N'$	Due to decay rate of product nucleus
$S = \frac{0.6\sigma\phi}{A}(1 - e^{\lambda t})\ Bq/g$	Value of radioactive atoms at time 't'
$S = \frac{0.6\sigma\phi}{A}\ Bq/g$	When $t >> T_{1/2}$

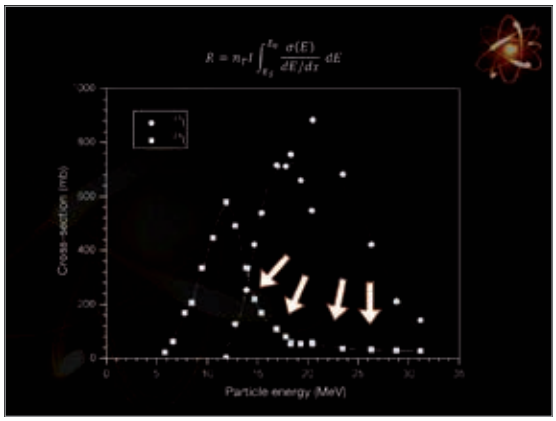
Corrections to the activation equation

1. Self shielding effect in the target
2. Power variation in the reactor
3. Flux depression
4. Burn up of target with time
5. Destruction of product nucleus

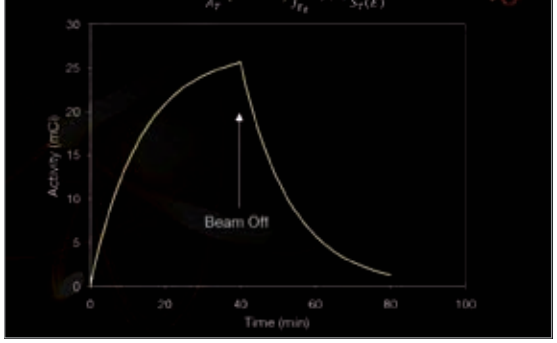


Yield and Reaction Cross-Sections
Part 2: Cyclotrons

$$R = n_T l \int_{E_2}^{E_0} \frac{\sigma(E)}{dE/dx}\, dE$$



$$Y = \frac{N_A l}{A_T}\left(1 - e^{-\lambda t}\right) \int_{E_0}^{E_1} \sigma_T(E) \frac{dE}{S_T(E)}$$



Conclusion

Vivek Maradia essay

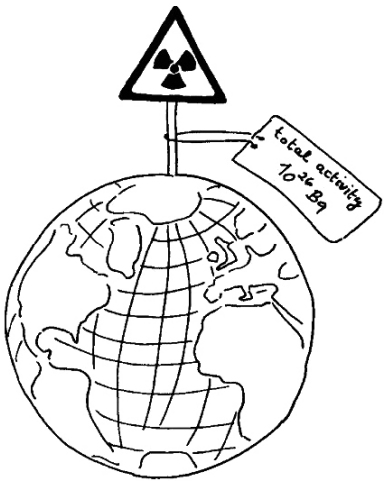
Introduction

Radiation has existed since the very beginning of the universe. The story of the discoveries that led to our present understanding of the many different kinds of radiation started a few centuries ago. It focused first on the most important visible forms of radiation that constituted the sunlight, and then extended to invisible radiation that we call ultraviolet and infrared radiation, the latter one being especially effective in heating homes and foods.

The scientific revolution that marked the end of the nineteenth century opened up a heretofore unknown word of radiation. It is striking that within only three years, several major discoveries dramatically changed the scope of science. From then on, experimental investigations were no longer limited to the macroscopic world. They extended to the microscopic world - not directly accessible to our senses.

For many years, the nature of the cathode rays produced by electric discharges in low pressure gases had puzzled physicists. In 1895 Wilhelm Conrad Roentgen discovered that cathode rays produce mysterious secondary radiation with extraordinary properties, X-rays. In 1897 Joseph John Thomson demonstrated that cathode rays were electrons - extraordinarily light particles charged with negative electricity. In the meantime, Henri Becquerel discovered weak but spontaneous radiation emitted from uranium.

The discovery of x-rays immediately had a tremendous impact on the scientific community and on the public. The first radiography, taken by Roentgen of his wife's hand, was known all over the world within a few weeks, even a few days, despite word being sent through ordinary mail. The discovery of uranic rays did not appear at first as spectacular. Then, early in 1898, Marie Curie, discovered that the radiation is a property of the atom itself. That same year, she discovered with Pierre Curie two new elements, polonium and radium, which spontaneously emitted millions of time more radiation than uranium, and she coined the term radioactivity - the spontaneous emission of radiation. It was a turning point. From then on, Marie Curie's main preoccupation in



studying radioactivity was to make radium and, more generally, the new elements and forms of radiation incomparable research tool, opening the way to dramatic breakthroughs in physics and chemistry, and later in medicine through radiotherapy.

Isotope production methods

There are numerous strategies for producing isotopes for research and applications.

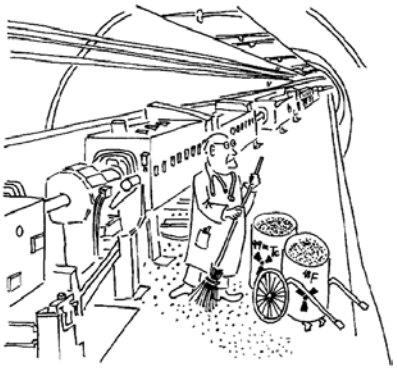
1. Production with reactors

Radioisotopes can be produced in reactors by exposing suitable target materials to the intense reactor neutron flux for an appropriate time. In light-water moderated, swimming pool-type reactors, the compact core is accessible from the top of the pool. Target materials to be irradiated are sealed in capsules, loaded in simple assemblies and lowered into predetermined core locations for irradiation. Afterwards, the irradiated targets are loaded in appropriate shielding containers and transported to hot chemistry labs for processing. In uranium, heavy-water moderated, tank-type reactors, sophisticated assemblies containing numerous target capsules are used for target irradiations. For both approaches, the quality and specific activity of the radioisotopes produced depends on both the target and the irradiation conditions.

A wide range of isotopes are made at reactors, from as light as Carbon-14 to as heavy as Mercury-203, with irradiations lasting minutes to weeks. For example, Mo-99 -- the parent to the widely used medical diagnostic radioisotope Tc-99m -- is usually produced via neutron-induced fission of targets with U-235 using a 4 to 8 day irradiation time.

2. Production via accelerators

Accelerators are used to bombard production targets with beams of charged nuclei impinge on targets to produce a wide range range of isotopes, including many proton-rich nuclei (F-18, C-11) that are not available at reactors. Beams of protons and deuterons are primarily used, but alpha particles and heavier ion beams can also in principle be used. Possible alternatives involve bombarding a primary target to produce neutrons or photons, which them impact the production target to form the isotopes of interest. The range of



Radioisotopes for nuclear medicine are created as waste product at accelerators."

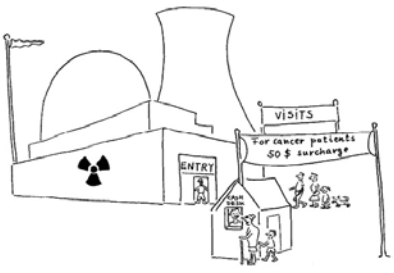
particle energies and intensities vary between facilities -- 10 - 100 MeV for commercial cyclotrons dedicated for isotope production, with higher energies available at some research accelerators. For example, the Brookhaven Linac Isotope Producer (BLIP) at Brookhaven National Laboratory uses a 200 MeV, 150 microAmp proton beam from the Alternating Gradient Synchrotron to bombard samples for the production of Ge-68/Ga-68, Sr-82/Rb-82, as well as Zn-65, Mg-28, Fe-52, Rb-83. Another is the Isotope Production Facility (IPF) at Los Alamos National Lab that uses the 100 MeV, 250 microAmp proton beam from the LANSCE linac to produce Ge-68/Ga-68 and Sr-82/Rb-82, as well as smaller amounts of Al-26 and Si-32.

3. Production via chemical separation

Even though Isotopes have nearly identical chemical behavior, chemical methods have been used for over 60 years to provide significant quantities of separated stable isotopes. Some of the earliest examples include the separation of Uranium isotopes by gaseous diffusion, chemical exchange processes to produce C-13 and N-15, and thermal diffusion and distillation to produce O-18, S-34, S-36, and some isotopes of the rare gases. Major separation techniques include: those that directly exploit the atomic mass of the isotopes; those that exploit slight differences in chemical reaction rates due to different atomic masses; and those based on the [often significantly different] atomic properties of different isotopes.

4. Electromagnetic enrichment and purification

Electromagnetic separation exploits the mass difference of isotopes to change their deflection in a magnetic field. This low-throughput technique is quite costly, but can yield some of the highest purities of separated samples. It is often used in conjunction with other approaches -- such as to increase the purity of samples obtained from gaseous diffusion. Devices called calutrons were historically used for electromagnetic purification. This approach can work for almost all elements, and is typically used for isotopes of Tl, Pd, Sr, Ca and the Lanthanide group.



The many uses of radioisotopes/radiation

From the moment we get up in the morning, until we go to sleep, we benefit unknowingly from many ingenious applications of radioisotopes and radiation. The water we wash with (origin, supply assurance), the textiles we wear (manufacture control gauging), the breakfast we eat (improved grains, water analysis), our transport to work (thickness gauges for checking steels and coatings on vehicles and assessing the effects of corrosion and wear on motor engines), the bridges we cross (neutron radiography), the

paper we use (gauging, mixing during production processes), the drugs we take (analysis) not to mention medical tests (radioimmunoassay, perhaps radiopharmaceuticals), or the environment which radioisotope techniques help to keep clean, are all examples that we sometimes take for granted.

Uses of radioisotopes are endless. Hear I wants to share my family's story, how my family benefited from radiation/radioisotope.

"It was one of those calls that we hope to never get. My mother was calling to say that she had just been diagnosed with cancer. Bone cancer! My stomach involuntarily flexed inward as if it had just been hit with a bowling ball - and my throat went dry. Surely this could not be.

Was the life of this human dynamo about to be cut short with cancer? And of all things, bone cancer - one of the most painful of all forms of this hideous disease?

After pausing to get a grip on my emotions, I mumbled something to the effect that we would seek a second opinion. After all, my mom was still living in the old farmhouse near the town of Rajkot, Gujarat. Although the local doctors were competent, I quickly tried to convince myself that she might benefit from going to Mumbai, where doctors had considerably greater degree of specialty.

We arranged for her to see an oncologist in Mumbai. Only minutes after he injected her with a special medication, the doctor brought the family together and gave us the news. "Mrs. Maradia," he exclaimed, "you are a fortunate woman." He pointed to a picture that looked strangely like an x-ray, but with dashing splashes of colour. "You do not have the hot spots characteristic of bone cancer. I suspect it is simply inflamed arthritis."

With a great sigh of relief, we drove mom back to home and celebrated with a hearty meal. She is living fine, with no sign of cancer. How in the world could that Mumbai doctor have been so confident in reversing the near-paralyzing diagnosis of Mom's general practitioner from Rajkot?

What was the magic injection?

Fresh-food preservation, spacecraft power, airport lights, historical dating, efficient engines, cancer detection, What can they possibly have in common?

The answer. **Radiation**.

Radiation? Yes, ionizing radiation. How could this possibly be? Isn't radiation that stuff we're so worried about in nuclear waste? Radiation is indeed an integral part of nuclear waste. But radiation, and ionizing radiation in particular, is a phenomenon that has been around for billions of years. It is only within the last century that humans have been able to harness it for a plethora of useful and many lifesaving applications. As we seeing, it is practically impossible to go through a day without directly benefiting from an enormous array of products or processes made possible by exploiting the awesome properties of radiation."

Conclusion

As we seen, four efficient techniques used to produce different radioisotopes and this isotopes benefiting human life. Let's use Marie Curie's discoveries for the greatest benefit to humanity. The only question is how long it will take for us to accept it. To step ahead, Let's celebrate Marie Curie's 150th birth anniversary (7 November 2017) as a "World Nuclear Radiation Day."

References

[1] Alan E. Waltar, 2004, Radiation and Modern Life, Prometheus Books, New York.

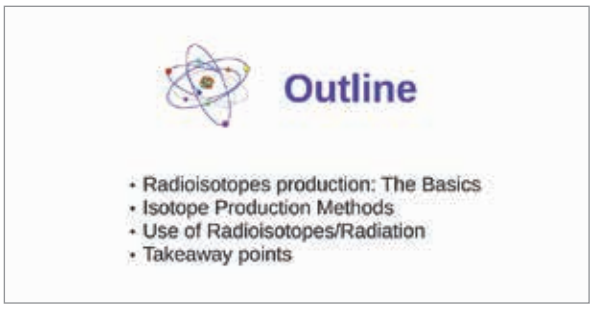
[2] Albert Reynolds, Bluebells and Nuclear Energy, pp. 29-30

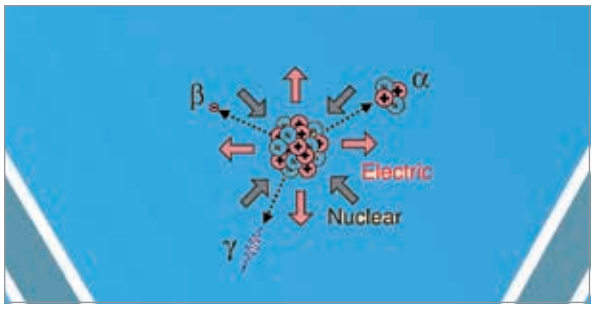
[3] The peaceful Atom," Uranium Information Centre, Ltd., Melbourne, Australia, 2003.

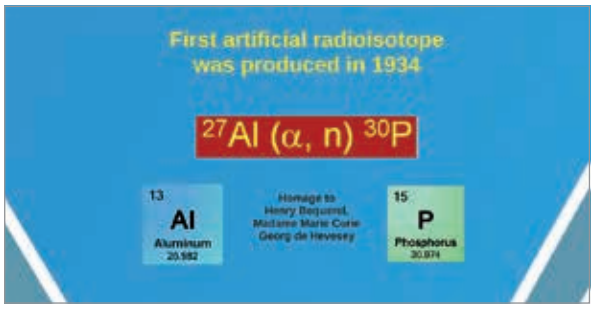
[4] The Many Uses of Nuclear Technology, WNA website, March 2014, http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Overview/The-Many-Uses-of-Nuclear-Technology/

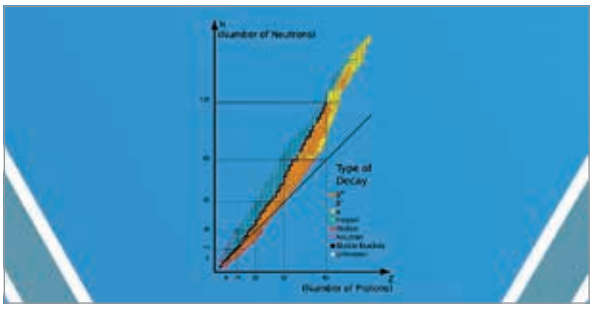
[5] Non-Power Nuclear Applications, WNA website, http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/

Vivek Maradia presentation







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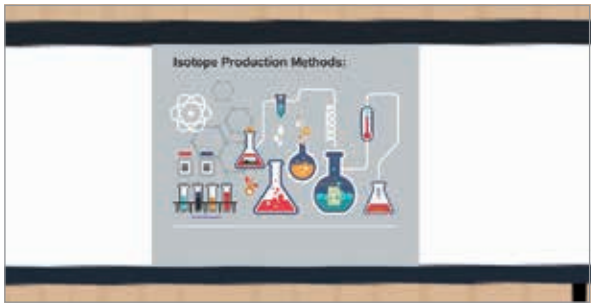
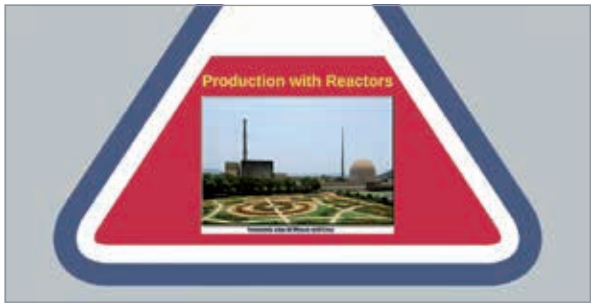
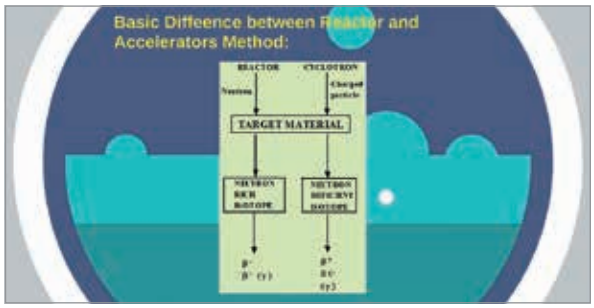
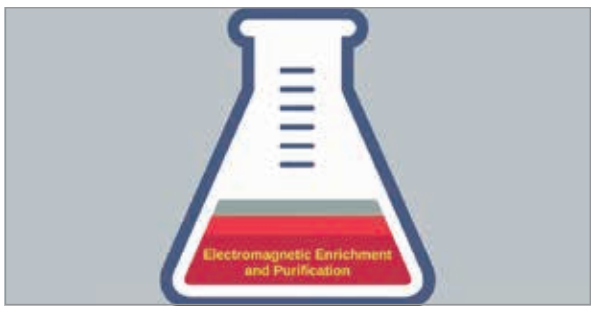

Isotope Production Methods:

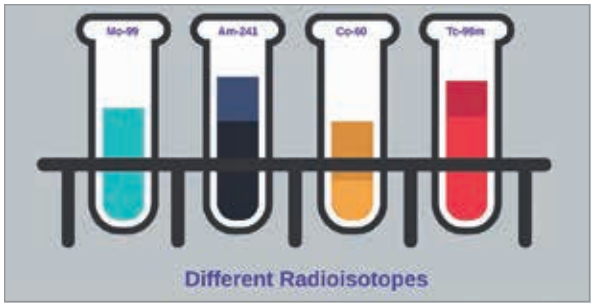

Production with Reactors

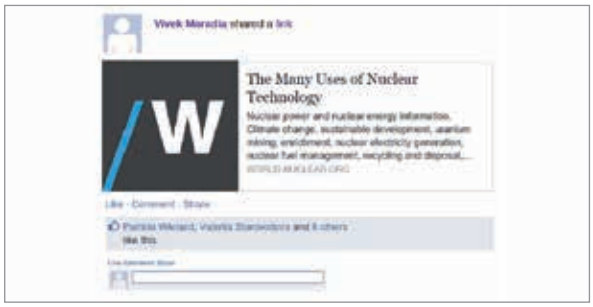

Production via Accelerators
Target
Dee
Ion Source
Pole
Deflector
Vacuum Tank
Oscillator Coupling


Basic Diffeence between Reactor and Accelerators Method:
REACTOR
CYCLOTRON
Neutron
Charged particle
TARGET MATERIAL


Production via Chemical Separation

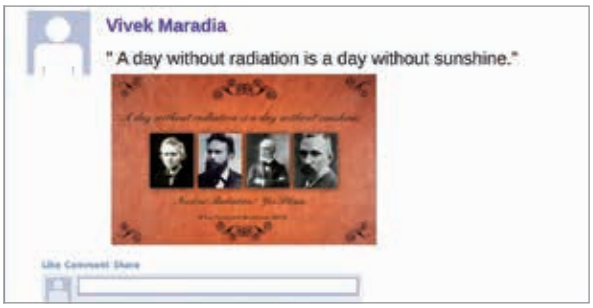

Electromagnetic Enrichment and Purification


Mo-99
Am-241
Co-60
Tc-99m
Different Radioisotopes


Vivek Maradia shared a link
The Many Uses of Nuclear Technology
Like · Comment · Share


Vivek Maradia
Team: (I)-0 mCi (India)
Nuclear Olympiad


Conclusion
Marie Curie


Vivek Maradia
" A day without radiation is a day without sunshine."
Like Comment Share

5 WNU Nuclear Olympiad 2015 - Final results

All World Nuclear University Olympiad finalists proved to be exceptional students who produced outstanding work for the competition. They are all to be congratulated on their efforts and the diversity of the skills required to make and promote a video, research and write an essay, and lastly present to an audience of more than two hundred at the IAEA Headquarters.

The table below shows the points each finalist received at each stage of the Nuclear Olympiad.

Team name	Country	Title of video	YouTube video likes	Essay	Oral	Final ranking
Alice Cunha da Silva	Brazil	Nuclear Saves Lives	5	3	4.5	1
Anton Philippe T. Tanquintic	Philippines	Nuclear Solutions for Today's Needs	3	4.25	4.75	2
Vivek Maradia	India	World Nuclear Radiation Day	4	2.75	3.25	3
Dhruv Dharamshi	India	Fascinating applications of Nuclear Science - A dream worth investing in	2	3	2.25	4
Zulhelmi Zulkifly	Malaysia	Nuclear for Brighter Future	1	2.25	3	5

6 Acknowledgements

The WNU is grateful to IAEA for the support and organization of the final stage of the Olympiad at the IAEA Headquarters on 17 September 2015.

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